Evaluating Subgrade Friction-Reducing Mediums for Rigid Pavements

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As early as 1924 the U. S. Bureau of Public Roads conducted studies to determine the magnitude of the resistance offered by the subgrade to the horizontal movement of concrete pavement slabs. These early studies clearly showed that this resistance varies considerably with the type of material on which the pavement rests. In recent years increased interest in prestressed concrete pavements indicates a need for mediums that offer a low resistance to slab movement.

This paper presents the results of a study of several friction-reducing mediums that have been proposed by designers of prestressed pavements. The data on these mediums were developed by moving 6-ft sq slabs horizontally, alternately forward and backward several times. The thrust necessary to cause horizontal movement of the slab and the magnitude of displacement caused by the thrust were measured from the time that the first detectable movement took place until free sliding began.

•FOR MANY YEARS pavement designers have known that low-friction mediums will substantially reduce the direct tensile stresses induced in concrete slabs by subgrade resistance. However, because these stresses are generally quite small for the relatively short slabs of conventional concrete pavements, little use was made of such mediums until the advent of prestressed pavements.

Prestressed pavement, with slab lengths ranging upward to 800 ft, requires low-friction mediums for the most efficient use of the applied prestressing force. A 50 percent reduction in the frictional resistance of the material on which the pavement rests could result in a 30 to 40 percent reduction in the prestressing force.

Previous investigations have established that the resistance offered to slab movement by the subgrade can be decreased by a variety of means. In 1924, Goldbeck (1) reported that the elimination of ridges and depressions in the subgrade or the introduction of a sand layer between the subgrade and the pavement causes an appreciable decrease in the coefficient of friction. Recently, Stott (2) of the Road Research Laboratory of Great Britain presented the results of a comprehensive investigation of various materials used as sliding layers, including polyethylene sheeting, paraffin wax, bitumen, and lubricating oil.

In the past, a thin sand layer has been the most commonly used medium to reduce friction between the slab and the subgrade. However, many engineers now believe that sand layers should not be used under the relatively thin prestressed highway pavements because of the possible aggravation of edge pumping.

The importance of friction-reducing mediums to prestressed pavement led the U. S. Bureau of Public Roads to undertake a study designed to develop comparative data on several types of mediums that have been proposed for such pavement.

SCOPE OF STUDY

In this study the resistance to slab movement was determined for the seven following conditions: (a) subgrade soil consisting of micaceous clay loam and referred to in

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TABLE 1

PHYSICAL PROPERTIES OF SUBGRADE AND SUBBASE MATERIALS, SHEET AND EMULSIFIED ASPHALTS

Property	Subgrade Soil	Granular Subbase	Blend Washed Sand and Gravel	Sand in Sheet Asphalt	Sand in Emulsified Asphalt
Mechanical analysis (% passing sieve size):			No information available.		
3-in.		100			
2-in.		98			
1½-in.		96			
1-in.		91			
¾-in.		84			
⅜-in.	100	70			100
No. 4	99	61		100	95
No. 10	98	54		98	87
No. 40	94	36		68	37
No. 80	-	-		30	9
No. 200	78	15		12.5	4
Liquid limit	40	33			
Plasticity index	15	16			
Classification	A-6(10)	A-2-6(0)		-	-
Penetration				60-70	60-70
Asphalt content, %				8.8	7.5

Figure 1. (a) Slabs between abutments, and (b) 5-in. slab loaded to weight equivalent of 11-in. slab.

this report as "plastic soil," (b) granular subbase consisting of material meeting the U. S. Bureau of Public Roads grading and plasticity requirements for Federal highway projects (3), (c) granular subbase consisting of a blend of washed sand and gravel, (d) granular subbase, same as (b), with 1-in. sand layer covered by one-ply building paper, (e) granular subbase, same as (b), with a layer of emulsified sand asphalt about 1 in. thick, (f) granular subbase, same as (b), with a thin leveling course of sheet asphalt covered by a double layer of polyethylene sheeting containing a special friction-reducing additive, and (g) granular subbase, same as (b), with a layer of sheet asphalt about ½ in. thick.

The physical properties and AASHO classification of the subgrade and subbase materials together with information on the sheet and emulsified asphalts are given in Table 1.

