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16. ABSTRACT
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A rather comprehensive study has been completed on the improving of the skid resistance of PCC pavements by serration. The type of grooving pattern used influences the reaction of people driving motorcycles or light cars over longitudinal (parallel to the centerline) serrations. It appears that the nature of the exisiting concrete surface, and the type of serration pattern influence the degree of improvement in friction values. A marked reduction in wet weather accidents has occurred in critical curve areas that have been serrated.

A detailed analysis of 1705 single vehicle accidents that occurred during rainy weather in 1964 indicated that 152 or nine percent of these happened during periods of heavy rainfall where dynamic hydroplaning might have been a possibility. Factors such as excessive speed under extremely poor driving conditions appear to be important in the reported skidding accidents during heavy rainfall.

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HIGHWAY RESEARCH REPORT

FIELD AND LABORATORY STUDIES ON SKID RESISTANCE OF PAVEMENT SURFACES

68-02

STATE OF CALIFORNIA

TRANSPORTATION AGENCY

DEPARTMENT OF PUBLIC WORKS

DIVISION OF HIGHWAYS

MATERIALS AND RESEARCH DEPARTMENT

RESEARCH REPORT

NO. M & R 633126

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STATE OF CALIFORNIA—TRANSPORTATION AGENCY

RONALD REAGAN, Governor

DEPARTMENT OF PUBLIC WORKS

DIVISION OF HIGHWAYS

MATERIALS AND RESEARCH DEPARTMENT

5900 FOLSOM BLVD., SACRAMENTO 95819

February 1968

Interim Report
M&R No. 633126

Mr. J. A. Legarra
State Highway Engineer

Dear Sir:

Submitted herewith is a research interim report titled:

FIELD AND LABORATORY STUDIES ON SKID RESISTANCE OF PAVEMENT SURFACES

ERNEST ZUBE
Principal Investigator

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Very truly yours,

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ACKNOWLEDGEMENT

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CONTENTS

INTRODUCTION

One of the most important properties of a pavement surface is its skid resistance characteristics. Recent studies (1) indicate that there are two different types of loss of traction on wet surfaces, namely viscous and dynamic hydroplaning. Viscous hydroplaning occurs when a thin fluid film is present on the pavement, and presently used methods of measurement for skid resistance deal with this form of loss of traction. Dynamic hydroplaning occurs when the pavement has a substantial thickness of water, approximately 0.2 inch, on the surface. Present methods of measurement do not provide an adequate indication of potential dynamic hydroplaning. One of the most important problems connected with loss of traction by viscous hydroplaning is the determination of a minimum value for remedial action. The purpose of this interim report is to present our available information on this phase of the work. Also included in the report are studies on remedial measures for low skid resistant surfaces, and a preliminary investigation of accident data in an effort to determine the importance of dynamic hydroplaning on California highways.

CONCLUSIONS

1. A correlation study involving the British Portable Tester indicates that the present California tentative figure of 0.25f for remedial action may be slightly below the minimum standards as used in England. It is interesting to note that the correlation places all results for minimum values in the range of 0.25f-0.30f.

2. A wet weather accident analysis indicates that most of the single car accidents occurred on curves, the average value for the friction factor being 0.22f. However, twenty-eight percent of the accidents that occurred on curves were on pavements of 0.25f-0.28f range. If further studies confirm this trend, then it would appear necessary to raise the tentative minimum to 0.28f on curves, depending somewhat on the radius. This is equivalent to the British minimum for all sites according to our calibration studies.

3. Preliminary studies indicate that friction values taken across the pavement may vary markedly. Some PCC pavements show marked drops in the friction factor in

the wheel tracks of the travel lane with little change in the between wheel track area or in the adjacent wheel tracks of the passing lane. This has not been found to occur with dense graded or open graded asphalt concrete pavements that show no signs of "bleeding". The importance of this finding is difficult to evaluate. It is proposed to continue this investigation by comparing transverse friction profiles with accident records on tangent and curve areas, and to run vehicle tests on these pavements.

4. A rather comprehensive study has been completed on the improvement of the skid resistance of PCC pavements by serration. The following statements are warranted:

a. In all cases the friction value is raised by pavement grooving. It appears that the nature of the existing concrete surface and the type of serration pattern influence the degree of improvement in the friction value.

b. The type of pattern influences the reaction of people driving motorcycles or light cars over longitudinally (parallel to the centerline) serrated areas of pavement. Complaints were serious with 1/4" x 1/4" grooves on 1" centers. 1/8" x 1/8" grooves on various centers did not raise complaints nor did V cuts 1/8" deep x 1/4" wide at the top separated by smaller V cuts.

c. Resistance to wear and polish of grooved areas has been excellent on two projects for periods of 5 1/2 and 8 1/2 years. However, other jobs show definite drops in the friction factor after 16-20 months of service life. More studies are required on this problem.

d. Accident studies on seven urban and rural freeway wet weather accident locations show a marked reduction in wet weather accidents, and a definite reduction in dry weather accidents. We believe that this is caused not only by the increase in friction factor during wet weather, but also is due to the "tracking" effect of the longitudinal serration which increases lateral stability of the vehicle.

e. At the present time the average cost of serration is approximately ten cents per sq. ft.

5. A detailed analysis of 1705 single vehicle accidents that occurred during rainy weather in 1964 indicated that 152 or nine percent of these happened during periods of heavy rainfall where dynamic hydroplaning might have been

a possiblity. Factors such as excessive speed under extremely poor driving conditions appear to be important in the reported skidding accidents during heavy rainfall. However, further accident analysis is probably warranted in order to confirm these preliminary findings based on a single year of accident data.

MEASURING EQUIPMENT

The California Skid Tester used in determining the coefficent of friction of pavement surfaces has been previously described (2). The present test method using this equipment is presented in Appendix "A". The measuring device has been calibrated against a towed trailer constructed by Professor R. A. Moyer of the University of California, Institute of Transportation (3). Previous studies by R. A. Moyer and others, indicated that the lowest skid resistance value for any given surface would be attained when the brakes are locked on a vehicle having smooth tread tires on a wet pavement with speeds around fifty miles per hour. It was felt that the California Skid Tester should be calibrated to simulate the worst conditions encountered by traffic. Therefore, in the correlation test program, the coefficient of friction values obtained from the Moyer unit using locked wheels, smooth tires, wet pavement and a speed of fifty miles per hour were compared to our readings obtained with a smooth tire, wet pavement and a tire speed of fifty miles per hour.

DEVELOPMENT OF INTERIM SKID RESISTANCE REQUIREMENTS FOR VISCOUS HYDROPLANING

In order to make effective use of test results derived from any form of skid test apparatus, the highway engineer must be provided with recommendations on minimum requirements for deciding on the necessity for remedial action. It is interesting to note that there is a large volume of literature on skid resistance measurements, but few recommendations for critical values that would be of aid to the engineer who must decide whether steps should be taken to improve the skid resistance of a given road surface.

During the period of 1950 to 1958, Professor Moyer determined the skid resistance of a large number of different pavements in the road system of the California Division of Highways (3 & 4). On the basis of this survey it was decided to tentatively use a value of 0.25f for remedial action, and to attempt to attain further information on the importance of geometric factors.

Since our available information on accident frequency correlation with skid resistance of the surface was very limited, it seemed desirable to obtain as much information as possible from the studies of other investigations. Two of the most complete studies are from the work of C. G. Giles in England and T. E. Shelburne in Virginia. Unfortunately, the equipment used in these studies is different from that used by this department. In order to make use of information attained by C. G. Giles and T. E. Shelburne this department purchased a British Portable Tester. The instruction book for the Portable Tester (5) provides a Table entitled, "Suggested Values of Skid Resistance for Use With the Portable Tester". The minimum values are based on a comprehensive accident analysis in England and vary depending on geometric factors. Also D. C. Mahone (6) presents a correlation between the British Portable Tester and the Virginia test car. This correlation permits a comparison with remedial action values proposed in Virginia.

Pavement surfaces were selected to provide a large range in coefficient of friction values. The selected pavements included Portland Cement Concrete, Asphalt Concrete and Screening Seal Coats. The asphalt concrete pavements included both dense and open graded surfaces. A series of measurements were made at selected locations using both the California Skid Tester and the British Portable Tester. At each location five readings were obtained with each instrument and averaged for a final reading.

A comparison of the recommended British values with the tentative California minimum figure is shown in Figure 1. Also shown is the Virginia minimum figure which was attained by using the correlation chart of D. C. Mahone, (6) which provides a correlation between the British Portable Tester and Virginia test car at 40 mph. Regarding the significance of the Virginia minimum, A. F. Marshall of Florida, (7) states; "Virginia's recent deslicking program was based upon a minimum friction coefficient of 0.40 at 40 mph. Based upon the feel of the vehicle during the skid tests, we consider wet pavement surfaces with friction coefficients below 0.40 at 40 mph as being definitely dangerous, between 0.40 and 0.45 as questionable and above 0.45 as being satisfactory for most conditions". Using D. C. Mahone's chart, 0.45 Virginia friction factor is equivalent to about 0.30f on our California scale.

A survey of 39 PCC pavements recently constructed in California shows an average friction factor of 0.34f. This value falls in the upper range of the British satisfactory to good bracket, and there are no problems associated with wet weather skidding accidents on these newly constructed pavements.

The analysis leads to the conclusion that California pavements having California tester skid resistance values above 0.30f should definitely be satisfactory. Based on the fact that England and Virginia receive more rains than California it seems logical to conclude that readings on the California tester above 0.28 should be satisfactory for probably all sites with the possible exception of curves.

The above noted correlations were very encouraging, and it was decided to initiate further studies involving skid resistance measurements at wet weather accident sites on California highways. Unfortunately the California Highway Patrol accident report does not require the officer to determine if skidding was involved in the accident. However, the officer, in his observations, may note that skidding was a factor in the accident.

J. P. Mills and W. B. Shelton in their paper on "Virginia Accident Information Relating to Skidding", (8), found that "fixed objects and non-collision types of accidents account for almost five out of seven skidding accidents, which clearly points out that the majority of all skidding accidents involve only one vehicle". Therefore, accidents occurring during wet weather involving only one vehicle with no recorded defects for either driver or the vehicle were selected from all reported wet weather accidents. Test sites were selected for preliminary survey on the basis of a concentration area which is defined as an area of three accidents within 0.1 mile. A number of these sites were chosen for skid testing. Other testing work has also been performed at sites selected by the District traffic department on the basis of wet weather accident information.

