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16. Abstract

An important factor to be considered in the design of prestressed concrete pavements is the friction characteristics of the slab-support interface. Due to the slab's length, detrimental tensile stresses may develop as the slab movements caused by temperature variations, moisture changes, concrete shrinkage, and/or creep are resisted by the friction at the interface.

This study investigated the effectiveness of single-layer and double-layer polyethylene sheeting in reducing the friction at the interface. A spray-applied bond breaker consisting of white machine oil cut with 1/3 gasoline was also tested.

The maximum coefficient of friction for each of the mediums was determined through three series of pushoff tests carried out on four experimental test slabs. The three series of tests were carried out over a period of a year to help determine the performance of the friction reducing mediums over time and changing seasons.

The study shows that the double layer polyethylene sheeting produces the lowest maximum coefficient of friction. However, the use of single-layer polyethylene is recommended because it is economical and its maximum coefficient of friction is low enough to prevent development of any detrimental tensile stress in the slab.

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FIELD EVALUATION OF SUBBASE FRICTION CHARACTERISTICS

by

Way Seng Chia
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Research Report 401-5

Prestressed Concrete Pavement Design -
Design and Construction of Overlay Applications
Research Project 3-8-84-401

conducted for

Texas State Department of Highways
and Public Transportation

in cooperation with the
U.S. Department of Transportation
Federal Highway Administration

by the

Center for Transportation Research
Bureau of Engineering Research
The University of Texas at Austin

September 1986

PREFACE

This report is one of a series that describes work done under the project entitled "Prestressed Concrete Pavement Design - Design and Construction of Overlay Applications." The project is a joint effort by the Texas Highway Department and the Center for Transportation Research at The University of Texas at Austin.

This report presents results from friction push-off tests carried out at Valley View, Texas, to determine the maximum coefficient of friction for several friction reducing mediums. This study was carried out to recommend friction reducing medium for use in demonstration prestressed concrete pavement projects in Cooke and McLennan counties.

Special appreciation is extended to all project staff and to the rest of the Center for Transportation Research personnel for their assistance and invaluable contributions. Special thanks are extended to Alberto Mendoza, Neil Cable, Joe Maffei, and Scott O'Brien for their efforts in collecting the data. Dr. M. Muthu's guidance and advice during the project is also recognized and appreciated.

Way Seng Chia
B. Frank McCullough
Ned H. Burns

LIST OF REPORTS

Report No. 401-1, "Very Early Post-tensioning of Prestressed Concrete Pavements," by J. Scott O'Brien, Ned H. Burns and B. Frank McCullough, presents the results of tests performed to determine the very early post-tensioning capacity of prestressed concrete pavement slabs, and gives recommendations for a post-tensioning schedule within the first 24 hours after casting.

Report No. 401-2, "New Concepts in Prestressed Concrete Pavement," by Neil D. Cable, Ned H. Burns, and B. Frank McCullough, presents the following: (a) a review of the available literature to ascertain the current state of the art of prestressed concrete pavement; (b) a critical evaluation of the design, construction, and performance of several FHWA sponsored prestressed concrete pavement projects which were constructed during the 1970s; and (c) several new prestressed concrete pavement concepts which were developed based on (a) and (b).

Report No. 401-3, "Behavior of Long Prestressed Pavement Slabs and Design Methodology," by Alberto Mendoza-Diaz, N. H. Burns, and B. Frank McCullough, presents the development of a model to predict the behavior of long prestressed concrete pavement (PCP) slabs and incorporate the predictions from the model into a design procedure.

Report No. 401-4, "Instrumentation and Behavior of Prestressed Concrete Pavements," by Joseph R. Maffei, Ned H. Burns, and B. Frank McCullough, describes the development and implementation of an instrumentation program used to monitor the behavior of a one-mile-long experimental prestressed concrete pavement and presents the results of measurements of ambient and concrete temperatures, horizontal slab movement, slab curling, concrete strain, very early concrete strength, concrete modulus of elasticity, and slab cracking.

Report No. 401-5, "Field Evaluation of Subbase Friction Characteristics," by Way Seng Chia, Ned H. Burns, and B. Frank McCullough, presents the results of push-off tests performed on four experimental test slabs at Valley View, Texas, to determine the maximum coefficient of friction of several friction reducing mediums for future implementation in the prestressed pavement projects in Cooke and McLennan counties.

ABSTRACT

An important factor to be considered in the design of prestressed concrete pavements is the friction characteristics of the slab-support interface. Due to the slab's length, detrimental tensile stresses may develop as the slab movements caused by temperature variations, moisture changes, concrete shrinkage, and/or creep are resisted by the friction at the interface.

This study investigated the effectiveness of single-layer and double-layer polyethylene sheeting in reducing the friction at the interface. A spray-applied bond breaker consisting of white machine oil cut with 1/3 gasoline was also tested.

The maximum coefficient of friction for each of the mediums was determined through three series of pushoff tests carried out on four experimental test slabs. The three series of tests were carried out over a period of a year to help determine the performance of the friction reducing mediums over time and changing seasons.

The study shows that the double layer polyethylene sheeting produces the lowest maximum coefficient of friction. However, the use of single layer polyethylene is recommended because it is economical and its maximum coefficient of friction is low enough to prevent development of any detrimental tensile stress in the slab.

SUMMARY

This report presents results of a series of field investigations on the effectiveness of three different friction reducing mediums in reducing the frictional slab-support interface. The three friction reducing mediums were (1) single layer polyethylene sheeting, (2) double layer polyethylene sheeting, and (3) a spray-applied bond breaker consisting of white machine oil cut 1/3 with gasoline.

The results of three series of pushoff tests conducted on four different experimental test slabs are presented. The first series of tests was conducted on May 31, 1984, the second series of tests on August 22, 1984, and the third series on April 23, 1985. As the three series of tests were carried out over a year, the performance of the friction reducing mediums was determined over time and seasonal changes. At the conclusion of the third series of tests, the slabs were picked up and physical inspections were carried out to determine the condition of the underlying membranes.

The maximum coefficient of friction for the three different friction reducing mediums were determined, and based on the findings of this study, a recommendation was made to use the single layer polyethylene sheeting in the demonstration prestressed pavement projects in Cooke and McLennan counties.

IMPLEMENTATION STATEMENT

This report presents recommendations for the design and use of friction reducing mediums for prestressed concrete pavement in the demonstration prestressed pavement projects in Cooke and McLennan counties.

Although two layers of polyethylene sheeting may provide a lower resistance value than a one layer system, only one layer is recommended for the projects in Cooke and McLennan counties.

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CHAPTER 5. CONCLUSIONS AND RECOMMENDATIONS

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CHAPTER 1. INTRODUCTION

BACKGROUND

During the design phase of any prestressed concrete pavement, an important factor to be considered is the friction characteristics of the slab-support interface.

Frictional forces develop when the prestressed slab contracts as a result of a drop in temperature, moisture reduction, concrete shrinkage, and/or creep. As the slab contracts the movements are resisted by the friction at the interface. The resistance to movement produces a direct tensile stress in the concrete. The local movements of the slab increase from zero at the center to a maximum at the edges. The tensile stresses produced in the slab by the restraint decrease from a maximum at the geometric center to zero at the free edges since the frictional resistance to the movements builds up from the slab ends. The higher the restraint, the higher will be the tensile stresses generated along the slab length. This situation is graphically presented in Fig 1.1.

This is where the friction reducing medium comes into play. The role of the friction reducing medium is to reduce the tensile stresses by reducing the frictional restraint between the slab and the underlying surface.

Also, with less frictional restraint, the post-tensioning will work more effectively. Higher compressive prestress can be reached at every point along the slab for a given post-tensioning force since loss due to restraint of the force applied at the ends through the tendon anchorages will be reduced. This condition is shown in Fig 1.2.

From a practical standpoint it is not possible to completely eliminate the frictional restraint and, in fact, it is not desirable to totally eliminate it. Reducing the frictional restraint too much would result in excessive joint widths, thereby increasing the potential for deterioration of the slab around the joints. Moreover, working and constructing on a slippery material may be difficult and even hazardous. Therefore, a compromise should be sought between all these factors when selecting a friction reducing medium.

Some of the materials used as friction reducing medium include sand, bitumen, oil, single or double films of polyethylene sheeting, etc.

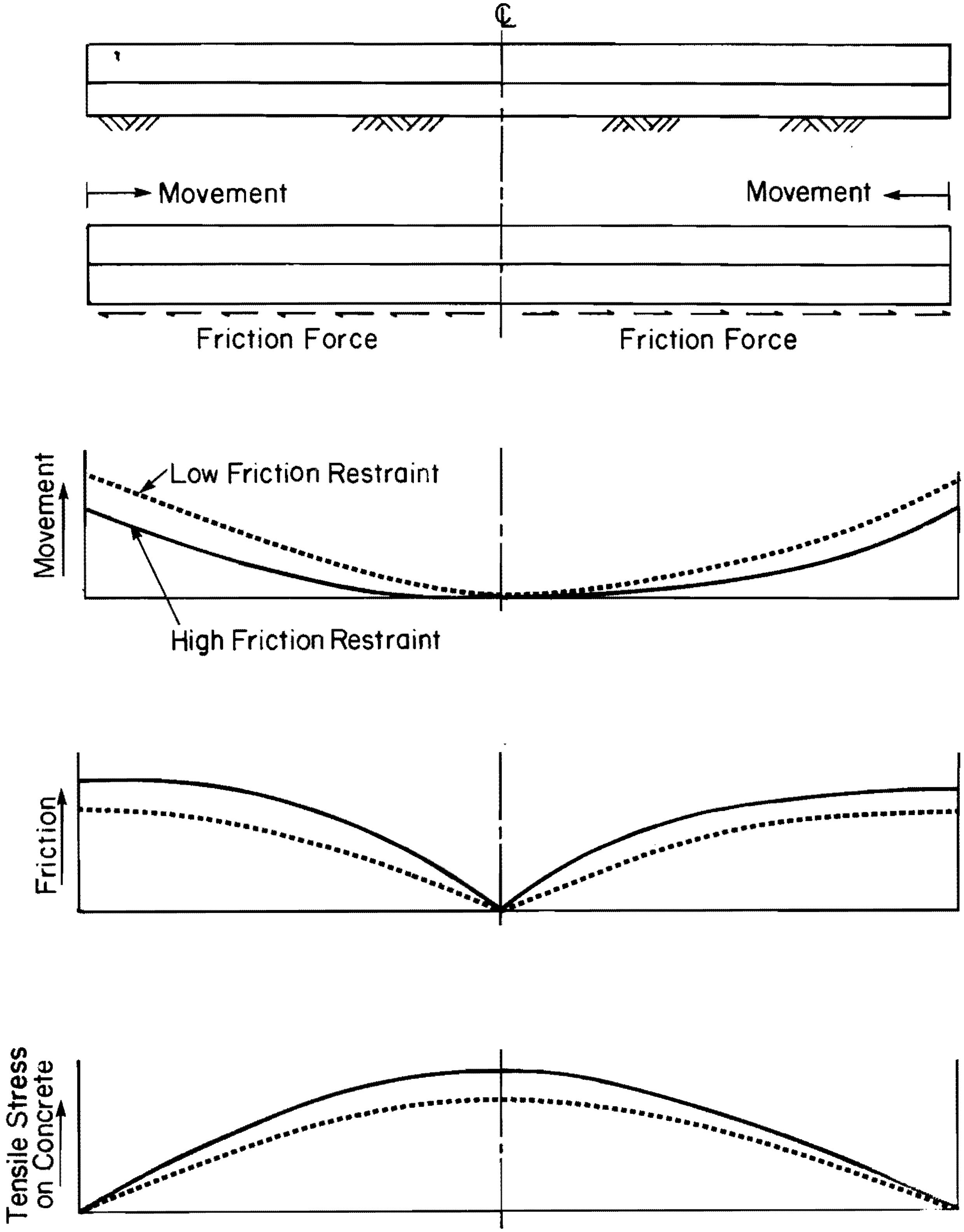

Fig 1.1. The effect of subbase restraint on the concrete slab's tensile stresses due to frictional resistance of movement.

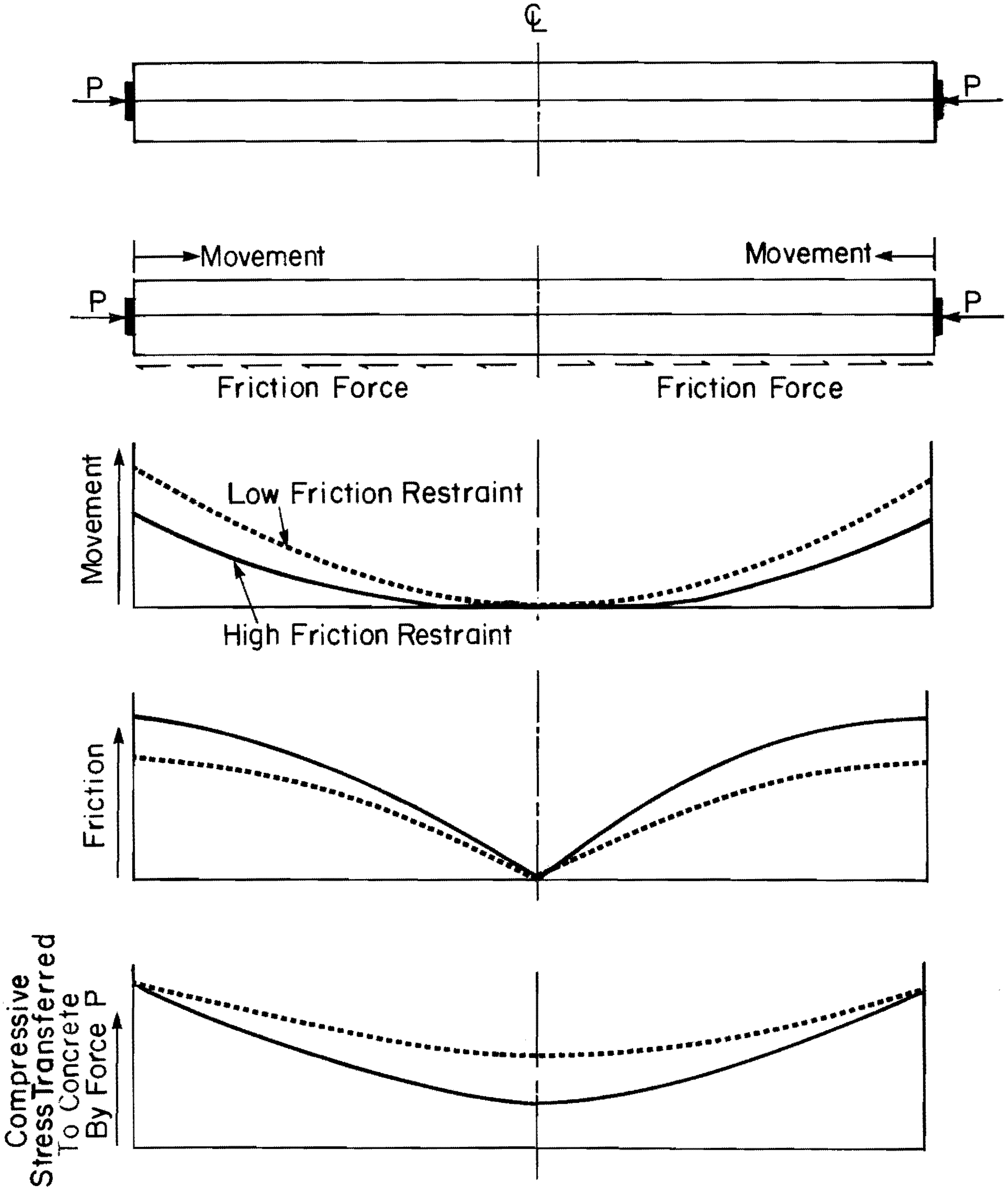

Fig 1.2. Effect of friction restraint on the compressive stress transferred to the concrete by the post-tensioning force P.

OBJECTIVES AND SCOPE OF REPORT

This report is the presentation of the field tests conducted near Valley View, Texas, for the design of the prestressed highway pavement demonstration projects in Cooke and McLennan counties.

The objectives of the field study are to

(1) evaluate the effectiveness of several different friction-reducing mediums,
(2) quantify the amount of friction losses in different types of post-tensioning tendons when stressed through loops involving different angle changes, and
(3) investigate alternative techniques of central stressing in pockets and the required dimensions of the pockets to eliminate the use of gap slabs between the prestressed pavement slabs.

This report evaluates the effectiveness of several friction-reducing mediums in reducing the frictional forces at the interface between the prestressed slab and the underlying subbase. The three friction-reducing mediums investigated are

(1) a double layer of 6-mil polyethylene sheeting,
(2) a single layer of 6-mil polyethylene sheeting, and
(3) a spray-applied bond breaker consisting of white machine oil cut 1/3 with gasoline.

The other objectives of the field tests at Valley View, Texas, relative to friction loss in the tendons are presented in another report.

CHAPTER 2. DESCRIPTION OF THE TESTS

EXPERIMENTAL APPROACH

The study of the friction-reducing mediums was done using push-off tests conducted on four experimental slabs. Figures 2.1 to 2.4 show the test slabs as they were originally designed.

(1) Test Slab No. 1: a 10 x 12 x 0.5 foot rectangular slab on a double layer of 6-mil polyethylene sheeting.

(2) Test Slab No. 2: a 10 x 12 x 0.5 foot rectangular slab cast on a spray-applied concrete curing compound (white machine oil cut 1/3 with gasoline) to serve as a debonding material.

(3) Test Slab No. 3: a 10 x 10 x 0.5 foot square slab on a single layer of 6-mil polyethylene sheeting.

(4) Test Slab No. 4: a 10 x 20 x 0.5 foot rectangular slab on a single layer of 6-mil polyethylene sheeting.

The objective of the first three test slabs was to evaluate three possible friction reducing mediums,. i.e., single and double layers of polyethylene sheeting and a sprayed-on material. Test Slabs 3 and 4 were to evaluate the effect of slab size.

To fully utilize the slabs, three separate sets of push-off tests were conducted over a period of one year. The first test was conducted on May 31 and June 1, 1984; the second test on August 22, 1984; and the third test on April 23, 1985.