For each condition, force-displacement curves were developed from data obtained by moving six-ft sq concrete slabs horizontally, alternately forward and backward several times to simulate the behavior of pavements in service. The force or thrust necessary to cause horizontal movement of the slab and the magnitude of displacement caused by the thrust were measured from the time that the first detectable movement took place until free sliding began.

The testing program was divided into a winter-spring study and a summer study, at which times the absorbed moisture in the subbase and subgrade was at the maximum and minimum of the annual cycle of moisture change, respectively.

All slabs were 5 in. thick. In order to develop data for force-displacement curves for 8- and 11-in. thick slabs, 100-lb weights were dispersed uniformly on top of the 5-in. slabs to provide the proper weight equivalency. A general view of the test slabs and a 5-in. slab loaded to the weight equivalency of an 11-in. slab are shown in Figure 1.

TEST PROCEDURE

Figure 2 shows the arrangement of the test slabs and the testing apparatus. Five, 1-ft sq wooden posts were set in the ground, 3 ft deep and 9 ft on centers, to serve as abutments for the thrusting force. The subbases and sliding mediums were placed symmetrically in 8-ft squares between the wooden posts. The 6-ft sq, 5-in. thick con-

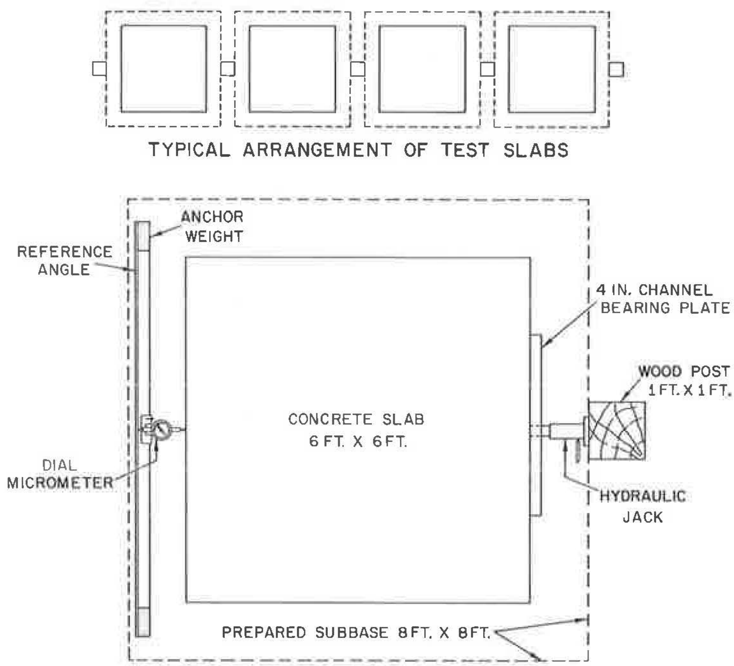

Figure 2. Arrangement of test slabs and testing apparatus.

crete slabs were cast in place, concentric with the 8-ft squares. A hydraulic jack applied the thrusting force to the concrete slab through a 3-ft long, 4-in. channel bearing plate. Horizontal displacement was measured with a micrometer dial on the side of the slab opposite to the thrusting force.

In most of the tests the thrusting force was applied continuously in increments at 5-min intervals as follows: 5-in. slab—200 lb, 8-in. slab—320 lb, and 11-in. slab—440 lb.

The thrusting force was held constant during the 5-min interval between the added increments. The displacement of the slab was measured immediately after the application of each increment of force and again just before the next increment was applied. These two readings were averaged to give a single value. Incremental loading was continued until the slab was sliding freely and the magnitude of the thrusting force could no longer be increased.

The thrusting force was removed every five minutes in load decrements as follows: 5-in. slab—400 lb, 8-in. slab—640 lb, and 11-in. slab—880 lb.

On release of the thrusting force, the slab tended to reverse direction. This return movement was also recorded in certain tests, being measured immediately after the removal of each decrement of force and just before the removal of the next decrement.

Force-displacement diagrams were also developed for the 5-in. slab on the granular subbase with a sand layer at two rates of loading other than the rate described above. One rate was very fast, in which 200 lb of force were applied every 10 sec and the other was twice as slow as the described rate, or 200 lb every 10 min.

In general, the slabs were moved back and forth three times or a total of six instrumented runs. The slab under test was protected from the elements by a canvas shelter.

