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Robert Thomas Dooley Jr.

COEFFICIENT OF FRICTION

OF

PAINTED STRUCTURAL STEEL SURFACES

A THESIS

Presented to

the Faculty of the Graduate Division

by

Robert Thomas Dooley, Jr.

In Partial Fulfillment

of the Requirements for the Degree

Master of Science in Civil Engineering

Georgia Institute of Technology

June, 1957

COEFFICIENT OF FRICTION

OF

PAINTED STRUCTURAL STEEL SURFACES

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Date Approved by Chairman: April 27, 1957

ACKNOWLEDGMENTS

The writer wishes to express his appreciation to the many persons whose assistance was of material benefit in the preparation of this thesis.

To Dr. F. W. Schutz, Jr., especial thanks are extended for his continued guidance throughout the entire project. To other members of the reading committee, Professors Austin B. Caseman and David B. Comer, III, acknowledgment is due for the many helpful comments on the text.

Thanks are given the following groups for the technical assistance and guidance given to the writer in preparation of this thesis as well as the supplying of material with which the experiments were performed:

Atlantic Steel Company
E. I. duPont de Nemours Laboratories
Lockheed Aircraft Corporation
Martin Senour Laboratories
Pittsburgh Paint Laboratories
Russell, Burdsall and Ward Bolt and Nut Company
Standard Oil Company
Steel Structures Painting Council.

Continued thanks and gratitude are due the writer's parents, Robert T. Dooley and Helen V. Dooley, for their unfailing encouragement during his pursuit of this project.

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COEFFICIENT OF FRICTION OF PAINTED STRUCTURAL STEEL SURFACES

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By: Robert Thomas Dooley Jr.

Advisor: Dr. F. W. Schutz Jr.

This study comprises a series of tests to determine the coefficient of friction of various protective coatings used on structural steel. These protective coatings consist of greases and the major structural steel paints used today by the steel fabricators.

The tests were conducted using a four bolt double lap joint. The surfaces of the plates were polished, and the fasteners used in the connection were standard high strength bolts calibrated with SR_4 strain gages. The bolts were torqued to 0.9 EPL, and the clamping force exerted on the plates was measured with great accuracy.

A test of unpainted surfaces produced an average coefficient of friction of 0.230. This value was computed using the load attained before an average slip of 0.001 inch occurred in the joint. Tests at the University of Washington have shown that mill scale faying surfaces produce higher values of friction than the polished surfaces, because of the interlocking action caused by surface irregularity.

A series of tests using the common structural steel paints produced a friction value before initial slip that was negligible. This series of tests supports the present specification of the Research Council on Riveted and Bolted Structural Joints of the Engineering Foundation, which prohibits the use of paint in joints where no slip is tolerated.

The effect of long time sustained loads on painted connections

was also investigated. The results showed that the coefficient of friction produced was 85 per cent of that of the short time load.

Of all paints tested the Red or Brown One-Coat Shop Primer (SSPC-Paint 13-55T) produced the highest friction values. Tests involving variations in thickness of paint coatings were performed and it was concluded that the amount of slip in a joint varies as the paint thickness.

Tests involving wet paints and greased surfaces showed promise in developing a friction force in the magnitude of those for the uncoated test. Tests of low pressure greases produced values of friction much higher than the same tests using high pressure greases. Inspection of the surfaces coated with grease showed that the grease is squeezed out between the surfaces and forced into the low regions of the plates. The actual contact surfaces of the plates were in a dry condition.

It is recommended that further study be made with the use of low pressure type greases as protective coatings.

Approved: ______________

Date of Approval : April 27, 1957

CHAPTER I

INTRODUCTION

The high strength bolt in itself is not a new device. Its application to large steel structures such as bridges and buildings is something new. The use of the high strength bolt in this work makes fact out of one of the "fictions" of riveted steel construction. This "fiction" is the idea that when the shank of a hot driven rivet shrinks, it develops a force that clamps the connected parts of a joint so tightly that stress may be transferred from one part to another by friction, rather than by bearing and shear in the rivets (1).

Engineers have long known that there is some frictional transfer of stress in almost all riveted joints. They also know that this stress transfer is not consistently developed and that its magnitude under ideal conditions is almost negligible. Frictional transfer is of little structural use in joints subjected to a static loading condition. A different condition is encountered in joints that are subjected to repeated loading conditions. Structural joints subjected to this loading demonstrate that stress concentrations that develop when rivets transfer stress by bearing against the sides of their holes will materially reduce the fatigue strength of the joints (2).

With this information known about the action of riveted joints, studies of bolted joints were made under the sponsorship of the Research Council on Riveted and Bolted Structural Joints of the Engineering Foundation.

Organized in 1947, the Research Council has pioneered all research on bolted joints. It is the duty of the Council to determine the suitability and capacity of different types of joints used in fabricated structural frames. Investigations made by the Council showed that ordinary structural bolts (ASTM Specification A-307) were only a little better than structural rivets. This finding led to the development of the heat treated carbon steel high strength bolt as specified by ASTM Specification A-325 (3).

Structural engineers who make use of high strength bolts design the joints as riveted and merely replace the rivets with bolts. But when these bolts are used, no provision is made for the greater strength afforded by the bolt. Using the required minimum bolt tension value of 32,400 pounds for a seven-eighth-inch high strength bolt, the clamping action attained is nearly twice as large as the maximum clamping action theoretically attainable in carbon steel structural rivets. Thus the bolts develop a friction force which transfers part or all the load normally causing shearing stress on the rivet. This shear force in a connection is usually critical. The frictional force that is developed decreases the shearing stress on the bolts and, in some cases, reduces the number of bolts required. It is with frictional force that this thesis is concerned.

The attitude of the Research Council toward slip in joints assembled with high strength bolts has been extremely cautious. In 1951, the first specification issued (4) prohibited the shop painting of all contact surfaces. Further study has indicated that painted surfaces are allowable where slippage into bearing can be tolerated (5).

Studies at the University of Washington have been concerned with the friction values produced by different protective surface coatings. With perfect alignment of the bolt holes and using mill scale faying surfaces the average coefficient of friction is 0.250 for unpainted joints (6).

The values of friction obtained from tests using a protective coating on mill scale faying surfaces might not be a true indication of the frictional force produced by the paint. The interlocking of the mill scale surfaces will influence this value. Few tests have been conducted on the common structural steel paints to see what the friction values would be if the interlocking actions caused by mill scale surfaces are disregarded.

The purpose of this thesis is to find which of the commonly used structural steel paints will produce the highest value of friction and to find a general measure of its magnitude. A side study was carried out to see the effect of wet paint and grease on joint surfaces. Variations of surface coating thickness were also investigated. Such variations might be produced by application of paint by spraying and brushing.

The majority of the joints were tested using a short time loading program. An additional long time load test was conducted for comparative use with the short tests, and for verification of any results obtained by the short time test.

CHAPTER II

EQUIPMENT AND CALIBRATION

The utilization of the SR_4 strain gage and high strength bolts as instrumented fasteners makes it possible to determine the clamping force exerted on a surface with great accuracy.

The fasteners used consisted of seven-eighths inch diameter high strength bolts, four and one-half inches long, manufactured according to ASTM Designation 325-A (3). On opposite sides of the shank, three-quarters of an inch down from the head, flat surfaces were milled one and one-half inches long and one-half inch wide. Small one-eighth inch holes were drilled through the top of the bolt to the flat surfaces. The surfaces were prepared and SR_4 strain gages, Type A-11, were applied according to the instructions furnished by the manufacturer. A protective coating of Petrosene wax was molded over the strain gages and lead wires to conform with the cylindrical shape of the bolt.

Each bolt had two gages attached with the lead wires running through the small holes to the Hathaway Type RS-20A Strain Indicator. For each active gage, there was a corresponding temperature compensation gage on a similar bolt. Therefore, for each bolt used in the joint, there were four gages connected in series to the strain indicator. Figure 1 shows a detailed drawing of the instrumented high strength bolt, and Fig. 2 shows a schematic wiring diagram of the bolt, instrument box, and strain indicator.

Calibration of the bolts was necessary before any field tests could be run. This calibration consisted of placing each bolt in pull heads and applying a known tensile force. As this load was applied by the testing machine, a corresponding strain in micro-inches per inch was read off the strain indicator. The readings obtained produced a straight line relation between strain and load (Fig. 9), with a slope of sixty micro-inches per inch to one thousand pounds of bolt tension.

During the tests of the joints, a noticeable decrease in bolt tension during the first series of tests was observed. This load decrease averaged about 900 pounds or 56 micro-inches of strain per bolt. The decrease of bolt tension can be accounted for by the local yielding of the plates around the bolt holes and the variations of room temperature during the test. The local yielding of the steel around the bolt holes was caused by the intense stresses produced by the high strength bolts. A test on the bolts indicated that creep of the bolts under the load of 32,400 pounds was negligible. After Series A was tested, the bolt tension drop off was never more than an average of about 200 pounds during any test (Fig. 34).

A recalibration of the bolts at the end of the tests indicated that the bolt calibration curve did not change with time during the period of tests.

The tensile properties of the six inch steel plates used for the joints are listed in Table 1. These results were obtained from the tests of ASTM Standard Tensile Coupons.

Detailed drawings of the plates are shown on Figs. 5 and 6. The bolt holes shown on these drawings were reamed one-sixteenth inch oversize to enable the test to continue past failure without bringing the bolt into shear or bearing. Failure is defined as a total average slip of one-sixteenth inch, which is now possible by the code if the holes are perfectly aligned. To assure alignment of the holes, two one-quarter inch pins were used, one at each end of the joint. After the instrumented bolt was centered in the hole and torqued to a specific elastic proof load value, the pins were removed and the test was started. Figure 4 shows a typical assembled connection being tested.

The plate surfaces included in the joint were machined clean and hand polished until all visual grooves were removed. The surfaces were tested with a Brush Electronics Company Model BL-110 Surfindicator to find an average value of smoothness. Figure 7 shows the Surfindicator in operation, and Table 2 gives the average plate values of smoothness.

These plates go together to make up 4 separate joint specimens which were used repeatedly throughout the series of tests. On the average, each joint was tested about ten different times. A summation of friction values (Table 4) and the degree of repeatability of these friction values will be discussed in detail in Chapter V.

The use of over-size washers was required to secure a total grip of three inches, which was necessary for the instrumented bolt. The washers were one-half inch thick and conformed to standard inside and outside diameter sizes as specified by American Standard Heavy Washers, ASA Standard B-27.2 (3). After the washers were case hardened, they were tested in a Wilson Model Jr-3 Rockwell Hardness tester. The hardness values ranged between C9 and C14 for all washers used.

To measure the average slip of the joint, two micrometer mechanical dials were mounted on the specimen, one on each side. Details of the instrumentation are shown in Figs. 4 and 6.

CHAPTER III

SURFACE COATINGS

Recommendations for the types of surface coatings to be tested were suggested by steel fabricators and various paint industries.

The paints used in series B through E are commonly used by all steel fabricators. Series F includes a paint now under consideration for use in steel construction. Series G. H. and I include greases of variable performance characteristics.

The following descriptions are intended to furnish an averall picture of the characteristics, performance, and composition of the surface coatings.

1. Red Lead and Raw Linseed Oil Primer* (Series B, J, and M)

TT-P-86a Type I (DuPont Paint)

This paint specification covers a very slow-drying red lead and raw linseed oil primer for use on structural steel. The paint will give better results if applied to a machined clean surface. When proper surface application is used, the paint has excellent wetting ability, rust inhibitive characteristics, and good durability. Red lead paint requires from 48 to 72 hours drying time at room temperature of 40° F, or above, in order to dry hard.

SSPC-Paint 1-55T is commonly used by steel fabricators because it is suitable for use in exposed industrial, rural, or marine atmospheres.

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*The material in description 1-5 is based on that in Steel Structures Painting Manual, Volume II (7).

This paint is suitable for application by brushing or spraying. If spraying is to be used, thinning might be required to obtain the proper consistency.

Ingredients	Required Wt. %		Typical Wt. %	Composition Vol. %
PIGMENT: (77.5 wt % min.)	Min.	Max.		
Red Lead (97% Pb_3O_4	99.6	-	77.2	26.1
Aluminum Stearate	0.3	0.4	0.3	0.9
VEHICLE: (22.5 wt % max.)				
Raw Linseed Oil	94.0	-	21.1	68.2
Driers and Thinners	-	6.0	1.4	4.8
			100.0	100.0

2. Red Lead, Iron Oxide, Raw Linseed Oil and Alkyd Primer (Series C)

SSPC-Paint 2-55T (Pittsburgh Paint)

This specification covers a red lead, iron oxide, raw linseed oil and alkyd primer for use on structural steel. The paint will give better results if applied to a surface that has been machined clean. When proper surface application is used, the red lead, iron oxide paint gives excellent rust inhibitive characteristics and properties needed for resistance to weathering prior to the finish coat. The paint requires about 24 hours drying time at a temperature of 40°F., or above, in order to dry hard.

SSPC-Paint 2-55T is a common paint used by the steel fabricators because of its excellent service when exposed in industrial, rural, or marine atmospheres.

This paint is applied by brushing or spraying. Thinning the paint to the proper consistency is often necessary when applied by spraying.

Ingredients	Required Wt. %		Typical Wt. %	Composition Vol. %
PIGMENT: (75 wt. % min.)	Min.	Max.		
Red Lead (97% Pb_3O_4	75.0	-	56.3	16.8
Red Iron Oxide (70% Fe_2O_3 min.)		24.7	18.4	11.0
Aluminum Stearate	0.3	0.5	0.3	0.8
VEHICLE:	Min.	Max.		
Raw Linseed Oil	56.0	-	14.0	39.8
Alkyd Resin Solids	21.0	28.0	5.2	12.9
Driers and Thinners	-	23.0	5.8	18.7
			100.0	100.0

3. Red Iron Oxide, Zinc Chromate, Raw Linseed Oil and Alkyd Primer

SSPC-Paint 11-55T (DuPont Paint) (Series D)

This paint specification is for a red iron oxide, zinc chromate, raw linseed oil and alkyd primer for use on structural steel. Best results are obtained when the surface is machined clean. With proper surface application the paint shows excellent rust inhibitive characteristics, good durability for normal periods of time, and excellent wetting ability. Red iron oxide, zinc chromate paint requires 24 hours drying time at a temperature of 40° F, or above, in order to dry hard.

SSPC-Paint 11-55T is used mostly for interior exposures, but is quite acceptable for exposure in industrial, rural, or marine atmospheres. It is very popular with the steel fabricators.

Application of this paint can be by brushing or spraying. If spraying is used, the paint can be thinned for proper consistency.

Ingredients	Required Wt. %		Typical Wt. %	Composition Vol. %
PIGMENT: (50 wt.% ± 2%)	Min.	Max.		
Red Iron Oxide (70%)	40	-	20.0	6.8
Magnesium Silicate	-	20	10.0	5.5
Zinc Chromate	40	-	20.0	8.5
VEHICLE: (50 wt.% ± 2%)				
Raw Linseed Oil	33	-	16.5	27.0
Alkyd Resin Solids	33	-	16.5	23.5
Thinners and Driers	-	34	17.0	28.7
			100.0	100.0

4. Red or Brown One-Coat Shop Paint (Series E, K, and L)

SSPC-Paint 13-55T (Pittsburgh Paint)

This paint specification is for an iron oxide shop paint, which is composed of tung-oil-ester gum varnish with raw and bodied linseed oils added to zinc chromate and red lead pigment. The paint will give best results when the surface is machined clean. Since this is a low cost paint it has only fair wetting abilities, only fair rust inhibitive characteristics, but it has sufficient resistance to weathering conditions for periods up to six months. This shop paint is quick drying.

It takes about 8 to 24 hours at 40° F or above to dry hard.

This SSPC-Paint 13-55T is acceptable for short periods when subjected to exposure at normal environments, but is best suited for dry interior exposures where infrequent condensation takes place.

This paint can be applied by flow coating, dipping, roller coating, brushing, or spraying. Thinning might be necessary when spraying is used, to get the paint to the proper consistency.

Ingredients	% by Wt.	Lbs./100 Gal.	% by Volume
PIGMENT: (55.5%)			
Red or Brown Oxide ($85\% Fe_2O_3$)	60	435	11.50
Red Lead 97% Pb_3O_4)	12	87	1.18
Zinc Chromate	3	22	0.76
Magnesium Silicate	25	181	7.65
VEHICLE: (44.5 wt.%)			
25 gal. Tung Oil-Ester Gum			
Varnish (43 wt.% non-volatile)	49	286	39.60
Raw Linseed Oil	16	94	12.20
Pale Heat Bodied Linseed Oil	17	99	12.20
Mineral Spirits and Driers	18	106	14.91
	100	1,310	100.00

5. Zinc Dust, Zinc Oxide, Phthalic Alkyd Resin Paint (Series F)

Fed. Spec. TT-P-641b Type II (Pittsburgh Paint)

This specification covers a very quick drying zinc dust, zinc oxide, phthalic alkyd resin paint for use on structural steel or in galvanizing. This paint will give best results on a machined clean steel or galvanized surface. It has good durability under weathering, even before the finish coating. While it has good rust inhibitive characteristics, the wetting ability for oily surfaces is very poor. This zinc dust paint will dry hard in 12 hours at a temperature of 40° F or above.

This TT-P-641B Type II Paint is best suited for areas where high humidity and condensation are present, or it is even good for fresh water immersion. Average results have been obtained from exposures in marine, rural, or industrial atmospheres.

Since this paint has to be mixed on the job, it can be applied to the surface by brushing and spraying. When spraying is used, the paint can be thinned to the proper consistency.

Federal Specifications TT-P-641B Type II (7)

Composition by Volume

Ingredient	Gallon
Zinc Dust	0.1350
Zinc Oxide	0.0425
Total Pigment	0.1775
Non-Volatile Vehicle	0.2940
Total Solids	0.4715
Volatile (thin. and dry.)	0.5285
	1.0000

6. Grease - Sovanex L No. 1 (Series H)

Standard Oil Company of Kentucky

These figures cover a very high pressure grease; they are only general guides, not specifications.

Grease Characteristics

Soap Penetration at 77° F					
Type	Unwkd.	Wkd.	Struct.	% Water	Color
Lime	370	305	Smooth	0.5	Yellow
	Max.	363	S. Fibre		

Mineral Oil				
S. V. Visc. ASTM Drop				
Percent	100 F	210 F	Point F	
80	300	-	400 Min	

7. Grease - Nebula No. 1 (Series G)

Standard Oil Company of Kentucky

These figures cover a very high pressure grease; they are general guides, not specifications.

Grease Characteristics

Soap Type	Calcium Complex
Color	Tan
Texture	Buttery
Penetration, worked at 77° F	300

Grease Characteristics (Con't)

Dropping Point, $^{\circ}$ F	None
Oil Viscosity, SSU at 100° F	500
Wheel Bearing Test	Pass
Bomb Oxidation, pressure drop	230
Water Resistance:	
Rotating Bearing, % loss, 120° F	No loss
Immersion in boiling water	Insoluble
4-Ball Wear Test, 7.5 Kg Load	
30 min. at 167° F., wear scar, mm	0.23

8. Grease - Gulflex Multi Purpose Grease (Series I)

Gulf Oil Company

These figures cover a multi-purpose grease; they are only general guides, not specifications.

Grease Characteristics

Dropping Point $^{\circ}$ F	370
Penetration, unwkd at 77° F	286
wkd at 77° F	287
NLGI Consistency	2
Soap Type	Lithium
Texture	Smooth
Color	Light Brown

Grease Characteristics (Con't)

Oil Viscosity, SSU at 210° F	81.8
Wheel Bear Test	Pass
Water Resistance:	
Rotating Bearing, % loss, 120° F	No loss
Immersion in boiling water	Insoluble
4-Ball Wear Test	Pass

CHAPTER IV

TEST PROCEDURE

The surfaces of the plates were thoroughly cleaned of all foreign material before any surface coatings were applied. The plates were soaked in carbon tetrachloride for a sufficient time and then wiped clean with a soft rag. Before application of any coating, the surface was cleaned with compressed air to remove any excess dust.