DEVELOPMENT OF EXPERIMENT

Site Preparation

The test slabs were constructed on May 15 and May 16, 1984. The test site was located approximately 1-1/2 miles south of Valley View, Texas. Prior to the construction of the slabs, the site was prepared to provide a smooth and uniform surface. For this purpose, a

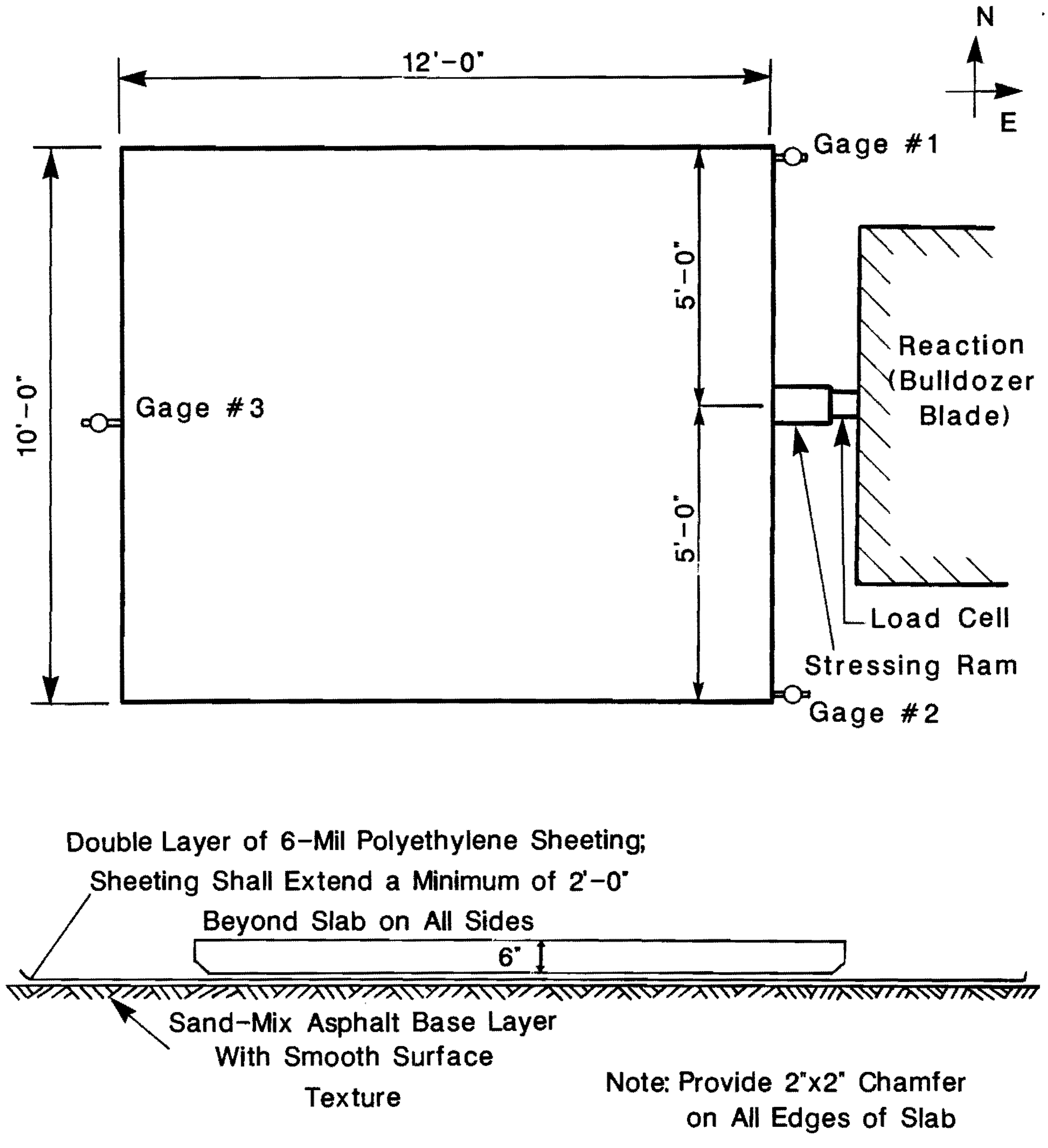

Fig 2.1. Layout for Test Slab No. 1 with double layer of polyethylene sheeting.

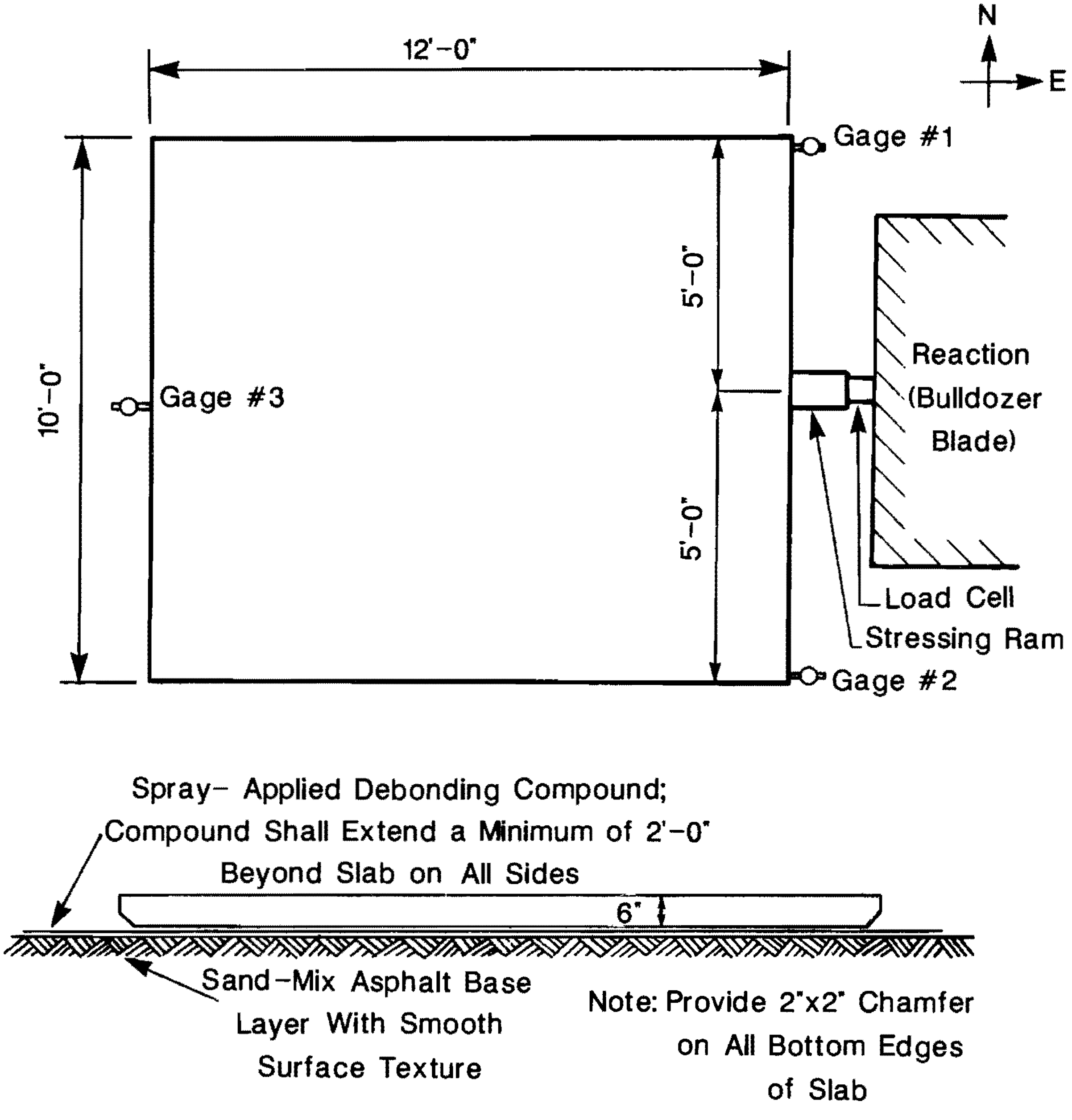

Fig 2.2. Layout of Test Slab No. 2 with spray applied debonding compound.

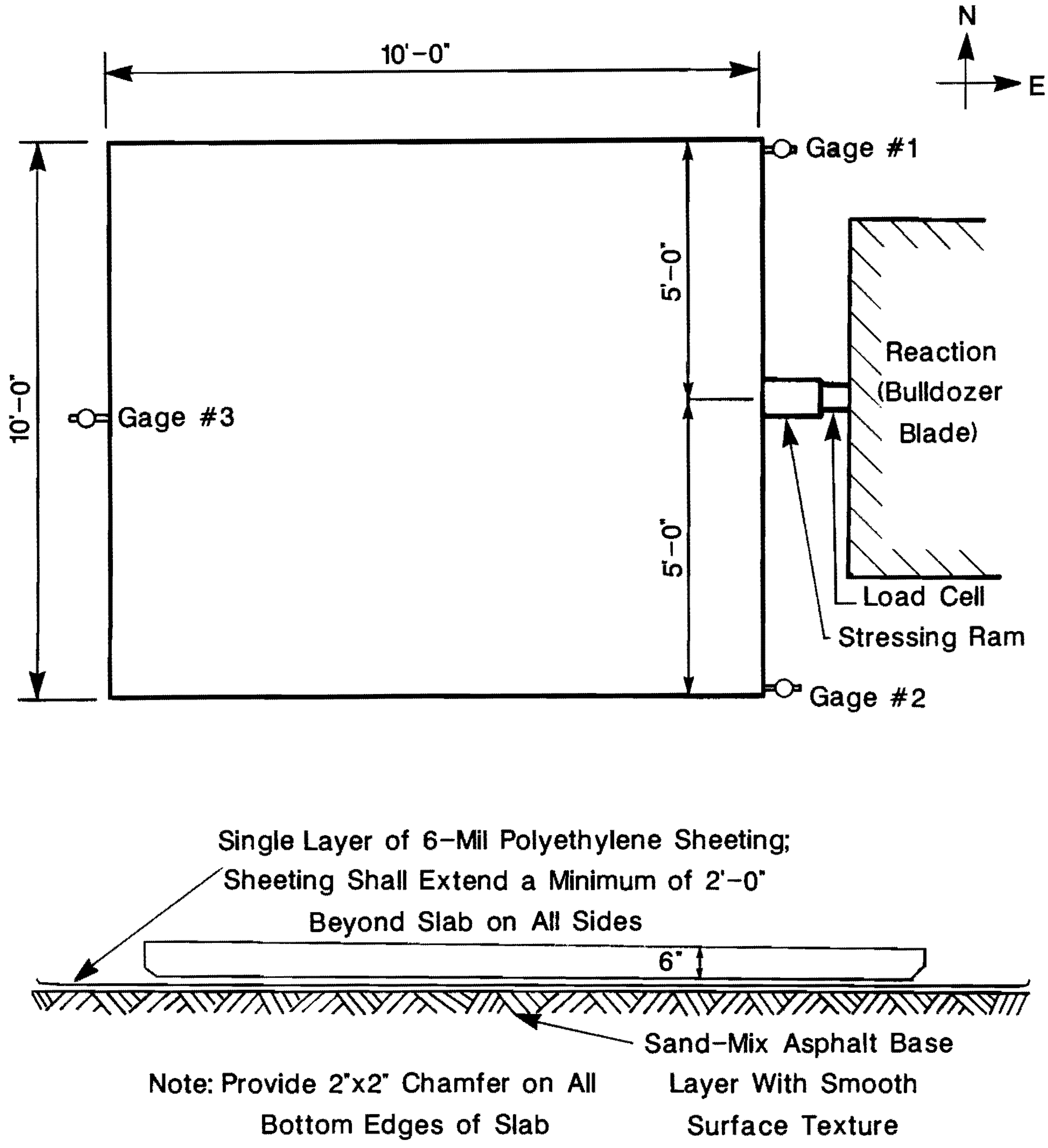

Fig 2.3. Layout of Test Slab No. 3 with single layer of polyethylene sheeting (small slab).

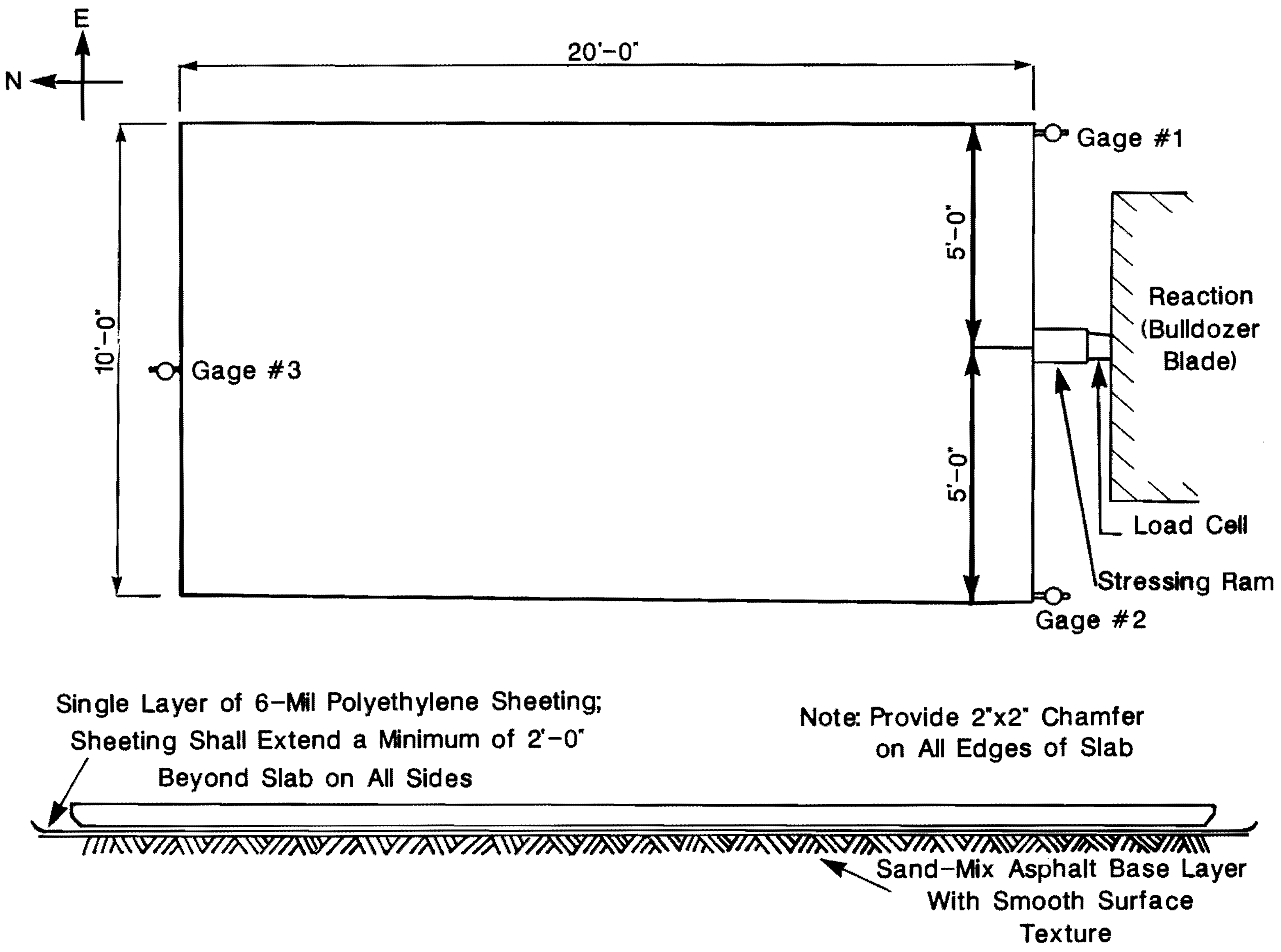

Fig 2.4. Layout of test slab no. 4 with a single layer of polyethylene sheeting (large slab).

sand mix asphalt pad was laid on top of the subgrade, as shown in Fig 2.5. To eliminate any undesirable external effects during the friction tests, care was taken to sweep off all scrap materials from the asphalt pad before the slabs were cast. Figure 2.6 shows the sweeping operation. Then, the locations of the slabs along the asphalt strip were marked with spray paint. Finally, the polyethylene sheeting was rolled out and cut to the required lengths for Test Slab Nos. 1, 3, and 4 as shown in Fig 2.7. For Test Slab No. 2 the bond breaker compound proposed by the contractor was applied directly to the surface of the asphalt pad. The bond breaker reacted with the asphalt and required several applications to obtain a uniform coating.

Construction of Slabs

First, the formwork for each slab was prepared, as shown in Fig 2.8. The strands were then put in place inside the formwork and secured with tie wire at points of intersection of crossing strands. The wood boxes for the blockouts were placed at the required locations and secured in place by boards nailed on top of the slab formwork and nails driven into the top of the boxes, as shown in Fig 2.9. The strain gages which were to be attached to the plastic post-tensioning duct were placed and their leads brought outside the formwork. The final arrangement of Test Slabs 1, 2, 3, and 4 before casting of the concrete is presented in Figs 2.9, 2.10, 2.11, and 2.12, respectively.

Casting of the concrete was done on May 16, 1984 . The four slabs were cast, vibrated, screeded, and trowel finished. Some additional strain gages were embedded in the concrete. Three different concrete deliveries were used for casting the slabs. Four 6 x 12-inch concrete cylinders and two concrete test beams were taken from each of the first two concrete deliveries for determining stress-strain relationships and strength properties. After trowel finishing all slabs, the exposed slab surfaces were sprayed with curing compound. Figure 2.13 shows a general view of the test site after the casting of the slabs.

EXPERIMENTAL TESTING PROCEDURES

The four slabs were tested on three separate occasions. The experimental set ups for the four test slabs are shown in Figs 2.1 through 2.4.

Fig 2.5. Sand mix asphalt pad prepared to provide a smooth surface for the test slabs.

Fig 2.6. Sweeping of the asphalt pad before construction of the slabs.

Fig 2.7. Placing of polyethylene sheeting on top of asphalt pad.

Fig 2.8. Preparation of form work for slabs.