TEST RESULTS

The data obtained in the testing of the slabs are shown in various ways in Figures 3-11. These figures illustrate certain characteristics of force-displacement behavior that have been reported by other investigators (2, 4).

Typical Data

Figure 3 shows typical data resulting from two of the tests. Each point on the curves represents an average value of six displacement tests, three in a forward and three in a backward direction. As the increments of force were applied, the successive increments of displacement increased in magnitude in a ratio that closely approximates a parabola. After free sliding occurred, the thrusting force could not be increased beyond that which initially caused the slab to slide. The slab returned slightly toward its original position on release of the thrusting force. This return movement is believed to be the result of elastic deformation of the soil and was measured in only a few of the tests, because it is of little value to the purpose of this study.

Rate of Application of Thrusting Force

The effect of the rate of loading on the displacement of a slab cast on the granular subbase with a sand layer is shown in Figure 4. The total thrusting force was applied in approximately 1½, 45, and 90 min for the fast, medium, and slow loading rates, respectively. From these data it is apparent that rate of loading has no appreciable effect on the displacement of slabs on sand layers. This finding agrees with that of Stott (2) who observed that restraint offered by a friction-reducing layer of sharp sand was not markedly affected by variations in the rate of slab movement between 0.08 and 0.5 in. per hour.

Successive Slab Movements

Examples of data obtained from these successive movements are shown in Figure 5 for 5-in. thick slabs cast on a sand layer, polyethylene sheeting, and emulsified sand asphalt. Once free sliding occurred at first movement, the slabs moved so rapidly under the accumulated thrusting force that accurate force-displacement measurements

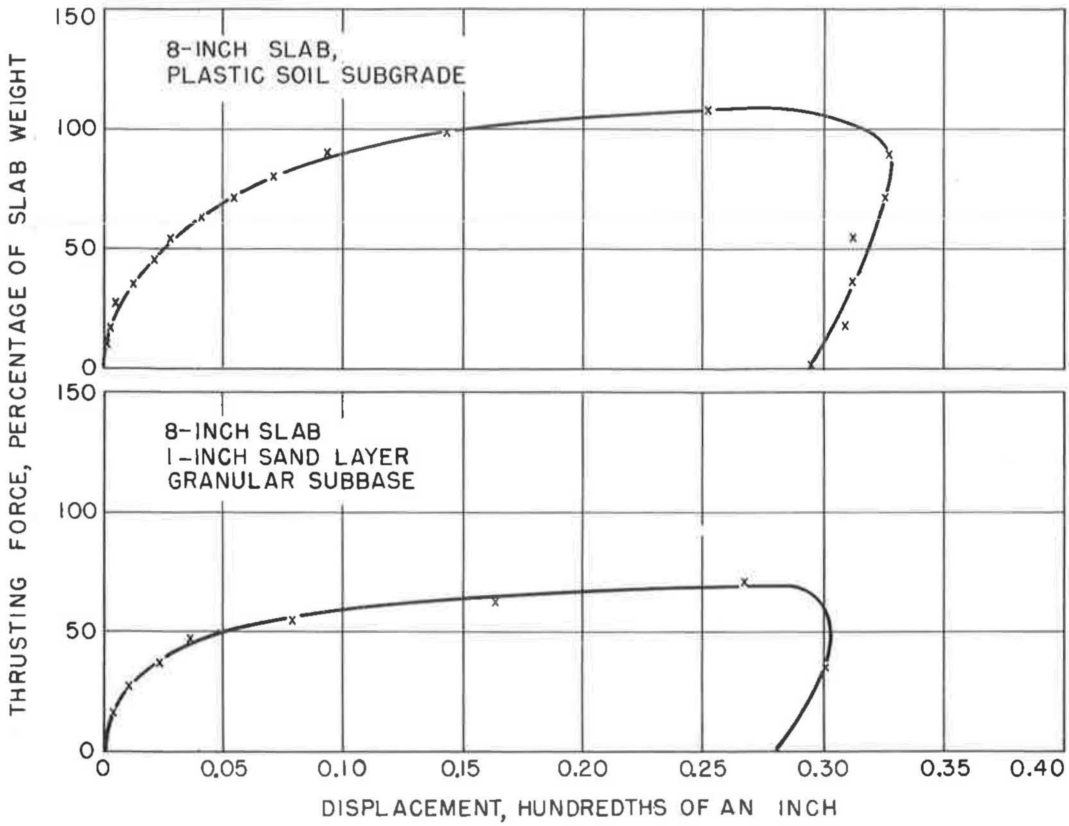

Figure 3. Typical force-displacement curves.

