

Thickness Design for Flexible Pavements

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INTRODUCTION

Throughout North America, the term "flexible pavement structure" is understood to include the subgrade, base course, and asphalt wearing surface, Figure 1. There is also general agreement that the designation "flexible pavement" refers to the combination of layers above the subgrade, that is, the base course plus the wearing surface, Figure 1. The lower portion of the base course is frequently referred to as the "sub-base". In this paper, to simplify the presentation, the term "base course" will include the sub-base.

The subgrade is usually constructed from the natural soil that occurs on or adjacent to the right-of-way. Very few subgrades have sufficient strength to support the wheel loads of modern traffic. For example, a subgrade with a bearing capacity of only 20 p.s.i. will fail very quickly by deep rutting under a loaded truck wheel having a tire inflation pressure of 80 p.s.i. Consequently, most subgrades require the additional load supporting capacity provided by the superimposed base course layer. When the base course is thick enough, it distributes an applied wheel load over such a large area of the subgrade, that the bearing capacity of the subgrade is not exceeded at any point, Figure 1.

It is a basic requirement of acceptable base course materials, that they do not lose strength when exposed to moisture. This condition is satisfied by the gravels, crushed stone, and similar granular aggregates that are most commonly selected for base courses in Canada. In local areas where granular materials are scarce, sandy soils that have been stabilized by the incorporation of bituminous binders or portland cement, are sometimes employed as base courses.

The wearing course is expected to provide a safe, smooth, surface, that is resistant to the destructive agencies of climate and traffic. For flexible pavements in North America, asphaltic concrete is the most common wearing course on primary highways, while road mixes or bituminous surface treatments are usually selected for secondary road surfaces.

BASIC PRINCIPLES OF SUBGRADE DESIGN

There are two primary objectives for subgrade design and construction,

- a) a subgrade that will provide the highest possible load carrying capacity throughout the year.
- b) a subgrade that is so thoroughly compacted that it will undergo a minimum of differential vertical movement throughout the useful service life of the superimposed flexible pavement.

Subgrade soils are usually the cheapest materials available for roadway or runway construction, while base course and surfacing components are the most expensive. The stronger the subgrade can be made, the smaller are the quantities of the relatively costly base course and surfacing materials required. The smaller the differential vertical movement in

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the subgrade and base course can be made, the smoother riding the paved surface will be throughout its useful life. Consequently, considerable expense is justified for soil selection and placement, drainage, high subgrade line, rolling, etc., to obtain a finished subgrade of high strength and adequate compaction.

If these two basic requirements for the subgrade are to be achieved, the following seven fundamental principles of subgrade design and construction must be applied,

1. Establish the right-of-way of a road or airport runway on sandy rather than on clayey soils wherever possible. Clay soils become weaker and weaker as they absorb more and more moisture, whereas sands maintain high supporting value in either the wet or dry condition.
2. When some choice exists between clayey and sandy soils for subgrade construction, but the quantities of sandy soils are limited, place the clay and other poor soils as low in the subgrade as possible, and conserve the sandy soil for the top layer of the subgrade.
3. By means of adequate drainage installations, protect the subgrade from sources of moisture that might enter and soften the subgrade soil, Figure 2.
4. Establish the top of the subgrade at least four feet above the ground water table, Figure 3. This helps to maintain the upper part of the subgrade in a drier and stronger condition.
5. Excavate pockets of frost-affected soils, (usually fine sands and silts), that are susceptible to acute frost heaving and frost boils, to one-half the depth of frost penetration, but to a minimum depth of two feet, and replace with soils of non-frost heave texture, Figure 4.
6. Deposits of peat, muck, or other highly organic soils should be either,
 - a) completely displaced from under the subgrade, Figure 5, by excavation, temporary surcharge, jetting with water, or blasting with dynamite, or
 - b) thoroughly consolidated during construction by temporary surcharge if there is ample time, or by the use of sand drains, Figure 6, if the construction period must be short.
7. Compact subgrade soils in relatively thin layers at approximately optimum moisture content by means of sheepsfoot, pneumatic-tired, or steel-wheeled rollers, or by vibratory compactors, etc., for at least the top 12 inches of cut sections, and for the full depth of embankments, Figure 7, to increase their density in place. Mechanical compaction tends to increase subgrade strength, provide more uniform subgrade bearing capacity, and reduce differential vertical movement.