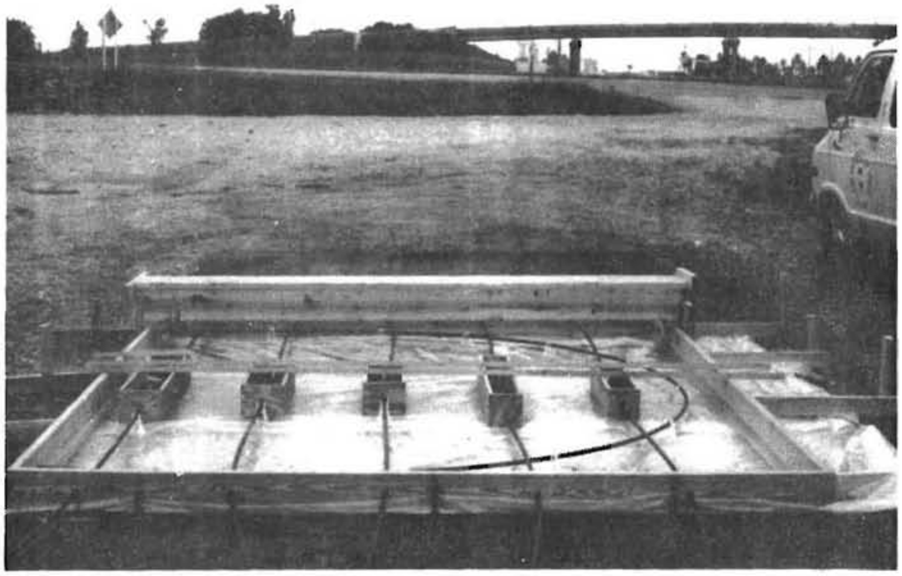

Fig 2.9. Layout of Test Slab No. 1 before casting the concrete.

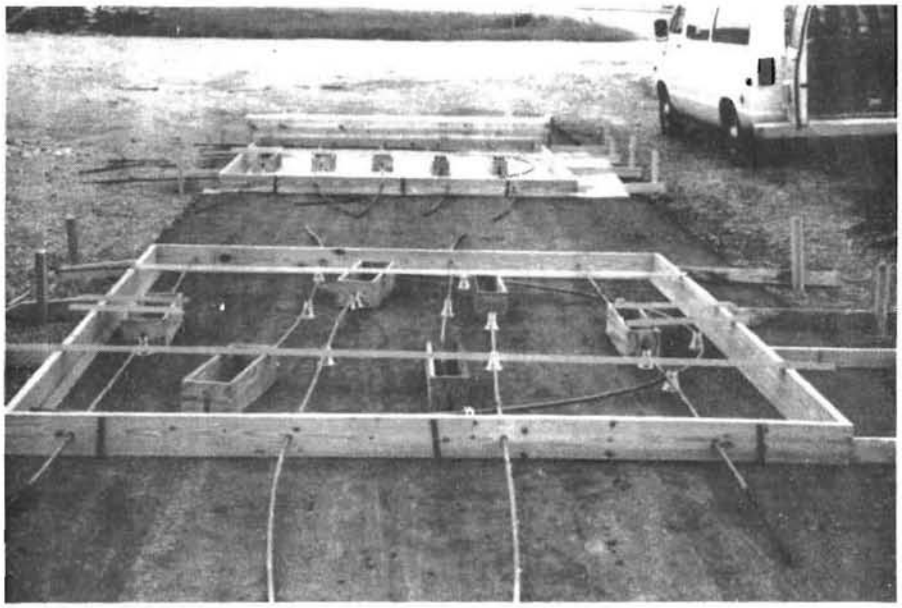

Fig 2.10. Layout of Test Slab No. 2 before casting the concrete.

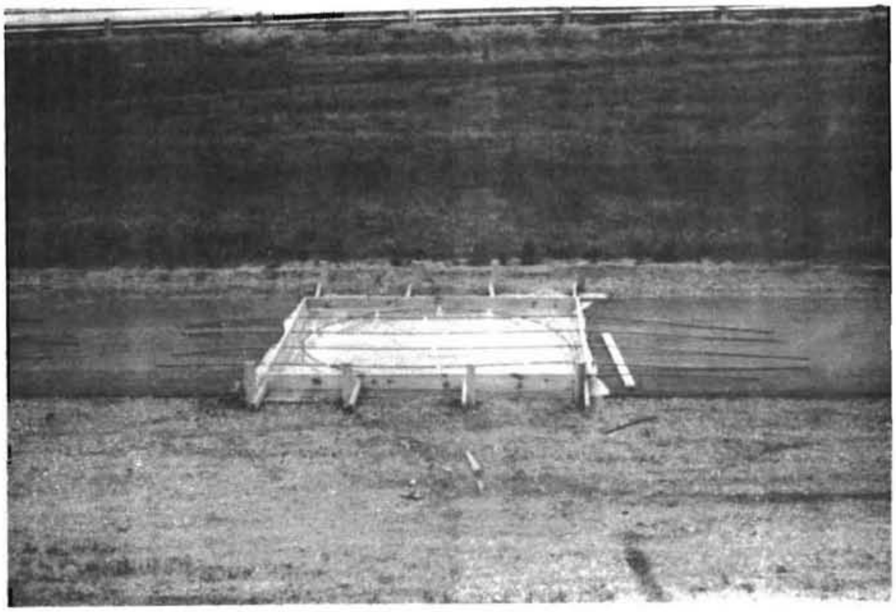

Fig 2.11. Layout of Test Slab No. 3 before casting the concrete.

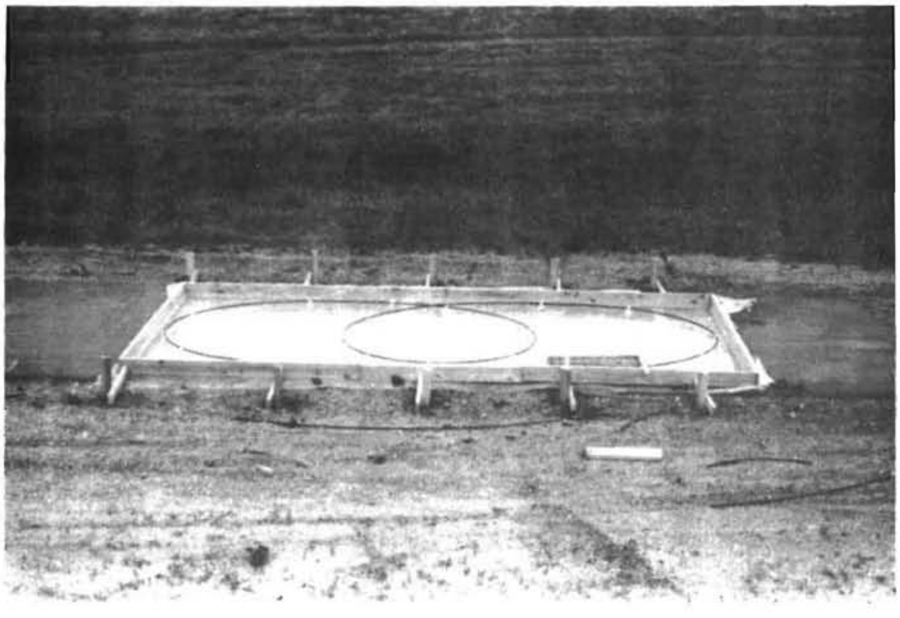

Fig 2.12. Layout of Test Slab No. 4 before casting the concrete.

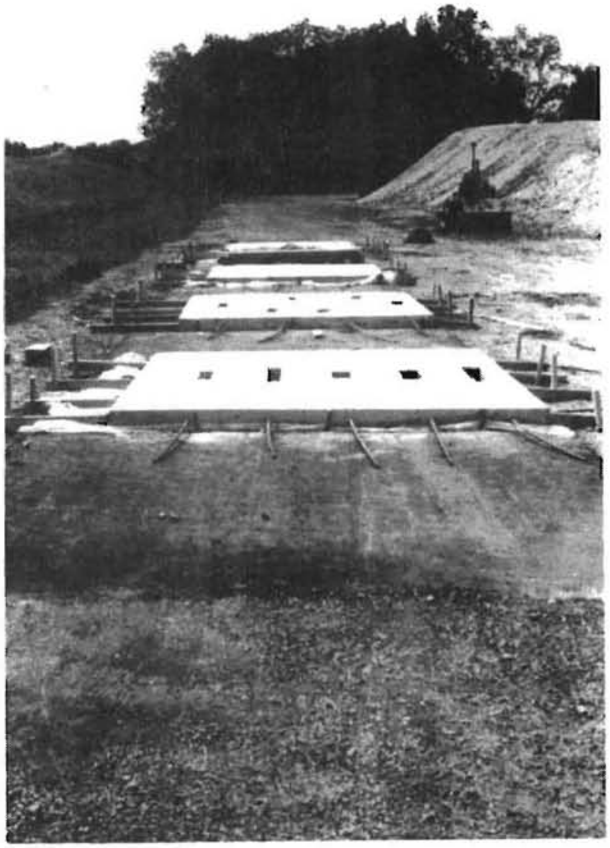

Fig 2.13. General view of the test site after casting of the slabs.

Test No. 1

Test No. 1 was conducted on May 31 and June 1, 1984. For the push-off test a D9 dozer was used. The load was applied in increments of approximately 0.5-kip with a 60-kip Enerpac center hole stressing ram reacting against the dozer blade and the test slab, as shown in Fig 2.14. The applied load was determined from the readings of a 100-kip load cell and checked against the stressing ram dial gage. Four 0.5-inch travel dial gages were used on each slab to measure the movements obtained with every load increment. Three dial gages were installed against the slab face being loaded and a fourth gage was placed on the opposite face to detect any possible differential movement. Figure 2.15 shows the method for supporting the dial gages and holding them in contact with the slab face.

Slabs 1, 2, and 3 were pushed by reacting against their east edge, whereas Slab 4 was pushed from its south edge as shown in Figs 2.1 through 2.4.

Test No. 2

Test 2 was conducted on August 22, 1984. The test slabs were re-tested in order to check any possible variations with time of the friction properties. These tests were conducted after the movements associated with hot weather. The retest was performed following exactly the same sequence as in the original push-off test of June 1, 1984.

Test No. 3

Test 3 was conducted on April 23, 1985, approximately 11 months after placement. The testing procedure was essentially the same as that for the first test. These tests represent a full cycle of seasonal temperature and moisture conditions.

Horizontal loading was applied to the slabs using a 60-kip center hole stressing ram reacting against the blade of a stationary bulldozer. The amount of load applied was determined using a load cell positioned between the ram and the bulldozer blade. The load cell reading was checked against the reading from the stressing ram pressure gage. For Slabs 2 and 3, the load was applied at the centerpoint of the east face of the slab. For Slab 4, the load was applied at the centerpoint of the south face of the slab. Slab 1 was loaded alternately on both its east and

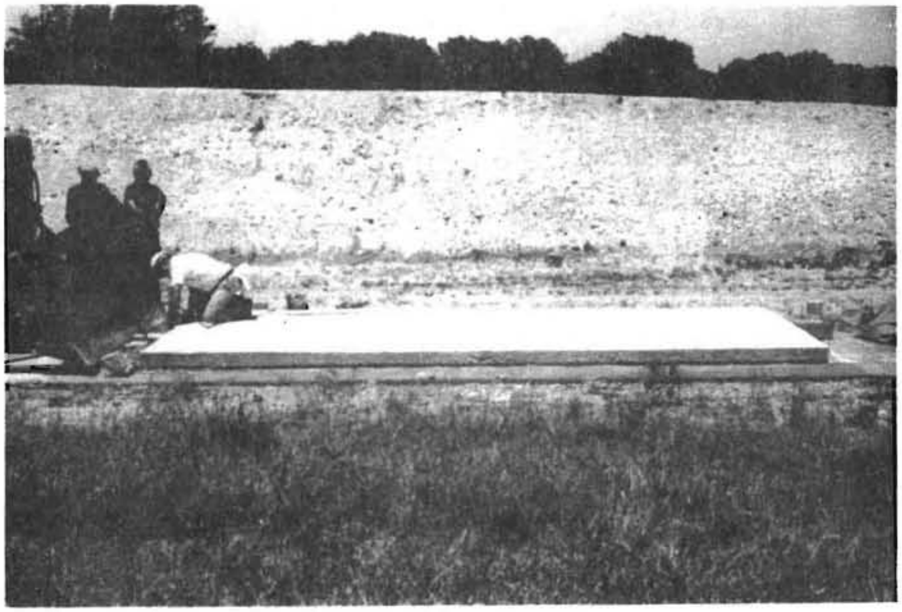

Fig 2.14. Stressing ram reacting against dozer blade and test slab.

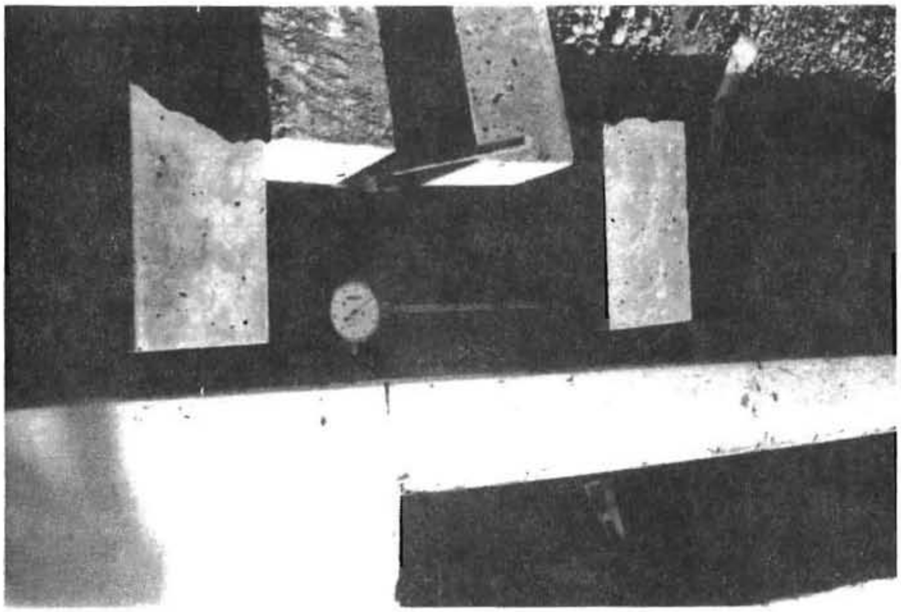

Fig 2.15. Dial gage placed against slab face.

west faces. For all slabs the loading was applied in increments of 1.0-kip until it was close to sliding, when the loading was applied in increments of 0.5-kip.

Three dial gages accurate to 0.0001-inch were used on each slab to measure the movements obtained with every load increment. Two dial gages were placed against the slab face being loaded, while one gage was placed against the opposite face to detect any possible differential movement or compression of the slab.

Loading of the slabs was applied incrementally until the maximum value was reached. After the maximum load value was reached, loading was stopped, the load was released, the dial gages were reset, and the loading was started up again, for the second set of readings. At least two sets of readings were recorded for each slab. For the second set of readings on Slabs 1 and 3, loading was continued until a total movement of about 1 inch was reached. For Slab 1, a third and fourth set of readings were taken as the slab was loaded from the opposite (west) side. A fifth set of readings was taken when the slab was loaded again from the east side. After all readings were taken on Slab 1, the slab was picked up so that the condition of the underlying membrane could be examined.

The experimental procedure of this series of tests differs from that of the first and second series of tests only in the following respects:

(1) The bulldozer used for the reaction was smaller than the one used in the first and second series. This affected the maximum amount of load which could be applied to Slab 2.

(2) In the first and second series of tests, loading was applied to the slabs until sliding began. In this series of tests, Slabs 1 and 3 were pushed until sliding beam, and then were pushed to a displacement of about 1 inch while readings of load were maintained.

(3) This series of tests included the loading of Slab 1 alternately from both its east and west faces, and included the visual inspection of the membrane underlying Slab 1.

(4) On the first series of tests, horizontal movement was taken as the average of the readings from four dial gages mounted against the slab. (One of the dial gages was mounted at the location of the stressing ram.) On the second series of tests, and on this series of tests, only three dial gages were used.

CHAPTER 3. PRESENTATION OF DATA

RECORD OF DATA

Data obtained from the three field tests are presented in Appendix A. The data are reported following the sequence described below.

Test Series No. 1

Slab 1. Three push-off tests were carried out. Table A.1 presents the three sets of readings for each of the four installed dial gages for the corresponding lateral loads. The weight of the slab was calculated from the computed volume and the density of concrete.

Slab 2. Only one push-off test was performed. The data obtained are presented in Table A.2.

Slab 3. Two push-off tests were performed. Table A.3 shows the results of the push-off tests.

Slab 4. Two runs of the push-off test were carried out, and the results are tabulated in Table A.4.

Test Series No. 2

The data from the re-testing of the four test slabs are presented in Tables A.5 through Table A.8. The push-off test was performed twice on Test Slabs 1, 3, and 4 and once on Test Slab 2.

Test Series No. 3

This was the final series of the three series of tests that were conducted. The data obtained from this series are presented in Tables A.9 thru A.13. Additional observations for this series are included below.

Slab 1. The first and second sets of readings are for the load being applied to the slab's east face. For the second set of readings, the slab was pushed to a total deflection of one inch. The peak force required to cause this movement was recorded as 5.2 kips. Once rapid displacement began, however, the force dropped to a value of 4.8 kips while displacement continued. This reading of load under continuing displacement seemed to depend on the rate of application of the load. If pressure were applied quickly to the stressing ram, the value of load applied would increase. If the stressing ram were pumped at a slower, steady rate, the value of load under continuing displacement would be lower. The third and fourth sets of readings for Slab 1 are for the load being applied to the slab's west face. The fifth set of readings is for the load being applied once again to the slab east's face.

Slab 2. Three sets of readings were taken for Slab 2. In each of the three runs rapid displacement of the slab was never initiated because sufficient load could not be applied. This was because, in the location of slab 2, the chocked wheels of the bulldozer could not provide a reaction to more than 5.5 kips of horizontal force.

