HIGHWAY DRAINAGE

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ABSTRACT

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The utilization of low permeability base and sub-base materials in road construction inhibits rapid outflow of water from pavements. The slow evacuation of the inflow induces water saturation conditions for long periods of time; thus, pavements become more susceptible to unexpected failures particularly under traffic impact. Research on effective highway drainage is very limited and the standards for road design and construction are still controversial.

This report examines the entire problem of road drainage with emphasis placed on potential influencing factors such as excess water, groundwater, soil permeability, etc. The theoretical aspects to be considered in developing a comprehensive design method are reviewed.

Based on Darcy's law and the inflow-outflow concept, a subsurface design method is proposed and illustrated by two example cases. The types and specifications of the materials required for the proposed method are stated. Focusing on Canadian standards, the different construction phases and maintenance operations of the drainage system are described. Further, due attention is given throughout the report to Canadian climatic conditions vis-a-vis the drainage phenomenon.

Having established the need for a rational design method, the report is concluded by presenting several recommendations identifying possible future research directions.

TABLE OF CONTENTS

CHAPTER | Page

LIST OF TABLES

LIST OF FIGURES

FIGURE		Page
4.1	Rough Guide for Estimating Coefficient of Permeability of Narrow Size-Ranged Aggregates with No Fines. . . .	49
4.2	Transmissibility of Drainage Layers — cu.ft./lay/foot..	51
4.3	Capabilities of Bases With Edge Drains to Remove Infiltration. Lower Lines are for Standard Types of Bases; Upper Lines are for Open-Graded Base, s = 0.001.	52
4.4	Coefficient of Transmissibility Versus w/s Ratio	53
4.5	The Permeability Required in Order to Drain Subsurface Drainage Layer in 1 Hour or Less.	55
4.6	Normograph for Solution of Perforated Pipe Diameters and Outlet Spacing.	57
4.7	Data for Example 1 — Secondary Highway.	60
4.8	Data for Example 2 — Expressway.	64
4.9	Combinations of Permeability and Layer Thickness Giving Transmissibilities from 5000 ft^3/day to 80000 ft^3/day.	69
5.1	General Layout of a Perforated Pipe Cross-Section. . . .	77
5.2	Slotted PVC Pipe — 1/4" I.D.	78
5.3	Typical Slotted Drain Viewed from Two Different Angles. .	79
5.4	Cross-Section of a Typical Steel Slotted Drain.	81
5.5	Typical Details of Outer Edges of Drainage Systems.	82
5.6	Prevention of Boiling By Intercepting Drains.	84
5.7	Slope Stabilization with Horizontal Drains.	85

NOMENCLATURE

A	-	Area
b	-	Half distance between drains; dimension
C	-	Coefficient of transmissibility
C	-	Safety factor
D_2	-	Two percent is finer
D_{15}	-	Fifteen percent is finer
D_{50}	-	Fifty percent is finer
D_{85}	-	Eighty-five percent is finer
g	-	Longitudinal grade of the road
H	-	Thickness; dimension
H_O	-	Hydrostatic head
h	-	Hydrostatic head
I	-	Inflow quantity
I	-	Design infiltration rate
I_c	-	Inflow quantity due to capillary water
I_g	-	Equivalent infiltration rate
I_H	-	Inflow quantity due to hydrogenesis
I_T	-	Inflow quantity due to adjacent wet areas, springs, groundwater
I_s	-	Inflow quantity due to surface infiltration
i	-	Hydraulic gradient

k - Coefficient of permeability

k_b - Coefficient of permeability of porous base

kg - "Global permeability" (effective permeability of a pavement area)

L - Length; dimension

ℓ - Length; dimension

n - Coefficient

n_d - Number of equipotential lines in a flow net

n_e - Effective porosity

n_f - Number of flow channels in a flow net

O - Outflow quantity

O_D - Outflow quantity due to subsurface drainage

O_E - Outflow quantity due to evaporation

O_p - Outflow quantity due to subgrade percolation

O_R - Outflow quantity due to pumping effect

O_S - Outflow quantity due to lateral seepage

Q - Seepage quantity rate

q - Unit discharge rate

q_s - Unit discharge rate into subgrade

S - Distance; dimension

S - Perce serviceability

s - Cross slope

T - Effective life

t - Time

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CHAPTER I

INTRODUCTION

The concept of roads belongs to one of the oldest construction disciplines. The ancient Romans had already been building stone roads long before the birth of Christ. Some remnants may still be found in Europe, the Middle-East, and North Africa.

The development of roads has been steadily increasing to serve the ever-growing needs of its abundant users. Ancient roads tended to follow the natural topography of the earth's features, such as stream lines, river banks, seashores, valleys, etc. In addition, other types of routes were made by animals (domestic or wild) as they made their way through the surroundings in search of food and shelter. Upon industrialization roadways became more significant, i.e., goods and materials were more widely transported, people were obliged to move over greater distances, and urban problems began to be more and more apparent.

The development of petroleum products and the subsequent widespread use of the automobile were the main reasons for today's enormous and complex highway systems. The demand for wider and better roads became accentuated after World War II as the number of cars increased drastically. Today, urban areas are growing at rates never before experienced and, as travel speed is getting significantly higher, the transported 'element' is increasing astronomically, thus increasing the demand for 'better roads' (in all its aspects of planning, construction, and maintenance). For example, if one were to establish a certain road, then the main criteria to be carefully considered are:

1. the importance of the road (a complete study between existing and projected systems)
2. its location
3. the extent of expropriation needed
4. properties of the surrounding soil
5. type of engineering design and construction impact upon the environment
6. construction and maintenance costs.

From an engineering point of view, roads should be designed to be functional. However, almost 95% of the roads in North America are subjected to rainfall rates beyond the handling capacity of their structure; this represents a serious maintenance problem. For example, there are more than 4,000,000 paved miles of roads in the U.S. alone, the construction and maintenance of which exhaust hundreds of millions of dollars from the taxpayers' money and the problem is even bigger in the underdeveloped and poorer countries. Thus, when certain planning decisions have to be made, better and more comprehensive road design becomes the backbone of any given project.

There is no doubt that the problem of drainage is at the heart of almost all problems which a given highway encounters because poor drainage can relatively transform a minor problem into a major problem; e.g., cracking of the asphalt or the concrete surface. Also, it is of paramount importance to those who live in cold regions because of the freezing and thawing effects.

The writer's practical experience in the highway construction field has produced an additional incentive to look into today's drainage problems. In this report, the road drainage phenomenon is examined in the light of three different angles, namely:

1. theoretical aspects
2. design aspects
3. construction and maintenance aspects.

The principal objective of this report is to give the reader first-hand information and a comprehensive idea about road drainage. Further, the report attempts to demonstrate a better design method compared to currently employed methods.

CHAPTER II

FUNDAMENTAL FACTS

Many independent aspects influence directly or indirectly, and to varying degrees, road drainage. The following sections are intended to provide an insight into the different mechanisms involved in the phenomenon.

2.1 DEFINITION

Drainage is defined in John S. Scott's Civil Engineering Dictionary as "the removal of water by flow or pumping from the ground or from the surface or other buildings" [33]. Drainage is also described as "the evacuation or the control of the excess of surface water or subsurface or used waters" [13]. The oldest urban/rural drainage system can be found in the Old Asian ruins of Mohenjo-Daro in the Indus Valley which was built around 2,000 B.C. The Chinese were known to have used an even more primitive drainage system than the Mohenjo-Daros during 2,300 B.C., controlling water in such a way as to later redirect it for agricultural use.

2.2 CLASSIFICATION OF WATERS

In order to have a comprehensive idea about 'highway versus drainage', one should first be familiar with the classification of water types. Water may be classifed ~~into~~ four major categories, as follows [34]:

1. Surface waters: these are all waters which are precipitated and spread over the surface without being collected into a channel or stream;
2. Stream waters: former surface waters which have reached a well defined watercourse with other waters originating from precipitation or springs;
3. Flood waters: former stream waters which have deviated from a watercourse and its overflow channels, and flowed over adjacent land or became stagnant. These disappear either by evaporation, infiltration, or return to a natural watercourse;
4. Ground waters: are divided into two classes, namely percolating waters and underground streams. Percolating waters are not easily distinguishable without excavation, nor do they have a definite channel [34].

   Where a stream sinks into the ground, pursues a subterranean course for some distance, and then emerges again, the portion beneath the surface as an underground stream.

2.2.2 WATER CLASSIFICATION AND HIGHWAY DRAINAGE

A well-drained road has to consider the hazards resulting from all four classes of waters, although one class may be more damaging than others. For example, in the case of flood waters, higher longitudinal profiles should be considered in order to overcome high water levels. Since floods occur seasonally, the designer can estimate the highest water level based upon frequency studies or landmarks, or even by consulting the residents who live in the area. In addition to the profile changes, wider ditches may be used, the slopes may be protected by top soil, rip-rap, synthetic tissues, or asphalt. The solution is thus confined to geometric design and proper maintenance.

As far as stream waters are concerned, culverts, pipe arches, and bridges act as control elements. The design should be accomplished properly and the construction done as accurately as possible to minimize washing, erosion or heaving action in colder regions. Culverts are the most frequently used elements, and they are an integral part of the drainage process. A brief discussion appearing later in this report will deal specifically with culverts.

Ground-waters and surface-waters act almost upon the entire length and width of a highway. They may remain in pavements indefinitely. Although they are more frequent during certain periods, they can occur at any time during a given year. Thus, they are considered the most important of the four classes of water as far as drainage is concerned.

2.3 STANDARD ROAD STRUCTURE VERSUS DRAINAGE

Ordinarily, road structure is generally considered to be the gravel or the crushed stone layers that are sandwiched between the subgrade (in cut) or the regular fill materials (in fill) and the asphalt concrete (A.C.) or Portland cement concrete (P.C.C.), depending on whichever is used [22]; sometimes P.C.C. is included in the structure itself.

Road pavements may generally be categorized as either flexible or rigid pavements. Portland cement concrete is only used in rigid pavements. Figure 2.1 illustrates a standard cross-section of a flexible pavement. This typical section (based on Canadian Good Road specifications) is widely used throughout Canada. While it may vary from one country to

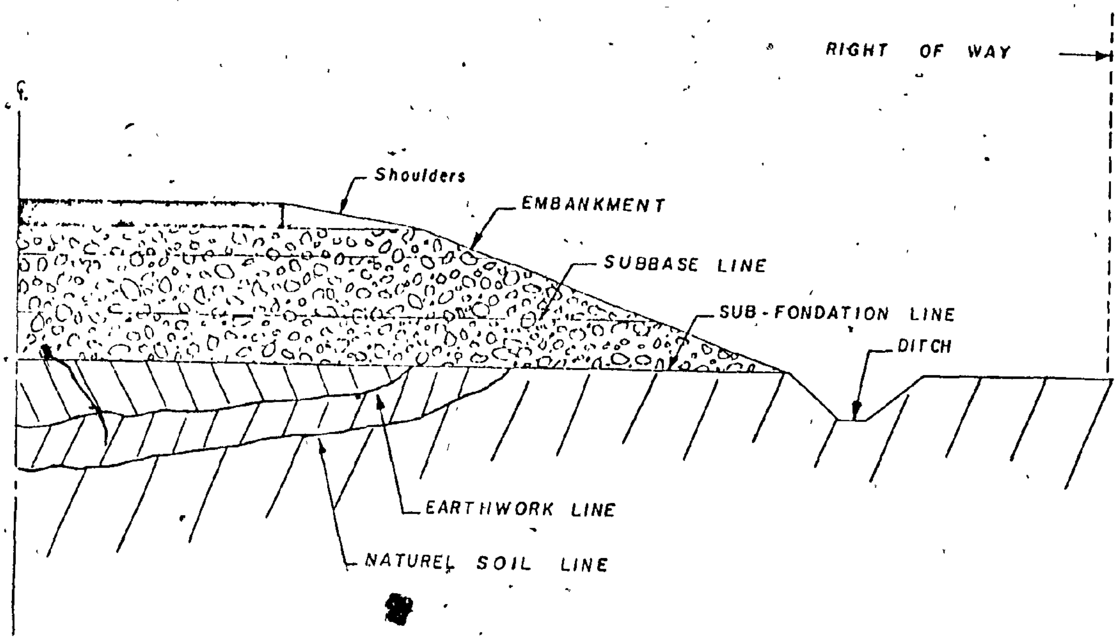


Fig. 2.1 — Standard modern cross-section of a flexible pavement in cold regions [27].

another, its basic components do not virtually change. For example, Fig. 2.2 shows a conventional road design used in the U.S. both in cut and fill; the presence of the subdrains gives some advantage over Canadian design (without subdrains).

However, both sections are far from being adequate, as will be shown later, for proper draining of any typical road. At this stage, it is important to provide a very brief description of the road structure which contains the following layers:

<u>The base</u>: is usually composed of crushed stone or crushed gravel with specific gradation (depending upon the designer). In rigid pavements it is either cement-treated or made of P.C.C. In flexible

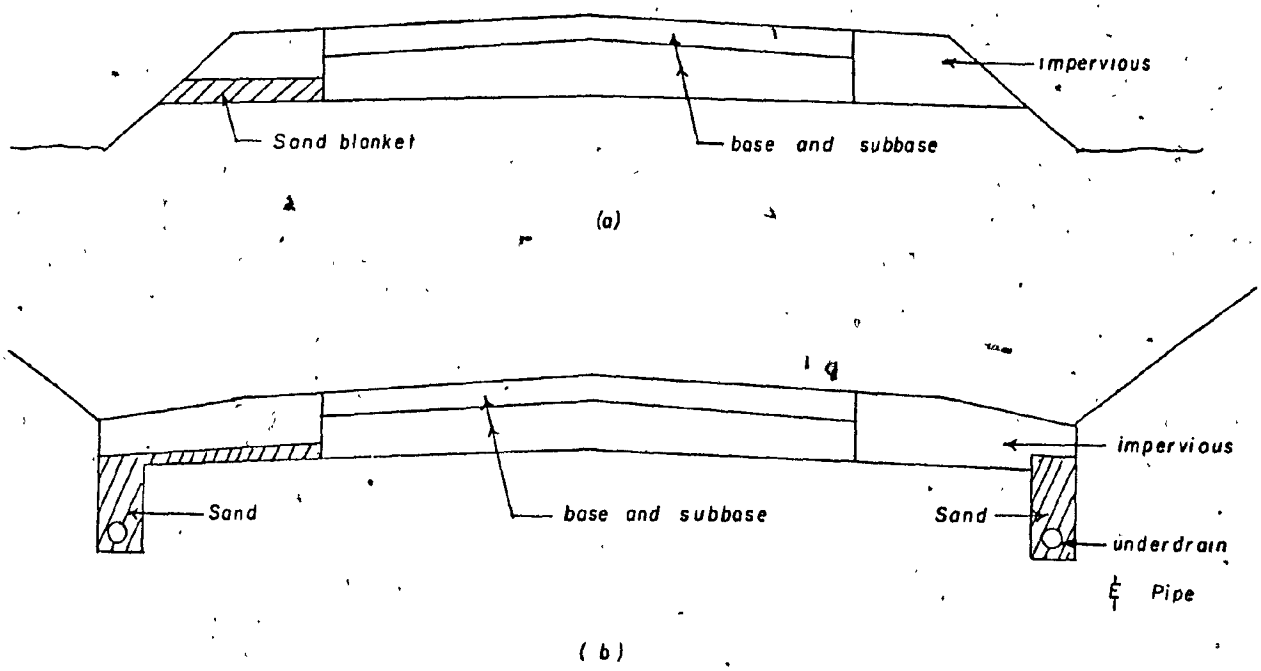


Fig. 2.2 — Conventional modern pavements based on U.S. standards: (a) Roads in fill (b) Roads in cut [16].

pavements, it is covered by black top (A.C.) while in rigid pavements it is usually an integral part of the surface layer (P.C.C.). Its thickness depends upon the type and volume of the traffic, but above all, it should depend upon the drainability characteristics of the road.

The sub-base: By definition, this is the layer below the base. It is composed of either crushed gravel or crushed stone. The thickness of this layer depends on the design standards and given conditions. In cold regions, if the natural soil (after the removal of the top soil) is made up of low permeability materials such as clay, silt, or their mixture, with another type of soil, then an anti-frost layer of soil has to be used [7]. The thickness of this layer is a function of the natural soil and it varies from 8" to 24". It is sandwiched between the natural ground (in cut) or ordinary fill materials (in fill) and the sub-base. The maximum permissible size of the stones should not exceed 4" in diameter. Throughout this report this layer will be designated as sub-foundation.

In order to drain the described road structure, two open ditches at each side of the road are typically used as main conduits. All surface or infiltrated waters in rural areas eventually end up in these two ditches. Whereas, in urban areas, sub-drainage network systems are used where roads are limited at each side either by curbs or by sidewalks. Figure 2.3 shows a typical cross-section of an urban road.

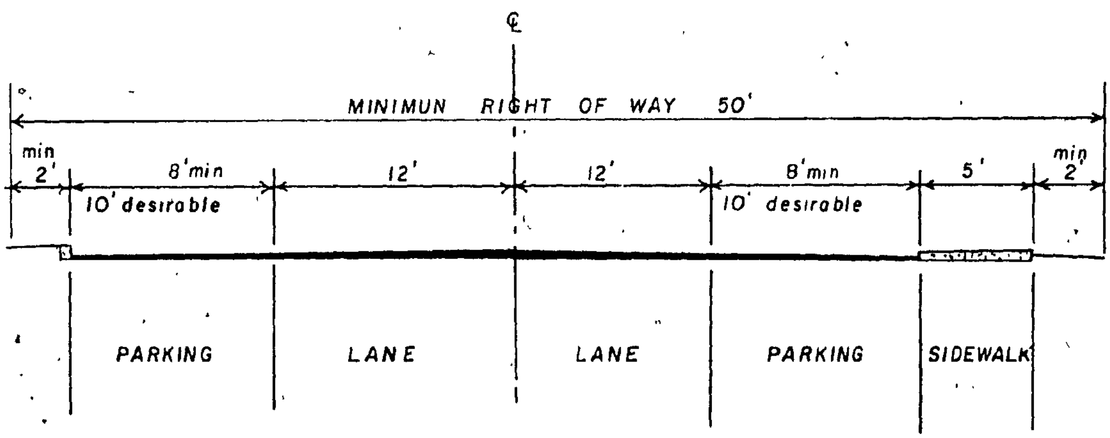


Fig. 2.3 — Standard width of a two-lane and two-parking urban road [22].

When the falling droplets of an intensive rainfall first impinge on the road surface, they penetrate through joints or cracks as they follow the road's designed slope. Once they reach the base, they eventually end up into perforated pipes which run longitudinally with respect to the road axis; the pipes are usually located at the start of the shoulder. Once these droplets penetrate the perforated pipes, they flow towards collector pipes which interrupt the perforated pipe at appropriate intervals. These collector pipes (located transversally with respect to the road axis) conduct the water to the ditches, which in turn conduct the water towards natural or artificial streams. This path is illustrated in Fig. 2.4. Although all standard highways are not drained as prescribed above, this path is the most convenient and the fastest way of draining a road structure.

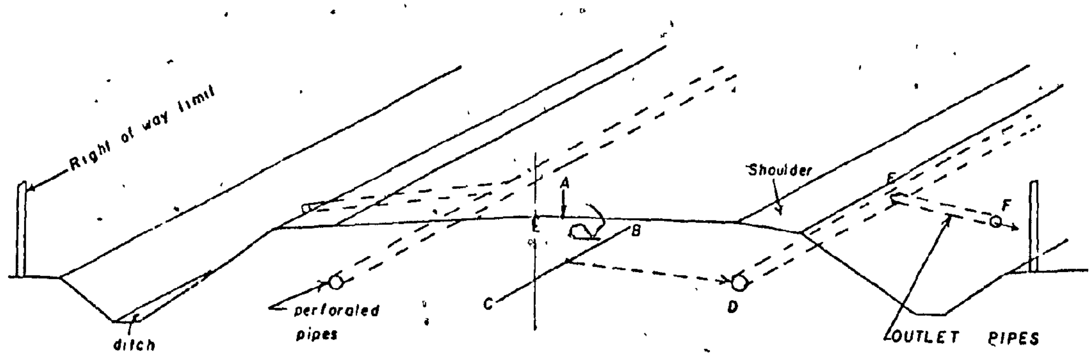


Fig. 2.4 — Water evacuation path of a highway which has a drainage system.

2.4 POOR DRAINAGE AND PAVEMENT DAMAGE

The many factors that influence the eventual deterioration of roads make the determination of a sole mechanism responsible for pavement failure very difficult, e.g., aging and oxidation of asphalt films deteriorate asphalt concrete pavements and bases, while in PCC fatigue and repeated strain are reflected by cracking and disintegration of the pavement. Since highways have large surface areas exposed to weathering and heavy traffic, and under the combined actions of fluctuating temperature, rainfall, and freezing, thawing and oxidation, damaging action takes place that shortens life expectancy, increases roughness, loosens materials on the surface, and finally erodes pavements. In all these factors, the presence of excess water seems to be the primary factor in early failure of pavements. But how can the presence of excess water damage a given pavement? The increase of water content in the base and sub-base causes a certain reduction in the supporting power of a road. In a situation where water thoroughly fills the layers, heavy wheel load impacts influence surface water similar to water-hammer action, causing ejection of materials from pavements and stripping of the asphaltic concrete from the base. In PCC, it disintegrates cement treated bases by re-arranging the internal structure of the fine grade materials.

