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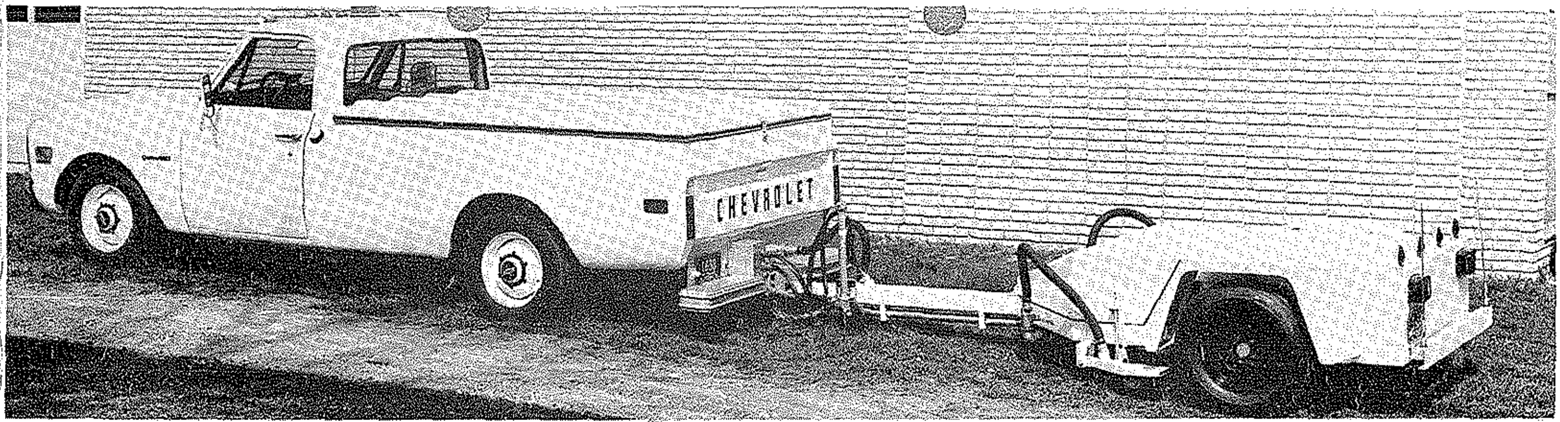

PC Concrete Texturing

MARCH, 1975

DEPARTMENT OF TRANSPORTATION

Division of Highways

Office of Materials

Special Investigation Section

Progress Report R-246

PC CONCRETE TEXTURING

March, 1975

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INTRODUCTION:

Skid resistance is a major concern of the safety engineer since wet pavement conditions are present for approximately 18% of the total accidents in Iowa according to studies by the Traffic and Safety Department. Many of these accidents may be influenced by the low skid resistant quality of the pavement. The size, shape, type, and arrangement of the concrete's particles interrelate with each other in a complex manner to give us frictional resistance.

It is interesting to review two of the types of vehicular skidding. One type of skidding is when the wheels of a vehicle are locked by braking and cease to rotate, but the vehicle continues to move. Another type is on horizontal curves when the vehicle moves at an angle to the intended path. Skid resistance is the force at the tire-pavement interface which tends to keep the vehicle from sliding. The measurement of this frictional resistance is called the coefficient of kinetic friction.

The Texas Highway Department, in Report No. 45-4, considers skid resistance as being composed of two terms:

1. An adhesion term between the tire and pavement which is defined by the molecular forces.
2. A deformation term between the tire and pavement defined by the energy absorption in the rubber resulting from contact with the surface projections, also referred to as hysteresis.

Skid resistance is highly reduced on wet pavements when compared to the skid resistance of a dry pavement. This phenomena is largely due to a drastic reduction in the adhesion term since the water acts as a lubricant between the surfaces.

The importance of determining skid resistance on driving surfaces is becoming more apparent every day. High priority to safety in the skid resistance area is given in the National Emphasis Program where it is stated that:

> "Each state should inventory the Federal-aid and State Highway systems for skid resistance. A program should be prepared which establishes priorities for correcting locations with a disproportionately high percentage of skidding accidents and for pavements where the coefficient of friction is less than the recommended minimum skid numbers included in Highway Safety Program Manual Volume 12. By December 31, 1975, a statewide inventory for skid resistance should be established and in operation. This inventory should encompass all paved roads with a posted speed limit of 40 MPH or higher".

Iowa first took steps in 1965 to set up a skid resistance program and built a test unit in accordance with ASTM Standard E274-70. Iowa also has a test unit built by the K.J. Law Engineers Inc. of Detroit, Michigan, in conformance with ASTM.

The braking force trailer is the type of device which is used by the Division of Highways, and has become the most popular method in the United States. The apparatus consists of a two-wheeled trailer and a towing vehicle which carries the recording instruments and a water tank. Water is sprayed under the test wheel, the brake is applied to the test wheel, a constant towing speed is maintained, and the skid induced forces acting in the plane of the test wheel are measured. Knowing the vertical load and the frictional force developed, the resulting skid number can be calculated.

The Division of Highways has also established a priority listing for conducting skid tests on pavement sections, taking into account the traffic volume, the length of time since last tests were made, and the skid values obtained in last tests. Assuming that a high traffic road is more susceptible to wear and polish than a lesser traveled road, we would retest the high traffic road after a shorter time interval than the low traffic road.

If a pavement section is suspected of being slippery, field personnel review the section taking into account pavement geometry and accident history at the location. If corrective action is in order, it may take the form of resurfacing, signing, pavement burning, etc. If the pavement surface has been altered, it is again scheduled for testing.

Therefore, Iowa currently has a program for conducting skid resistance tests on the Interstate, Primary and Secondary Road Systems with a posted speed limit of 40 miles per hour or more. This program will aid in the evaluation of pavement materials and the determination of the effectiveness of maintenance practices to increase skid resistance.

Due to the importance of skid resistance on highway safety various methods have been used to increase this quality of the pavement. Texturing is one concept which merits consideration as a method of increasing skid resistance on portland cement concrete. A desirable surface has a high coefficient of kinetic friction between the tire and pavement and must be able to retain high coefficients in spite of the effects of polishing and the environment. A pavement should also have a sufficient number of flow channels to provide rapid, efficient dissipation of water. This will delay the buildup of water pressure at the tire-pavement interface thereby minimizing the phenomenon known as hydroplaning.

PURPOSE:

The purpose of this investigation was to determine which method of texturing provides the best skid resistance properties on portland cement concrete pavement.

SCOPE:

Since skid resistance varies with pavement texture, several texturing methods were investigated. The project, FN-63-5(7)--21-86 in Tama County, contained ten test sections each utilizing a different texturing method of the plastic concrete. The texturing methods incorporated in this investigation were:

1. Two layer wetted burlap (one drag) longitudinal
2. Light longitudinal broom
3. Light longitudinal broom weighted
4. Light longitudinal broom followed by transverse steel comb

5. Transverse steel comb
6. Light transverse fiber broom
7. Transverse heavy nylon bristle broom
8. Single burlap (longitudinal)
9. Two sections of burlap (144 sq. ft.) spaced 12'
10. Single burlap drag 144 sq. ft. with 6" frayed end

PROCEDURE:

The portland cement concrete pavement was constructed between October 27, 1969 and November 7, 1969, by the Fred Carlson Company. The paving train consisted of a slip-form operation with specialized equipment used to obtain the texturing required. Due to cold weather the curing was by conventional curing methods overlayed with 6 inches of straw.

The Barton Corporation, now consolidated with the CMI Corporation, provided a machine to perform the texturing operations. The machine was the Bartcure 770 which, like the paving train, has an electronic - hydraulic guidance system. The steering system is sensed from a pre-set wire. The Bartcure 770 will perform texturing operations either longitudinally or transversely. Any combination of texturing or curing may be accomplished by one operator.

The combing operation produced grooves in the plastic concrete approximately 1/8 inch wide and varying in depth from 1/8 to 1/4 inch. Even though the steel comb incorporated equally spaced tines, the resulting grooves were randomly spaced due to the flexibility of the wires in the comparatively rigid plastic concrete. This random spacing reduces the tendency to develop the humming sounds that are generated on grooved pavements under a constant spacing. Photographs of the comb are shown in Figure 1.

MATERIALS:

The materials used in this investigation were sufficient quantities of cement, fine aggregate, and coarse aggregate for the paving of full depth, 24 foot pavement, with a total project length of 1.556 miles. The fine aggregate was a natural sand and the coarse aggregate was dolomitic limestone. The concrete mix conformed to the 1964 Standard Specifications for a C-3 Mix.

Detailed test results on the fine and coarse aggregates as well as mix design information are given in Appendix A.

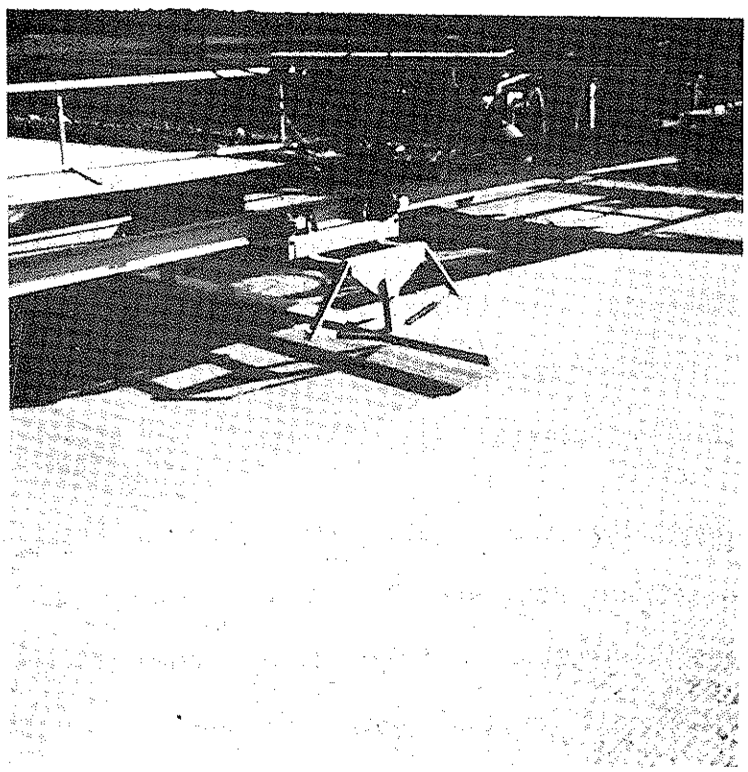
INTERPRETATION OF RESULTS:

Texture and Texture Depth

As stated earlier, construction processes, pavement materials, and design all affect the skid resistant properties of pavement surfaces. Since these have a direct affect on skid resistance, they should be examined to determine if the resulting pavement surfaces provide and maintain adequate skid resistance. Test methods such as the sand patch and silicone putty method were used in an attempt to predict the skid resistance of pavement surfaces.

Two procedures for determining the average texture depth of a selected portion of pavement surface are given in the tests entitled

The Steel Tined Comb



Light Longitudinal Broom
Transverse Steel Comb Operation

Figure 1

"Method of Test for Determining the Texture Depth of Pavement Surface by Use of the Sand Patch Method" and "Measurement of Texture Depth by the Silicone Putty Method". Procedures for these tests are given in Appendix B.

Figure 5 in Appendix B shows the results of the sand patch tests and silicone putty tests for each of the ten test sections. The standard deviations for the silicone putty method were consistently lower than those for the sand patch method. Texture depths by the silicone putty method occasionally showed greater depths than by the sand patch method even though they were obtained four years afterwards. This is probably due to small undulations on the pavement surface which may have affected the silicone putty.

It would seem that the greater the texture depth the greater should be the skid number. In RRL Report No. 20 by B.E. Sabey, research in this area resulted in a rather large scatter of results. Two very broad conclusions were, that in order to restrict large speed gradients, the texture depth should be at least 0.025 inches and that if the texture depth is less than 0.010 inches large decreases in skid number are likely.

Research by Sabey seems to indicate that the coefficient of kinetic friction depends almost entirely upon the state of polish at low speeds. That is, the skid number seems to be dependent upon microtexture rather than the easily visible asperitic characteristics of a pavement. Then as speed increases the macrotexture tends to take on a more important role. The coarseness of texture affects the decrease in skid number with speed.

Our results seem to support Sabey's research that macro-texture takes on an increasingly important role in skid resistance as speed increases. This is supported by our data in that there is a significantly better correlation between skid number and texture depth at 50 mph than at 30 mph. At 50 mph the correlation was a very significant 0.956. At 30 mph the correlation was only 0.796.

By comparing the percentage decrease in skid number between 30 and 50 mph a correlation between skid number and texture depth can be made. In this comparison we are making allowance for the fact that the decrease in coefficient above 30 mph will be influenced by the initial coefficient. For example, if a surface has a low skid number at 30 mph the decrease of that number at higher speeds will not be large. A correlation of 0.853 was found indicating a relationship although not one of high significance.

A linear correlation between texture depth using the silicone putty method and the speed gradient was made by the computer. The coefficient of correlation was only 0.194 indicating a very poor relationship. When an average texture depth was taken, rather than using individual points, a correlation of 0.753 was obtained.

No significant correlation was found between change in skid number per million vehicle passes (called the wear factor, "K") and texture depth.

Tabulated satistical correlations and graphical representations of these test results are presented in Figures 6 through 16 in Appendix B. Photographs of cores taken in the wheel paths showing the texture of each section are also shown in Appendix B, Figures 17-21.

Road Roughness and Road Meter

Road roughness readings were also taken on the test sections. Road roughness values, as determined through the use of the Bureau of Public Roads Roughometer test method, is a comparative index expressed as inches of roughness per mile. Average values of road roughness for P.C. slip-form pavement are approximately 69 in./mi. for a particular section of pavement. However, there is no correlation between road roughness and skid number or texture depth which can be made. As seen in Figure No. 2 all of the sections tested are probably satisfactory with respect to road roughness. Data is not available on test section number 10 due to barricades which made this section inaccessible.

Figure No. 2 also shows the road meter roughness values for each test section. These values represent the Present Serviceability Index (PSI) of the pavement. The PSI was developed by the AASHO Road Test as an objective means of evaluating the ability of pavement to serve traffic. The Present Serviceability Index is primarily a function of longitudinal and transverse profile with some influence from cracking and patching. Since the pavement was new, no deductions for cracking and patching were necessary on the test sections.

The Bureau of Public Roads has established a PSI scale for new pavements. The band ranges would be considered satisfactory for use in Iowa. However, a minimum of 4.1 for PSI would be necessary to be considered as a "good" rating. Therefore, the BPR nomenclature has been modified as follows:

PSI	RATING
Above 4.5	Outstanding
4.5-4.1	Good
4.1-3.7	Fair
3.7-3.3	Poor
Below 3.3	Very Poor

Note that all of the pavement sections have a rating of "Outstanding" except for three sections which are well into the "Good" range.

Skid Number -- Speed Gradient

It is evident that the various asperitic characteristics which make up a pavement's macrotexture are crucial to the dissipation of water at the tire-pavement interface. "High wet weather skidding accident rates have been shown to result from inadequate macrotexture", according to the FHWA in Instructional Memorandum 21-2-73.

The speed gradient, which is the ratio of the change in skid number to a change in speed, is affected not only by the dissipation of water through the pavement flow channels but also by internal drainage into the pavement surface. Speed gradients which are measured under field conditions of speed and water film thickness are more indicative of the true skid resistant properties than are conventional macrotexture measuring procedures. Speed gradient measurements are determined by using conventional methods for determining skid resistance.

The skid number - speed gradient is therefore useful in that

Surface Texturing of P.C. Concrete

Tama FN-63-5(7)--21-86

Testing Dates 11-12,13-1969

Section No.	Date Constructed	Stationing	Type of Texturing	Skid Resistance SN EB	Skid Resistance SN WB	Texture Depth Inches	Road Meter Roughness Value EB	Road Meter Roughness Value WB	Road Roughness In./Mi. EB	Road Roughness In./Mi. WB
1	10-27-69	664+84 - 680+00	Two layer wetted burlap (one drag) longitudinal	53	52	.042	4.52	4.53	78	75
2	10-28-69	680+00 - 690+00	Light longitudinal broom	54	59	.044	4.50	4.53	58	58
3	10-28-69	690+00 - 692+00	Light longitudinal broom weighted	42	50	.041	4.40	4.57	80	80
4	10-28-69	692+00 - 697+00	Light longitudinal broom followed by transverse steel comb	53	58	.082	4.55	4.57	76	86
5	10-28-69	697+00 - 702+00	Transverse steel comb	48	52	.064	4.61	4.61	71	71
6	10-28-69 10-29-69	702+00 - 707+00	Light transverse fiber broom	61	60	.041	4.41	4.40	78	89
7	10-29-69	707+00 - 712+00	Transverse heavy nylon bristle broom	71	71	.053	4.53	4.59	74	63
8	10-29-69	712+00 - 734+36	Single burlap (longitudinal)	49	51	.027	4.60	4.57	69	71
9	10-30-69	734+36 - 741+64	Two sections of burlap (144 sq. ft.) spaced 12'	57	--	.030	4.24	4.36	73	73
10	11-6-69	741+64 - 747+00	Single burlap drag 144 sq. ft. with 6" frayed end	--	--	.034	----	----	--	--

Values were not available on Section 10 due to barricades which made it impossible to maintain adequate testing speeds.

Figure #2

it shows how skid number varies with speed. The mathematical expression is:

$$G_{A-B} = \frac{SN_A - SN_B}{B-A}$$

Where A,B=Test speeds at which the skid number is determined

SN_A, SN_B= The skid numbers associated with speeds "A" and "B"

G_{A-B}= The speed gradient between speeds "A" and "B"

As the equation indicates, a low gradient results when there's a small change in skid number with a large change in speed. Therefore, a desirable characteristic for high speed operation would be a high skid number and a low speed gradient.

Figures 23 through 32 in Appendix C show skid number versus speed, the slope of which is speed gradient for each of the textured test sections being investigated. The divergence of the graph determined from actual field measurements and that determined from the FHWA formula is due to the fact that kinetic friction does not vary linearly with speed as the FHWA formula assumes. Figure No. 22 in Appendix C gives a skid resistance summary.

Figure No. 3 tabulates the skid numbers for each test section for both of the skid trailers being used. The speed gradients are also tabulated using the average of these skid numbers which were obtained on May 10, 1973. The standard speed gradient, according to ASTM E-274, is the slope on the SN-speed curve between 30 and 50 mph. Sections 4 and 5 have the lowest speed gradient with the largest skid numbers.

Wear Factor

In general, the extent of the texture wear for PCC pavement is indicated by the increase in speed gradient. Therefore, if one knows the behavior of the skid number under traffic an evaluation of the rate of deterioration of skid resistance properties can be made.

In order to find the wearability of the textured pavements, the relationship between skid number and traffic volume on the test section is desirable. The Average Daily Traffic (ADT) for the investigated section of U.S. 63 as determined by Transportation Data Base are as follows:

Year	ADT
1969	1690
1970	1780
1971	1930
1972	2080
1973	2080

Figures 33 through 37 in Appendix D are a plot of skid number versus traffic volume for each of the test sections. The effect of traffic on skid number can be seen by comparing skid number, or change in skid number, with traffic volume. The amount of wear can also be compared to vehicular traffic. This gives a more reliable indication of the wearability of a pavement since it can be compared to any other section of highway. By plotting against time, as in Figures 38 through 42 in Appendix D, we can only compare sections which have the same traffic volume. Most of these

SECTION NUMBER	SKID NUMBER						SKID NUMBER AVERAGE			SPEED GRADIENT		
	OLD TRAILER			NEW TRAILER								
	30 MPH	40 MPH	50 MPH	30 MPH	40 MPH	50 MPH	30 MPH	40 MPH	50 MPH	30-40	40-50	STAND-ARD
1	47	39	35	42	36	32	44.5	37.5	33.5	0.70	0.40	0.55
2	49	41	34	42	35	33	45.5	38	33.5	0.75	0.45	0.60
3	44	38	35	39	34	32	41.5	36	33.5	0.55	0.25	0.40
4	50	46	42	46	40	40	48	43	41	0.50	0.20	0.35
5	49	45	41	46	42	40	47.5	43.5	40.5	0.40	0.30	0.35
6	46	40	35	41	37	33	43.5	38.5	34	0.50	0.45	0.48
7	48	39	35	40	34	32	44	36.5	33.5	0.75	0.30	0.58
8	46	39	33	41	36	34	43.5	37.5	33.5	0.60	0.40	0.50
9	47	36	33	41	35	33	44	35.5	33	0.85	0.25	0.55
10	47	41	35	44	37	34	45.5	39	34.5	0.65	0.45	0.55

Data taken on 5-10-73

FIG. 3

graphs have an abrupt initial drop in skid number which is caused by the loss of initial texture. In the Tama Test Sections, the traffic is obviously the same in all sections and they can therefore be compared with the other sections on the basis of time. To compare the Tama sections with any other section in the state must involve consideration of traffic volumes since it is the combination of polishing and texture loss at the tire-pavement interface that is most responsible for this reduction in skid resistance.