THICKNESS REQUIREMENTS FOR FLEXIBLE PAVEMENTS

A strong, well-compacted, subgrade will be obtained, if the seven basic principles of subgrade design and construction just reviewed, have been applied.

The next major problem in thickness design for flexible pavements can be expressed very simply,

“For any given wheel load, what is the **minimum** thickness of granular base course that must be employed to avoid failure of the underlying subgrade?”

Base course materials are relatively expensive. It is for this reason that good engineering practice focuses attention on the **minimum** thickness of base course to be selected for any project.

This problem has been studied by a great many organizations. The method described in this paper was developed by Canada's Department of Transport on the basis of many hundreds of repetitive plate bearing tests conducted on the paved runways at about 40 Canadian airports.

When these load test data were analyzed, it was found that the minimum thickness of granular base course needed to carry any specified wheel load over any given subgrade, can be obtained from the following simple design equation,

$$T = K \log \frac{P}{S}$$

where T = required thickness of granular base in inches,

P = gross single wheel load to be carried on the runway of highway.

S = subgrade support measured for the same contact area as that of the load P ,

K = the base course constant, which is an inverse measure of the supporting value of the base course per unit thickness.

Based on the design equation, $T = K \log \frac{P}{S}$, Figure 8 has been prepared, which facilitates the selection of the minimum thickness of granular material required for a runway or taxiway, etc., to carry any given aeroplane wheel load over any specified subgrade. Figure 9, based on the same equation, provides similar thickness design information for highway wheel loads over any given subgrade.

Figures 8 and 9 are very easy to use. For example, suppose that a flexible pavement for a highway is to be designed for a load of 12,000 pounds on a single wheel, and that the supporting value of the subgrade when measured with a 12-inch diameter bearing plate at 0.2 inch deflection for 10 repetitions of load, is 3,000 pounds. What minimum thickness of granular base course should be selected?

First of all, along the top of Figure 9, locate the subgrade supporting value of 3,000 pounds on a 12-inch diameter bearing plate at 0.2 inch deflection for 10 repetitions of load. Proceed vertically down from this subgrade strength value to the curve representing a single wheel load of 12,000 pounds. From this point of intersection, continue horizontally to the left hand margin, and read off the thickness indicated, which is 21 inches.

If the wearing course is to consist of a thin bituminous surface treatment, the total thickness of flexible pavement (base course and wearing surface) required, would be 21 inches. One inch of well-designed asphaltic concrete is equivalent in strength to at least 1.5 inches of granular base. Consequently, if the wearing course were to be 3 inches of asphaltic concrete, the flexible thickness requirement would become 16.5 inches of granular base plus 3 inches of asphaltic concrete, or a total thickness of 19.5 inches.

It should be emphasized that the thickness requirements of Figure 9 are based upon certain standard conditions. These are, (a) a subgrade strength that is uniform throughout the year, and throughout the life of the flexible pavement, (b) the highest volume of traffic that can be crowded onto the highway, (c) the full wheel load is carried on a single tire, (d) vehicles are travelling at high speed on a rural highway, and finally (e) out of the very wide range of wheel loads that make up the

traffic stream, it is assumed that the particular wheel load for which the flexible pavement thickness should be selected, is known. In actual practice, all of these standard conditions are seldom encountered. Consequently, the thickness requirements shown in Figure 9 must usually be modified to take into account the way in which the actual conditions associated with each project differ from the standard conditions on which Figure 9 is based. Some of these lead to a reduction in the thicknesses of Figure 9, while others cause these thicknesses to be increased. These factors have been discussed quite thoroughly in an earlier paper by the writer published elsewhere, (Flexible Pavement Thickness Requirements, Proceedings, The Association of Asphalt Paving Technologists, Volume 25, 1956), and will not be repeated here. However, because of their major importance, two of these factors will be reviewed briefly. They are, the influence of (a) climate, and (b) traffic volume, on flexible pavement thickness.

INFLUENCE OF CLIMATE ON THICKNESS REQUIREMENTS

During the spring break-up period, Canadian roads are much weaker than at other times during the year, and it is usual practice to impose load limit reductions of as much as fifty per cent for the several weeks when frost is leaving the ground. Following World War II, a committee of the Highway Research Board of the United States was established to study the loss in strength of flexible pavements during spring break-up. The State Highway Departments of Minnesota, North Dakota, etc., where frost penetration is deep, participated in the work of this committee. Its program consisted of measuring the strength of flexible pavements at a large number of selected locations at various times throughout the year, by means of plate bearing tests.