Free water in pavements causes buoyancy of supersaturated layers, reduces unit weights and thus reduces frictional strength. In A.C. pavements, it accelerates the shrinkage and cracking process as well as disintegration, oxidation and flexibility (which in turn induces cracking and deterioration of the bases). Free water can prevent the natural self-healing of cracks by admitting clays and other fine materials in the cracks [8].

In cold regions and in the presence of frost-susceptible materials, the presence of free water contributes to the so-called 'D' cracking. and to the 'blow-up' of P.C.C. pavements [17].

In the process of developing the Guidelines for FHWA,* the Design of Sub-surface Drainage Systems for Highway Structural Sections [29], several diamond drilled test pits and auger holes were drilled, and careful studies were carried out for any damage caused by water. One of these sites located on a 50-ft. fill of a 17-year old interstate highway showed severe damage from excess water, due to precipitation. A hole was cored underneath the wheel path of a truck line, and indicated that the cement treated base (CTB) had deteriorated into cohesionless material that could be removed with a spoon. Another hole was then cored into the passing lane, which showed solid cement-treated base with concrete, indicating that the loss in cohesion in the truck lane was undoubtedly caused by the combined actions of traffic and water.

In another test, the State Highway Department of Georgia carried out investigations on three sections of damaged pavement in 1969, and none of these observed showed any evidence of subgrade distress [1].

In the light of these experiments the two major types of effects of excess water in pavements are explained as follows:

1. Pumping type effects: The pumping mechanism is a fairly simple one. When a base gets saturated and the water remains stagnant, creating a bath-tub condition, under wheel impacts water ejects the finer particles out through joints and small cracks. The ejection of the fines along with water can be seen clearly as a truck passes over a joint in the roadway soaked with excess water. The water will jump high, carrying the

*Federal Highway Administration.

fines out of the base materials. The absence of these finer grains will increase the volume of voids, which will cause thin cracks along the surface due to lack of support. These cracks will in turn permit more water to be released, thus causing the eventual total failure of the pavement. Figure 2.5 shows the pumping action under the wheel impact both in flexible and rigid pavements.

2. 'D' Type Cracks in P.C.C.

Deterioration of this type is initiated when atmospheric moisture penetrates open joints and cracks, which together with water already present beneath the pavement, raise the degree of saturation of the worse aggregate to a critical level. During freezing, pressures generated in the aggregate through hydraulic pressures or ice formation, will cause disruption of the aggregate and the surrounding mortar. With continued freezing and thawing, existing cracks may provide additional channels for the migration of moisture into the slab and also provide additional regions for ice formation and the generation of excessive pressure operating to widen the existing cracks. When these cracks propagate, the entire pavement slab will turn into rubble. Figure 2.6 illustrates typical 'D' type cracking of an interstate highway in the central USA. Since it is virtually impossible to prevent moisture flow through joints and cracks, the rapid elimination of water by good drainage reduces damage by 'D' cracking.

All the damage resulting from poor drainage plus the other deteriorating factors such as fatigue, oxidation, and high traffic volumes, accelerates the rate of damage with age (i.e. the serviceability of the pavements).

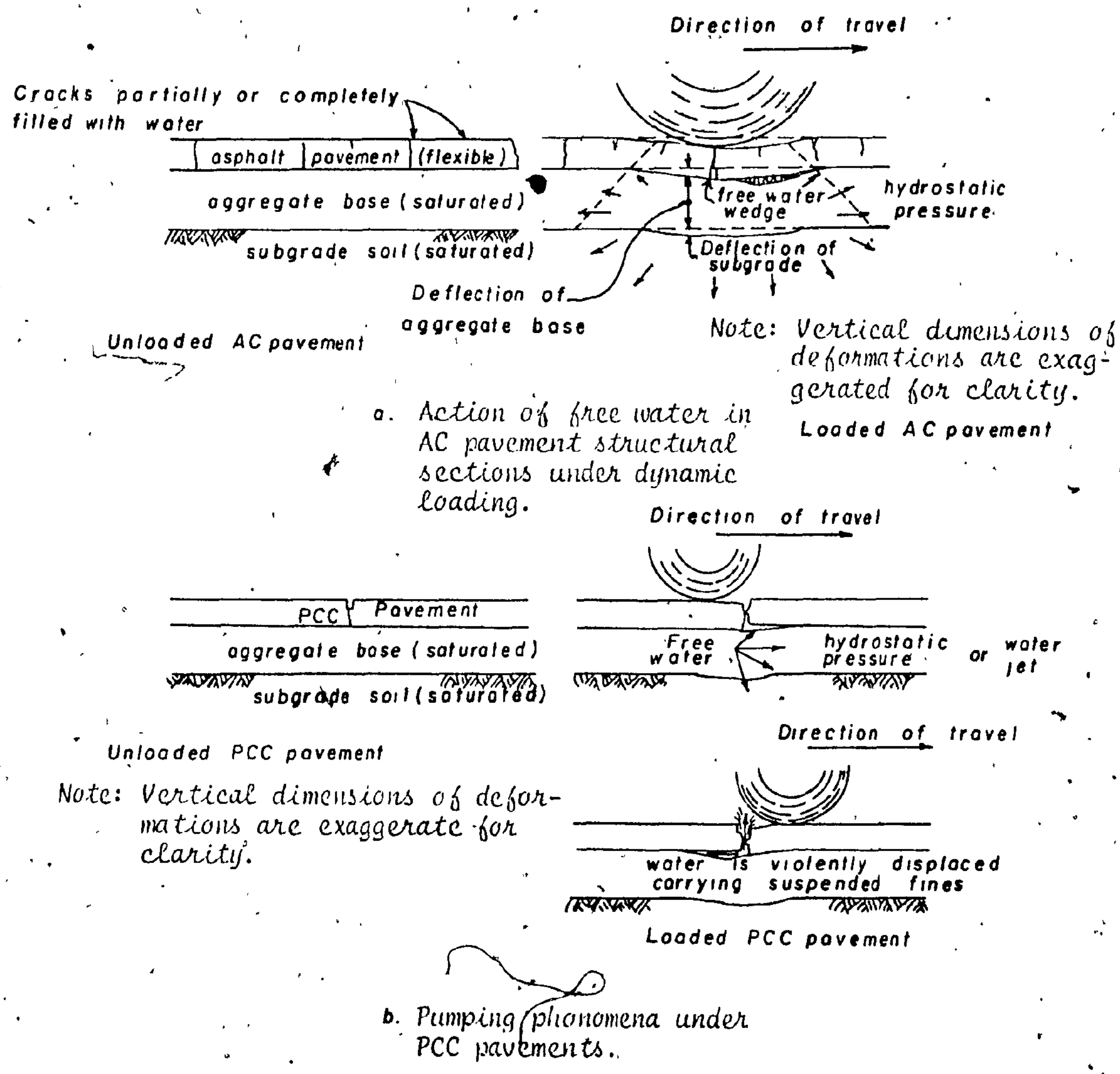


Fig. 2.5- Pumping action under wheel impact; (a) Flexible pavements (b) Rigid pavements [29].

Fig. 2.6 — Typical 'D' type cracking, Interstate Highway, Central USA [29].

The percentage serviceability (S) may be expressed by the following equation [9]:

$$S(\%) = 100\ (T^2 - t^2)/T^2 \quad \ldots\ldots\ldots\ldots\ldots \quad (2.1)$$

where T is the actual effective life in years, and t represents the age at a given time for which the value of S is desired.

Figure 2.7 demonstrates how serviceability diminishes with time. Four pavements, each having effective lives of 10, 20, 30 and 40 years respectively are presented. It can be seen that for a pavement

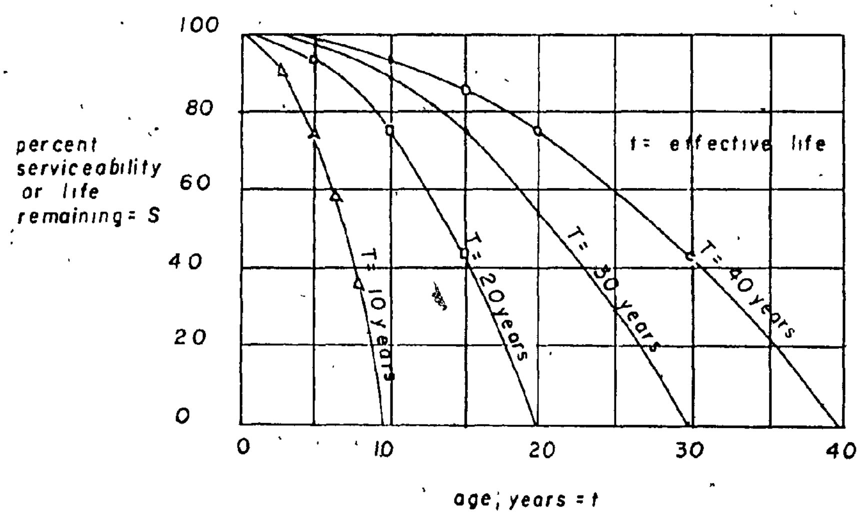


Fig. 2.7 — Hypothetical rates of losses in serviceability of pavements of various amounts of effective life [9].

which is expected to have an effective life of 20 years, it should still have 75% of its serviceability left after 10 years. On the other hand, if its serviceability is lowered by 25% in the first 5 years, then its effective life might be reduced to 10 years. If through proper drainage the effective life is lengthened to 30 years, then the serviceability will be lowered to 12% at the end of 10 years and only to 6% if the effective life is lengthened to 40 years. As for the problem of pavement structural section's drainage, the Final Report of the U.S. FHWA [17] in 1973 presented several conclusions, which included the following:

(a) Water can get into most pavements through joints, cracks, porous surfaces, high shoulders, and so on, since the present state of the art does not assure watertightness of pavements for long periods of time. Thermal changes, traffic and other environmental changes and effects are continuously working to develop openings in pavements;

(b) The rates of damage to most pavements are much greater where excess water is in structural sections than when there is little or no excess water there;

(c) Rainfall rates in most parts of the United States and Canada are greater than coefficients of permeability of subgrades (natural or compacted), hence the well-known bathtub condition (i.e. when highway's structure is saturated with water and the outlet possibilities are non-existent), tends to exist in most pavements for significant amounts of time each year;

(d) As a consequence of items (b) and (c), most modern roads, airfields, and other important pavements are actually very slowly draining systems, and many contain excess water for extensive periods of time a number of times each year, which greatly accelerates losses in serviceability and increases repair and replacement costs.

2.5 Soil Permeability

Soil permeability is the rate of diffusion of a gas or liquid under pressure through soil [33]. Normally, soils which possess low coefficients of permeability are considered to have poor drainage quality. In highway drainage, soil permeability is an indispensable factor, and since the coefficient of permeability may range from 5 ft/day to 200,000 ft/day, one might find roads which are 1 to 15,000 times more drainable than others. There are certain factors that influence the soil permeability; these factors are:

1. Grain size: It has been shown that permeability can be expected to vary with the square of the diameter of soil particles, e.g. Fig. 2.8 illustrates typical permeabilities of soils and aggregates. The influence of fines on the permeability of manufactured filter aggregates is demonstrated in Table 2.1, which lists ranges in permeability of some washed aggregates grading from 1 inch to finer than the 100 mesh sieve.

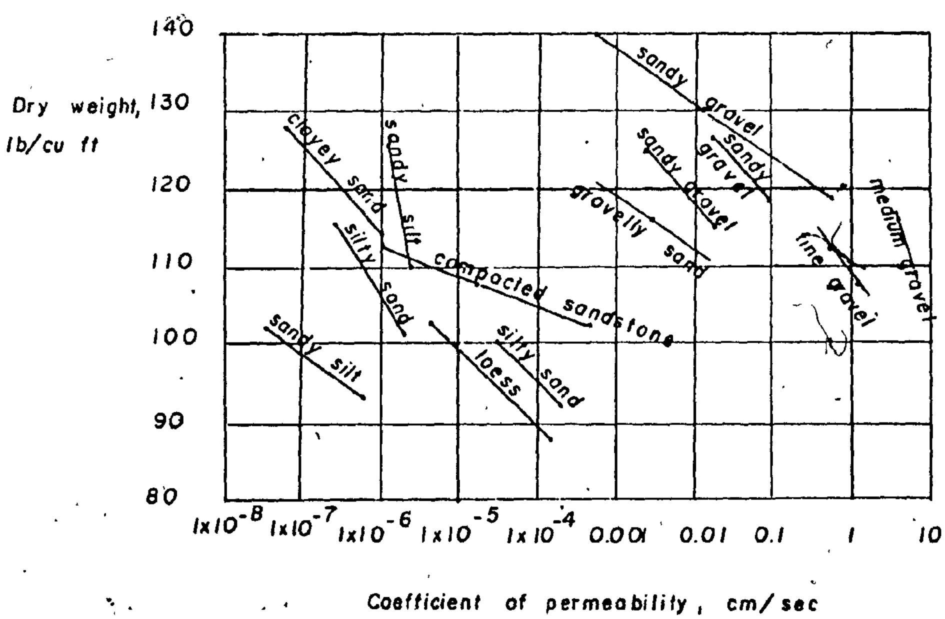


Fig. 2.8 — Typical ranges of coefficient of permeability of various soils [10].

Percentage Passing Number 100 Sieve	Permeability, ft/day
0	80 - 300
2	10 - 100
4	2 - 50
6	0.5 - 20
7	0.2 - 3

Table 2.1 — Influence of Percent of Minus 100 Fraction on Permeability of Washed Filter Aggregates [10].

2. Particle Arrangement: Water deposited soils are usually constructed in a series of horizontal layers that vary in grain-size distribution and permeability. These deposits are generally more permeable in a horizontal than vertical direction. The arrangement of soil particles can influence permeability in two ways:

a. by sorting or stratification

b. by detailed orientation of particles and the balling-up of fines or broad dispersion of fines.

3. Viscosity of the Water: Viscosity of a given fluid varies with temperature, and since in highways, water is usually in a normal temperature range, viscosity may be considered constant as far as permeability is concerned.

4. Dispersion of Fines: Soil particle arrangement can have a major influence on permeability (and other soil properties). For example, if soils are compacted in a relatively dry state, a comparatively harsh

permeable structure is usually formed. On the other hand, if large amounts of moisture are present, the particles tend to slide over one another into a relatively well-knit, smooth, impermeable type of structure.

5. Density: Density, although less important than grain size and soil structure, can have a substantial influence on permeability. The denser a soil and the smaller the pores, the lower its permeability. Thus, for this reason, the consolidation of a soil enters in the picture, where the lesser the consolidation of the soil, the higher its permeability.

6. Discontinuities: These can lead to serious trouble with hydraulic structures. In highways, for instance, compacted clays (subgrade) can contain shrinkage or shear cracks that render such formations many times more permeable than the clay between the cracks. The same is true for jointed cracks.

7. Size of Soil or Rock Mass: In the process of determining the coefficients of permeability of earth masses in the development of projects in which seepage conditions will be changed by the project, it is important that the scope of the study take into account the size of the soil or rock masses that will influnece seepage behaviour.

Table 2.2 provides common ranges of permeability of soils varying from fine clays to gravels [30].

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

<table>
<tr><th></th><th>10^{2}</th><th>10^{1}</th><th>1.0</th><th>10^{-1}</th><th>10^{-2}</th><th>10^{-3}</th><th>10^{-4}</th><th>10^{-5}</th><th>10^{-6}</th><th>10^{-7}</th><th>10^{-8}</th><th>10^{-9}</th></tr>
<tr><td>DRAINAGE</td><td colspan="6">GOOD</td><td colspan="2">POOR</td><td colspan="4">PRACTICALLY IMPERVIOUS</td></tr>
<tr><td rowspan="2">Soil Types</td><td colspan="2" rowspan="2">Clean gravel</td><td colspan="3">Clean sands, clean sand and gravel mixtures</td><td colspan="4">Very fine sands, organic and inorganic silts, mixtures of sand silt and clay, glacial till, stratified clay deposits, etc.</td><td colspan="3" rowspan="2">"Impervious" soils, e.g., homogeneous clays below zone of weathering.</td></tr>
<tr><td></td><td colspan="6">"Impervious" soils modified by effects of vegetation and weathering.</td></tr>
<tr><td rowspan="3">Direct Determination of k</td><td colspan="7">Direct testing of soil in its original position — pumping tests. Reliable if properly conducted. Considerable experience required.</td><td colspan="5"></td></tr>
<tr><td colspan="5">Constant-head permeameter. Little experience required.</td><td colspan="7"></td></tr>
<tr><td colspan="3"></td><td colspan="2">Falling head permeameter. Reliable. Little experience required.</td><td colspan="4">Falling-head permeameter. Unreliable. Much experience required.</td><td colspan="3">Falling-head permeameter. Fairly reliable. Considerable experience necessary.</td></tr>
<tr><td>Indirect Determination of k</td><td colspan="5">Computation from grain-size distribution. Applicable only to clean cohesionless sands and gravels.</td><td colspan="4"></td><td colspan="3">Computation based on results of consolidation tests. Reliable. Considerable experience required.</td></tr>
</table>

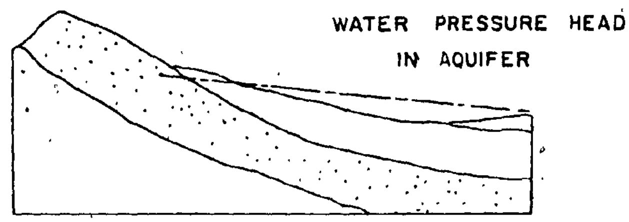
Table 2.2 — Common ranges of permeability of soils varying from fine clays to gravels [30].

2.6 EFFECTS OF HIGHWAY CONSTRUCTION ON GROUND-WATER

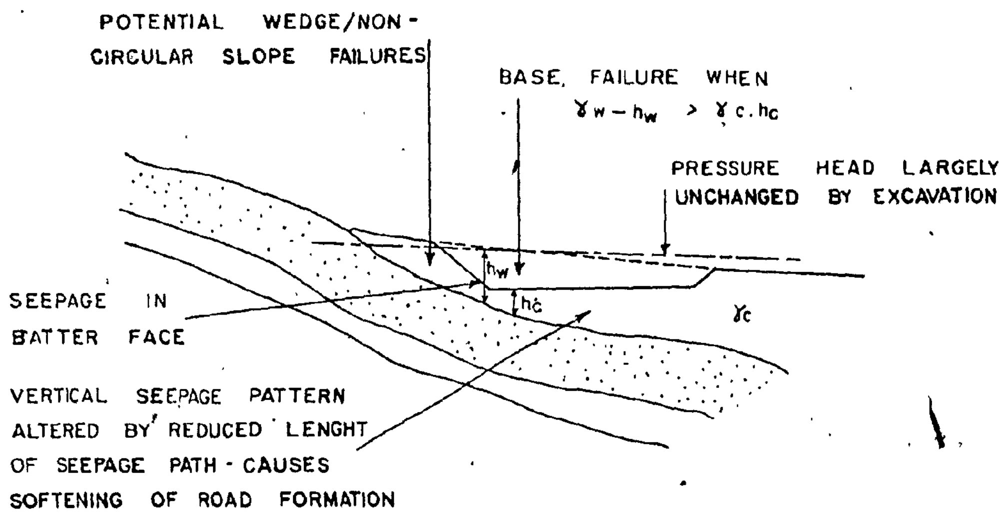
For a better drainage in the process of road design, the designer must consider the effects that the construction work will have on the ground-water regime both in the short term and in the final equilibrium condition. The following is a brief description of situations that may arise due to ground-water both in cut and fill conditions.

2.6.1 In cut: Delays in highway construction are mainly attributed to ground-water than to any other reason. On high free water table situations, problems may include seepage from cut faces or slopes, particularly in stratified deposits, the collapse of uniform fine sands, bogging down of construction plans and extensive spoiling by wetting of material which could otherwise have been used elsewhere on the project. Where a cut is through moist clay, or intercepting a more permeable artesian aquifer, seepage may cause liquification and mud flows in cut slopes and softening of formation materials. If the artesian head exceeds the overburden pressure, the base of the cut will be forced up (refer to Fig. 2.9). When for economic reasons boring and pits are terminated just below the depth of a cutting, underlying artesian conditions can easily be missed, leading to problems during construction.

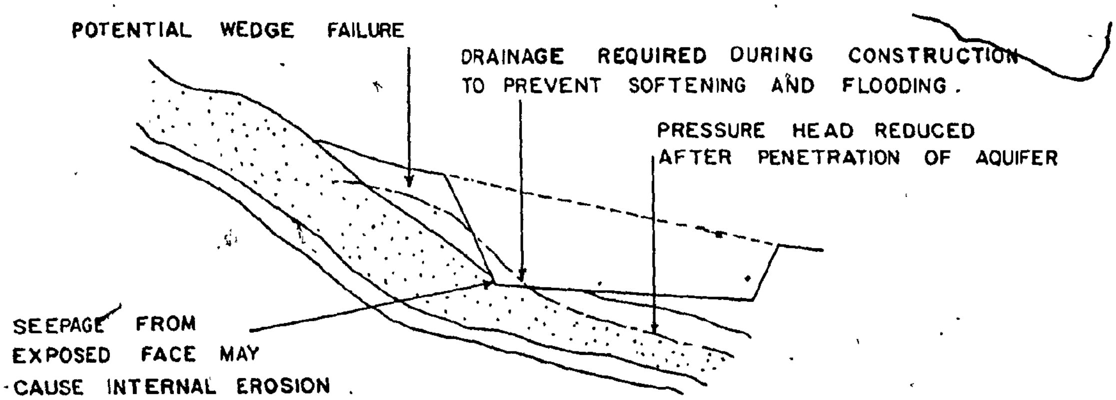
2.6.2 In fill: Being situated above ground level, fills count for fewer problems than cuts. However, they may compact an underlying aquifer causing lower permeability and a back-up of ground-water. Where settlements are large, fill may become immersed in flowing ground-water which may erode certain fine grained materials. The presence of high piezometric pressures on pre-existing shear planes or soft clay bands in



a- STRUCTURAL CONDITION FAVOURABLE TO DEVELOPMENT OF AN ARTESIAN SLOPE



b- SHALLOW CUT-AQUIFER NOT PENETRATED



c- DEEP CUT-AQUIFER PENETRATED

Fig. 2.9 -- Permeable artesian aquifer and roads in cut; (b) Shallow cut (c) deep cut. [18].

sloping ground below an embankment may result in instability [18, 19]. Wherever spring lines or relatively high water tables are encountered, movement of heavy earth-moving plants can cause severe degradation of the road formation which may necessitate special stabilization treatment before continuing with operations.