It is evident that data on pavement wear should be obtained under actual traffic conditions for each texturing method employed in this investigation. Figures 33 through 37 in Appendix D, which are plotted on Log-Log paper to produce a straight line, will give the "wear factor" of the pavement by measuring the slope of the line. Data on these curves do not include the abrupt initial drops in skid numbers caused by the loss of initial texture. The wear factor, slope "K", may be determined from the following formula:

$$K = \frac{\text{Log } SN_1 - \text{Log } SN_2}{\text{Log } VP_1 - \text{Log } VP_2}$$

Where SN_1 = Initial skid number
SN_2 = Final skid number

VP_1 = Vehicle passes at SN_1
VP_2 = Vehicle passes at SN_2

By knowing the wear factor of a particular pavement it is possible to predict how soon refurbishing of the pavement, because of inadequate skid values, will be needed. (See Figure No. 4 for estimated times for each test section). The steeper the

WEAR FACTOR AND PAVEMENT DETERMINATION

TEST SECTION	TEXTURE	WEAR FACTOR	TIME TO REACH SN=30		ΔSN	SPEED GRADIENT
			M.V.P.	YEARS		
1	Two layer wetted burlap (one drag) longitudinal	-0.139	22.3	29.4	13	0.55
2	Light longitudinal broom	-0.071	150	198	17	0.60
3	Light longitudinal broom weighted	-0.118	14.8	19.5	10	0.40
4	Light longitudinal broom followed by transverse steel comb	-0.068	1280	1685	9	0.35
5	Transverse steel comb	-0.044	29,730	39,160	5	0.35
6	Light transverse fiber broom	-0.184	13.0	17.1	21	0.48
7	Transverse heavy nylon bristle broom	-0.164	13.5	17.8	31	0.58
8	Single burlap (longitudinal)	-0.194	10.2	13.4	13	0.50
9	Two sections of burlap (144 sq. ft.) spaced 12'	-0.174	11.8	15.5	18	0.55
10	Single burlap drag 144 sq. ft. with 6" frayed end	-0.197	13.0	17.1	9	0.55

FIG. 4

slope "K", the more rapid the pavement deterioration since it will take less vehicles to reduce skid numbers to undesirable levels. Therefore, pavements with large values of "K" should probably be restricted, if permitted at all, to low volume roads. Sections 4 and 5 gave superior results in this area. Section 2 exhibited fair results but had a rather large speed gradient.

The wear factor is an indicator of the loss of skid resistance with traffic exposure and not just properties of the aggregates used. The wear factor is dependent upon the speed at which the skid number is measured, according to the FHWA in Instructional Memorandum 21-2-73. A durable surface which does not wear under traffic will exhibit a much lower wear factor at high speeds due to its ability to retain its initial speed gradient.

The use of studded snow tires is a major concern in Iowa. The stress at the stud-pavement interface is much higher at high speeds than at low speeds. Consequently, the use of studded snow tires cause a very rapid loss of texture and high wear factors.

Ideally, mixes should be designed so that adequate skid resistance is provided during the design life of the pavement. For high volume traffic conditions, it is desirable to use mix designs and aggregates which will result in wear factors below .05, according to the FHWA in Instructional Memorandum 21-2-73. Conditions of high traffic volumes, high operating speeds and large percent of wet weather time will justify systems with higher skid resistance and lower wear factors. Low traffic volumes, and small percent of wet weather time may justify the allowance of a higher wear factor and a possible subsequent loss of skid resistance. However, polishing has been found to be less severe for a given number of passes spread over a number of years than it is for the same number of passes occurring in one year according to the FHWA. Therefore, an aggregate which would polish rapidly under heavy traffic volumes may provide an adequate level of skid resistance throughout the life of the surface on a low traffic volume road.

CONCLUSIONS:

The following conclusions can be made about the textured sections:

1. The longitudinal burlap drag and broom sections had an initial texture which provided satisfactory skid numbers. However, large changes in skid number, large speed gradients, and extremely large wear factors make these sections unsatisfactory as a texturing method.

2. The transverse broom sections had very good skid numbers on the initial texture. However, very large skid number changes resulted as the initial texture wore away. Large speed gradients and very large wear factors also make these sections unsatisfactory.

3. The transverse steel comb sections performed the best. The change in skid number, the speed gradient, and the wear factor were all relatively low for these sections. The texture on these sections is especially good from a hydroplaning aspect due to the grooving. This is compounded by the relatively long skid life of both sections. The noise on these sections is louder than on others but is not deemed objectionable.

RECOMMENDATIONS:

1. Continued data should be collected on each of the test sections in order to further substantiate the reliability of present data.

2. Future projects should make use of transverse combs and variations of the comb on straight portions of highway.

APPENDIX A

MATERIALS

Test Data And Mix Design

The fine aggregate producer was Martin-Marietta, at the Cedar Bend Pit in Black Hawk County. The contractor was Fred Carlson. The following test data on the fine aggregate is representative of the material used.

SIEVE	% PASSING	% PASSING (SPECS)
3/8	100	100
#4	98	95-100
#8	90	75-100
#16	75	When fine aggregate is sieved through sieves 4,8,16,30,50, and 100, not more than 40% shall pass one sieve and be retained on the next.
#30	46	
#50	12	
#100	1.0	
#200	0.2	0.-1.5

Specific Gravity (SSD)=2.660

Compressive Strength of Mortar:

Ratio of Sample/Standard: 1.74

The coarse aggregate producer was Martin-Marietta at the Smith Quarry in Benton County. The contractor was Fred Carlson. The following test data on the coarse aggregate is representative of the material used.

SIEVE	% PASSING	% PASSING SPECS
1-1/2"	100	100
1"	86	50-95
3/4"	58	35-80
1/2"	34	------
3/8"	15	10-40
#4	1.1	0-5
#200	0.3	0-1.5

% Objectional Substances--

3 Shale + No. 2: 0.1%

Specific Gravity (SSD): 2.651

% Absorption (SSD): 2.88

% Wear on L.A Abrasion Grading A: 24

% Psg. After 16 Cycles of F&T in
Water-Alcohol Solution = 1.4

The mix design used was a C-3 mix and conformed to the following:

BASIC ABSOLUTE VOLUMES OF MATERIAL
PER UNIT VOLUME OF CONCRETE

Mix No.	Cement Minimum	Water	Air	Fine Aggregate	Coarse Aggregate
C-3	0.114172	0.163840	0.06	0.297395	0.364593

APPROXIMATE QUANTITIES OF DRY MATERIALS
PER CUBIC YARD OF CONCRETE

Mix No.	Bbls.	Lbs.	Fine Agg. Tons	Coarse Agg. Tons
C-3	1.606	604	0.6640	0.8140

All materials incorporated were in compliance with the 1964 Standard Specifications for a C-3 Mix.

APPENDIX B

METHOD OF TEST FOR DETERMINING THE TEXTURE DEPTH OF PAVEMENT SURFACE BY USE OF THE SAND PATCH METHOD

PROCEDURE:

A. Apparatus

1. Metal pan 11-1/2"x11-1/2" with edges raised approximately one inch. Extending through the center of the pan is a metal ring of approximately 5.75 in. diameter, placed in such a way that the ring extends approximately 0.50 in. below the pan.

2. A 2"x1"x9" neoprene strike off bar to which has been attached a 1/8"x1"x9" strip of aluminum.

3. Natural silica sand from Ottawa, Illinois, graded as follows:

SIEVE	PERCENTAGE RETAINED
No. 100 (149 micron)	98 $\pm$ 2
No. 50 (297 micron)	72 $\pm$ 5
No. 30 (595 micron)	2 $\pm$ 2
No. 16 (1190 micron)	None

4. Balance with a capacity of at least 2000 grams, and accurate to at least 0.1 gram.

5. An 8"x8" smooth glass calibration plate.

6. Wire brush and soft hand brush.

B. Calibration

1. Pre-weigh approximately 500 grams of sand.

2. Place the metal pan on a level calibration plate in such a way that the ring is in contact with the glass plate.

3. Overfill the ring with sand by pouring the sand first around the edges of the ring, and working toward the center in a circular motion.

4. Strike off the excess sand by making one pass with the strike off bar held at approximately a 45° angle, keeping the aluminum strip at the top of the strike off bar.

5. Weigh the sand not contained in the metal ring. The difference between this weight and the initial sand weight will be the amount of sand contained in the ring.

6. Repeat steps B1 - B5 until five (5) measurements are made which agree within 5 grams. Average the five (5) measurements to establish the calibration value.

C. Test Procedure

1. The pavement surface selected for test must be dry. If the pavement has not been subjected to traffic, scrub the test surface with a wire brush to remove any loosely bonded particles or curing compounds that will be worn away by a small amount of traffic. Otherwise, the pavement surface should be swept with a soft hand brush.

2. Pre-weigh a sufficient amount of sand to insure an overfilling of the ring.

3. Use the same technique and procedures employed in the calibration (Steps B1 - B5) to determine the amount of sand necessary to fill the ring.

D. Calculations

1. Calculate the average texture depth by the following formula:

$$T = (W_S - W_C) \left(\frac{1}{U_S \times A} \right)$$

Where:

T=Texture depth in inches.
W_S=Weight in grams of sand necessary to fill the ring on the pavement surface.
W_C=Weight in grams of sand necessary to fill the ring on the calibration plate.
U_s=Unit weight of sand = 25.15 gr./cu. in.

A=Area of ring in square inches.

E. Precautions

1. Because of slightly different techniques between operators, it is imperative that the person conducting the tests also perform the calibration.

2. This test should be performed only on a relatively calm day to prevent sand loss.

MEASUREMENT OF TEXTURE DEPTH BY THE SILICONE PUTTY METHOD

SCOPE:

This method describes a procedure for determining the average macrotexture depth of a selected portion of a highway pavement surface.

SUMMARY OF METHOD:

A known volume of silicone putty is formed into an approximate sphere and placed on the pavement surface. A 6 inch plate with a 4 in. diameter by 1/16 in. deep recess is centered over the putty and pressed down in firm contact with the surface. The average diameter of the resulting flat-topped ring of putty is recorded. The volume of putty is selected so that on a smooth, flat surface with no texture, the silicone putty will completely fill the recess giving a 4 in. diameter flat topped circle. A decrease in diameter of the deformed putty is related to an increase in texture depth thus giving a rapid and simple index of pavement macrotexture.

SIGNIFICANCE:

The friction between a tire and the highway surface required for various vehicle maneuvers on a wet pavement, particularly in braking, depends in part on the thickness of the water film between the contact surfaces. This thickness, in turn, is controlled by the water drainage characteristics of the pavement as well as tire tread design and condition. Pavement drainage is influenced strongly by its surface macrotexture, one measure of which is the so-called texture depth. Additionally, an important contribution to friction at the tire-pavement interface is the hysteresis energy losses which occur as a result of cyclic deformation of the tread rubber; these are also influenced by texture depth.

The texture depth determined by this method is a number representing the ratio of the volume of the putty used to the resultant measured circular area covered. Accordingly, it is only an indirect measure of pavement macrotexture wave-length and amplitude, and gives no information on shape, distribution or other factors which may influence pavement surface drainage or hysteresis losses. Additionally, it is assumed that the putty completely fills all voids under the measured circular area.

APPARATUS:

The apparatus required for calibration and texture depth measurement consists of the following:

1. A circular plate 6 in. diameter x 1 in. thick machined* from flat acrylic plastic sheet with a centrally machined 4 in. diameter x 1/16 in. deep recess on one side.
2. 50 pound (22.6 kg) weight with convenient handle.**
3. Steel wire bristle brush.
4. Stiff bristle general utility scrubbing brush.
5. 250 ml polyethylene "squeeze" washing or dispensing bottle fitted with a delivery tip drawn to give a fine directed stream of dewetting agent.

---

*Plastic sheets, usually known as "Plexiglas", manufactured by the Rohm & Haas Co., Philadelphia, Pa., or "Lucite", manufactured by E.I. du Pont de Nemours Co., Wilmington, Delaware, have been used satisfactorily.

**Such weights made by Fairbanks-Morse have been found to be satisfactory for the purpose.

6. Synthetically produced, wear resistant, cellulose, polyurethane, or other type of polymer foam sponge suitable for quick removal of excess dewetting agent from the pavement surface.

7. An engineers scale capable of measuring putty diameter to 0.01 in.

8. A metal pry bar (for separation of the circular plate from the pavement at the end of test)

9. A 3 oz. seamless tin plate container with fitted lid (such as used in ASTM D6)

10. Flat plateglass plate for use as a reference check surface, approximately 8 in. x 8 in. x 1/2 in.

MATERIALS:

The following materials are required to conduct this test.

1. A filled high viscosity polysiloxane polymer, known as silicone putty.* Approximately 15.9 g of this material will be required to completely fill the recess in the test plate on a flat surface. It is usually possible to completely remove the putty from most pavement surfaces after a test is completed, and reuse this material in subsequent tests. However, it has proven to be advantageous to provide a number of pre-weighed putty specimens at the test site, transported in the covered 3 oz. containers described in 9 above.

2. Dilute solution of dioctyl sodium sulfosuccinate for use as a wetting and parting agent between the pavement surface and silicone putty test specimen. This solution can be made by mixing 5 ml of 75 percent aqueous Aerosol OT solution** with 5 gal (19 l) of distilled water.

SAMPLING:

It is well known that in a given nominally uniform section of highway pavement, surface macrotexture may vary significantly from

---

*A material marketed as "silly putty", available from Arnold Clark, Inc., Box 741, New Haven, Conn. has been found suitable for this purpose.

**Available from many general laboratory supply houses.

spot to spot. On the other hand, the area covered by the putty in this test is only a small fraction of the total pavement surface to be evaluated. Accordingly, appropriate selection of test locations will be a significant factor in achieving the objective of this test procedure. In a given section of pavement, putty depth measurement shall be made on at least 6 different locations. These may be selected as follows:

1. Random sampling procedure (preferred method). On a diagram of the pavement surface section to be measured, place a rectangular grid producing at least 1000 square cells, each designating a location on the pavement surface, and number these cells serially by any systematic method. Select 6 of these numbers from a table of random digits, and make tests at the center of the cell numbers so indicated.

2. Selective sampling (for preliminary or quick evaluation tests only). Visually inspect the pavement section to be evaluated, and select, on the basis of such observation, 6 locations which appear to be most representative of the texture of the entire section.

PROCEDURE:

At the locations selected for texture depth measurements, proceed as follows:

1. Remove all loose stones, other debris and contaminants by vigorous application of the steel wire brush.

2. Remove remaining sand and dust from the surface by careful dry brushing with the scrubbing brush.

3. Wet a section at least as large as the test plate with a spray of dilute Aerosol OT solution from a squeeze bottle.

4. Remove excess Aerosol OT solution by dopping or wiping the surface with the sponge.

5. Form silicone putty into an approximate sphere and place on the pavement surface.

6. Center the recess of the test plate over the putty and press the plate down in firm contact with the road surface. Use of the 50 pound weight to exert pressure for approximately 1 minute will usually suffice to bring the edges of the test plate into contact with the pavement surface. Time

intervals over 5 min. should be avoided.

7. Make four diameter measurements with an angular spacing of 45 deg., with an engineer's scale to the nearest 0.01 in. (0.25 mm). The average of these readings is taken as the diameter of the pressed-down circle of putty.

8. Remove the test plate from the pavement surface, using a pry bar if necessary. At the same time the putty also should be removed from the surface. In most instances, complete removal of the putty can be achieved by lightly pressing the putty ball against the few fragments which may try to cling to the surface. In the few cases where more than a few hundredths of a gram of putty cannot be removed, it will be necessary to use a fresh putty specimen of the correct weight.

CALIBRATION:

Before the apparatus is used for field measurements, the standard procedure shall be followed in the laboratory, using the flat plate glass surface as a standard. If the putty has been weighed out correctly, it should completely fill the test plate recess, i.e., the putty circle shall have a diameter of 4 in.

CALCULATION OF TEXTURE DEPTH:

Texture depth is calculated from the putty diameter by the following equation:

$$T_p = \frac{1}{D^2} - 0.0625$$

Where T_p = texture depth, inches

D = average putty circle diameter, inches

or

$$T_p = \frac{2.54}{D^2} - 0.1585$$

Where T_p = texture depth, cm.

D = average putty circle diameter, cm.

TEXTURE DEPTH TEST RESULTS

SECTION & TEXTURING	NO. COMPARISON	SAND PATCH METHOD AVE. T.D.+	SAND PATCH METHOD STD. DEV.	SAND PATCH METHOD AVE. T.D.++	SAND PATCH METHOD STD. DEV.	SILICONE PUTTY METHOD AVE. T.D.+++	SILICONE PUTTY METHOD STD. DE
1. Two layer wetted burlap (one drag) longitudinal	6	0.042	0.012	0.019	0.008	0.019	0.002
2. Light longitudinal broom	6	0.044	0.009	0.014	0.008	0.020	0.007
3. Light longitudinal broom weighted	6	0.040	0.014	0.012	0.005	0.021	0.002
4. Light longitudinal broom followed by transverse steel comb	6	0.082	0.009	0.048	0.014	0.043	0.007
5. Transverse steel comb	6	0.064	0.007	0.044	0.009	0.034	0.008
6. Light transverse fiber broom	6	0.040	0.009	0.015	0.008	0.020	0.002
7. Transverse heavy nylon bristle broom	6	0.053	0.012	0.026	0.007	0.022	0.004
8. Single burlap (longitudinal)	6	0.027	0.011	0.012	0.006	0.016	0.003
9. Two sections of burlap (144 sq. ft.) spaced 12'	6	0.030	0.008	0.013	0.008	0.018	0.001
10. Single burlap drag 144 sq. ft. with 6" frayed end	6	0.034	0.008	0.014	0.009	0.020	0.003

\+ Data Taken 11-12-69.
++ Data Taken 5-18-70.
+++ Data Taken 5-11-73.

FIG. 5

STATISTICAL CORRELATION OF TEST RESULTS

GRAPH NO.	VARIABLES y	VARIABLES x	NO. OF COMP.	REGRESSION LINE	LINEAR CORR.	STAND. DEV., σy
7	SN_{30}	TD*	10	y=0.182x+40.458	0.796	1.95
8	SN	TD	10	y=0.277x+32.041	0.858	2.73
9	SN_{50}	TD	10	y=0.343x+27.054	0.956	3.03
10	$SN_{50}-SN_{30}$	TD	10	y=-0.164x+13.514	-0.776	1.78
11	$\frac{SN_{50}-SN_{30}}{SN_{30}}$	TD	10	y=-0.417x+31.394	-0.853	0.04
12	G_{30-40}	TD	10	y=-0.010x+0.853	-0.590	0.14
13	G_{40-50}	TD	10	y=-0.007x+0.499	-0.583	0.10
14	G	TD	10	y=-0.008x+0.685	-0.753	0.09
16	-K	TD	10	y=-0.005x+0.248	-0.716	0.06

Data Collected 5-10-73 and 5-11-73.

*Silicone putty method used for texture depth determinations.