The different protective coatings were applied to the surface and allowed to dry the specified drying time recommended by the Steel Structures Painting Manual (7). A description of each test performed, as to type of surface coating, surface condition, and drying time, can be found in Table 3.

The plates were assembled and the bolts were centered in the holes by use of templates. Each bolt was torqued to a value of about 32,000 pounds. The micrometer mechanical dials were mounted to the sides of the plates for the purpose of measuring slip, and the bolts were given final adjustment to 32,400 pounds. This bolt load is the equivalent of 1,944 micro-inches of strain as read on the strain indicator.

A constant strain rate was used for all tests. A reading of 0.025 inches per minute was selected and set on the Thymetrol variable speed control of the Riehle Type PS-450 Universal Screw Power Testing Machine. A load range from 0 to 90,000 pounds was used in the tests of series A, D, E, G, I, J, K, and L. Each reading was accurate to the nearest 200 pounds. A load range from 0 to 45,000 pounds was used in tests of series B, C, F, H, and M. Each reading was accurate to the nearest 100 pounds.

In the first series of tests, the joints were with uncoated plates (Series A); that is, plates with no surface coating. The plates were assembled, the bolts were centered in the holes and torqued to 32,400 pounds, and the slip dials were mounted and zeroed. The load was applied at a constant rate of strain, until the load indicator seemed to falter or slow down. At this point the machine was stopped. The slip dials and bolt tension readings were recorded. In all cases the load indicator did not falter or slow down in the early stages of the uncoated tests, but readings were taken about every 3,000 pounds to provide points for the load-slip curves.

At the major slip load of series A, there was a loud noise and a sharp decrease in load, caused by an instantaneous slip. The major slip load is defined as the load at which the joint has an average slip of over 0.001 inch. After the sharp decrease in load, the machine was stopped, and the corresponding slip dials and bolt tension readings were recorded. The test was continued in the same manner until the load exceeded the slip failure load. The term slip failure is defined as an average slip in the joint of over 0.0625 inch.

The second series of tests (Series B, C, D, E, F, L, and M) included the common structural steel paints used in steel construction after drying. The plates were assembled, the bolts were centered in the holes and torqued to 32,400 pounds, and the slip dials were mounted on the plates and zeroed. The load was applied at a constant rate of strain until the load indicator faltered or slowed down. At this point the machine was stopped, and the slip dials and bolt tension readings were recorded. These readings were taken past slip failure at 3,000 pound intervals to provide points for the load-slip curve.

The third series of tests (Series G, H, I, J, and K) included all greased and wet surfaces. The surfaces of the plates were covered with the protective coating, and the plates were assembled immediately. The bolts were centered in the holes and torqued to the required minimum value of 32,400 pounds. The slip dials were mounted to the side of the plates. The specimens were loaded in the same manner as were the uncoated plates (Series A).

Considering all the previously mentioned tests as short time loading tests, a long time load test was performed on the Red or Brown One-Coat Shop Primer (SSPC-Paint 13-55T). The purpose of this test was to see what effect time would have on the performance of the paint. The procedure of testing was quite different from that of previous tests. The plates were assembled, the bolts were centered in the holes and torqued to 32,400 pounds, and the slip gages were mounted on each side of the plates. The load was applied at a constant rate of strain until the load indicator seemed to falter or slow down. At this point the machine was stopped. The slip dials and bolt tension readings were recorded. This same procedure was followed until a load of 5,000 pounds was reached. At this value, the load was maintained constant, plus or minus 250 pounds, by alternately stopping and starting the machine. At different intervals of time, the slip dials and bolt tensions were recorded. This procedure was continued until the joint passed the "constant time period". This "constant time period" is defined as a minimum period of one hour in which the load remains constant, and the average slip of the joint changed less than 0.0002 inch. This same test procedure was followed at average intervals of 4,000 pounds until slip failure occurred.

The long time load test took a total of 72 hours before slip failure occurred. In search of a test method which would produce friction values in less time, a similar joint was tested using a constant strain factor for loading and a surface coating of Red or Brown One-Coat Shop Primer (SSPC-Paint 13-55T). It was thought that by keeping the strain constant and allowing the load to drop off, a curve could be plotted which would give accurate values of friction in less time. This test was started in the same manner as the test of series B, C, D, E, and F. At average load intervals of 4,000 pounds, the machine was stopped and the specimen was held at a constant strain. Over a period of time the load was allowed to decrease until it reached the point of maximum drop off, that is, no drop in load over a period of 30 minutes. At this point, the load was increased another increment and the same procedure was followed until slip failure was encountered. The slip dials and bolt tension readings were recorded throughout the test. The total length of time of this test was 15 hours.

CHAPTER V

DISCUSSION OF RESULTS

Using the values recorded as test data, the coefficient of friction was calculated for each series of tests (Fig. 34). The normal force used for the slip failure coefficient of friction was a summation of the bolt tension readings at slip failure. In determining the normal force for the coefficient of friction at the major slip load, the summation of the bolt tension readings just before major slip was used.

The results obtained from the Series A tests using unpainted bare plates indicate that the average value of the coefficient of friction of polished faying surfaces was 0.230. This friction value could be counted on in design under the present code, since the average slip in the joints tested was only 0.001 inch. Load slip curves are shown in Fig. 10.

The average value of friction from Series A was 0.230. This value, of course, was obtained using polished faying surfaces which would never be encountered in steel construction. Tests of similar joints using mill scale faying surfaces have been run at the University of Washington (6), and the average coefficient of friction obtained was 0.250. The mill scale faying surfaces produced the higher value of friction due to the interlocking action caused by the irregularity of the surfaces. It has long been the consensus of engineers that the misalignment of bolt holes would tend to increase the value of friction. Research at the University of Washington (6) has indicated that the average coefficient of friction with misalignment of bolt holes is 0.340. This higher value is caused by the edges of the bolt holes cutting into each other thereby increasing the interlocking action. This comparison is only a side study however, and is not the main purpose of this thesis.

Using 0.230 as the average friction value of the polished plates, an equivalent shear stress on the bolt of 12,500 psi was developed. The average stress developed on the net section of the plates was 14,800 psi. These values are under the allowable stresses now allowed by steel specifications.

Using the TT-P-86a Type I coating (Series B), the average major slip load of 500 pounds is negligible, and the frictional value at slip failure averages 0.065 (Fig. 11). The red lead surface coated joint slipped under the smallest of loads and proved to be the poorest paint tested for frictional purposes. This value could not be counted on in design where cases of no slip would be specified.

The performance of the SSPC-Paint 2-55T (Series C) was similar to that of the TT-P-86a Type I. The average value of friction at slip failure was 0.083. The joint slipped under the slightest load (Fig. 12), and the paint could not be counted on in design to develop any friction force before some slip would take place.

The average value of friction produced by the SSPC-Paint 11-55T (Series D) was 0.121 (Fig. 13). Although the value of friction at slip failure is 100 per cent greater than that of the TT-P-86a Type I Paint, the friction produced at major slip is negligible and could not be counted on.

The TT-P-641b Type II Primer (Series F) had a performance characteristic similar to that of TT-P-86a Type I. It produced an average friction value at slip failure of 0.074 (Fig. 15), and slipped under the slightest load. Results indicate that this paint, which is just being introduced into steel construction, produces frictional forces which are negligible in cases where no slip could be tolerated.

The results of tests conducted with the SSPC-Paint 13-55T (Series E) indicated that the average friction value of 0.156 was the best obtained for all dry paints tested. The performance of this paint (Fig. 14) was similar to all of the other paints tested, but the coefficient of friction attained at the slip failure load was 300 per cent higher than the value of TT-P-86a Type I now so commonly used by all fabricators.

In general, no paint tested produced a coefficient of friction that could be counted on in the cases where no slip could be tolerated. Table 3 gives a summary of all tests, showing friction values both at the major slip load and the slip failure load.

Tests which included surface coatings of grease produced friction values ranging from 0.080 to 0.282, depending on the character of grease. The high pressure greases tested (Series G and H) gave the lowest values of friction (Figs. 16 and 17). The high pressure grease was not squeezed out between the surfaces when the tension in the bolts was applied to the joint. It did not break down but acted as a lubricant between the plates. The multi-purpose grease, which was easily squeezed out from between the plates, produced a friction value in the same range as those obtained from uncoated plates. Load slip curves can be found on Fig. 18.

At the end of the multi-purpose grease test, the condition of the surfaces was inspected. The grease had been forced into the low regions of the surfaces, and where actual contact with the other plate had been made, the surface was in a dry condition.

Tests of wet paints (Series J and K) also produced higher friction values than those found for dry painted surfaces (Figs. 19 and 20). This can be explained easily because the paint was forced or squeezed from between the plates similar to the actions of the multi-purpose grease.

Figure 27 shows a comparison of curves resulting from tests using wet paints, multi-purpose grease, and dry surfaces. It is readily seen that the friction value at the major slip load could be counted on in cases where no slip could be tolerated.

Figure 28 shows a comparison of the performance of the three types of grease used. In all cases the friction value at major slip load is reliable and could be used. A definite comparison can be seen as to the advantage of a low pressure grease over a high pressure grease.

Figures 29 and 30 indicate what changes in friction value will result by varying the thickness of the dry paint coatings. From the results of the tests on TT-P-86a Type I and SSPC-Paint 13-55T, there is a decrease in frictional value with increase in thickness of paint. The reason is that as the layer of material becomes thicker between the plates, it tends to break up and act as ball bearings between the plates, thus reducing frictional resistance.

Results from tests indicate that all paints containing Red Lead or Zinc Dust have a low coefficient of friction. These two items act as lubricants between the plates and cause a plane of weakness which will tolerate slip at very low loads.

To correlate the results from the short loading test, a long time test was run on the SSPC-Paint 13-55T. Figure 25 shows a comparison between a short time loading curve and the long time loading curve. The major slip load of both tests are similar, and the friction values of the tests at the slip failure load are slightly different. The friction value of the long time test was found to be 85 per cent of the value for the short time tests. In general, the curves of both tests run similar to one another.

Just as a load increment was applied to the joint, in the long time test, the slip was very rapid; but as time increased under the constant load, the average slip decreased until after a period of time the change in average slip of the joint was negligible. The slip time curve plotted of Fig. 31 shows the average slip versus time and indicates how the rate of slip decreases with time. Painted joint behavior over very long periods of time has been studied (6) and the general trend of the curve covering these long periods of time is similar to the long time load test run on SSPC-Paint 13-55T.

A joint was tested using the constant strain factor rather than the constant load factor as a basis for comparison. By connecting the points where the load remained constant along with the strain, a curve was plotted for comparison with a curve produced by the long time load test. The results of this test can be found on Fig. 26. There seems to be a definite correlation between this long time constant strain test and the long time constant load test. In the long time constant load test it was found that the friction value produced was 85 per cent of the friction value of the short time load test. Correspondingly, in the long time constant strain test the friction valve produced by connecting the points of constant load was 85 per cent of the friction value of the short time load test. These results indicate that the same friction values of the long time load test were obtained by the long time constant strain test in much less time. A possible explanation of any differences in results may be in the use of different sets of plates and the lack of enough tests to get a good averaging effect.

A plot of time against drop off of load shown on Fig. 32 indicates how the drop off decreases with time.

Table 4 shows a summation of friction values for similar tests on all plates. The small variations in the summations of these values indicate the relative consistency of the joints and also indicate that all plates are smooth to the same degree. The summation of the friction values indicate that no specimen was consistently high or low. As proved by the consistency of the results, the values obtained are reliable.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

The Research Council's recommendations for painted connections are justified by this investigation (5). The paints included in these tests, which are commonly used by the steel fabricators, are not of the quality to produce a frictional force large enough to prevent slippage under presently used working loads.

The present restriction by the code (5) of painted surfaces where slip cannot be tolerated can be verified by the fact that for all paints tested, the friction force developed before slip is negligible.

In the case where slip can be tolerated, the Red or Brown One-Coat Primer (SSPC-Paint 13-55T) produced the highest coefficient of friction ($u = 0.15$). The Red Lead and Raw Linseed Oil Primer (TT-P-86a Type I) possessed the lowest coefficient of friction of all the paints. Tests indicate that clean polished surfaces in structural steel joints have an average coefficient of friction of 0.23. Because of the polished surfaces, the frictional resistance produced by each fastener is less than the allowable shear stresses specified for rivets by AASHO (8), AREA (9), or AISC (10).

Wet paints applied to the surface of structural steel produce higher friction coefficients than the same dry paints on the surfaces. Low pressure greases produce friction coefficients upwards to the values obtained with uncoated surfaces. All joints covered with coatings which can be squeezed out when bolt tensions are applied act the same as dry uncoated joints.

The thickness of the surface coating affects the friction value produced in the joint. The thicker the surface coating, the lower is the coefficient of friction.

Paints that contain metallic dust produce low friction values when used in a painted connection. The particles act as ball bearings and slip occurs under the slightest loads.

In the constant load test, the largest amount of slip occurs at the first application of the load, and the rate of slip decreases with time until the point is reached where the friction force is greater than the slip force and all movement stops.

Of all the commonly used structural steel paints tested the Red or Brown One-Coat Shop Primer (SSPC-Paint 13-55T) produced the highest value of friction.

The values of friction presented are values for short time tests. However, these values do not vary a great deal from those of the long time test. Indications are that the long time test values for friction coefficients will be 0.85 times the values found in these short time tests.

Findings of these tests indicate that no structural steel paints used today will produce friction values which can be counted on in cases where no slip can be tolerated. As a result of these findings, no further investigation is suggested using paints as protective coating in cases where slip cannot be tolerated. From the results of tests using grease as a protective coating, it was found that high friction values were obtained. It is suggested that further investigation of the use of grease as a protective coating might prove very profitable. It might be possible to spray structural steel with a protective coating of grease instead of paint, which is now used.

APPENDIX

TABLES

Table 1. Tensile Properties of the Plates

Coupon	Plate Thickness Inches	Upper Yield PSI	Ultimate Strength PSI	Reduction of Area Per Cent
1-A	1/2	37,900	60,400	46.3
1-B	1/2	35,700	61,700	52.9
1-C	1/2	35,800	61,700	48.3
2-A	1	35,980	60,000	54.1
2-B	1	38,150	62,660	56.3
2-C	1	34,550	61,025	57.0
2-D	1	40,200	59,560	51.5

Table 2. Average Plate Values of Smoothness

Specimen	Plate	Average RMS	Average AA
1	A	24-25	22-23
	B-1	25-26	23-24
	B-2	28-29	25-26
	C	23-24	21-22
2	A	31-32	29-30
	B-1	33-34	31-32
	B-2	29-30	27-28
	C	30-31	28-29
3	A	28-29	26-27
	B-1	28-29	26-27
	B-2	26-27	24-25
	C	32-33	30-31
4	A	25-26	23-24
	B-1	28-29	26-27
	B-2	24-25	22-23
	C	27-28	25-26

Table 3. Summary Chart of Friction Values

Series No.	Surface Coating	Surface Condition	Joint No.	Drying Time Hrs.	Major Slip load u	Slip Failure load u
A-1	Uncoated	Dry	1	-	0.240	-
A-2			2	-	0.200	-
A-3			3	-	0.230	-
A-4			4	-	0.250	-
B-1	TT-P-86a Type I	1 brush coat	1	72	0	0.060
B-2		Dry	2	72	-	0.069
B-3			3	72	-	0.063
B-4			4	72	-	0.069
C-1	SSPC-Paint 2-55T	1 brush Coat	1	48	-	0.078
C-2		Dry	2	48	-	0.091
C-3			3	48	-	0.086
C-4			4	48	-	0.079
D-1	SSPC-Paint 11-55T	1 brush coat	1	24	-	0.106
D-2		Dry	2	24	-	0.123
D-3			3	24	-	0.138
D-4			4	24	-	0.118
E-1	SSPC-Paint 13-55T	1 brush coat	1	24	-	0.183
E-2		Dry	2	24	-	0.148
E-3			3	24	-	0.133
E-4			4	24	-	0.160
F-1	TT-P-641b Type II	1 brush coat	1	24	-	0.070
F-2		Dry	2	24	-	0.063
F-3			3	24	-	0.074
F-4			4	24	-	0.088
G-1	Nebula No. 1	1 heavy coat	1	-	0.072	0.121
G-2		1 thin coat	2	-	0.063	0.085
G-3		1 thin coat	3	-	0.078	0.179
H-1	Sovarex L No. 1	1 thin layer	1	-	0.068	0.080
H-2			2	-	0.077	0.098
I-1	Gulflex	1 thin layer	1	-	0.162	0.282
I-2			2	-	0.172	0.257

Table 3. (Con't) Summary Chart of Friction Values

Series No.	Surface Coating	Surface Condition	Joint No.	Drying time hrs.	Major Slip Load u	Slip Failure Load u
J-1	TT-P-86a Type I	1 wet layer	3	-	0.105	0.160
J-2			3	-	0.113	0.160
K-1	SSPC-Paint 13-55T	1 wet layer	3	-	0.201	0.228
K-2			3	-	0.191	0.228
L-1	SSPC-Paints 13-55T	2 brush coats	1	48	-	0.132
L-2		(dry)	2	48	-	0.119
L-3		1 spray coat	3	24	-	0.155
L-4		(dry)	4	24	-	0.163
M-1	TT-P-86A Type I	2 brush coats	3	144	-	0.060
M-2		(dry)	4	144	-	0.055
M-3		1 spray coat	1	72	-	0.064
M-4		(dry)	2	72	-	0.068

Table 4. Joint Friction Values

Surface Coating	1	2	3	4	Average
None	0.240	0.200	0.230	0.250	0.230
TT-P-86A TypeI	0.060	0.069	0.063	0.069	0.065
SSPC-Paint 2-55T	0.078	0.091	0.086	0.079	0.083
SSPC-Paint 11-55T	0.106	0.123	0.138	0.118	0.121
SSPC Paint 13-55T	0.183	0.148	0.133	0.160	0.156
TT-P-641b Type II	0.070	0.063	0.074	0.088	0.074
Summation of friction values of the joint including the unpainted surfaces	0.737	0.694	0.724	0.724	
Summation of friction values of the painted surfaces only	0.497	0.494	0.494	0.514	