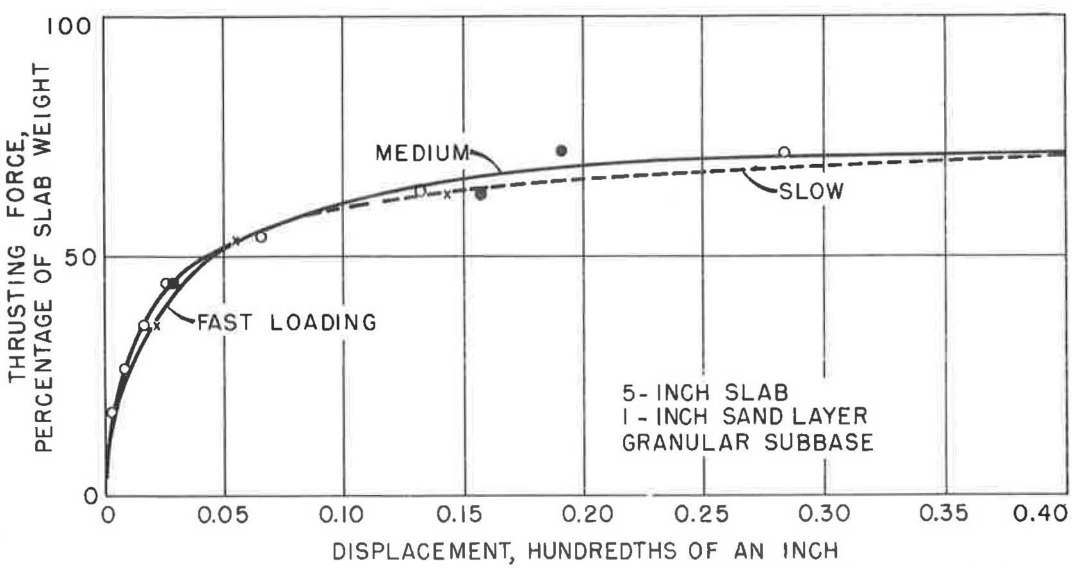

Figure 4. Effect of rate of loading on force-displacement relations.