FIG. 6

SKID NUMBER (30 MPH)
VS. TEXTURE DEPTH

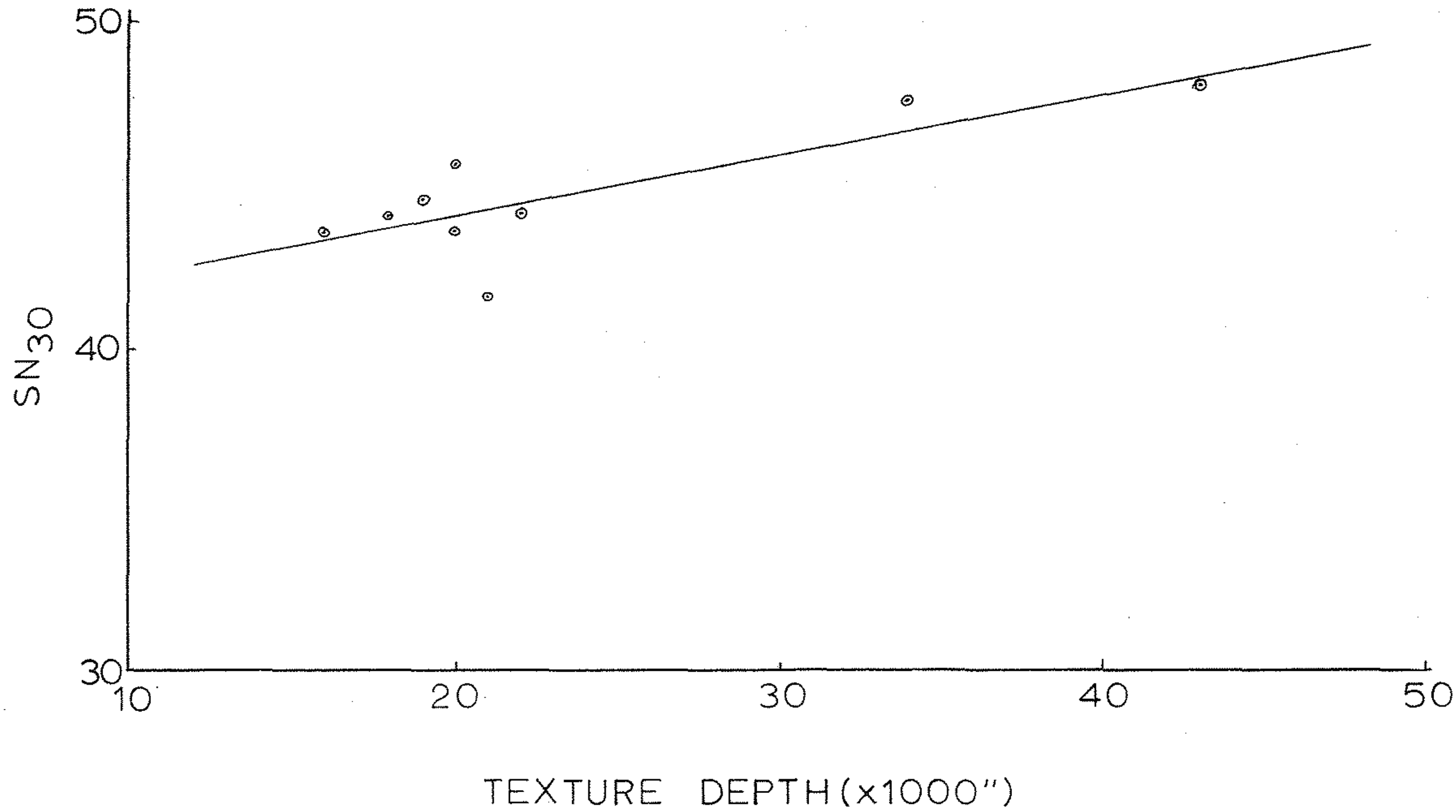


FIG. 7

SKID NUMBER (40 MPH)
VS. TEXTURE DEPTH

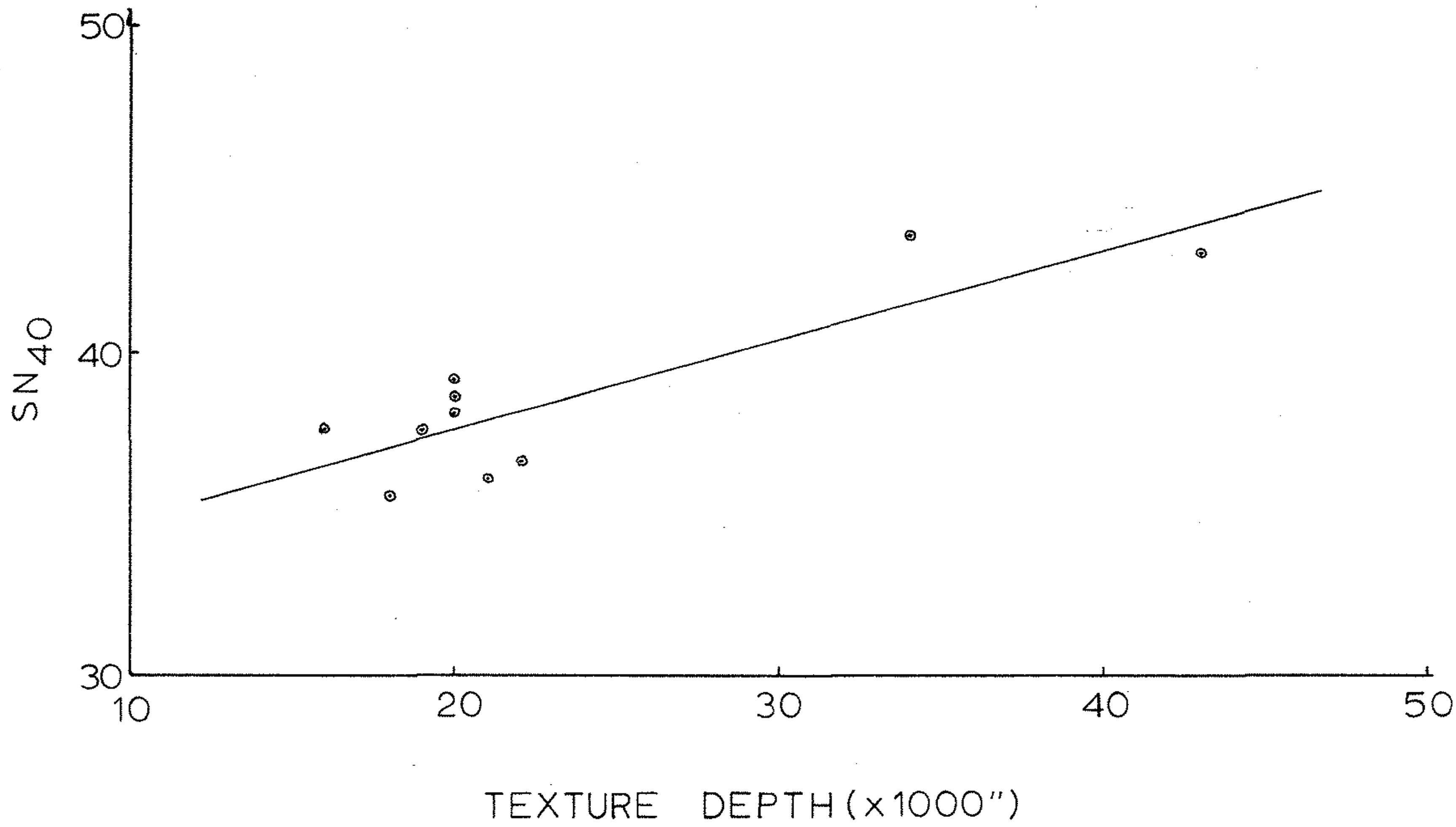


FIG. 8

SKID NUMBER(50 MPH)
VS. TEXTURE DEPTH

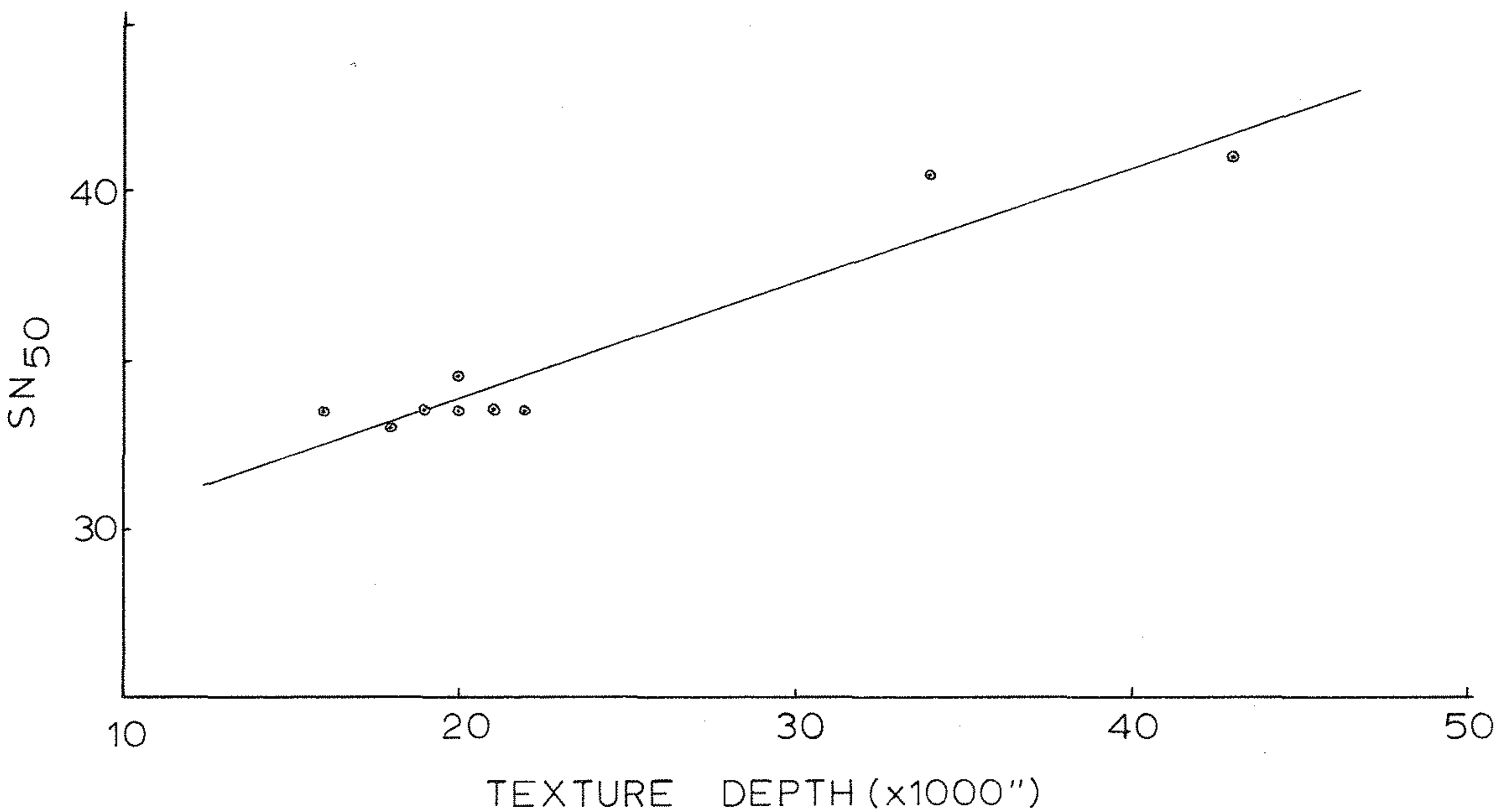


FIG. 9

SKID NUMBER CHANGE VS. TEXTURE DEPTH

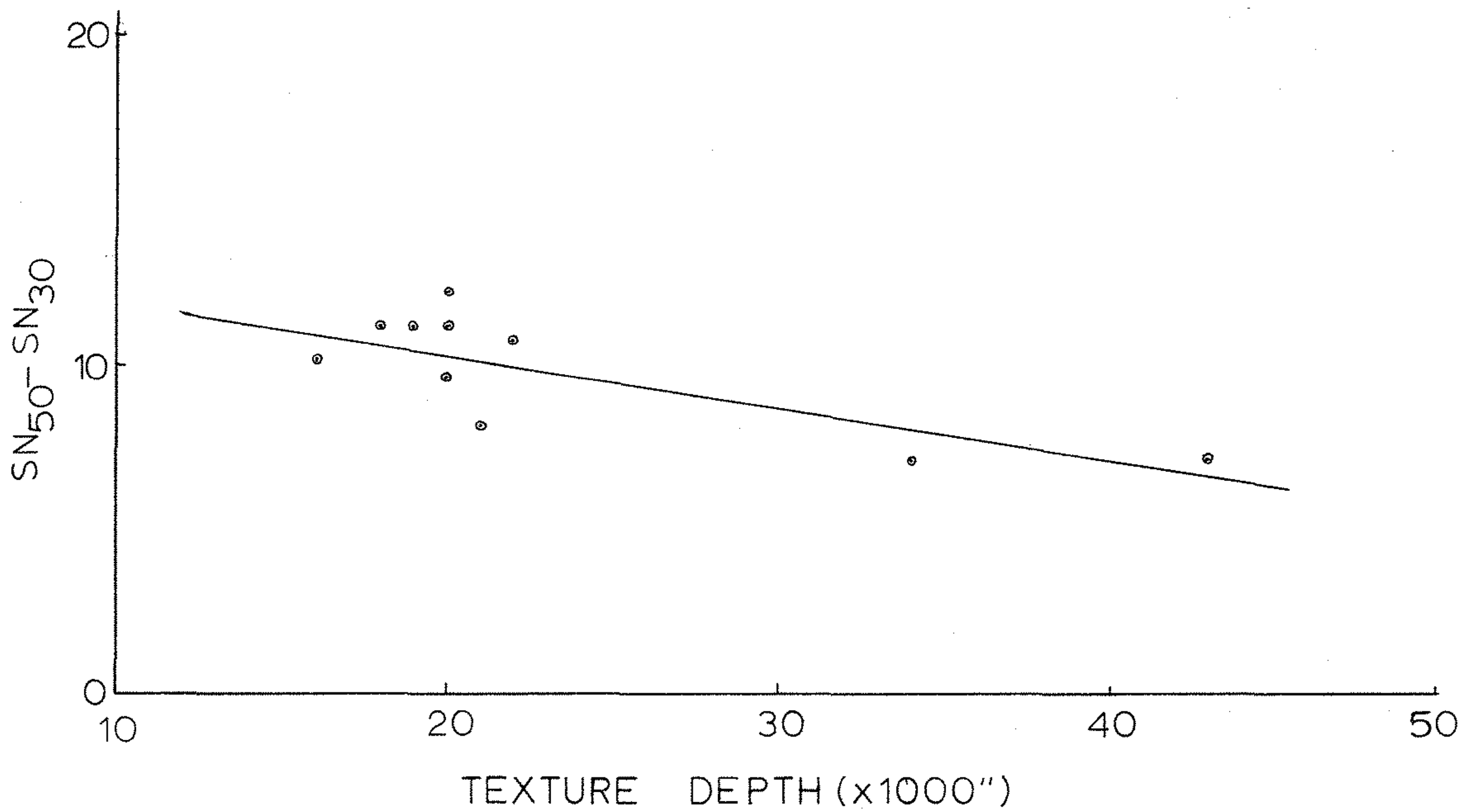


FIG. 10

% DECREASE IN SKID NUMBER VS. TEXTURE DEPTH

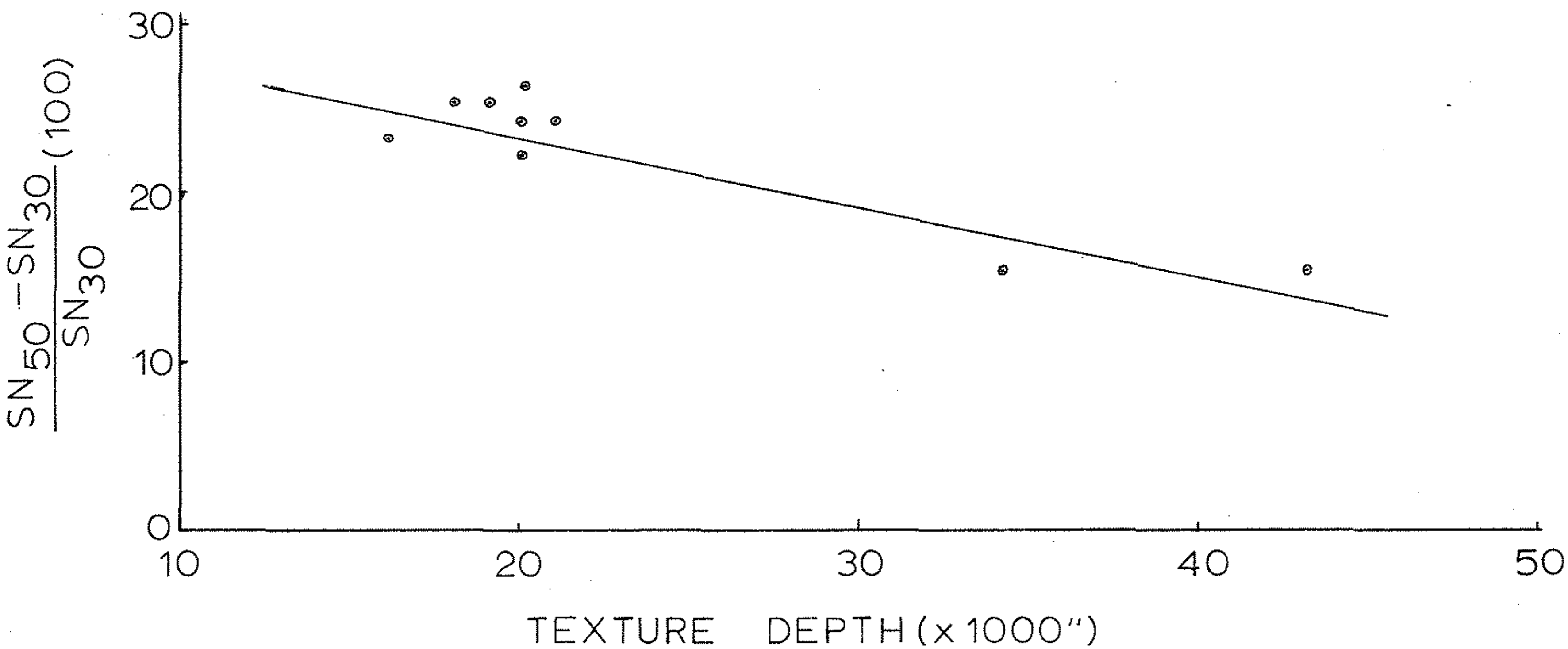


FIG. 11

SPEED GRADIENT(30-40 MPH)
VS. TEXTURE DEPTH

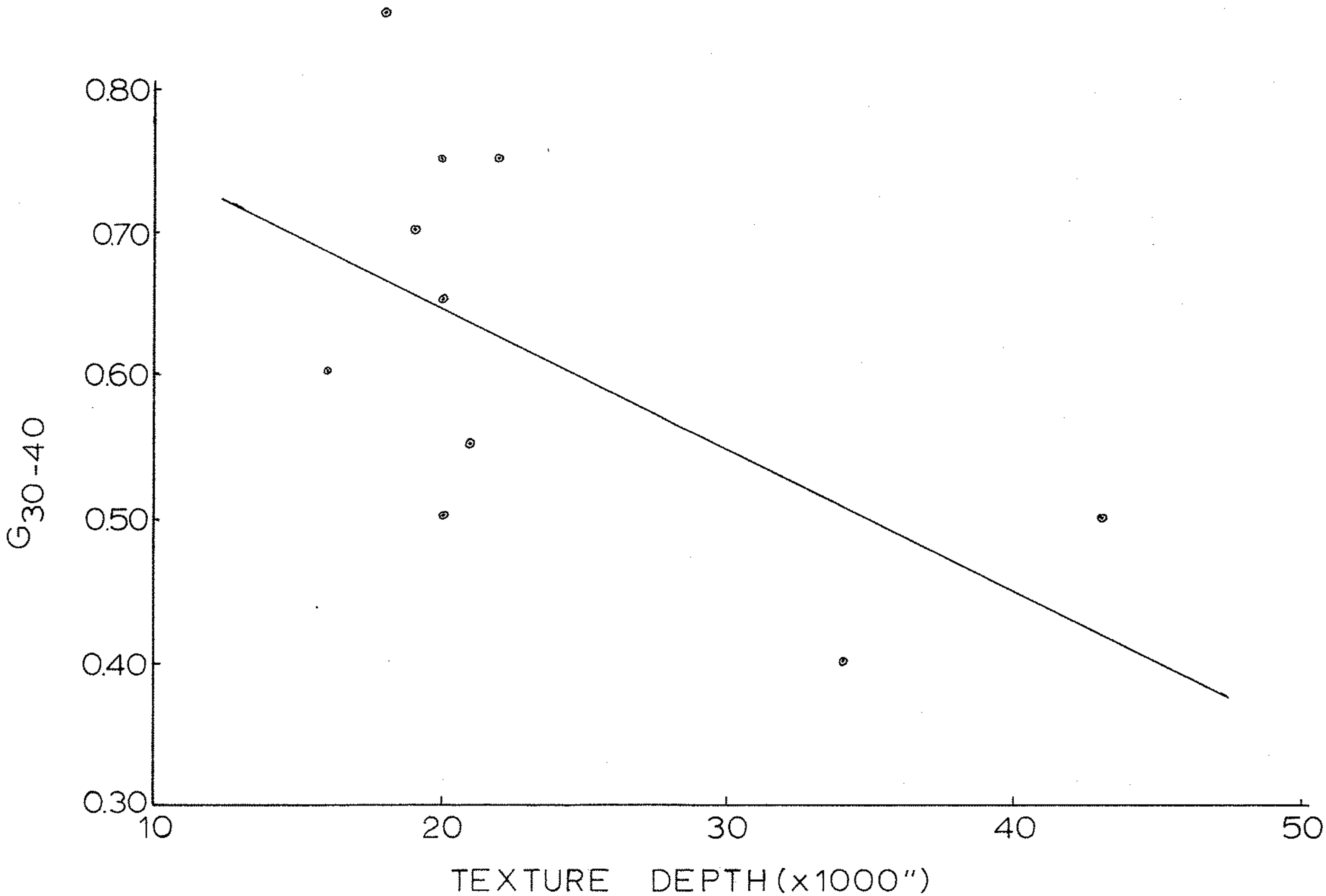


FIG. 12

SPEED GRADIENT (40-50 MPH) VS. TEXTURE DEPTH

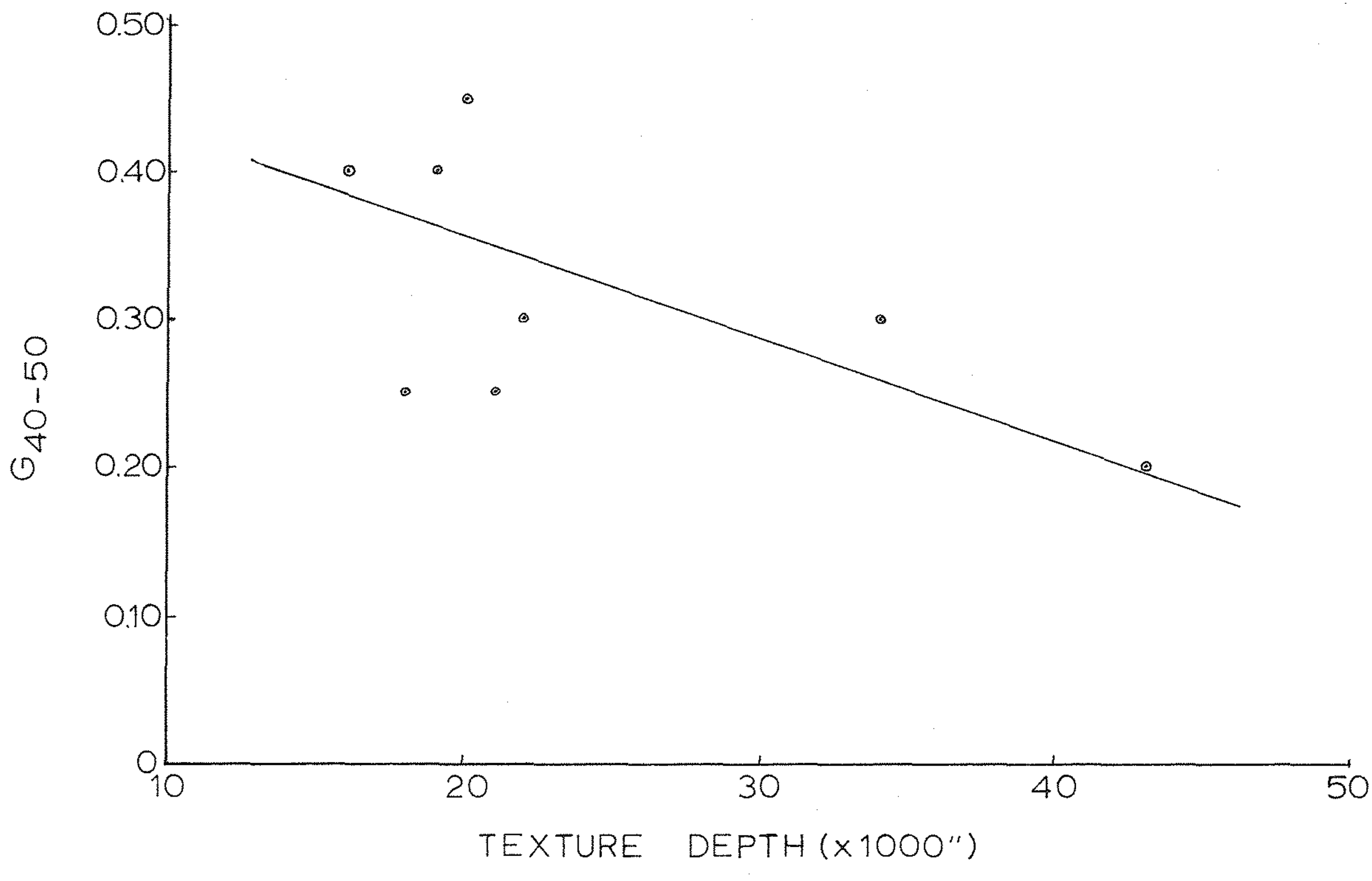


FIG. 13

STANDARD SPEED GRADIENT
VS. TEXTURE DEPTH

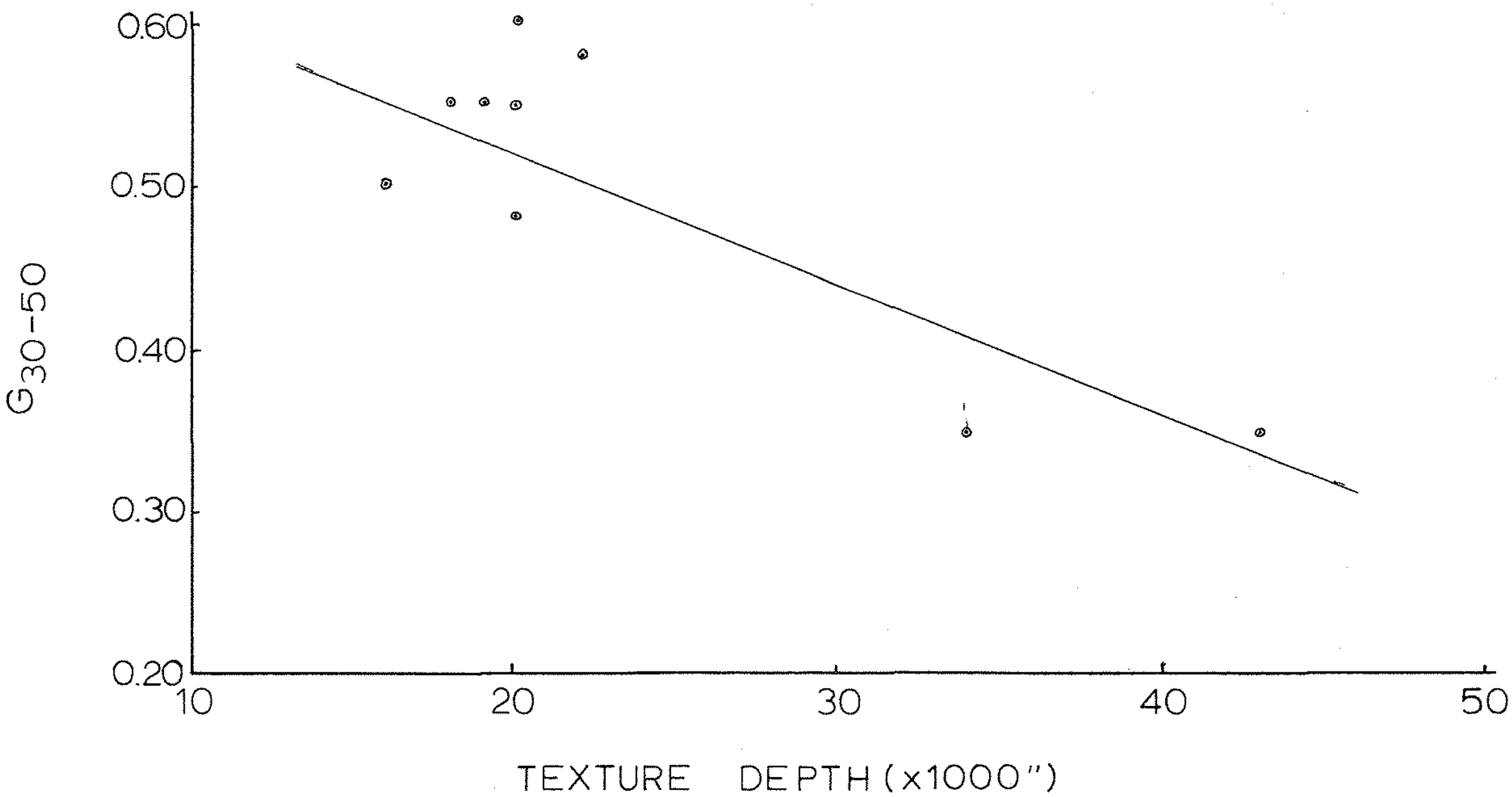


FIG. 14

SILICON PUTTY

SPEED GRADIENT VS. TEXTURE DEPTH