The results of this investigation are shown in Table A and Figure 2. The average friction value is 0.22f. We note that a definite number of the sites have readings above 0.25f with none above 0.28f. Since practically all of these sites are on curves we may conclude that the present tentative minimum figure is too low for curves, and a better value would be 0.28f. It is interesting to note from Figure 1 that this figure is the same as the British minimum for all sites.

An important factor in deciding on a minimum friction value is the transverse friction profile across the lane. Csathy, (9), states, "Significant skid resistance variations across the width of the road may lead to skidding accidents regardless of what the actual minimum value is". The California Skid Tester is very suitable for transverse studies, and a series of preliminary measurements have been performed on a number of rural pavements. Two profiles for PCC pavement are shown in Figure 3. There is a rapid drop in friction values in the wheel tracks of the travel lane with little change between the wheel tracks and in the lightly travelled passing lane. On the other hand, this radical drop in the wheel tracks of the travel lane is not found for asphalt concrete or a screening seal coat, Figure 4. An interesting comparison is shown in Figure 5, where the friction profile for PCC and Open Graded Asphalt Concrete are compared. Both pavements are of the same age, and on the same roadway carrying the same traffic. It should be stressed that this study is of a preliminary nature and must be extended before definite conclusions may be reached. Actual vehicle tests on sections of roadway having different profiles would provide very important information on vehicle reaction.

STUDIES ON IMPROVING THE SKID RESISTANCE OF EXISTING PAVEMENTS

Introduction

Providing and maintaining a skid resistant surface is a very important factor in the performance of any highway. All types of pavement surface will eventually show some reduction in coefficient of friction values during their service life. This reduction is caused by wear and polish of traffic, especially by heavy trucks.

Several years ago the California Division of Highways became aware that some sections of concrete freeways, especially on curves, were having an unusual number of accidents occurring during wet or rainy weather. After considering the use of acid treatment of the surface or the application of a coal tar-epoxy screening seal coat, it was decided to study the effect of grooving the pavement.

The objectives of the program are as follows:

1. To determine the efficiency of serration in raising the skid resistance.

2. To determine the resistance of a grooved pavement to wear and polish of traffic.

3. To determine the extent of reduction in wet weather accidents in critical areas by serration of the pavement.

Pattern Studies

Grooves may be cut in the pavement in either a longitudinal, (parallel to the centerline), or transverse direction. All grooving to date has been performed in a longitudinal direction. We are of the opinion that this leads to increased lateral stability, and tends to guide the vehicle through a critical curve area. This has been confirmed by studies performed in Texas, (10). However, studies in England (11) indicate that grooving perpendicular to the centerline is better in this connection, and further effort will be required to resolve the problem.

Groove patterns vary. The most common type is rectangular in form and may be varied in width and depth and distance between centers of grooves. Other types have rectangular form, but the bottom is partially rounded, and the edges at the pavement surface are also rounded. Others have a large V cut separated by smaller V cuts.

A number of patterns have been used in our serration work to date. This was done in order to determine the increase in the friction factor, wear resistance, and possible vehicle handling problems. In all cases the grooves are all in a longitudinal direction. Table B shows the patterns used on the various projects, and increase in the friction value after grooving and the change during service life. Figure 6 shows the effect of grooving on the average coefficient of friction value for the various PCC pavement projects.

In all cases the friction value is raised by pavement grooving. However, it appears that the nature of the existing concrete surface and the type of pattern effect the degree of improvement in the friction value. As an example there is a much greater improvement in the friction value for project H than on projects F and G for 1/8" x 1/8" rectangular grooves on 1" centers. This is also confirmed by the results from projects J and K where two different patterns are compared on two different projects.

The type of pattern on any specific project effects the degree of improvement. On project K three different patterns (Table B) were placed in consecutive one hundred foot test sections in the travel lane. The original coefficient of friction values were identical, but two of the patterns produced a very high degree of improvement as compared to the third pattern.

Project I in District 07 is an aged asphalt concrete pavement. The surface was rather dry in appearance and quite brittle. Therefore, it was decided to groove this pavement using 1/4" by 1/4" grooves on 1" centers. Shortly after completion complaints were received from drivers of motorcycles and light cars. The complaints were that the vehicle tended to "track" and appeared to be caught in a manner resembling being caught in street car tracks. This was confirmed by Highway Patrol operators. On the other hand, Christensen Style 15 with V cuts 1/4" wide on the Placerita Canyon Bridge provided no problems with test motorcycles driven up to 70 mph. There was some vibration up to 50 mph with Style 9, but this tended to fade out at higher speeds. Style 9, see Table B project J, has 3/16" wide rectangular grooves with rounded bottom and edges. These studies indicate that rectangular longitudinal grooves should not be wider than 1/8" in order to prevent possible problems from motorcycles and light passenger cars. However, V cuts do not appear to cause problems although 1/4" wide at the surface.

A very important characteristic of any treatment for raising the existing friction value is its resistance to wear and polish of traffic. Results of friction measurements with time on various grooved projects are shown in Table B and Figure 7. Not enough time has elapsed on the majority of the projects to draw any firm conclusions. It appears, however, that the nature of the aggregate and mortar strength may influence the resistance to wear and polish of the grooved areas. However, it is interesting to note that projects A and B are on the travel lane of heavily travelled freeways having a high percentage of trucks. All the projects shown in Figure 7 are in snow free areas. Project H in Table B is in a partial snow region subject to chain control. After the first winter the surface does not appear to be damaged by chain action.

This project will be closely watched since project M in Table C has shown considerable spalling between the grooves which are on one inch centers. This spalling has been caused by chain action and has caused some complaints in regards to controllability of a car even under dry pavement conditions.

Accident Studies

A summary of all of the presently available accident data are shown in Tables C, D and E. Six of these locations were on urban freeways in the vicinity of Los Angeles. Accident data was also reviewed for comparison purposes on a mile of unserrated asphalt concrete freeway, see Table E. The Los Angeles projects had one year before and after accident analysis periods. An additional project M on Interstate 80 near the Nevada state line had a two year period for before and after accident analysis. This freeway is rural and required longer periods to obtain meaningful data. In the case of the Los Angeles area freeways, the number of wet or rainy days was determined in both the before and after accident periods. There were 30 wet days in the before period and approximately 15 wet days in the after period. Fifteen additional wet days were accumulated from the following year and the accidents on these days were added to the after period.

A study of Table C indicates that the total accidents were reduced 78 percent. Of this, wet pavement accidents were almost completely eliminated (96 percent) and dry pavement accidents dropped 28 percent.

The reduction in dry weather accidents, if confirmed by further observation, appears to be significant. There is no reason to doubt that the dry friction value of these pavements was sufficiently high. In our opinion the decrease in dry weather accidents may be the result of the ability of the grooves to "track" or aid as a guide for a vehicle partially out of control in the curve area. Such loss of control would most commonly be caused by entering the curve at high speed and then rapid deceleration within the curve area. Such action could cause loss of control. The longitudinal grooves by acting as "tracks" could resist lateral movements and add stability to the vehicle. In the case of the wet pavement condition we may therefore assume that longitudinal grooving in curve areas not only increases the friction factor, but also acts as a stabilizer against lateral instability.

Table D shows the exposure in million vehicle miles, accident rates, and other information. Both wet and dry pavement accident rates were calculated relative to the number of wet or dry days. These rates could not be calculated at the Interstate 80 location, project M, since the number of wet days was not available.

All of the accident rates on wet days were much higher than the average state highway rates at both urban and rural locations. Since the number of wet days is very few in southern California, the resulting exposure is also very small. When this is divided into the relatively large number of accidents occurring on wet pavement, the result is an unusually high rate. All locations (excepting one) had higher than average total accident rates in the before grooving period. The urban concrete surfaced freeways all had below average (< 1.61) rates in the after period. The two rural locations (both concrete surfaced) still had higher than average total accident rates (> 1.00) despite sizeable drops in rates after pavement serration.

For comparison purposes the accident rate on a one mile stretch of asphaltic concrete pavement just south of the serrated project N was compared with the unserrated control section. The results are shown in Table E and clearly indicate the excellent reduction in wet weather accidents following grooving. In the same period the control section had a gain in wet weather accidents.

It is proposed to continue this accident analysis, and periodical skid resistance surveys to determine possible increase in accidents as the friction value changes during service life.

Cost of Grooving

On seven jobs in District 07 the cost of grooving was in the range of seven to nine cents per square foot. In some other Districts the cost is somewhat higher. The best average is approximately ten cents per square foot.

Summary

In summary it appears that pavement grooving performed in a direction parallel to the centerline will definitely reduce the wet weather accident rate in low friction value areas of PCC pavements. Excellent reduction of wet weather accidents occurred after grooving of an old asphalt concrete pavement. However, this pavement was very hard and brittle, and we do not recommend grooving of any normal asphalt concrete pavement since kneading by traffic may rapidly close the grooves. It seems preferable to apply a screening seal coat, slurry seal coat or dense or open-graded mix.

The friction value is raised following grooving. The rate of change in friction value from wear and polish of the grooved area appears to depend on the characteristics of the original concrete pavement, since two pavements with heavy truck traffic showed little change in friction values after a number of years of service. On the other hand some pavements show quite rapid drops after only seventeen months of traffic. Further results are required.

Motorcycle and light car tests clearly indicate that 1/4" x 1/4" grooves will create problems in vehicle control. It is recommended that cuts no greater than 1/8" x 1/8" be used if vertical grooves are cut in the pavement. 1/8" deep x 1/4" wide V grooves do not appear to create any problems. Further studies are required before any specific spacing may be recommended. However, since approximately equal accident reductions were noted for 1/2 inch and 3/4 inch spacing it is recommended that 1/8" x 1/8" on 3/4" centers be used. It is highly desirable that further areas be grooved with a series of patterns as was done on the Ventura project in order to determine effectiveness in raising the original coefficient of friction, and resistance to wear and polish under equivalent concrete and traffic conditions.

PRELIMINARY STUDIES ON DYNAMIC HYDROPLANING

Essentially, dynamic hydroplaning may be defined as the condition under which the tire footprint is actually lifted off the pavement by the action of fluid pressure and then rides on a fluid film of some finite thickness. Dynamic hydroplaning has been studied mainly by those concerned with wet weather landings of high speed aircraft (1). However, some authorities believe that dynamic hydroplaning may be a factor in uncontrolled skids of motor vehicles during periods of heavy rainfall.