For both cut or fill, extra precaution should be taken by the designer to predict as accurately as possible the presence and conditions of ground-waters. It is preferable to spend a greater amount of money in drilling and sampling, rather than being faced with an unstable ground-water situation during construction.

2.7 Culvert Geometry and Pavement Drainage

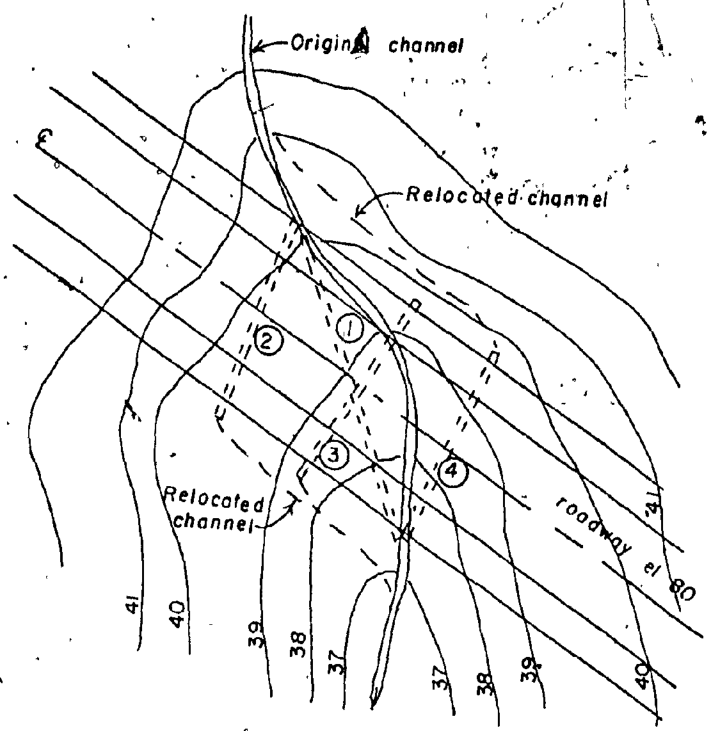
Culvert practice is a complete subject by itself, although culverts do not influence directly the removal of excess water from pavements. They can, however, indirectly hinder the normal operation of subdrainage systems. A simple example is the linkage through joints which can add unwanted water to the pavement structure. Another common problem (in cold regions) is the heaving of pavements; pavements swell at culvert locations and cracks occur during the spring thaw period. These cracks transfer surface water down to the base layer. One way to avert heaving of culverts is to employ non-frost susceptible (granular) materials around culverts in transition, especially when the crown (culvert's highest point from the inside) is not far below from the road surface. Economically speaking, there are many culverts that the annual investment in the U.S. alone is well over $200 million, to which might be added a cost for maintaining and replacing those that are poorly designed and may cause damage to the pavement, or may become hazardous to the road users [43].

Culverts in modern highways may be classified according to two general uses: the first is maintaining the natural drainage channels. The second is in continuation of ditch drainage through access roads to connect with natural drainage channels [15]. In order to prevent pondering, embankment erosion, and the reach of stream water to the pavement itself, the following geometric considerations should be looked at in different culvert construction fields:

1. Location of culverts: In general, the best overall drainage operation will occur when the culvert is located in the original flow channel. However, culverts may also be located on one side of the natural channel, thereby shifting the location of both the inlet and outlet

2. Channel Division: The diversion of channels is done also for economic reasons, because if a natural watercourse crosses the roadway obliquely, it may be economical to divert the natural flow through a shorter culvert by crossing the roadway at a right angle. Figure 2.10 illustrates four plans of three possible channel diversions

3. Transverse Interceptor Culverts: An interceptor culvert is located where it is necessary to drain low portions of drainage ditches. In other words, if the direction of flow in a ditch is concentrated in a common low point, and the water has to cross the highway (by a culvert) in order to catch a stream or the adjacent ditch, then the culvert used is an interceptor culvert. Usually, here, high flows are not encountered, but inadequate design may cause flow over the roadway.



Plan No. 1 - skewed crossing, no channel relocation required.

Plan No. 2 - inlet in original channel, downstream channel relocated.

Plan No. 3 - inlet and outlet displaced with upstream and downstream channel relocation.

Plan No. 4 - outlet in original channel, upstream channel relocated.

Fig. 2.10 — *Channel diversion due to culverts* [31].

4. Ditch Drainage Under Access Roads: This is the most common form of culverts encountered. In design, the culvert should maintain the natural drainage of the ditch [31]; it should achieve continuous flow in the ditch with as little interference or change in the water surface as possible.

The preceeding sections have attempted to provide a general background and presented some fundamental facts in relation to the subject in question. The following Chapter will proceed to describe the various methods of handling excess water through an efficient qualitative and quantitative theoretical technique.

CHAPTER III

THEORETICAL CONSIDERATIONS AND GOVERNING FACTORS

The inflow-outflow phenomenon is a basic criterion in developing a rational drainage design method. Thus, it is imperative to start off the discussion by explaining Darcy's Law and the concept of flow nets.

3.1 DARCY'S LAW

The flow of water upward from soil formations into sections of road, or downward through porous pavement into structural sections, downward into permeable subgrades, horizontally in bases or through shoulders, do follow certain fundamental laws of nature. Darcy's law is commonly used in estimating the flow rate [10]; it can be expressed in a variety of forms as illustrated below:

$$Q = kiA$$

$$Q = kiAt$$

$$Q = v_d A$$

$$Q/i = kA$$

$$v_d = ki = Q/A$$

$$v_s = ki/n_e = v_d/n_e$$

v_d = average velocity through the total cross-sectional area

where —

Q = seepage quantity

i = hydraulic gradient in the direction of flow

A = cross-sectional area perpendicular to the flow

t = time

. . . . (3.1)

The seepage velocity, V_s, is the average velocity through the pore volume, and the effective porosity, n_e, is the portion of the cross section in which the water is flowing.

3.2 FLOW NETS

In order to develop an equation for flow of water through porous media, the following assumptions are, generally, invoked:

1. the soil is homogeneous
2. the voids are completely filled with water
3. no consolidation takes place
4. soil and water are incompressible
5. flow is laminar, i.e., Darcy's Law is valid.

Based on the continuity concept, a quantity of water entering any element must be equal to the quantity of water leaving the same element [36]. Stated mathematically:

$$\partial u/\partial x + \partial v/\partial y + \partial w/\partial z = 0 \quad \ldots\ldots\ldots\ldots (3.2)$$

where u, v, w are discharge velocities in the x, y, and z directions. Considering Eq. 3.1 in the form $v_d = ki$, the components of the discharge velocity become: $u = -kdh/dx$, $v = -kdh/dy$, and $w = -kdh/dz$; replacing these in Eq. 3.2:

$$\frac{\partial[-k(dh/dx)]}{\partial x} + \frac{\partial[-k(dh/dy)]}{\partial y} + \frac{\partial[-k(dy/dz)]}{\partial z} = 0$$

Considering the coefficient of permeability, k, as a constant, the partial differentiation of the above equation yields the following:

$$\frac{\partial^2 h}{\partial x^2} + \frac{\partial^2 h}{\partial y^2} + \frac{\partial^2 h}{\partial z^2} = 0 \quad \ldots\ldots\ldots\ldots (3.3)$$

This is a Laplace type equation for three-dimensional flow of water through porous media. In two dimensions it has the form:

$$\frac{\partial^2 h}{\partial x^2} + \frac{\partial^2 h}{\partial y^2} = 0 \quad \ldots\ldots\ldots\ldots (3.4)$$

where the term h represents the head.

Solutions to Eq. 3.4 are generally obtained by graphical flow nets, although different approaches can be followed such as finite difference techniques, finite element method, analog models, etc. The graphical flow net solution consists of two families of curves that intersect at right angles to form a pattern of square figures. The lines of one family are called flow lines while the others are called equipotential lines. The flow lines represent possible flow paths through a cross section. The equipotential lines represent lines of equal energy or head. Figure 3.1 shows general conditions for seepage lines. Although the number of indivi-

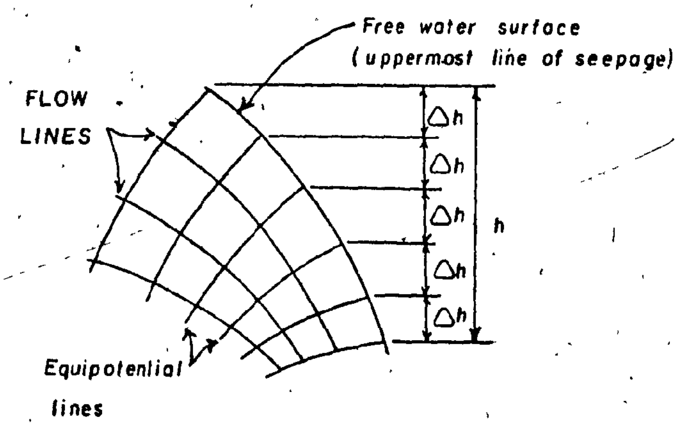


Fig. 3.1 — General conditions for seepage lines.

dual paths is nearly infinite, the flow lines drawn in any flow net are but a few of the paths that water can take in flowing through a cross-section.

3.3 Inflow-Outflow and Continuity Equations

The inflow-outflow concept is the basic step towards a comprehensive design to eliminate the exesss water from pavements. For the structural sections of a road not to be filled with excess water, the outflow capabilities of the pavements must be at least equal if not greater than the inflows from all sources, i.e.:

$$\Sigma O \geqslant \Sigma I \quad \ldots\ldots\ldots\ldots \quad (3.5)$$

In Eq. 3.5, I represents all inflow sources and O represents all outflow sources. Taking into account all possible inflow and outflow sources, Eq. 3.5 can be written in a more comprehensive form as:

$$O_E + O_S + O_P + O_R + O_D \geqslant I_S + I_C + I_T + I_H \quad \ldots\ldots \quad (3.6)$$

The terms in the above equation have the following meanings:

O_E = surface evaporation (usually negligible)

O_S = loss by lateral seepage

O_P = loss by subgrade percolation or drainage

O_R = loss by pumping through cracks or joints

O_D = water removed through subsurface drainage

I_S = surface infiltration (often major source)

I_C = capillary water from water table (usually minor)

I_T = water transfer from adjacent wet areas or from underlying ground-water or springs, etc.

I_H = hydrogenised water (usually negligible).

In the past, it was believed that I_C and I_H were major contributors to excess water pressure in highways and I_S was almost negligible. However, numerous investigations by the FHWA have shown that I_S (surface infiltration) largely from rainfall, and I_T (for ground-water), are the only significant source of water in pavements. In cases where surface infiltration is the only major source of inflow, and O_S, O_P, and O_R are small enough to be neglected, the outflow-inflow balance becomes:

$$O_D \geqslant I_S + I_T \quad \ldots \ldots \ldots \ldots \ldots \ldots (3.7)$$

It is preferable to include a factor of safety, C, in estimating the quantities of water that need to be removed. Including this assumption, Eq. 3.5 becomes:

$$\Sigma O \geqslant C \Sigma I \quad \ldots \ldots \ldots \ldots \ldots \ldots (3.8)$$

and consequently Eq. 3.7 can be written as:

$$O_D \geqslant C(I_S + I_T) \quad \ldots \ldots \ldots \ldots (3.9)$$

Most actual situations in highways can be truly represented by Eq. 3.9. However, in reaching realistic solutions when estimating the permeability, the safety factor, C, ought to be at least 4 or 5. Here, Darcy's Law or flow nets may be used for making this estimate. Then the required thickness of the primary drainage layer can be determined from the transmissibility of the base.

Referring to Fig. 2.4 and examining the potential flow path designated as A-B, B-C, C-D, D-E, E-F, and by letting Q represent the seepage discharge capabilities of the various parts of the flow sequence (estimated by Darcy's Law or any other analytical or experimental method), the following expression needs to be satisfied if water is to be evacuated successfully from pavement structures:

$$Q_{AB} \leq Q_{BC} \leq Q_{CD} \leq Q_{DE} \leq Q_{EF} \quad \text{. . . . . (3.10)}$$

This concept is called the equation of continuity. Both Eqs. 3.9 and 3.10 are useful in developing a design criterion for a subsurface drainage system.

3.4 DRAINAGE TIME ESTIMATION

Along with inflow/outflow and continuity equations, the time factor is a fundamental element in developing a drainage design theory.

An efficient drainage system should take into consideration the time factor, which should be fast enough not to permit the pooling of water long after a storm. This is particularly important in cold regions in which freezing occurs to significant depths; calculations should be made to make certain that no water can remain in structural section drainage layers long enough to freeze.

Travel times in drainage systems can be determined using Darcy's Law to calculate the seepage velocity, v_s. Thus,

$$t = s/v_s \quad \text{. . . . . (3.11)}$$

where s = distance and t = travel time. The FHWA Guidelines suggest that for highways the maximum travel time for water in cold regions to be 1/2 hour and in all other areas where drainage is needed an allowable time of one hour to be used.

Another important element of the time factor is the amount of lag in the fall of saturation after inflow ceases. If effective subsurface drains are not provided, the outflow may be largely downward into the subgrade. Flow nets such as the one shown in Fig. 3.2 can provide a way to estimate the outflow by subgrade drainage. From a flow net, the total

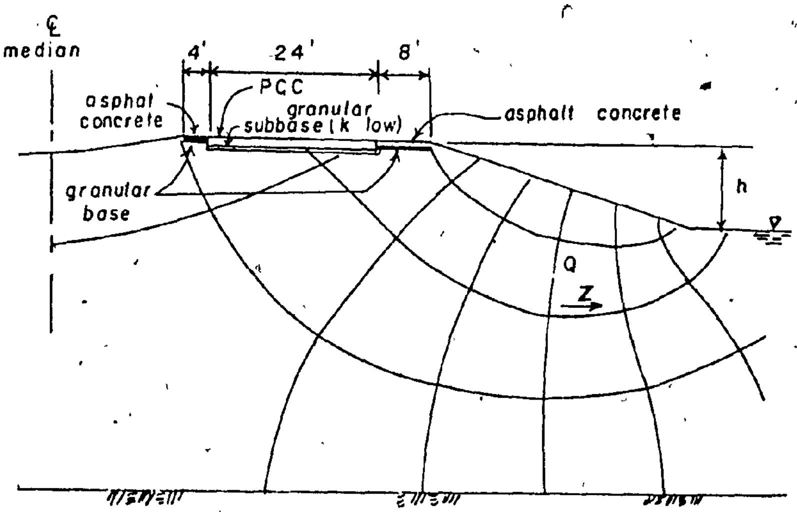


Fig. 3.2 — Outflow by subgrade drainage [16].

seepage quantity can be estimated as follows:

$$Q = khn_f/n_d \quad \quad (3.12)$$

where k is the effective permeability in the downward direction, h is the head causing the flow, n_f/n_d is the shape factor of the flow net in which n_f is the number of channels and n_d the number of equipotential drops.

Another way to calculate the rate of downward seepage is by using

$$Q = kiA$$

where the hydraulic gradient can be determined by measuring the spacing between equipotential lines under the structural section and computing "i" from i = h/l. For the calculation of unit seepage quantity (where A=1 sq. ft.), Eq. 3.1 becomes:

$$q = ki \qquad (3.13)$$

To estimate the time taken to drain the road structure after a rainfall stops, the following procedure is considered. If the volume of the water contained in joints, base layers, voids, and pore spaces in pavements is designated as Q_p, then the time for this quantity of water to drain out is estimated from the equation:

$$t_{100} = Q_p/q_s \qquad (3.14)$$

where t_{100} represents the time for 100% of the quantity of water Q_p, and q_s is the rate of discharge (downward seepage into the subgrade).

Supposing a base drainage is designed with longitudinal collector pipes, the following formula may be used for relating the factors affecting the rate of drop in saturation in the base after it has become completely filled with water [40]:

$$t_{50} = \frac{n_e D^2}{2880\ kH_0} \qquad (3.15)$$

where —

t_{50} = the time for 50% drainage sloping base

n_e = effective porosity

D = sloping width

k = permeability coefficient in ft/min

H_0 = H + sD, where H is the base thickness and s is the cross slope of the base.

When coefficients of permeability are expressed in feet per day, the latter formula becomes:

$$t_{50} = \frac{n_e D^2}{2kH_o} \quad \ldots \ldots \ldots \ldots \quad (3.16)$$

Equations 3.15 and 3.16 are useful in calculating the total number of hours per year that free water can remain in a structural section due to surface infiltration. This depends on local rainfall rates that will exceed any given amount. The rainfall rate that can keep a given pavement filled with water will vary with the width of the pavement, its slope, its surface runoff characteristics, components and permeabilities of structural sections, the permeability of the subgrade, and the depth of the water table, where most of these parameters are taken care of in Eq. 3.15.

For example: given n_e = 25%, D = 22 feet, k = 10,000 ft/day, H = 1.5 ft and the combined slope (road and shoulder) is 0.038. From this data, H_o = 1.5 + 0.038(22) = 2.336 ft. and from Eq. 3.16, t = 0.25(22)²/ 2(10,000)(2.336) = 0.0026 days or 3.73 minutes, which represents the time for 50% drainage for the given road conditions.

3.5 Estimating Inflow Rates

In the right-hand side of Eq. 3.6 the inflow sources I_C and I_H usually contribute very small quantities of water, the inflow for practical solutions can be sufficiently realistic if I_S and I_T are considered for design purposes. In the case of I_T, if the slopes are done properly, the problem of wet shoulders could be disregarded also, and if the highway profile is well positioned and well constructed, then this will take care of the problem of wet areas, while proper culvert design and construction will eliminate problems due to springs. The only element that remains to be estimated in I_T is the underlying ground-water. Therefore, basically two types of inflows need to be determined; surface infiltration and ground-water inflows.

3.5.1 SURFACE INFILTRATION

The amount of surface infiltration depends upon two factors: (a) the amount of water allowed into the drainage layer by the wearing course, i.e., the permeability of the wearing course, and (b) the amount of supply available (design precipitation rate).

The permeability factor that evaluates seepage due to surface infiltration is used under the term 'global permeability' (k_g) which is the average or effective coefficient of permeability of a small amount of pavement including discontinuities such as cracks, joints, or other open areas that allow water to enter. If a pavement is built on an open-graded (macadam) type road with subdrainage system, the average global permeability can be calculated by measurement of the outflow from the drains during and after rainstorms. Another way to estimate the global permeability of pavements is to conduct an inflow test on pavements in places where the pavement at the spot has a free discharge underneath.

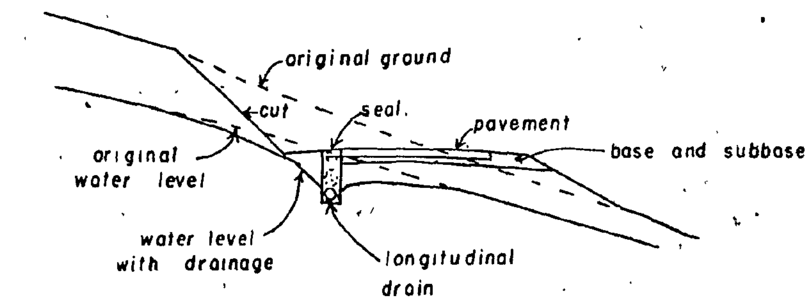
When dependable values become available on the 'global permeability' they could offer a practical method of estimating the surface water infiltration. But the amount of the water entering a pavement depends on many other important factors as well, such as age and condition of the pavement, maintenance and effectiveness of sealing operations. For large paved areas, the true permeabilities are estimated on the basis of design precipitation rates.

The U.S. Federal Highway Administration Guidelines have recommended using hour per year frequency precipitation rates as a design precipitation rate. This is translated to the maximum rainfall in one hour that can be expected to occur on the average once a year. There are maps where hours per year frequencies are provided, serving as a general guide for design, illustrating practical design precipitation rates.

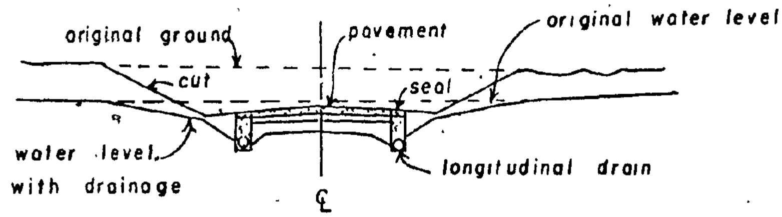
According to the mentioned guidelines, for the design of infiltration rates, only one-third to two-thirds of the design precipitation rate is used, because only a certain percentage of a given rainfall will infiltrate the pavement, while the remaining percentage will flow to the side ditches following the transversal slope of the highway. To obtain the design infiltration (surface) rate for Portland cement concrete pavements, the Guidelines suggest multiplication of the design infiltration rate with a factor varying between 0.50 and 0.67, and between 0.33 and 0.50 for asphalt concrete pavements.