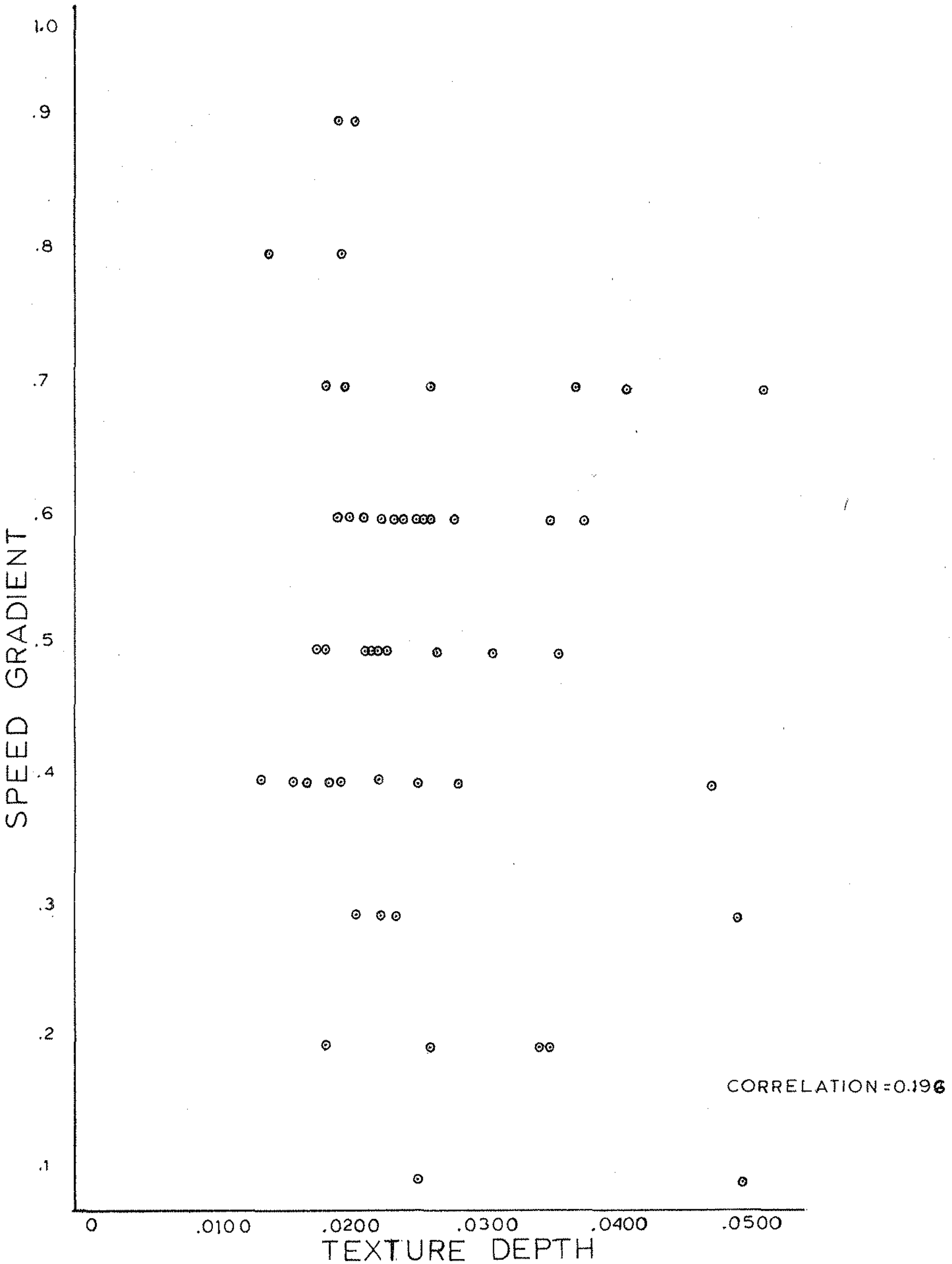
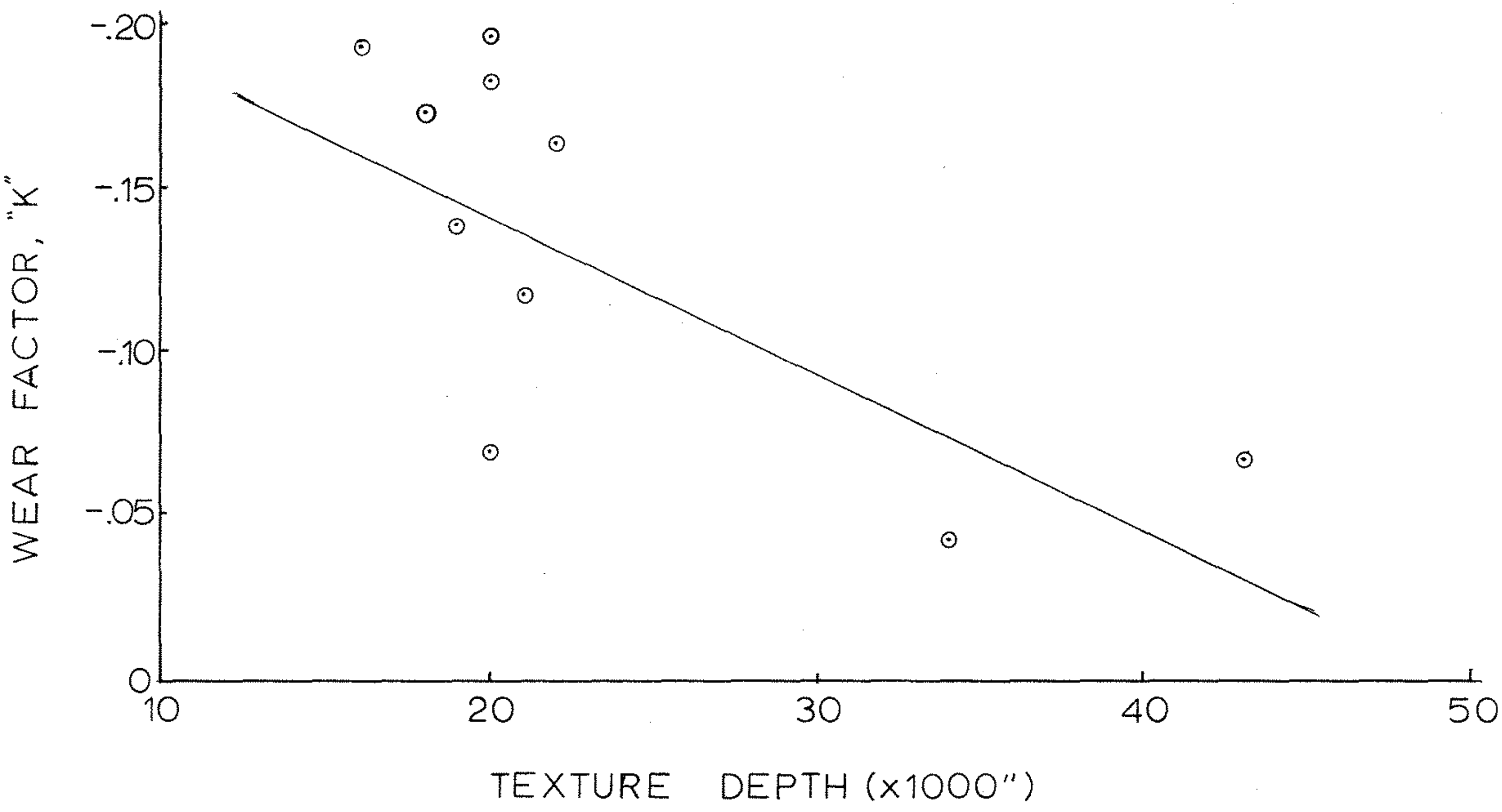
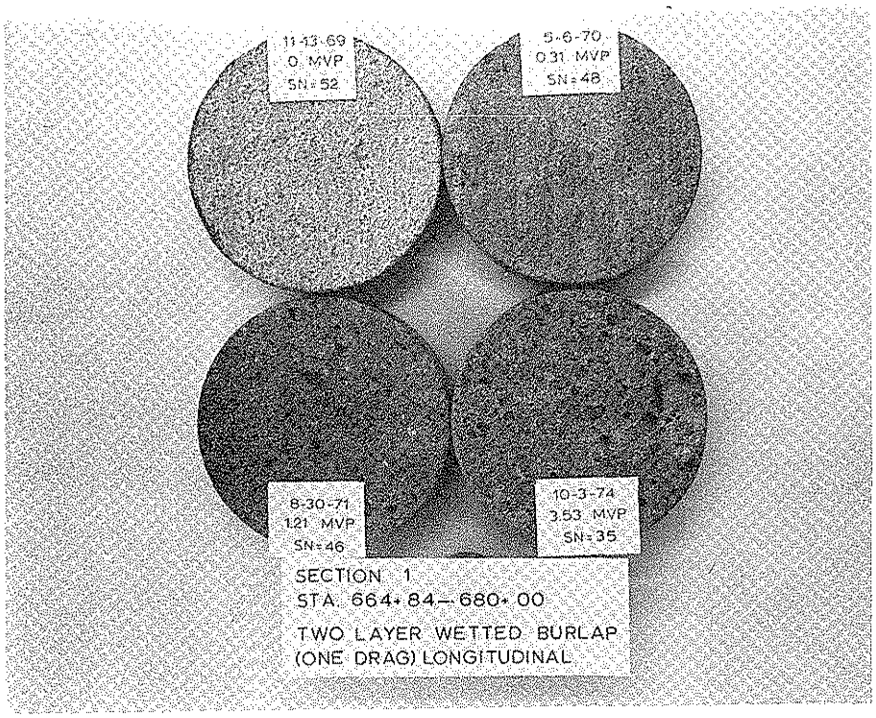


FIG. 15

WEAR FACTOR VS. TEXTURE DEPTH



F[illegible]. [illegible]


11-13-69
0 MVP
SN=52
5-6-70
0.31 MVP
SN=48
8-30-71
1.21 MVP
SN=46
10-3-74
3.53 MVP
SN=35
SECTION 1
STA. 664+84—680+00
TWO LAYER WETTED BURLAP
(ONE DRAG) LONGITUDINAL

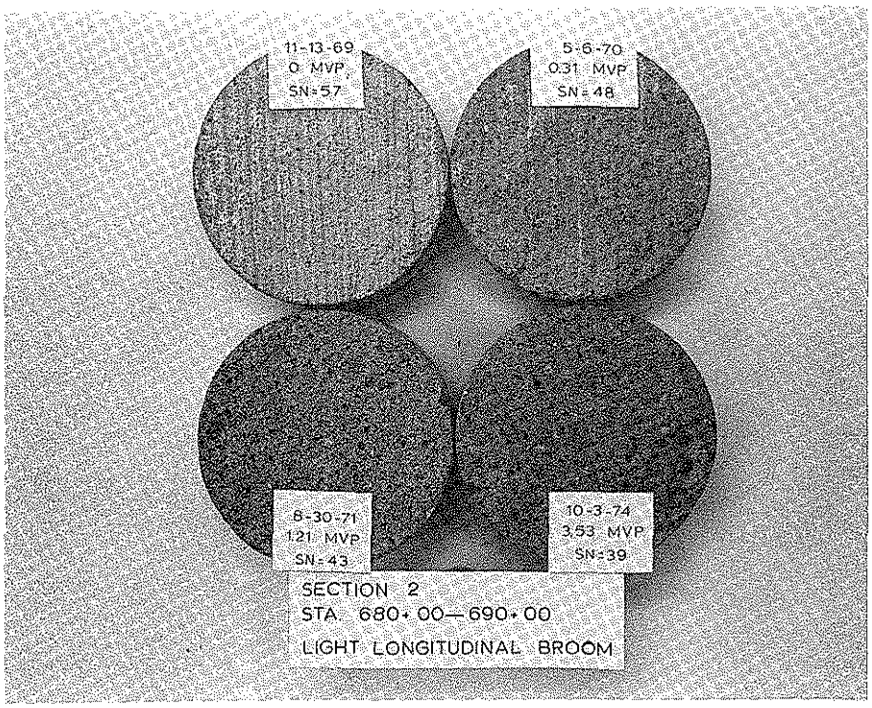

11-13-69
0 MVP
SN=57
5-6-70
0.31 MVP
SN=48
8-30-71
1.21 MVP
SN=43
10-3-74
3.53 MVP
SN=39
SECTION 2
STA. 680+00—690+00
LIGHT LONGITUDINAL BROOM

FIG. 17


11-13-69
0 MVP
SN=46
5-6-70
0.31 MVP
SN=43
8-30-71
1.21 MVP
SN=41
10-3-74
3.53 MVP
SN=34
SECTION 3
STA. 690+00—692+00
LIGHT LONGITUDINAL BROOM
WEIGHTED

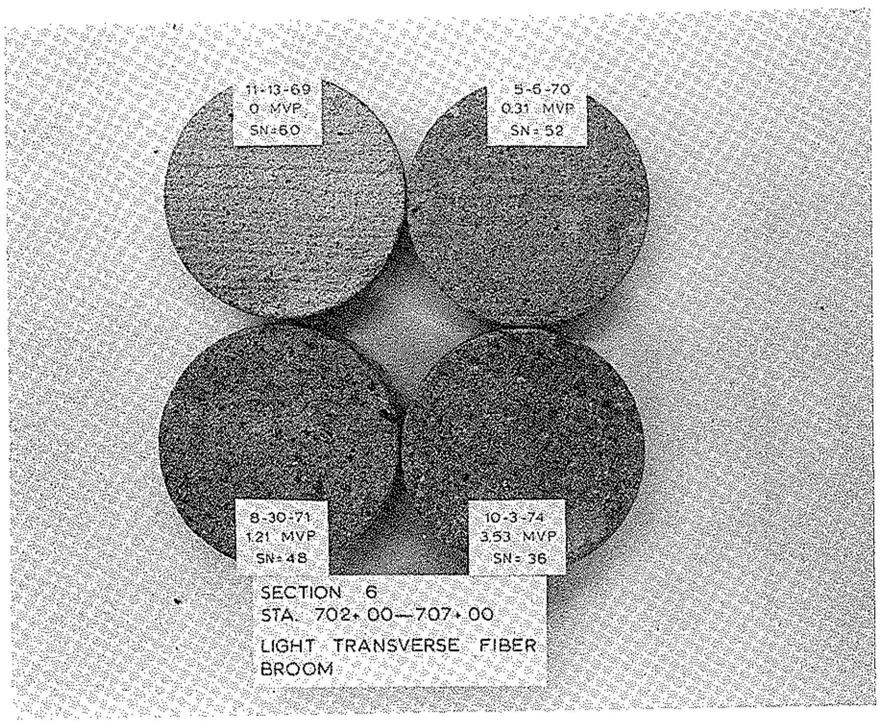
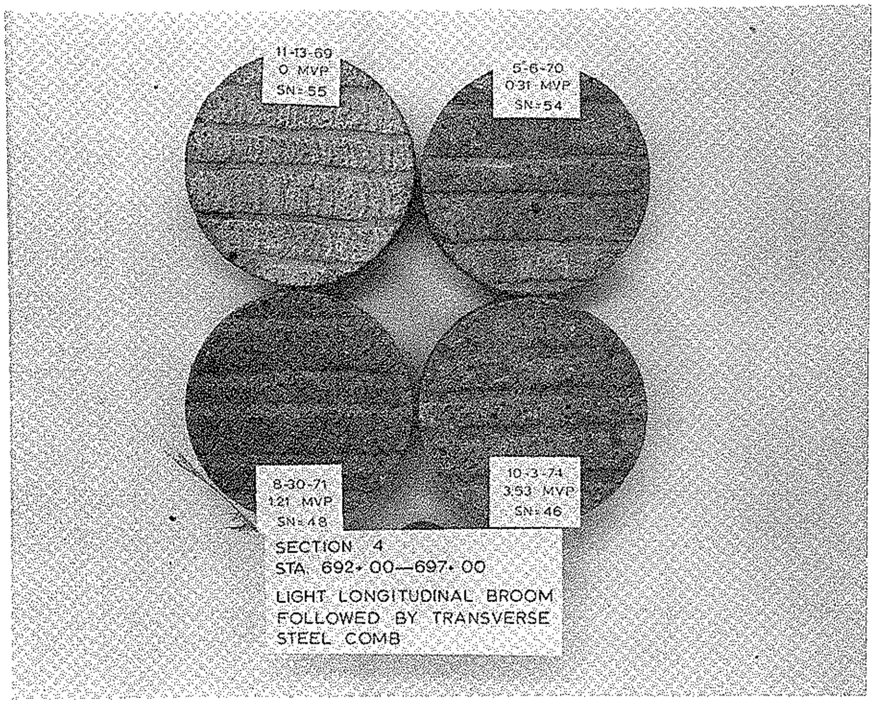