The general results of this committee's investigation are illustrated in Figure 10, which demonstrates that during the spring break-up period, the strength of a flexible pavement is reduced to as little as 45 per cent of the strength measured at the same location the previous fall. Furthermore, the strength does not return to a high value immediately following spring break-up, but gradually increases to a maximum in the late fall. Tests made by several Provincial Highway Departments, and by the Canadian Department of Transport, indicate that the general trend of the results illustrated in Figure 10 also apply in Canada. The Department of Transport has found the spring break-up strength of the paved runways at one airport to be as low as 25 per cent of their strength during the previous fall.

By using information like that of Figure 10, it is relatively easy to determine what minimum thickness of flexible pavement must be provided to avoid load limit restrictions during spring break-up. The method employed is described in the publication already referred to.

EFFECT OF TRAFFIC VOLUME ON THICKNESS DESIGN

The thickness requirements illustrated by Figure 9 are for the highest volume of traffic that a crowded highway can carry. Only a few primary highways must be designed to support this intensity of traffic. Consequently, it is important to have a method that will indicate by how much the thickness of a flexible pavement can be reduced as the volume of traffic is decreased. Figure 11 can be used as a general guide for this purpose.

Figure 11 demonstrates that if the thickness requirement for a given highway is represented by 100 per cent for unlimited traffic, then for light traffic volume of the same composition, the required thickness can be reduced by 50 per cent. Similarly, for medium traffic volume of the same composition, the thickness requirement can be decreased by 25 per cent. In the publication referred to earlier, a precise method is described for relating traffic volume and wheel load composition to flexible pavement thickness requirements.

INFLUENCE OF OTHER FACTORS ON THICKNESS REQUIREMENTS

The flexible pavement thicknesses illustrated by Figure 9 may be influenced by a number of other important factors such as impact, eccentricity of axle loadings (more weight on one side of a loaded vehicle than on the other), excessive crown, stationary wheel loads (parking areas or the extra traffic lane for vehicles in difficulty), dual wheels, tandem axles, braking stresses, greater thicknesses of asphalt surfaces, and paved shoulders. The effect of each of these variables has been reviewed in the publication already mentioned. This has shown that an increase in flexible pavement thickness is needed for eccentric axle loadings, excessive crown and braking stresses. On the other hand, dual wheels, greater thicknesses of asphalt surfaces, paved shoulders, and stationary wheel loads (parking areas), tend to reduce the thicknesses shown in Figure 9. Impact can be disregarded when determining thickness requirements.

If the thicknesses indicated by Figure 9 are adequate for the design wheel load on a single axle, the use of tandem axles may either increase or reduce the thickness needed, depending upon the load on the tandem axles and the spacing between them.

SUMMARY

1. Definitions of "flexible pavement structure" and "flexible pavement" are given.
2. The major objectives of subgrade design and construction are a strong and thoroughly compacted subgrade.
3. Seven basic principles of subgrade design and construction are reviewed.
4. A method for determining the minimum thickness of granular base course required to carry any specified wheel load over any given subgrade is described.
5. The influence of climate, traffic volume, and a number of other variables on flexible pavement thickness requirements is discussed briefly.