FIGURES

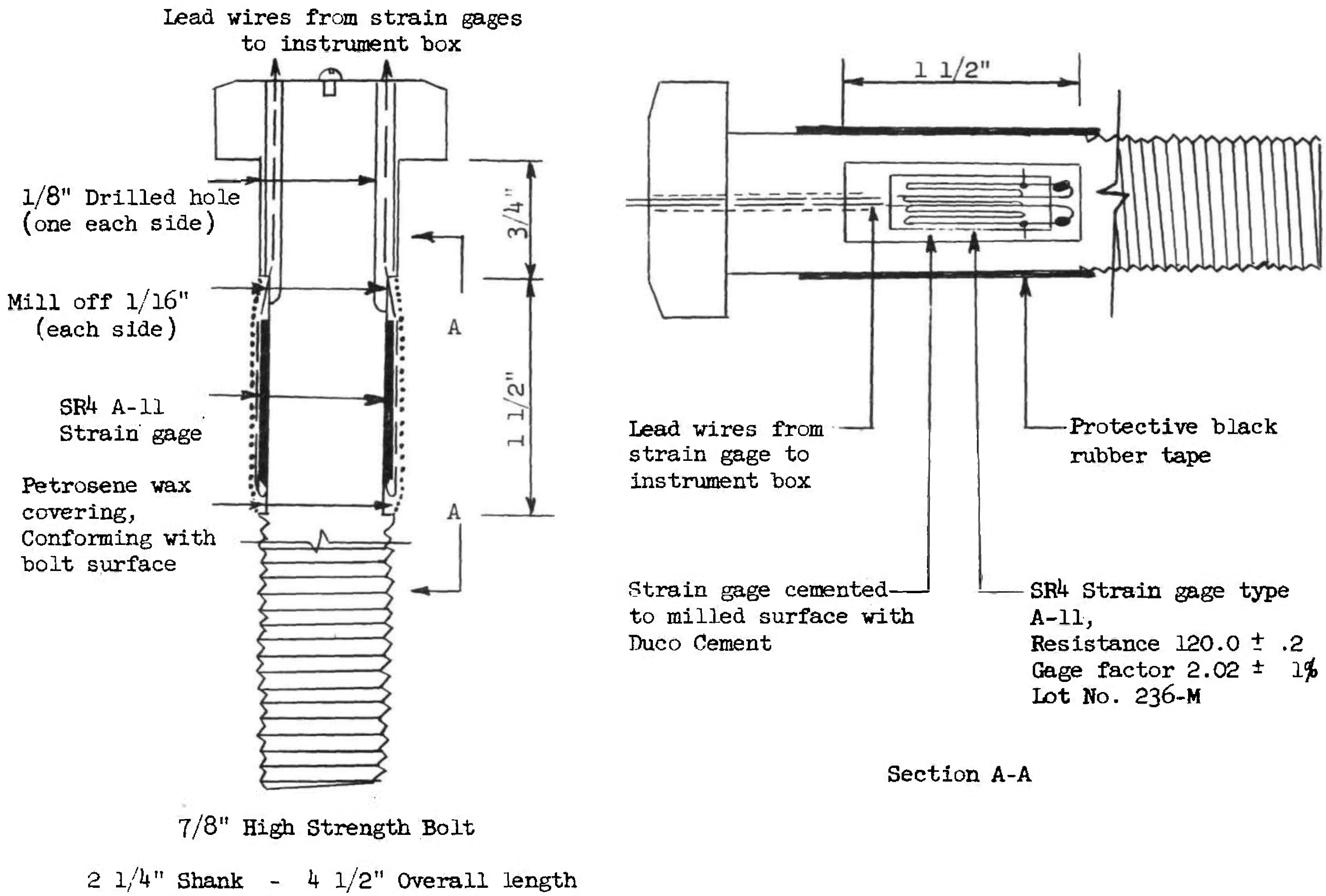


Fig. 1. Instrumented High Strength Bolt

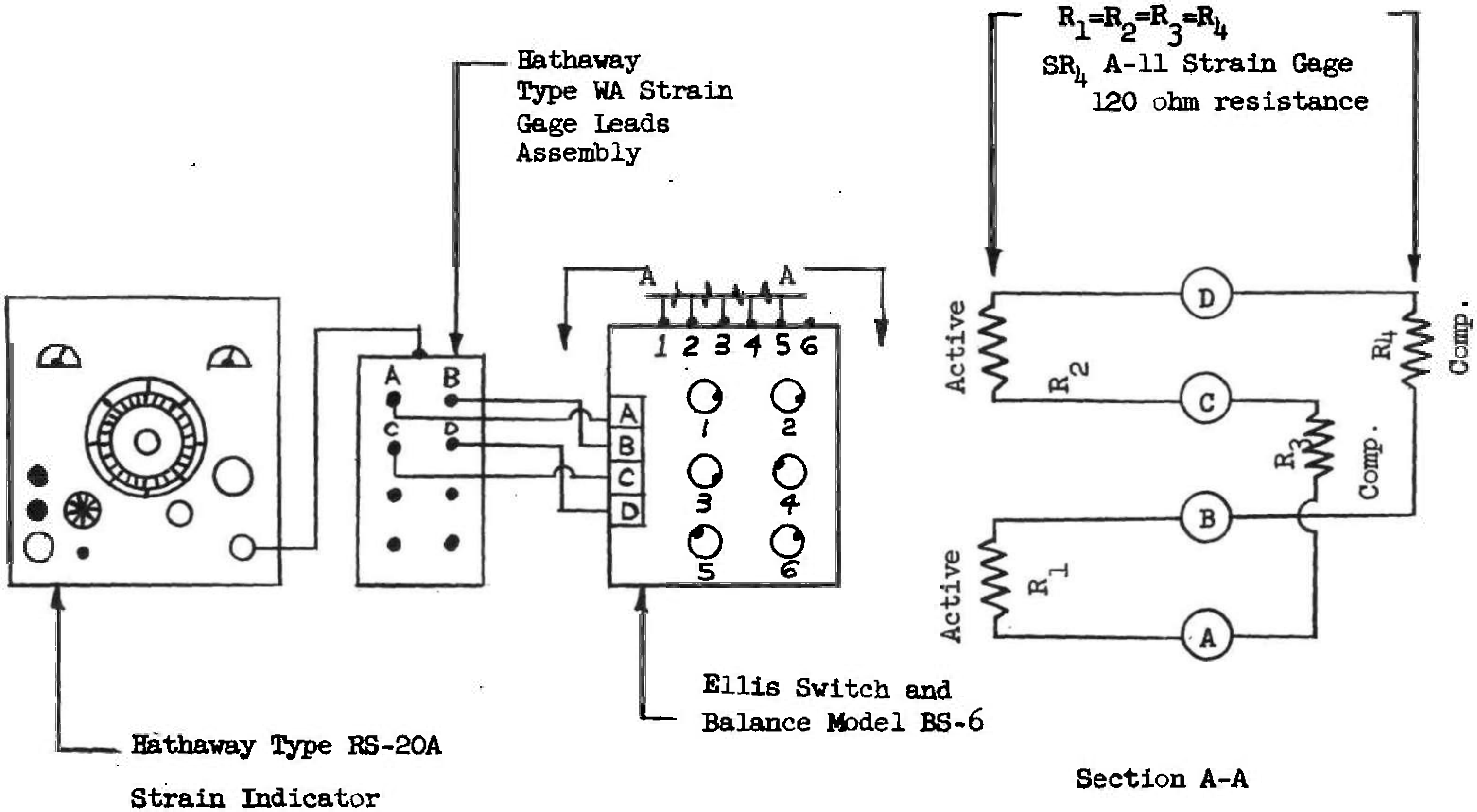


Fig. 2. Schematic Wiring Diagram of Strain Equipment

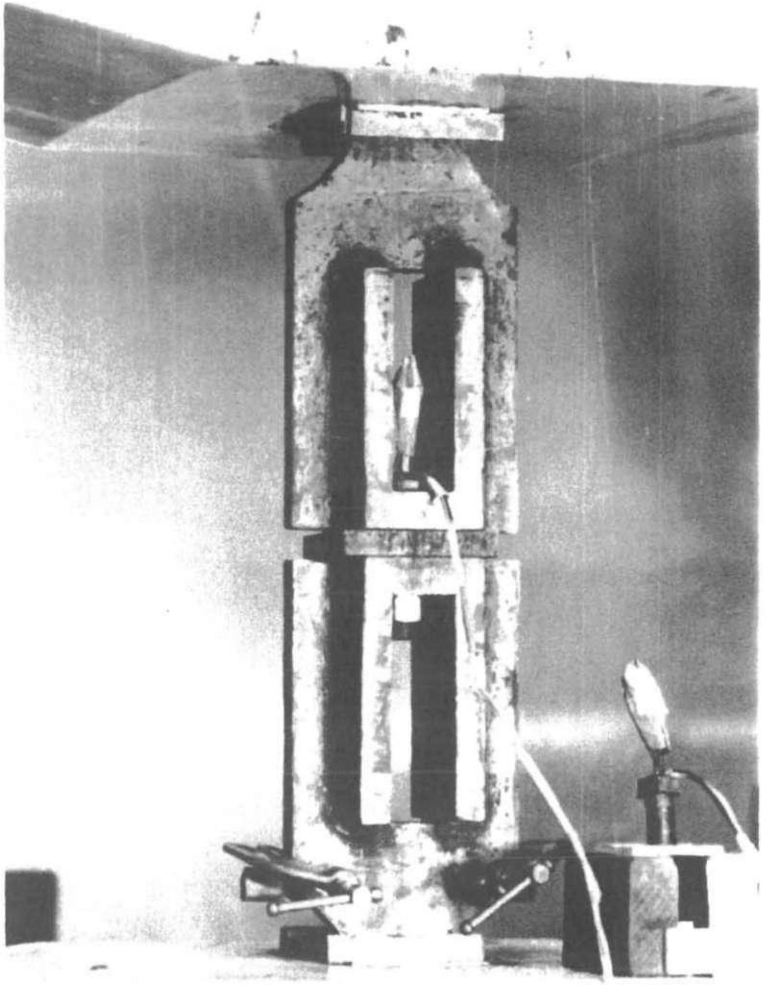


Fig. 3. Instrumented Bolt in Pull Head

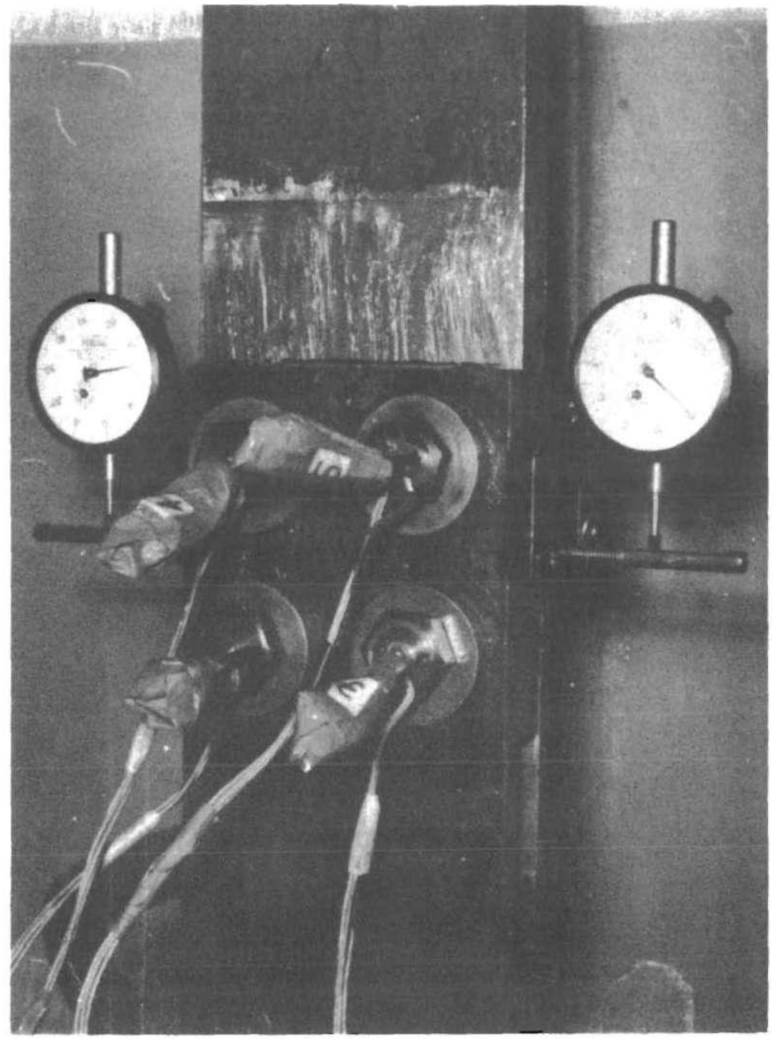


Fig. 4. Typical Painted Connection

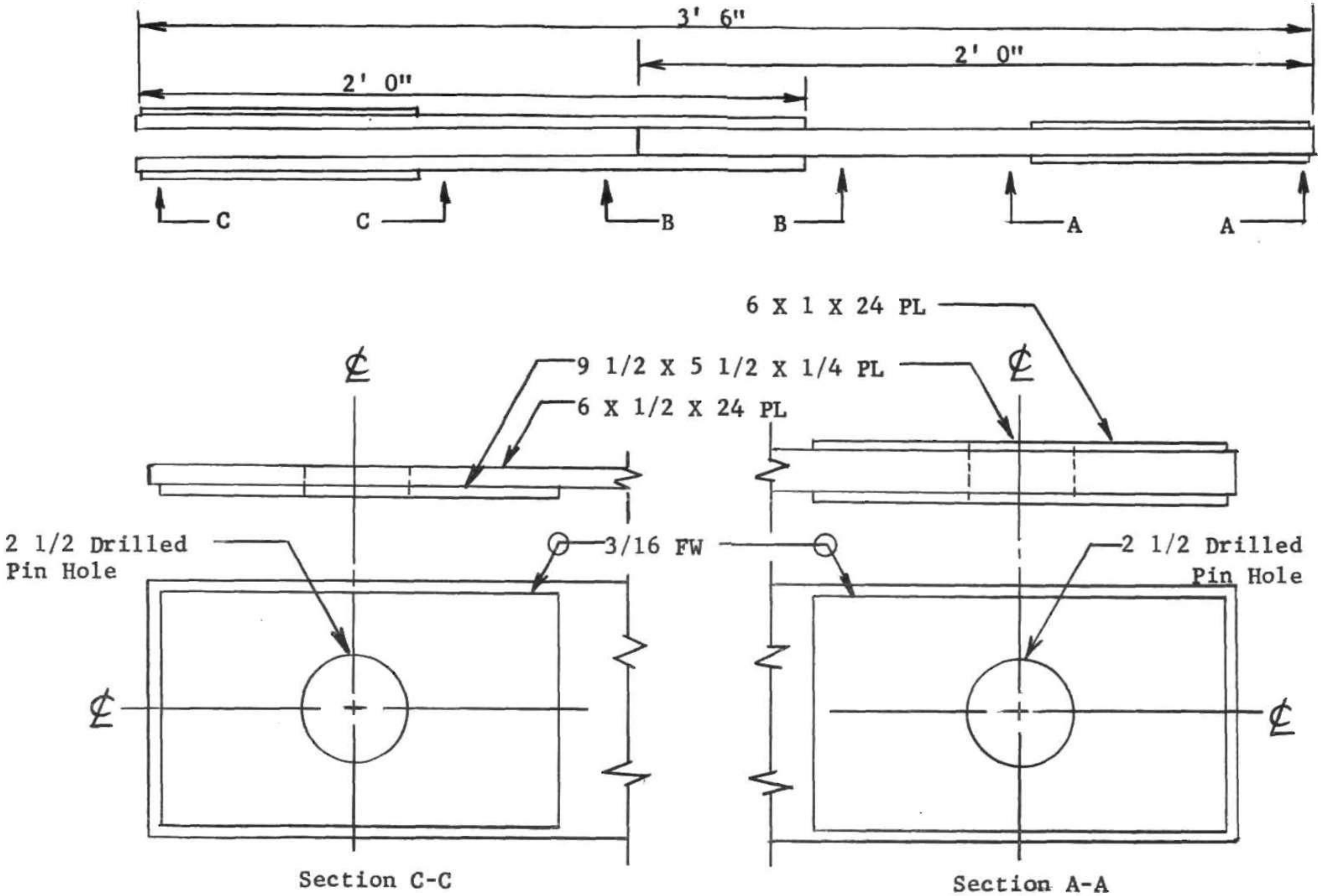


Fig. 5. Detail of Test Specimen

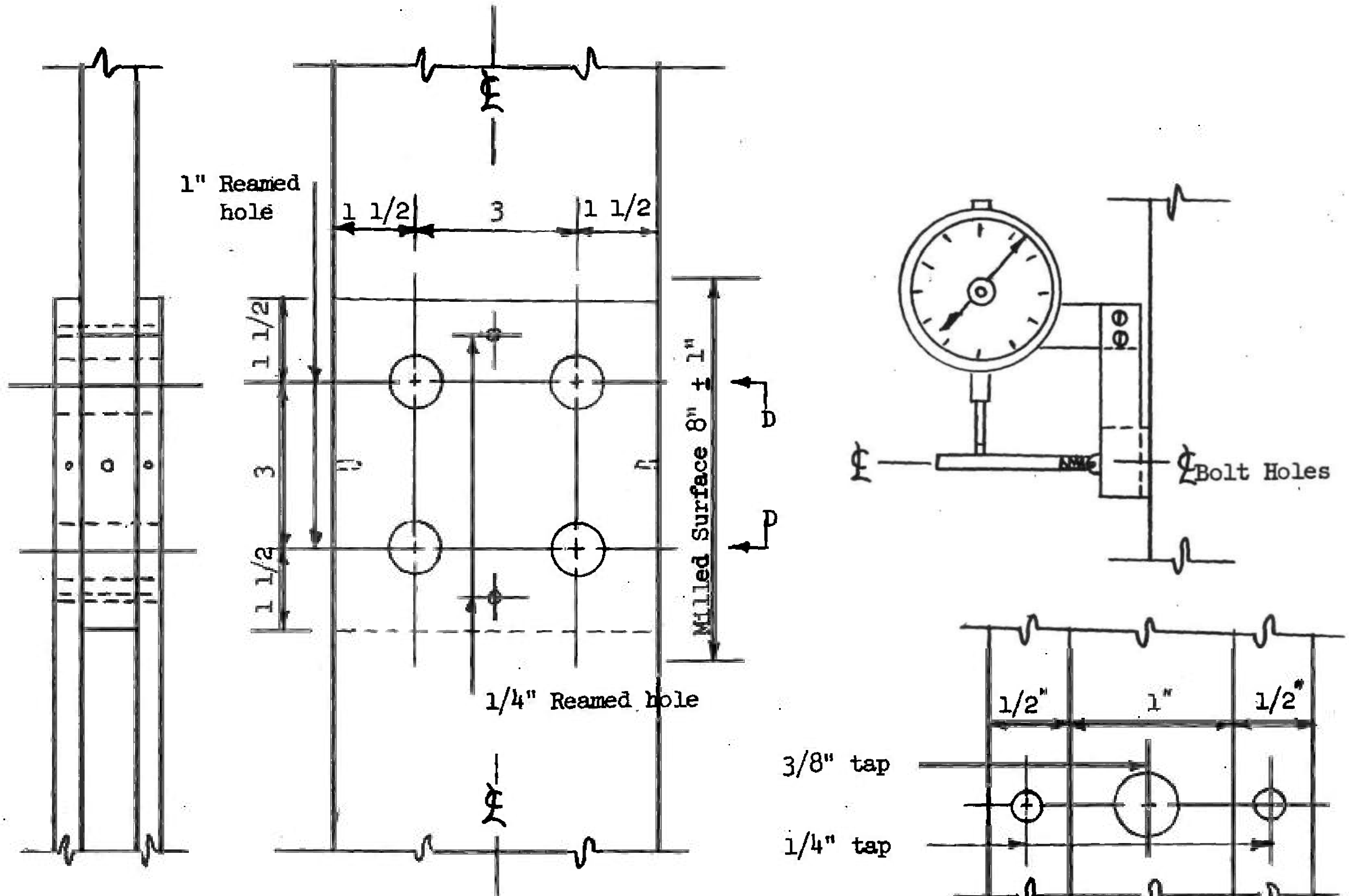