11-13-69
0 MVP
SN=60
5-6-70
0.31 MVP
SN=52
8-30-71
1.21 MVP
SN=48
10-3-74
3.53 MVP
SN=36
SECTION 6
STA. 702+00—707+00
LIGHT TRANSVERSE FIBER
BROOM

FIG. 18


11-13-69
0 MVP
SN=55
5-6-70
0.31 MVP
SN=54
8-30-71
1.21 MVP
SN=48
10-3-74
3.53 MVP
SN=46
SECTION 4
STA. 692+00—697+00
LIGHT LONGITUDINAL BROOM
FOLLOWED BY TRANSVERSE
STEEL COMB

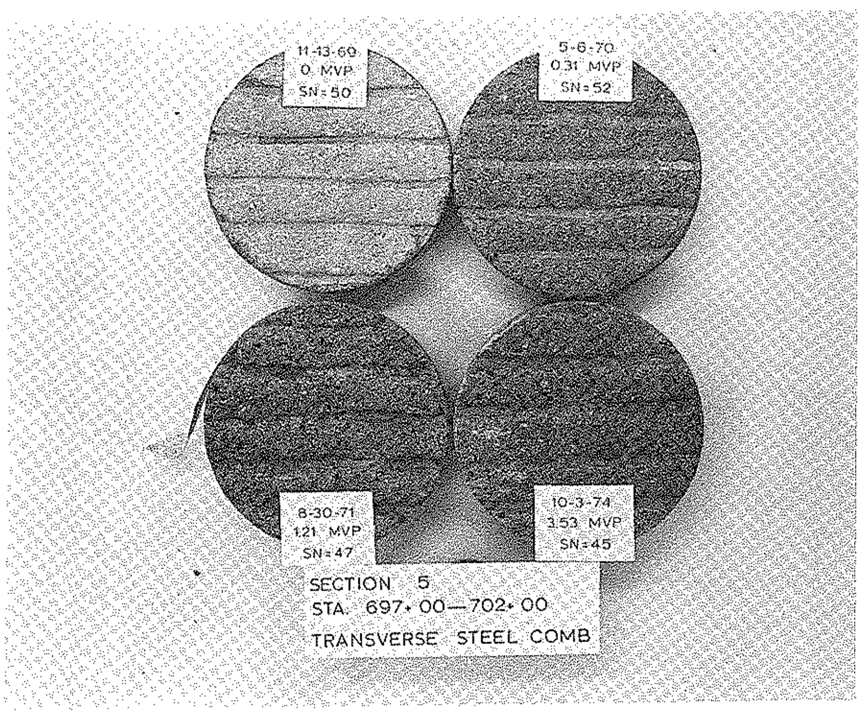
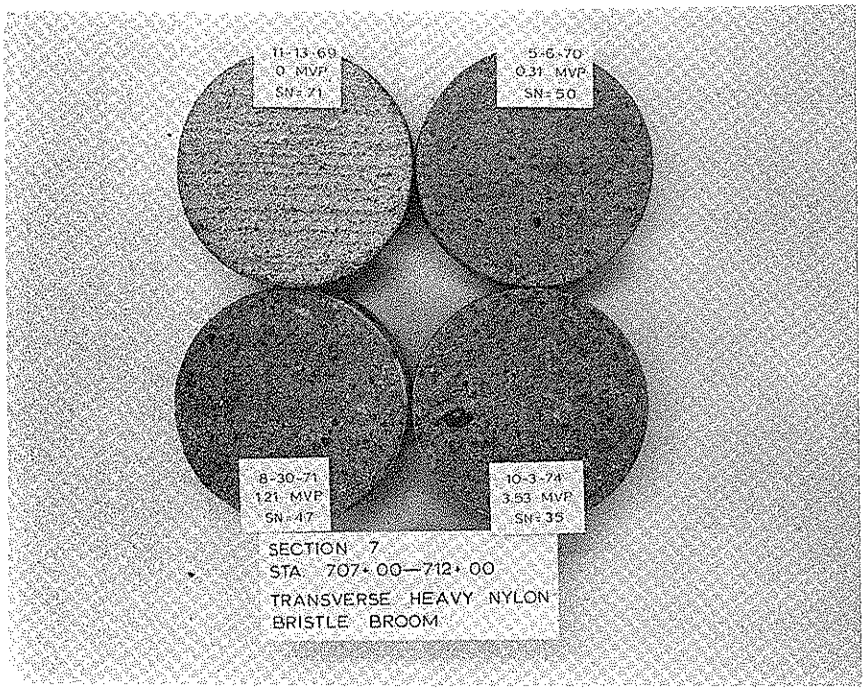

11-13-69
0 MVP
SN=50
5-6-70
0.31 MVP
SN=52
8-30-71
1.21 MVP
SN=47
10-3-74
3.53 MVP
SN=45
SECTION 5
STA. 697+00—702+00
TRANSVERSE STEEL COMB

FIG. 19


11-13-69
0 MVP
SN=71
5-6-70
0.31 MVP
SN=50
8-30-71
1.21 MVP
SN=47
10-3-74
3.53 MVP
SN=35
SECTION 7
STA 707+00—712+00
TRANSVERSE HEAVY NYLON
BRISTLE BROOM

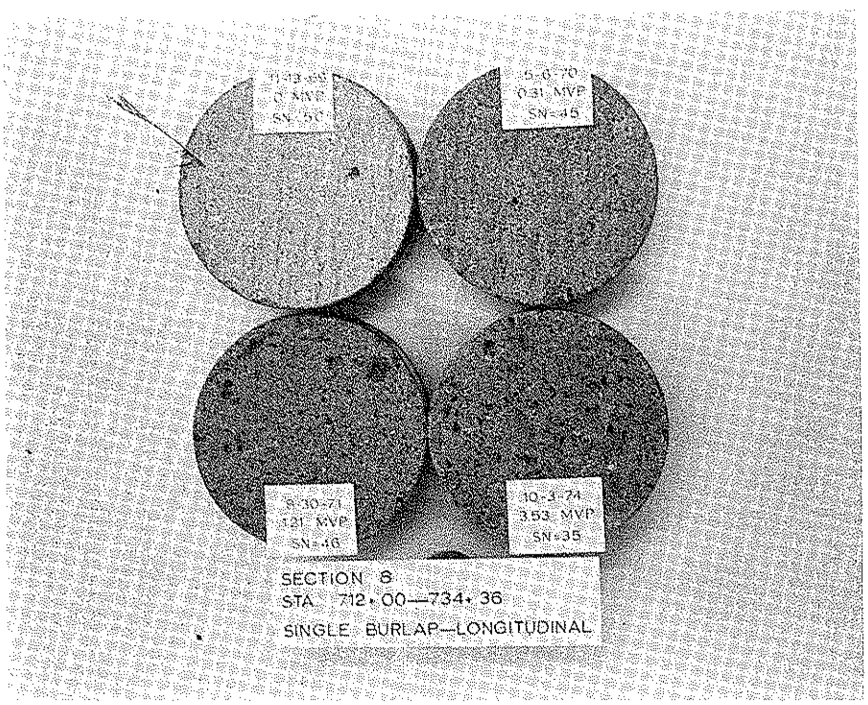

5-6-70
0.31 MVP
SN=45
8-30-71
1.21 MVP
SN=46
10-3-74
3.53 MVP
SN=35
SECTION 8
STA 712+00—734+36
SINGLE BURLAP—LONGITUDINAL

FIG. 20


11-13-69
0 MVP
SN=57
5-6-70
0.31 MVP
SN=52
8-30-71
1.21 MVP
SN=46
10-3-74
3.53 MVP
SN=34
SECTION 9
STA. 734+36—741+64
TWO SECTIONS OF BURLAP
(144 SQ. FT.) SPACED 12'


11-13-69
0 MVP
SN=---
5-6-70
0.31 MVP
SN=51
8-30-71
1.21 MVP
SN=49
10-3-74
3.53 MVP
SN=36
SECTION 10
STA. 741+64—747+00
SINGLE BURLAP DRAG (144 SQ. FT.)
WITH 6" FRAYED END

FIG. 21

APPENDIX C

SKID RESISTANCE SUMMARY
TAMA-FN-63-5(7)--21-86

SECTION	1		2		3		4		5		6		7		8		9		10	
DATE	EB	WB	EB	WB	EB	WB	EB	WB	EB	WB	EB	WB	EB	WB	EB	WB	EB	WB	EB	WB
11/12,13/69	53	52	54	59	42	50	53	58	48	52	61	60	71	71	49	51	57	--	--	--
4/10/70	48	50	48	50	42	48	53	55	51	51	55	57	52	52	46	48	51	53	51	48
5/6/70	48	49	48	47	42	45	53	55	53	51	51	54	49	51	46	45	52	52	53	49
10/26/70	47	46	46	46	44	42	50	49	46	46	50	49	49	48	43	45	48	49	50	47
10/29/70	48	52	48	51	43	48	51	52	49	48	52	52	48	51	47	49	50	52	51	50
4/9/71	45	42	41	41	38	40	49	49	48	47	46	44	43	42	43	43	41	43	47	46
9/2/71	45	47	42	44	41	41	47	49	46	48	47	50	45	50	45	47	44	49	50	48
4/24/72	46	47	44	44	41	40	48	49	47	47	45	45	44	45	45	47	44	45	48	49
10/24/72	43	44	40	43	39	40	45	48	46	44	42	44	40	43	40	44	40	46	44	45
5/4/73	39	39	39	41	36	36	44	48	43	47	38	41	40	41	36	39	38	41	41	39
5/22/74	35	39	39	38	34	34	46	45	45	46	36	38	35	36	35	36	34	35	36	39
4/8/75	38	40	40	39	38	38	43	43	42	43	34	39	38	38	38	38	36	40	40	41