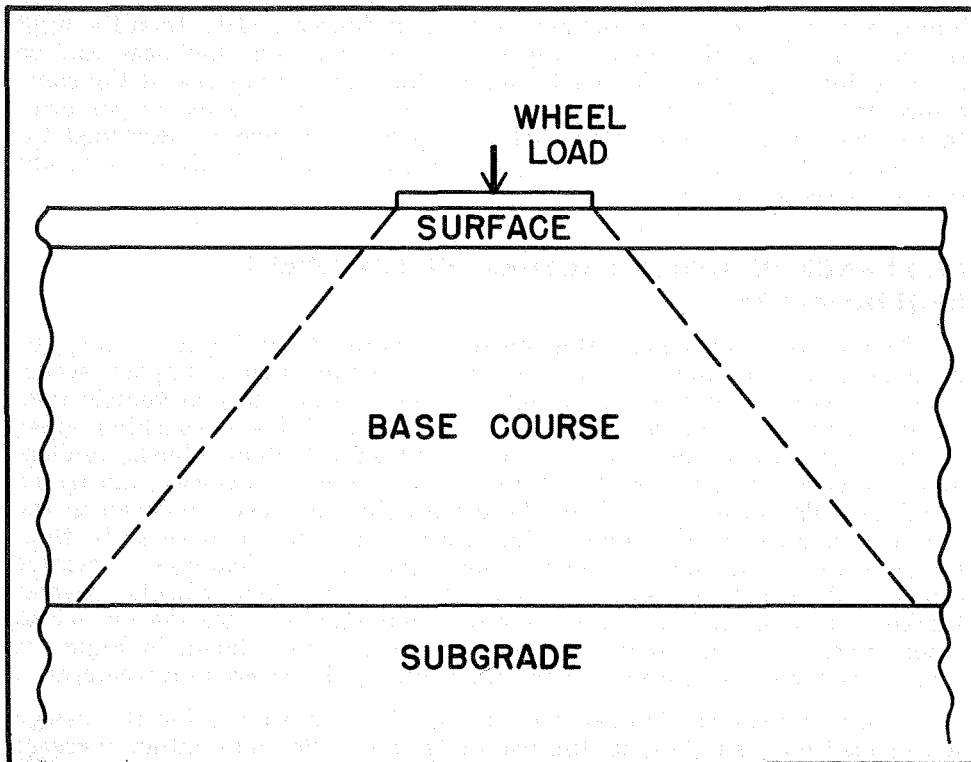
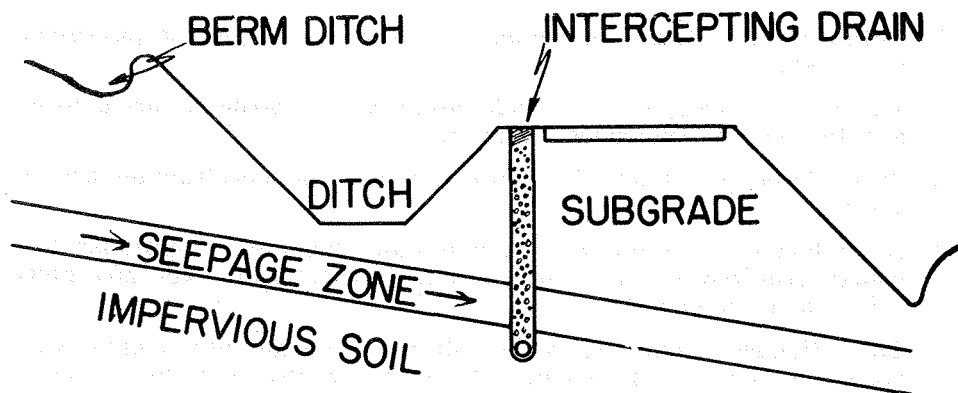
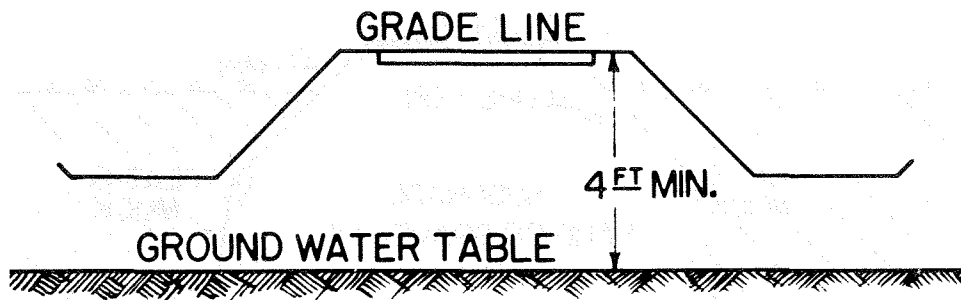


FIG.1 DISTRIBUTION OF LOAD THROUGH FLEXIBLE PAVEMENT.