The important parameters of significance to dynamic hydroplaning of aircraft or motor vehicles are the speed of the vehicle, tire inflation pressure, tire condition, depth of water and surface texture.

A preliminary analysis has been completed in an attempt to determine the importance of dynamic hydroplaning as a cause of accidents. In order to try to eliminate as many causes as possible only single car accidents in 1964 and during periods of actual rain were analyzed. This was the latest year that records were available when the analysis was started in 1966. During the year 1964 there were 13,917 wet pavement accidents which was 9.7% of all accidents. There were 9,480 accidents during actual rain or 6.6% of all accidents. Of the accidents occurring during rain there were 1,705 which involved only a single vehicle. These were selected for further analysis and the Highway Patrol reports were carefully studied. A study of the reports showed that 152 accidents out of the 1,705 occurred during heavy rainstorms, where there was the possibility of a sizeable thickness of water cover on the pavement. Information on these accidents is shown below:

Speed						Road Section		Tire Condition		Vehicle	
20 30	30 40	40 50	50 60	60 70	70 80	Tangent	Curve	Not Stated	Smooth	Compact	Standard
3	12	34	60	42	1	85	66	112	37	38	114

Total Accidents = 152

All of the above noted accidents occurred at individual locations. We also note the high proportion of speeds in the 50-70 mph range. This appears to be a high rate of speed for vehicle operation during a heavy rainstorm. Thirty-seven of the vehicles had poor tire condition either on the rear tires or on all four tires. Of interest is the finding that 55% of the accidents occurred on tangent sections. Normally most wet pavement accidents occur on curves.

Thirty-one of the accidents were reported to be caused by water on the road, puddles, or hydroplaning. Hydroplaning was mentioned as the cause in seven instances. Eighteen of these accidents occurred on tangents and twelve on curves.

In summary during the year 1964 there were 9,480 accidents in which rain was falling at the time of the event. This group contained 1,750 single vehicle accidents. 152 of the single vehicle accidents occurred at the time of heavy rainfall where hydroplaning was a definite possibility. Of these accidents Highway Patrol reports in seventeen cases mention water on the pavement in the form of puddles or hydroplaning as the accident cause. The fact that a sizeable number of the accidents in the potential hydroplaning group were traveling at speeds in the range of 50-70 mph indicates that excessive speed for the very poor weather conditions may have been a very responsible factor in either directly causing the accident or indirectly influencing the tendency of the vehicle to hydroplane.

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TABLE A

Coefficient of Friction Values of Wet Weather Accident Sites

Location Number	Average Coefficient of Friction Outer Wheel Track, Travel Lane	Description of Roadway
1	0.22	Curve area, asphalt concrete
2	E.B.=0.16 W.B.=0.18	S curve area, asphalt concrete
3	0.26	Near road junction, asphalt concrete
4	0.18	Curve through bridge, asphalt concrete
5	0.18	Curve, asphalt concrete
6	0.17	Curve, asphalt concrete
7	0.22	Curve, PCC pavement
8	0.26	Fairly short radius, reverse curves, asphalt concrete
9	0.25	Curve on overpass, PCC pavement
10	0.17	Cross road approach, asphalt concrete
11	N.B.=0.15 S.B.=0.19	Curves and tangent, asphalt concrete
12	0.20	Off-ramp, asphalt concrete
13	0.20	Bridge approach, asphalt concrete
14	0.24	Steep grades and sharp curves. Asphalt concrete
15	0.19	Curve, PCC pavement
16	N.B.=0.24 S.B.=0.28	Bridge deck, PCC pavement
17	N.B.=0.13 S.B.=0.11 0.28	 Tangent-AC pavement-Accidents Tangent- " " No Accidents
18	0.18	Curve, downgrade, PCC pavement

TABLE A
Coefficient of Friction Values of Wet Weather Accident Sites

Location Number	Average Coefficient of Friction Outer Wheel Track, Travel Lane	Description of Roadway
19	0.15	Curve, PCC pavement
20	0.21	Reversing curves with an intervening tangent on overhead. PCC pavement
21	0.18	Intersection area, asphalt concrete plus heavy fog seal
22	0.24	Sharp left curve with slight grade. Asphalt concrete
23	0.27	Sharp right curve with 3% downgrade. Asphalt concrete
24	0.27	Slight left curve on gradual upgrade. Asphalt concrete
25	0.25	Tangent near intersection. Asphalt concrete
26	0.21	Tangent-full freeway. Asphalt concrete plus heavy fog seal
27	0.21	Tangent near on-ramp. Lane changes by vehicles. PCC pavement
28	0.21	Left curve with off-ramp on right. Asphalt concrete plus heavy fog seal
29	N.B.=0.26 J.B.=0.27	Sharp left curve. Steep downgrade. Asphalt concrete
30	0.24	Sharp curve
31	0.28	Gradual curve to right. Slight grade. PCC pavement
32	0.22	Gradual curve to left. No grade. PCC pavement
33	0.25	Gradual curve to left. 1.5 to 3.5% downgrade. Asphalt concrete
34	0.20	Sharp S curve and steep downgrade-slippery when wet sign. Asphalt concrete
35	0.24	Gradual curve to left. Slight upgrade. Asphalt concrete

TABLE A
Coefficient of Friction Values of Wet Weather Accident Sites

Location Number	Average Coefficient of Friction Outer Wheel Track, Travel Lane	Description of Roadway
36	0.26	Gradual curve. Slight upgrade. Asphalt concrete
37	0.14	Off-ramp. Asphalt concrete plus heavy fog seal
38	0.21	Curves plus short tangent. PCC pavement
39	0.25	Curve, PCC pavement
40	0.23	Curve, PCC pavement
41	0.27	Curve, PCC pavement
42	0.20	Tangent, PCC pavement
43	0.19	Curve, PCC pavement
44	0.23	Curve, PCC pavement
45	0.16	Tangent-AC pavement treated with seal
45A	0.30	Tangent-AC pavement. No treatment-No accidents

TABLE B

Change in Average Friction Values Following Grooving

Project No.	Pavement Type	Location	AADT/1000	Serration Pattern	Age Mos.	Ave. Friction Value
A	PCC Bridge Deck	10-Sta-4-A	24	Rectangular Grooves 1/8"x1/8" on 3/8" Centers	Before	0.26
					After	0.33
					45	0.33
					101	0.36
B	PCC Bridge Deck	04-Ala-7-Alb	80	Rectangular Grooves 1/8"x1/8" on 3/8" Centers	Before	0.26
					After	0.32
					41	0.28
C	PCC	06-Kern-5-PM6.94-7.47	16	Rectangular Grooves 1/8"x1/8" on 3/8" Centers	Before	0.19
					After	0.32
					67	0.34
D	PCC	07-Ora-5-PM23.3-23.6	45	Rectangular Grooves 1/8"x1/8" on 1/2" Centers	Before	0.25
					After	0.35
					17	0.30
E	PCC	07-LA-5 PM29.5-30.0	104	Rectangular Grooves 1/8"x1/8" on 3/4" Centers	Before	0.23
					After	0.31
					17	0.27
F	PCC	07-LA-405 PM2.1-2.6	131	Rectangular Grooves 1/8"x1/8" on 1" Centers	Before	0.20
					After	0.24
					17	0.22

TABLE B

Change in Average Friction Values Following Grooving

Project No.	Pavement Type	Location	AADT/1000	Serration Pattern	Age Mos.	Ave. Friction Value
G	PCC	07-LA-405 PM3.8-4.1	139	Rectangular Grooves 1/8"x1/8" on 1" Centers	Before	0.19
					After	0.21
H	PCC	03-Pla,Nev-80 Var.	9	Rectangular Grooves 1/8"x1/8" on 1" Centers		
H-1		E.B. Lane PM42.56-42.			Before	0.24
					After	0.37
					12 Mo.	0.34
H-2		W.B. Lane PM45.45-45.60	9	"	Before	0.25
					After	0.32
					12 Mo.	0.29
H-3		W.B. Lane PM5.00-5.27	9	"	Before	0.19
					After	0.29
					12 Mo.	0.27
H-4		E.B. Lane PM6.55-6.65	9	"	Before	0.15
					After	0.30
					12 Mo.	0.25
H-5		W.B. Lane PM9.01-9.19	9	"	Before	0.19
					After	0.30
					12 Mo.	0.27

TABLE B

Change in Average Friction Values Following Grooving

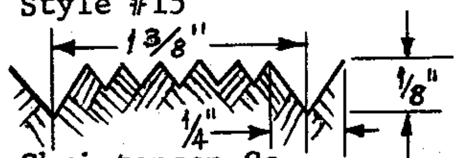
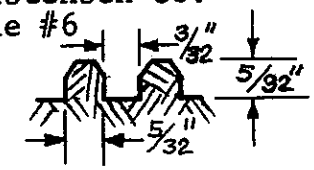
Project No.	Pavement Type	Location	AADT/1000	Serration Pattern	Age Mos.	Ave. Friction Value
I	AC	07-LA-101 PM8.8-9.3	134	Rectangular Grooves 1/4"x1/4" on 1" Centers	Before	0.23
					After 17	0.28 0.29
J	PCC	07-LA-14-27.89 Placerita Canyon Bridge	13	Christensen Co. Style #9-3/16" Wide, 1/8" deep on 3/4" Centers	Before	0.16
					After	0.26
				 Style #15	Before	0.16
					After	0.33
K	PCC	07-Ven-101	21	Christensen Co. Style #6	Before	0.20
					After	0.37
				Christensen Co. Style #9-3/16" wide, 1/8" deep on 3/4" Centers (See No. J)	Before	0.20
					After	0.31
				Christensen Co. Style #15-(See No. J)	Before	0.19
					After	0.37

TABLE C

Effect on Number of Accidents Following Grooving

Proj. No.	Location & Pvt. Type	Serration Pattern	Curvature Radius Ft.	Curvature Dir.	AADT/1000	Accidents Before Wet	Before Dry	Before Tot.	After Wet	After Dry	After Tot.	% Change Wet	% Change Dry	% Change Tot.
D	U.-Ora-5 PM23.3-23.6 PCC	1/8"x1/8"on1/2" Centers-Rect. Grooves	2000'	Rt.	45	46	4	50	1	7	8	-98	+75	-84
E	07-LA-5 PM29.5-30.0 PCC	1/8"x1/8"on3/4" Centers-Rect. Grooves	2000'	Lt.	104	12	6	18	2	2	4	-83	-67	-78
L	07-LA-10 PM22.6-22.8 PCC	1/8"x1/8"on3/4" Centers-Rect. Grooves	1020'	Lt.	164	26	16	42	0	6	6	-100	-63	-86
F	07-LA-405 PM2.1-2.6 PCC	1/8"x1/8"on 1" Centers-Rect. Grooves	Tangent		131	21	9	30	0	11	11	-100	+22	-63
G	07-LA-405 PM3.8-4.1 PCC	1/8"x1/8"on 1" Centers-Rect. Grooves	3000'	Rt.	139	4	6	10	0	4	4	-100	-33	-60
M	03-Nev-80(1) PM19.8-20.2 PCC	1/8"x1/8"on 1" Centers-Rect. Grooves	1400'	Lt.	9	5	9	14	0	6	6	-100	-33	-57
N	07-LA-101 PM8.8-9.3 AC	1/4"x1/4"on 1" Centers-Rect. Grooves	2050' 2052'	Revers-ing	134	139	55	194	6	35	41	-96	-36	-79
Total						253	105	358	9	71	80	-96	-32	-78

(1) Two year before and after period. All others one year.