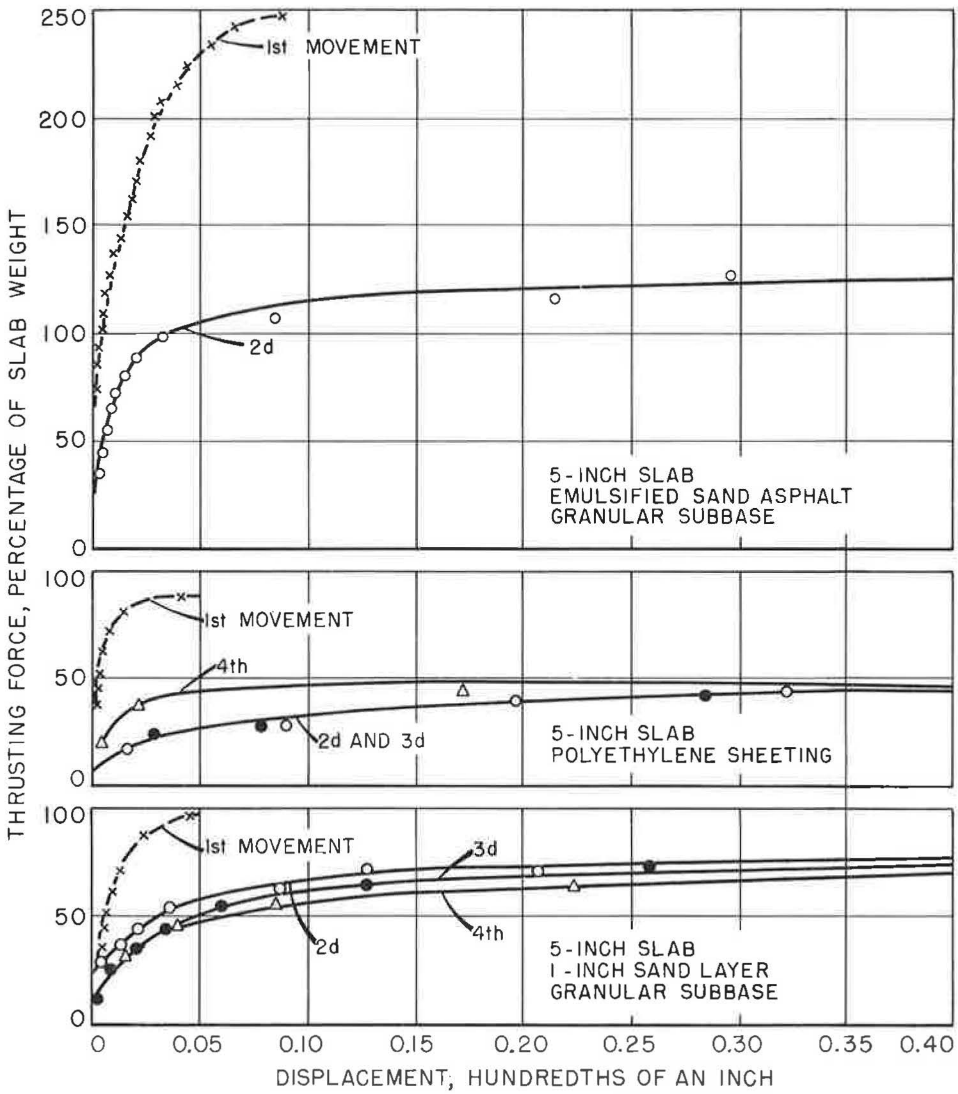

Figure 5. Effect of successive slab movements on force-displacement relations.

were unattainable. This accounts for the plotted data on the first-movement curves being terminated at the point where free sliding began.

Figure 5 shows that all three of the proposed friction-reducing mediums produced, as expected, greater resistance to slab displacement for the first movement than for the following movements. It is evident, however, that a condition of essential stability of resistance is obtained after only two or three movements. The data also show that the magnitude of the coefficient of friction or thrusting force at free sliding (expressed in terms of percentage of slab weight) is considerably greater for the emulsified sand asphalt than for the polyethylene sheeting and the sand layer.

Tests of the emulsified sand asphalt were discontinued after the second movement of the slab because of the large thrusting force necessary to cause free sliding. Likewise, tests of the sheet asphalt were concluded after the first movement because the thrusting force required to start free sliding was three times the weight of the slab. Both of the materials bonded themselves to the bottom of the slab, thus indicating the need for an intermediate sliding medium if used beneath prestressed pavements.

Winter-Summer Comparisons

Force-displacement relations were obtained in the summer and again in the winter-spring period for 5-, 8-, and 11-in.-thick slabs on the plastic subgrade soil, granular subbase, blend of washed sand and gravel, and the sand layer. The foregoing mediums are identified previously as conditions 1 through 4, respectively. A 5-in. slab was cast on each of the mediums and, in turn, weighted to the equivalent of 8- and 11-in. slabs. The data developed in these tests are shown in Figures 6-9, with each plotted value being the average of five slab movements. The first movement of the slab in a test series was not included in the average. Consequently, the values represent a condition of essential stability of resistance to slab movement. The subgrade was not frozen at the time of the winter-spring tests.

The force-displacement relations for the slabs on the plastic subgrade soil are shown in Figure 6. For a displacement up to about 0.1 in., it is evident that less thrusting force was required to move the slabs in the winter than in the summer. However, in the free-sliding range, the thrusting force necessary to move the slabs in the winter was at least equal to that required for summer movement. The moisture in the top $\frac{1}{2}$ in. of the subgrade soil was 22 and 25 percent, respectively, at the time of the summer and the winter-spring tests.

There is a tendency for the coefficient of friction to decrease in magnitude with an increase in slab thickness. This same tendency was observed by Teller and Sutherland (4) who noted that it may be related to resistance to movement caused by an elastic or semi-elastic deformation within the soil itself.

Figure 7 presents the force-displacement relations for those slabs on the granular subbase. Experience has shown that the surface of granular subbases may vary considerably in roughness with the type of granular material and construction practices. In this study the surface of the granular subbase was considered to be relatively smooth and quite sandy in texture.

The relations observed indicate that (a) the magnitude of the friction coefficient for the granular subbase, unlike that for the plastic subgrade, tends to remain constant with an increase in slab thickness, and (b) the shape of the force-displacement curve for the granular material, again unlike that for the plastic soil, is unaffected by moisture conditions related to the season of the year.