Fig. 6. Detail of Test Specimen

Section D-D

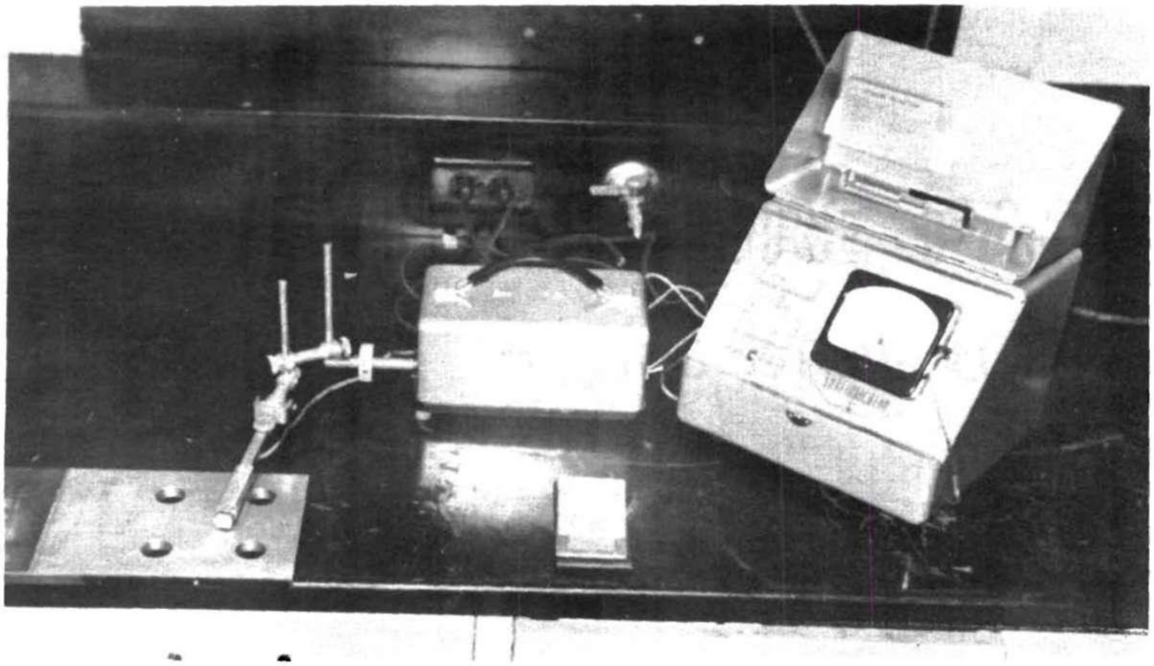


Fig. 7. Operation of Surfindicator

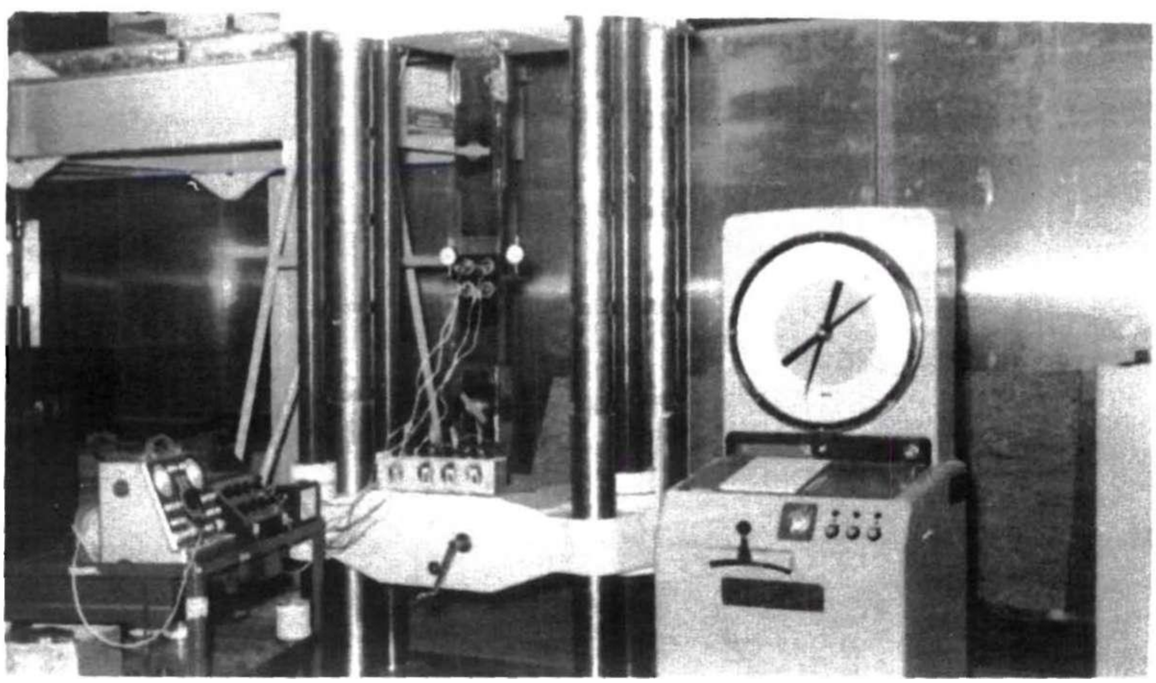


Fig. 8. Overall View of Test Specimen

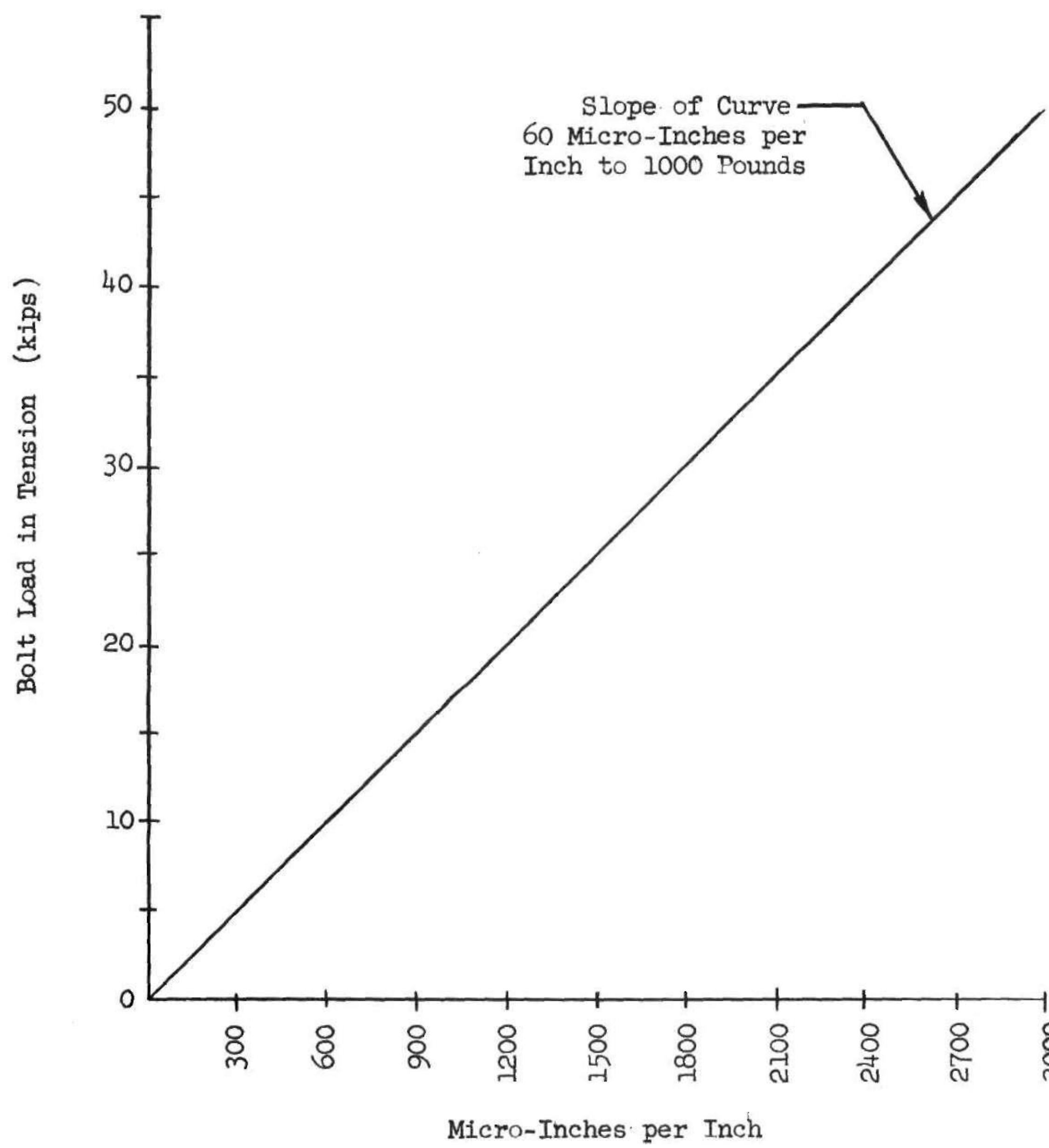


Fig. 9. Bolt Calibration Curve

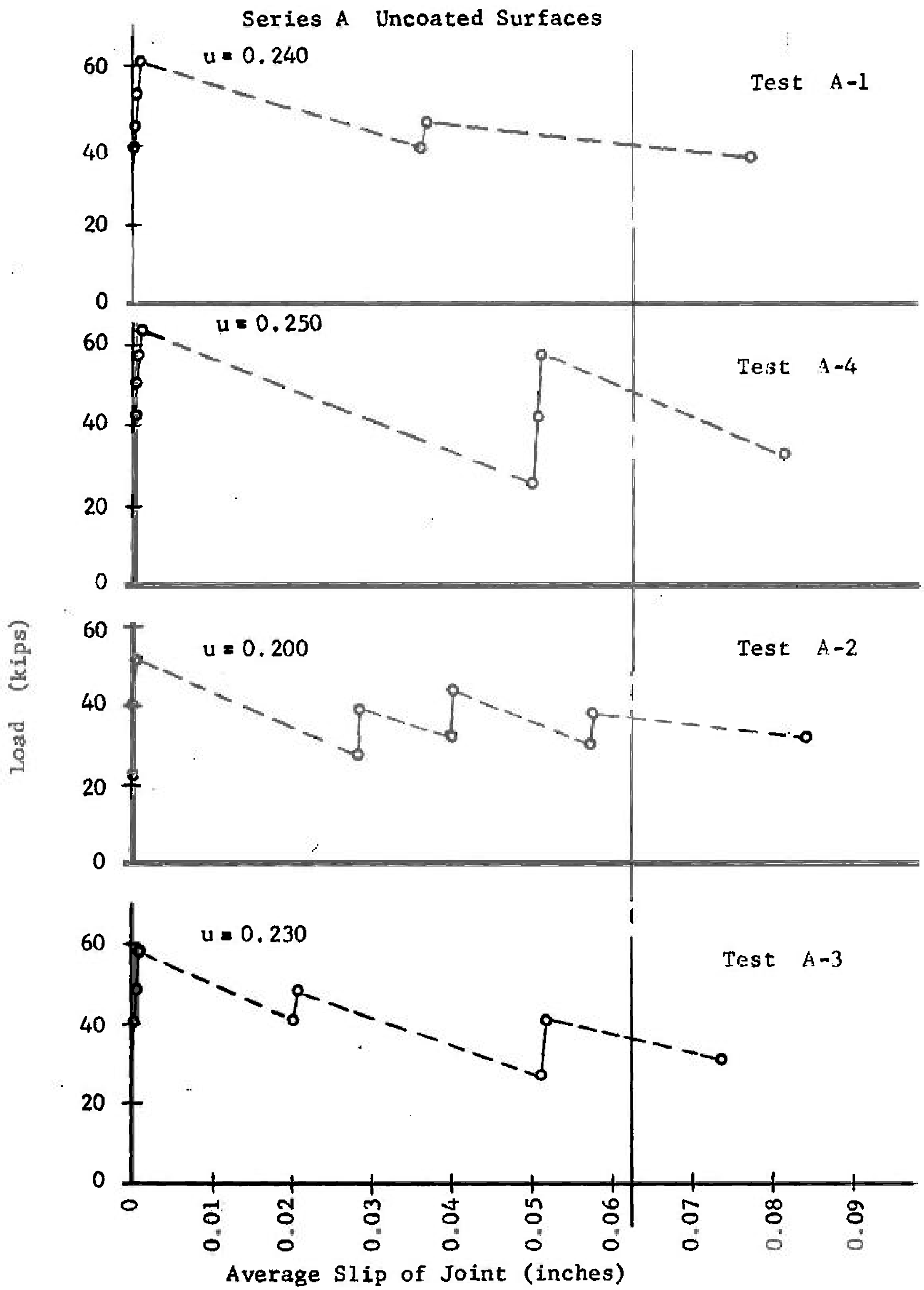
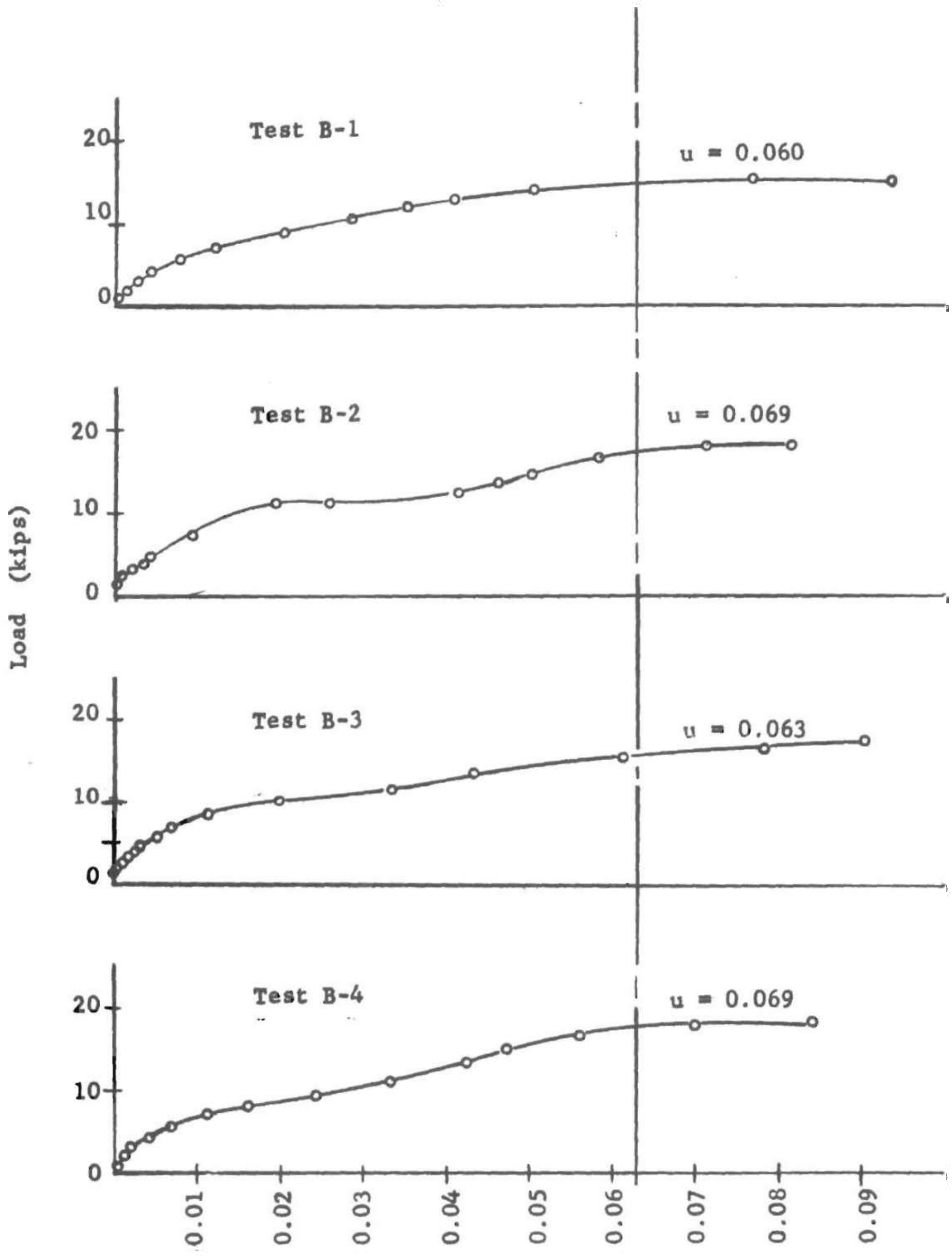


Fig. 10. Curves for Uncoated Surfaces

Series B TT-P-86a Type I Primer



Average Slip of Joint (inches)