TABLE D

Effect on Accident Rate Following Grooving

Proj. No.	Pvt. Type	U-Urban R-Rural	State Ave. Acc. Rate	Before						After					
				Wet		Dry		Total		Wet		Dry		Total	
				MVM	Rate	MVM	Rate	MVM	Rate	MVM	Rate	MVM	Rate	MVM	Rate
D	PCC	R	1.00	0.18	255.56	1.96	2.04	2.14	23.36	0.20	5.00	2.26	3.10	2.46	3.25
E	PCC	U	1.61	0.77	15.58	8.54	0.70	9.31	1.93	0.78	2.56	8.71	0.23	9.49	0.42
L	PCC	U	1.61	0.49	53.06	5.46	2.93	5.95	7.06	0.49	0.00	5.50	1.09	5.99	1.00
F	PCC	U	1.61	0.97	21.65	10.80	0.83	11.77	2.55	0.98	0.00	10.97	1.00	11.95	0.92
G	PCC	U	1.61	0.59	6.78	6.64	0.90	7.23	1.38	0.63	0.00	6.98	0.57	7.61	0.53
M	PCC	R	1.00	-	-	-	-	1.02	13.73	-	-	-	-	1.31	4.58
I	AC	U	1.61	2.04	68.14	22.78	2.41	24.82	7.82	2.01	2.99	22.45	1.56	24.46	1.68
Total for PCC Pvts.			1.48	3.00	36.33	33.40	1.23	37.42	4.38	3.08	0.97	34.42	0.87	38.81	1.00

Note

MVM = Million Vehicle Miles

$$\text{Rate} = \frac{\text{Number of Accidents}}{\text{MVM}}$$

TABLE E

Comparison of Number of Accidents on Grooved and Control Asphalt Concrete Pavement

Proj. No.	Location & Pvt. Type	Serration Pattern	Curvature		AADT/1000	Accidents								
			Radius Ft.	Dir.		Before			After			% Change		
						Wet	Dry	Tot.	Wet	Dry	Tot.	Wet	Dry	Tot.
I-1	07-LA-101 PM7.8-8.8 AC	No Serration (Control)	Var.	Revers-ing	123	36	59	95	41	75	116	+14	+27	+22
I	07-LA-101 PM8.8-9.3 AC	1/4"x1/4"on 1" Centers-Rect. Grooves	2050 2052	Revers-ing	134	139	55	194	6	35	41	-96	-36	-79

Figure 1

CORRELATION STUDIES ON MINIMUM FRICTION VALUE FOR REMEDIAL ACTION

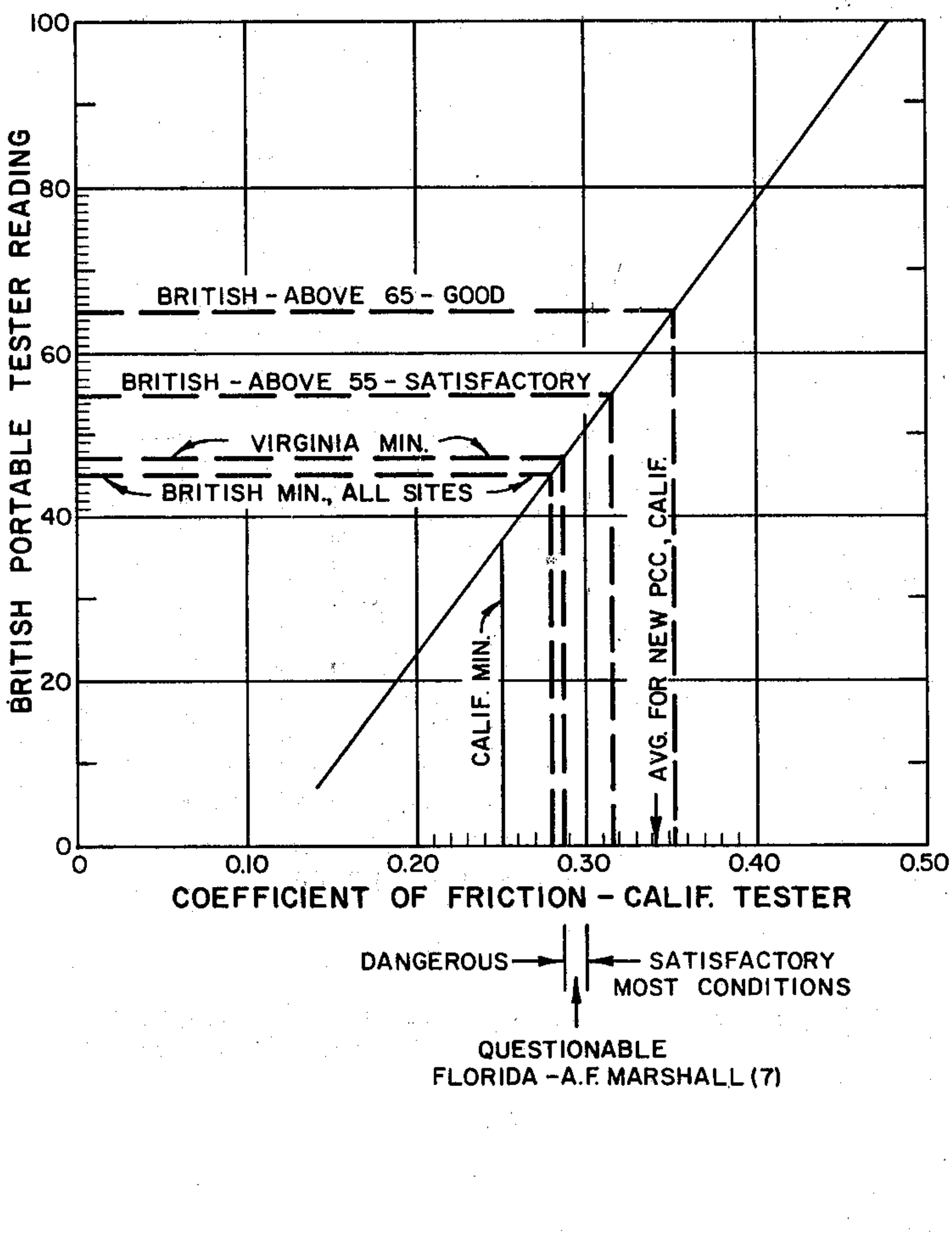
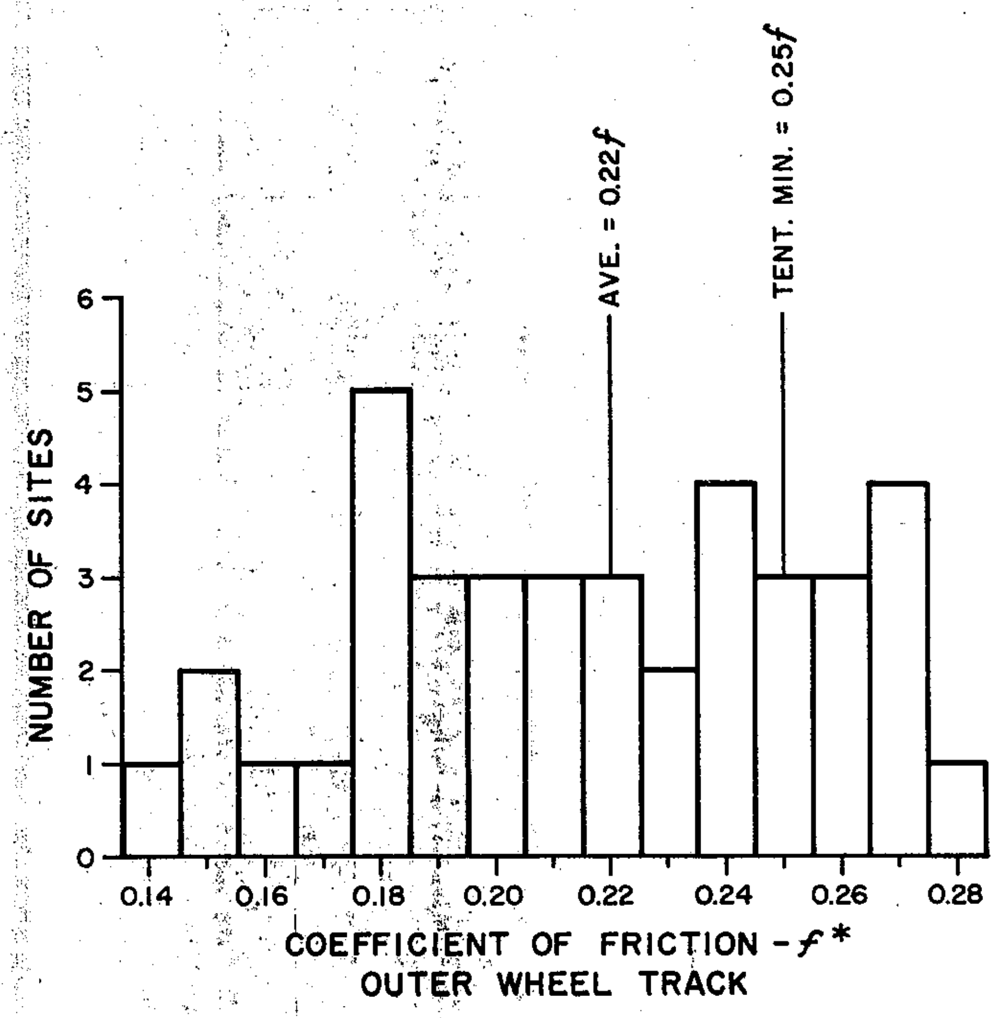


Figure 2

COEFFICIENT OF FRICTION VALUES AT WET WEATHER ACCIDENT SITES ON CURVES



* COEFFICIENT OF FRICTION VALUES DETERMINED AT 50 mph WITH WET PAVEMENT, SMOOTH TIRES AND LOCKED WHEELS.