Slab 3. Two sets of readings were taken for Slab 3. For the second set of readings, the slab was pushed to a total deflection of 1.2 inches. The peak force required to cause this movement was recorded to be 5.5 kips. Once rapid displacement began, the force dropped to a value of 4.2 kips while displacement continued.

Slab 4. Two sets of readings were taken for Slab 4. In both runs, readings were taken only until sliding began.

CHAPTER 4. DISCUSSION OF RESULTS

MAXIMUM COEFFICIENT OF FRICTION

The maximum coefficient of friction U_{max} is given by the relationship

$$U_{max} = P_{max}/W$$

where

P_{max} = lateral load when sliding begins (kips) and

W = weight of slab (kips).

RESULTS AND OBSERVATIONS

Test Series No. 1

The graphical representations of the force/displacement curves are presented in Appendix B, Figs B.1 to B.8. Tables B.1 to B.4 show the average maximum coefficient of friction U_{max} for the four test slabs.

From the analysis of the results of this first series of tests, the following points can be made.

(1) The coefficients of friction obtained from the push-off tests are summarized in Table 4.1. The double layer of polyethylene sheeting was the most effective friction reducing medium tested, with a maximum coefficient of friction U_{max} equal to 0.467. The single layer of polyethylene sheeting resulted in maximum coefficients of friction higher than that obtained for the double layer by more than 70 percent. The difference in maximum coefficients of friction obtained between Test Slabs 3 and 4 (both single layers of polyethylene sheeting) can be explained by any of the following factors.

TABLE 4.1. SUMMARY TABLE OF MAXIMUM COEFFICIENTS OF FRICTION U_{MAX} AND MOVEMENTS AT SLAB SLIDING FROM PUSH-OFF TEST

Test Slab Number	Friction Reducing Material	Maximum Coefficient of Friction U_{MAX}	Movement at Sliding (In.)
1	Double Layer of Polyethylene Sheeting	0.467	0.0045
3	Single Layer of Polyethylene Sheeting	0.824	0.01
4	Single Layer of Polyethylene Sheeting	0.92	0.02
2	Spray-Applied Bond Breaker	> 3.19	> 0.03

(a) The difference in smoothness of the surface of the asphalt pad between the sites where both slabs were laid.

(b) The difference in shape and physical dimensions of the surface of contact between the slabs and the asphalt pad, since Slab 3 is square whereas Test Slab 4 is rectangular. Also, the latter is wider and substantially longer than the former.

(c) Other sources of experimental error associated with the natural variability of the conditions from one test to the other.

(2) Instead of reducing the frictional restraint, the spray-applied bond breaker proposed by the contractor glued the bottom of Test Slab 2 to the supporting asphalt.

The average friction coefficient versus movement curves for all the materials tested in the push-off tests are presented in Fig 4.1.

Problems associated with the handling and placement of the polyethylene sheeting are anticipated unless these activities are carefully planned. In addition, some construction difficulties are possible because of the slick surface of the polyethylene sheeting, especially when a double layer is used.

Test Series No. 2

The friction coefficient versus displacement curves for all the slabs tested on June 1 and retested on August 22, 1984, are presented in Fig 4.2. It is apparent from Fig 4.2 that most materials maintained their friction relieving properties with the exception of the double layer of polyethylene film (Test Slab 1) whose curve shifted substantially toward the single layer polyethylene curve.

Table 4.2 summarizes the friction properties from the testing and the retesting of the slabs, and the percent change of the coefficients of friction. Again, the only material that shows a significant increase in the maximum coefficient of friction is the double layer of polyethylene film laid under Test Slab 1. The increase was almost 50 percent.

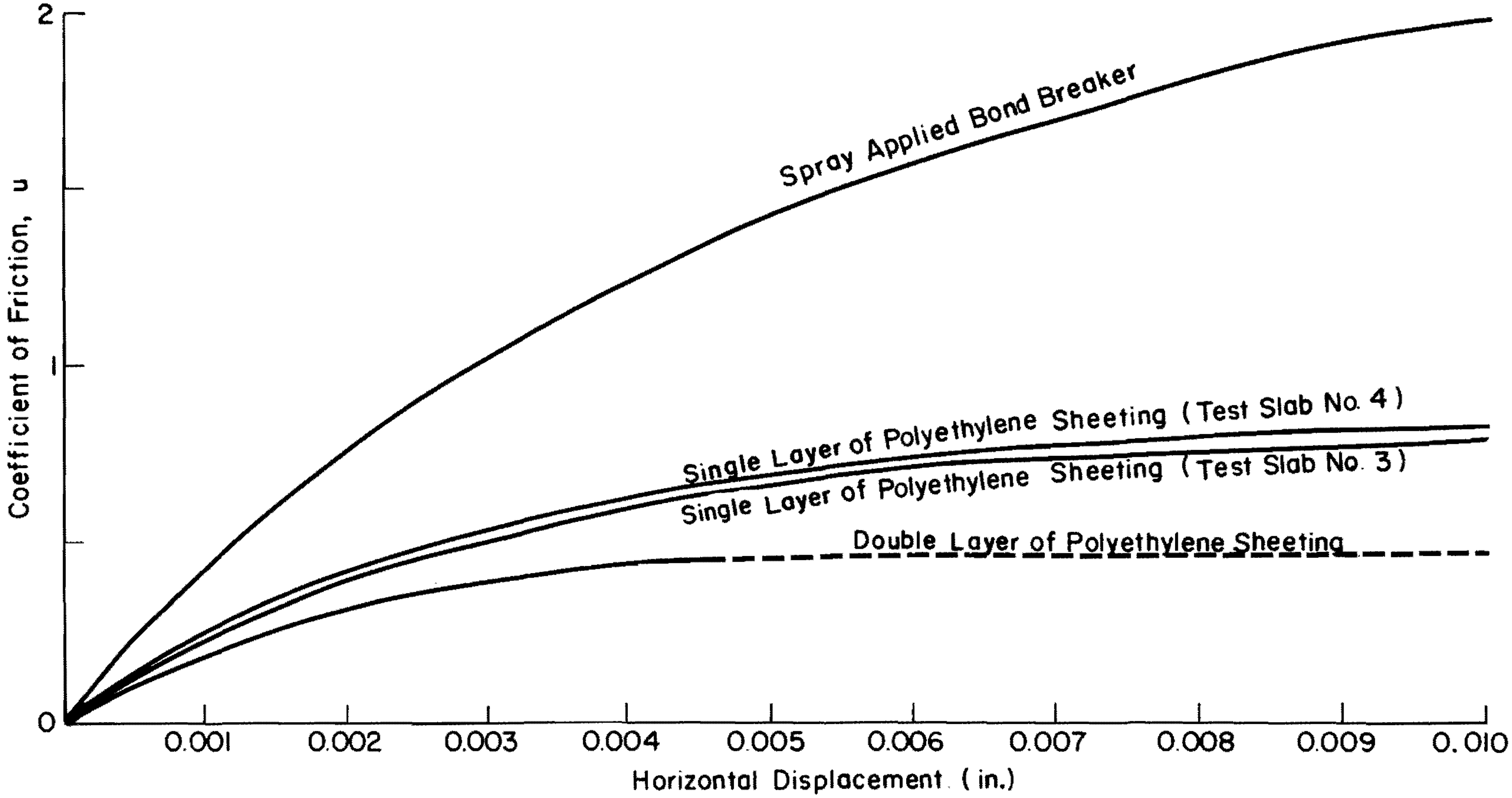

Fig 4.1. Average coefficient of friction versus horizontal displacement curves for all friction reducings mediums tested in the push-off test.

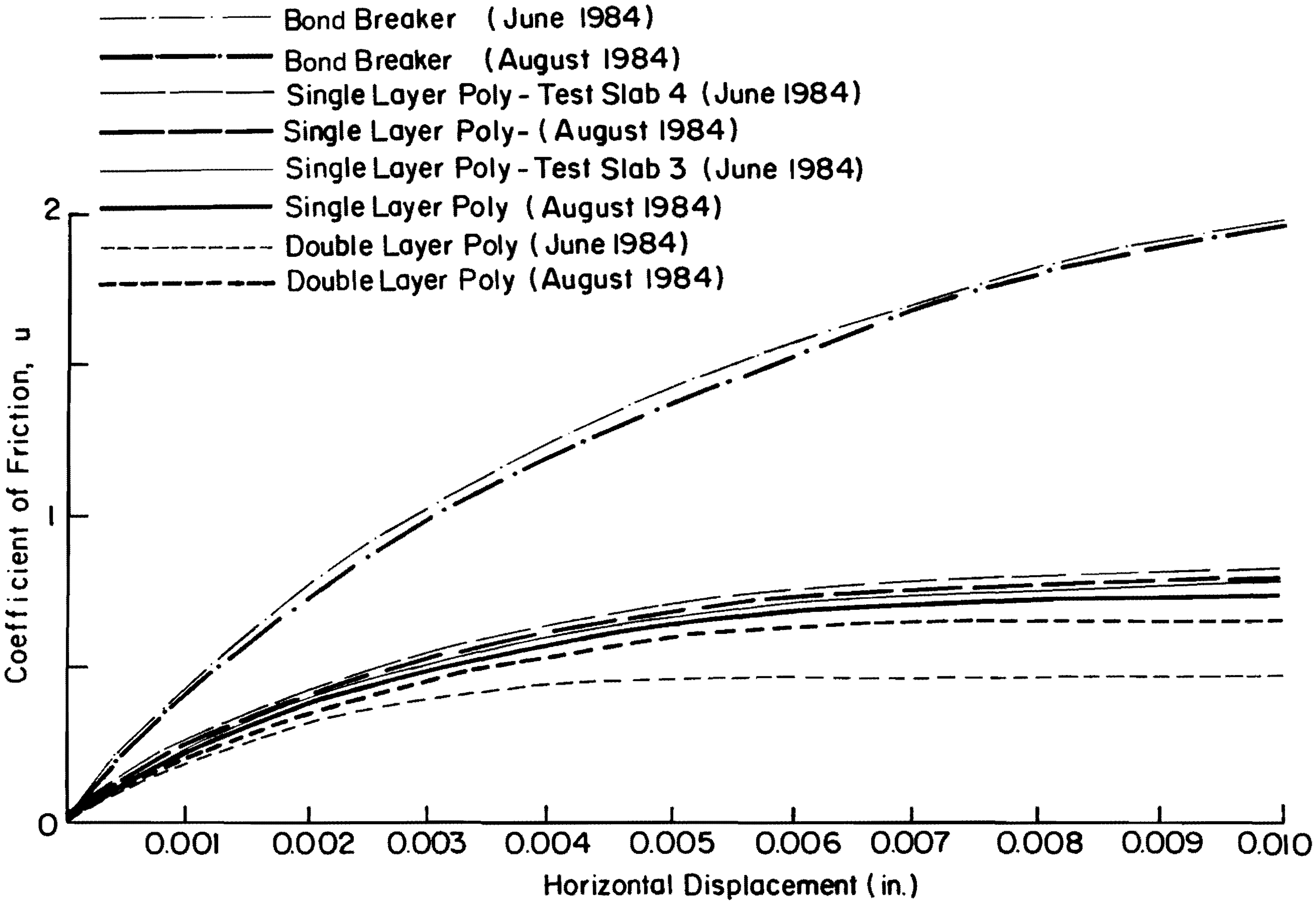

Fig 4.2. Average coefficient of friction versus horizontal displacement curves for all friction relieving materials tested in the push-off test.

TABLE 4.2. SUMMARY TABLE OF MAXIMUM COEFFICIENTS OF FRICTION AND MOVEMENTS AT SLIDING FROM PUSH-OFF PERFORMED ON JUNE 1, 1984 AND AUGUST 22, 1984

Test Slab Number	Friction Relieving Material	Test Performed on June 1, 1984		Test Performed on August 22, 1984		Change in Coefficient of Friction (Percent)
		Maximum Coefficient of Friction	Movement at Sliding (In.)	Maximum Coefficient of Friction	Movement at Sliding (In.)	
1	Double Layer of Polyethylene Film	0.467	0.0045	0.702	0.0063	+ 50
2	Spray-Applied Bond Breaker	> 3.19	> 0.03	> 3.19	> 0.003	~
3	Single Layer of Polyethylene Film	0.824	0.001	0.90	0.009	+ 9
4	Single Layer of Polyethylene Film	0.92	0.02	0.85	0.02	- 7

It is believed that a possible cause of the large increase for the two layers maximum friction coefficient is that, over the summer, the two layers may have locked together and acted more as one layer.

Test Series No. 3

To compare results from the third test, the following procedure was adopted. For each load increment applied, the average displacement of the slab was calculated as the mean of the displacements registered on the three dial gages. For each set of readings, load versus displacement data were plotted using the average displacements. A curve was fitted through the data points for each set of readings. For comparison with the earlier tests, only the first two sets of readings were considered for Slab 1. For Slab 2, three sets of readings were plotted. For slabs 3 and 4, two sets of readings each were plotted.

For each slab, an average load versus displacement curve was drawn by graphically interpolating between the curves for each set of readings. The values of load versus displacement given in Table 4.3 are taken from this average curve. The values of coefficient of friction corresponding to the displacements of Table 4.3 are found by dividing the push-off load by the slab's weight. The values of coefficient of friction versus displacement given in Table 4.3 were used to plot Figs 4.3 to 4.6.

Comparison with Previous Results

Table 4.4 and Figs 4.3 through 4.6 compare the results of this series of friction tests with the results of the first and second series of tests. For Slabs 1, 3, and 4 there are considerable variances from the earlier results. For Slab 2, the results correspond more closely.

The most important parameter for comparison is the maximum coefficient of friction. Values of maximum coefficient for the three series of tests are summarized in Table 4.4. For Slabs 3 and 4, respectively, the maximum coefficient of friction found in the third series of tests was 16 and 38 percent lower than that found in the first series of tests and 23 and 33 percent lower than that found in the second series of tests. The reason for this decrease in coefficient of friction in the third test is not clearly understood. Two possible explanations are given below:

TABLE 4.3. AVERAGE VALUES OF LOAD VERSUS DISPLACEMENT

Test Slab	Weight (kips)	Displacement (In.)	Force (kips)	μ
1	7.88	0.0000	0.7	0.09
		0.0001	1.5	0.19
		0.0002	2.0	0.25
		0.0003	2.3	0.29
		0.0005	2.7	0.34
		0.0007	2.9	0.37
		0.0010	3.2	0.41
		0.0015	3.5	0.44
		0.0020	3.7	0.47
		0.0030	3.9	0.49
		0.0040	4.0	0.51
		0.0070	4.2	0.53
2	7.84	0.0000	0.4	0.05
		0.0001	1.4	0.18
		0.0002	1.9	0.24
		0.0003	2.4	0.31
		0.0005	3.1	0.40
		0.0007	3.7	0.47
		0.0010	4.4	0.56
		0.0015	5.3	0.68

(continued)

TABLE 4.3. (CONTINUED)

Test Slab	Weight (kips)	Displacement (In.)	Force (kips)	μ
3	6.98	0.0000	1.0	0.14
		0.0001	1.6	0.23
		0.0002	1.9	0.27
		0.0003	2.2	0.32
		0.0005	2.6	0.37
		0.0007	2.9	0.42
		0.0010	3.3	0.47
		0.0015	3.8	0.54
		0.0020	4.2	0.60
		0.0030	4.6	0.66
		0.0040	4.8	0.69
		0.0070	4.8	0.69
4	13.9	0.0000	1.3	0.09
		0.0001	2.0	0.14
		0.0002	2.4	0.17
		0.0003	2.8	0.20
		0.0005	3.4	0.24
		0.0007	3.8	0.27
		0.0010	4.7	0.34
		0.0015	5.7	0.41
		0.0020	6.4	0.46
		0.0025	6.9	0.50

TABLE 4.4. SUMMARY OF MAXIMUM COEFFICIENTS OF FRICTION AND MOVEMENTS AT SLIDING FROM PUSH-OFF TESTS

Test Slab Number	Friction Relieving Material	Test Performed on June 1, 1984		Test Performed on August 22, 1984		Test Performed on April 23, 1985	
		Maximum Coefficient of Friction	Movement at Sliding (In.)	Maximum Coefficient of Friction	Movement at Sliding (In.)	Maximum Coefficient of Friction	Movement at Sliding (In.)
1	Double Layer of Polyethylene Film	0.47	0.004	0.70	0.006	0.53	0.007
2	Spray-Applied Bond Breaker	> 3.19	0.03	> 3.19	0.003	> 0.68	0.001
3	Single Layer of Polyethylene Film	0.82	0.001	0.90	0.009	0.69	0.007
4	Single Layer of Polyethylene Film	0.92	0.02	0.85	0.02	0.57	0.005

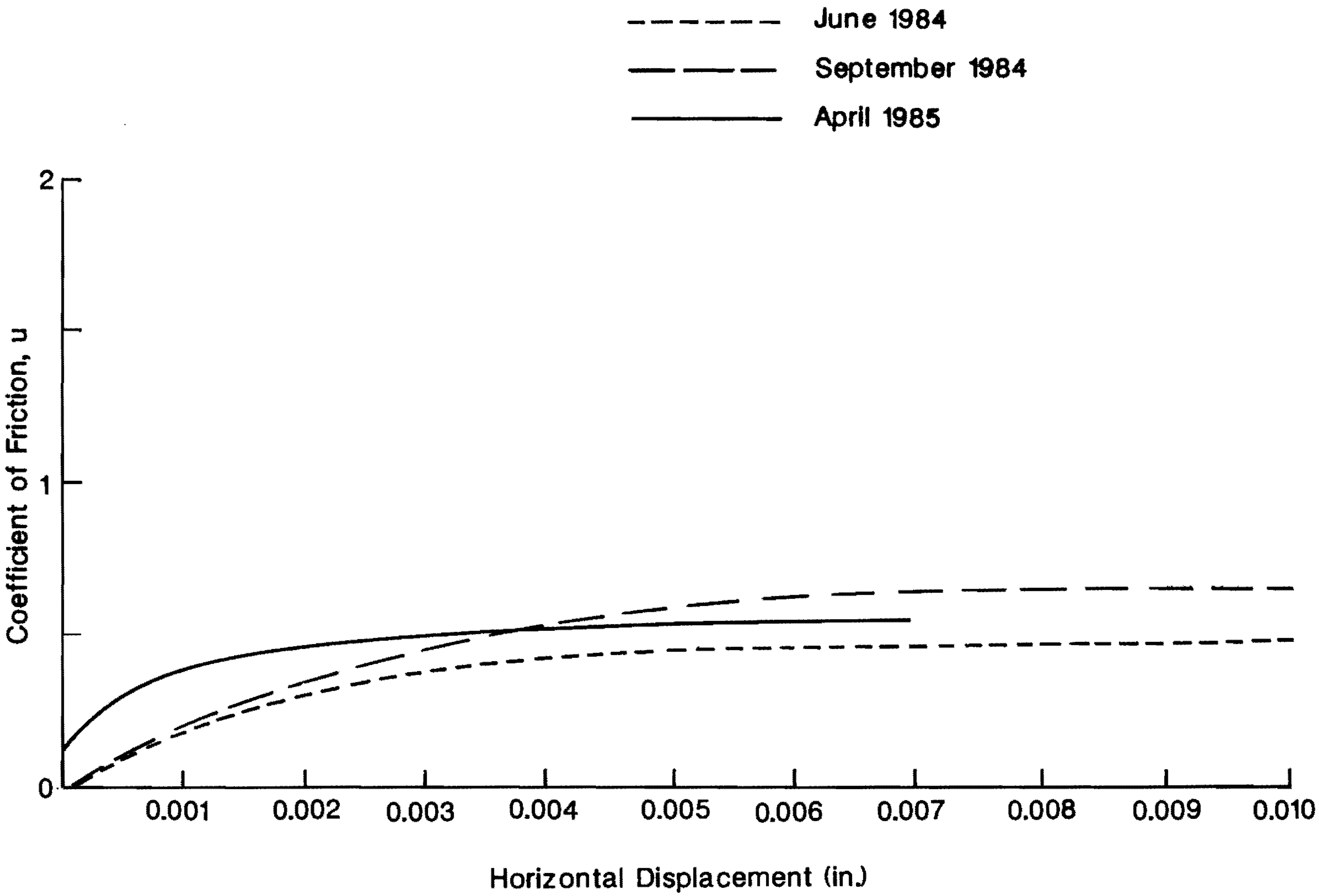

Fig 4.3. Average coefficient of friction versus horizontal displacement curves for the double layer of polyethylene.