Figures 8 and 9 present the summer and winter-spring relations for the slabs on the blend of washed sand and gravel and for the slabs on the 1-in. sand layer, respectively. Except for the winter data of the 5-in. slab, the relations for the blend of washed sand and gravel are quite similar to those found for the granular subbase. The data of Figure 9 show conclusively that the coefficient of friction for the slabs on the 1-in. sand layer is unaffected by seasonal variations in subgrade moisture or by slab thicknesses. These conditions appear to be typical for slabs on granular materials.

Force-displacement relations were obtained only in the summer for the slabs on the double layer of special polyethylene sheeting used to cover a thin leveling course of sheet asphalt. From these relations, shown in Figure 10, it is evident that slab thickness has little effect on the magnitude of the coefficient of friction.

Summary of Friction Coefficients for 5-In. Slabs

Coefficient of friction data for the 5-in. thick slabs on each of the seven different mediums included in this study are summarized in Figure 11. The seven mediums are arranged from left to right in the descending order of the magnitude of related coefficient of friction values. The numbers in parentheses identify the mediums with the seven conditions mentioned earlier in this report. These values are the maximum developed in the tests at free sliding, regardless of the season of the year.

Two significant facts are apparent from the data shown in Figure 11. First, the friction coefficient for the initial movement of a slab is appreciably greater than that for the average of subsequent movements, ranging from approximately 35 percent greater for the 1-in. sand layer to about 90 percent for the emulsified asphalt. Secondly, the polyethylene sheeting produced the lowest coefficient of friction values, about 0.9 for first movement and 0.5 for subsequent movements, followed by the 1-in. sand layer with nearly 1.0 for first movement and about 0.7 for subsequent movements.

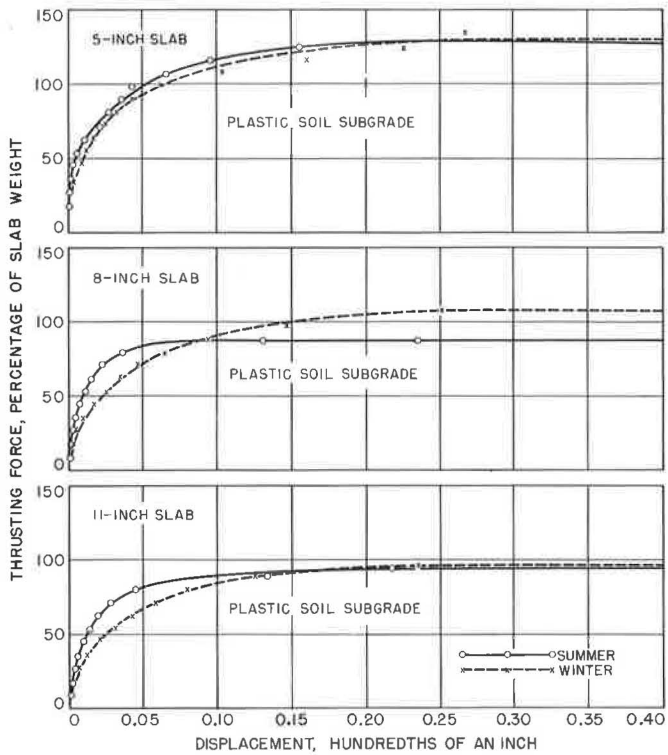

Figure 6. Force-displacement curves for concrete slabs on plastic soil.

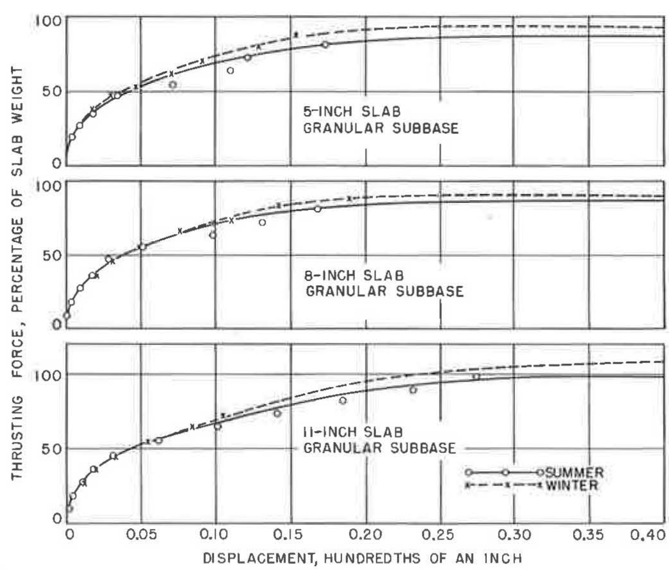

Figure 7. Force-displacement curves for concrete slabs on granular subbase, BPR grading and plasticity requirements.