3.5.2 GROUNDWATER INFLOWS

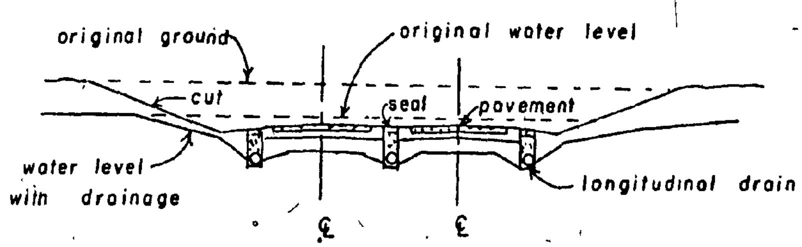
The effects of ground-water over highways both in cut and fill conditions have been previously mentioned. However, the most convenient way to control it is by using a subsurface drainage system at critical sections or wherever they become necessary. Figure 3.3 shows typical longitudinal drains for several roadbed conditions and ground-water levels needing control. Figure 3.3a shows control over sidehill seepage, while Fig. 3.3b illustrates the necessity of fairly deep longitudinal drains when the cut is below the elevation of the normal water table; Fig. 3.3c deals with wide road control over ground-water with three lanes of longitudinal drains.



(a)



(b)



(c)

Fig. 3.3 — Longitudinal drains for different roadbed conditions [10].

The need for drains is determined through piezometer readings, observation wells, general observations, etc. Where adequate drains are not provided, water can often be seen bleeding from joints or cracks in highways. In estimating inflows, any ground-water or other sources of inflow that may be anticipated to reach the pavement sections should be added to surface infiltration in determining the amount to be removed by the subsurface drainage system. When ground-water seepage quantities are evaluated, they should be of the same unit as the surface infiltration unit (say inches/hour).

Suppose that it is expected that ground-water will be flowing upward into a structural section from an underlying permeable aquifer. In such a situation, effective soil permeability and hydraulic gradient also play significant roles. Fig. 3.4 is a chart giving the equivalent infiltration per square foot of roadbed for a range of subgrade permeabili-

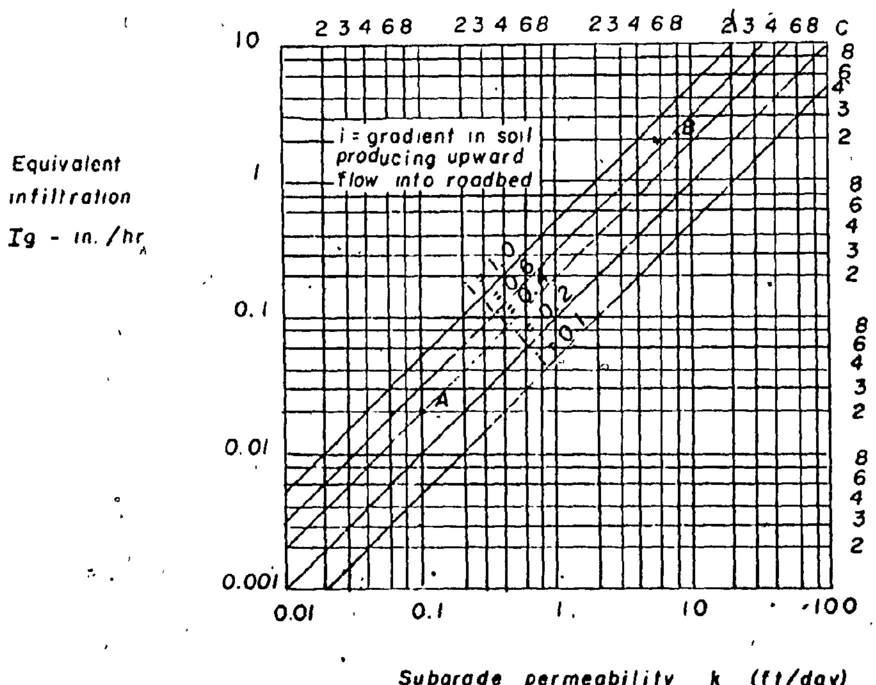


Fig. 3.4 — Subgrade permeability in function of equivalent infiltration per square foot of roadbed [29].

ties and hydraulic gradients. If soil permeabilities are relatively low (generally under 0.1 ft/day or 3 x 10^{-5} cm/sec), the inflowing quantities will usually be insignificant compared to the surface infiltration.

3.6 ESTIMATING OUTFLOW RATES

Considering the factors which appear on the right hand side of Eq. 3.6, it can be assumed that the outflow due to surface evaporation, O_E, and loss by pumping, O_R, are negligible for design purposes. Only a small amount of loss occurs through O_E and O_R compared to the total loss.

When over longer periods of time, part of the inflow into the pavement will eventually percolate downward to the subgrade, the resulting outflow factor, O_P, will be small if the subgrade has low permeability. However, in areas where the subgrade has high permeability, the amount of outflow will be significant, and in warm weather it will provide adequate drainage. This is not true in cold regions because in the spring, for example, water from melting ice and rainwater will mix and become trapped in the pavement sections and the top of the subgrade by unmelting ice beneath it. This is known as the 'spring breakup' that can severely damage pavement.

In this report, methods of estimating O_S and O_P will be examined and then lateral drainage of base courses and drains will be discussed.

3.6.1 DRAINAGE THROUGH SHOULDERS

Usually, the drainage through shoulders is insufficient to eliminate excess water rapidly. This is mainly due to the type of materials used in shoulders which are fine-grained. However, in Oregon, where gravel 'ballast' having a gradation from 1/4 to 1 1/2 inches was used, good shoulder drainage due to high permeability was attained [9]. If rounded aggregates are used, they will eventually be shoved under traffic. This can be eliminated if highly angular materials are used under the shoulders.

A convenient method of calculating the outflow through shoulders is by Darcy's Law in the form $q = kh(n_f/n_d)$ (which is incorporated with flow nets). An example to illustrate the procedure follows. Assume that a shoulder is over a granular blanket and the main discharge is due to the joint between the pavement and the shoulders and from the structural section. If h = 2 ft. (thickness of the base & subbase and AC) and n_f/n_d = 0.06, then q = 0.12(k). Different coefficients of permeability would yield different values for the discharge. Since the conventional materials for base and subbase have coefficients ranging from 1 to 10 ft/day or less, then the corresponding discharge according to the relationship is 0.12 ft^3/day to 1.2 ft^3/day which is not a significant amount after all.

3.6.2 DRAINAGE INTO SUBGRADES

Normally, compacted subgrades have a coefficient of permeability of the order of 10^{-3} cm/sec (0.03 ft/day) [29]. This indicates that any beneficial drainage into subgrade is often quite small. Table 3.1 gives possible drainage rates into subgrades for pavements in fill. In Table 3.1 the natural water table is assumed to be relatively deep. According to Table 3.1 drainage into subgrade is generally considered almost negligible.

Subgrade permeability, k		Drainage rate
cm/sec	ft/day	(ft /day/lin.ft)
1×10^{-6}	0.003	0.02
1×10^{-5}	0.03	0.18
1×10^{-4}	0.3	1.8
1×10^{-3}	3.0	18.0
1×10^{-2}	30.0	180.0

Table 3.1 — Possible drainage rates into subgrade for pavement on an embankment [29].

3.6.3 BASE DRAINS, BASE COURSES AND LATERAL DRAINAGE

If pavements on impermeable subgrades include longitudinal pipe drains along lower edges, the only significant drainage often occurs by lateral seepage to the edge drains. The geometry of the road's cross-section alone can do little in helping to achieve better drainage of bases. A dramatic improvement can be obtained if highly permeable materials were used in base construction. There are two factors that are important in seepage of flat layers; the thickness of the layer and the hydraulic gradient. In base drainage, both are relatively small, thus the permeability of the base material is crucial for drainage purposes.

Considering a typical road cross-section like the one illustrated in Fig. 2.4, where the drains are at the beginning of the base level, two important behaviours can be expected from such a situation: the number of flow channels in the flow net increases in proportion to the number of joints feeding water through the pavement and the hydraulic gradient becomes steeper in the vicinity of the collector pipe. Based on these factors, if a flow net is constructed the minimum required permeability of the drainage layer is proportional to the transmissibility of the layer. Incidently, because the thickness of the base layer is generally small, it is difficult to construct flow nets for seepages. Therefore, most solutions of this report will use the total inflow quantity and the slope of the drainage layer (or hydraulic gradient) in estimating required coefficients of permeability by Darcy's Law; although this approach involves simplifying approximations, the simplification is generally on the conservative side. Figure 3.5 illustrates the discharge capabilities (estimated by Darcy's Law) of drainage layers having a thickness of 6 inches.

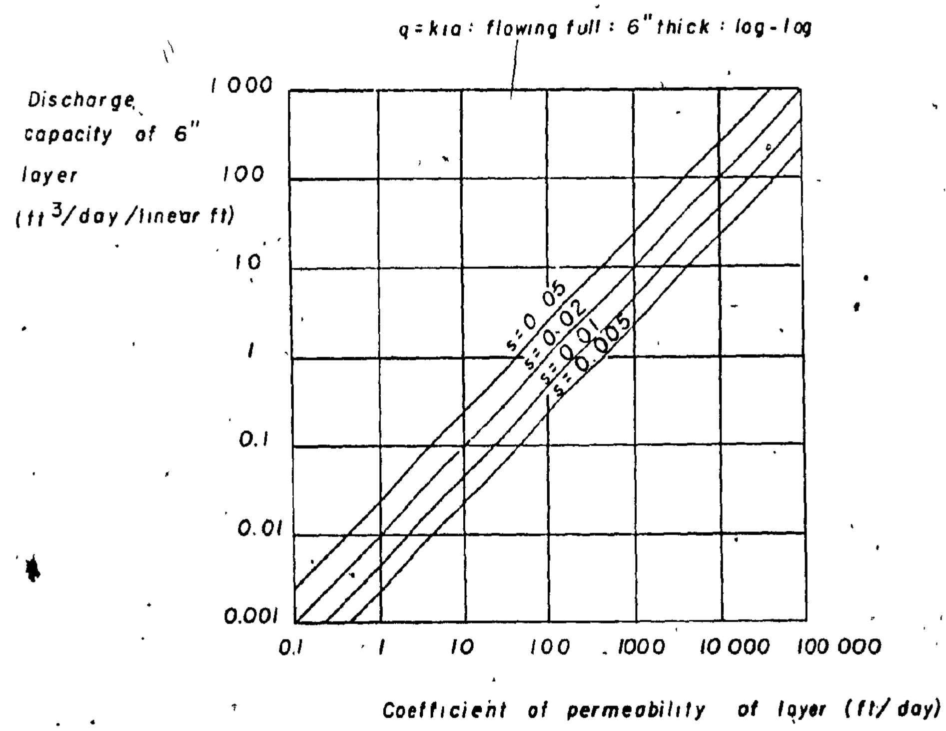


Fig. 3.5 — Discharge capacity of a 6-inch layer in function of the coefficient of permeability of the layer [16].

In a study of agricultural lands with tile drains [26], the following equation for surface infiltration for flat layers that can be removed by the drains was developed:

$$q = kh^2/b^2 \quad \text{. . . . . (3.17)}$$

where —

q = the uniform surface infiltration discharge to side drains

k = the coefficient of permeability of the soil

h = the thickness

b = half the distance between drains.

Equation 3.17 can be proven by employing Eq. 3.12, obtained independently from Eq. 3.17, where (in Eq. 3.12), 'h' is the thickness of the layer.

After studies on the shape factor of different base layers, it was established that it is approximately equal to the ratio h/b of the base in question. Dividing both sides of Eq. 3.12 by 'b' and rearranging:

$$q/k = (h/b)^2 \quad \text{. . . . . (3.18)}$$

According to Eq. 3.18, wide shallow layers would be much slower draining than a narrow relatively thick layer of the same material and permeability. Also, it can be expected from geometry alone that wider pavements will be more difficult to drain than narrow ones.

Having presented briefly the theoretical aspects, the following chapter will proceed to describe design practices.

CHAPTER IV

PAVEMENT SUBSURFACE DESIGN

4.1 GENERAL

In the process of developing a design procedure for subsurface drainage, numerous studies have been carried out in order to investigate the cause of failure of poorly drained pavements. Morrison [28] for instance, has attributed failure to poor subgrades, inadequate drainage or lack of maintenance. The U.S. Army Corps of Engineers [41] have undertaken studies on base coarses on frost-susceptible subgrades and have come to the conclusion that the pavement thickness and base thickness were not sufficient to prevent the formation of ice lenses in the subgrade. Based on the experiments of FHWA, where several segments of roads were constructed with a definite drainage system, it was found that such roads had more resistance to failure than conventional roads.

Supposing that it is decided to provide a subsurface drainage system for a given segment of a highway, the first issue coming to mind is the composition of the subsurface drainage system. A subsurface drainage system has the following components:

1. An open-graded base drainage layer, located directly under AC or PCC, starting at one side of the pavement and extend-

ing to the other side, encircling the collector pipe

2. A suitable sub-base or filter layer and where necessary, an impervious membrane over the sub-grade. In Canada, an additional layer is used as sub-foundation

3. A collector drain (perforated or slotted) that runs longitudinally. In cold regions the drain is placed in a rectangular trench below frost penetration level. In normal or mild regions, it is placed in a shallow V-trench

4. Outlet pipes which run out of the road structure transversly enabling the water to reach the longitudinal side ditch

5. Outlet markers on visible posts which protect extending pipes, and indicate the location of the pipes for routine maintenance checks.

However, based on the conclusions of the FHWA [17], highway designers should consider the following situations where subsurface drains are not needed:

a. In locations where ground-water, spring inflow, etc., are absent, the annual rainfall is below 8 inches, and the amount of snow or ice which reaches structural sections of pavement is insignificant

b. In locations where the subgrade is very permeable and the natural water table is very deep, plus the subgrade is not subject to freezing conditions

c. The road itself is not subject to heavy traffic.

4.2 Base Layer Requirements

As far as the drainage system in question is concerned, the base layer has to be very permeable (having a coefficient of permeability of at least 3000 feet per day). In order to obtain high permeability, certain gradation of clean aggregates has to be used; this gradation can contain any of the following sizes [44]:

a. max. 3/8" to min. No. 4

b. max. 3/4" to min. No. 4

c. max. 3/4" to min. 1/2"

d. max. 1" to min. No. 4

e. max. 1" to min. 1/2".

However, to obtain the most optimum gradation, there are two criteria concerning the open-graded materials for the best drainage layer which should be met viz. :

1. The 85 percent size of open-graded aggregates should be less than 4 times the 15 percent size; the purpose of this is to narrow the range of particle size. This criterion is expressed mathematically by the following equation:

$$D_{85} \text{ (85\% is finer)} < 4D_{15} \text{ (15\% is finer)} \quad \ldots\ldots\ldots \quad (4.1)$$

2. For the purpose of preserving cleanliness of aggregates, 2% of the layer should be at least 0.1 in. in diameter; this is expressed by the following equation:

$$D_2 \text{ (2\% is finer)} \geqq 0.1 \text{ in.} \quad \ldots\ldots\ldots\ldots\ldots \quad (4.2)$$

Figure 4.1 is a useful chart for approximately determing D_{15} of the aggreates once the coefficient of permeability is known, or, vice-versa.

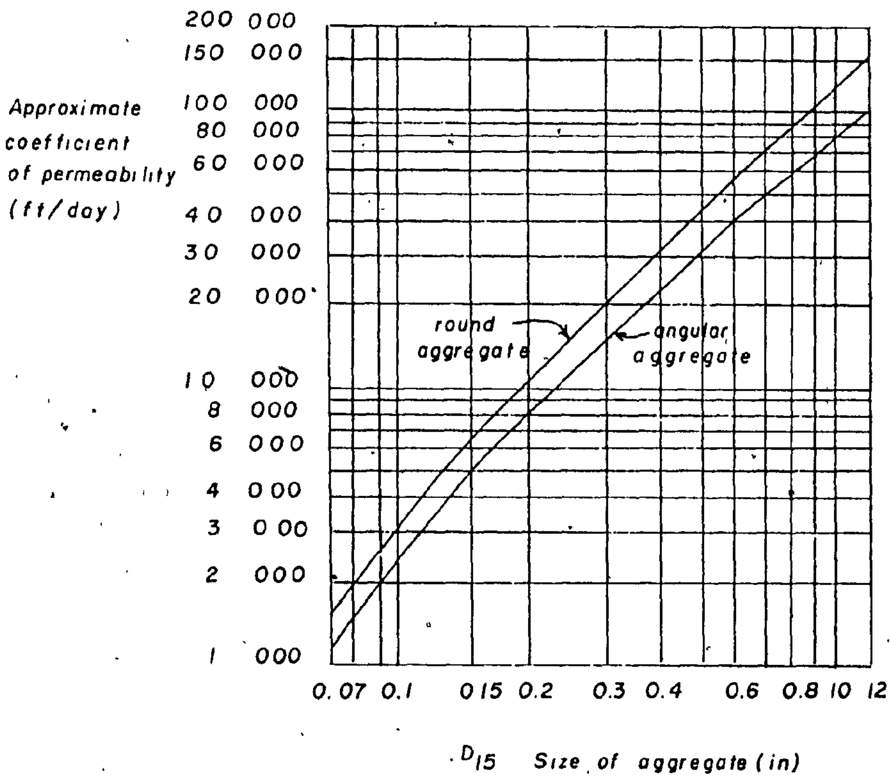


Fig. 4.1 — Rough guide for estimating coefficient of permeability of narrow size-ranged aggregates with no fines [9].

4.3 DESIGN PROCEDURE

The design method, presented herein, was developed by FHWA [17]. It is practical and its operations are carried out with the aid of prepared charts. It is composed of the following basic steps:

a. outflow water quantity

b. water flow required time

c. diameter and spacing of the collector pipe.

Once these three steps have been determined and checked the results should yield an adequate design.

4.3.1 OUTFLOW WATER QUANTITY

To evaluate the quantities that can be removed, Darcy's law can be employed. The most important factor of the base layer in a drainage design is its transmissiblity.

$$\text{Transmissibility} = kA = \frac{Q}{I} \quad \ldots \ldots \ldots \ldots \ldots (4.3)$$

Transmissibility may be expressed as kt where t is the thickness of the drainage layer (because A = t x 1 foot). Figure 4.2 represents various transmissibility curves where the drainage layer clear thickness is plotted against the coefficient of permeability of the layer's material. If the transmissibility and the coefficient of permeability of the layer are known, then the thickness of the layer can be determined from this chart. It can be seen from Fig. 4.2 that for a given value of transmissiblity, the required thickness of the drainage layer decreases as the coefficient of permeability increases. Theoretically, maximum value can be achieved by using materials with highest coefficient of permeability.

Another useful chart is Fig. 4.3, where inflows (including surface infiltrations and any other inflows converted to unit infiltration), are plotted versus width of pavement for different coefficients of permeability. In this chart two assumptions are made: firstly, the thick-

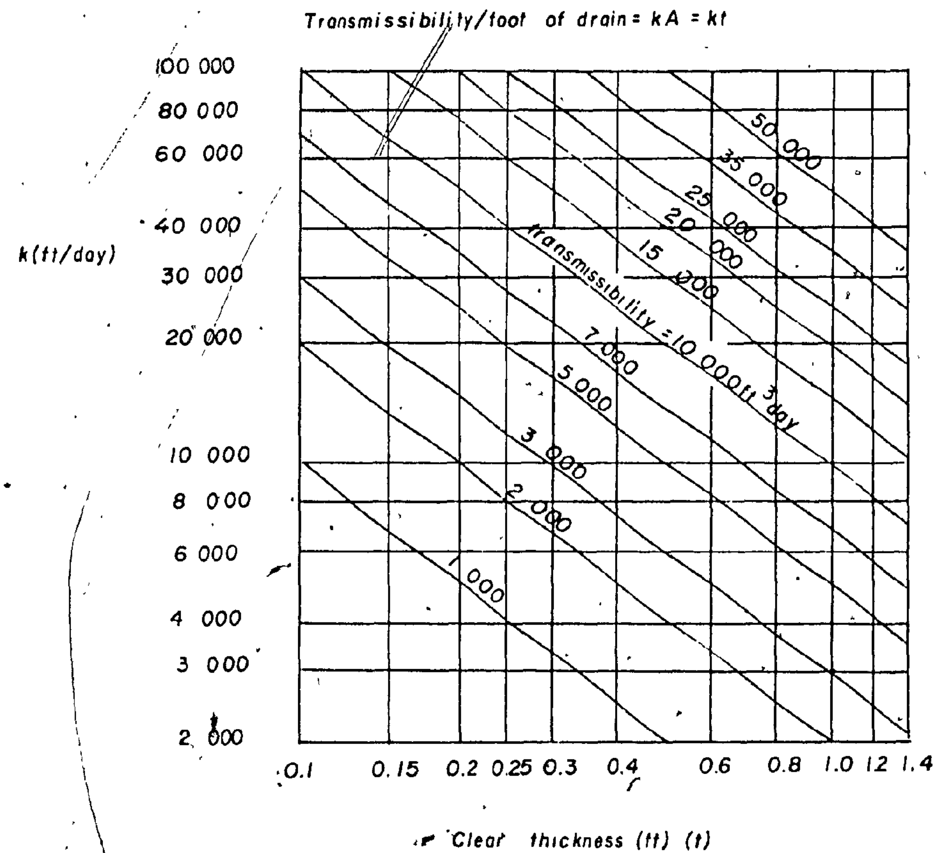


Fig. 4.2 — Transmissibility of drainage layers — cu. ft./lay/foot [9].

ness of the layer is 0.5 ft. and secondly, a cross-slope of .01 is equal to the average hydraulic gradient in a drainage layer. This chart helps the designer to differentiate between the drainage capabilities of a standard-type of base layers (lower lines) and open-graded base layers (upper lines) which are recommended here. For example from Figure 4.3, a pavement about 33 ft wide (equivalent to 3 lanes) with a coefficient of permeability of 10,000 ft/day can remove a total inflow rate of 1 in./hour.