FIG. 22

STANDARD SPEED GRADIENT
SKID NUMBER VS. SPEED
SECTION 1

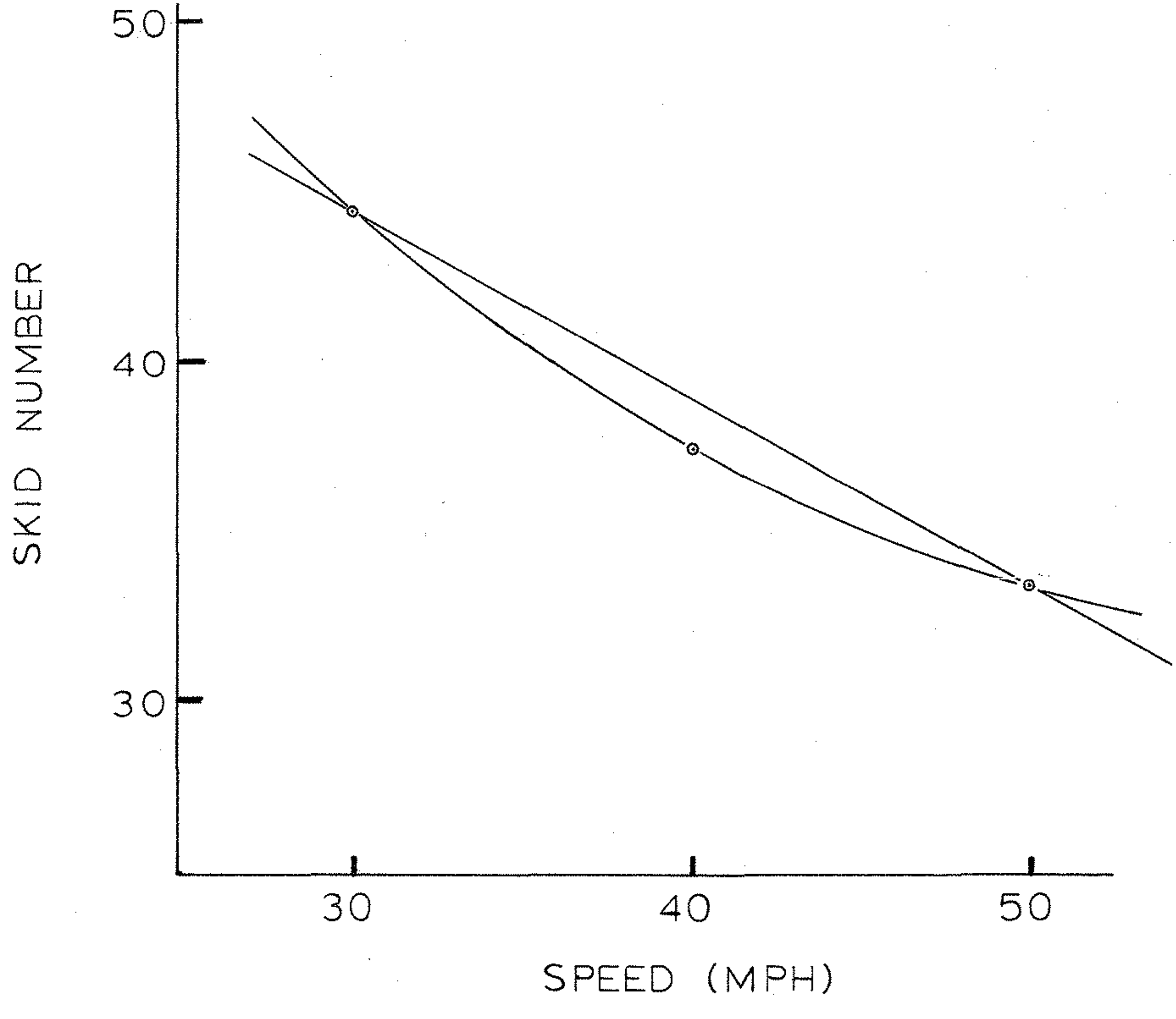


FIG. 22

STANDARD SPEED GRADIENT
SKID NUMBER VS. SPEED
SECTION 2

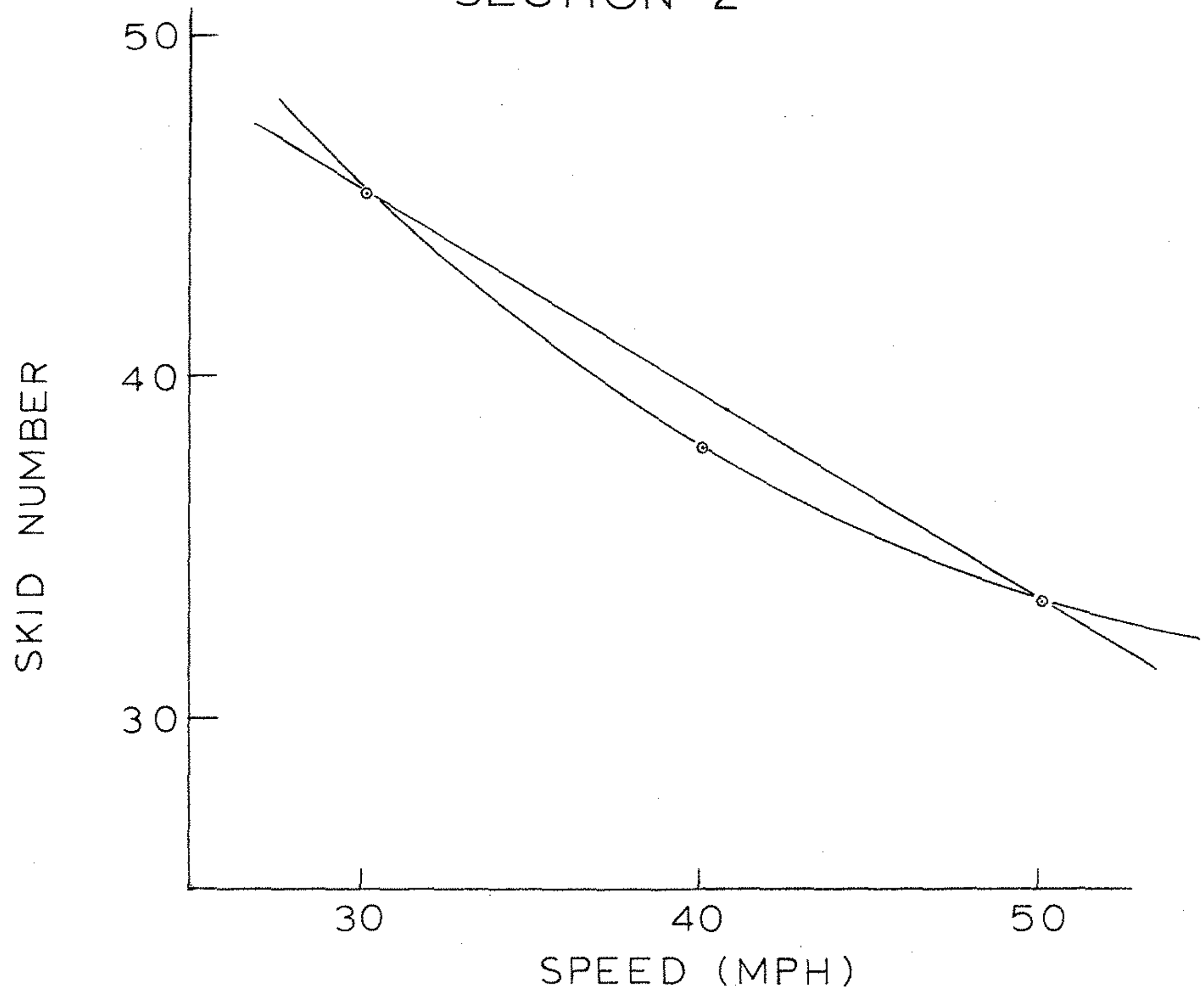


FIG. 24

STANDARD SPEED GRADIENT
SKID NUMBER VS. SPEED
SECTION 3

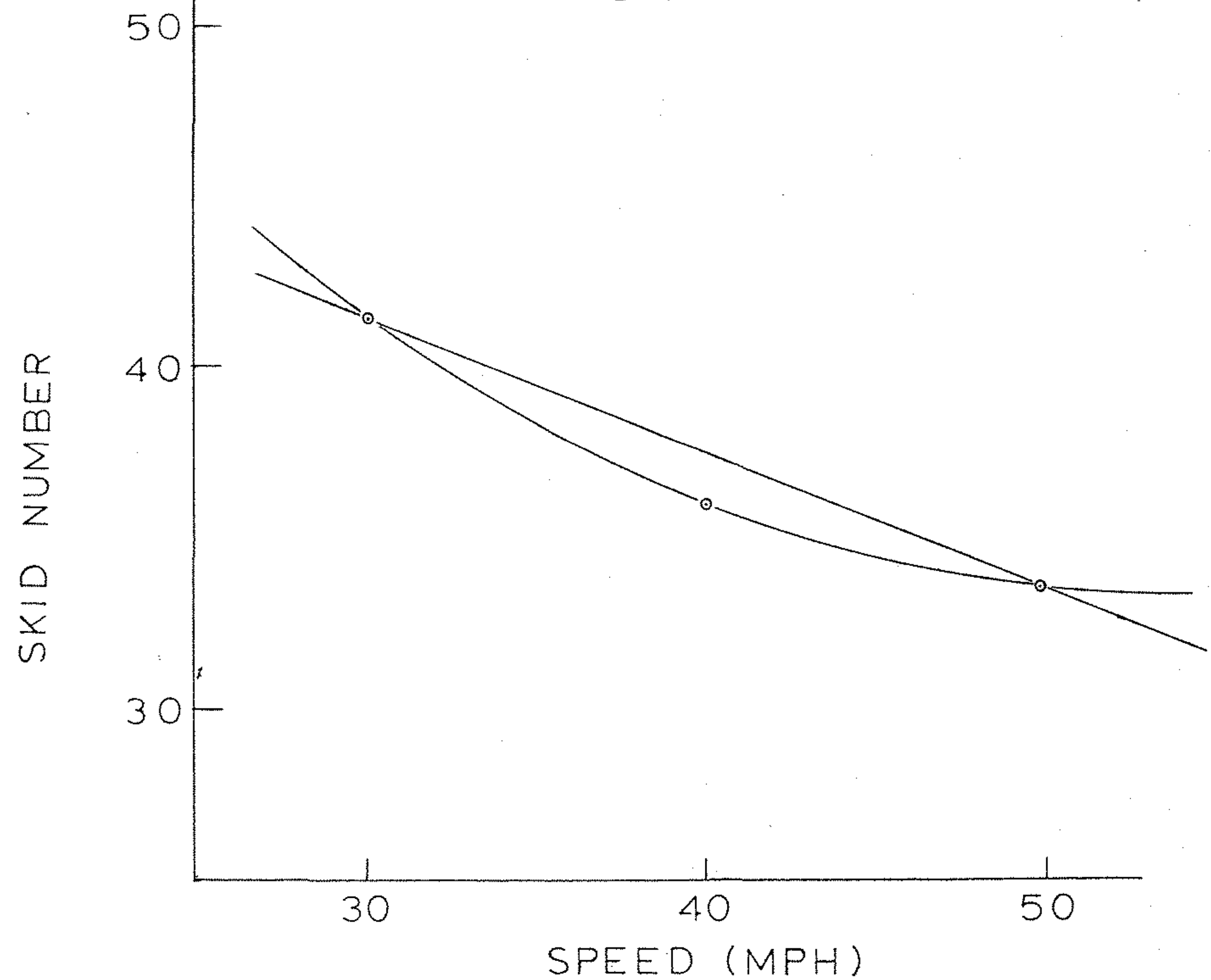


FIG. 2

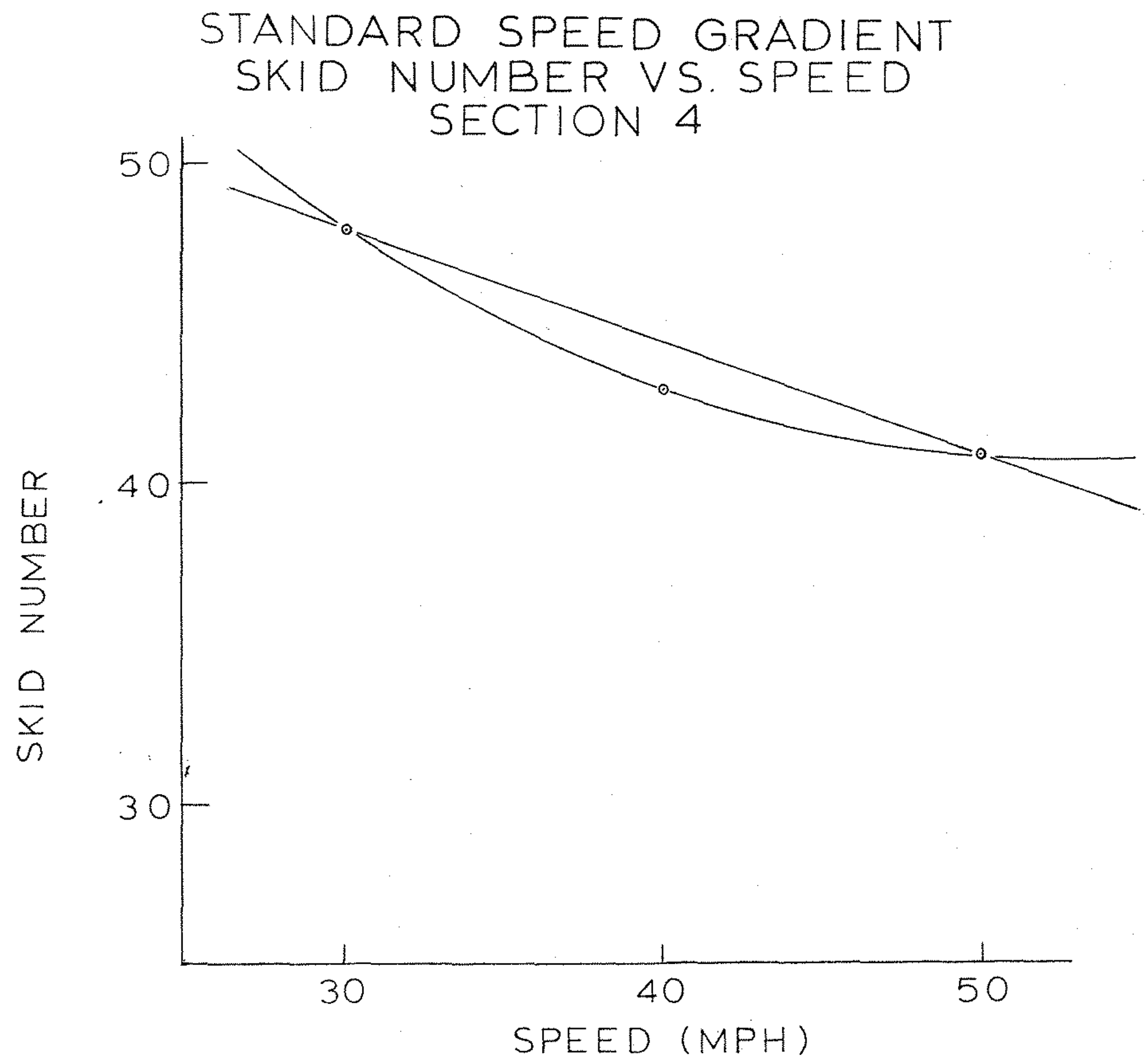

STANDARD SPEED GRADIENT
SKID NUMBER VS. SPEED
SECTION 4
SKID NUMBER
50
40
30
30
40
50
SPEED (MPH)

FIG. 26

STANDARD SPEED GRADIENT
SKID NUMBER VS. SPEED
SECTION 5

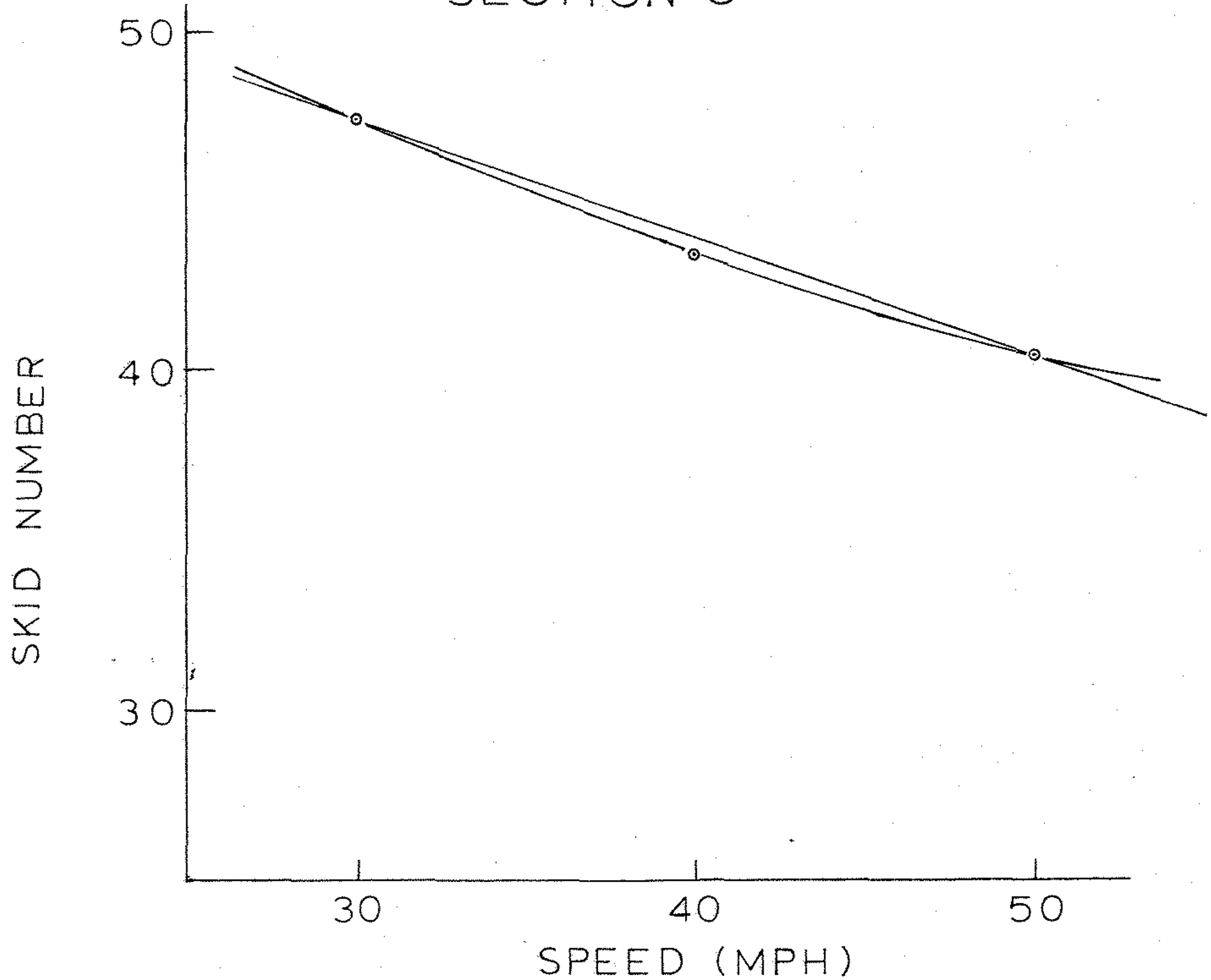


FIG. 27

STANDARD SPEED GRADIENT
SKID NUMBER VS. SPEED
SECTION 6

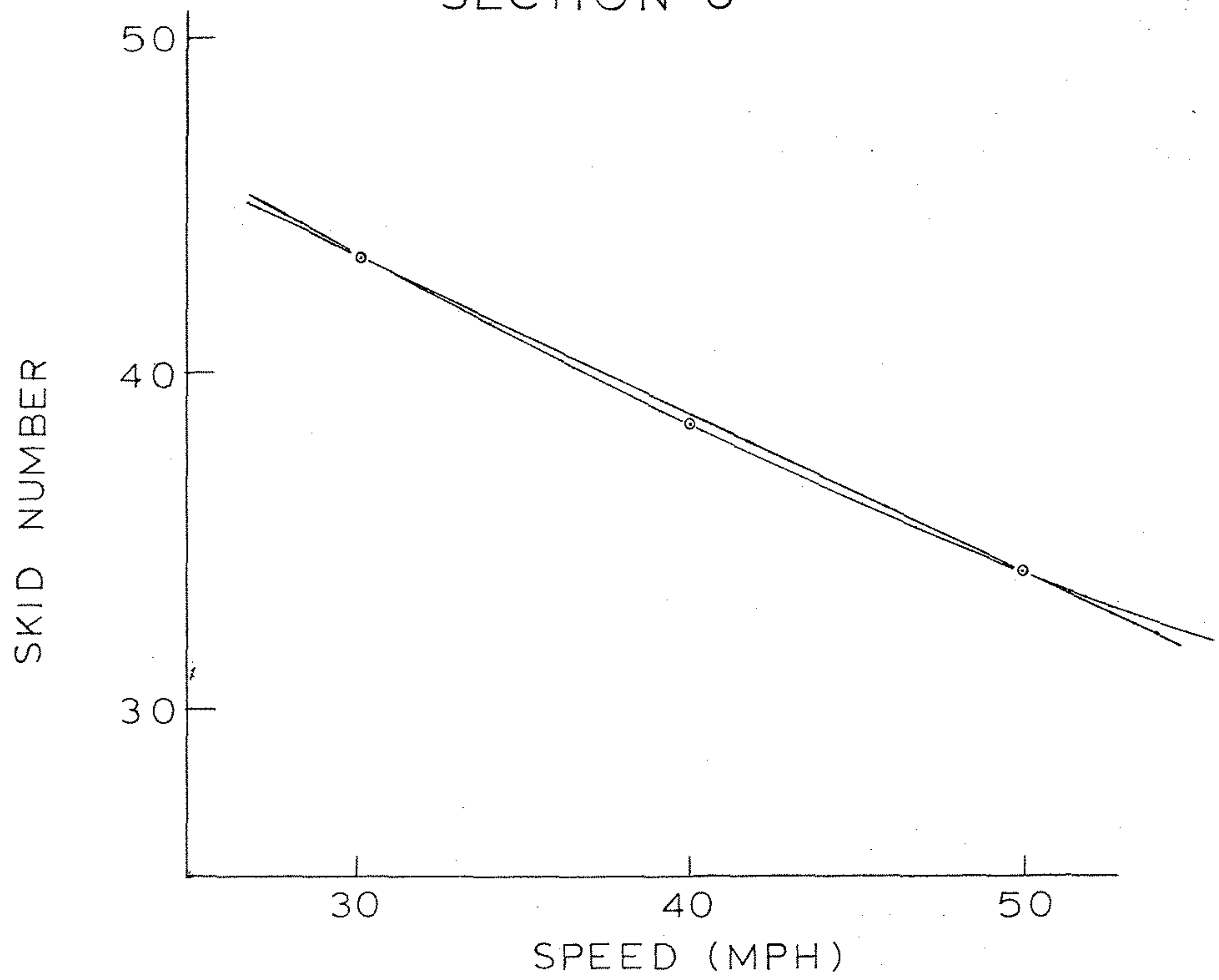


FIG. 28

STANDARD SPEED GRADIENT
SKID NUMBER VS. SPEED
SECTION 7

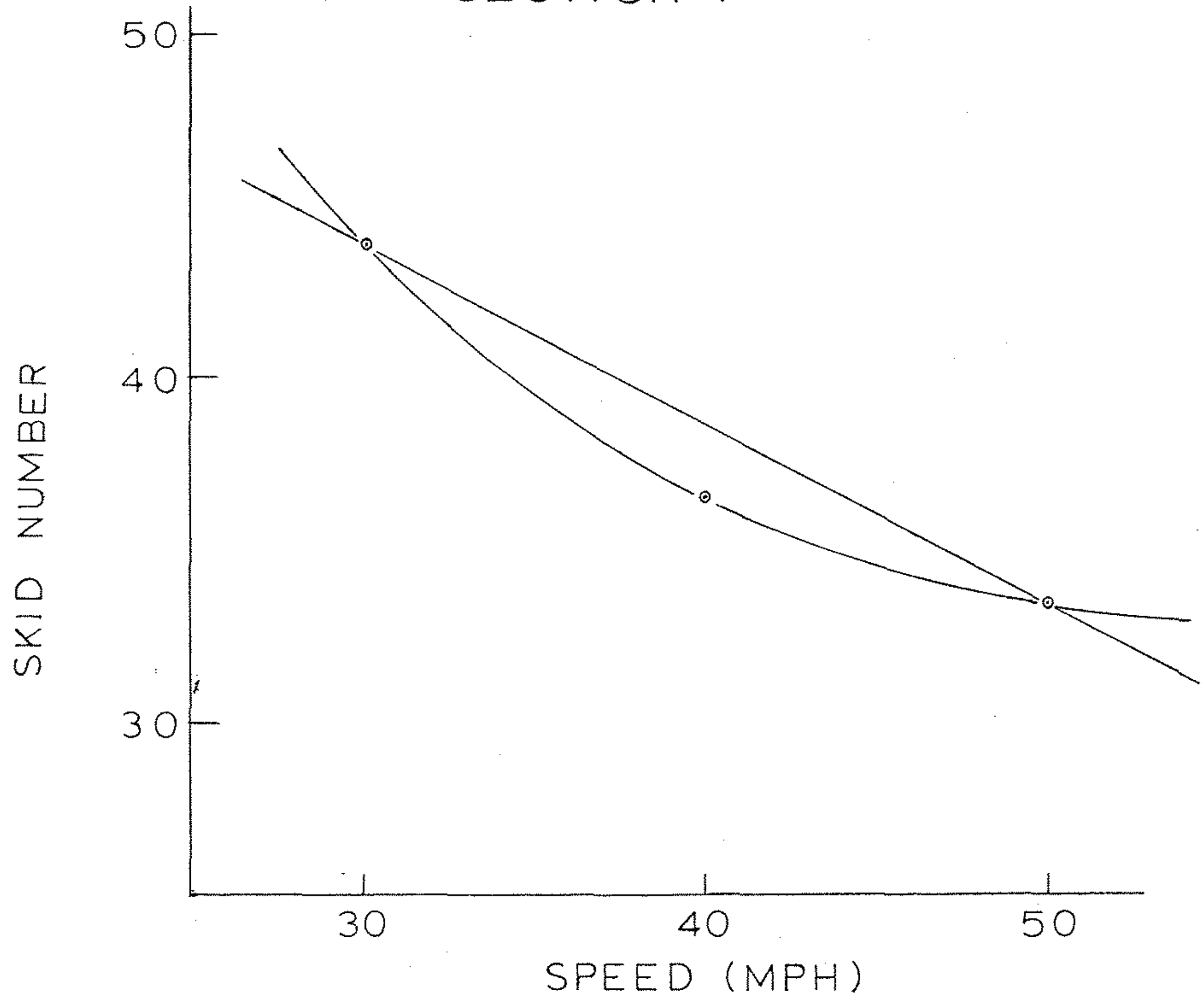


FIG. 2[illegible]

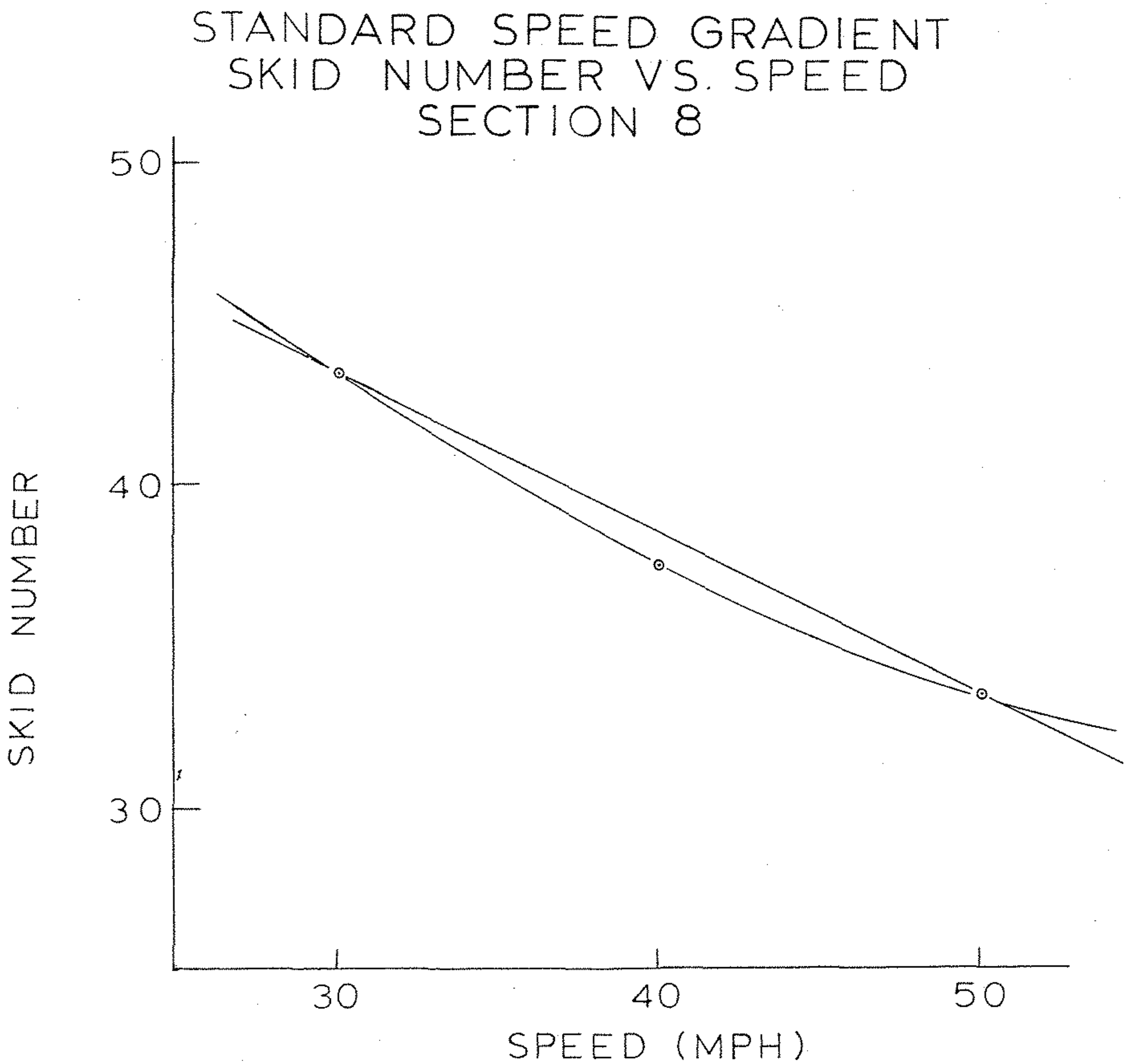

STANDARD SPEED GRADIENT
SKID NUMBER VS. SPEED
SECTION 8
SKID NUMBER
50
40
30
30
40
50
SPEED (MPH)