Figure 3

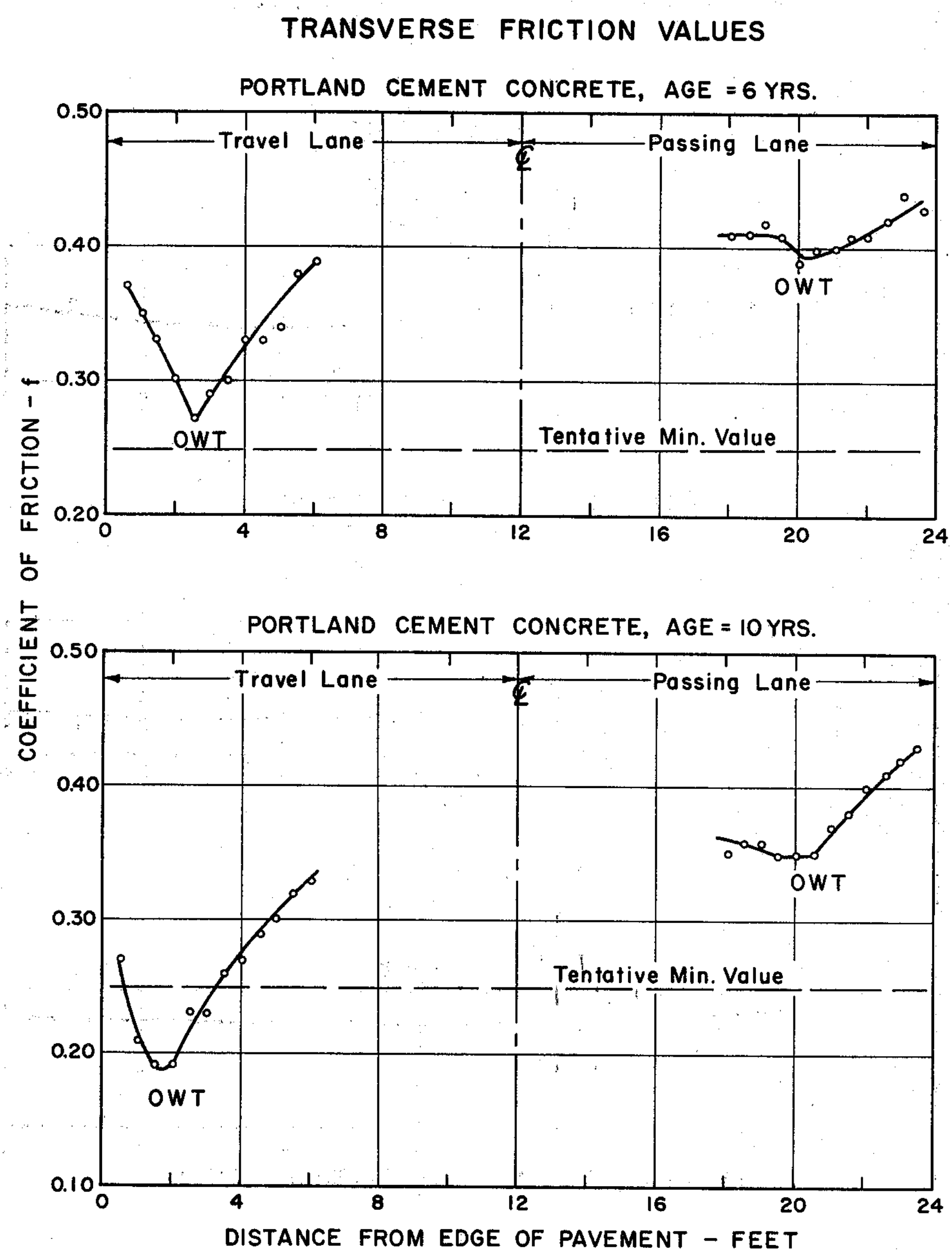

TRANSVERSE FRICTION VALUES
PORTLAND CEMENT CONCRETE, AGE = 6 YRS.
Travel Lane
Passing Lane
OWT
OWT
Tentative Min. Value
0.50
0.40
0.30
0.20
0
4
8
12
16
20
24
COEFFICIENT OF FRICTION - f
PORTLAND CEMENT CONCRETE, AGE = 10 YRS.
Travel Lane
Passing Lane
OWT
OWT
Tentative Min. Value
0.50
0.40
0.30
0.20
0.10
0
4
8
12
16
20
24
DISTANCE FROM EDGE OF PAVEMENT - FEET