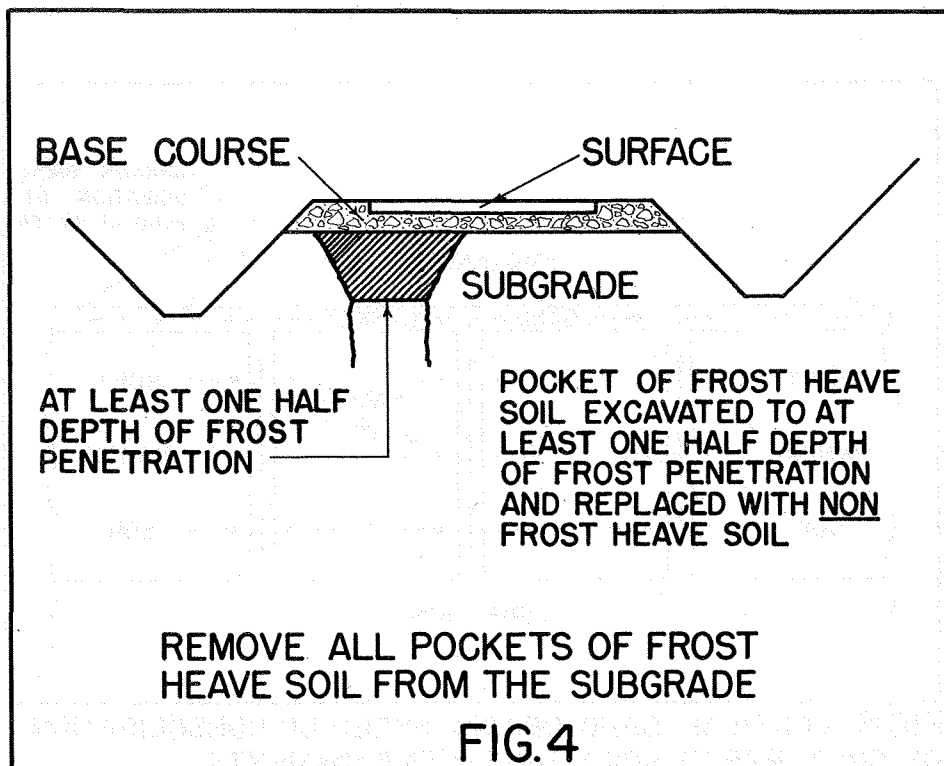
ADEQUATE DRAINAGE CONSISTS OF INTERCEPTING & REMOVING ALL FREE SURFACE & UNDERGROUND WATER WHICH MAY DAMAGE THE ROADWAY.

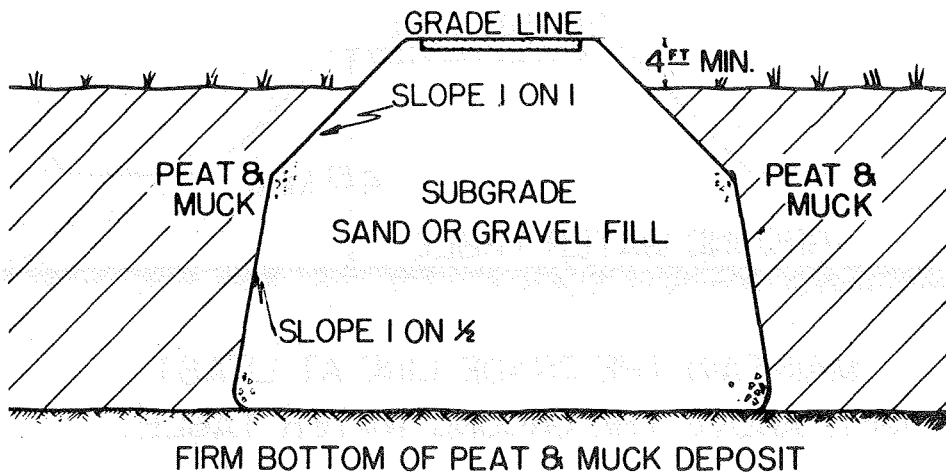
FIG. 2



MAINTAIN THE GRADE LINE AT LEAST
4 FT. ABOVE THE GROUND WATER TABLE.