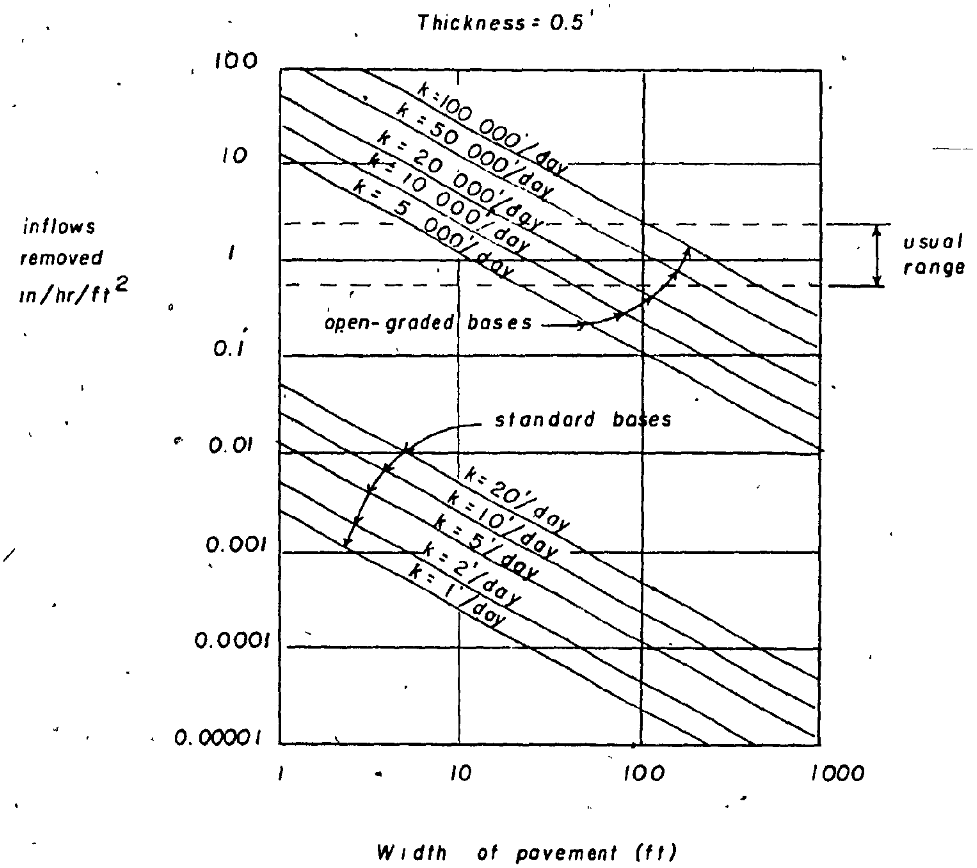


Fig. 4.3 — Capabilities of bases with edge drains to remove infiltration. Lower lines are for standard types of bases; upper lines are for open-graded base, s = 0.001 [9].

In order to check the required coefficient of permeability in actual design, Fig. 4.4 is very useful. It can be utilized for determining the required thickness and permeability of open-grade subsurface drainage layer that will remove a specified design infiltration rate, I. The value of I should be determined from maps at 1 hour/1 year frequency precipitation rate as recommended by FHWA 1973 guidelines. A factor of 1/3 or 2/3 should be applied (as it was mentioned earlier), to determine the design infiltration rate I. The parameters in the chart are identified as follows:

w = total width of drainage layer and pavement (ft)

I = design infiltration rate (in./hr.)

C = $k_b t_b$ (in.ft./day) = coefficient of transmissibility

k_b = permeability of drainage layer (ft./day)

t_b = thickness of drainage layer (in.)

s = cross-slope of pavements

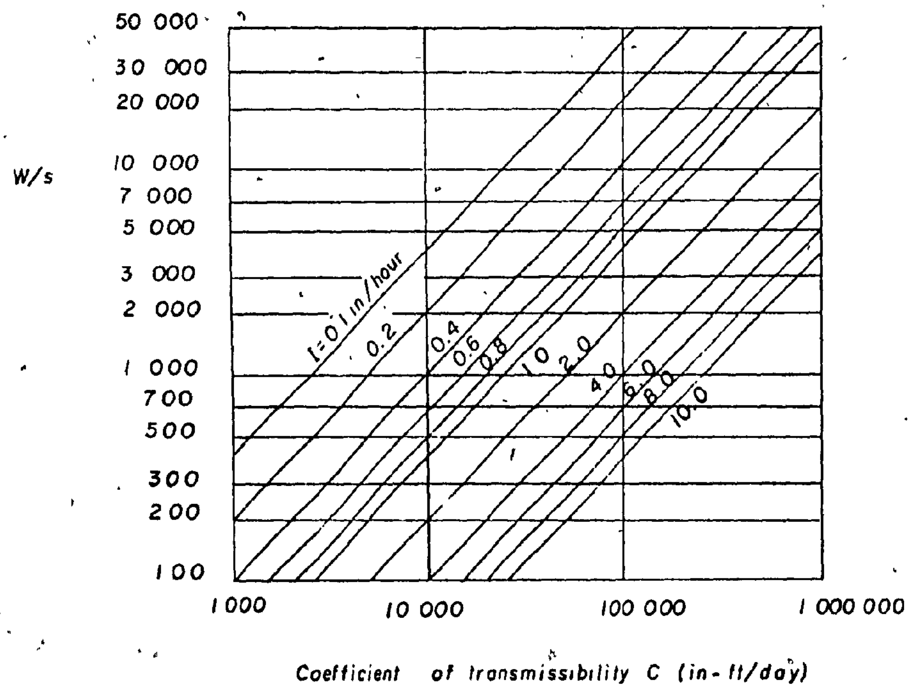


Fig. 4.4 — Coefficient of transmissibility versus w/s ratio [17].

In designing a drain, the actual thickness of the drainage layer should be one inch greater than the theoretical thickness determined from Darcy's law; this is a safety factor against contamination of upper and lower limits. As an illustration, assume that an open-graded layer will be employed in pavement as part of a subsurface drainage system. Let the thickness of the layer be 5 in., the width of the pavement 24 feet and the cross-slope 2%. Therefore, $w/s = 24/.02 = 1200$ ft. If the design infiltration rate is 1.5 in./hour, then from the chart, the required coefficient of transmissibility is 50,000 in.ft./day. Thus from the equation $C = k_b t_b$, the required coefficient of permeability $k_b = 10{,}000$ ft./day which falls in the usual range of Fig. 4.4.

4.3.2 WATER FLOW REQUIRED TIME

After finding the capacity of the drainage layer for water removal, the next important step is to determine the maximum required time actually needed for water to be completely out of the pavement. In cold regions, no significant amount of water that enters should remain long enough to freeze during sudden drops in air temperature. During temperature fluctuation periods (freezing at nights and warming during the daytime), water can change rapidly from a freezing to liquid state causing repetitive damages which must be prevented by 'fast' drainage.

In order to determine the time, Darcy's law is employed. For any assumed travel time the coefficient of permeability can be calculated, however, the chart of Fig. 4.5 facilitates this task. This chart represents a family of curves of highway thicknesses from 3 in. to 9 in. The grade of the highway is plotted versus base coefficient permeability for one-, two-, three- and four-lane highways. In this chart the cross-slope is taken as

0.02 (most common) and the effective porosity, $n_e = 0.2$; for an allowable drainage time of 1 hour, each lane is taken as 12 ft [17]. A simple example

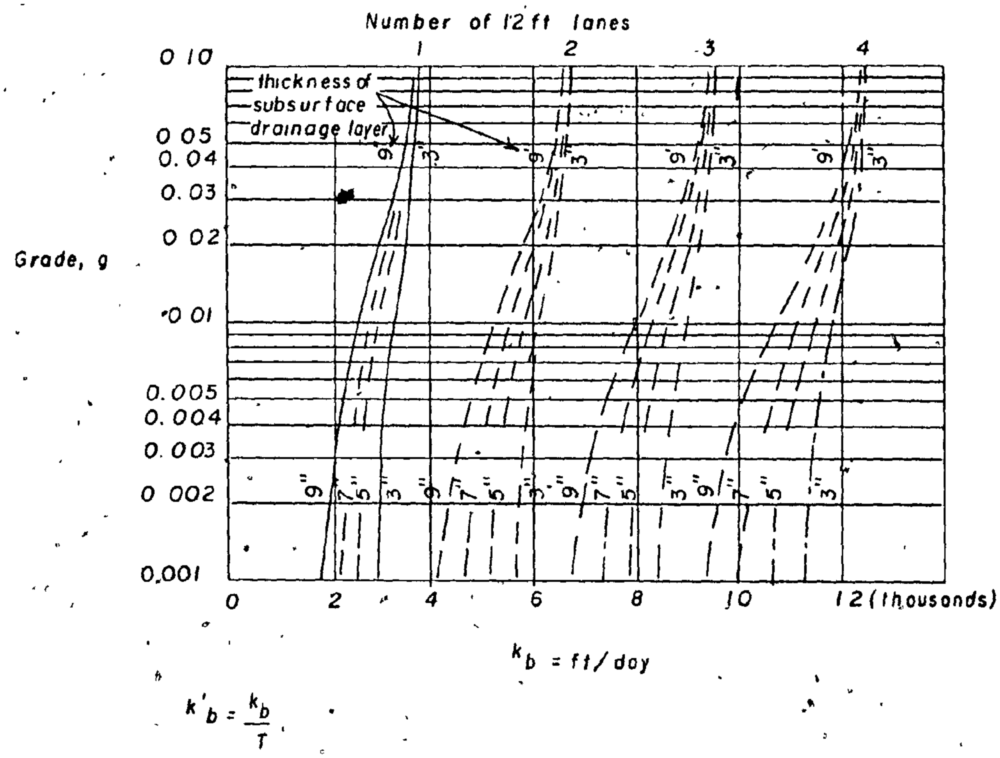


Fig. 4.5 — Permeability required in order to drain subsurface drainage layer in 1 hour or less [17].

will illustrate the use of this chart. Suppose that a two-lane highway, having longitudinal grade of 3 percent (g = 0.03) and a 5" thick layer, requires to have a minimum coefficient of permeability of 13,000 ft./day to remove the design infiltration. In order that the maximum travel time does not exceed 1 hour, Fig. 4.5 can give a satisfactory check by entering the 5-inch drainage layer for two-lane highways having a grade (g) of 0.03; the coefficient of permeability can be read at the bottom of the chart as 6,300 ft./day. This is less than 13,000 ft./day. Therefore, the design is satisfactory; in other words, the road possesses a coefficient of permeability for the given condition of 13,000 ft./day for which 6,300 ft/day is the minimum required value. A comprehensive example is given at a later stage.

Should a shorter travel time be needed, the following formula could be used to determine the minimum allowable permeability:

$$k_b' = \frac{k_b}{T} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4.4)$$

where

T = desired time

k_b = permeability of drainage layer with T (time to drain) = 1 hr.

k_b' = required permeability of drainage layer when T is less than 1 hour.

The value of k_b is obtained from the chart for 1 hour. Using the same numerical example, with the required time being 45 minutes instead of 60 minutes, then k_b' = 6300/0.75 = 8400 ft/day which is still less than 13000 ft/day.

4.3.3. <u>DIAMETER AND SPACING OF THE COLLECTOR PIPE</u>

The FHWH proposed the monograph of Fig. 4.6 which can help in determining the diameter of the perforated (or smooth bore) pipe and the distance between outlets.

Given: a) width of pavement (w) in feet

b) the design infiltration rate (I) in in/hr

c) percent pipe gradient (g),

the steps for the use of the normograph are as follows:

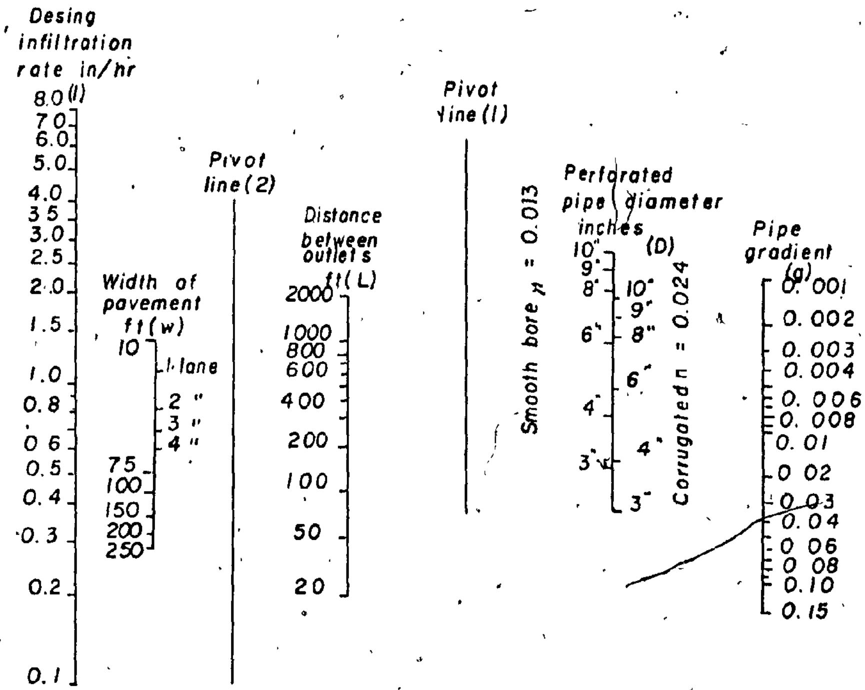


Fig. 4.6 — Normograph for solution of perforated pipe diameters and outlet spacing [17].

1. The designer assumes the type (smooth or corrugated) and the diameter of the perforated pipe
2. A line is extended from the 'pipe gradient' line through the 'diameter' line to the pivot line (1)
3. Another line is drawn from the given (I) through the given (w) to the pivot line (2)
4. The points on the pivot lines (1) and (2) are connected by intersecting 'the distance between outlets' line.

The value on the reading is the required distance for the assumed diameter.

The designer is also free to assume the spacing of the outlet pipe and use the normograph to determine the nearest required diameter. In any case, the operation should be repeated for different combinations of diameter and spacing and then the pair (diameter and spacing) most suitable for the project is chosen.

In most cases, the pipe gradient is equal to the gradient of the centerline of the pavement, although in special cases it may not be so. For instance, in areas of very flat longitudinal grades it might be more economical to steepen the grade of the pipe to permit the use of smaller diameter pipes.

4.4 Design Examples

Having acquired the basic tools and the necessary theoretical background it is now possible to solve typical actual problems to illustrate the design of subsurface drainage systems that will be adequate for:

1. The transmissibility required to drain the estimated inflow
2. The permeability required to give the inflow water the sufficient freedom of rapid flow.

4.4.1 <u>EXAMPLE ONE</u> [9]

Given: Secondary highway or Regional highway

One lane each direction (total of two lanes)

Longitudinal grade 5 percent ($g = .04$)

Cross-slope 2 percent ($S = .02$)

Design precipitation rate 2.5 in/hr

Infiltration factor; 0.5

Effective porosity of drain, 0.02

No ground-water, or subgrade effects.

<u>The required transmissibility</u>

Darcy's law should be applied on a 1 ft-wide strip in the direction of the flow. The length of the flow path $\overline{AC}$ from Fig. 4.7:

$$L = \overline{AC} = L = \sqrt{\overline{AB}^2 + \overline{BC}^2} = \sqrt{44^2 + 22^2} = 49 \text{ ft.}$$

(Since $AB = 22 \times \frac{.04}{.02} = 44$ ft)

Find the hydraulic gradient (i):

$$i = \frac{\Delta h_{AL}}{L}, \text{ where } L = 49 \text{ ft}$$

$$\Delta h_{AB} = g(AB) = 0.04\ (14) = 1.76 \text{ ft}$$

$$\Delta h_{AB} = S(BC) = .02(22) = 6.44 \text{ ft}$$

$$\Delta h_{AC} = 1.76 + .44 = 2.2 \text{ ft}$$

$$\text{Thus, } i = \frac{2.2}{49} = 0.045$$

From Darcy's law, the required transmissibility is $kA = \frac{Q}{i}$, where

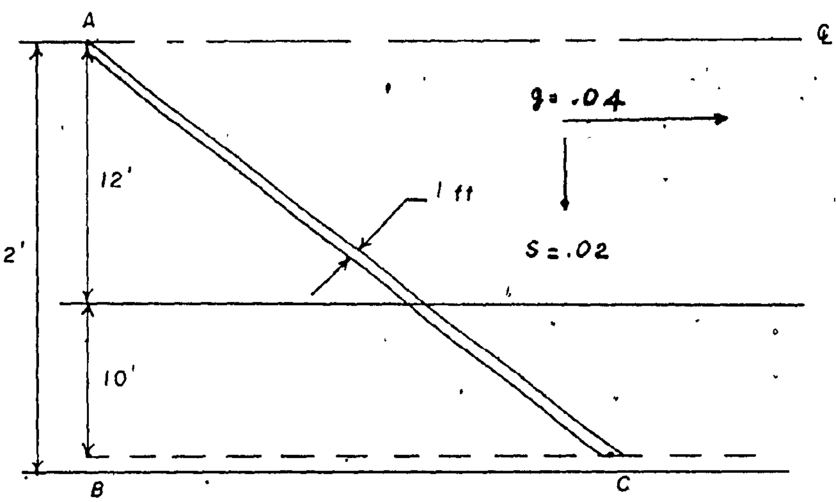


Fig. 4.7 — Data for example 1 - Secondary Highway.

the design precipitation rate is: $2.5 \times \frac{1}{2} = 1.25$ in/hr

or $g = 1.25 \text{ in/hr} \times \frac{24}{12} = 2.5$ ft/day.

Therefore, Q for all the area (49 ft²) is:

$$A = 49 \times 2.5 = 122.5 \text{ ft}^3/\text{day}.$$

Using the above equation and replacing values for Q and i, then:

$$\text{Transmissibility} = kA = \frac{Q}{i} = \frac{122.5}{0.045} = 2722 \text{ ft}^3/\text{day}.$$

This indicates that the base layer drainage for this road must have a transmissibility of at least 2722 ft³/day. Based on the above transmissibility value, the thickness of the base layer may be determined by assuming several drainage layer thicknesses and then checking their permeability. It should be mentioned that the thinner the layer, the higher the permeability.

First Assumption: Assume a drainage layer thickness of 6 in., i.e., effective thickness of 6" - 1" = 5 in. or 0.417 ft. Therefore,

$$A = 0.417 \text{ ft} \times 1.0 \text{ ft} = 0.417 \text{ ft}^2$$

$$k = \frac{kA}{A}, \text{ where } kA = 2722 \text{ ft}^2/\text{day}$$

$$k = \frac{2722}{0.417} = 6538 \text{ ft/day}$$

Second Assumption: Assume a drainage layer thickness of 4 in., i.e., effective thickness of 4" - 1" = 3 in. or 0.25 ft. Thus,

$$A = 0.25 \text{ ft} \times 1.0 \text{ ft} = 0.25 \text{ ft}^2$$

Then, from

$$k = \frac{kA}{A}, \text{ where again } kA = 2722 \text{ ft}^2/\text{day})$$

$$k = \frac{2722}{.25} = 10{,}890 \text{ ft/day.}$$

An additional analysis is required to structurally determine the bearing capacity of the layer (e.g., California Bearing Ratio Method), and most likely a 4-inch-layer is less desirable for such a highway.

A thickness of 6 in. will be used with an effective thickness of 5 in.

<u>Minimum Required Coefficient of Permeability (k)</u>

For the minimum required k the chart, on Fig. 4.4. should be used.

First, the ratio w/s is 22/.02 = 1100 ft. (It should be noted that w/s is equal to the ratio of the seepage distance to the hydraulic gradient L/i). Combining this ratio with I = 1.25 in/hr, the value of the coefficient of transmissibility C can be read from Fig. 4.4 as 33,000 in. ft/day.

As $C = k_b t_b$, then $k_b = \frac{C}{t}$ = 33,000 in.ft/day. For effective thickness of 5 inches, k_b = 33000/5 = 6600 ft/day. This is slightly higher than 6532 ft/day. However, it should be considered from a practical point of view as a valid check to the value obtained with Darcy's law for an effective thickness of 5 in.

Required (k) for a drainage time of one (1) hour

The chart in Fig. 4.5 may be used to check the required 'k' for a drainage time of 1 hour. The check is as follows: the family of curves should be used for 2 lanes since the shoulder = 10 ft; for the given longitudinal grade of 0.04 and the effective thickness of 5 in, the coefficient of permeability can be read at the bottom of the chart at 6500 ft/day. This is less than the required transmissibility (k) of 6532 ft/day. The assumed layer's drainage section is therefore satisfactory.

Size of open-graded material

After minimum design requirements have been established, the drainage layer specification would be: the thickness of the open-graded layer = 6 in. And the minimum coefficient of permeability would be: 6352 ft/day + 25% of 6352 ft/day(as safety factor) = 8165 ft/day, (say 8500 ft/day).

From the chart in Fig. 4.1, for a k value of 8500 ft/day, the layer should have a D_{15} between 0.17 and 0.20 inches.