Figure 4

TRANSVERSE FRICTION VALUES

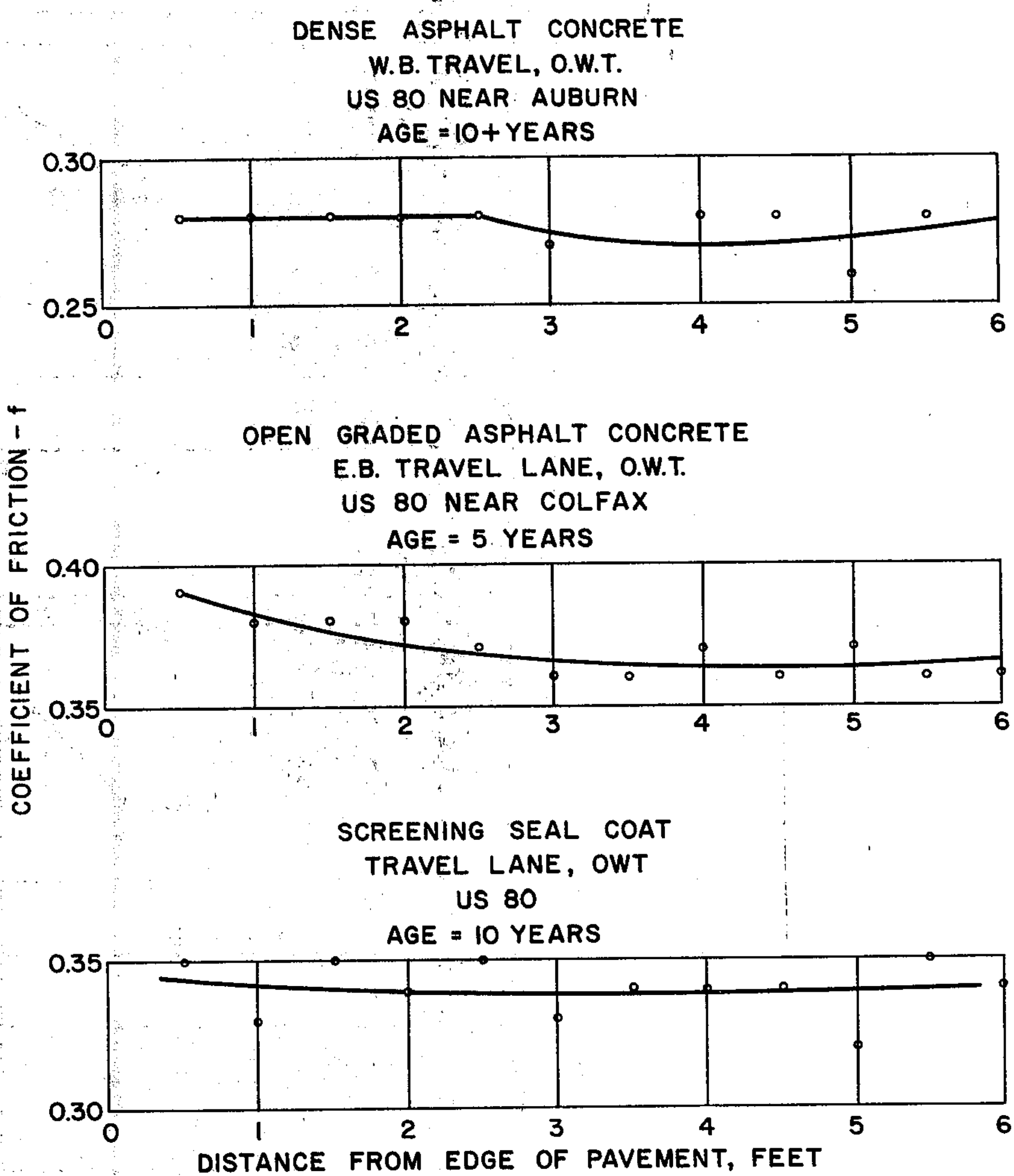


Figure 5

TRANSVERSE FRICTION VALUES

WEAR AND POLISH IN OUTER WHEEL TRACK OF TRAVEL LANE

U.S. 99 SOUTH OF SACRAMENTO

AGE = 6 YEARS

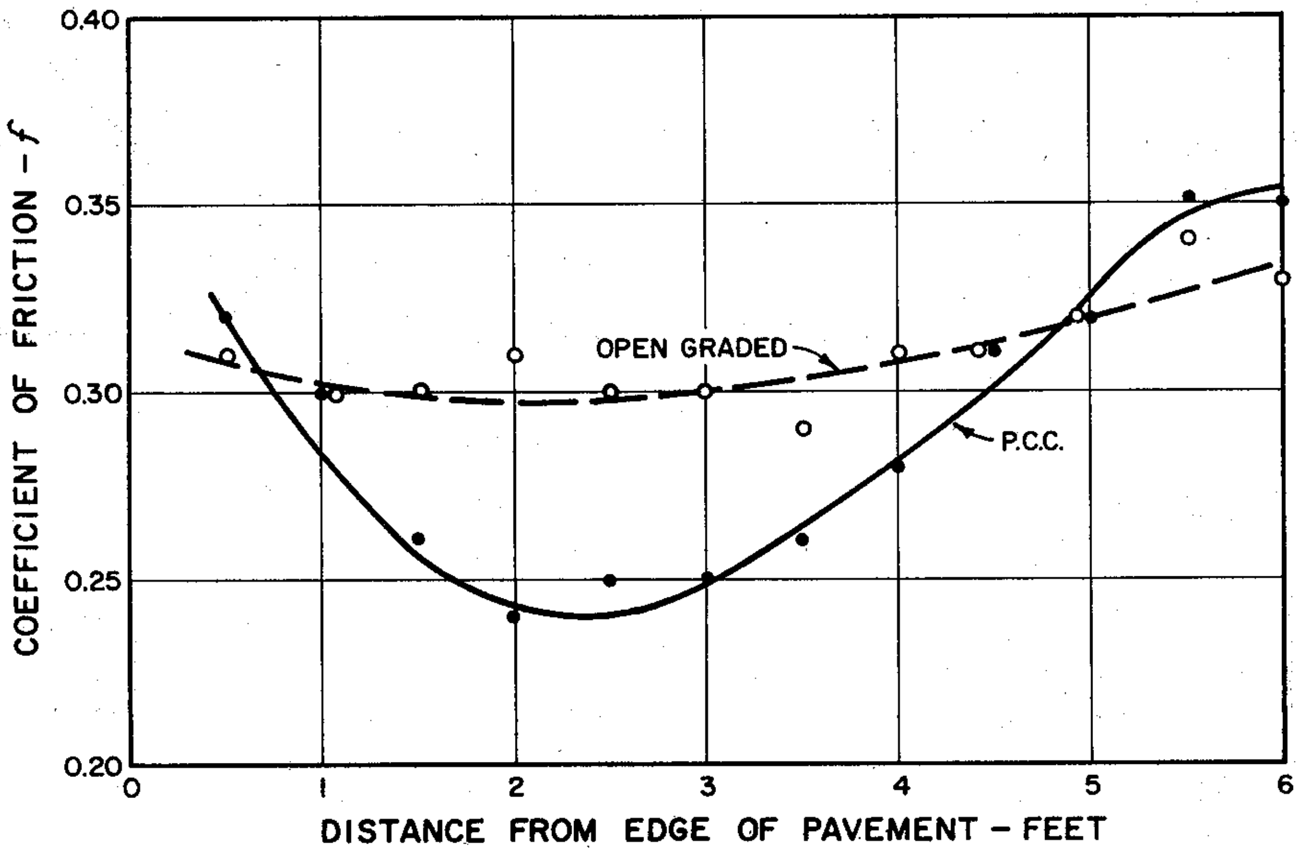


Figure 6

EFFECT OF GROOVING PATTERN ON AVERAGE COEFFICIENT OF FRICTION VALUE OF PCC PAVEMENTS

KEY

- ● $\frac{1}{8}$" x $\frac{1}{8}$" on $\frac{3}{8}$" Centers, Rectangular Grooves
- ⊙ $\frac{1}{8}$" x $\frac{1}{8}$" on $\frac{1}{2}$" Centers, Rectangular Grooves
- ⊡ $\frac{1}{8}$" x $\frac{1}{8}$" on $\frac{3}{4}$" Centers, Rectangular Grooves
- ■ $\frac{1}{8}$" x $\frac{1}{8}$" on 1" Centers, Rectangular Grooves
- △ Christensen Style 6
- ▲ Christensen Style 9
- ◇ Christensen Style 15

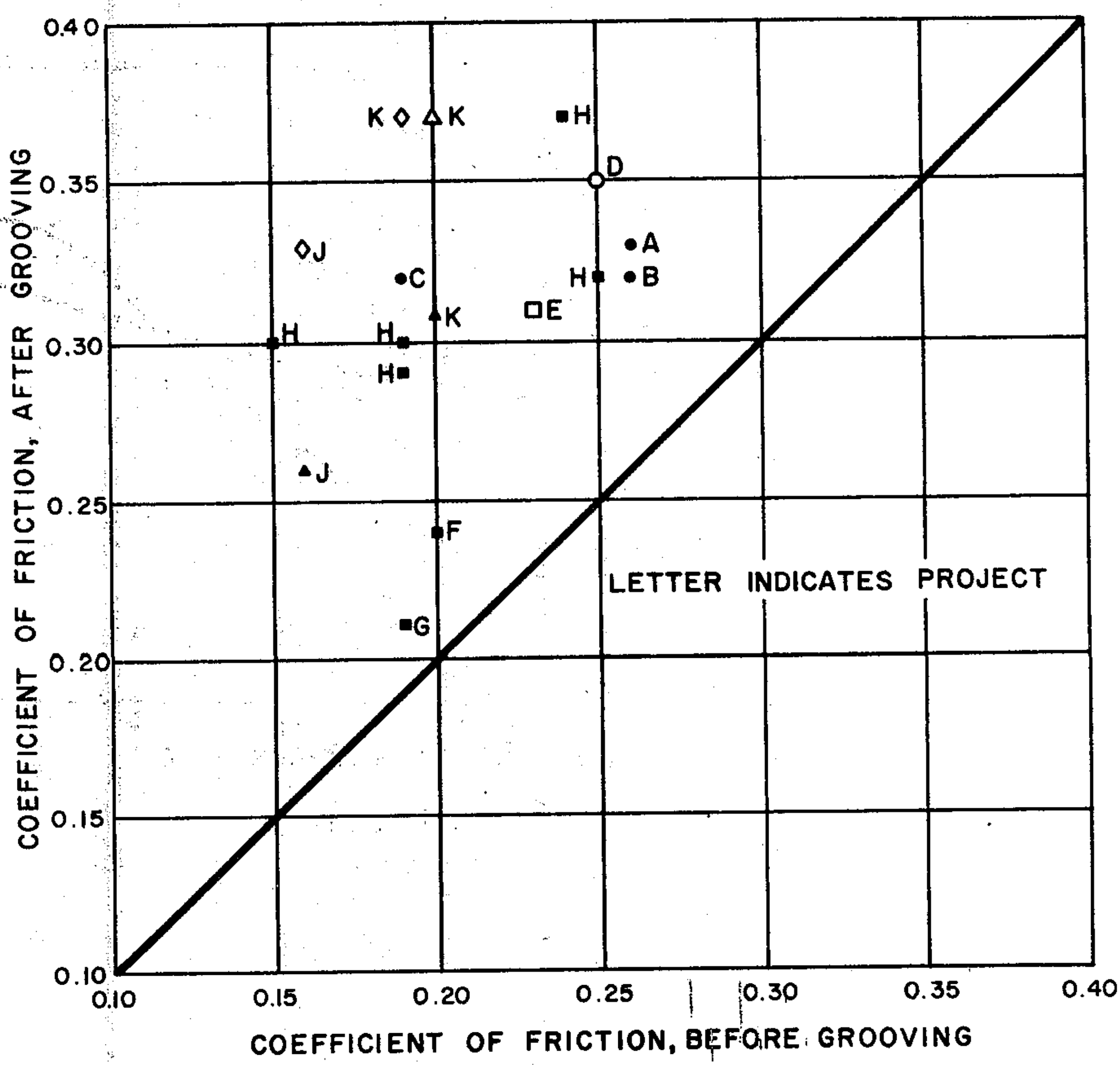
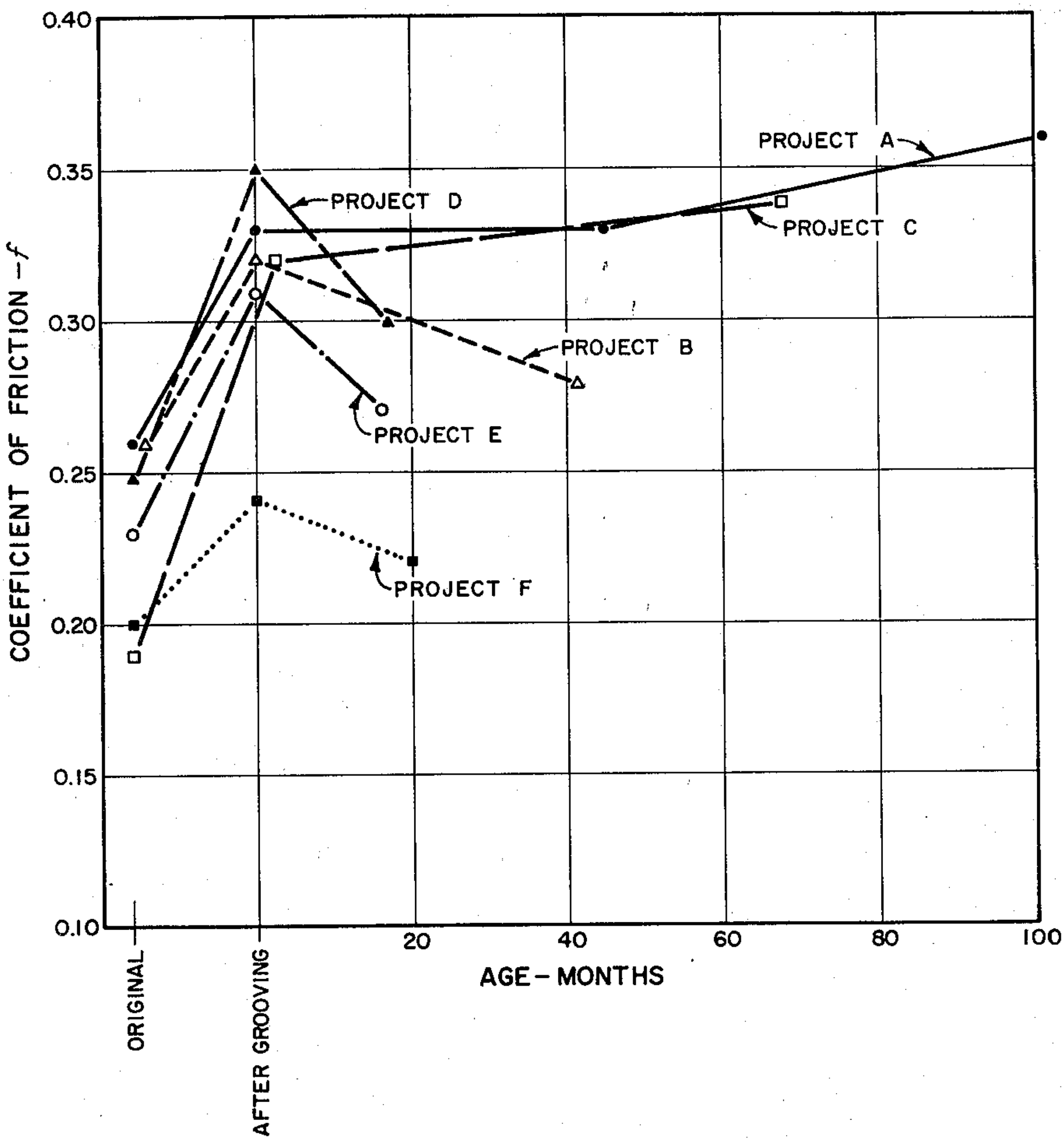


Figure 7

CHANGE IN FRICTION VALUES FOLLOWING GROOVING OF PCC PAVEMENTS



State of California
Department of Public Works
Division of Highways

MATERIALS AND RESEARCH DEPARTMENT

Test Method No. Calif. 342-C
October 3, 1966

METHOD OF TEST FOR PAVEMENT SURFACE SKID RESISTANCE

Scope

This method describes the apparatus and procedure for obtaining surface skid resistance values of Bituminous and Portland Cement Concrete pavements.