Fig. 11. Curves for Dry TT-P-86a Type I Primer

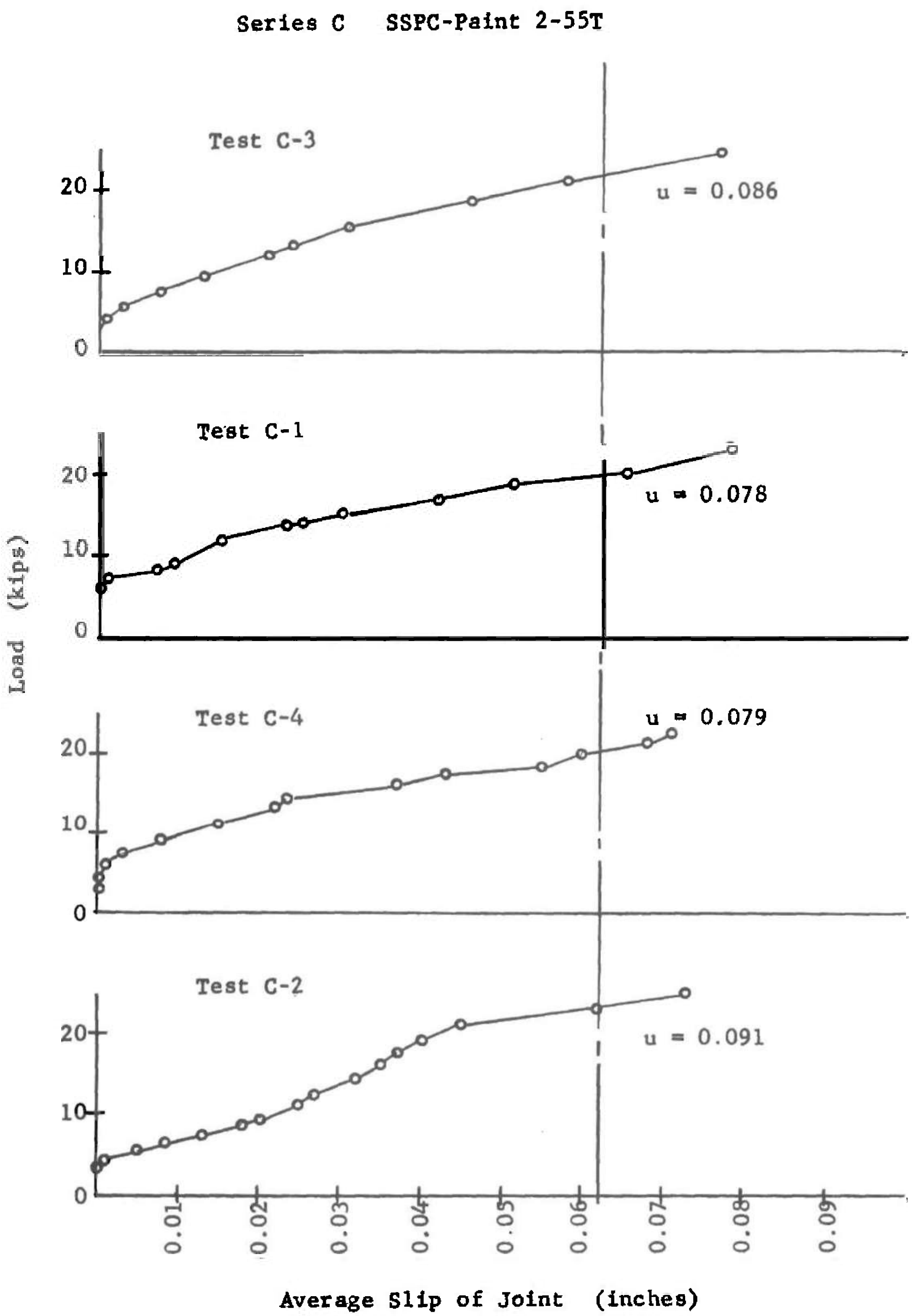


Fig. 12. Curves for Dry SSPC-Paint 2-55T

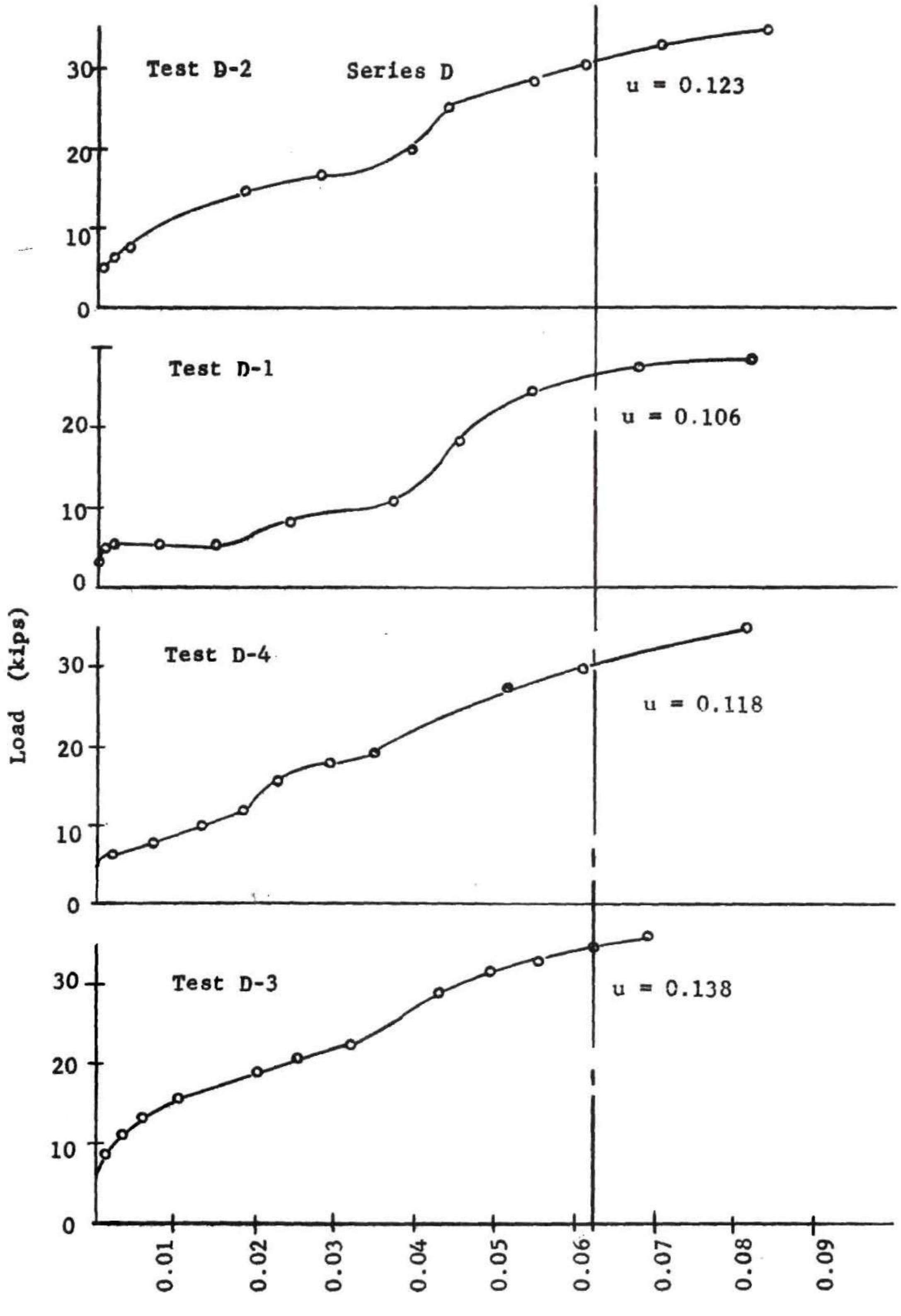


Fig. 13. Curves for Dry SSPC-Paint 11-55T

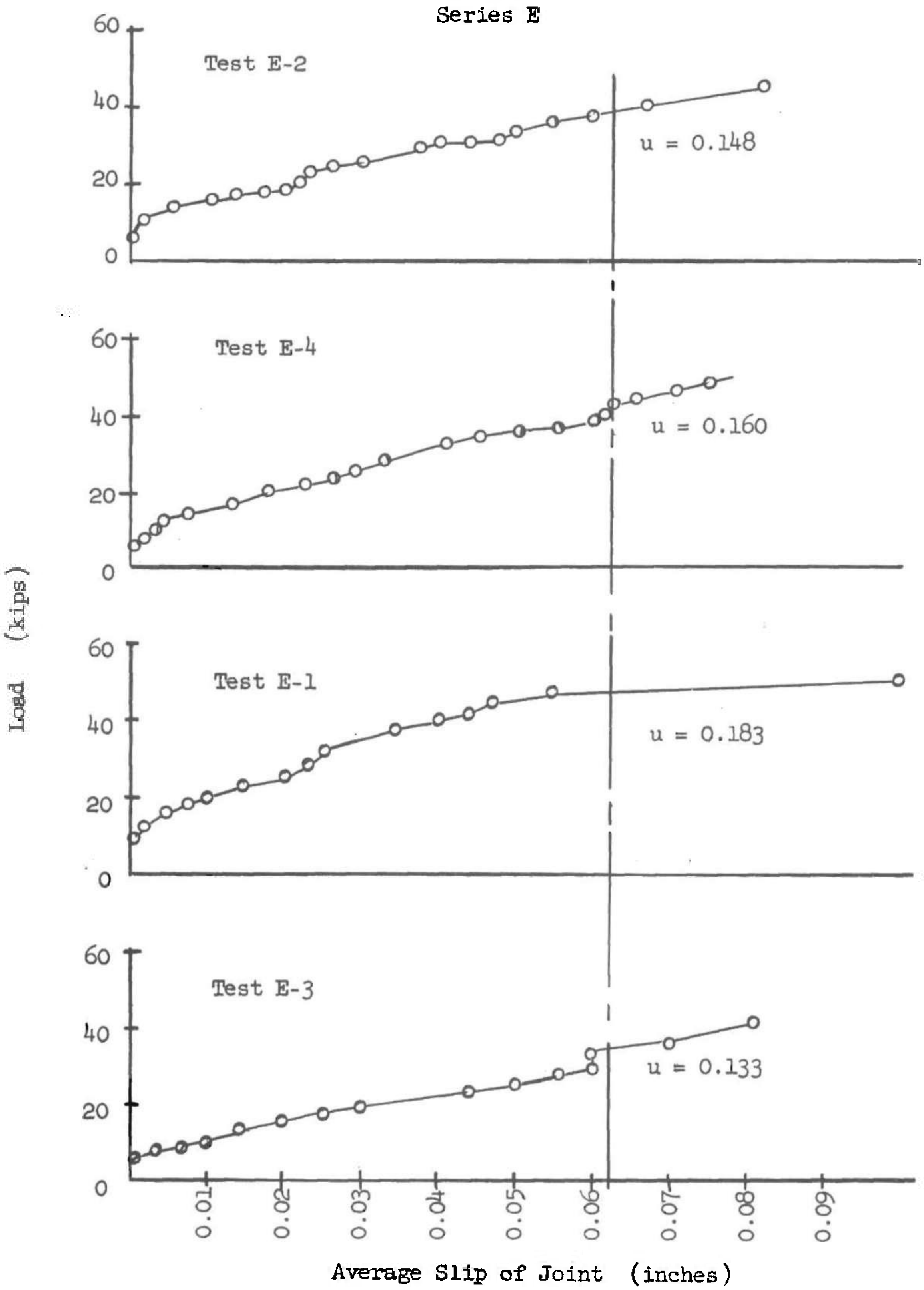


Fig. 14. Curves for Dry SSPC-Paint 13-55T

Series F TT-P-641b Type II

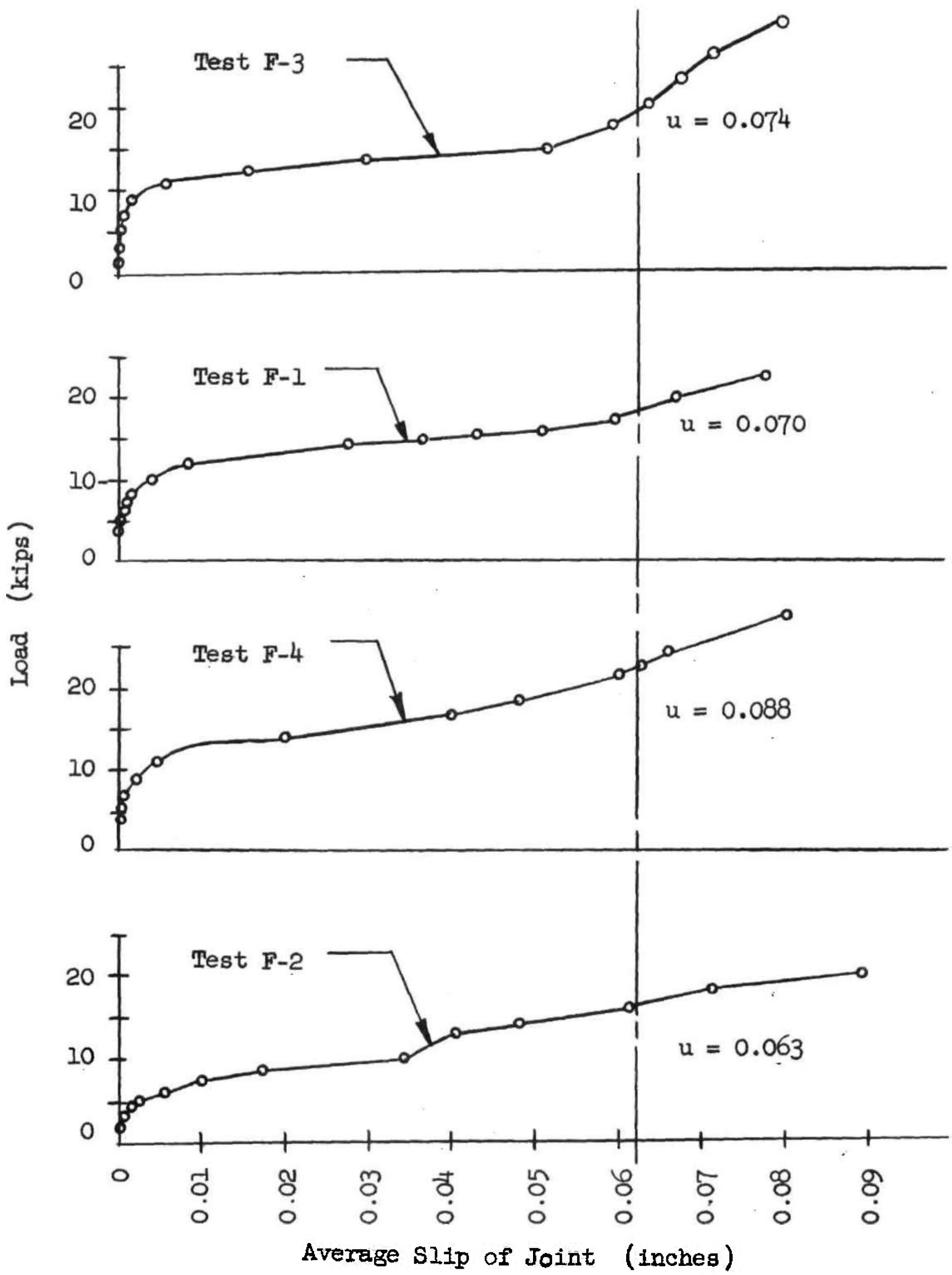


Fig. 15. Curves for Dry TT-P-641b Type II

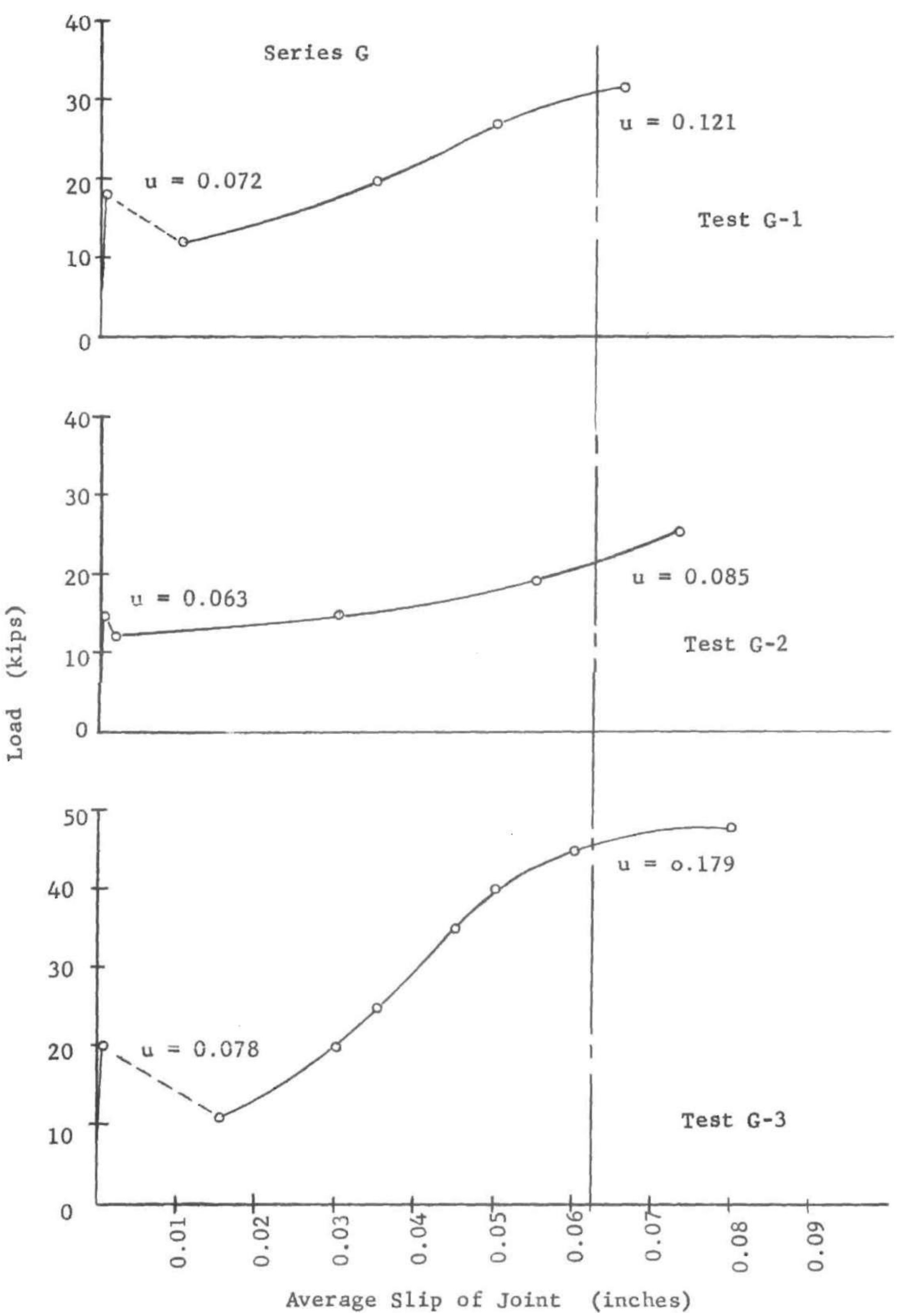


Fig. 16. **Curves for Nebula No. 1 Grease**

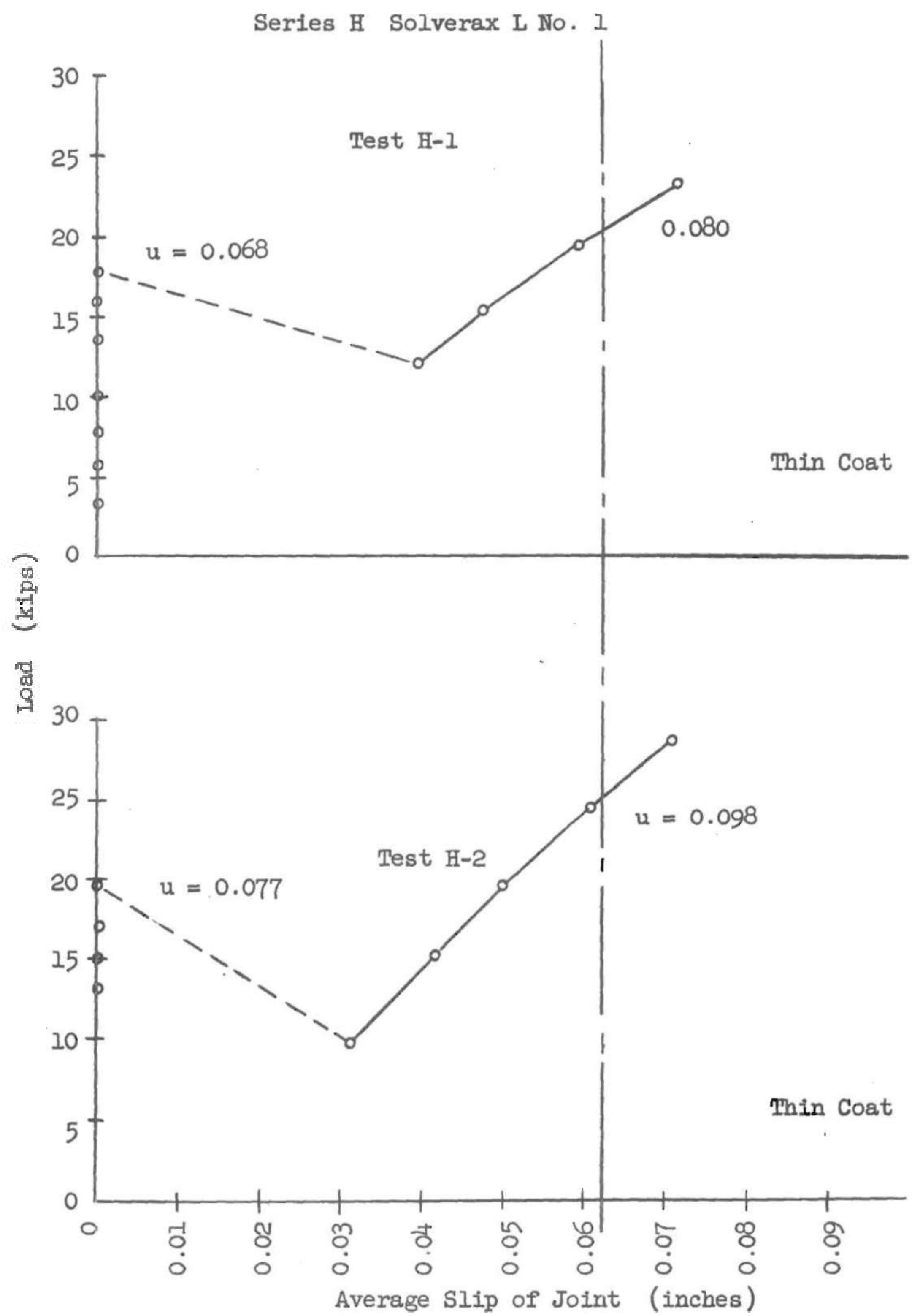


Fig. 17. Curves for Soverax L No. 1 Grease

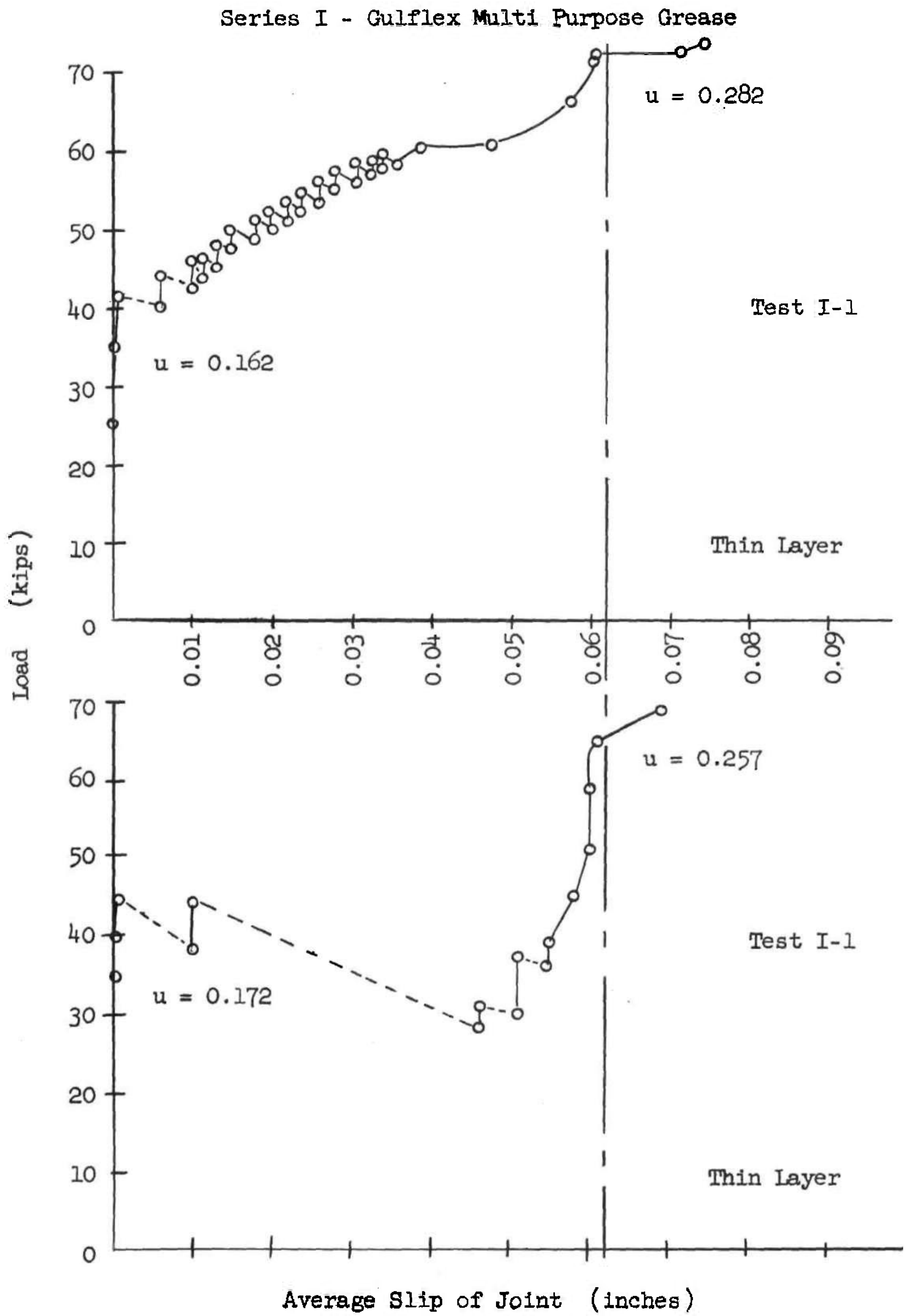


Fig. 18. Curves for Gulflex Multi Purpose Grease

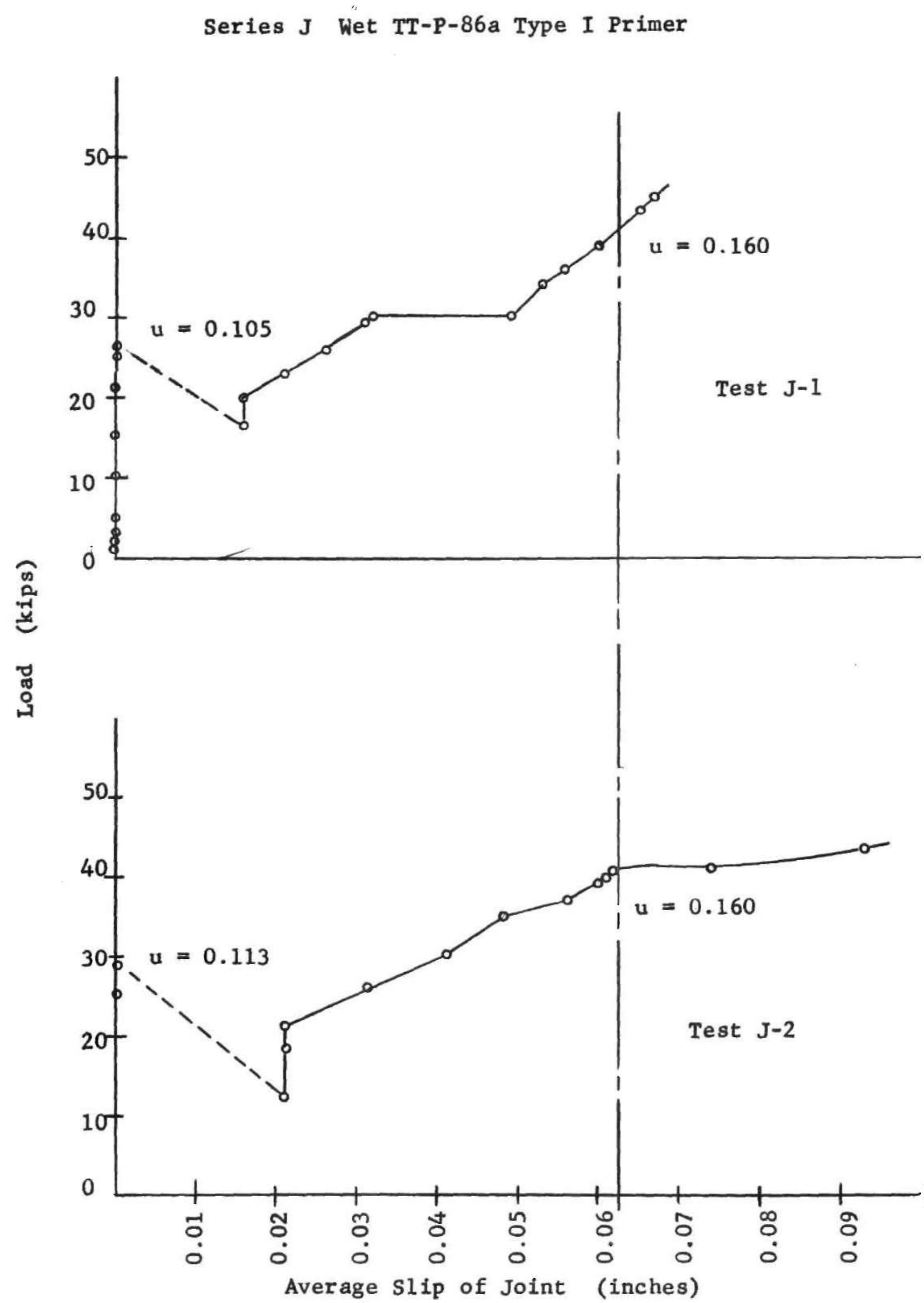


Fig. 19. Curves for Wet TT-P-86a Type I Primer

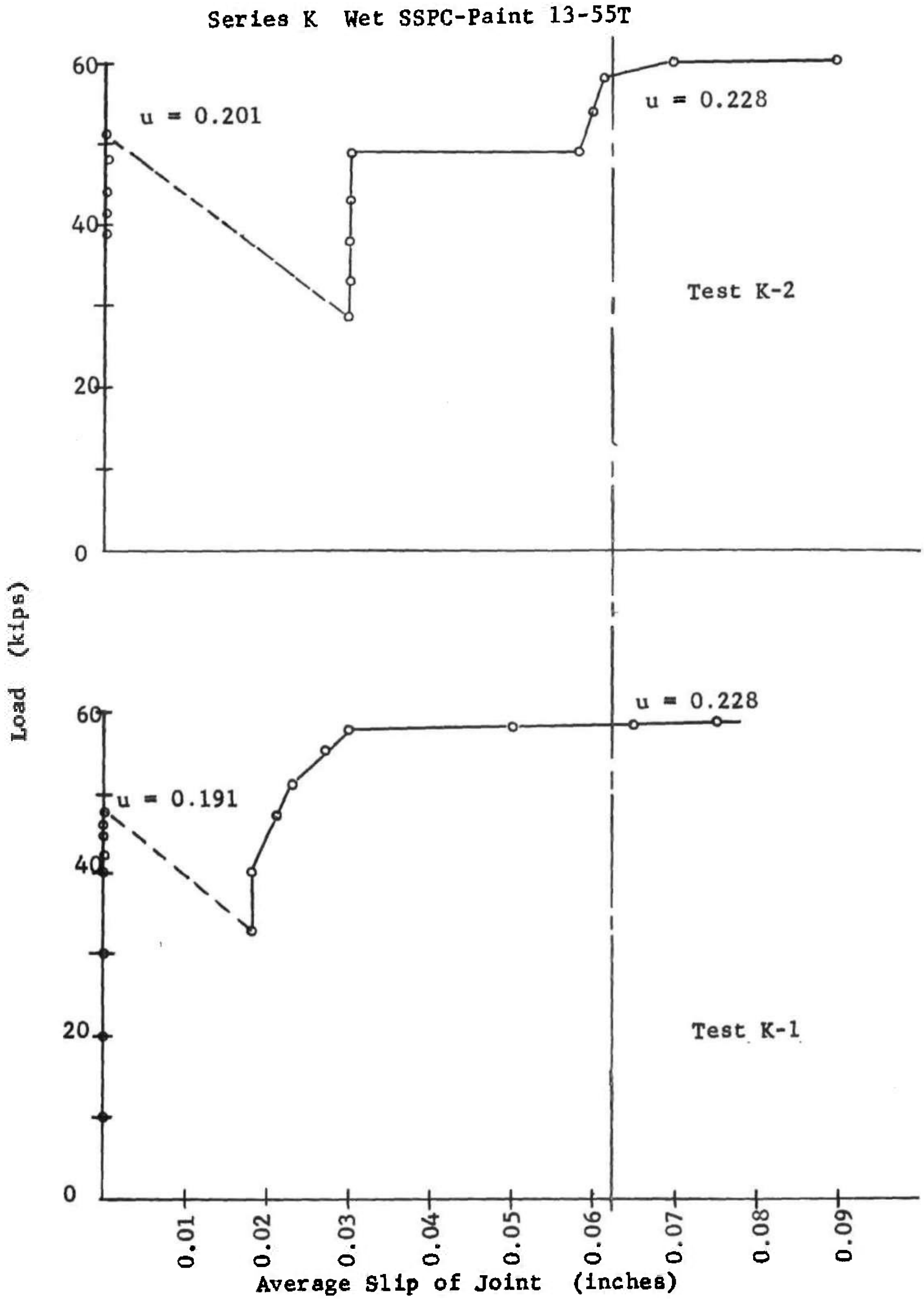