Size of drain pipe and outlet pipe spacing

The nomograph in Fig. 4.6 is used for the spacing of the outlet pipes and drains' diameter size. A 5" diameter (corrugated) pipe is assumed. From this and g = 0.04, a line from right to left is drawn, which intercepts pivot line (1). From I = 1.75 in/hr and w = 22, a second line is drawn which intersects the pivot line (2). By joining the points on the two pivot lines, the spacing can be read as 800 ft on the distance line. Because this is a considerably large spacing (maximum spacing should not exceed 450 ft) [29], a shorter pipe spacing should be used. Thus, a 5" diameter size will remain adequate.

Summary

The drainage base layer system involves, (i) a thickness of 6 in. (ii) coefficient of permeability of 8500 ft/day (iii) D_{15} per cent size material in the range of 1/6 to 1/5 inches (iv) outlet pipe spacing of 400 ft (v) drain diameter of 5 inches (corrugated).

4.4.2 EXAMPLE TWO [9]

Given: Highway with two lanes in each direction (with shoulder 10 ft large)

Longitudinal grade of 0.006

Cross slope, s = 0.02

Design precipitation rate of 2.0 in/hr

Infiltration factor of 3/5

Effective porosity of drain = 0.2

Ground-water inflow with k equal to 12 ft/day

Ground-water upward hydraulic gradient, i = 0.4

The required transmissibility

Firstly, Darcy's Law is to be applied on a 1-ft. strip of roadway in the direction of the flow. Calculating the length of flow path AC from Fig. 4.8:

$$AB = 34 \times 0.006/0.02 = 10.20 \text{ feet}$$

$$L = AC = \sqrt{\overline{AB}^2 + \overline{CB}^2} = \sqrt{10.2^2 + 34^2}$$

$$= 35.5 \text{ feet}$$

The hydraulic gradient (i) is found as follows:

$$h_{A-B} = 10.2(0.006) = 0.0612$$

$$h_{B-C} = 34(0.02) = 0.68$$

$$h_{A-C} = h_{A-B} + h_{B-C} = 0.0612 + 0.68 = 0.74$$

$$\therefore \quad i = h_{AC/L} = 0.74/35.5 = 0.021$$

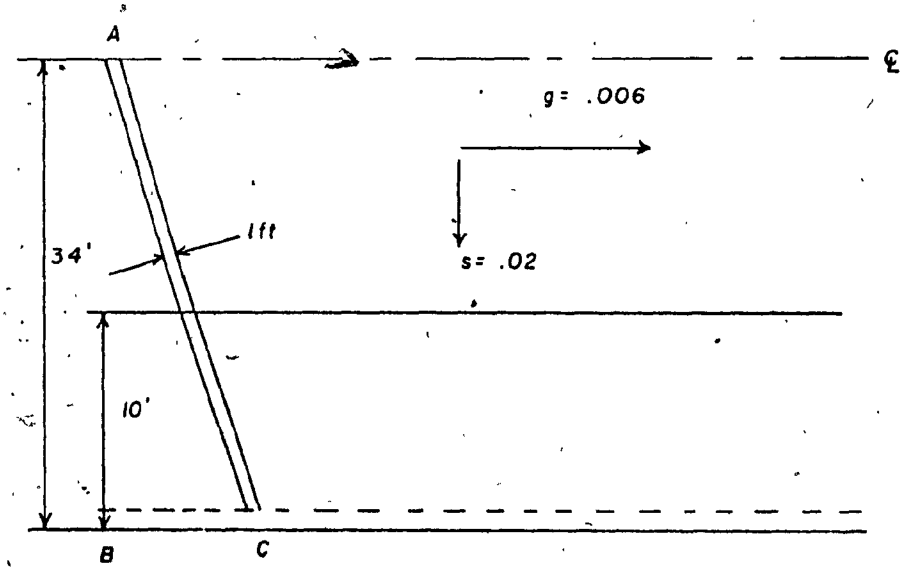


Fig. 4.8 — Data for Example 2 — Expressway.

The required transmissibility given by Darcy's Law is $kA=Q/i$.

The design precipitation rate is 2 x 3/5 = 1.2 in/hr.

q per linear foot = 1.2 x 24/12 = 2.4 ft/day.

Therefore, Q_I (due to infiltration) = 35.5 x 2.4 = 85 ft^3/day.

Here, the ground-water inflow should be elevated and added to Q_I.

With Darcy's Law, the ground-water is estimated from the following:

$$Q = kiA$$

$$Q_g = (12)(0.4)(35.5) = 170.0 \text{ ft}^3\text{/day}$$

The total Q is $Q_t = Q_I + Q_g$ = 85 + 170 = 255 ft^3/day. Hence, the transmissibility = kA = Q/i = 255/0.021 = 12,150 ft^3/day. This means that the base layer drainage for this road must have a transmissibility of at least 12,150 ft^3/day. Based on this value, the thickness of the base layer must be determined. As in numerical example 1, this can be accomplished by assuming several drainage layer thicknesses and checking the permeability, which is the most important drainage characteristic of the base layer.

First, a drainage layer thickness of 6 inches (effective thickness of 5 inches or 0.417 ft) is assumed. Thus, A = 0.417 x 1.0 ft = .417 ft. From k = kA/A (where kA = 12,150 ft^3/day), k = 12150/0.417 = 29137 ft/day.

Secondly, a drainage layer thickness of 8 inches (effective thickness of 7 inches or 0.583 ft) is assumed, where A = 0.583 ft^2. Then, k = 12150/0.583 = 20840 ft/day.

A drainage layer thickness of 9 inches is also assumed, having an effective thickness of 8 inches, or 0.67 feet, and A = 0.67 ft^2. Therefore, k=kA/A = 12150/0.67 = 18134 ft/day.

If the economic implications of each layer are compared with one another, it can be seen that the thicker (more expensive) the layer, the lower its coefficient of permeability (less expensive). However, if the lowest of permeability (18134 ft/day) and the highest of (29137 ft/day) are compared to their respective layer thicknesses, it can be seen that the 9-inch layer's is 50% more than the other layer's thickness. On the other hand, the difference in their permeability is not striking, and a permeability coefficient of 18134 ft/day is still quite high. Therefore, it is more likely that as far as the price difference relative to permeability is concerned, it is less than the difference for layer thickness.

A thickness of 6 inches would be acceptable, and structurally, a 6-inch base is adequate.

Minimum required coefficient of permeability (k)

For the minimum required k, the charts in Fig. 4.4 should be used. First, the ratio w/s is 34/0.02 = 1700 ft. Here, the ground-water should be taken into account in calculating design infiltration rate (I).

$$Q_g = 170 \text{ ft}^3/\text{day} \qquad I_g = Q/A = 170/35.5 = 4.8 \text{ ft/day}$$

Thus, $I_g = 4.8 \times 12/24 = 2.4$ in/hr.

Therefore, the total equivalent infiltration rate, that is rainfall and ground-water, equals:

$$I_t = I_s + I_g$$

$$I_t = 1.2 + 2.4 = 3.6 \text{ in/hr.}$$

Entering w/s and I_t in the chart in Fig. 4.4, the coefficient of transmissibility is found [C = 145,000 ft/day]. Therefore, k = C/t, and k = 145,000/5 = 29,000 ft/day. This is a close value compared to the one found by Darcy's Law on the first assumption.

Required (k) for a drainage time of one (1) hour

The chart in Fig. 4.5 should be used to check the required 'k' for a drainage time of one hour. The family of curves should be used for 3 lanes since the shoulder = 10 feet. Therefore, for an effective thickness of 5 inches and longitudinal grade of 0.006, the coefficient of permeability can be read at the bottom of the chart as 8300 ft/day, which is far less than required. Thus, the assumed drainage section is satisfactory.

Size of open-graded material

After the minimum design requirements have been established, the drainage layer specifications are:

- thickness of open-graded layer = 6 in.
- minimum coefficient of permeability = 29137 + .25(29137)
  = 36421 or 36500 ft/day.

From the chart of Fig. 4.1, for a k of 36500 ft/day, the layer should have a D_{15} (15 percent size) in the range of 0.44 to 0.56 inches.

Size of drain pipe and outlet spacing

Fig. 4.6 is used for the spacing of the outlet pipes and drain diameter size. A diameter of 6 inches (corrugated) is assumed. From this diameter and g = 0.006, the line from right to left intersects (1). From I = 3.6 in/hr. and w = 34 ft, a second line is constructed which intersects the pivot line (2). By joining the points on the two pivot lines, the spacing can be read which is 95 ft. This is relatively a short spacing, and if a greater diameter is chosen, a longer spacing will be obtained, which could be economical. If corrugated pipe with 8 in. ø is used instead of 6 in., the spacing is found (by the same method) to be 200 feet.

Summary

The drainage base layer description is:

- thickness of 8 inches
- k = 36500 ft/day
- D_{15} = 7/16 to 9/16 inches size

Outlet pipe:

- spacing = 200 ft
- drain diameter = 8 inches (corrugated)

4.5 Approximate Design Method

A quicker method of design can be achieved with the help of the transmissibility charts in Fig. 4.9. The chart is composed of a family of transmissibility curves roughly from 5000 ft^3/day to 80,000, plotted as 'effective thickness' in inches versus 'coefficient of permeability' k (ft/day). The coefficient of permeability ranges from 0.0 to 120,000 ft/day, while the effective thickness of the layer ranges from 0.0 to 10.0 inches. The chart was developed by the U.S. Federal Highway Administration in studying subsurface systems [17]. The designer should obtain at first hand the required transmissibility. Then the thickness of the drainage layer or the coefficient of permeability could be found by using this chart.

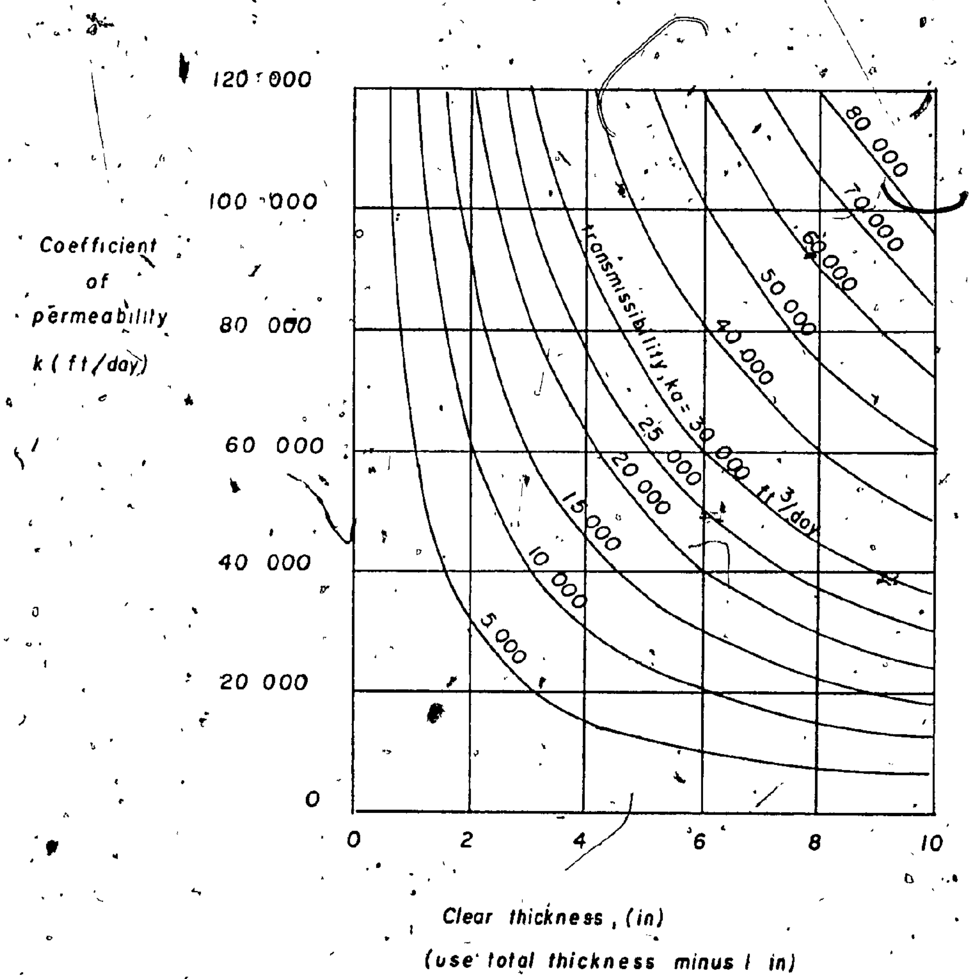


Fig. 4.9 — Combinations of permeability and layer thickness giving transmissibilities from 5000 ft³/day to 80000 ft³/day [17].

For example, assume for a certain case the coefficient of transmissibility to be 20,000 ft^3/day. For an effective thickness of 7-in. the permeability is 34,000 ft/day while for an effective thickness of 5-in., permeability is 48,000 ft/day, and for an effective thickness of 3-in., the coefficient of permeability is 80,000 ft/day. With all these values, the designer should be able to choose the most economical and structurally sound section.

For the purposes of comparison, the results of numerical examples 1 and 2 obtained by the conventional method and with the use of charts (Fig. 4.9) are displayed below:

Example	Transmissibility	Total Layer Thickness	Conventional	With a Chart
1	2722 ft^3/day	6-inch	8500 ft/day	7000 ft/day
2	12150 ft^3/day	6-inch	36500 ft/day	32000 ft/day

Table 4.1 — Comparison between the results of Example 1 and Example 2, obtained by conventional method and approximate method.

The values obtained by the chart method are close to the original values obtained conventionally (safety factor not included).

At any rate, the approximate method should be used to have only a preliminary design for the proposed drainage system; the system should be designed by the normal method.

In practice, a highway drainage system will not always perform as expected, the reasons being the many unpredictable factors such as atmospheric conditions, varying ground topography, fluctuation of the number of users of the road system, dynamic ground-water activity, contamination of materials, negligence during construction by workers, etc. Nevertheless, a proper design provides a certain assurance that under the assumed conditions, the system will perform satisfactorily.

Up to this point, the need for highway drainage was identified, the type and mechanism of damage caused by excess water was exposed, several methods of water accumulation and disposal from highway sections were described, and a criterion for controlling outflow was presented, theory and design procedures were formulated. Having covered the above mentioned parts, it is important to complement the picture in the following chapter by reviewing actual construction methods of the drainage system itself. The composition and the general trend of the used materials need to be treated. In addition, a brief remark about the maintenance of the design elements is also presented. All these will attempt to give answers to the remaining issues.

CHAPTER V

CONSTRUCTION AND DRAINAGE MATERIALS

5.1 DRAINAGE MATERIALS

5.1.1 THE BASE LAYER

In previous parts of this report, the basic characteristics of base layer materials have been mentioned. Any material which will be used in a drainage system should be tested for the following main characteristics: (a) gradation (b) durability [21] (c) resistance to fragmentation [2] (d) organic matters [42] (e) abrasion [4,3]. Some of the tests can be taken in the pit, e.g., organic matters, while other tests should be taken after the material has been hauled toward the road, i.e., in-situ gradation.

When the permeability of extremely coarse layers is tested, care should be exercised because the flow most probably will be semi-turbulent; thus, Darcy's Law may tend to over estimate the discharge capabilities of the layers. From gradation's point of view, in order to ensure high permeability and prevent segregation, the base layer's materials should not be bigger than one inch nor contain materials finer than No. 4 [16] standard sieve size. This can provide permeabilities in the range of 6000 ft/day to 120000 ft/day, which in turn will result in high values of transmissibility. For example, in a study by Childers [11], it was found that a relatively low permeability such as 100 ft/day requires that materials running into the crusher not contain more than 20 percent of particles passing #10 standard sieve size; compaction can also reduce permeability.

It may be concluded that the presence of small sized sieve particles is what mostly inhibits permeability.

In the literature, the word 'dual-layer' is commonly used in relation with subdrainage systems. This term means an open-graded layer plus a protective layer (filter). However, in cold regions, and especially when construction is carried out on unfavourable subgrades, a second protective layer (sub-foundation) is used. In the absence of the second protective layer in cold regions, the contamination of the first protective layer due to repetitive heaving and thawing will eventually clog the drainage base layer itself. The thickness of this layer is related to the subgrade soil. Table 5.1 shows some suggested thicknesses for various soils.

It should be mentioned that together with the protective layer, a material made of cloth is widely used [14]. The use of this material is practical because it is ready-made, it easily meets the specifications, and it is easy to install (it is light and can be rolled over the subgrade directly) as compared to heavy gravel-type protective layer materials.

The characteristics of both plastic filter cloths and ordinary filters are described as follows:

Soils or Ordinary Borrow Classified as—	— Sub-foundation (densified thickness, at center) — National or Regional Road	Municipal Road
GM and GC	30 cm (12 inches)	15 cm (6 inches)
SM and SC	45 cm (18 inches)	30 cm (12 inches)
CL, ML, OL*, OH*, CH, MH	60 cm (24 inches)	45 cm (18 inches)

* These organic soils should be subject to special attention.

Table 5.1 — Guide to the thickness of granular borrow materials [37].

5.1.2 FILTERS

Filter protection was introduced by K. Terzaghi to prevent heave and piping failure in dams [35]. He used coarse-grained layers placed over an appropriate 'filter' that prevented the intrusion of fines into the water-removing layer. Since then, this practice has been widely used. The U.S. Corps of Engineers established the following relationship for filter design:

$$\frac{D_{15}\text{ (of filter)}}{5} \leq D_{85}\text{ (of soil)} \quad \ldots\ldots\ldots (5.1)$$

In order to ensure uniformity of gradation, an additional criterion has been suggested:

$$\frac{D_{50}\text{ (of filter)}}{25} \leq D_{50}\text{ (of soil)} \quad \ldots\ldots\ldots (5.2)$$

If these two criteria are satisfied, the chances for soil fines to mix with the filter materials would diminish. Special care should be taken whenever the subgrade is made of highly unstable soils, such as silt, clay and unstable sand. In these conditions, a thicker layer of filter should be placed to protect the base layer.

5.1.3 SYNTHETIC FABRICS

Highway engineers are increasingly using this type of material as filter and for other uses in road construction. Some of the advantages of these fabrics are as follows:

1. It is easy and rapid to install and manipulate, e.g., it can be cut with a knife around manholes, etc.
2. Remarkable strength; most construction equipment can drive on it without tearing it
3. Highly successful in preventing clay from mixing with the highway structure.

In cold climate where an extra layer is necessary between the sub-grade and the sub-base, the use of fabrics reduces the thickness of the additional layer; it is equivalent to twelve inches of sand or any acceptable gravel [14].

Another important use of fabrics, as far as drainage is concerned, is its employment to engulf perforated pipes completely so that fine materials will not block the holes of the pipe, because fabrics are highly permeable. Table 5.2 shows the main characteristics of the fabrics [38].

The nature of the fabric consists of one of the following three categories: polyester, polyamide, and a combination of nylon fibers and polypropyline fibers [27]. In Canada, the use of the fabrics started in the early seventies; European countries used it earlier.

Filter Cloth	Type 7609	Type 7612
Primary matter	100% polyester (dia. 28 μm)	100% polyester (dia. 28 μm)
Density	1.38 g/cm^3	1.38 g/cm^3
Weight	300 g/m^2	400 g/m^2
Color	white	white
Tensile force, ASTM D1682	87 kg	110 kg
Tearing limit, 4-GP-2 12.2	45.8 kg	59 kg
Splitting limit, 4-GP-2 11.2	24.5 kg/cm^2	32.3 kg/cm^2
Stretch at rupture	70-100%	70-100%
Filtration diameter	20-80 μm	20-80 μm
Water permeability from a 35 cm head	16.7 ml/cm^2/sec	13.2 ml/cm^2/sec

Table 5.2 — Important properties of fabrics, type 7609 & type 7612 [38].

5.1.4 TRENCH DRAIN BACKFILL

The main characteristic of the backfill materials in a trench is its ability to transmit water to the drains. Whenever the natural ground is hard or unstable, a special bedding material should be used to protect the drains. The bedding is preferable to be made of uniform gradation and not containing very coarse materials. As far as backfill materials are concerned the U.S. Corps of Engineers [10] have established the following relationship between the drain openings and the backfill materials.

$$\text{For slots: } \frac{\text{85\% size of filter material}}{\text{slot width}} > 1.2 \quad \ldots\ldots \quad (5.3)$$

$$\text{For circular holes: } \frac{\text{85\% size of filter material}}{\text{hole diameter}} > 1.0 \quad \ldots\ldots \quad (5.4)$$

5.1.5 DRAINS

These pipes collect the water from the base layer and transmit it to outlet pipes. The types of drains are:

1. <u>Perforated Pipe</u>: It was first introduced in 1925 and was made of steel. In normal use, from 6- to 10-inch diameters should be adequate to most highways. Figure 5.1 shows the general layout of a perforated pipe cross-section [6]. The coefficient of roughness, n, of corrugated, perforated drains ranges from 0.013 to 0.020 [12]. Table 5.3 displays dimensions, thickness, and spacing of perforations of these pipes.

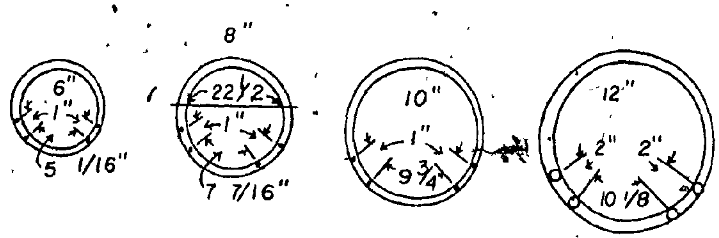


Fig. 5.1 — General layout of a perforated pipe cross-section [12].