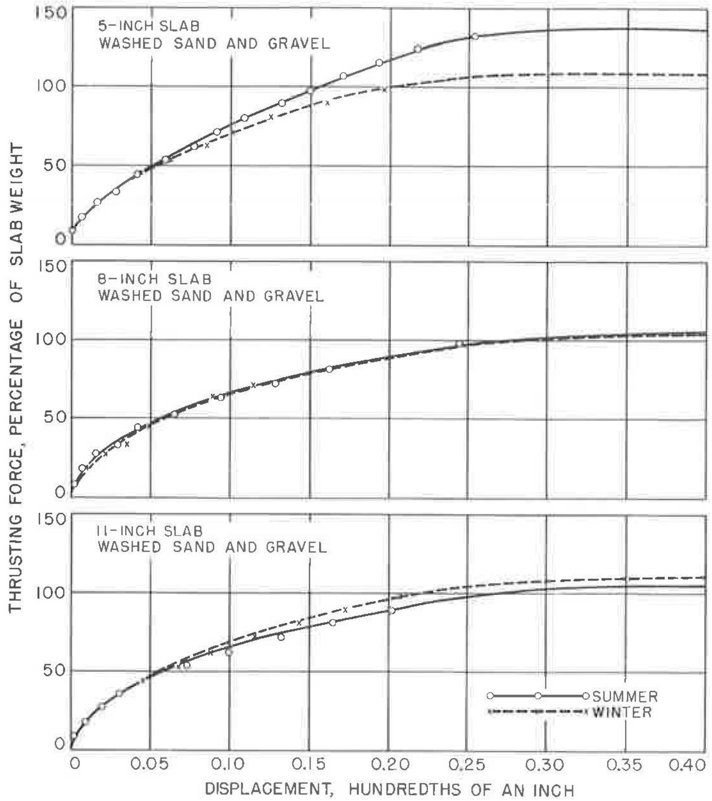

Figure 8. Force-displacement curves for concrete slabs on blend of washed sand and gravel subbase.

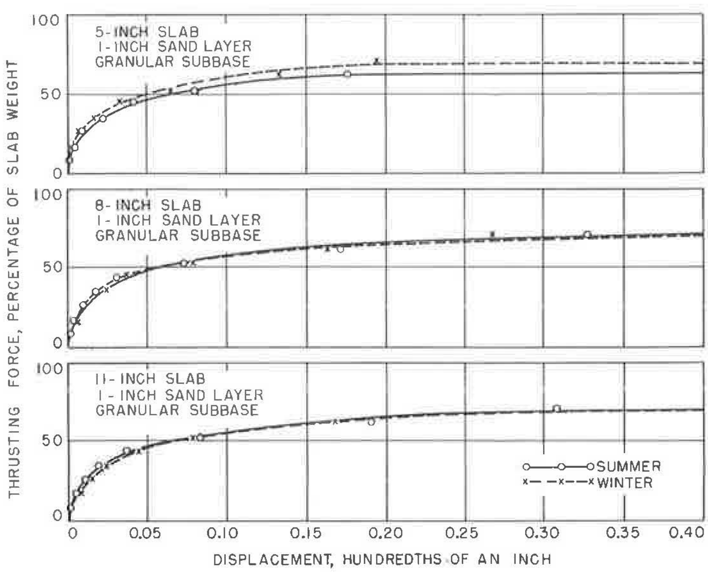

Figure 9. Force-displacement curves for concrete slab on granular subbase plus 1-in. sand layer.