Fig. 20. Curves for Wet SSPC-Paint 13-55T

Series L Double Coat SSPC-Paint 13-55T

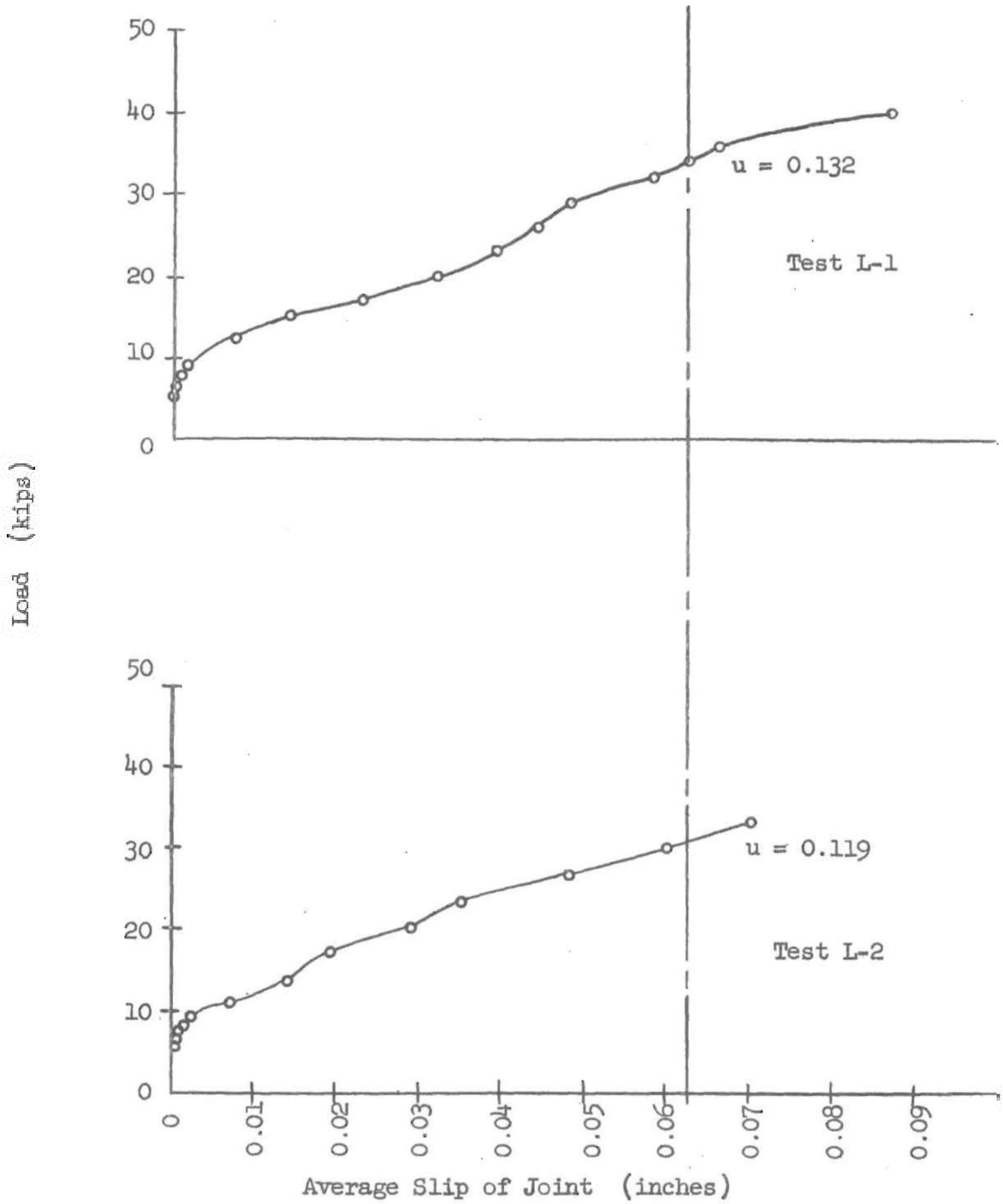


Fig. 21. Curves for Double Coating of SSPC-Paint 13-55T

Series L Spray Coat SSPC-Paint 13-55T

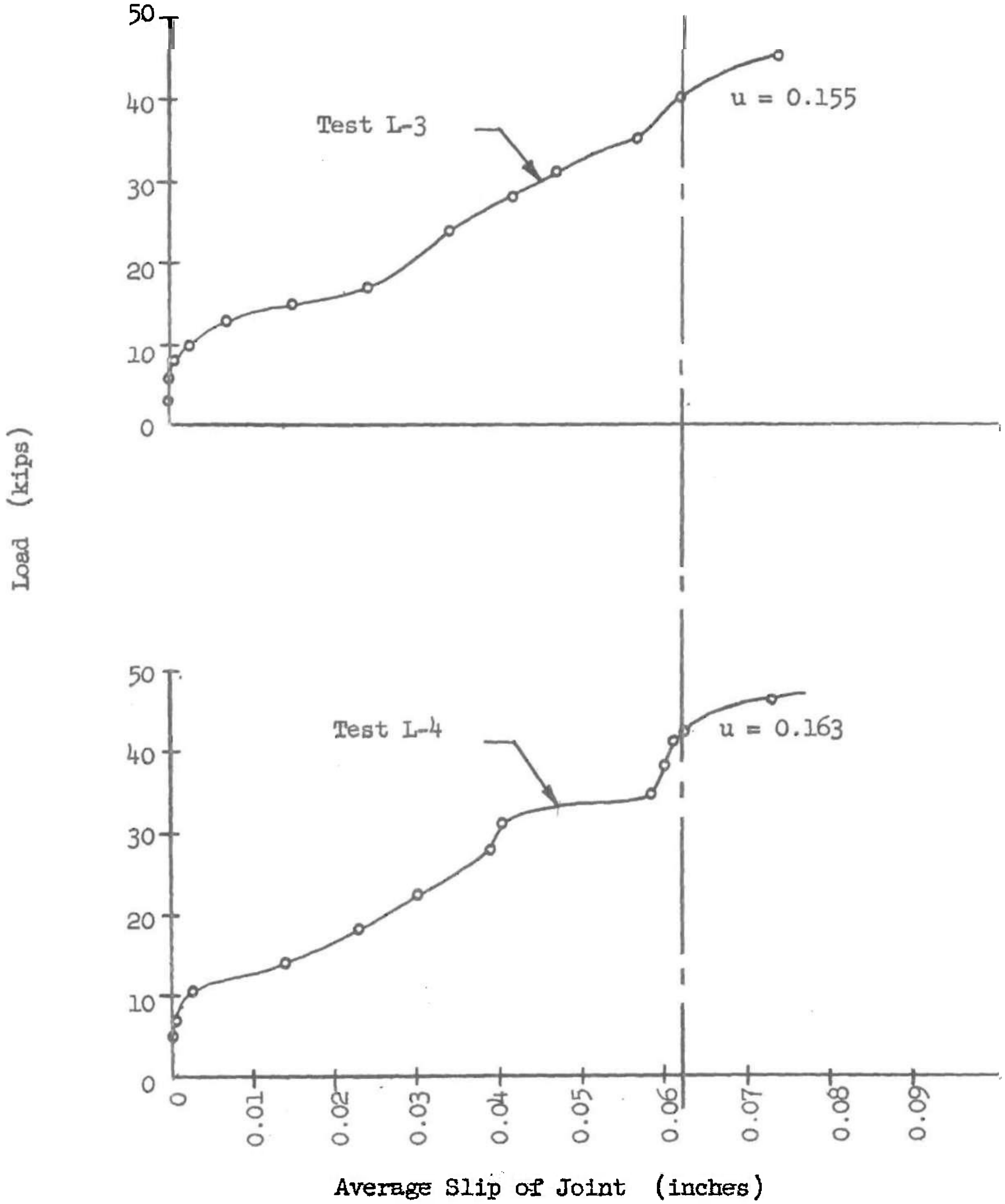


Fig. 22. Curves for Spray Coating of SSPC-Paint 13-55T

Series M Double Coat TT-P-86a Type I

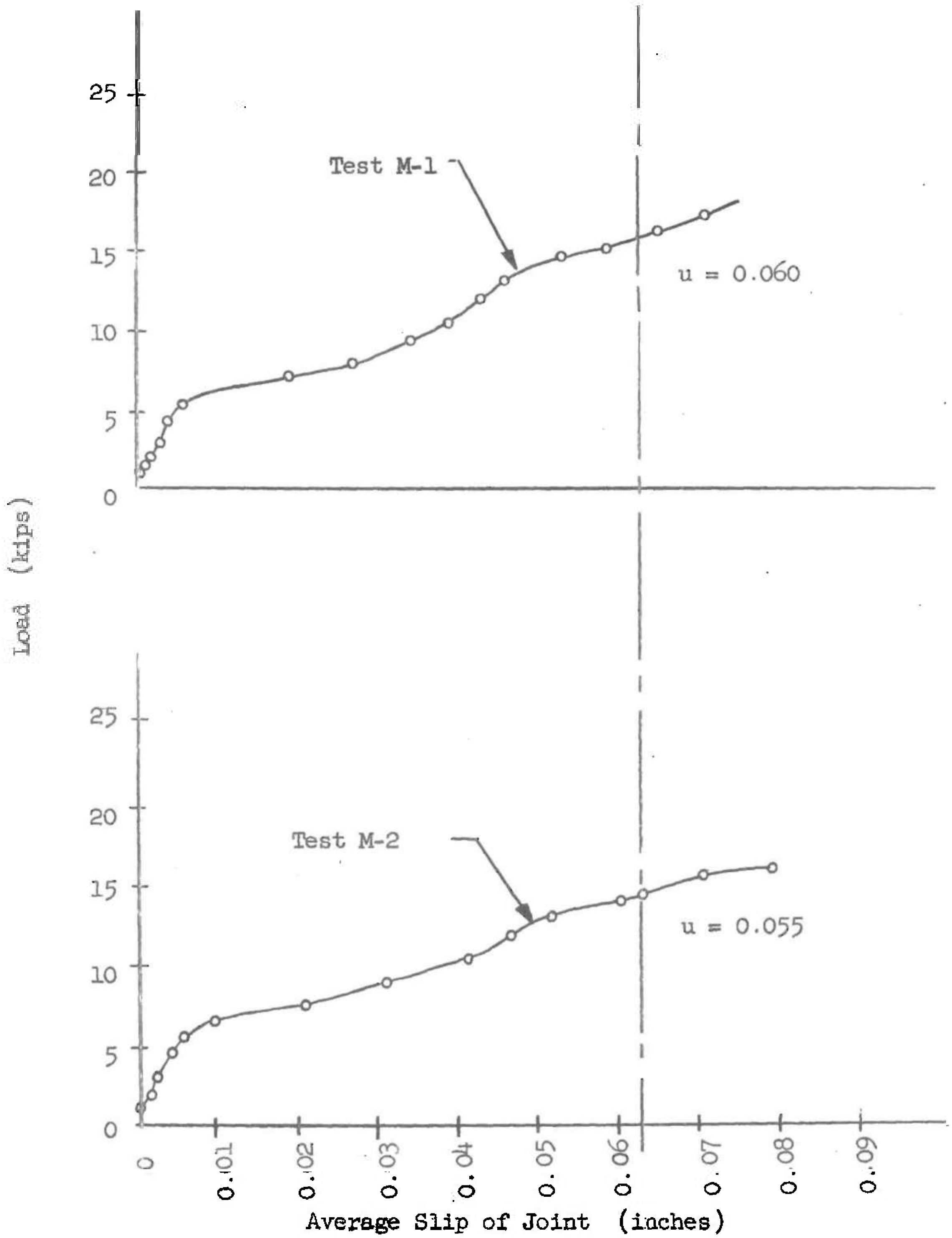


Fig.23. Curves for Double Coating of TT-P-86a Type I

Series M Spray Coat TT-P-86a Type I

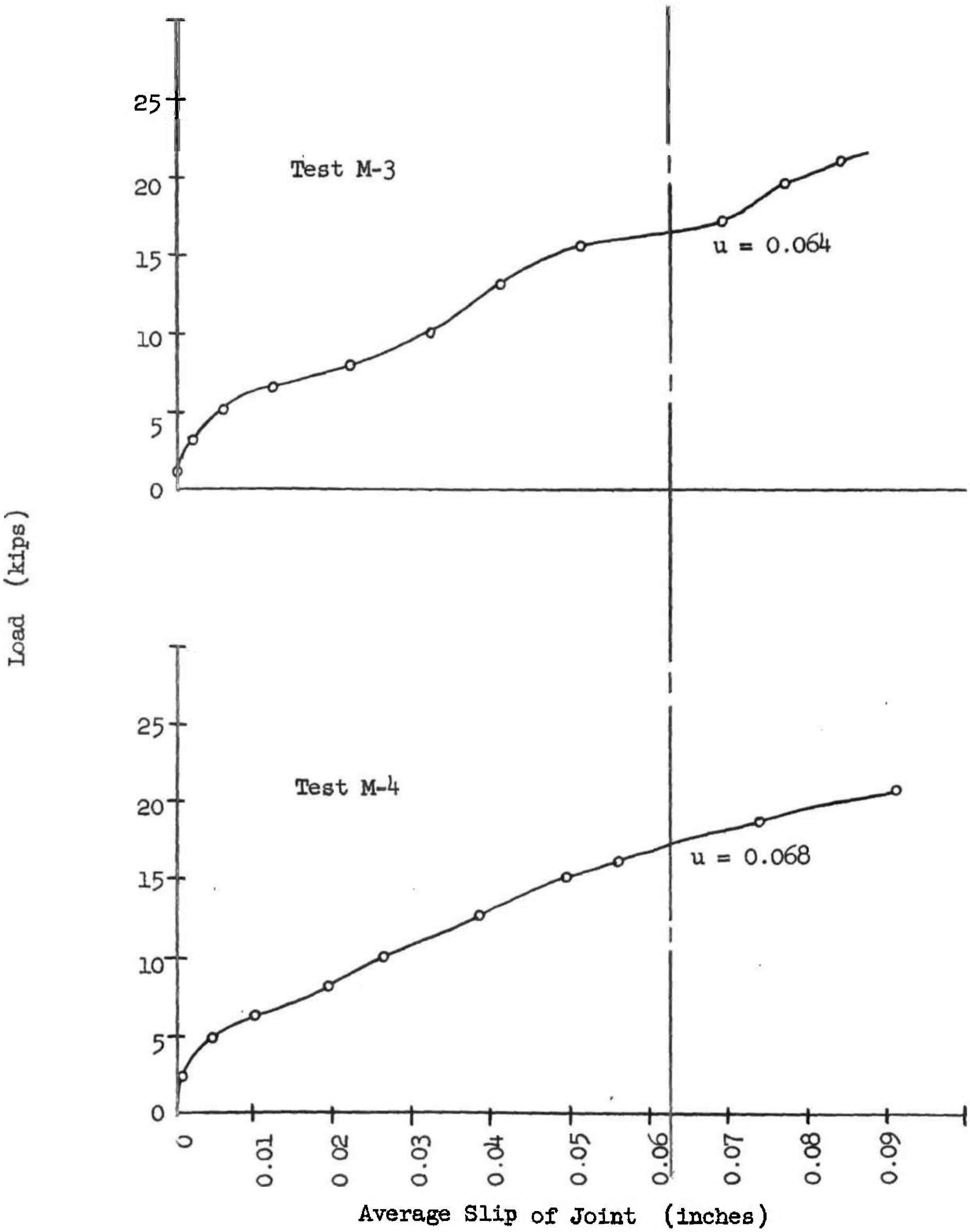


Fig. 24. Curves for Spray Coating of TT-P-86a Type I

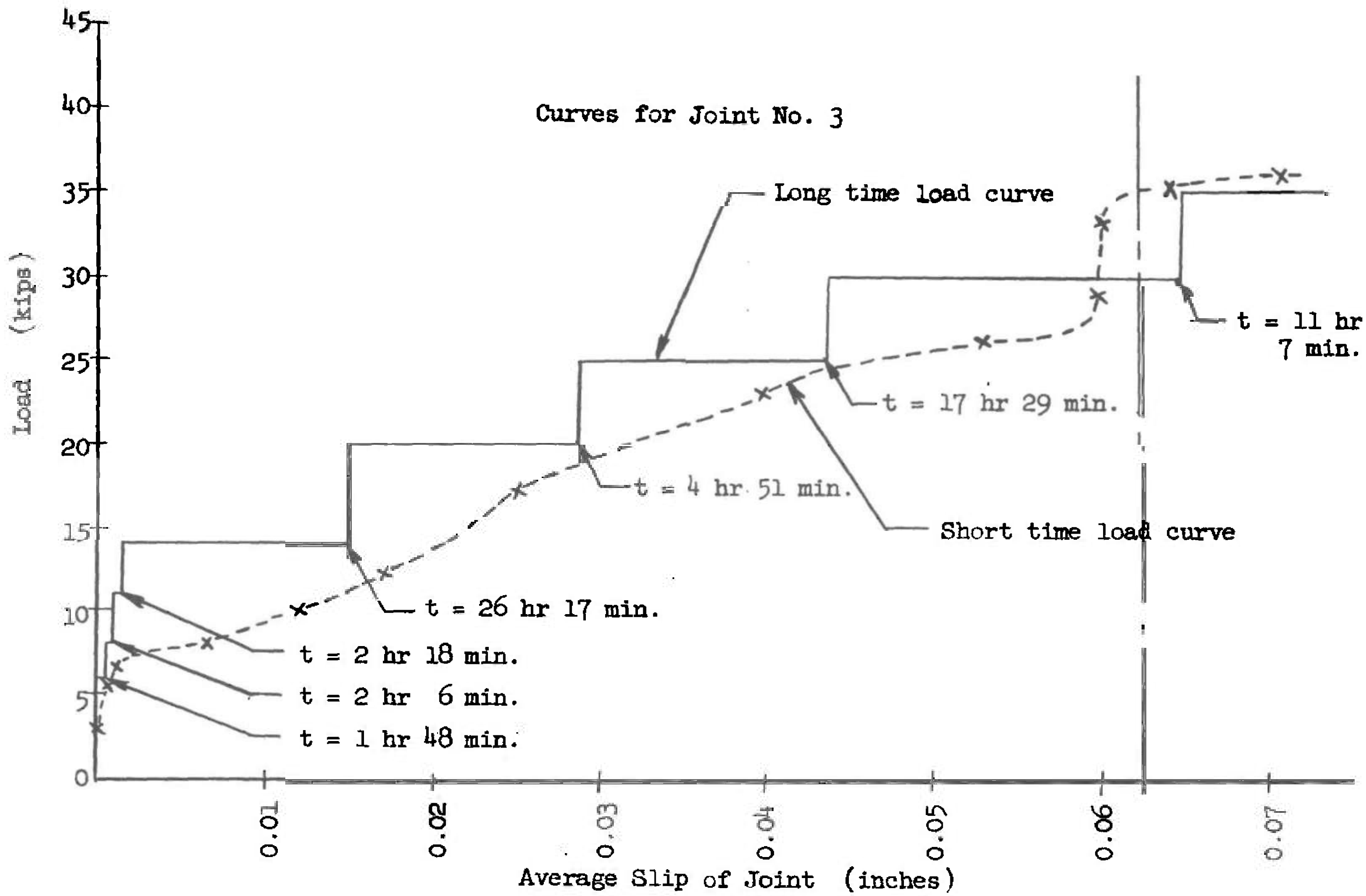


Fig. 25. Long vs Short Time Loading Test for SSPC - Paint 13-55T

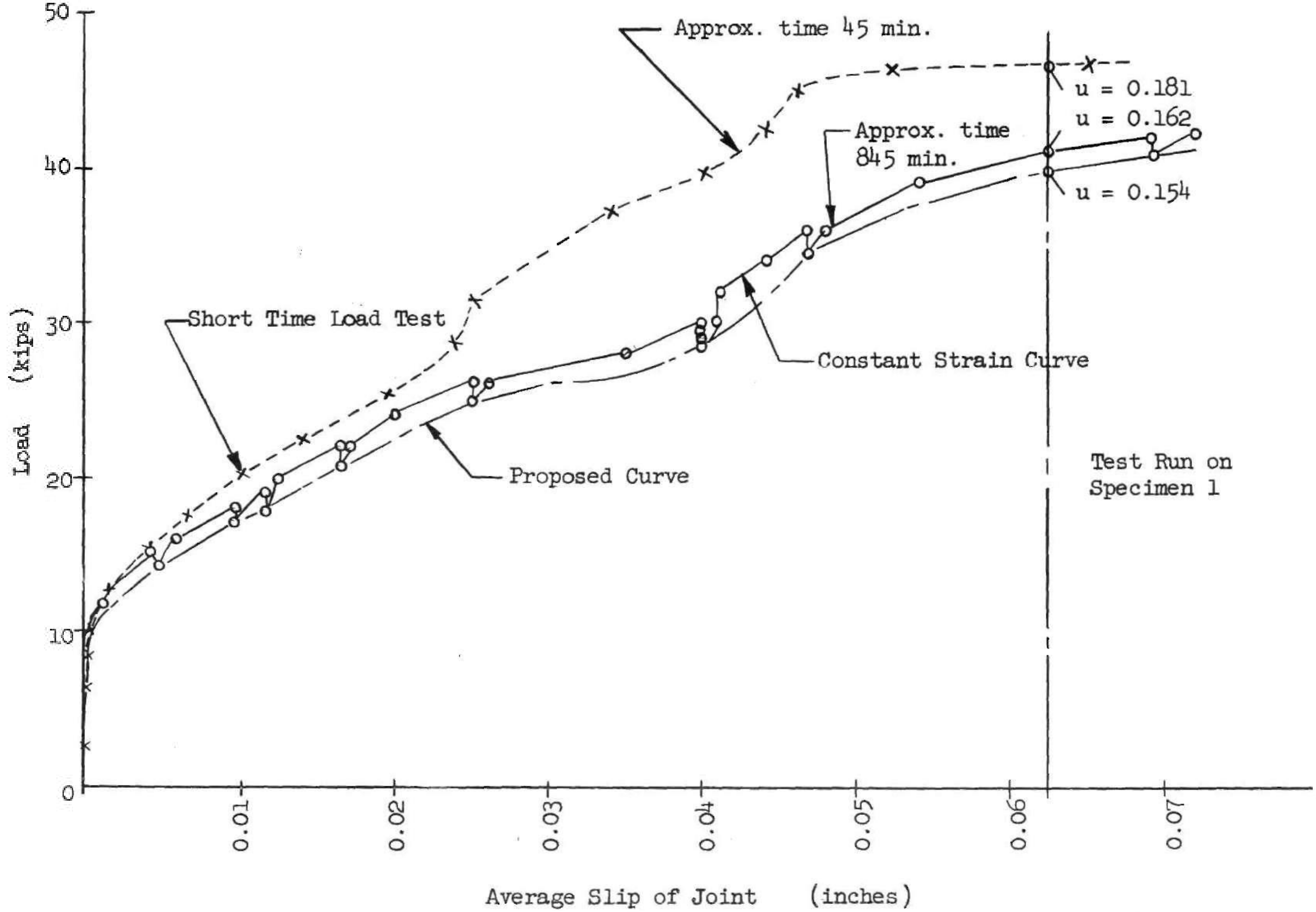


Fig. 26. Constant Strain Curve for SSPC - Paint 13-55T