FIG. 30

STANDARD SPEED GRADIENT
SKID NUMBER VS. SPEED
SECTION 9

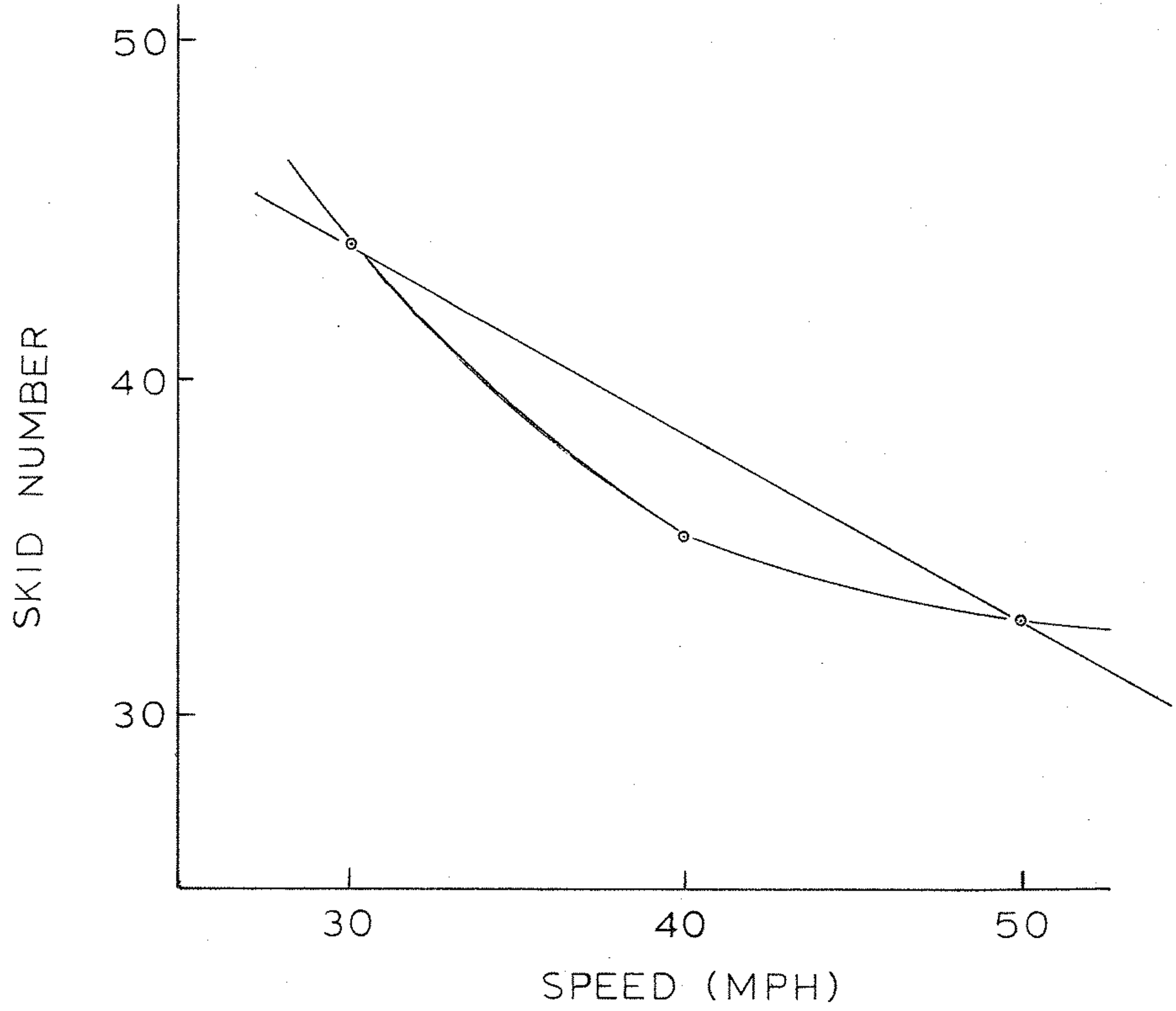


FIG. 3

STANDARD SPEED GRADIENT
SKID NUMBER VS. SPEED
SECTION 10

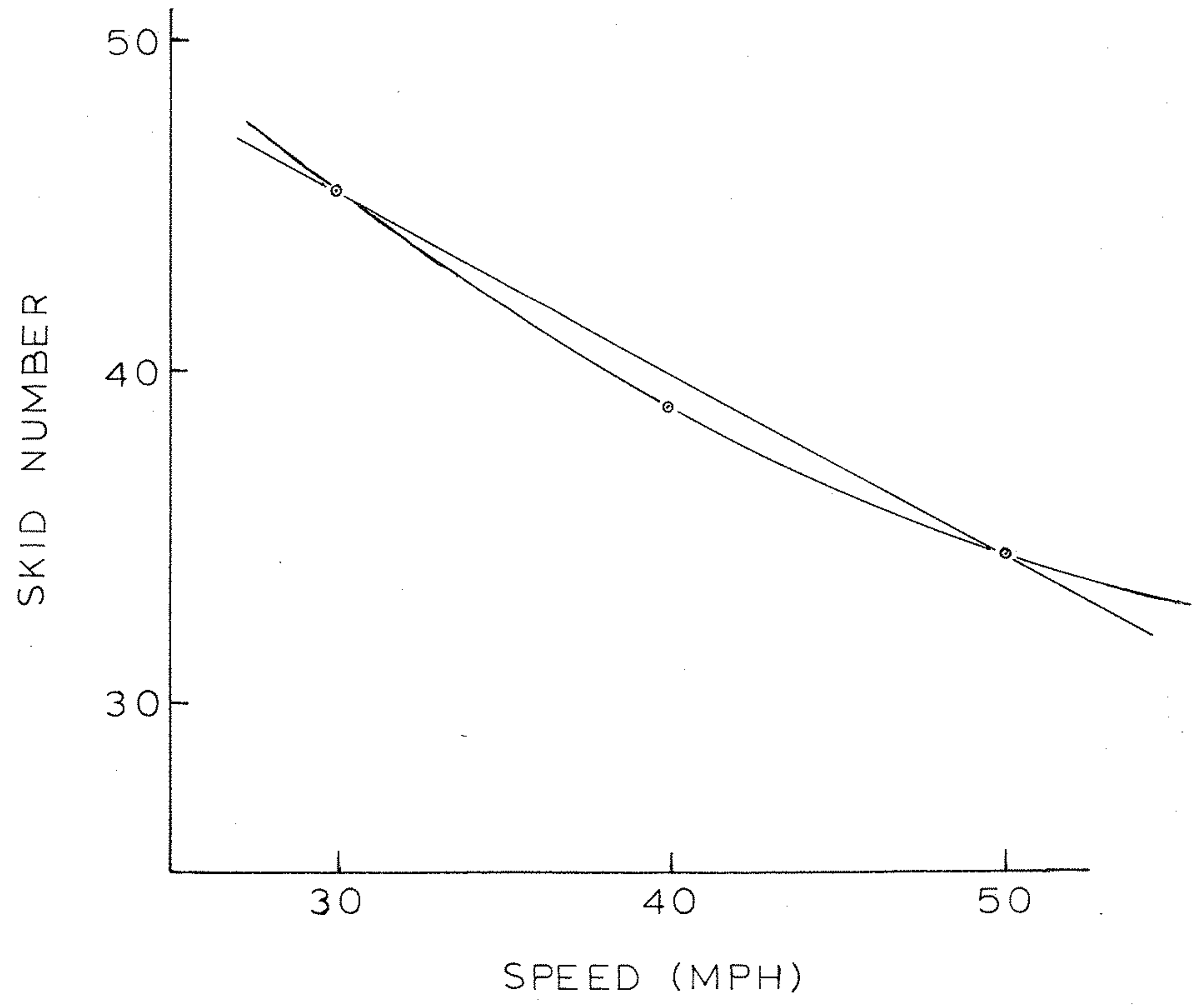


FIG. 32

APPENDIX D

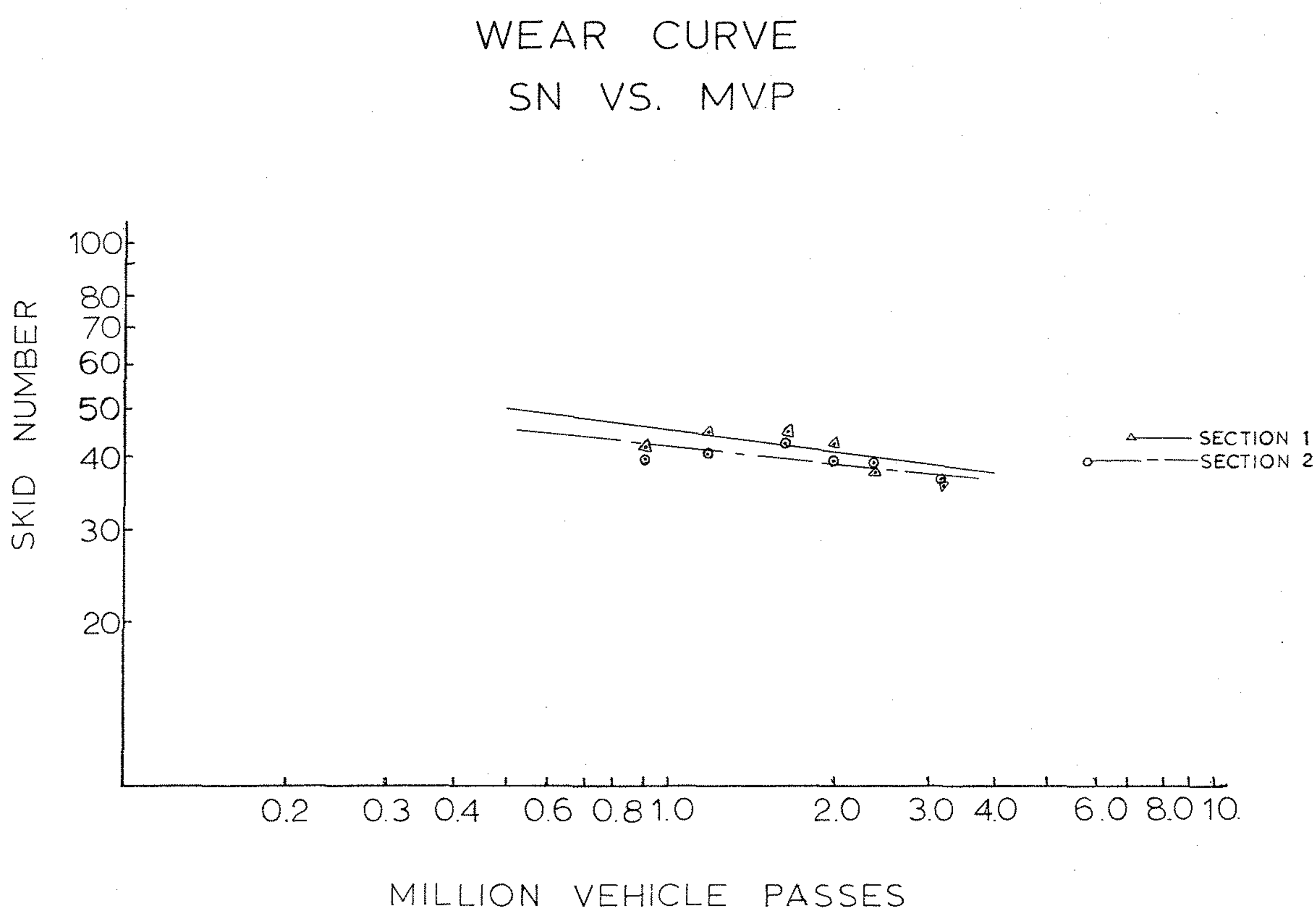

WEAR CURVE
SN VS. MVP
SKID NUMBER
100
80
70
60
50
40
30
20
0.2
0.3
0.4
0.6
0.8
1.0
2.0
3.0
4.0
6.0
8.0
10.
MILLION VEHICLE PASSES
SECTION 1
SECTION 2

FIG. 33

WEAR CURVE
SN VS. MVP

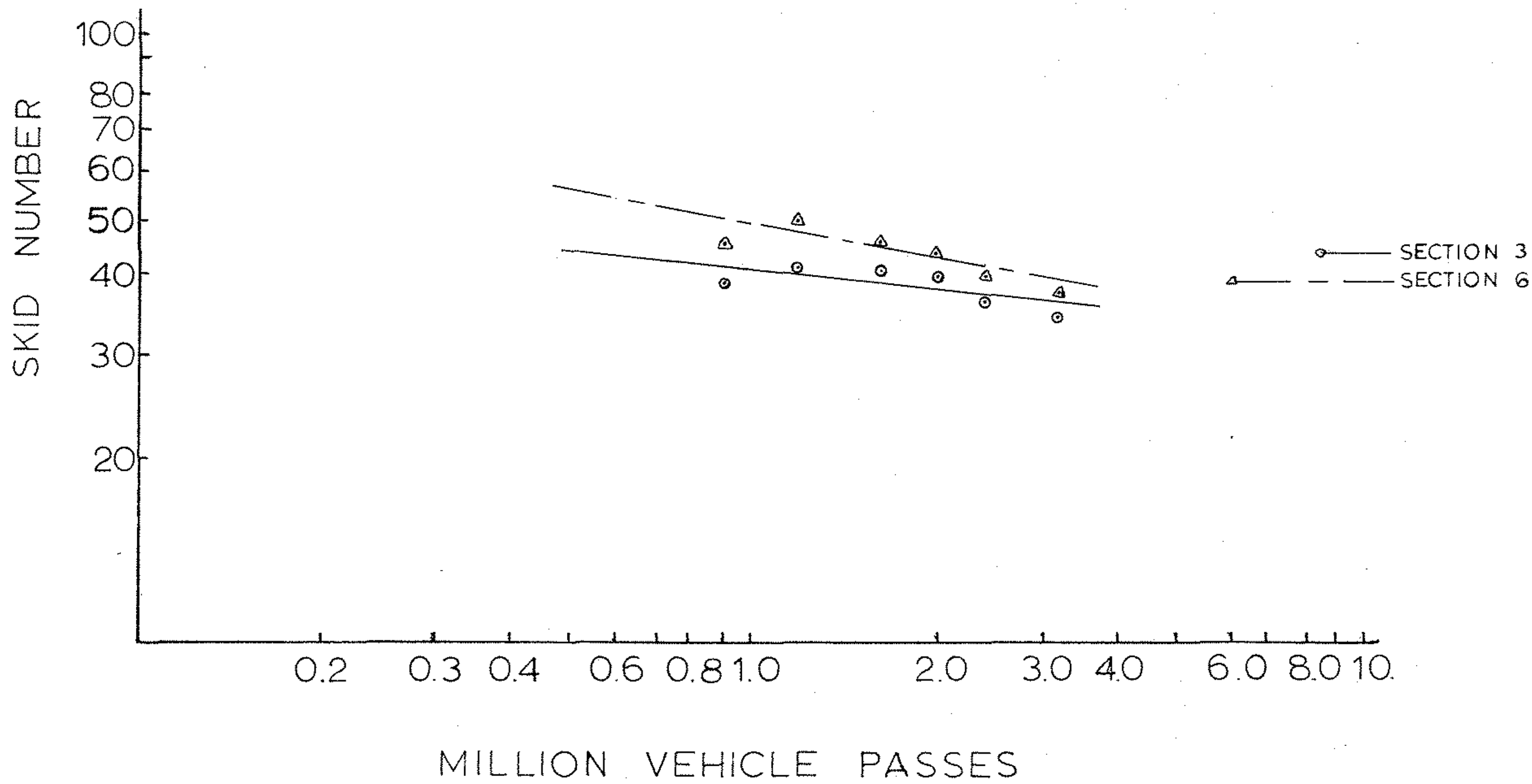


FIG. 34

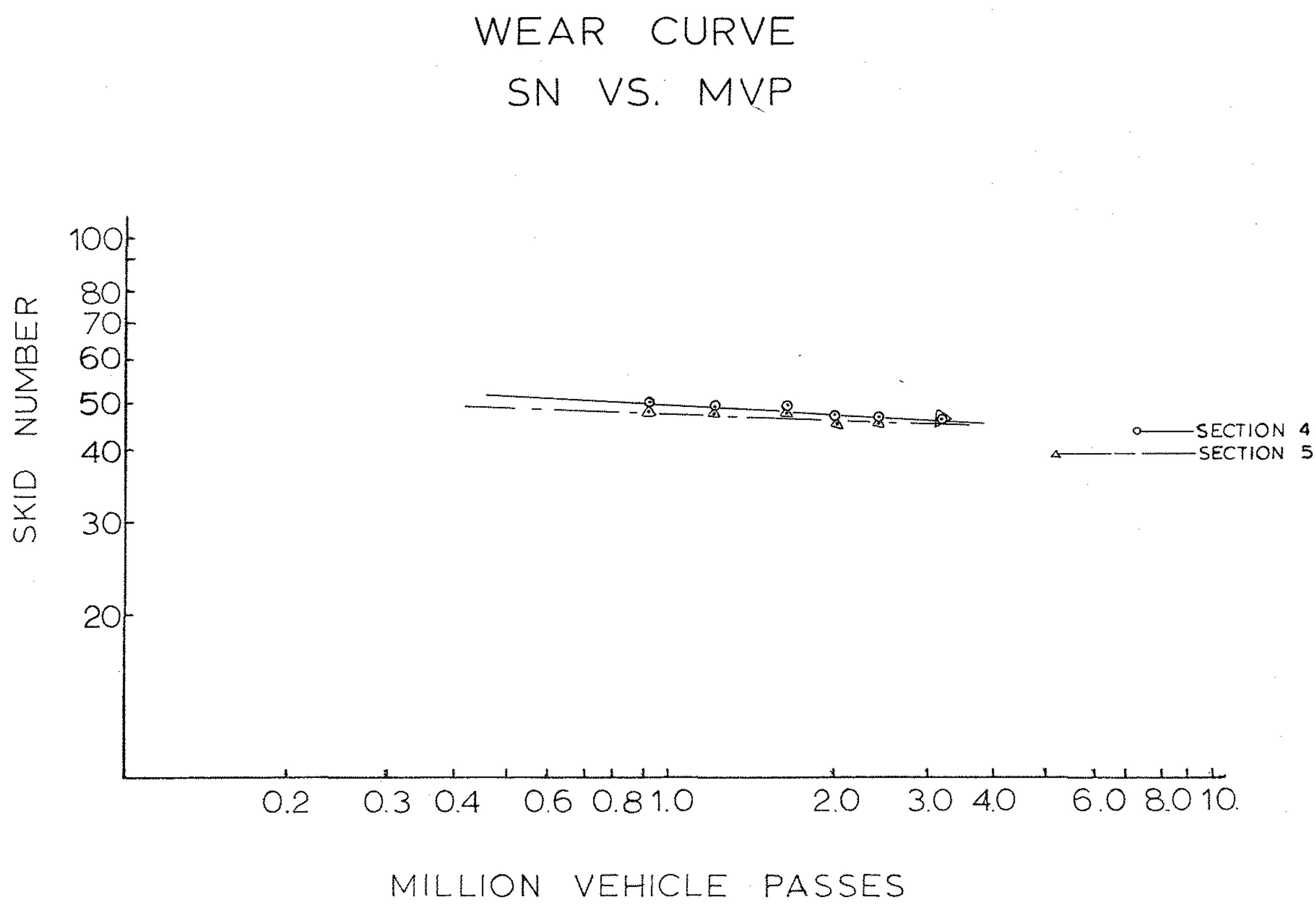
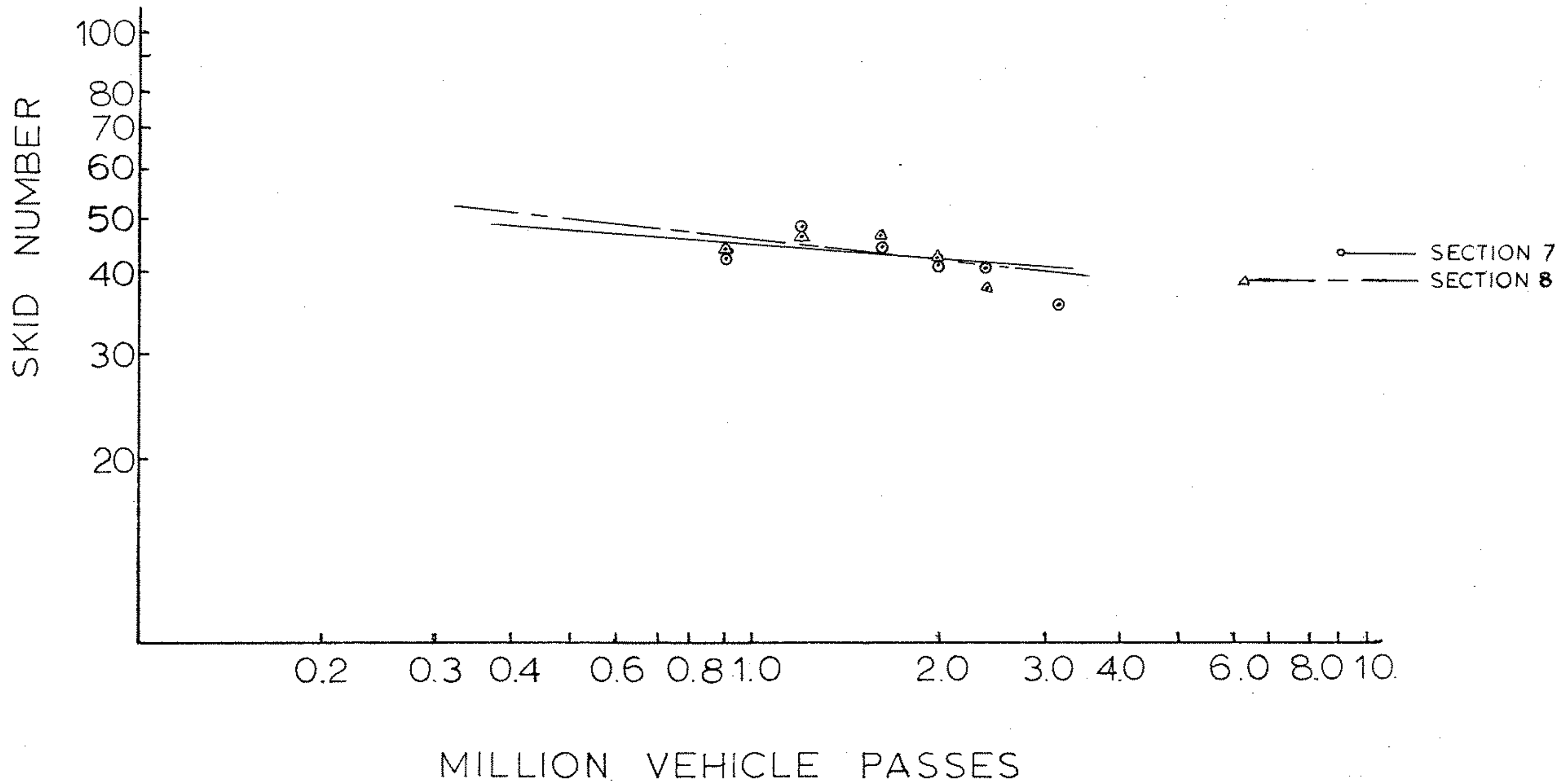