FIG. 3





REMOVE ALL PEAT AND MUCK
FROM UNDER THE SUBGRADE

FIG. 5

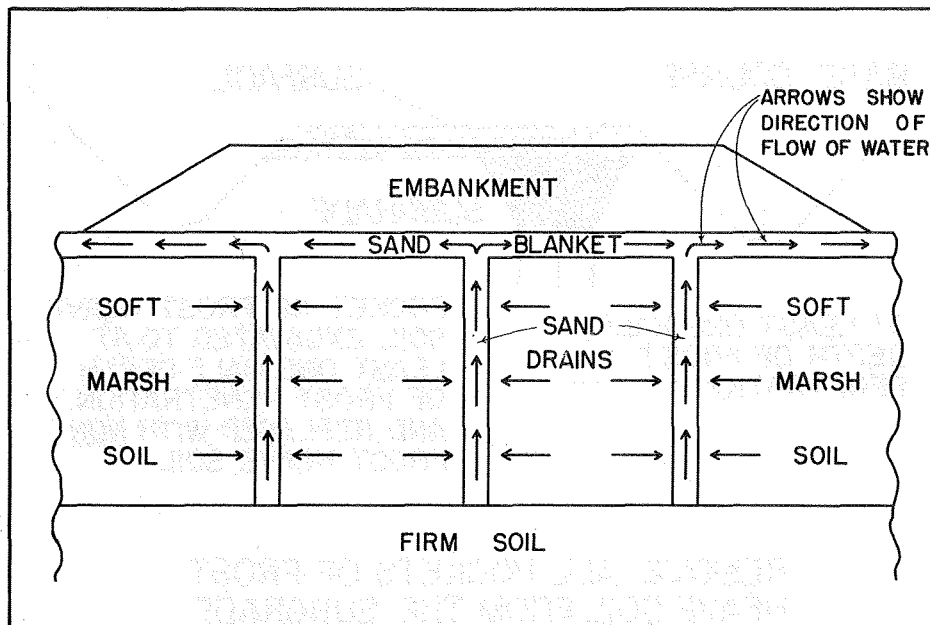


FIG. 6 VERTICAL SAND DRAINS SPEED UP CONSOLIDATION OF SOFT MARSH SOILS UNDER EMBANKMENTS.