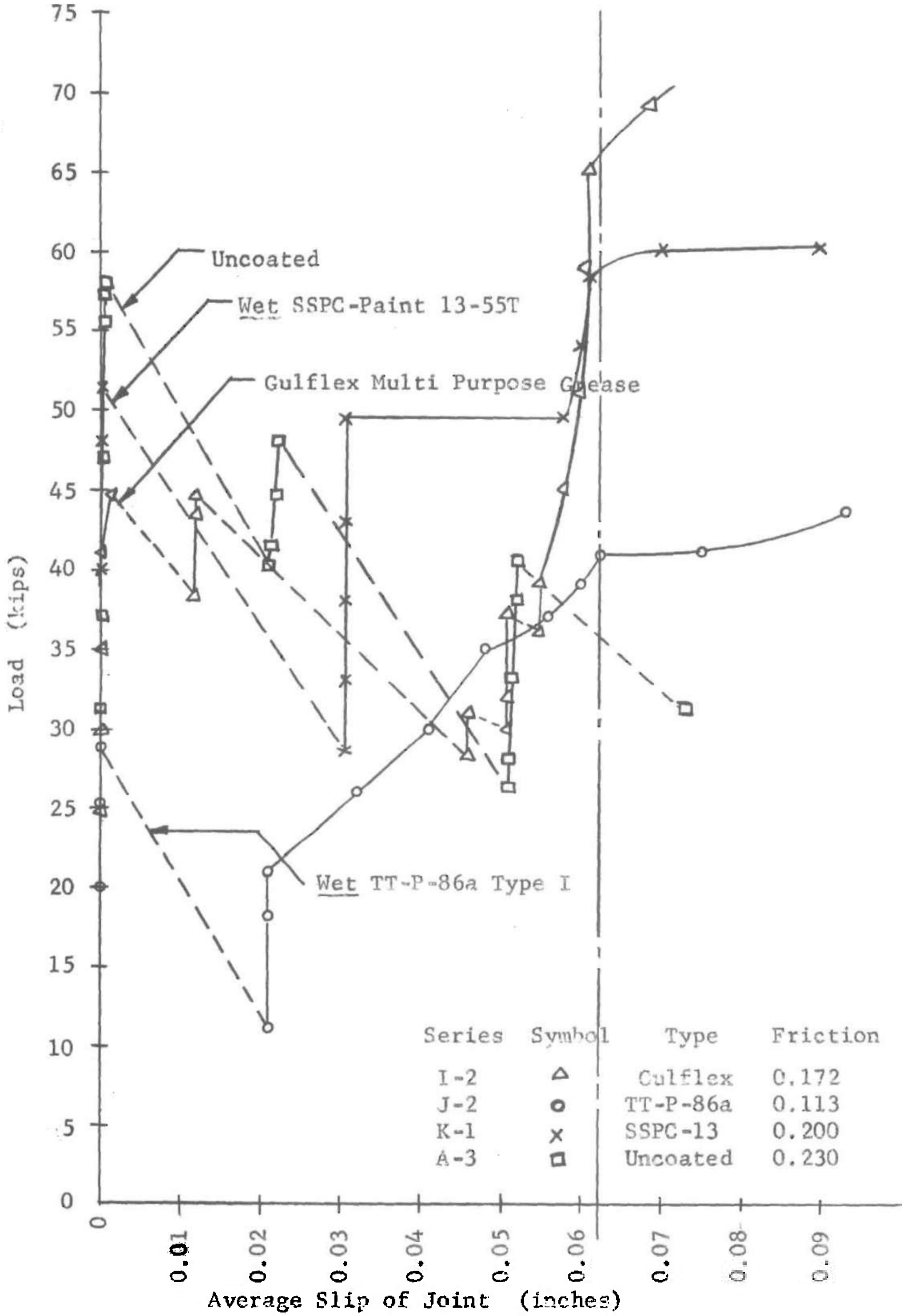


Fig. 27. Comparison of Slip Performances

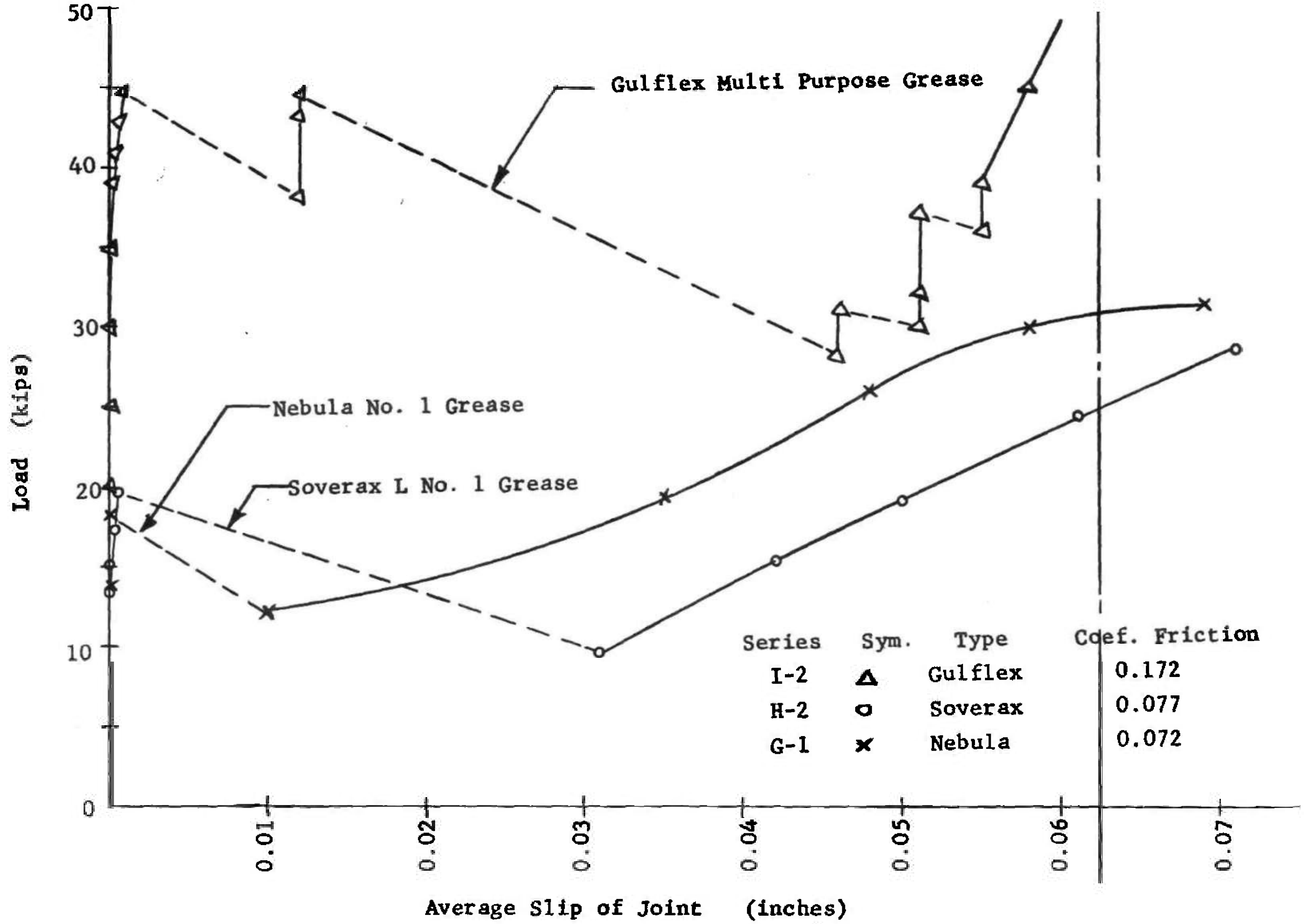


Fig. 28. Comparison of Grease Performances

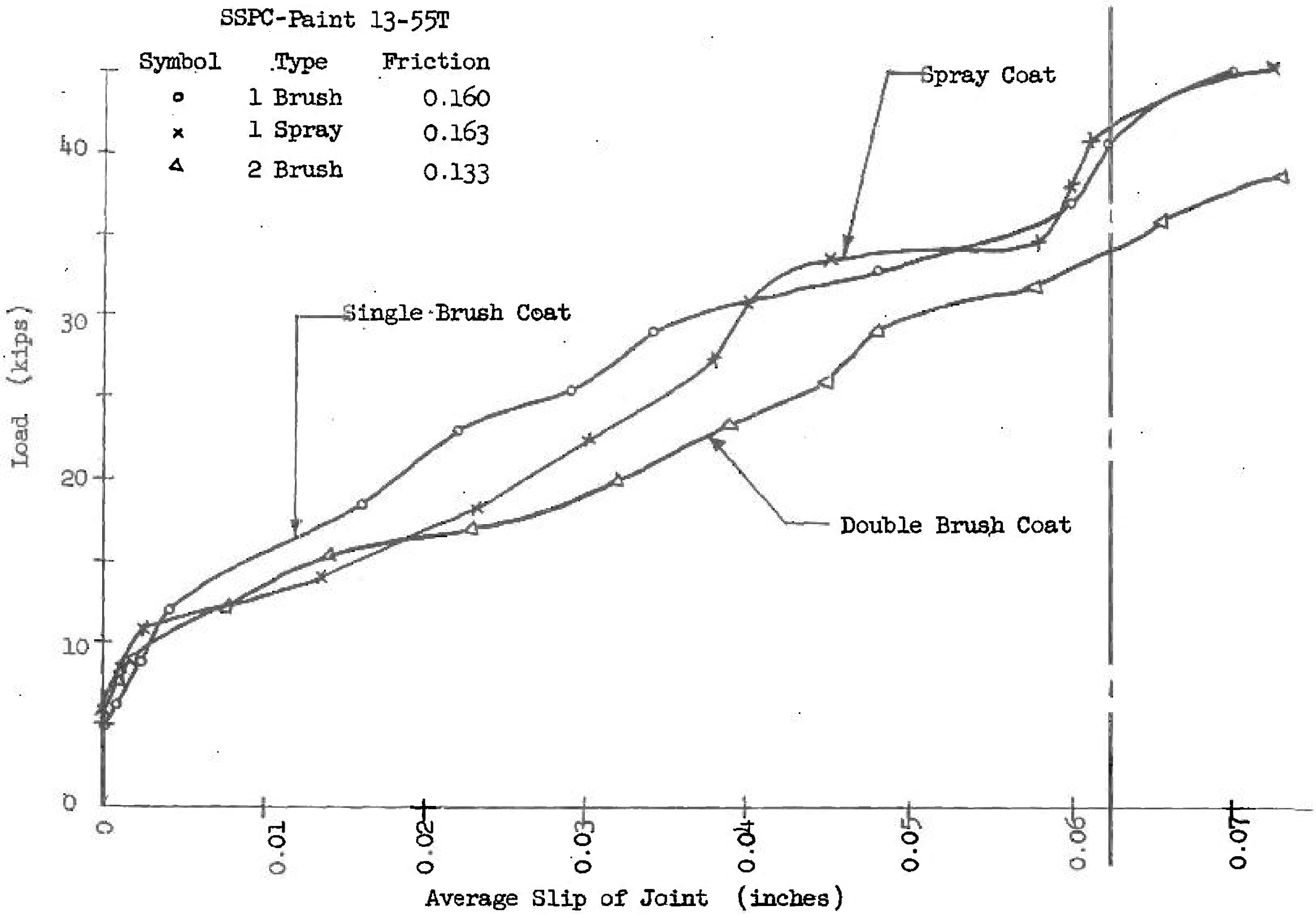


Fig. 29. Curves for Variations in Thickness of SSPC-Paint 13-55T

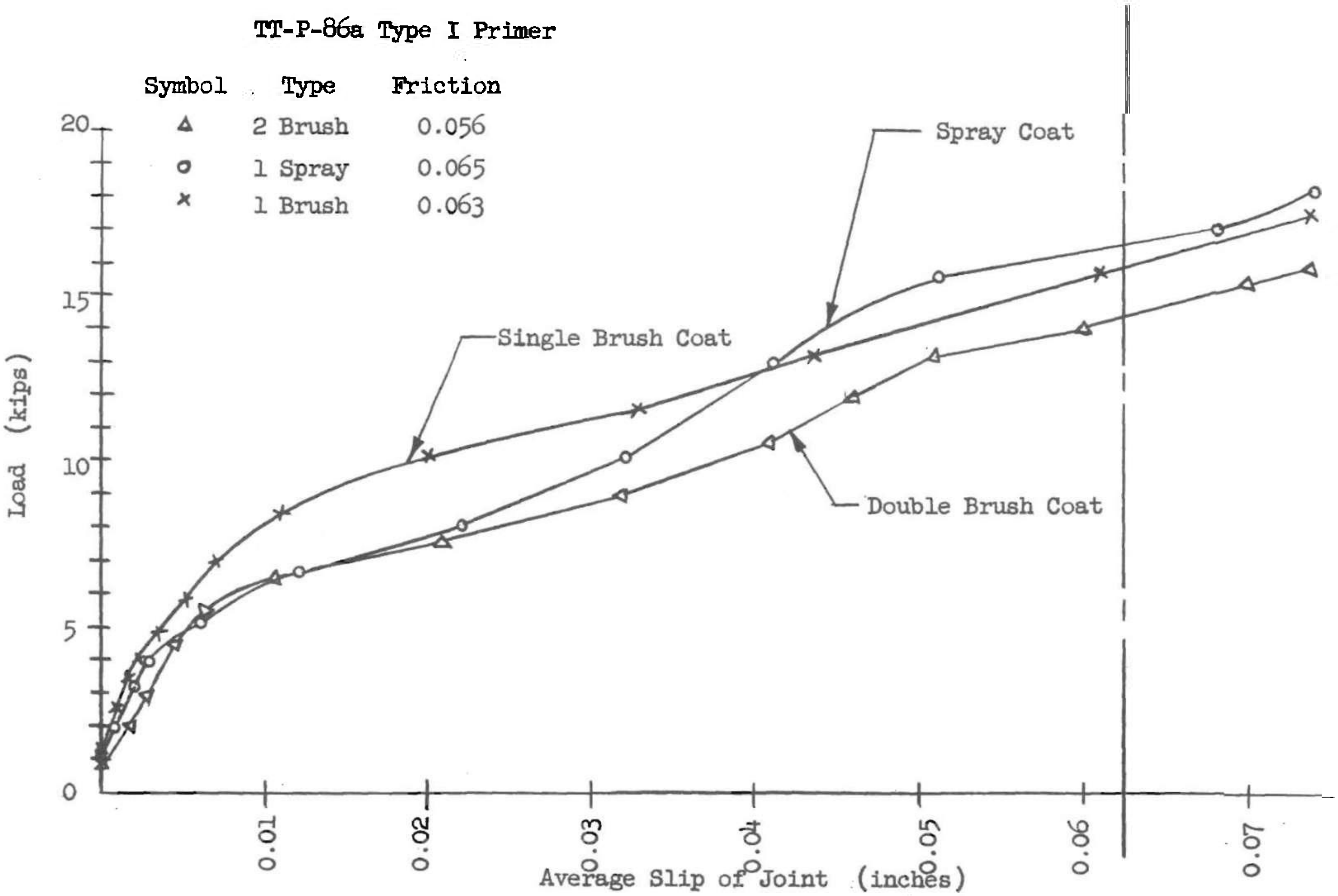


Fig. 30. Curve for Variations in Thickness of TT-P-86a Type I Primer

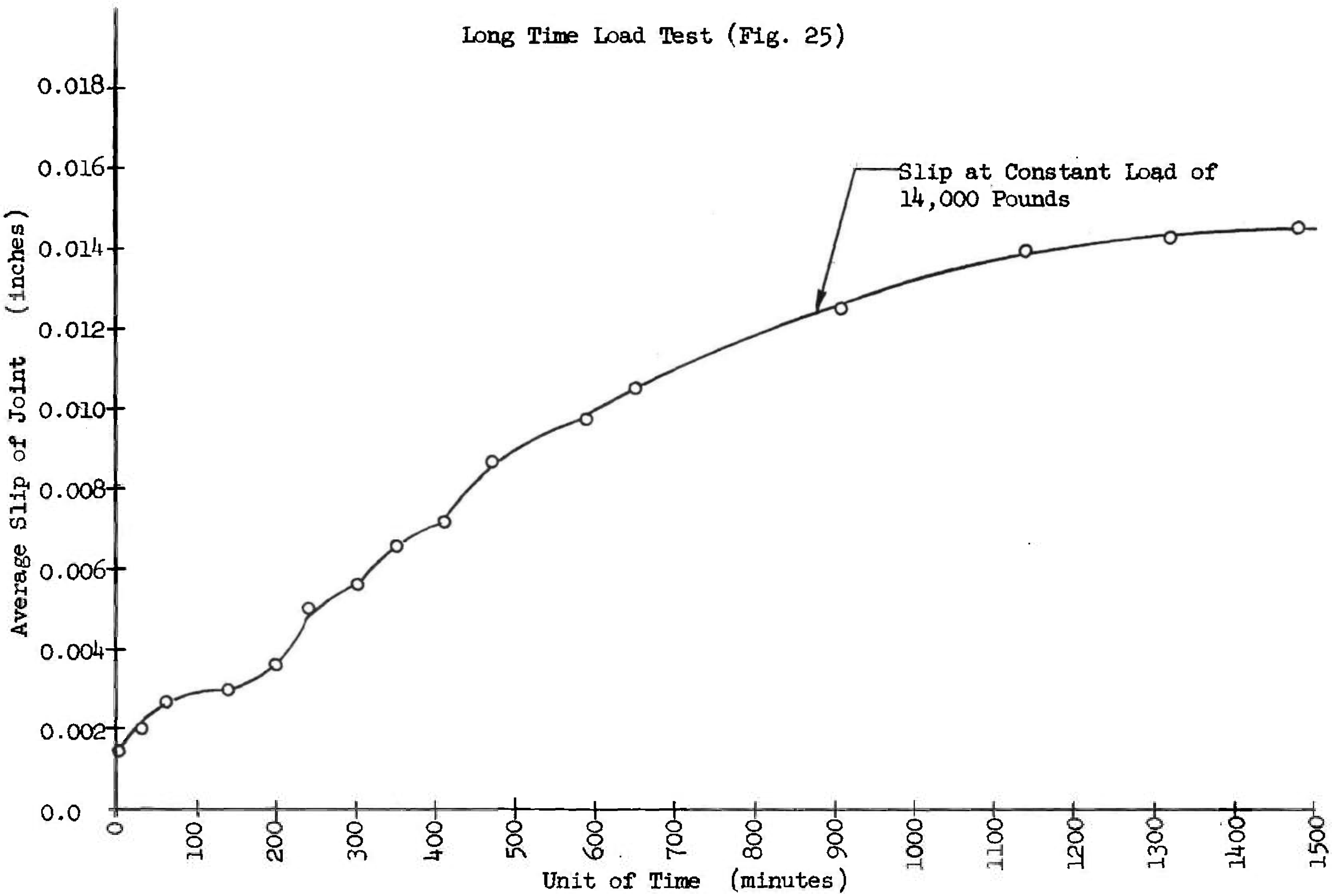


Fig. 31. Average Slip per Unit of Time at 14,000 Pound Load Level of Long Time Load Test

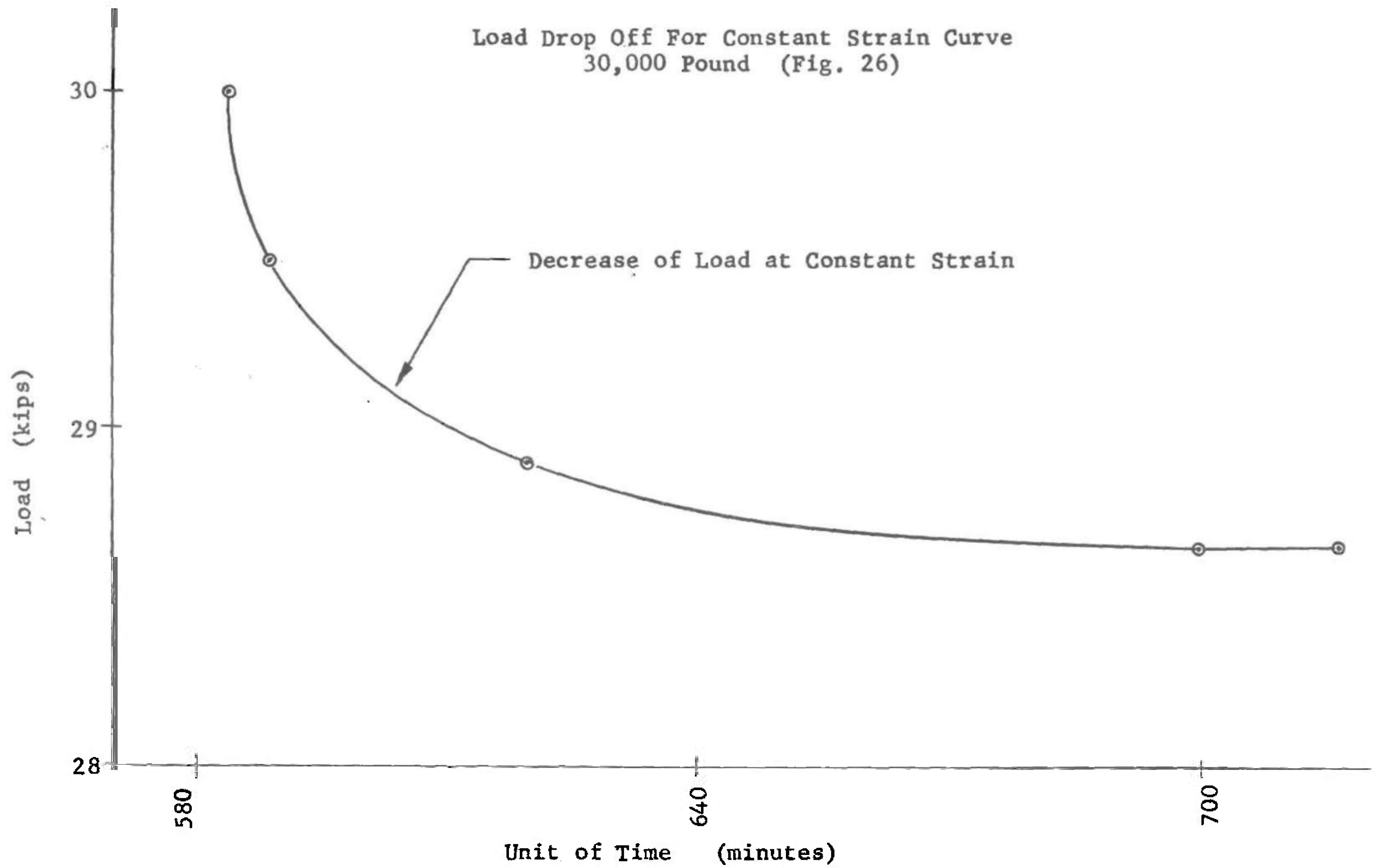


Fig. 32. Decrease of Load Per Unit of Time at 30,000 Pound Load Level of the Constant Strain Test

Formula used to calculate the coefficient of friction

$F = uN$ Where F = the force applied by the testing machine
u = the coefficient of friction