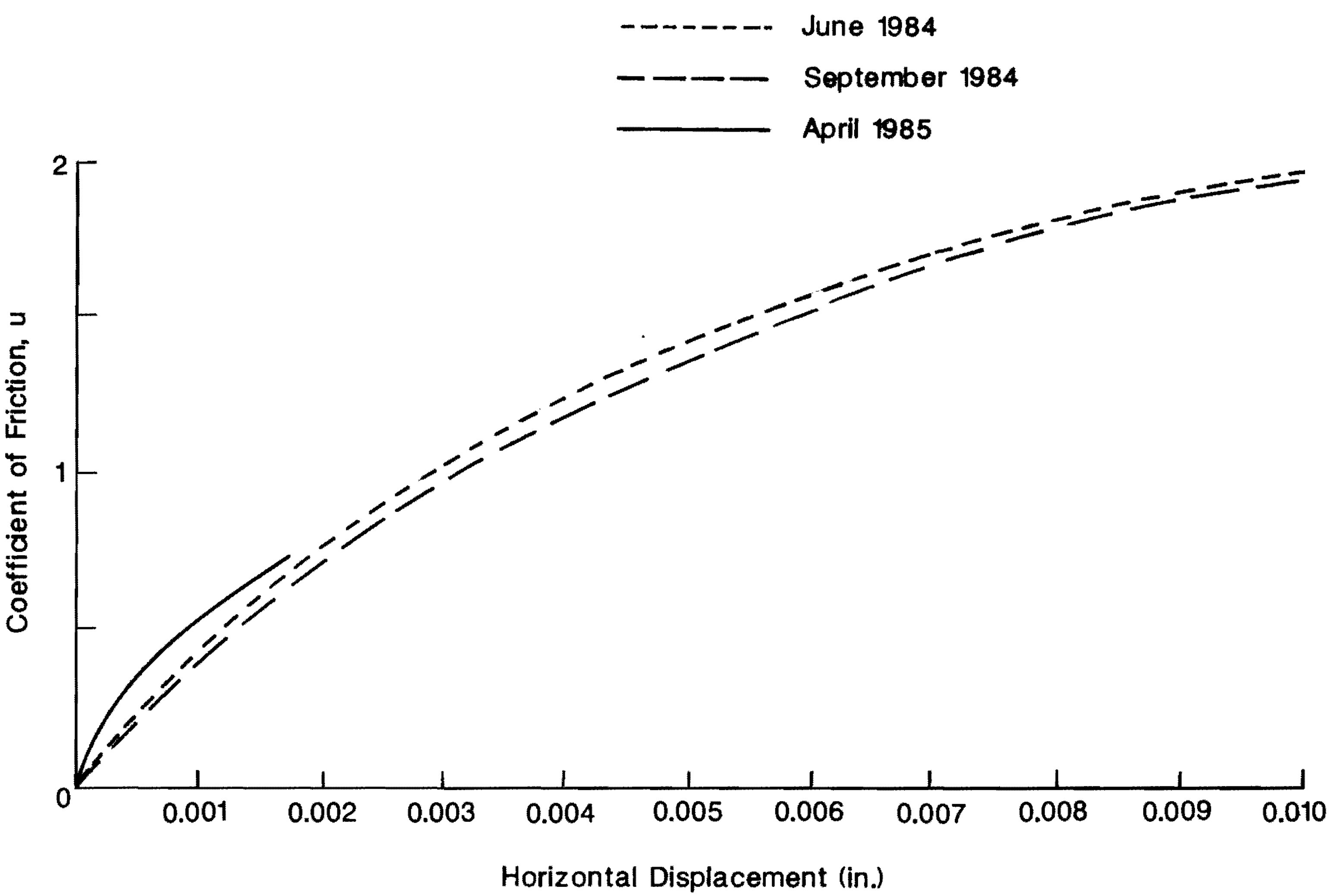

Fig 4.4. Average coefficient of friction versus horizontal displacement curves for the sprayed-applied bond breaker.

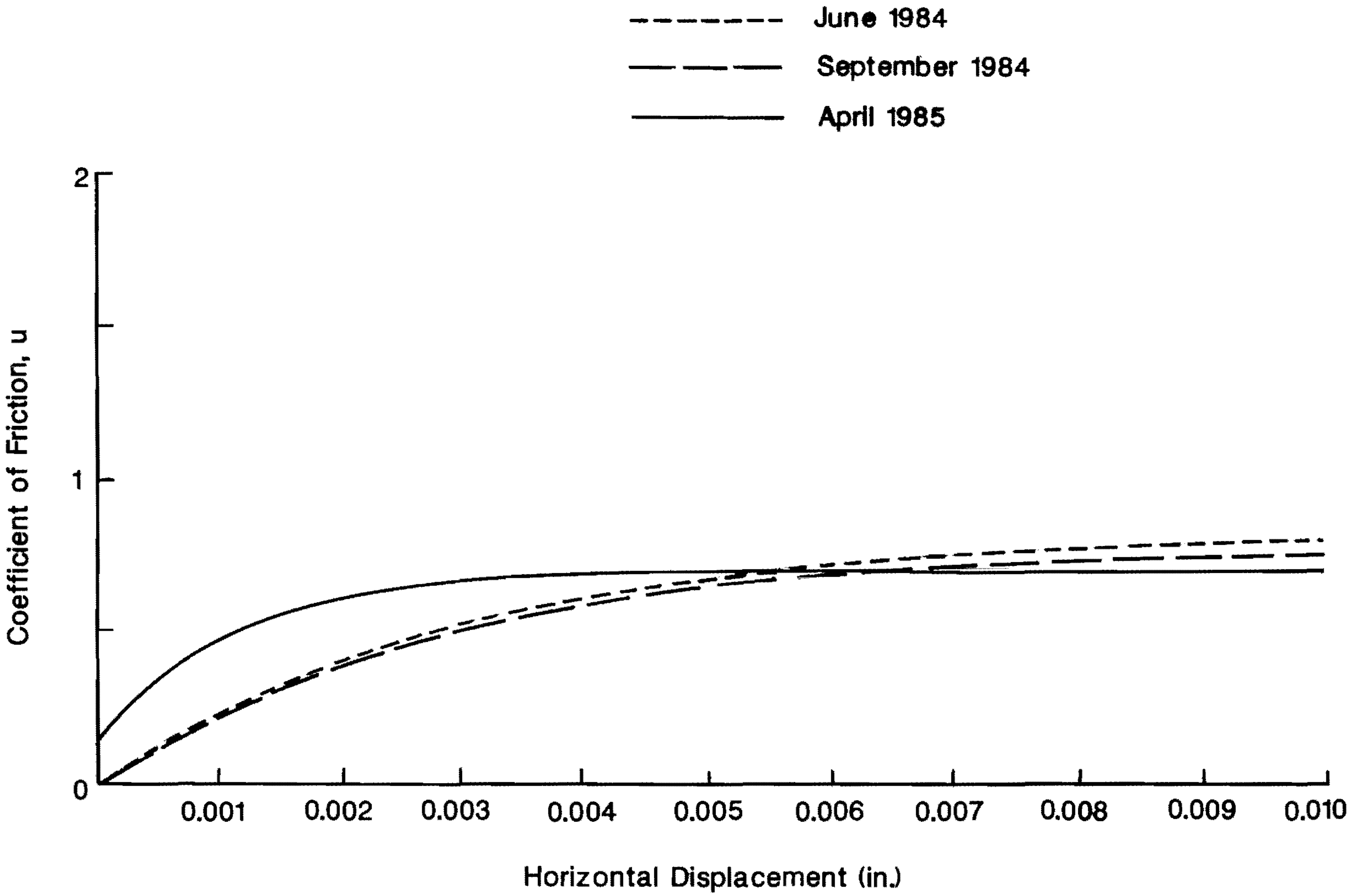

Fig 4.5. Average coefficient of friction versus horizontal displacement curves for the single layer of polythylene, test slab no. 3.

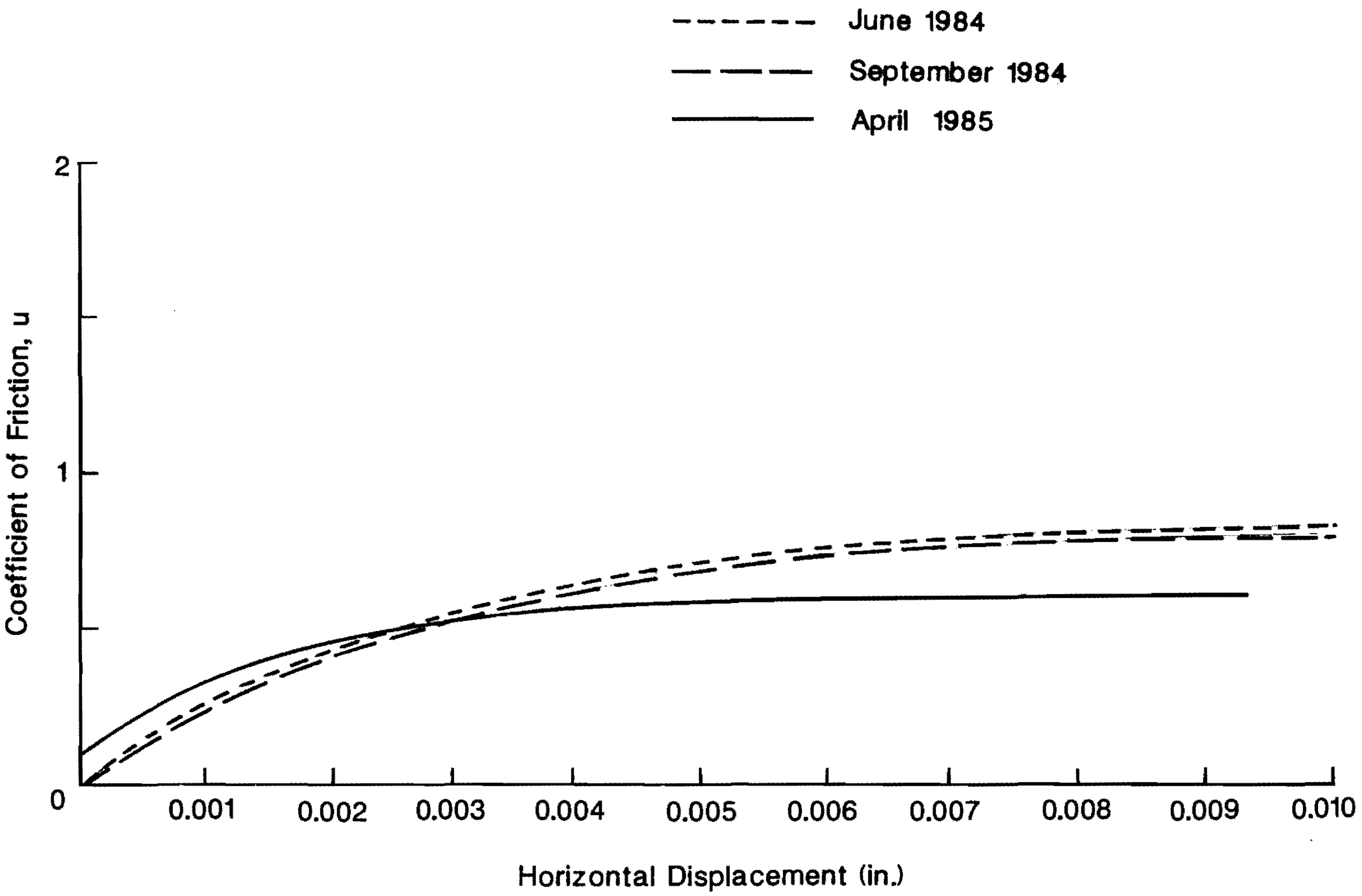

Fig 4.6. Average coefficient of friction versus horizontal displacement curves for the single layer polyethylene, test slab no. 4.

(1) The effect of weather or temperature changes in the seven-month period between the second and third series of tests may have caused movement of the slabs which "loosened up" the single layer of polyethylene.

(2) Since the personnel conducting the first and second series of tests were not present at the third series of tests, differences in testing technique may have caused some discrepancy. It was noted that the rate of loading affected the peak load obtained. Differences in testing technique could not, however, be responsible for the entire discrepancy between the third series of tests and the first and second series of tests.

For Slab 1, the value of the maximum coefficient of friction for the third series of tests was 13 percent higher than that for the first series of tests and 24 percent lower than that for the second series of tests. This is the only slab for which there had been any large variance between the results of the first and second series of tests. This increase in maximum coefficient of friction was attributed to a bonding of the two layers of polyethylene. The ensuing decrease in coefficient of friction recorded in the third series of tests is not, however, due to a subsequent debonding of the two layers of polyethylene. This conclusion is based upon the visual inspection of the double layer membrane (described later) and on the fact that a decrease in maximum coefficient of friction was also recorded for Slabs 3 and 4, which had only a single layer of polyethylene.

Coefficient of Friction at Large Displacement

When Slabs 1 and 3 were pushed to a total deflection of about one inch, it was observed that the amount of load required to maintain sliding was lower than the amount of load needed to initiate sliding. This friction behavior is described by the characteristic curve of Fig 4.7. Because these tests were load controlled rather than displacement controlled, the decreasing portion of this curve (Region II of Fig 4.7) could not be closely described. Also, the value of the "dynamic" coefficient of friction (Region III of Fig 4.7) is dependent upon the rate of loading of the slab. It was observed that the static friction peak force required to move Slab 1 (two layers of polyethylene) and Slab 3 (one layer of polyethylene) was higher in each case than the kinetic friction force once rapid motion began. While the measured values are not

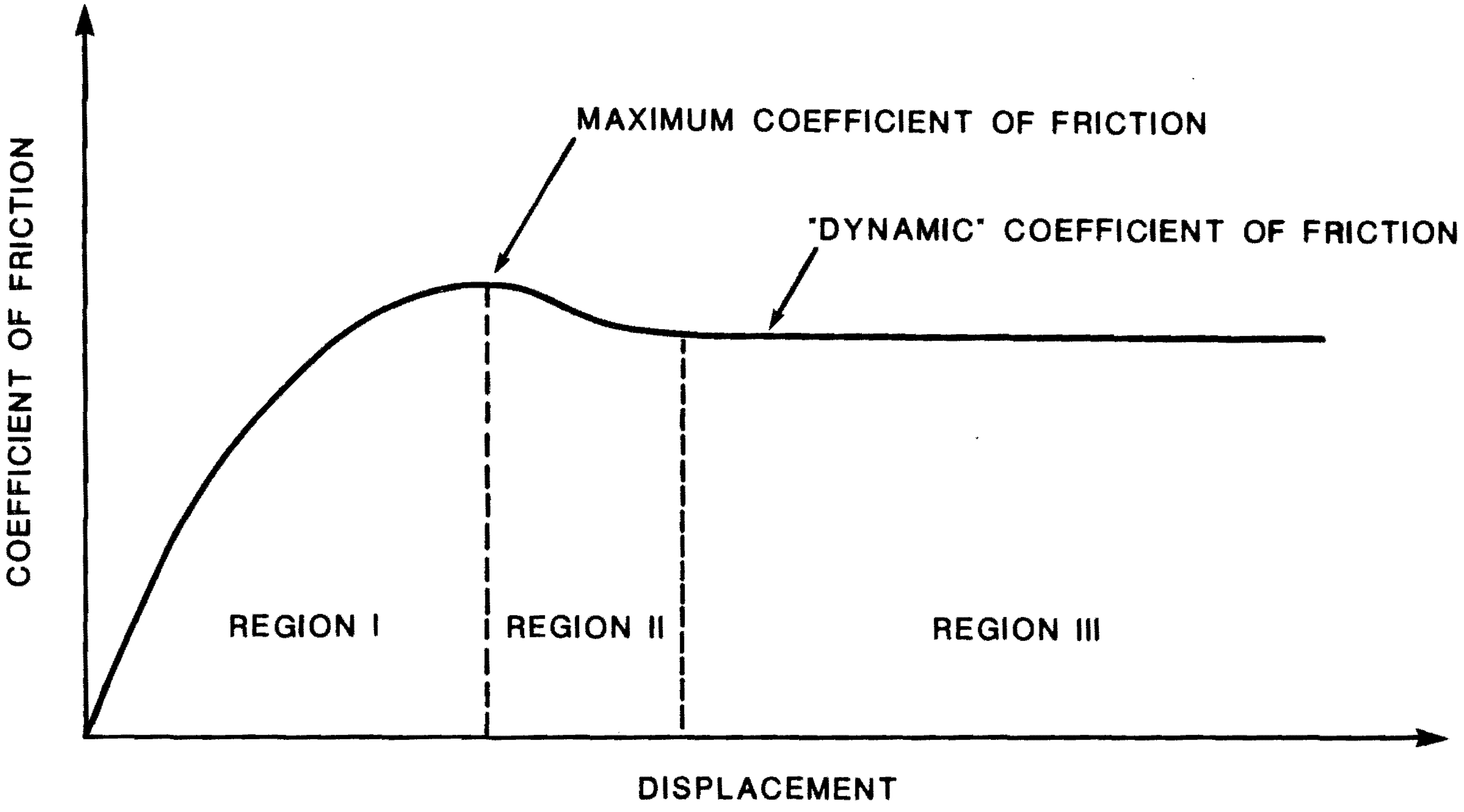

Fig 4.7. Characteristic curve of coefficient of friction versus displacement.

exact for the "dynamic" coefficient as noted, they are significantly different for these two slabs. For Slab 1 the static friction was only 8 percent above the kinetic friction force, while the static friction force for Slab 3 was 31 percent above the kinetic friction force (region III of Fig 4.7). This may be considered as an indication that the two-layer polyethylene membrane was a "better lubricant" than the single-layer membrane, analageous to the behavior observed with metals. For well lubricated metals the static and kinetic forces would be equal while for poorly lubricated metals the static force will be about 30 percent higher than the kinetic force. It was also observed during the displacement of Slabs 1 and 3 that the polyethylene membrane, both single-layer and double-layer, moved along with the concrete slab during displacement. This indicates that in both cases the friction being measured occurred between the bottom surface of the polyethylene and the asphalt surface.