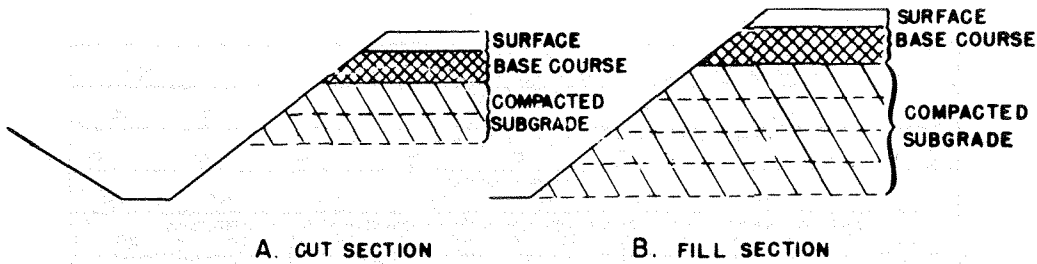


DIAGRAM ILLUSTRATING DEGREE OF PROCTOR COMPACTION REQUIRED FOR CUT AND FILL SECTIONS

FIG. 7

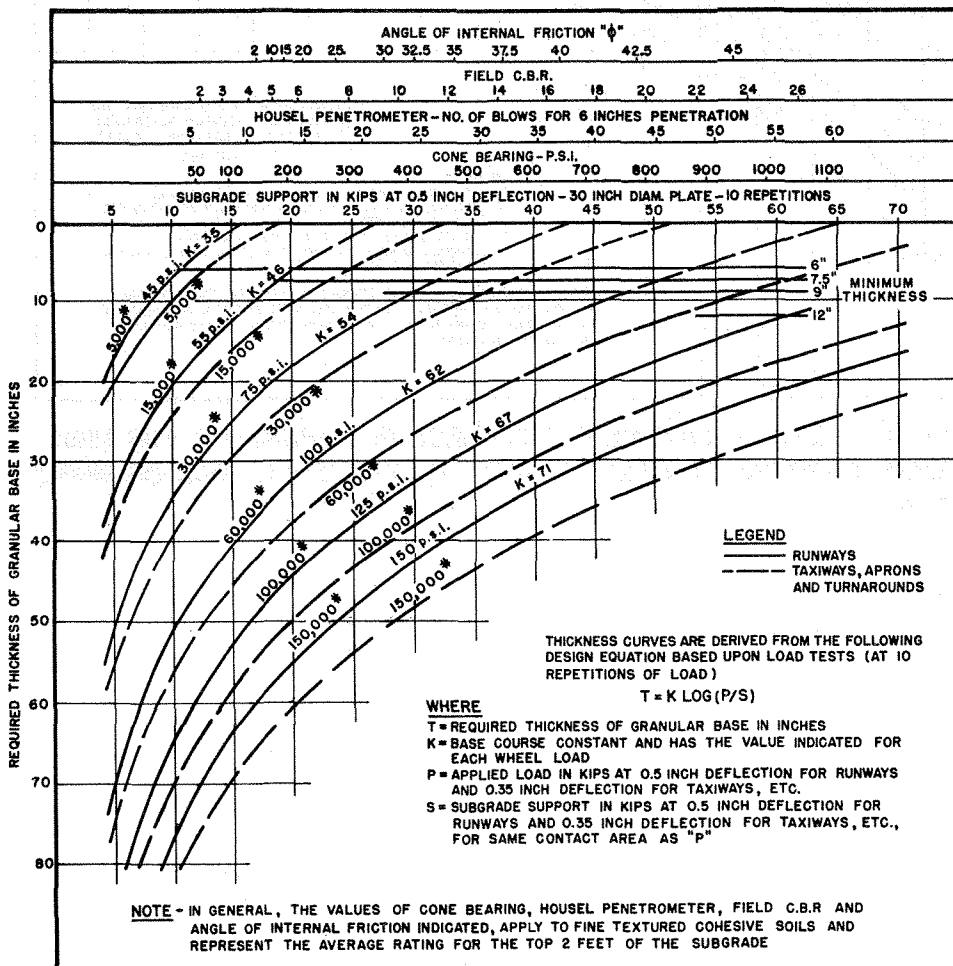


FIG. 8 DESIGN CURVES FOR FLEXIBLE PAVEMENTS FOR RUNWAYS AND TAXIWAYS, ETC. FOR AEROPLANE WHEEL LOADINGS (FULL LOAD ON SINGLE TIRE)

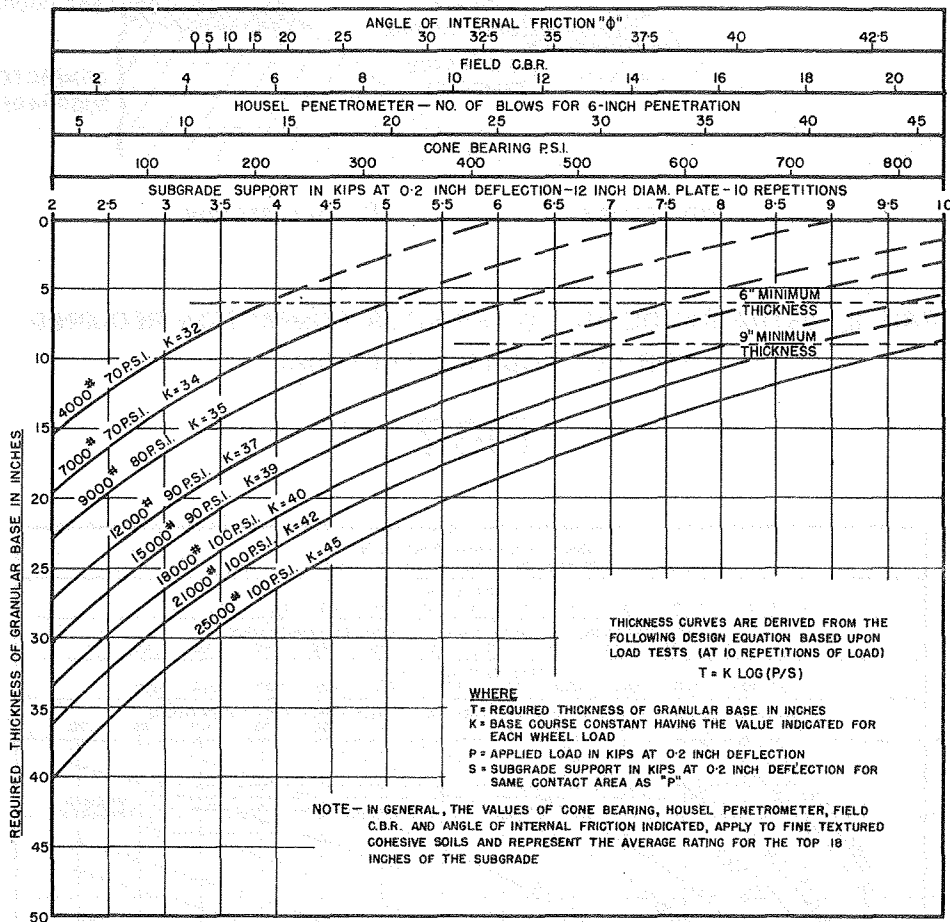


FIG.9 FLEXIBLE PAVEMENT THICKNESS REQUIREMENTS FOR HIGHWAYS CARRYING MAXIMUM TRAFFIC VOLUME (FULL LOAD ON SINGLE TIRE).