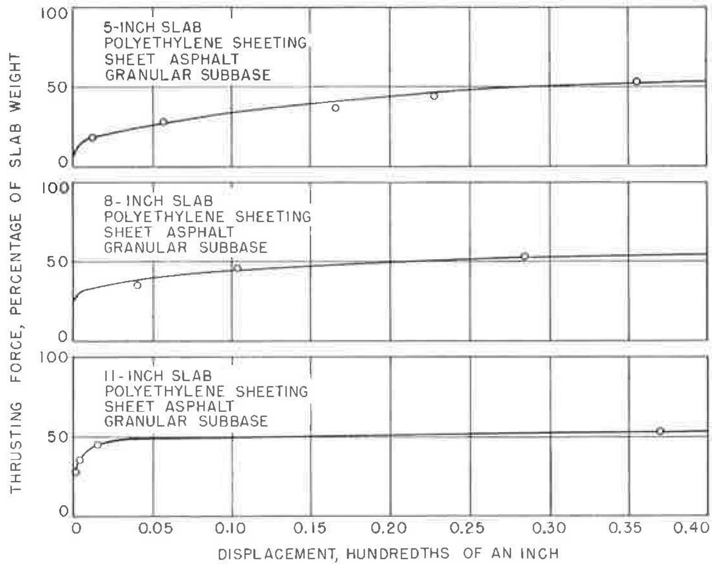

Figure 10. Force-displacement curves for leveling course of asphalt covered with a double layer of polyethylene sheeting.

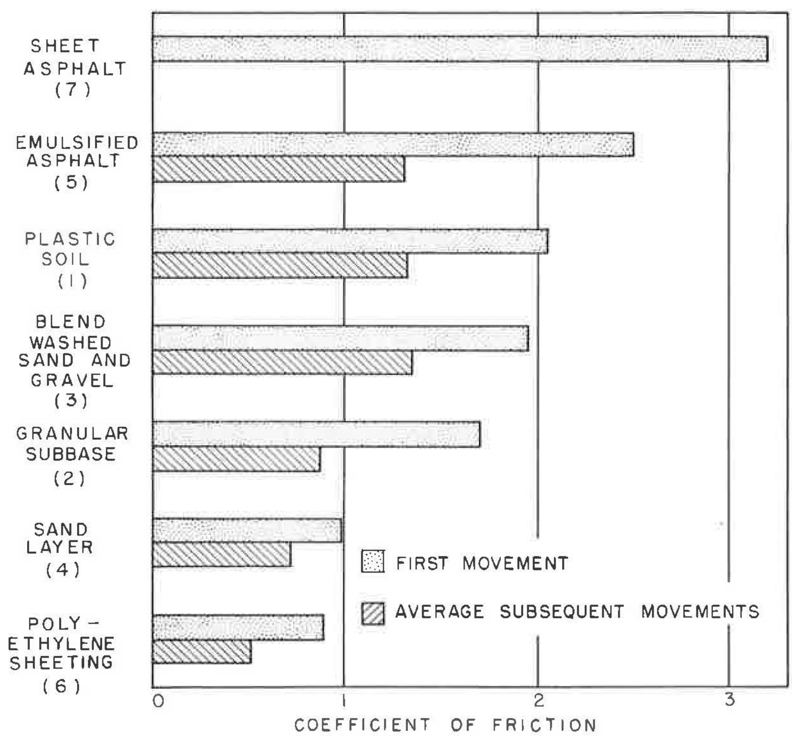

Figure 11. Summary of coefficients of friction for 5-in. slabs.

CONCLUSIONS

The following conclusions are based on the analysis of the data developed in this study.

1. For granular materials, the magnitude of the coefficient of sliding friction is unaffected by slab thicknesses ranging from 5 to 11 in. and by seasonal variations in subgrade moisture content. For the double layer of polyethylene sheeting on the thin leveling course of sheet asphalt, the magnitude of the coefficient of friction is unaffected by slab thickness. The effect of seasonal variations in subgrade moisture on the friction coefficient for the polyethylene sheeting was not determined in this study.

2. For sand layers, the coefficient of friction is unaffected by rate of application of the thrusting force (rate of loading), ranging from 1½ min to 90 min for total applied force. The effect of rate of loading was not determined for the other mediums included in this study.

3. The coefficient of friction for the initial movement of a slab is appreciably greater than for subsequent movements, with a condition of essential stability of resistance being obtained after only two or three cycles of movement.

4. A thin sand layer and a double layer of polyethylene sheeting on a thin leveling course of sheet asphalt are effective friction-reducing mediums.

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