Procedure

A. Apparatus

1. Skid test unit.

a. Reference is made to Figures I through III in connection with the following description of the construction of the test unit. A 4.80/4.00 x 8, 2-ply tire with (25 ± 2 psi) air pressure (A), manufactured with a smooth surface, together with rim, axle and driving pulley is mounted on a carriage (B). The tire is brought to desired speed by motor (H). The carriage moves on two parallel guides (C), and the friction is reduced to a low uniform value by allowing three roller bearings fitted at 120° points to bear against the guide rod at each corner of the carriage. The bearing assembly may be noted on Figure III (D). The two guide rods (C) are rigidly connected to the end frame bars (E). The front end of this guide bar frame assembly is firmly fastened to a restraining anchor. The bumper hitch provides for swinging the skid tester to the right or left after positioning the vehicle. The rear end of the frame assembly is raised by a special adjustable device (F), Figure II, so as to hold the tire ¼-inch off the surface to be tested. This device is so constructed that the tire may be dropped instantaneously to the test surface by tripping the release arm (G), Figure II. Tachometer (K) indicates the speed of the tire.

2. Hitch for fastening unit to vehicle.
3. Special level to determine grade of pavement.

a. A 28″ long standard metal carpenter's level, Fig. IV, is fitted at one end with a movable gauge rod which is calibrated in % of grade.

B. Materials

1. Glycerine.
2. Water.
3. 2-inch paint brush.
4. Thickness gauge ¼-inch (a piece of ¼-inch plywood 2′ x 1″ is satisfactory).

C. Test Procedure

1. Determine and record grade with special level, see Fig. IV.

a. Place level on pavement parallel to direction of travel with adjustable end down grade.

b. Loosen locking screw and raise level until bubble centers and then tighten locking screw on sliding bar.

c. The grade is indicated on the calibrated sliding bar.

2. Remove apparatus from vehicle and attach to bumper hitch, Fig. V.

3. Position apparatus with tire over selected test area and parallel to direction of traffic.
4. Raise tire and adjust to ¼-inch ($\frac{1}{16}$″ tolerance) above surface to be tested with device (F).
5. Wet full circumference of tire and pavement surface under tire and 16″ ahead of tire center with glycerine, using a paint brush.
6. Set sliding gauge indicator (P) against carriage end.
7. Depress starting switch (J) and bring the speed to approximately 55 mi/hr.
8. Release starting switch.
9. The instant the tachometer shows 50 mi/hr trip arm (G) dropping tire to pavement.
10. Read gauge (N) and record.
11. Release rebound shock absorber.
12. Move to next section and repeat.
13. In any one test location, test at 25′ intervals in a longitudinal direction over a 100′ section of pavement.

D. Precautions

1. The rear support rod (O), Fig. II, must be cleaned by washing frequently with water and a detergent to prevent sticking.

2. Sliding gauge indicator (P) must be kept clean so that it will slide very freely.

3. On slick pavements glycerine remaining on the pavement should be flushed off with water to prevent possible traffic accidents.

E. Field Construction Testing of Portland Cement Concrete Pavement

The following procedure shall be followed in the field testing of a portland cement concrete pavement for specification compliance of the minimum friction value. A minimum of seven days after paving shall lapse before testing.

1. Visually survey the total length of pavement for uniformity of surface texture. Note all areas which do not have definite striations or which appear smooth. Conduct this survey with the Resident Engineer or an Assistant who has knowledge of any difficulties in attaining a proper surface texture during construction. The attached photograph, Figure VIII, may be used as an aid in the evaluation of the existing texture in relation to the coefficient of friction, but is not to be used in lieu of actual coefficient of friction measurements.

2. The determination of test locations, as outlined below, *shall apply only to that portion of the pavement which has well formed striations. All areas that appear smooth, or those that have been ground shall be excluded.* (See E-3 for procedure to follow for smooth pavements).

a. Select a minimum of three test locations for each day's pour and check a minimum of three pour days per contract.

Determine the location of test sites in a random manner through use of a Random Number table. The use of this method requires that the area for test be uniformly textured and placed in one operation. As an example, a 4-lane pavement may be placed with a three lane width in one operation and the fourth lane placed separately. Each of these areas must be treated separately in selecting test locations. The following example illustrates the use of this table.

A section of pavement is 24′ wide and 4000′ long and is part of a 4-lane freeway. This section of pavement has been placed in one operation and skid tests are required. From 2-a, it is required that three test locations be determined.

Using the random numbers, as shown, choose the three locations in the following manner:

Random Numbers	
Longitudinal	*Lateral*
0.6	6
0.9	9
0.2	2
0.7	7
0.5	5
0.1	11
0.4	4
0.8	8
0.3	3

Starting at any point and proceeding up, or down, but not skipping any numbers, read three pairs of numbers and set up each location as follows:

	Distance from Start of Pour	*Distance from Right Edge of Pour Looking up Station*
Location A	0.6 × 4,000′ = 2,400′	6 × 2 = 12′
Location B	0.9 × 4,000′ = 3,600′	9 × 2 = 18′
Location C	0.2 × 4,000′ = 800′	2 × 2 = 4′

In case any location as determined above falls in a smooth or ground area which does not appear representative of the general surface texture, then choose the next number in the random table and select a new location.

At each test location obtain the first reading at the specified random location (using the method described under C-Test Procedure). Obtain the next four readings at 25′ intervals beyond the first reading. Obtain all readings at sites parallel to the centerline of the lane. After correction for grade as shown in F, average the five readings. Record this average as the friction value for the specific test location.

3. In all areas that present a smooth textured appearance or have been ground, the following shall apply:

a. Check a minimum of three ground area locations and all smooth appearing surfaces on each contract.

b. If the area is less than 100′ in length perform at least three individual tests in separate spots, correct for grade and average the results.

c. If the area is greater than 100′ in length, select sufficient test locations to insure that the area is above the minimum requirement. If the average value of all locations is below the required minimum then perform additional tests until the area is localized for remedial action.

F. Calculations

1. Make grade corrections using charts shown in Figures VI and VII.

2. Average the 5 corrected readings in any one test location. *Example*—The following readings were taken at 25′ intervals in a test location. The grade of the pavement, determined as described in C-1, was +4%.

Station	*Measured Coefficient of Friction*	*Corrected Coefficient of Friction**
1+00	0.33	0.38
1+25	0.34	0.39
1+50	0.34	0.39
1+75	0.33	0.38
2+00	0.33	0.38
Final Average for Test Site		0.38

* Corrected coefficients of friction were taken from chart in Figure VI.

G. Reporting of Results

For all results determined under E-2, report the result for each station location and the average of 5 readings and the grand average. For all results determined under E-3, part (b), report the result for each station location and the average. For E-3, part (c), report the result for each station location and the average for each set of five determinations.