2. <u>P.V.C.-Slotted Drains</u>: The P.V.C. pipes are more recent as compared to perforated pipes and are lighter and more flexible, thus easy to manipulate, transport and install. The width of slots varies from 0.01 up to 0.1 inches. Figure 5.2 illustrates a six-inch P.V.C. drain pipe. If slot width is correctly found by equation 5.3, then it will ensure free flow of water into the pipe without clogging.

Nominal Internal Diameter	Minimum No. of Rows of Perforations	Minimum Width Unperforated Segment	Normal Thickness Specified
6" (150mm)	4	4.5" (115mm)	.052 (1.3mm)
8" (200mm)	4	7" (180mm)	.052 (1.3mm)
10" (250mm)	4	9" (225mm)	.064 (1.6mm)
12" (300mm)	6	9.5" (240mm)	.064 (1.6mm)
15" (380mm)	6	13" (330mm)	.064 (1.6mm)

Table 5.3 — Dimensions, thicknesses, and spacing of perforation of perforated pipes [6].

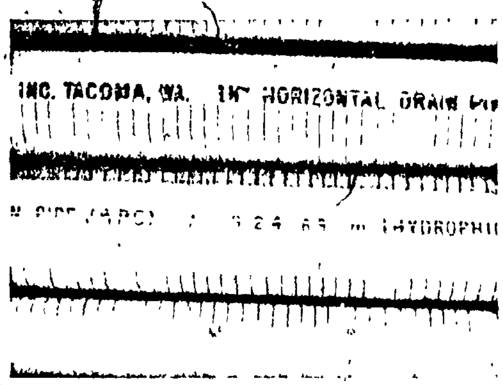


Fig. 5.2 — Slotted PVC pipe — 1/4" I.D. [10].

3. Steel-Slotted Drains: Highway surface drainage by slotted drains is a new concept. Figure 5.3 shows a typical slotted drain viewed from two different angles. Slot openings are 1-3/4" wide. The disadvan-

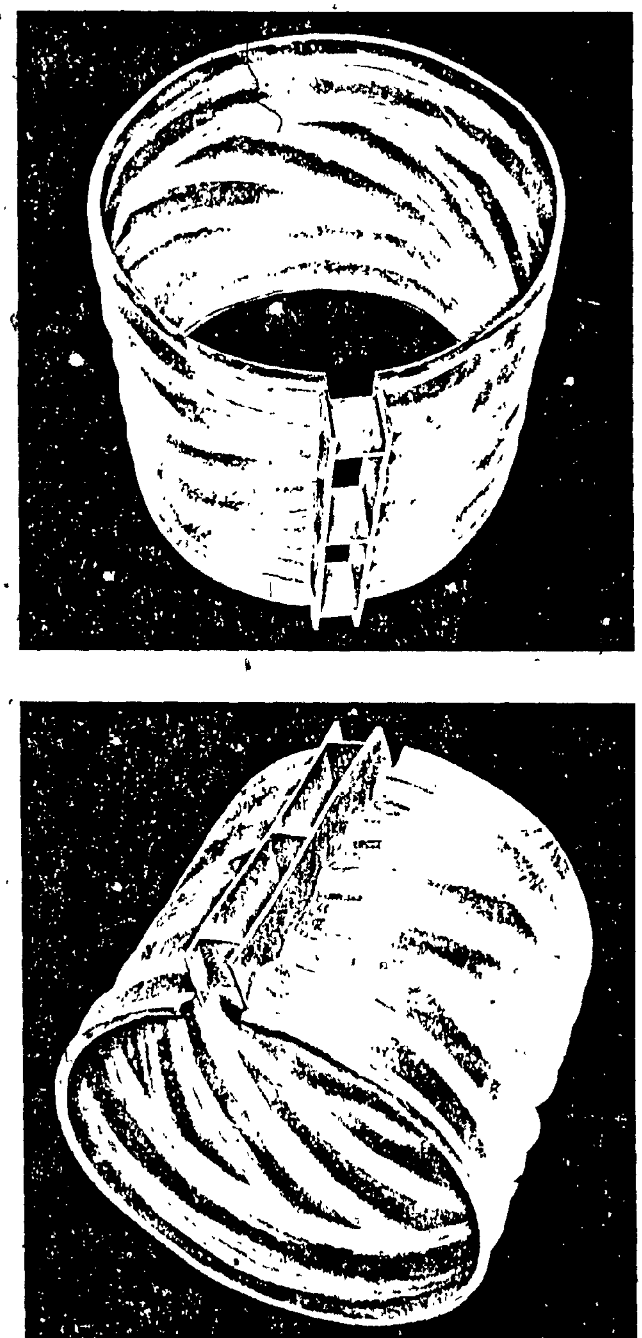


Fig. 5.3 — Typical slotted drain viewed from two different angles [5].

tage of these drains lies in their incapability to remove infiltrated waters. However, they are highly efficient in removing surface water. If the water flows at a depth of less than 0.2 feet, the drain acts as a weir and follows regular formulas for weir-type flow. If the water flows at a depth of more than 0.2 feet, the drain acts as an orifice and follows regular formulas for orifice-type flow [5]. Figure 5.4 shows 'in situ' position of a typical steel slotted drain. The standard sizes of these drains range from 12 inches to 30 inches.

The principal characteristics of this drain are: (a) it provides practical solution to the disposal of surface water runoff (b) in cold regions, it does not hinder snowplow operations and minimizes ice-hazard caused by ponding (c) it is safe for bicycles and pedestrians (d) it has less chances to be clogged and it is easy to clean (by pressure hose).

Although these pipes will not drain infiltrated waters their rapid removal of surface water helps substantially to solve ordinary drainage problems and reduce their impact especially in the absence of ground-water.

5.2 Different Arrangement Features

Now that different drainage materials have been identified, the basic layouts and details of their actual arrangement should be presented before proceeding to construction and later to maintenance sections.

A basic rule is that a draining system should never conflict with road geometry; i.e., road geometry should be designed such that it will facilitate drainage operation.

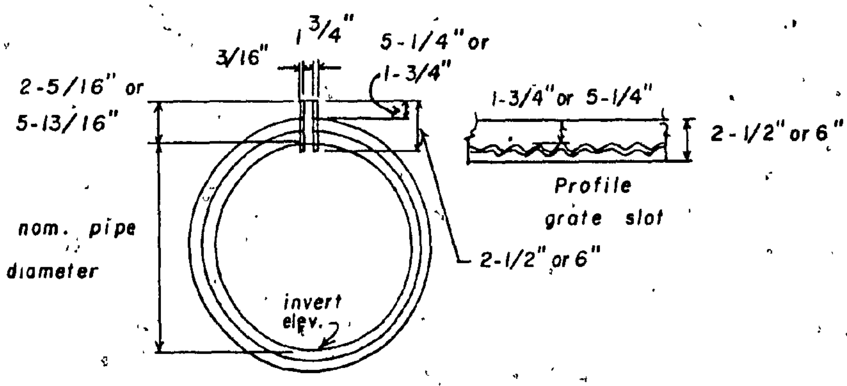


Fig. 5.4 — Cross-section of a typical steel slotted drain [5].

5.2.1 TYPICAL CASES

Typical details of the outer edges of the previously-discussed drainage system (under normal conditions) are shown in Figure 5.5. The characteristics of each part in the figure are:

a. For pavements that will have few heavy wheel loads at or near the outer joint or on the shoulder, the longitudinal drain can be located at the outer edge of the pavement, as shown in Figure 5.5a

b. As pumping effects usually happen around the joints, then in order to protect this area, the longitudinal drain pipes can be put slightly outside the joint, as shown in Fig. 5.5b. This method is more expensive than the one previously described

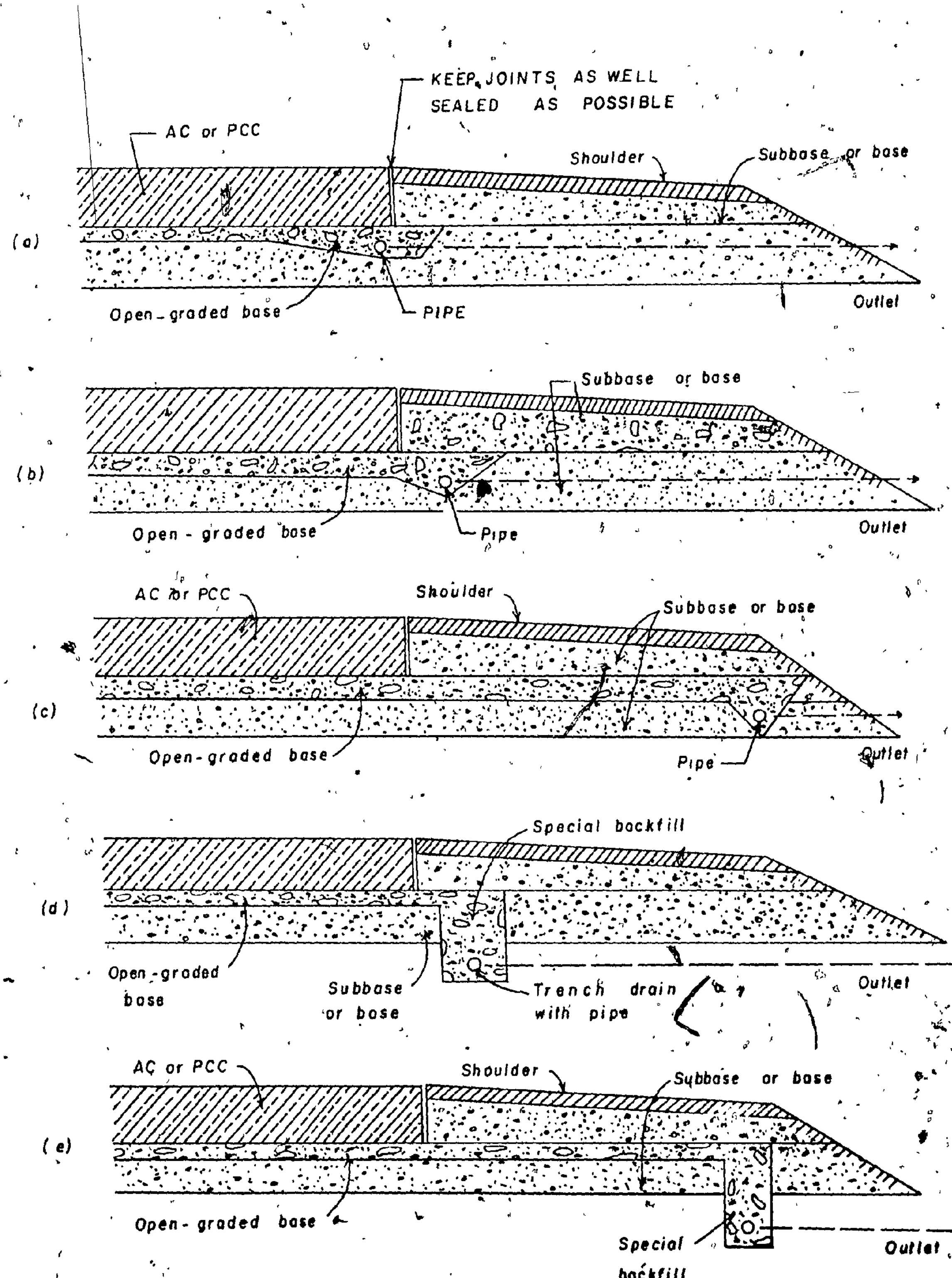


Fig. 5.5 -- Typical details of outer edges of drainage systems.

c. If the road is more important and the entire shoulder has to be protected, the drainage layer can be extended and the longitudinal collector drain located at the outer far edge, as shown in Fig. 5.5c

d. In cold regions where sufficient frost penetration is expected, deep rectangular trenches should be used (as shown in Figs. 5.5d and 5.5e). The presence of high ground water also requires the use of rectangular trenches. In many situations where there is no ground-water and no appreciable frost penetration, shallow "V" trenches will suffice for the longitudinal collector drains, as Fig. 5.5c shows.

It is advisable wherever deep trenches are dug in erodable subgrades, to line the walls of the trench with plastic filter cloth (fabrics). This will protect the special backfill filter from being contaminated.

5.2.2 SPECIAL CASES

Prevention of possible boiling: Consider Fig. 5.6, where the subgrade is unstable and has a percolating zone on top of a saturated zone. There is a strong possibility of boiling on the fill side and consequently, sliding of the embankment. In this case, a deep trench has been used which penetrates below the saturated zone, the backfill being very permeable. With the aid of an interceptor drain, the boiling problem could be avoided. The same drain can also assume its function in draining the base layer.

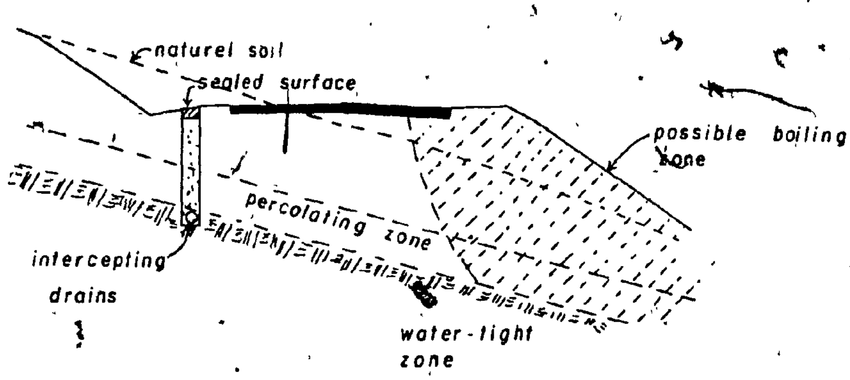


Fig. 5.6 — Prevention of boiling by intercepting drains [12].

Slope stabilization: Figure 5.7 shows an example of a typical slope stabilization case. The presence of P.V.C. pipes lowers the saturation level of the original ground-water. The double ditch is intended to prevent erosion. By doing so, not only the cut face will be reinforced, but this operation will ease the burden from the main drainage pipe in evacuating the highway's excess water.

The use of mechanical pump: Another special case arises when a highway is located in a deep cut and water evacuation by gravity is not possible. In this situation all the drained water should be directed to a sump. When the water reaches a predetermined level in the sump, it will activate a pump that will pump up and out the accumulation of water. This is a rather expensive method of draining, but luckily it does not happen often since the gravity method is the most frequently encountered situation.

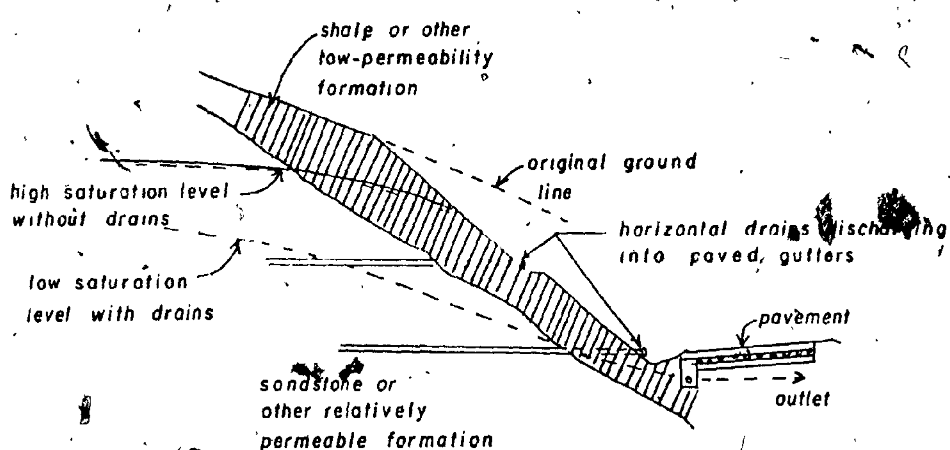


Fig. 5.7 — Slope stabilization with horizontal drains.

Urban roads: After minor modification the drainage system discussed in this report could be adapted to urban streets too. Figure 5.8 presents drainage features that can protect city pavements permanently from damage due to surface infiltration and ground water intrusion. Once again, the principal part of the system is a hydraulically-designed open-graded drainage layer (around 6 inches thick) which feeds surface and ground water to longitudinal pipes. This drainage system under city

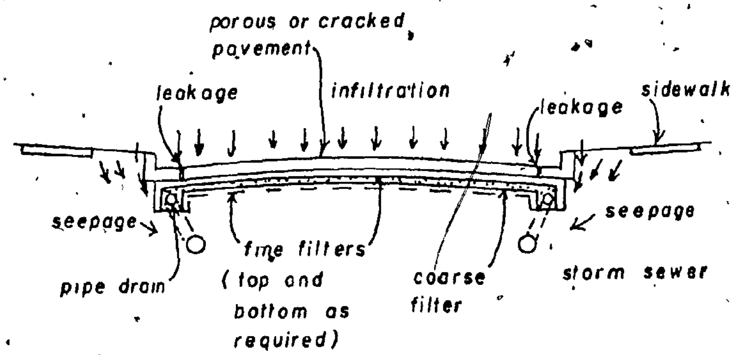


Fig. 5.8 — Drainage system for highways in urban zones [10].

streets not only protects pavements from damage due to excessive water, but also protects gutters and sidewalks from being undermined by the washing of soil into joints and cracks in sewers, which is a common occurrence in sand and silty soils, especially at street intersections.

Road Geometry: It is very important that the designer visualizes the drainage system in three dimensions and search for any possible odd situation in which water could be trapped because of road geometry or that it will meander for long distances without reaching an outlet. In reverse super-elevated curves, for instance, transverse and edge drains, are needed to prevent long meandering of the seepage path. In sag-vertical curves, the designer should provide a cross drain at one or more locations, depending on the degree of the curvature. The drains should be located at the lowest point on the sag curve, because at this location the water tends to concentrate most.

Outlet pipes: Another area the designer should pay particular attention to is the location of outlet pipes of subsurface drainage systems. The topography should be examined so that no off-ramps are present. A check should be done so that there will be no structure or other feature, either man-made or natural, to interfere with free gravity flow from the system. If suitable exits are not available at predetermined locations, then the designer should use longer spacings. The outlets should be high enough so that the free gravity flow towards the ditches is assured. In cold regions, the outlet pipes should be insulated and flap gates should be mounted at the outlet to keep the cold air out.

5.3 CONSTRUCTION OF A SUBSURFACE DRAINAGE SYSTEM

In order to achieve the intended life of a subsurface drainage system, the construction of a highway should be done systematically, and above all every stage should be constructed with care. The following are some of the phases of a highway construction which are essential to the normal functioning of subsurface drainage systems.

5.3.1 SUBGRADE PREPARATION

In subgrade preparation, the first operation will be the stripping of the top soil (usually six to twelve inches thick). If the subbase is more than three feet above the natural soil, then it would not be necessary to strip [21]. The second step will involve the excavation of ditches along each side of the road. By doing so, all accumulated water will be directed to a safe outlet. Sometimes it will be necessary to construct sediment traps to ensure the free flow in the ditches [23]. The third step will be the compaction of the natural ground. The subgrade should be densified to at least 90% of its dry density of the maximum proctor compaction test. The soil has to be compacted to a minimum of 6 inches. In high fills (of mganitude of five feet and over) the compaction of the natural soil can be neglected, because the weight and the successive compaction of the fill layers will densify the natural ground as well as stabilize it automatically.

In cold regions, whenever the natural ground of a cut-section contains blocks larger than eight inches in diameter, then natural ground should be sacrificed to a maximum depth of two feet. This operation will serve two purposes: firstly, the block might cause severe heaving problems and secondly, they might trap water during construction.

Always, a certain slope should be maintained to direct the flow towards the ditches. The most common slope is 2%, but it is desirable to use higher percentages. Therefore, the subgrade should be uniformly prepared so that it will satisfy the required slope specification.

Special attention should be paid to earth moving equipment because they usually disturb the surface uniformity of the subgrade. Care should be taken so that once the subgrade has been compacted, it should not be disturbed during the rest of the construction period.