Finally, it was observed that, when Slab 1 was pushed in the return direction, there was less frictional resistance. The maximum coefficient of friction in the initial direction, east to west, was 0.53. When the slab was pushed in the return direction, west to east, and then east to west again, the maximum coefficient of friction averaged 0.46.

Visual Inspection of the Double Layer Membrane

After the testing was completed, Slab 1 was picked up and the double layer polyethylene membrane was inspected. It was observed that both layers adhered to the concrete when the slab was lifted. The two layers were not strongly fused together and could easily be pulled apart; however it was clear that during the push-off tests the two layers of polyethylene moved as one.

The overall condition of the membrane was good. There were some small tears ranging in size from 1/8 to 1/2-inch, usually penetrating both layers of polyethylene, which were probably caused by small pieces of gravel under the slab. These tears probably helped in keeping the two layers of polyethylene interlocked but otherwise were not detrimental to the friction relieving capabilities of the material.

CHAPTER 5. CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

(1) Based on the three series of tests, the best friction reducing medium is the double layer polyethylene sheeting. Its maximum coefficient of friction ranged from 0.47 to 0.70.

(2) The maximum coefficient of friction of the single layer polyethylene sheeting ranged from 0.57 to 0.92, and the measured values decreased with time.

(3) The physical dimensions of the test slab also seems to affect the maximum coefficient of friction. The results from the larger rectangular test slab show lower coefficients of friction in two of the three series of tests when compared to those from the square specimen.

(4) Both the single layer and double layer polyethylene sheeting were observed to move along with the concrete slab during displacement. This indicates that the friction measured occurred between the bottom surface of the polyethylene sheeting and the asphalt surface.

(5) The spray-applied bond breaker consisting of white machine oil cut with 1/3 gasoline does not work as a bond breaker for pavement overlays.

(6) The large variances in the maximum coefficient of friction between the three series of tests indicate that the weather and temperature may have some influence on the performance of the friction reducing medium.

RECOMMENDATIONS

(1) It is recommended that the single layer polyethylene sheeting be used for the prestressed pavement projects in Cooke and McLennan counties for the following reasons:

   (a) Economics.
   (b) The maximum coefficient of friction for the single layer polyethylene sheeting is low enough that no adverse tensile stresses will be produced in the slabs.
   (c) Less problems are experienced during construction operations with a single layer.

(2) To insure adequate reduction in the frictional restraint, all scrap materials should be removed from the asphalt pad surface before casting of the prestressed pavement slabs. Also, care must be taken to avoid damaging the polyethylene sheeting while placing it or when working on top of it.

(3) To better determine the friction properties of friction reducing mediums for prestressed pavements, a displacement controlled push-off test with a slow-rate of loading is recommended. This kind of test will more closely simulate the temperature induced movements of the prestressed slabs.

(4) Further push-off tests should be carried out to investigate friction characteristics between various friction reducing mediums and different kinds of subbase support.

REFERENCES

(1) Cable, Neil, and Alberto Mendoza, "Field Tests Conducted Near Valley View, Texas, from the Design of the Prestressed Highway Pavement Demonstration Projects in Cooke and McLennan Counties," Technical Memorandum No. 401-17, Center for Transportation Research, The University of Texas at Austin, August 1984.

(2) Mendoza, Alberto, "Repetition of the Friction Tests on the Test Slabs Constructed Near Valley View, Texas, for the Design of the Prestressed Highway Project in Cooke Counties," Technical Memorandum No. 401-20, Center for Transportation Research, The University of Texas at Austin, October 1984.

(3) Maffei, Joe, "Third and Final Series of Friction Tests on the Test Slabs Constructed Near Valley View, Texas," Technical Memorandum No. 401-27, Center for Transportation Research, The University of Texas at Austin, August 1985.

(4) Noble, C.S., B. Frank McCullough, and W. R. Hudson, "Summary and Recommendations for the Implementation of Rigid Pavement Design, Construction, and Rehabilitation Techniques," Research Report 177-22F, Center for Highway Research, The University of Texas at Austin, September 1979.

APPENDIX A.

RECORD OF DATA FROM FIELD TESTING

TABLE A.1. FORCE DISPLACEMENT DATA FROM PUSH-OFF TESTS (TEST SLAB 1)

TEST SERIES NO.: 1
DATE OF TEST: MAY 31, 1984

Set of Readings	Peak Load P (K)	Displacements			
		D-1 (In.)	D-2 (In.)	D-3 (In.)	D-4 (In.)
1st	1.00	0.0005	0.0004	0.0004	0.0005
	1.45	0.0009	0.0009	0.0008	0.0009
	2.18	0.0017	0.0025	0.00016	0.0021
	2.91	0.0028	0.0038	0.0024	0.0034
	3.27*	- -	- -	- -	- -
	3.63	- -	- -	- -	- -
2nd	1.00	0.00071	0.0004	- -	0.0005
	1.45	0.00101	0.0008	- -	0.0008
	2.18	0.0019	0.0019	- -	0.0015
	2.91	0.0031	0.0034	0.003	0.0026
	3.27*	- -	- -	- -	- -
	3.63	- -	- -	- -	- -
3rd	1.00	0.0006	0.0007	0.0001	0.0006
	1.45	0.0009	0.0011	0.0004	0.0010
	2.18	0.0014	0.0020	0.0013	0.0015
	2.91	0.0021	0.0030	0.0022	0.0023
	3.63	0.0028	0..0035	0.0032	0.0029
	4.36	0.0041	0.0047	0.0049	0.0041
	4.50*	- -	- -	- -	- -

*When sliding begins - P(K) - P_{max}

TABLE A.2. FORCE/DISPLACEMENT DATA FROM THE PUSH-OFF TEST AND MAXIMUM COEFFICIENT OF FRICTION U_{MAX} (TEST SLAB 2)

TEST SERIES NO.: 1
DATE OF TEST: MAY 31, 1984

Set of Readings	Peak Load P (K)	Displacements			
		D-1 (In.)	D-2 (In.)	D-3 (In.)	D-4 (In.)
	0.73	0.0001	0.0002	- -	- -
	1.46	0.0004	0.0007	- -	0.0002
	2.19	0.0007	0.0009	0.0001	0.0004
	2.92	0.0010	0.0013	0.0001	0.0006
	3.65	0.0013	0.0020	0.0001	0.0008
	4.38	0.0016	0.0022	0.0002	0.0010
	5.11	0.0021	0.0022	0.0005	0.0013
	5.84	0.0025	0.0022	0.0008	0.0014
	6.57	0.0030	0.0022	0.0012	0.0017
	7.30	0.0035	0.0022	0.0014	0.0020
	8.03	0.0040	0.0031	0.0020	0.0027
	8.76	0.0046	0.0037	0.0024	0.0030
	9.49	0.0051	0.0042	0.0027	0.0034
	10.22	0.0058	0.0047	0.0032	0.0038
	10.95	0.0064	0.0052	0.0036	0.0042
	11.68	0.0070	0.0058	0.0040	0.0046

*When sliding begins - P(k) = P_{max}

(continued)

TABLE A.2. (CONTINUED)

Set of Readings	Peak Load P (K)	Displacements			
		D-1 (In.)	D-2 (In.)	D-3 (In.)	D-4 (In.)
	13.15	0.0086	0.0070	0.0052	0.0056
	14.61	0.0100	0.0081	0.0061	0.0064
	16.06	0.0117	0.0093	0.0076	0.0073
	16.79	0.0128	0.0111	0.0085	0.0079
	17.52	0.0141	0.0126	0.0098	0.0087
	18.98	0.0159	0.0147	0.0114	0.0098
	19.71	0.0170	0.0160	0.0124	0.0106
	20.44	0.0182	0.0176	0.0136	0.0115
	21.17	0.0204	0.0192	0.0156	0.0127
	21.90	0.0219	0.0217	0.0173	0.0137
	22.63	0.0236	0.0238	0.0194	0.0147
	23.36	0.0268	0.0272	0.0226	0.0168
	24.09	0.0300	0.0313	0.0267	0.0191
	24.82	0.0355	0.0320	0.028	0.0232
	25.55	- -	- -	- -	- -

*When sliding begins - P(k) = P_{max}

TABLE A.3. FORCE/DISPLACEMENT DATA FROM PUSH-OFF TEST (TEST SLAB 3)

TEST SERIES NO.: 1
DATE OF TEST: MAY 31, 1984

Set of Readings	Peak Load P (K)	Displacements			
		D-1 (In.)	D-2 (In.)	D-3 (In.)	D-4 (In.)
1st	0.72	- -	- -	- -	0.0000
	1.45	0.0004	- -	0.0000	0.0001
	2.18	0.0011	- -	0.0001	0.0002
	2.91	0.0019	0.0045	0.0007	0.0006
	3.63	0.0033	0.0063	0.0019	0.0015
	4.36	0.0054	0.0088	0.0034	0.0029
	4.92	0.0085	0.0098	0.0054	0.0052
	5.82	0.0146	0.0098	0.0092	0.0095
	6.00*	- -	- -	- -	- -
2nd	0.72	0.0001	0.0002	- -	- -
	1.45	0.0006	0.0010	- -	0.0002
	2.18	0.0011	0.0019	0.0011	0.0004
	2.91	0.0019	0.0031	0.0025	0.0008
	3.63	0.0029	0.0045	0.0032	0.0013
	4.36	0.0041	0.0060	0.0047	0.0020
	4.91	0.0057	0.0076	0.0057	0.0030
	5.50*	- -	- -	- -	- -

*When sliding begins - P(k) $= P_{max}$

TABLE A.4. FORCE/DISPLACEMENT DATA FROM PUSH-OFF TEST (TEST SLAB 4)

TEST SERIES NO.: 1
DATE OF TEST: MAY 31, 1984

Set of Readings	Peak Load P (K)	Displacements			
		D-1 (In.)	D-2 (In.)	D-3 (In.)	D-4 (In.)
1st	0.72	- -	0.0003	- -	- -
	1.45	0.0002	0.0012	0.0004	0.0001
	2.18	0.0008	0.0022	0.0010	0.0003
	2.19	0.0012	0.0037	0.0013	0.0005
	3.64	0.0016	0.0052	0.0018	0.0007
	4.36	0.0021	0.0062	0.0022	0.0010
	5.09	0.0026	0.0072	0.0027	0.0013
	5.82	0.0031	0.0080	0.0031	0.0018
	6.55	0.0035	0.0088	0.0035	0.0021
	7.28	0.0045	0.0097	0.0038	0.0027
	8.02	0.0053	0.0104	0.0044	0.0033
	8.75	0.0063	0.0117	0.0055	0.0045
	9.48	0.0088	0.0136	0.0071	0.0065
	10.20	0.0114	0.0144	0.0093	0.0088
	10.93	0.0151	0.0192	0.0125	0.0121
	11.65	0.0194	0.0256	0.0162	0.0161
	12.44	0.0250	0.0290	0.0211	0.0210
	13.00*	- -	- -	- -	- -
	13.14	0.0350	- -	- -	- -

*When sliding begins - P(k) = P_{max}

(continued)

TABLE A.4. (CONTINUED)

Set of Readings	Peak Load P (K)	Displacements			
		D-1 (In.)	D-2 (In.)	D-3 (In.)	D-4 (In.)
2nd	0.72	- -	0.0002		- -
	1.45	0.0001	0.0009		- -
	2.18	0.0003	0.0017		0.0001
	2.91	0.0008	0.0027		0.0003
	3.64	0.0011	0.0032		0.0004
	4.36	0.0016	0.0040		0.0006
	5.09	0.0020	0.0045		0.0008
	5.82	0.0024	0.0050		0.0011
	6.55	0.0028	0.0065		0.0014
	7.28	0.0033	0.0071		0.0017
	8.02	0.0038	0.0078		0.0020
	8.75	0.0045	0.0085		0.0025
	9.48	0.0050	0.0095		0.0030
	10.20	0.0059	0.0105		0.0036
	10.93	0.0069	0.0117		0.0045
	11.65	0.0082	0.0130		0.0056
	12.40	0.0120	0.0145		0.0089
	12.50*	- -	- -		- -

*When sliding begins - P(k) = P_{max}

TABLE A.5. FORCE/DISPLACEMENT DATA FROM PUSH-OFF TESTS (TEST SLAB 1)

TEST SERIES NO.: 2
DATE OF TEST: AUGUST 22, 1984

Set of Readings	Peak Load P (K)	Displacements		
		D-1 (In.)	D-2 (In.)	D-3 (In.)
1st	1.0	0.0005	0.0005	0.0003
	2.0	0.0012	0.0014	0.001
	3.0	0.0023	0.0023	0.002
	4.0	0.0036	0.0034	0.0032
	5.0	0.0060	0.0054	0.0052
	5.5	0.0012	0.012	0.01
2nd	1.0	0.0004	0.0006	0.0003
	2.0	0.0018	0.002	0.0012
	3.0	0.0022	0.0024	0.002
	4.0	0.0032	0.0036	0.0032
	5.0	0.0052	0.006	0.0050
	5.5	0.010	0.012	0.010

TABLE A.6. FORCE DISPLACEMENT DATA FROM PUSH-OFF TESTS (TEST SLAB 2)

TEST SERIES NO.: 2
DATE OF TEST: AUGUST 22, 1984

Set of Readings	Peak Load P (K)	Displacements		
		D-1 (In.)	D-2 (In.)	D-3 (In.)
	2.5	0.0005	0.0005	0.0004
	5.0	0.002	0.0018	0.0016
	7.5	0.0028	0.003	0.0028
	10.0	0.005	0.0048	0.0046
	12.5	0.006	0.006	0.0058
	15.0	0.0089	0.0088	0.0086
	17.5	0.013	0.0132	0.013
	20.0	0.015	0.0155	0.015
	22.5	0.024	0.024	0.022
	25.0	0.034	0.0302	0.032

TABLE A.7. FORCE DISPLACEMENT DATA FROM PUSH-OFF TESTS (TEST SLAB 3)

TEST SERIES NO.: 2
DATA OF TEST: AUGUST 22, 1984

Set of Readings	Peak Load P (K)	Displacements		
		D-1 (In.)	D-2 (In.)	D-3 (In.)
1st	1.0	0.0008	0.00075	0.0007
	2.0	0.002	0.0015	0.0012
	3.0	0.0026	0.0021	0.0018
	4.0	0.0045	0.0043	0.004
	5.0	0.0085	0.0081	0.0076
	5.5	0.023	0.0202	0.020
2nd	1.0	0.0008	0.0008	0.0006
	2.0	0.002	0.0018	0.0016
	3.0	0.0024	0.0023	0.0021
	4.0	0.0047	0.0045	0.004
	5.0	0.0082	0.0085	0.0079
	5.5	0.026	0.021	0.019

TABLE A.8. FORCE DISPLACEMENT DATA FROM PUSH-OFF TESTS (TEST SLAB 4)

TEST SERIES NO.: 2
DATE OF TEST: AUGUST 22, 1984

Set of Readings	Peak Load P (K)	Displacements		
		D-1 (In.)	D-2 (In.)	D-3 (In.)
1st	1.0	0.0004	0.0003	0.00026
	2.0	0.00052	0.0005	0.00045
	3.0	0.0012	0.001	0.0008
	4.0	0.0018	0.00167	0.0012
	5.0	0.003	0.0025	0.002
	6.0	0.004	0.0036	0.0032
	7.0	0.006	0.0057	0.005
	8.0	0.008	0.0082	0.007
	9.0	0.0017	0.170	0.0015
	10.0	0.032	0.0307	0.031
	11.0	0.05	0.0027	0.04
2nd	1.0	0.0003	0.0003	0.00025
	2.0	0.00048	0.0005	0.0004
	3.0	0.0009	0.001	0.0009
	4.0	0.0015	0.002	0.0018
	5.0	0.0022	0.003	0.0025
	6.0	0.0035	0.004	0.0035
	7.0	0.0055	0.006	0.0056
	8.0	0.008	0.0082	0.008
	9.0	0.015	0.017	0.0012
	10.0	0.028	0.0262	0.022
	11.0	0.04	0.945	0.04