WEAR CURVE
SN VS. MVP
SKID NUMBER
100
80
70
60
50
40
30
20
0.2
0.3
0.4
0.6
0.8
1.0
2.0
3.0
4.0
6.0
8.0
10.
MILLION VEHICLE PASSES
SECTION 4
SECTION 5

FIG. 35

WEAR CURVE
SN VS. MVP



F.G. 3

WEAR CURVE
SN VS. MVP

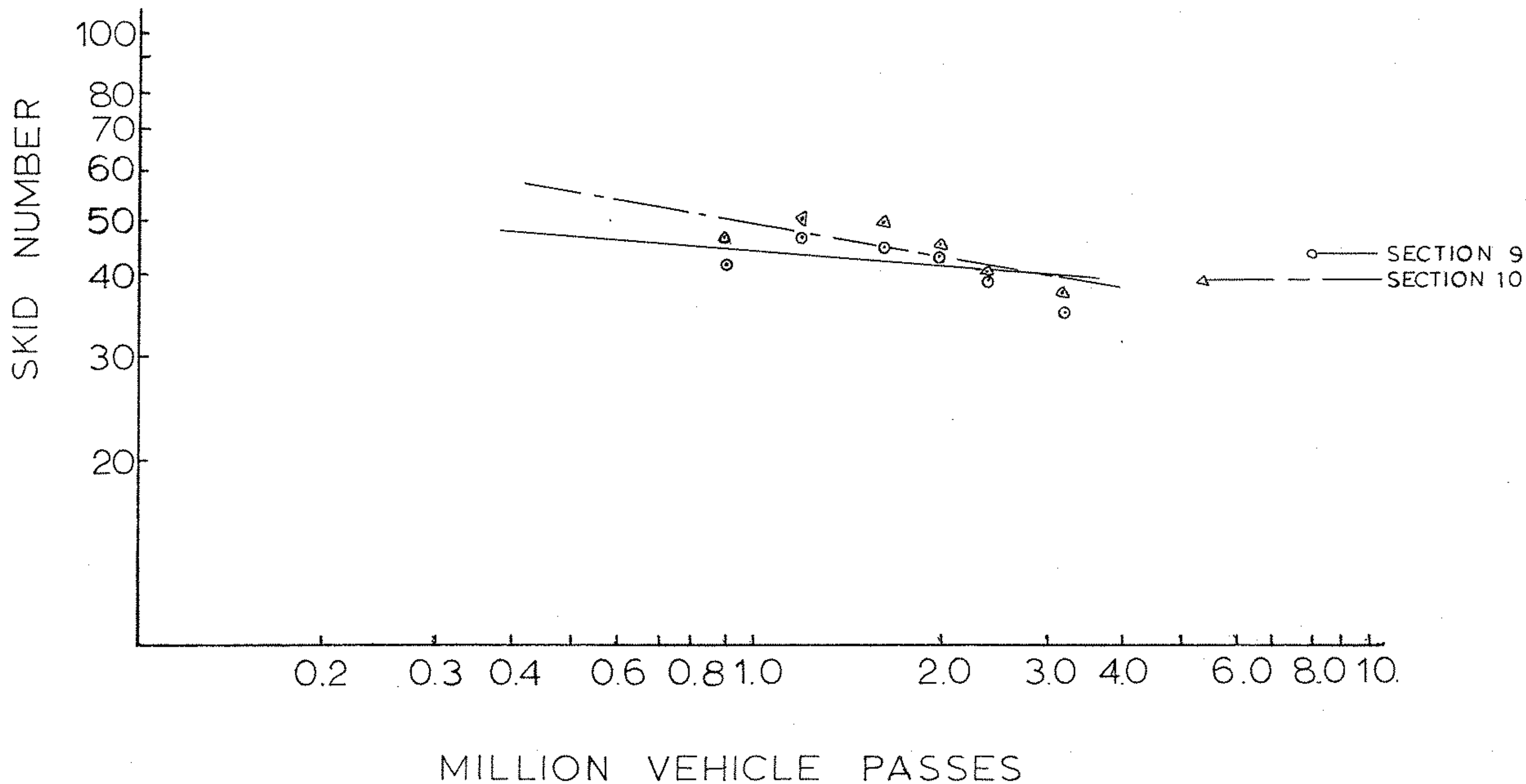


FIG. 37

SKID NUMBER VS. TIME

FIG. 38

SKID NUMBER VS. TIME

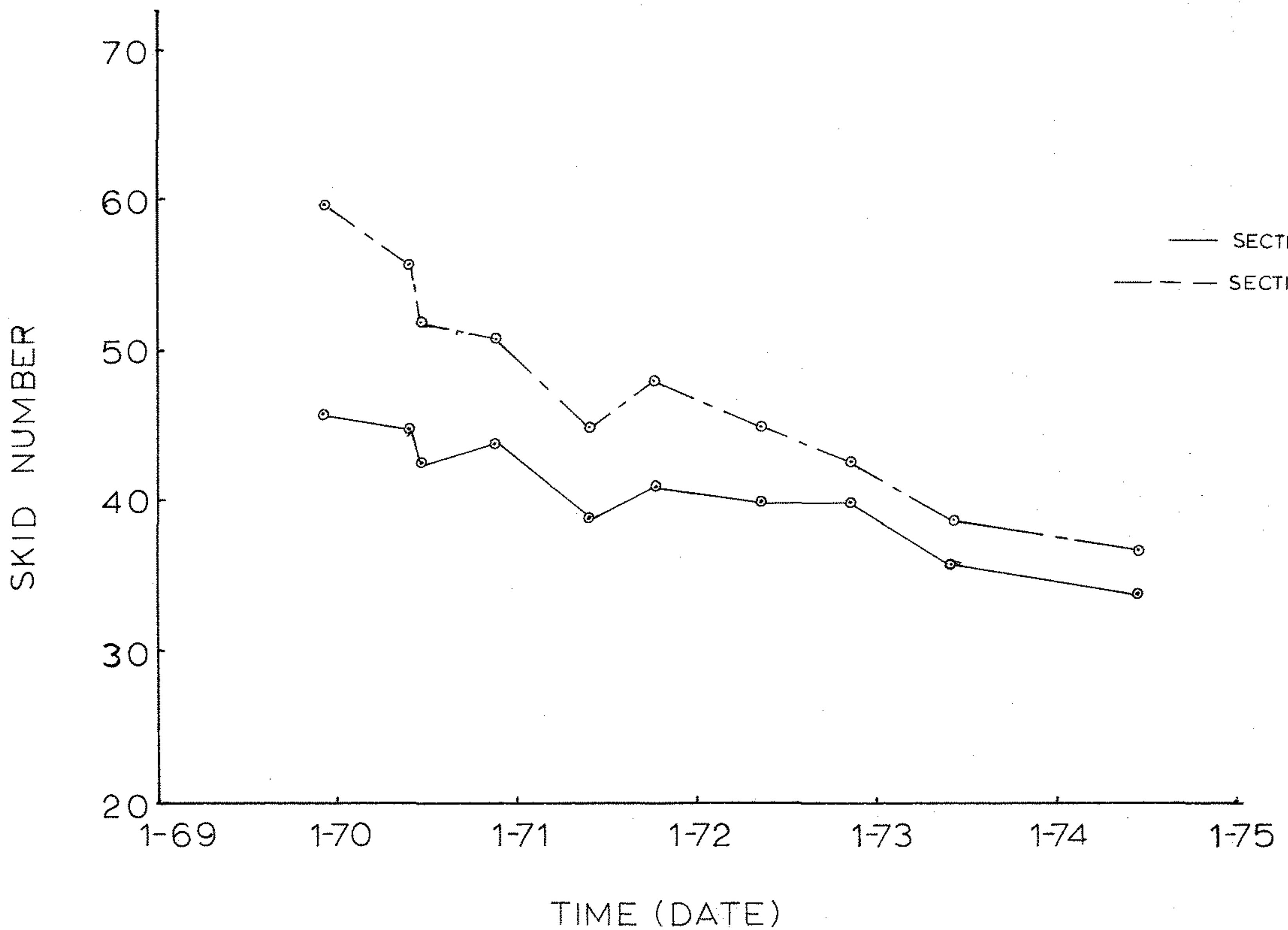


FIG. 39

SKID NUMBER VS. TIME

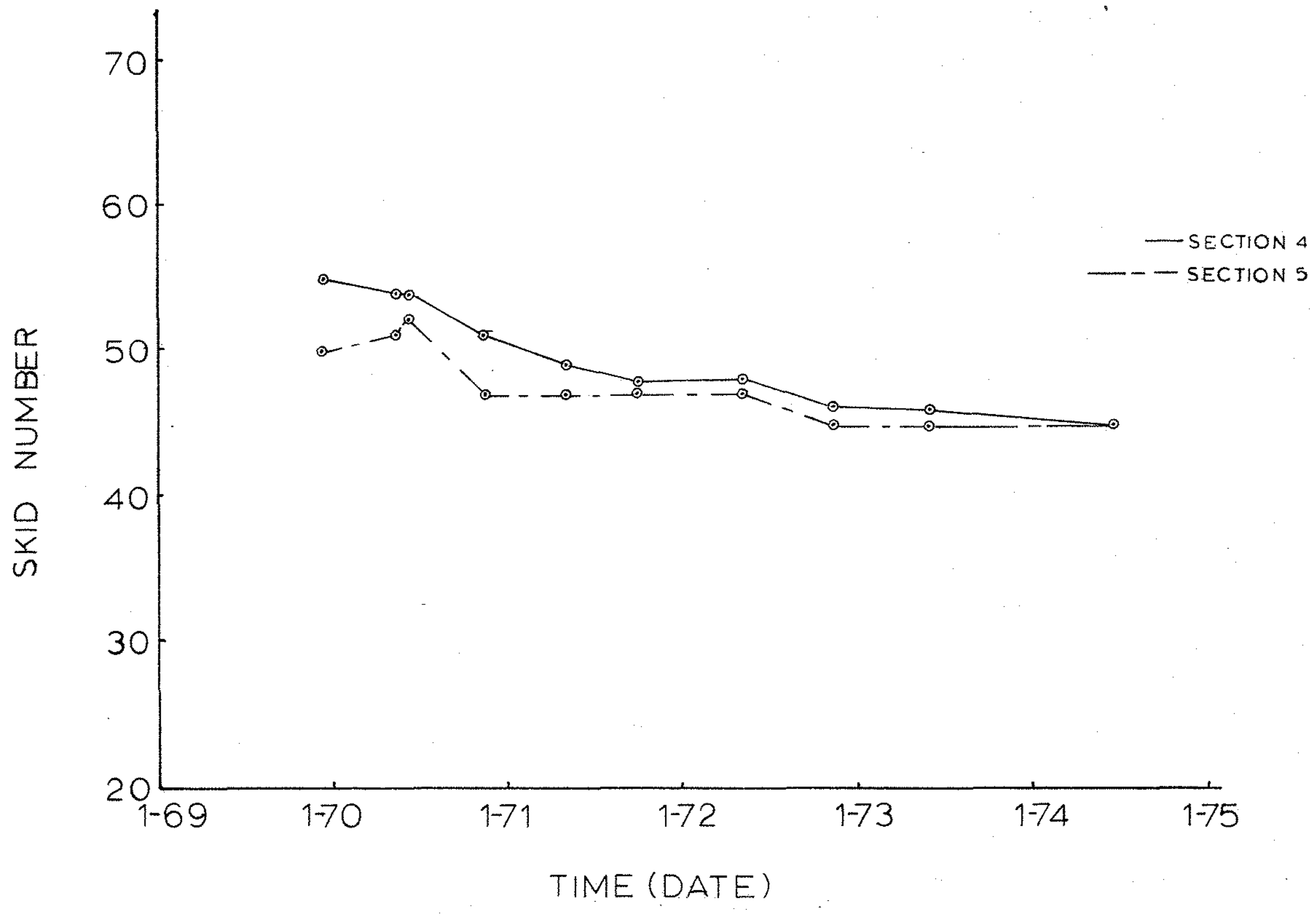


FIG. 4

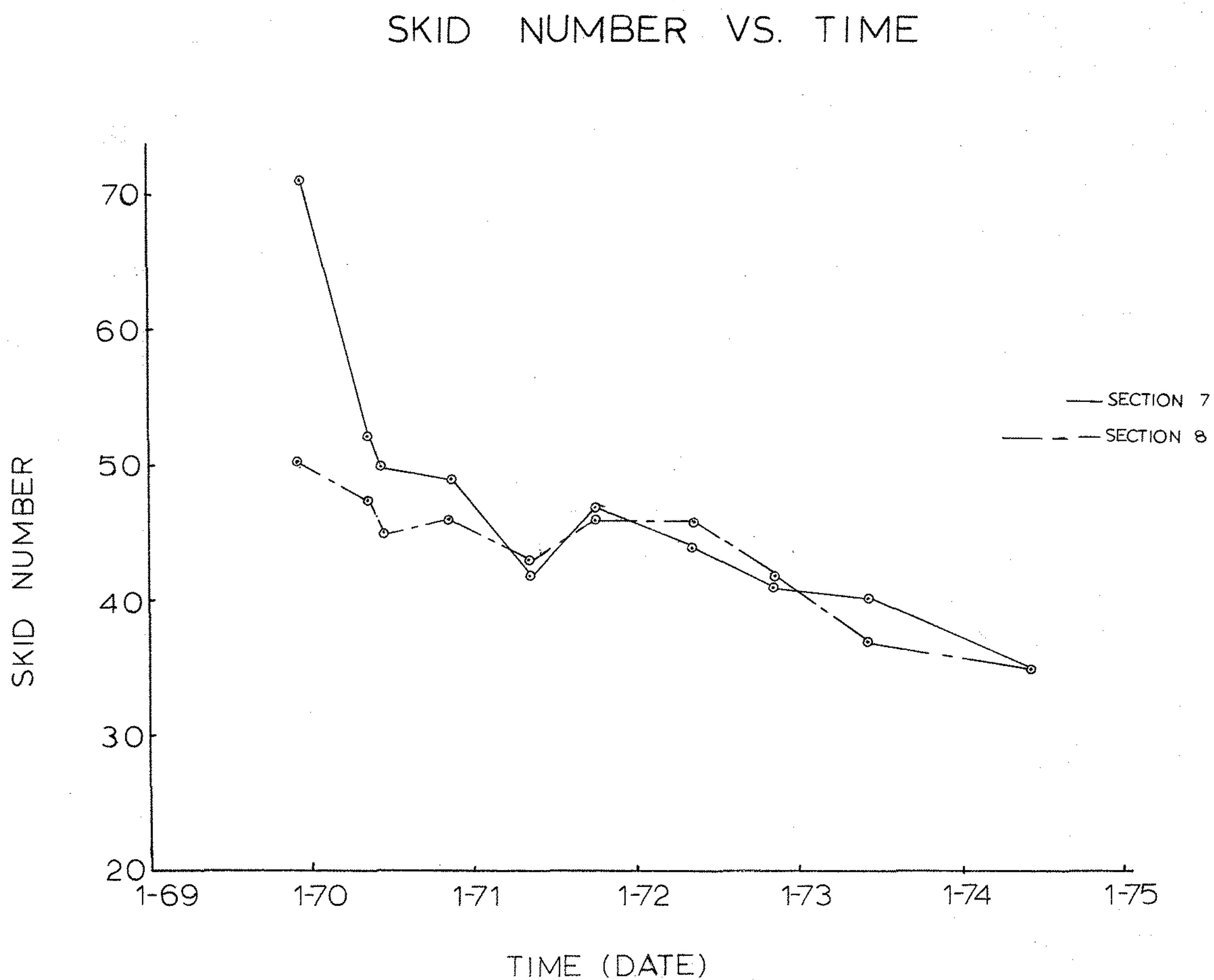

SKID NUMBER VS. TIME
SKID NUMBER
70
60
50
40
30
20
1-69
1-70
1-71
1-72
1-73
1-74
1-75
TIME (DATE)
SECTION 7
SECTION 8

FIG. 41

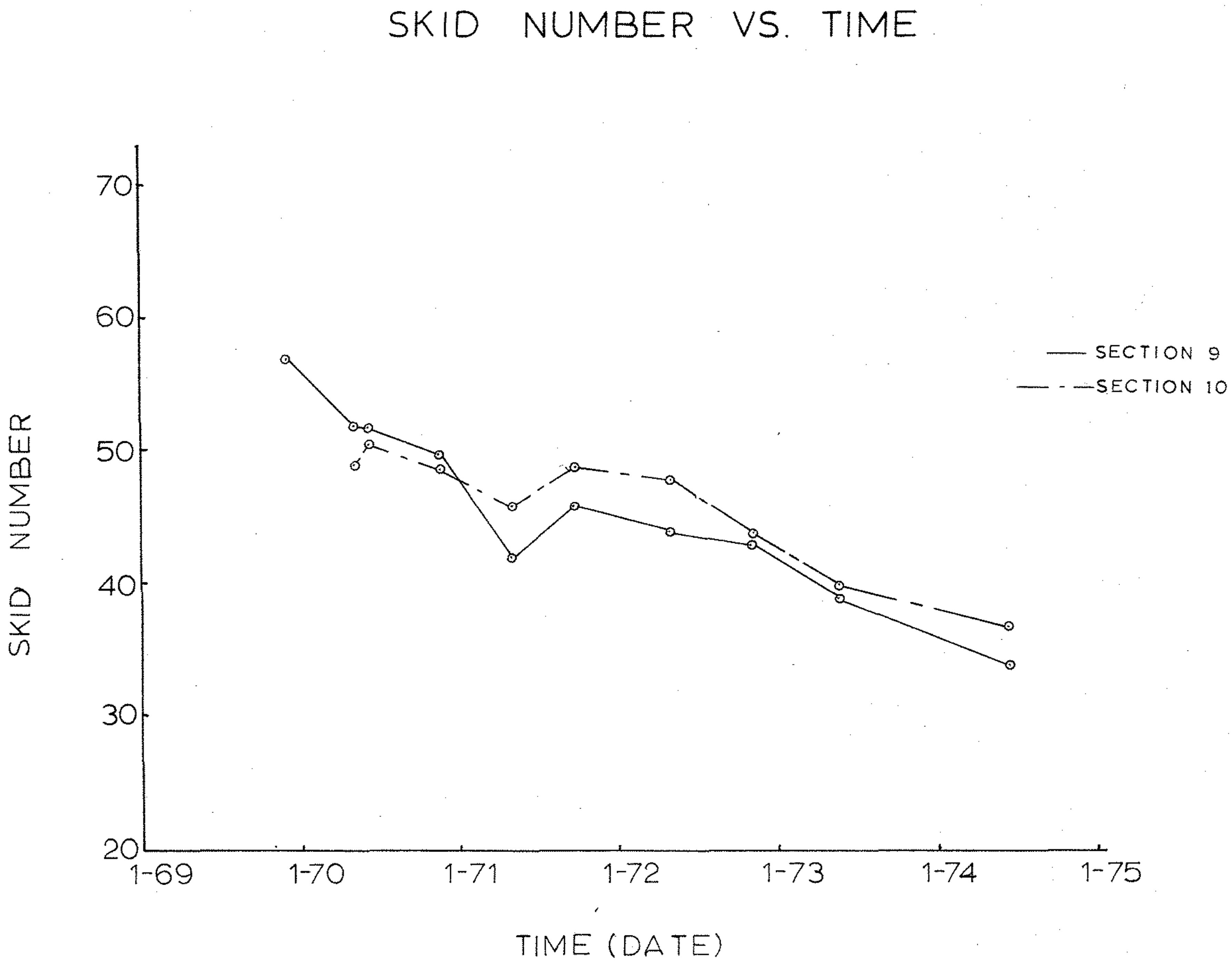

SKID NUMBER VS. TIME
SECTION 9
SECTION 10
SKID NUMBER
70
60
50
40
30
20
1-69
1-70
1-71
1-72
1-73
1-74
1-75
TIME (DATE)

FIG. 4?