N = the normal force - the total clamping force of the high strength bolts

EXAMPLE SERIES A EXAMPLE

Test A - 4

F = 63,900 lbs. (major slip load applied by the testing machine)

u = - (coefficient of friction at the major slip load)

N = 253.9 lbs. (summation of the last bolt tension readings before the major slip occurred X 2)

$u = 63{,}900/253.9$

$u = 0.250$

EXAMPLE SERIES A EXAMPLE

Test B - 1

F = 14,950 lbs. (major slip applied by the testing machine)

u = - (coefficient of friction at the slip failure load)

N = 253.0 (summation of the last bolt tension readings before the slip failure load X 2)

$u = 14{,}950/253.0$

$u = 0.060$

Fig. 33. Calculation of the Coefficient of Friction

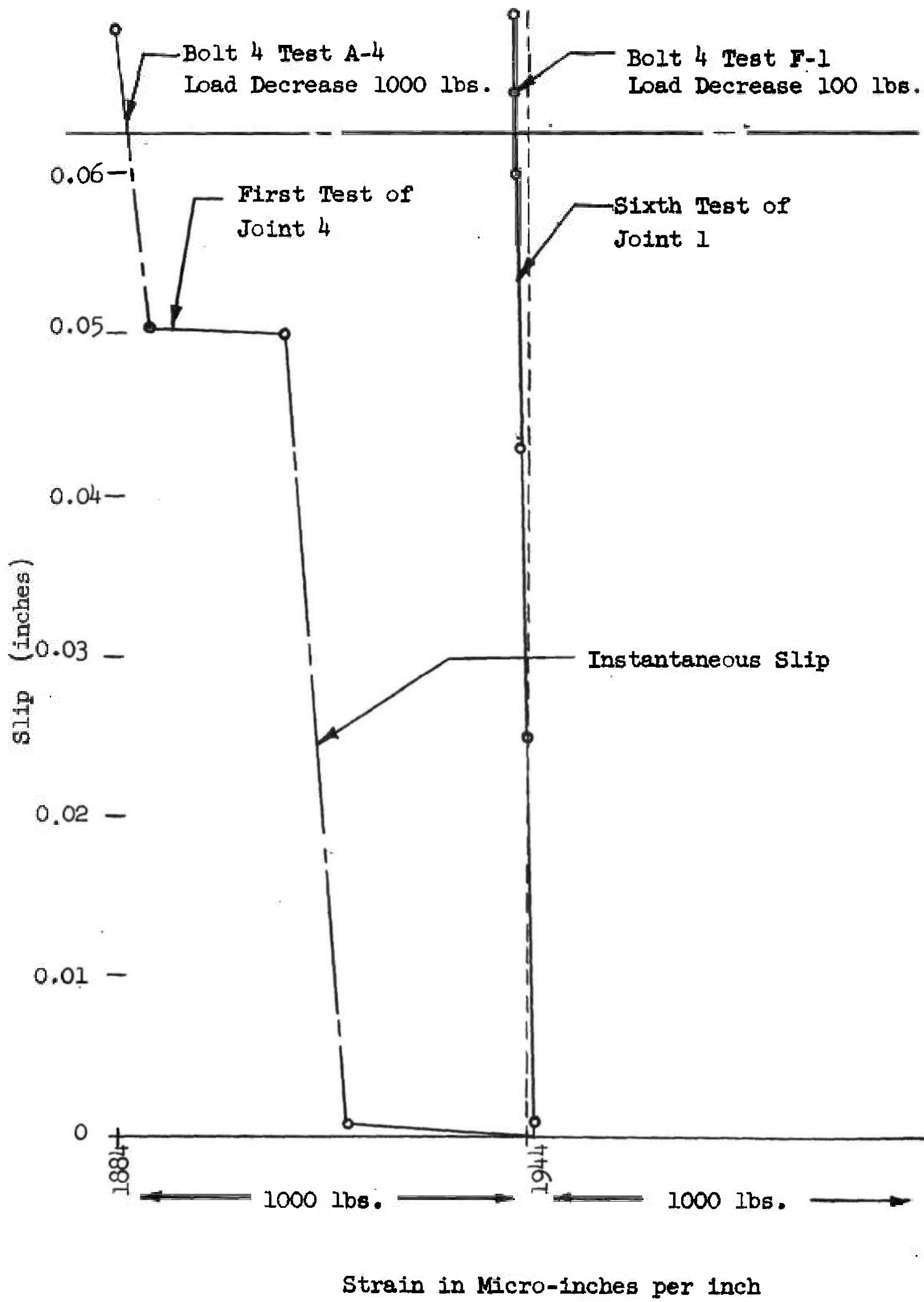


Fig. 34. Bolt Load Variation Curve

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