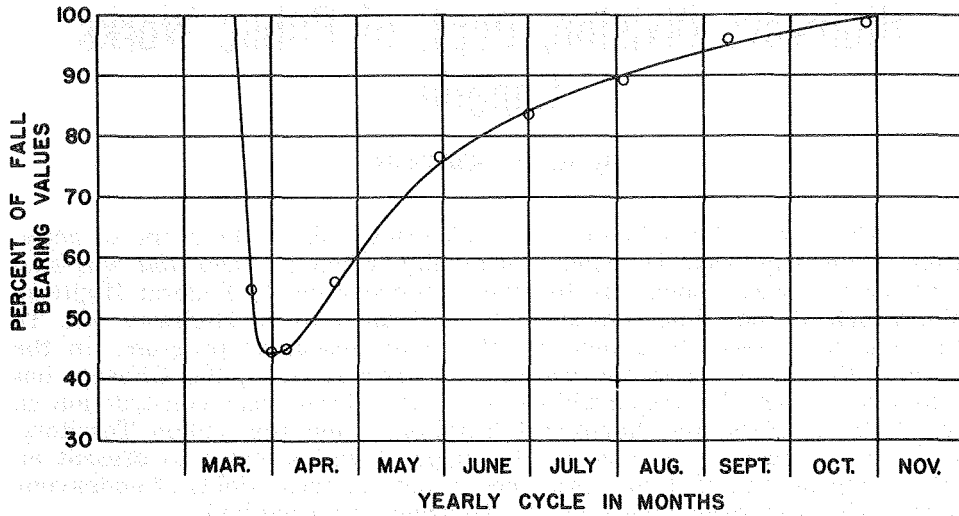


FIG.10 YEARLY CYCLE OF LOSS AND RECOVERY OF HIGHWAY SUPPORTING VALUES IN REGIONS SUBJECT TO DEEP FROST PENETRATION. (MOTL COMMITTEE REPORT).

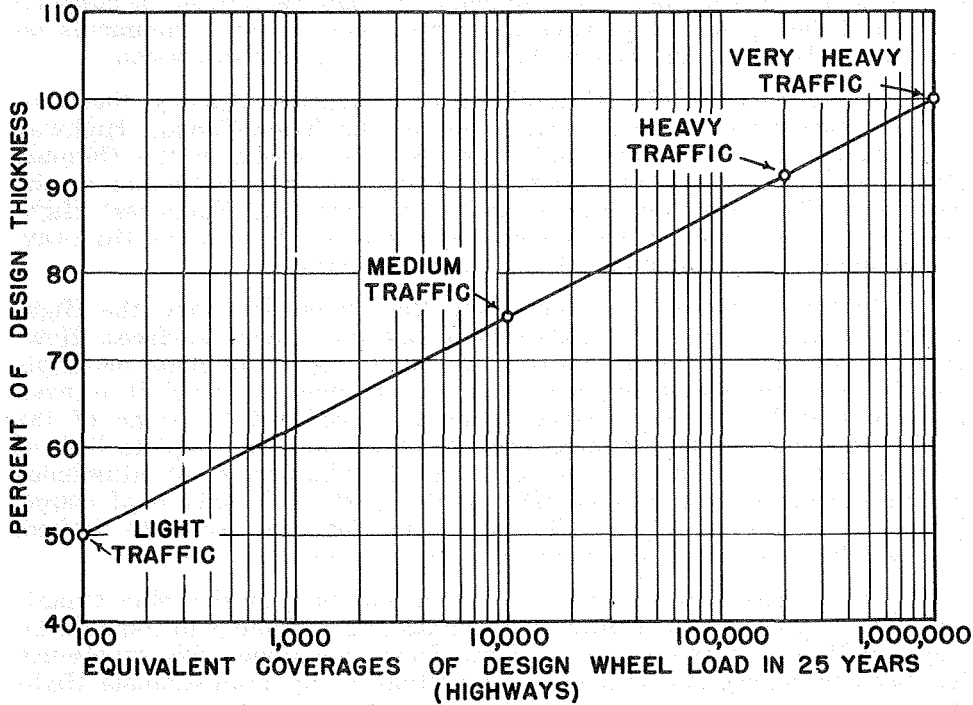


FIG.II PERCENT OF DESIGN THICKNESS REQUIRED FOR VARIOUS INTENSITIES OF HIGHWAY TRAFFIC.