TABLE A.9. FORCE DISPLACEMENT DATA FROM PUSH-OFF TESTS (TEST SLAB 1)

TEST SERIES NO.: 3
DATE OF TEST: APRIL 23, 1985

Set of Readings	Peak Load P (K)	Displacements		
		D-1 (In.)	D-2 (In.)	D-3 (In.)
1st	1.0	0.0000	0.0000	0.0000
	2.0	0.0000	0.0000	0.0003
	3.0	0.0004	0.0007	0.0012
	3.5	0.0019	0.0018	0.0022
	4.0	0.0076	0.0038	0.0068
2nd	1.0	0.0000	0.0000	0.0003
	2.0	0.0000	0.0002	0.0007
	2.5	0.0002	0.0004	0.0010
	3.0	0.0002	0.0007	0.0013
	3.5	0.0004	0.0011	0.0018
	4.0	0.0017	0.0016	0.0029
	4.5	0.0098	0.0052	0.0085
	5.2	1.0000	1.0000	1.0000

TABLE A.10. FORCE DISPLACEMENT DATA FROM PUSH-OFF TESTS (TEST SLAB 1)

TEST SERIES NO.: 3
DATE OF TEST: APRIL 23, 1985

Set of Readings	Peak Load P (K)	Displacements		
		D-1 (In.)	D-2 (In.)	D-3 (In.)
3rd	1.0	0.0002	0.0000	0.0001
	2.0	0.0028	0.0000	0.0018
	2.5	0.0058	0.0022	0.0046
	3.8	- -	- -	- -
4th	1.0	0.0001	0.0000	0.0000
	2.0	0.0001	0.0005	0.0002
	2.5	0.0002	0.0010	0.0005
	3.0	0.0009	0.0017	0.0013
	3.5	0.0038	0.0032	0.0030
	4.2	- -	- -	- -
5th	1.5	0.0003	0.0007	0.0005
	2.0	0.0005	0.0017	0.0015
	2.5	0.0010	0.0040	0.0040
	3.0	0.0114	0.0170	0.0155

TABLE A.11. FORCE DISPLACEMENT DATA FROM PUSH-OFF TESTS (TEST SLAB 2)

TEST SERIES NO.: 3
DATE OF TEST: APRIL 23, 1985

Set of Readings	Peak Load P (K)	Displacements		
		D-1 (In.)	D-2 (In.)	D-3 (In.)
1st	1.0	0.0000	0.0004	0.0000
	2.0	0.0002	0.0006	0.0000
	3.0	0.0005	0.0010	0.0001
	4.0	0.0009	0.0014	0.0003
	5.0	0.0014	0.0019	0.0006
2nd	1.0	0.0000	0.0000	0.0000
	2.0	0.0002	0.0001	0.0004
	3.0	0.0005	0.0002	0.0006
	4.0	0.0008	0.0006	0.0009
	5.0	0.0012	0.0009	0.0014
	5.5	0.0016	0.0012	0.0017
3rd	1.0	0.0000	0.0000	0.0002
	2.0	0.0000	0.0000	0.0004
	3.0	0.0004	0.0003	0.0006
	4.0	0.0008	0.0006	0.0010
	5.0	0.0018	0.0009	0.0015

TABLE A.12. FORCE DISPLACEMENT DATA FROM PUSH-OFF TESTS (TEST SLAB 3)

TEST SERIES NO.: 3
DATE OF TEST: APRIL 23, 1985

Set of Readings	Peak Load P (K)	Displacements		
		D-1 (In.)	D-2 (In.)	D-3 (In.)
1st	1.0	0.0000	0.0000	0.0000
	2.0	0.0001	0.0001	0.0004
	3.0	0.0008	0.0012	0.0012
	3.5	0.0013	0.0020	0.0019
	4.0	0.0018	0.0019	0.0032
	4.5	0.0055	0.0085	0.0068
	4.8	- -	- -	- -
2nd	1.0	0.0000	0.0000	0.0000
	2.0	0.0002	0.0000	0.0002
	2.5	0.0003	0.0002	0.0004
	3.0	0.0006	0.0006	0.0006
	3.5	0.0009	0.0012	0.0009
	4.0	0.0009	0.0018	0.0012
	4.5	0.0009	0.0025	0.0012
	5.0	0.0030	0.0043	0.0031
	5.2	0.0058	0.0093	0.0083
	5.5	1.2000	1.2000	1.2000

TABLE A.13. FORCE DISPLACEMENT DATA FROM PUSH-OFF TESTS (TEST SLAB 4)

TEST SERIES NO.: 3
DATE OF TEST: APRIL 23, 1985

Set of Readings	Peak Load P (K)	Displacements		
		D-1 (In.)	D-2 (In.)	D-3 (In.)
1st	1.0	0.0000	0.0000	0.0000
	2.0	0.0005	0.0000	0.0000
	3.0	0.0010	0.0002	0.0004
	4.1	0.0015	0.0005	0.0007
	5.0	0.0020	0.0008	0.0010
	6.0	0.0027	0.0012	0.0017
	7.0	0.0034	0.0019	0.0024
2nd	1.6	0.0001	-0.0001	0.0000
	2.1	0.0003	-0.0001	0.0000
	3.0	0.0006	+0.0001	0.0000
	4.3	0.0010	0.0005	0.0006
	5.0	0.0012	0.0007	0.0008
	6.0	0.0014	0.0013	0.0015
	7.0	0.0036	0.0025	0.0027
	8.0	0.0060	0.0046	0.0049

APPENDIX B.

FORCE/DISPLACEMENT CURVES FOR TEST SERIES NO. 1

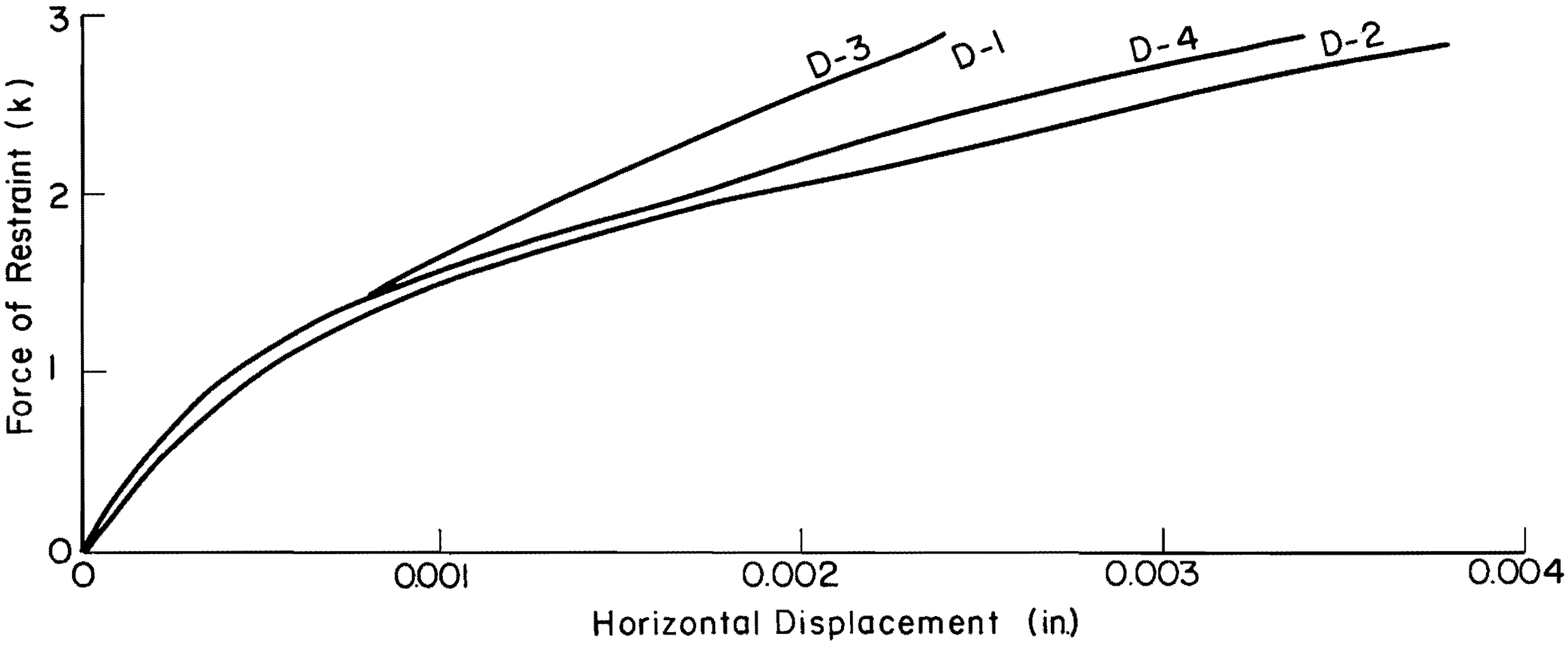

Fig B.1. Force/Displacement curves for first set of readings (test slab no. 1).

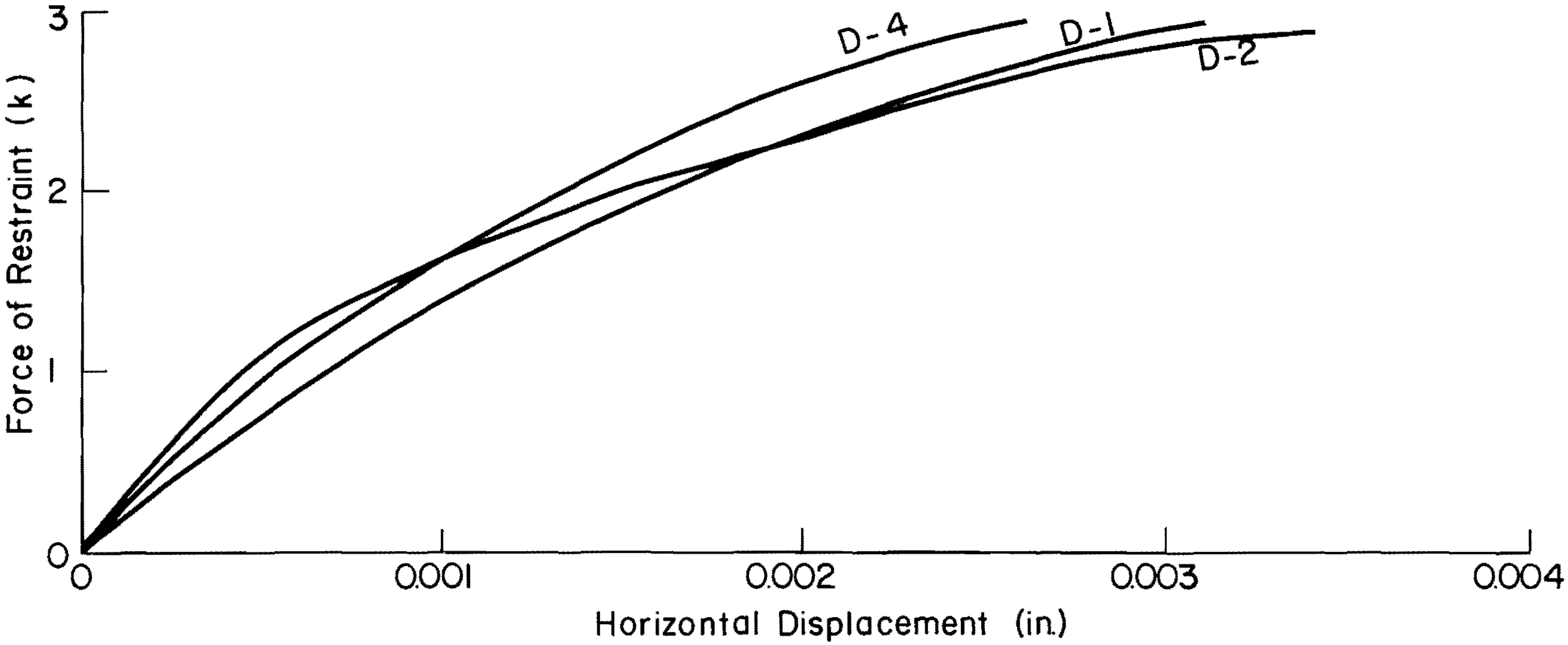

Fig B.2. Force/Displacement curves for second set of readings (test slab no. 1).

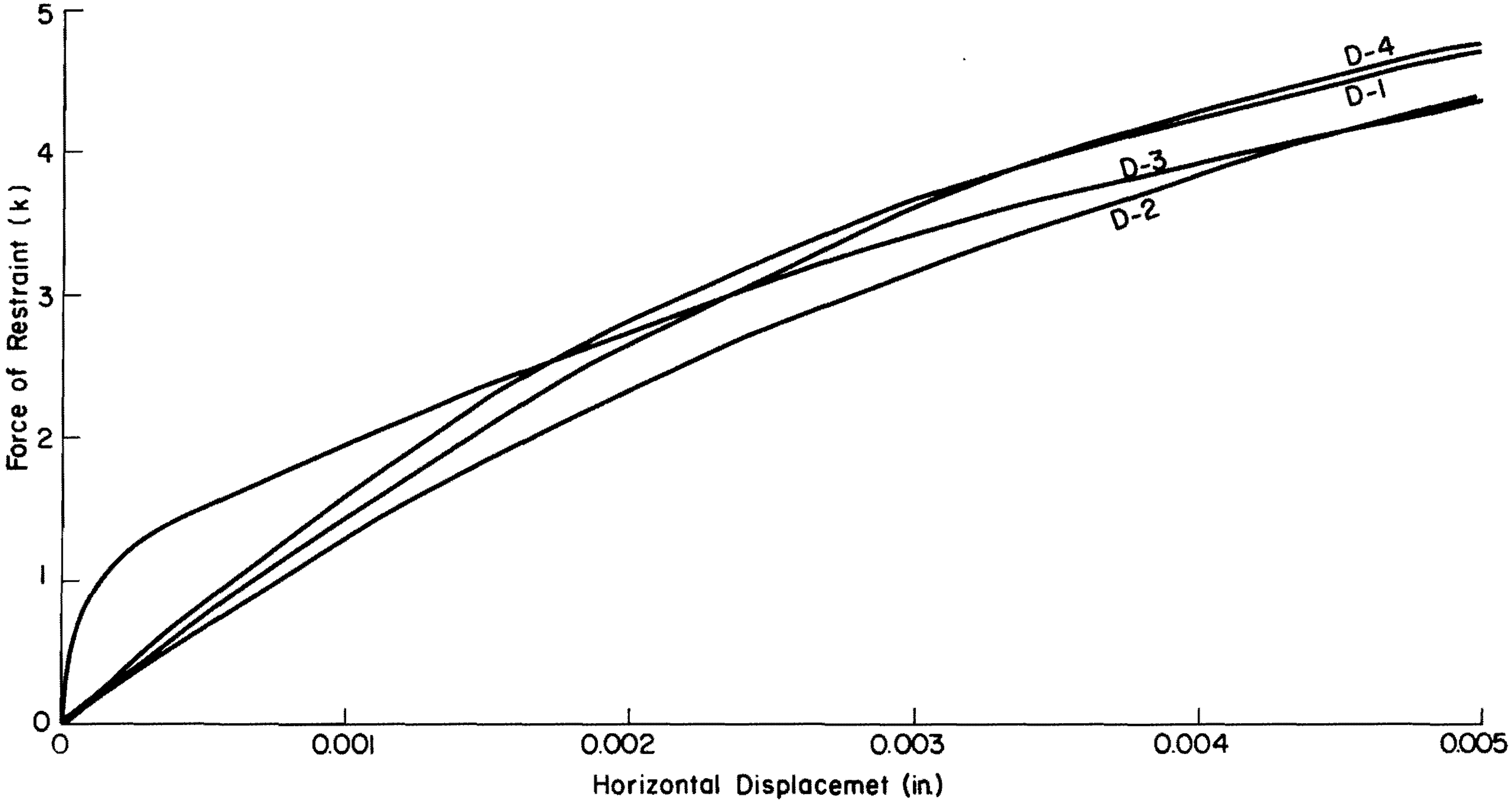

Fig B.3. Force/Displacement curves for third set of readings (test slab no. 1).

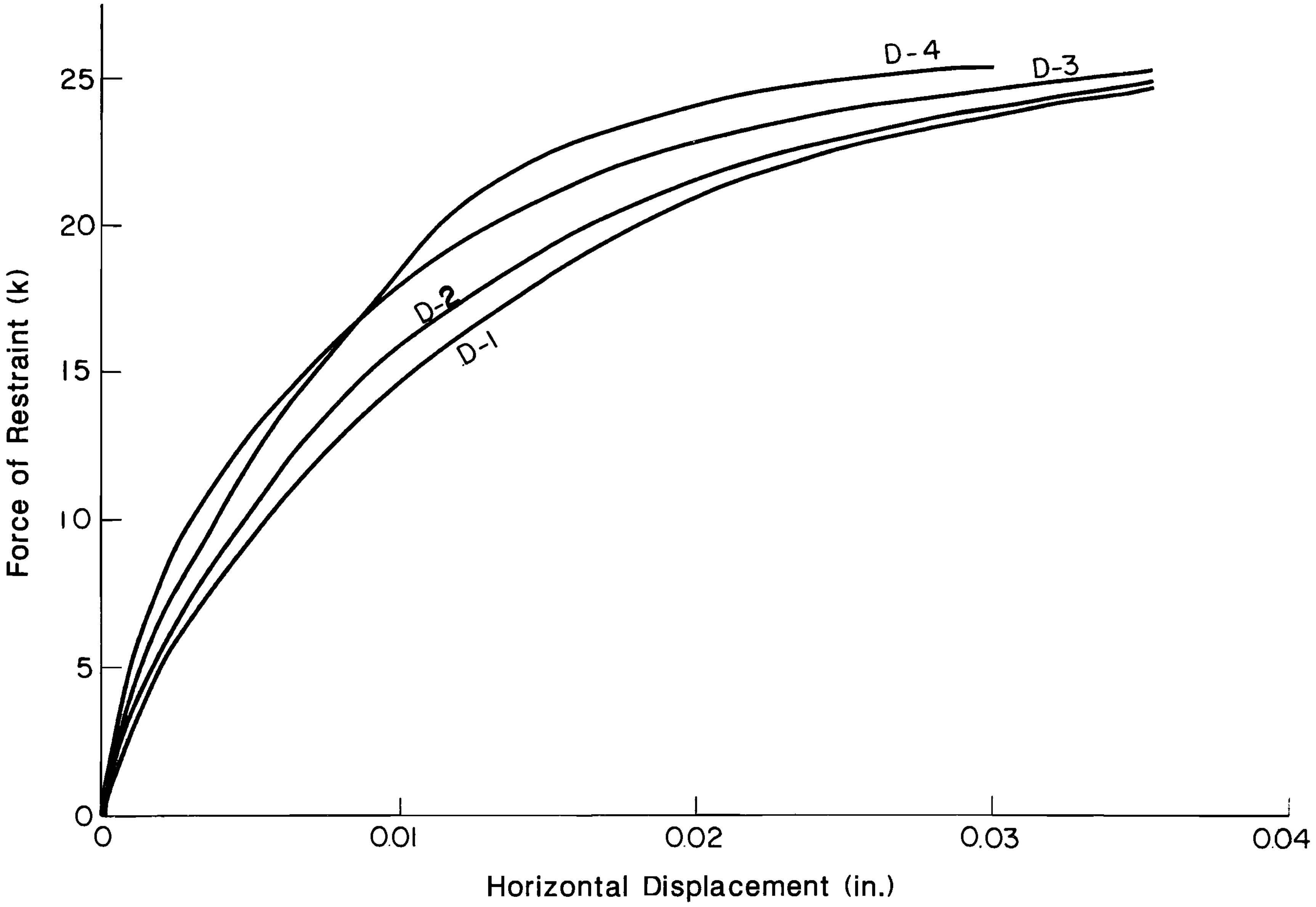

Fig B.4. Force/Displacement curves for push-off test (test slab no. 2).