5.3.2 TRENCH EXCAVATION AND PIPE INSTALLATION

Trench excavation can be done immediately after the ditch excavation is completed. It is usually carried out simultaneously with subgrade preparation. The excavation operation can be executed with the aid of a small- to medium-size shoevel, because according to specifications, the minimum width of the trench is equal to the inside diameter of the pipe plus nine inches (see Fig. 5.9). If the natural ground is rough, a smooth

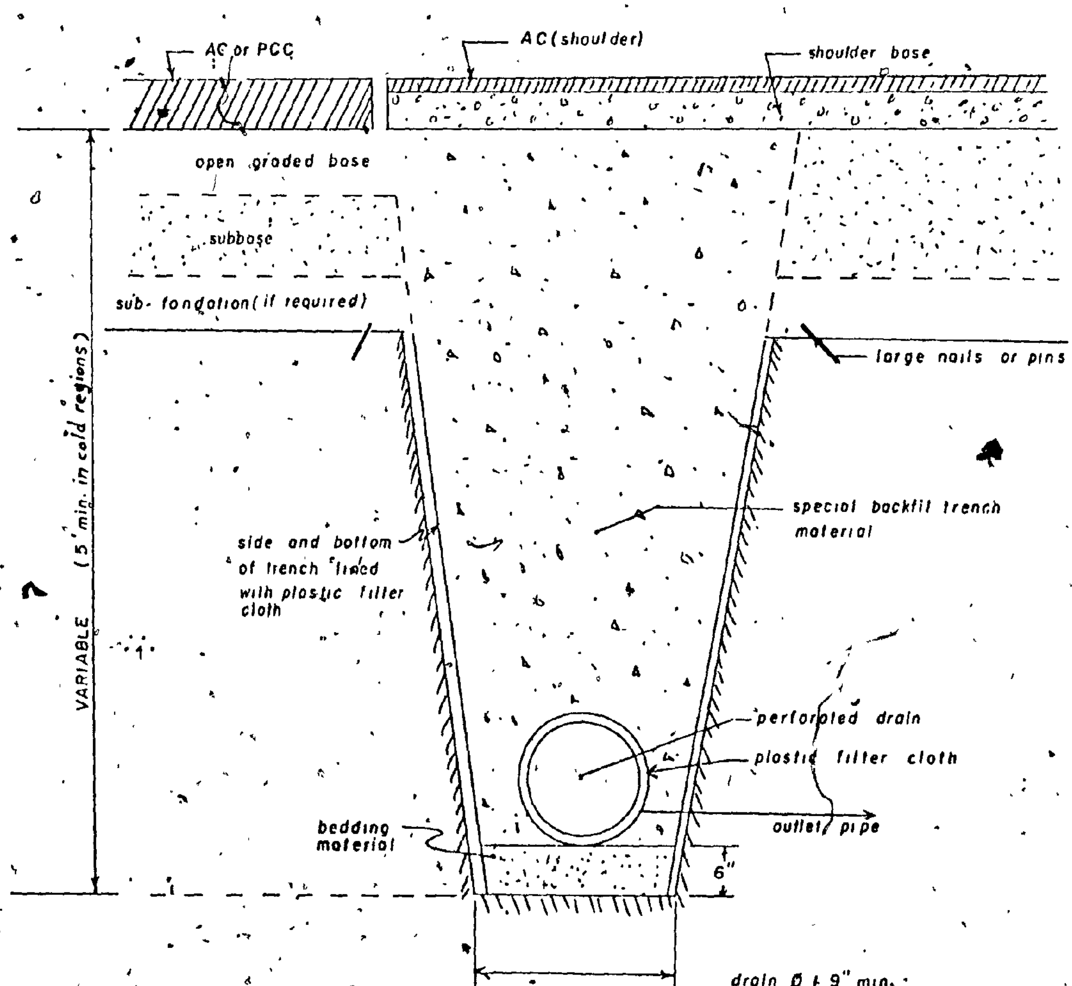


Fig. 5.9 — Detail of a trench drain with plastic filter cloth.

bedding layer six to twelve inches thick should be provided.

During the placement of the pipes, care should be taken in order to avoid breaking of the pipes and to prevent the intrusion of debris or other foreign matter into the pipes that may impede the free flow of water. For all subdrains, according to ARMCO publications [6], it is desirable wherever possible, not to use a slope less than 0.2%. Before the backfill, the designed slope should be carefully checked. To ensure longer pipe life, the pipes sometimes are asphalt-coated by embedding them into pools filled with liquid asphalt.

5.3.3 OUTLETS

Outlet pipes are not perforated because they do not convey water directly from structural sections. The backfill around the outlet pipes should be of low permeability. This will prevent the soil piping along the pipe or the trench. It is preferable to build a stone wall on the slope of the road at the outlet pipe to prevent sliding of materials along the shoulder and the slope from blocking the outlet pipes.

In high flow areas flap gates may be needed to prevent entering sand and other matter into these pipes. To facilitate maintenance, wooden or metal posts should be placed at each outlet pipe.

5.3.4 BACKFILL

After the pipes have been installed and checked the backfill material should be placed as quickly as possible, thus minimizing the entrance of foreign matter, mud, debris and so forth, into the trench. The material should be placed uniformly in order to avoid segregation. Figures 5.10 and 5.11 show the dumping and backfilling operations. The

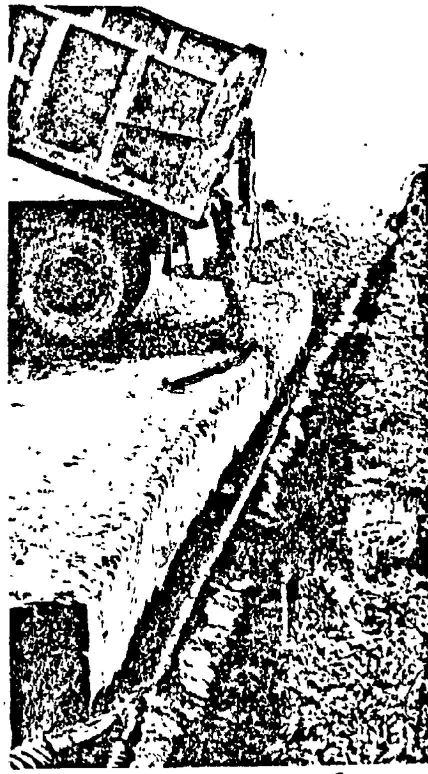


Fig. 5.10 — Dumping operation of a trench material [5].

backfill materials should be compacted into successive layers, and the layer thicknesses should not exceed 12 inches. The backfill layers should not be over-compacted because they can reduce the permeability of the filter material. If fabrics are used, care must be taken so that the backfill material will not damage them.

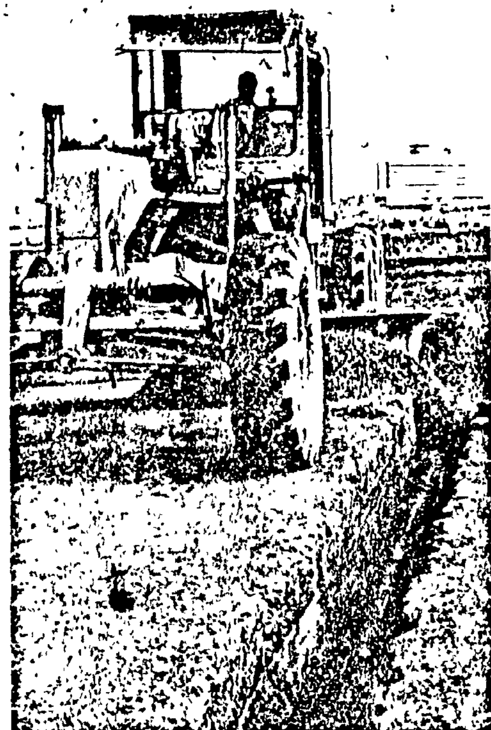


Fig. 5.11 — Backfilling operation of a trench [5].

5.3.5 THE ROAD STRUCTURE

The construction of the base, sub-base, sub-foundation, special filter layers should be carried out according to the specifications of of highway construction codes.

During the construction period, particular attention should be paid in order to avoid contamination of these layers. Contamination may be caused by loose subgrade particles or by dirt which can be found on the tires of heavy construction equipment. If during construction, water has been trapped on the surface of the highway platform, then, before proceeding to the hauling of highway materials, the trapped water should be evacuated safely.

Segragation of the materials should be avoided. This is very important because the gradation of highway materials is formulated such that after compaction, the finer particles will tend to fill the voids causing a more stable substance. This can only happen if the materials are graded according to the specifications. This gradation not only will make the highway layers more stable, but it will help obtain the required degree of compaction easier. Each layer should be parallel to the cross grade of the highway. The hauling operation should at least be directed in a way that the circulation of heavy equipment will not be permitted to travel over finished cross grades.

5.3.6 LAYING OF WEARING COURSFS

Before laying the AC layer on the open-graded base drainage layer, the latter should be prepared according to highway specifications. The purpose of this preparation is: (a) to give the road surface the required theoretical shape, and (b) to recompact the road surface which might be disturbed due to traffic.

When PCC wearing course is placed over open-graded base drainage layer, special procedures should be developed so that the flow of cement mortar will be prevented from flowing down into this layer. When cement mortar penetration into the drainage layer is doubtful, a reliable method of testing can be carried out by pouring cement on small surfaces over the drainage layer, then vibrating it to simulate actual construction procedure. After the vibration, the slab will be removed and the drainage layer will be examined. A simpler method to determine whether the mortar cement will penetrate the drainage layer is the dumping of the concrete. If the slump is under three or four inches, it is very unlikely that any significant penetration will occur.

Nevertheless, if very coarse open-graded bases are used, a thin layer of stone chips at least one fourth the fifteen percent size of the open-graded base could be used as a smoothing course and as a seal against mortar penetration into the drainage area [17]. Mortar penetration should always be detected because it is harmful as far as drainage is concerned.

5.3.7 INLETS

Inlets are special openings which collect the surface water and convey it to a subsurface drainage pipe. In installing inlets, the gates should not be placed higher than the surface of water. This will cause water pondering (hazardous in cold regions). They should not be placed lower than the surrounding surface, since this can cause driving problems. The inlet gate should be properly oriented to maximize the inlet capacity. Whenever inlets are set back from the normal curb line, a danger to the traffic is created. According to the Highway Research Board Report [24], a guard rail should be placed at such places.

5.4 ROADS AND DRAINAGE SYSTEMS MAINTENANCE

Not only the drainage system, but the whole highway itself will have longer life expectancy and function effectively as intended if careful and timely maintenance operations are carried out in the spirit of preventing any possible deterioration.

Normal maintenance, if carried out as it should be, could save an enormous amount of money. Effective maintenance eliminates major construction operations in the long-run. Precaution should be taken so that normal maintenance operations will not damage subsurface drainage systems through careless conduct. On the other hand, the lack of these operations should not reduce the efficiency of the drainage systems. In the following sections, some of the more important maintenance operations are going to be discussed.

5.4.1 SURFACE MAINTENANCE

The road surface, during its lifetime, accumulates many undesirable elements such as mud, blown sand, wind-blown silt, and gravel from shoulders. These materials need to be removed rapidly to prevent skidding problems. If these materials are left for longer time over the surface of the highway, they will, through rain, reach inside the base layer through joints and other openings.

During asphalt repairs or hot AC placement operations over drainage-base layers, care should be taken in order to avoid the penetration of liquid asphalt into the base layer. Outlets should be free from dumped foreign matter, as this is important for maintaining steady discharge of the drainage system itself.

5.4.2 MAINTENANCE OF OUTLETS

If in a certain project erosion problems are not foreseen, then it is most likely that pipe outlets will be completely blocked by debris; weed or grass can impede the outflow through these outlets. This can be prevented by the sterilization of the soil in the surrounding areas of the pipe. The maintenance of outlet pipes does not require large amounts of time. A general inspection of the outlets should be carried out at least twice a year [39]. At every inspection, the outlet should be cleaned, if necessary.

5.4.3 MAINTENANCE OF MARKERS

Outlet pipe markers are very important as far as maintenance is concerned. The object of maintenance of outlet markers is: (a) to keep the markers visible, and (b) to check that at every outlet pipe a marker post is present. Outlet markers are sometimes damaged by vandalism, lack of maintenance, etc. Therefore, they should be inspected periodically.

5.4.4 GENERAL MAINTENANCE

All maintenance workers should be aware of the importance of drainage structures to the highway. It is essential that all general highway maintenance operations ensure free flow of water to safe outlets. Therefore, when outlets discharge into natural or constructed ditches, periodic checks should be made to be sure that the ditches are kept free of obstructions.

Special attention is to be paid to the surface water. The inlets and other structures should always be kept free of any debris that may block the flow of water. In cold regions, the presence of surface water could be very dangerous, especially at intersections. For instance, according to "The Design for Canadian Roads and Streets" [32], in order to provide for adequate drainage at an intersection, a minimum grade of 0.5% is recommended. Not only all inlets should be free of debris, but this minimum grade should also be respected.

Nevertheless, all structures such as manholes, drop structures, energy dissipation structures, splash blocks, etc. should be periodically inspected and repaired if necessary. After all, as the "Handbook of Steel Drainage and Construction Products" [25] states: "Often, a small repair job will prevent a large repair job, or even complete failure, later on."

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

Based on the subject presented the following conclusions are made:

1. The slow evacuation of water from the road foundation is the main cause of highway failures. Generally, the presence of water has a detrimental effect on pavements. In cold regions, excess water in pavements is a serious problem because of the frost action; even thick sub-foundations do not provide a complete remedy (especially in cuts).

2. The major contributors to the inflow-outflow concept are ground-water and surface-water. Ground-water, up to a certain extent, can be predicted through preliminary surveys; however, no survey will produce information that is completely certain. Consequently, the designed drainage systems should be flexible enough to be modified to suit the conditions encountered on the site during construction, if necessary.

3. Present highway structures do not permit quick evacuation of excess water. They do not use highly-permeable bases

together with perforated or slotted pipes as a basic component of a typical cross section. Also, the life of highways built according to present standard specifications are shorter than the life of those roads which are provided with special drainage systems.

4. Subsurface drainage has generally been looked upon as a qualitative problem with general solutions, while in reality it is a quantitative problem that warrants definite solutions. The scientific approach presented established the fact that better drainage could be attained by highly-permeable base layer, which is accompanied by perforated or slotted pipes and outlet pipes. It has also been shown that a wide, shallow base-layer would be much slower in drainage than a narrow, thick layer of the same material and permeability.

5. The drainage system proposed is generally less important in fill than in cut, because in fill the absence of groundwater somehow neutralizes the problem. Fairly permeable layers of base and sub-base (in fills) could provide acceptable drainage without the use of collector pipes.

6. Special attention should be paid to dirt that is left on the pavement. In open agricultural zones, a considerable amount of top soil can be found on pavements, especially in autumn. This can infiltrate into the open-graded layer with the aid of rainfall.

7. Ever since the first modern road was designed at the end of the eighteenth century, road engineers had a negative approach towards spending an extra amount of money for drainage purposes. Considering all factors, the cost of road building has increased by 250% over the last fifteen years. Yet, well-drained pavements will almost always be more cost-effective than undrained ones, because the former designs require smaller quantities of vital construction materials over their effective lifetime.

6.2 Recommendations

This study gives rise to a number of interesting points that warrant further study. The following are the most important unanswered problems:

1. At the present time no practical and economical method is available that will keep pavements water-tight for more than a brief length of time after construction. Most existing drainage methods tend to be expensive for practical use; research is needed in order to find new practical and economical methods of evacuation of excess water from pavements.

2. As far as groundwaters are concerned more accurate prediction methods should be found through research. Also, more economical remedies should be sought for immediate groundwater problems during the construction period.

3. In cold regions, no experimental study has so far been carried out concerning the drainage method discussed in this report. Therefore, small segments of test roads located in cold regions should be built according to the design method proposed. In addition, models representing different conditions should be built and tested.

4. By using highly permeable base-layer materials, where fines are practically absent, it will be difficult to compact this layer up to the minimum degree of compaction required by Canadian specifications. Thus, new methods of materials should be developed which will increase the compactability of this layer without sacrificing its quality of permeability.

5. Studies should be carried out to overcome the side-effects of early temporary thawing (e.g. unexpected January thaw). In such a period, water that is drained through the base layer freezes upon contact with deeper layers; this freezing inhibits the drainability of this layer which will be saturated and could harm the pavement during temporary and spring thaw periods.

6. In view of highway material shortage, many laboratories have been engaged in finding suitable substitutes. Cloth fabrics for example are successfully used in lower layers of a road. It has been suggested that fly-ash among its many uses, can be used as backfill around drainage pipes. More research is needed for finding new materials and for effectively recycling materials for re-use.

7. In urban areas, the problem of the contamination of the drainage water with toxic materials is becoming more and more serious. Studies should be carried out to find out appropriate solutions to this polluting problem.

8. As far as construction cost and economics are concerned, the highway engineer should undertake a cost feasibility analysis (for all highway projects) when making a decision on whether to use a drainage system or not. Hence, the answer to the integration of a drainage system into a highway should be obtained rationally rather than intuitively.

LIST OF REFERENCES

1. ADAMS, L. G. "Report on Flexible Pavement Distress in the Atlantic Area". State Highway Department of Georgia, Atlanta, 1969.

2. American Standards for Testing Materials, "Public Roads", ASTM-D-289, January, 1929.

3. American Standards for Testing Materials, "Resistance of Large Size Coarse Aggregate by Use of the Los Angeles Machine", ASTM C535, 1964.

4. American Standards for Testing Materials, "Resistance to Abrasion of Small Size Coarse Aggregate by Use of the Los Angeles, Machine", ASTM C131,1937.

5. ARMCO, "Armco Slotted Drains", Armco Canada Ltd. Company Catalogue, 1976.

6. ARMCO, "Perforated Pipe", Armco Canada Ltd., Company Catalogue, 1976.

7. BESKOW, Gunnar, "Soil Freezing and Frost Heaving with Special Application to Roads and Railroads", The Swedish Geological Society, Series C, No. 375, Nov. 1947.

8. BROVOLD, N. Frederick, and Majidzarteh, KARMAN, "State of the Art: Effect of Water on Bitumen-Aggregate Mixtures", HRB, Special Report, No. 98, 1968.

9. CEDERGREN, R. Harry. "Drainage of Highway and Airfield Pavements". John Wiley & Sons, 1974.

10. CEDERGREN, R. Harry. "Seepage Drainage and Flow Nets". John Wiley and Sons Inc., New York, 1977.

11. CHILDERS, F.A. "Drainage Materials Study". Georgia State Highway Department, October 1968.

12. CMPI, "Comment Resoudre les Problemes de Drainage avec l'Acier", Corrugated Metal Pipe Institute, Technical Manual, 1965.

13. Comment la Marche, "Drainage", Vol. 2, No. 28, Montreal, 1978.

14. VALLAIRE, Guy. "Le Textile dans la Construction de 14 Routes". Ministere des Transport, Quebec, Sept. 1976.

15. Department of Public Works, State of California, "California Culvert Practice". Second Edition, Highway Division, 1955.

16. Federal Highway Administration, "Guidelines, 1973a", FHWA, issued Washington, D.C., 1973.

17. Federal Highway Administration, "Studies for Development of Guidelines for the Design of Subsurface Drainage Systems for Highway Structural Sections", Final Report, FHWA, Washington, D.C., 1973.

18. GOODMAN, R.C. et al. "Groundwater Investigation and Control in Highway Construction: Part One", Highway and Road Construction International, June, 1976.

19. GOODMAN, R.C. et al. "Groundwater Investigation and Control in Highway Construction: Part Two", Highway and Road Construction International, July, 1976.

20. Gouvernement du Quebec, "Cahier des Charges et Devis Généraux", Ministere des Transports, Quebec, 1972.

21. Gouvernement du Quebec, "Determination de la Resistance a la Desagregation des Granulats en Utilisant des Solutions de Sulfate de Magnesium ou de Sulfate de Sodium", BNQ 2622-908, Quebec, 1973.

22. Gouvernement du Quebec, "Normes Techniques Routiers, Towe 1", Ministere des Transports, Direction General du Genie, Quebec, Juillet, 1977.

23. Highway Research Board, "Erosion Control or Highway Construction", NRC, Synthesis of Highway Practice, 18, 1973.

24. Highway Research Board, "Traffic-Safe and Hydraulically Efficient Drainage Practice", NRC, Synthesis of Highway Practice 3, 1969.

25. Highway Task Force, "Handbook of Steel Drainage and Construction Products", Second Edition, American Iron.

26. KIRKHAM, D. and De ZWENN, J.W. "Field Measurements for Tests of Soil Drainage Theory", Proceedings, Soil Science of America, Vol. 16, 1952.

27. Ministere des Transports, "Bulletin Routier", Direction des Communications, Vol. 3, No. 2 (Region 1), Rimouski, Sept. 1977.

28. MORISON, R. L. "Causes of Failure of Pavements", Highway Supervision and Construction, Vol. 38, No. 13, 1931.

29. O'BRIEN, Ken and Associates. "Guidelines for the Design of Subsurface Drainage Systems for Highway Structural Sections", Federal Highway Administration, issued 1973.

30. PECK, R.B. and TERZAGHI, K. "Soil Mechanics in Engineering Practice". Wiley, New York, 1948.

31. Portland Cement Association. "Handbook of Concrete Culvert Pipe Hydraulics", PCA, 1964.

32. Roads and Transportation of Canada. "Geometric Design Standards for Canadian Roads and Streets", Transport Canada, Ottawa, 1976.

33. Scott S. John. "A Dictionary of Civil Engineering". Penguin Books, 1967.

34. Task Force on Hydrology and Hydraulics. "Guidelines for the Legal Aspects of Highway Drainage", AASHTO, Highway Drainage Guidelines, Vol. V, 1977.

35. TERZAGHI, Charles. "Effect of Minor Geologic Details on the Safety of Dams". American Institute of Mining and Metallurgical Engineers, Technical Publication, 1929.

36. TERSAGHI, K. "Theoretical Soil Mechanics". John Wiley & Sons, Inc., New York, 1943.

37. TESSIER, G. Robert. "Guide de Construction Routier", Ministere des Transport, Deuxiéme edition, Quebec, 1973.

38. Tex-el. "Membrane Synthétique Non Tissée Aiguilletic à Fibres 100% Polyester", Company Catalogue, Ste-Marie (Beauce), 1976.

39. The Asphalt Institute. "Drainage of Asphalt Pavement Structures", Manual Series, No. 15, May 1966.

40. U.S. Army Corps of Engineers. "Drainage and Erosion Control-Subsurface Drainage Facilities for Airfields". Technical Manual, TM-5-820-2, Washington, D.C., August, 1965.

41. U.S. Army Corps of Engineers. "Roads, Runways, and Miscellaneous Pavements", Technical Manual, TM5-624, May 1947.

42. U.S. Dept. of Agriculture. "Methods of Soil Analysis for Soil-Fertility Investigations". Circ. #757, 1947.

43. WITHERSPOON, D.F. et al. "Hydraulic Design of Culverts". Proceedings of A.S.C.E., Vol. 88, No. HY6, September, 1962.

44. WOODS, B. Kenneth. "Highway Engineering Handbook". Mc-Graw Hill Company, 1960.