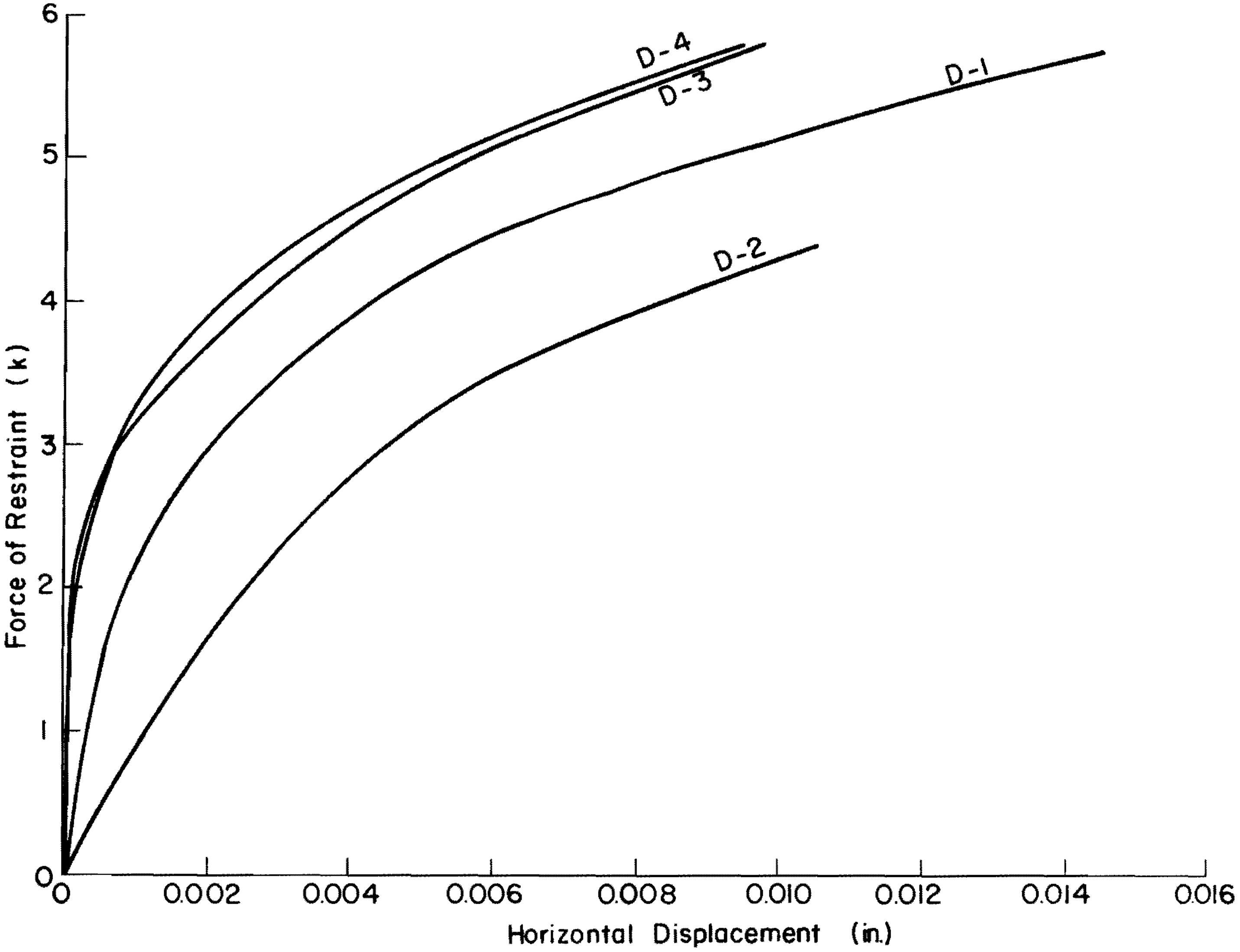

Fig B.5. Force/Displacement curves for first set of readings (test slab no. 3).

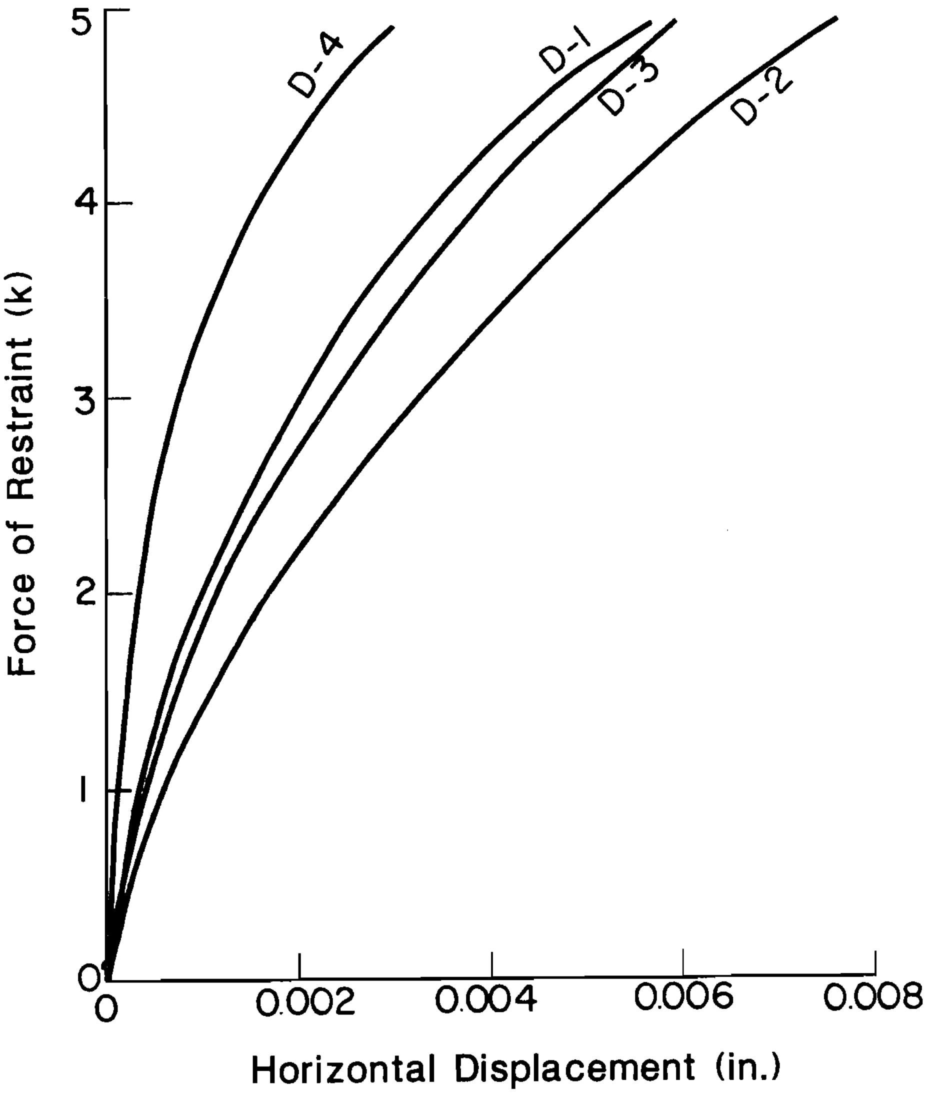

Fig B.6. Force/Displacement curve for second set of readings (test slab no. 3).

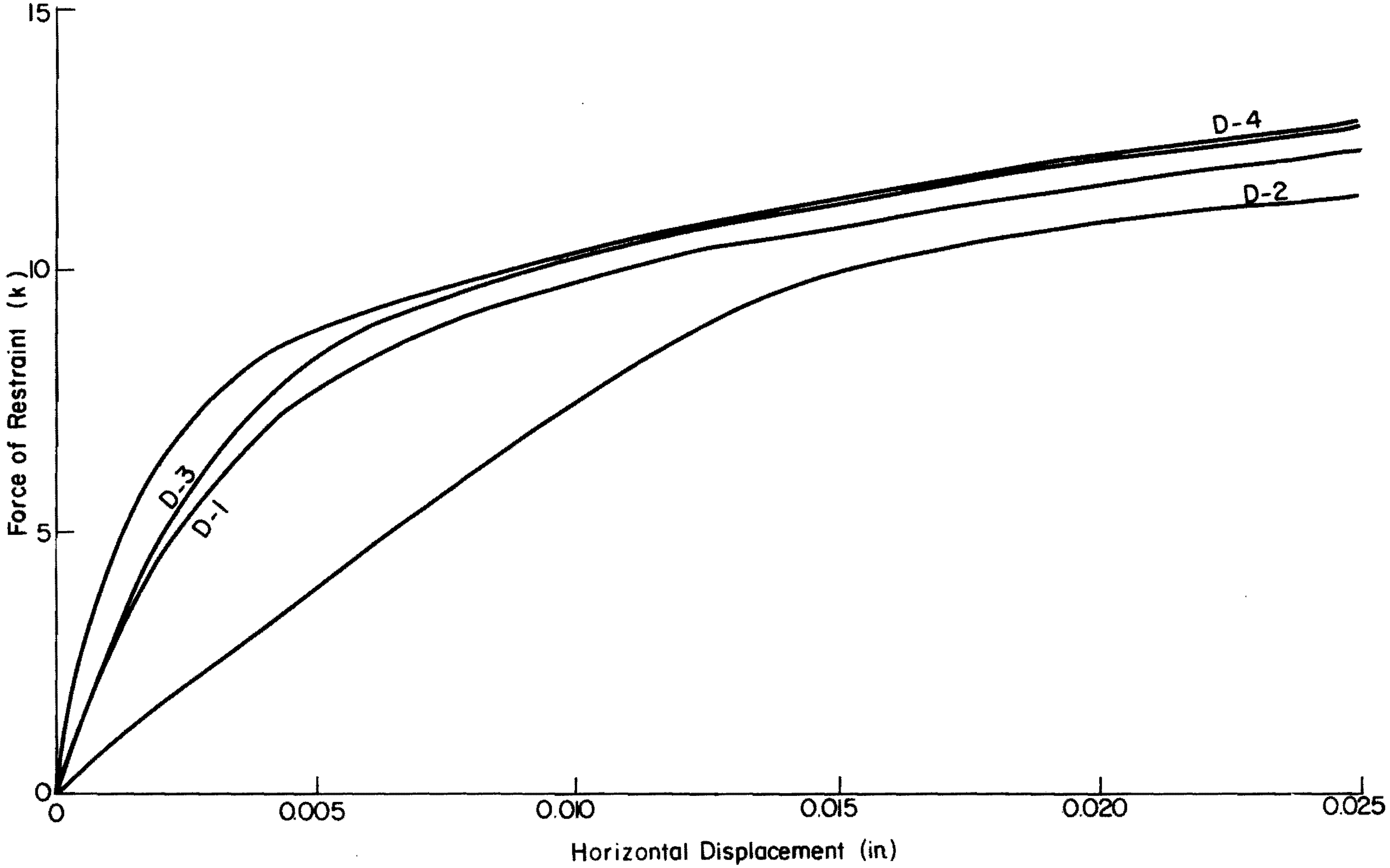

Fig B.7. Force/Displacement curves for first set of readings (test slab no. 4).

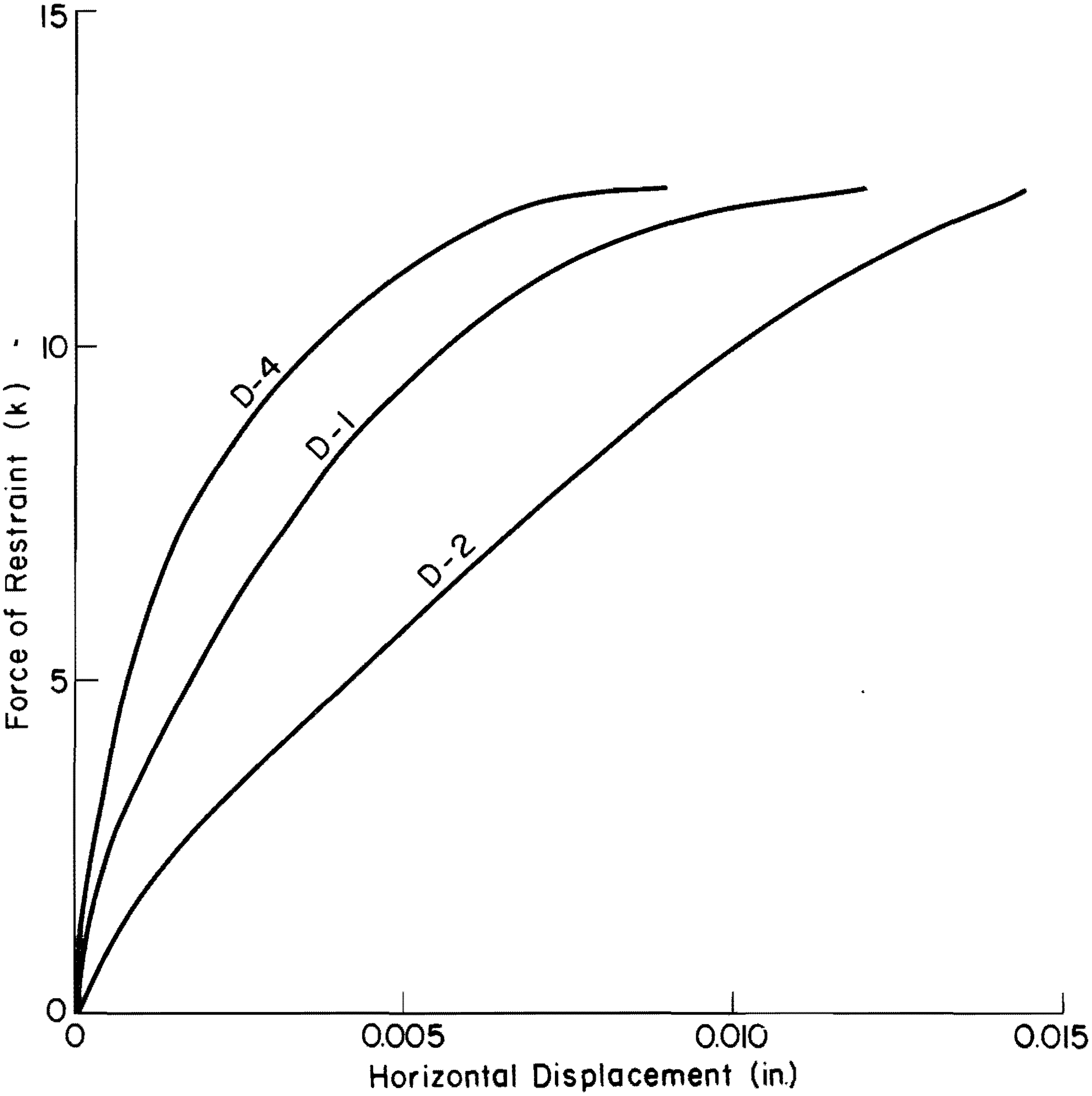

Fig B.8. Force/Displacement curve for second set of readings (test slab no. 4).

TABLE B.1. AVERAGE MAXIMUM COEFFICIENT OF FRICTION U_{MAX} (TEST SLAB 1)

Run	P_{max}	U_{max}
1	3.27^k	0.415
2	3.27^k	0.415
3	4.50^k	0.571
Average	3.68^k	0.467

Weight of Slab = W = 7.880 kips
Max Coefficient of Friction = $U_{max} = P_{max}/W$

TABLE B.2. AVERAGE MAXIMUM COEFFICIENT OF FRICTION U_{MAX} (TEST SLAB 2)

Run	P_{max}	U_{max}
1	> 25.0	> 3.19

Weight of Slab = W = 7.840 kips
Max Coefficient of Friction = U_{max} = P_{max}/W

TABLE B.3. AVERAGE MAXIMUM COEFFICIENT OF FRICTION U_{MAX} (TEST SLAB 3)

Run	P_{max}	U_{max}
1	6.0^k	0.86
2	5.5^k	0.79
Average	5.75^k	0.824

Weight of Slab = W = 6.976 kips

Max Coefficient of Friction = U_{max} = P_{max}/W

TABLE B.4. AVERAGE MAXIMUM COEFFICIENT OF FRICTION U_{MAX} (TEST SLAB 4)

Run	P_{max}	U_{max}
1	13.0^k	0.94
2	12.5^k	0.90
Average	12.75^k	0.92

Weight of Slab = W = 13.83 kips
Max Coefficient of Friction = $U_{max} = P_{max}/W$