REFERENCE
A California Method

End of Text on Calif. 342-C

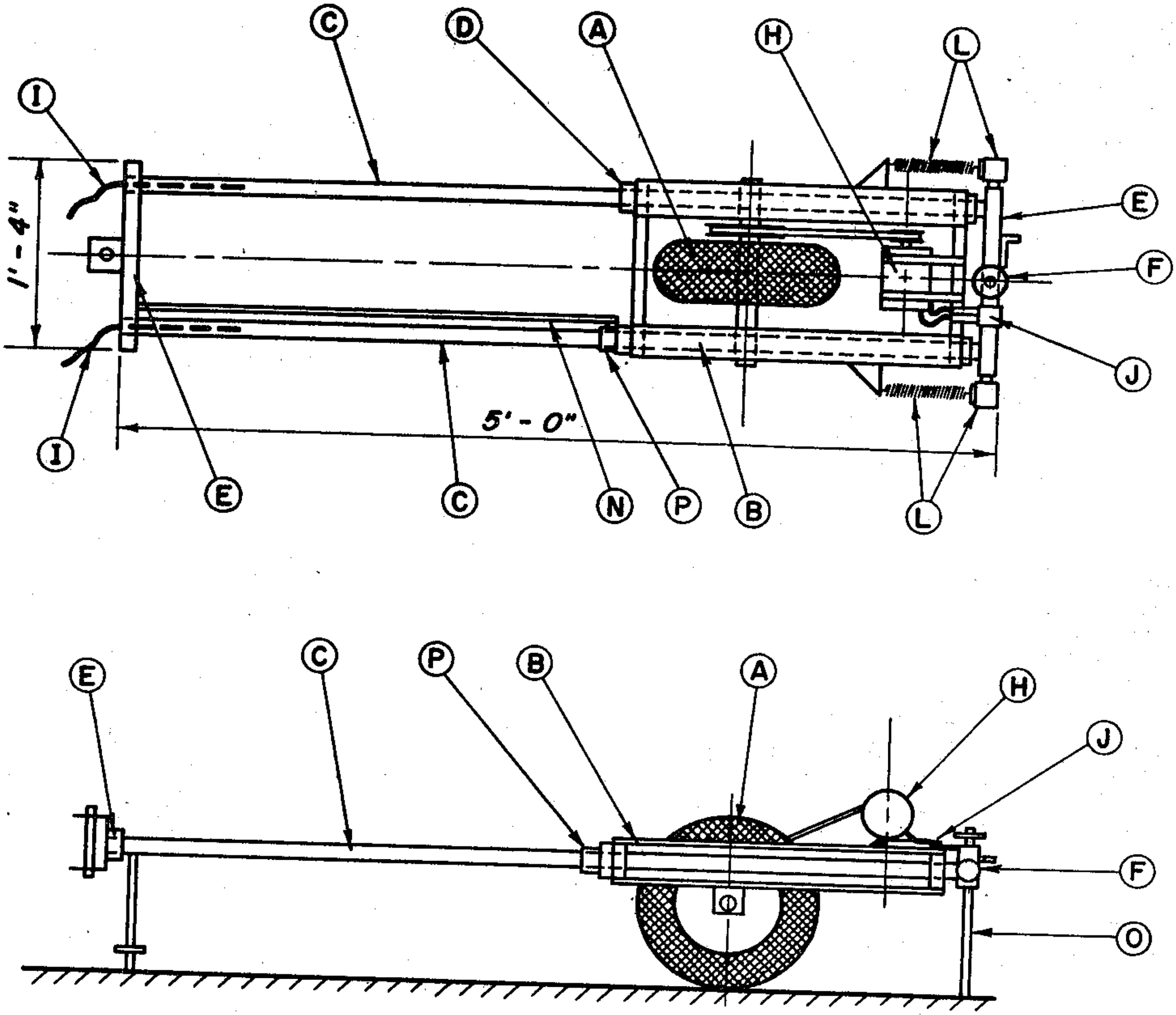


FIGURE I
DIAGRAM OF SKID TESTER

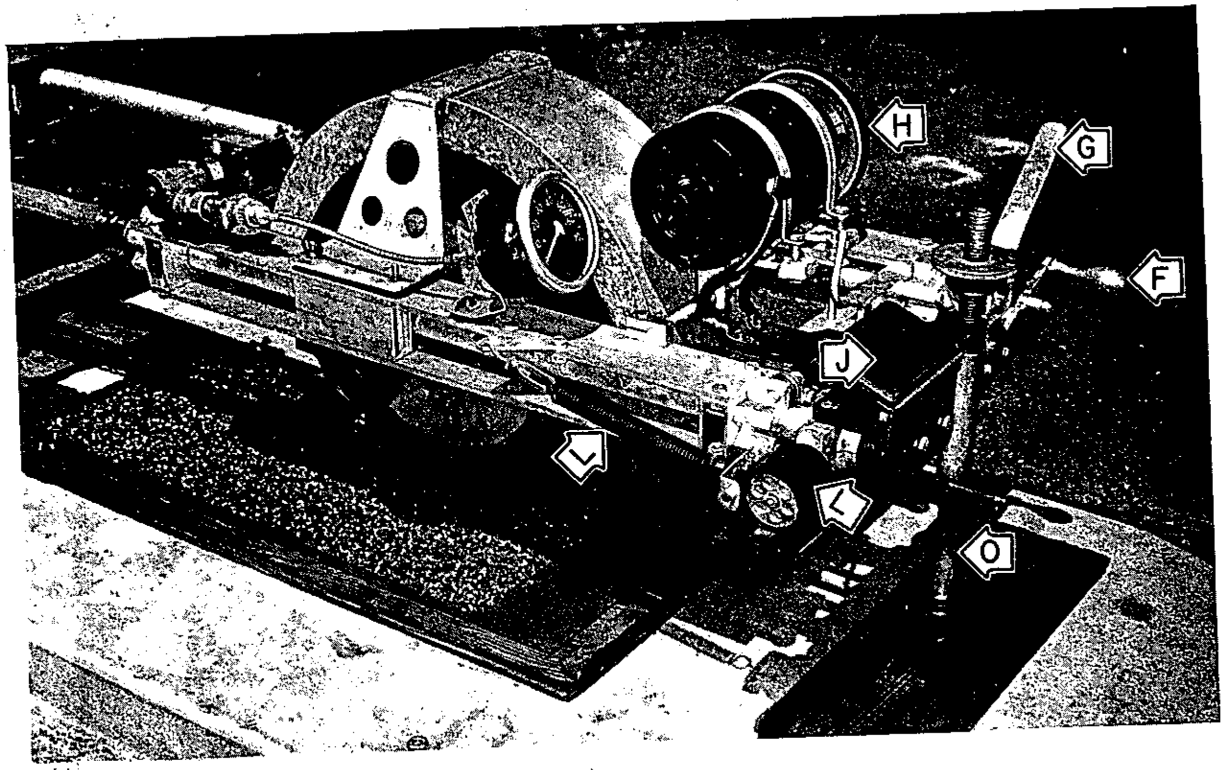


FIGURE II

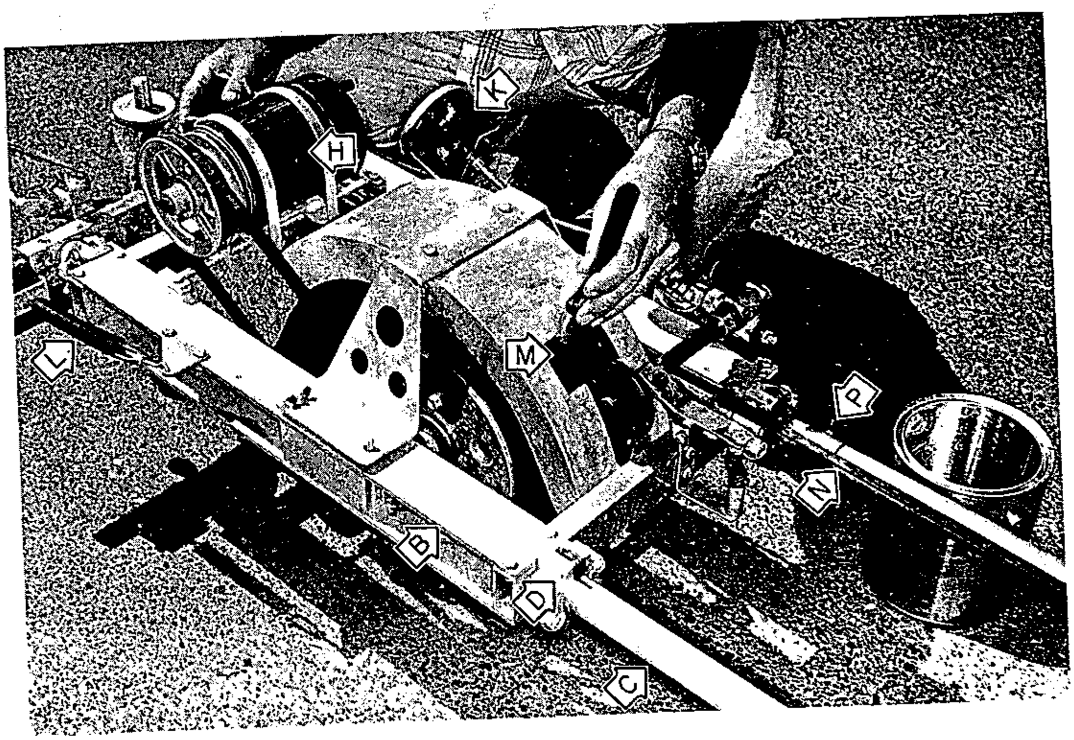


FIGURE III
CLOSE-UP VIEWS OF SKID TESTER

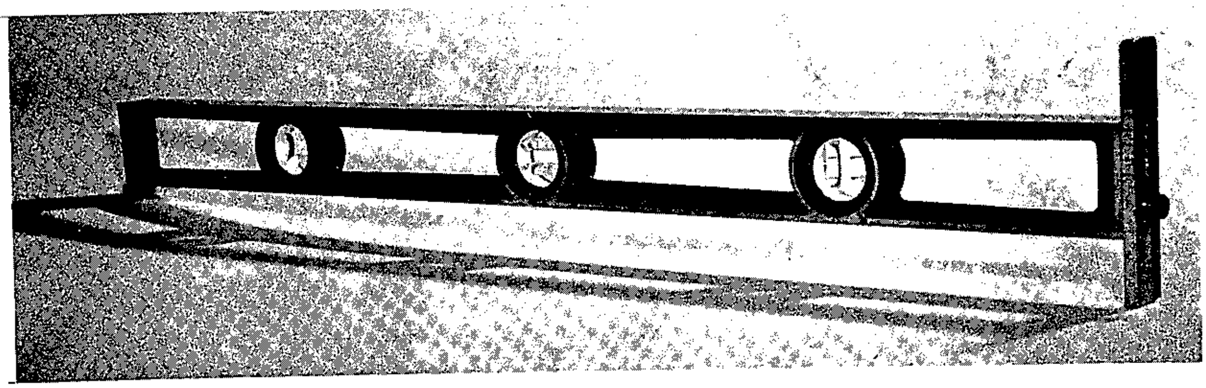


FIGURE IV
LEVEL FOR DETERMINING GRADE

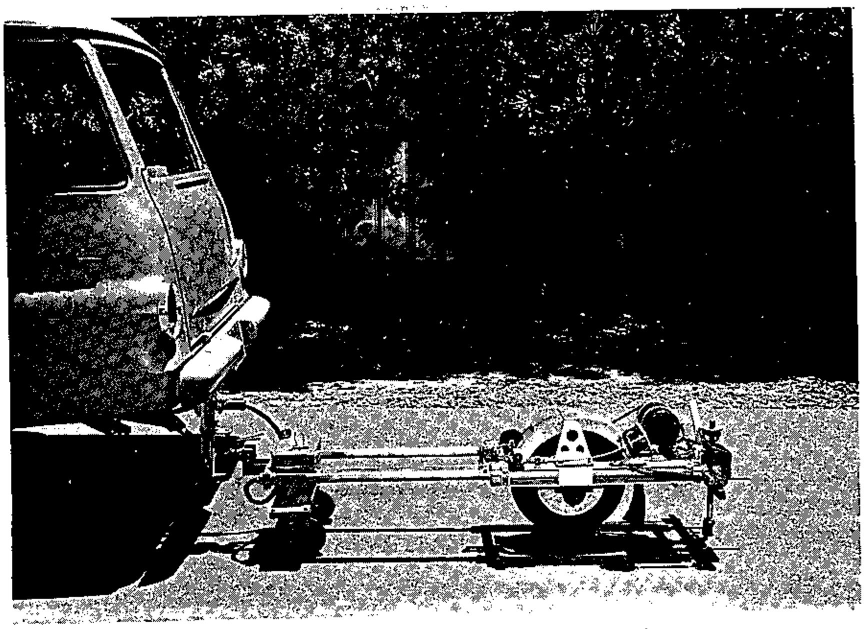


FIGURE V
APPARATUS IN POSITION FOR TESTING

COEFFICIENT OF FRICTION CORRECTION CHART FOR MEASUREMENTS MADE ON GRADES

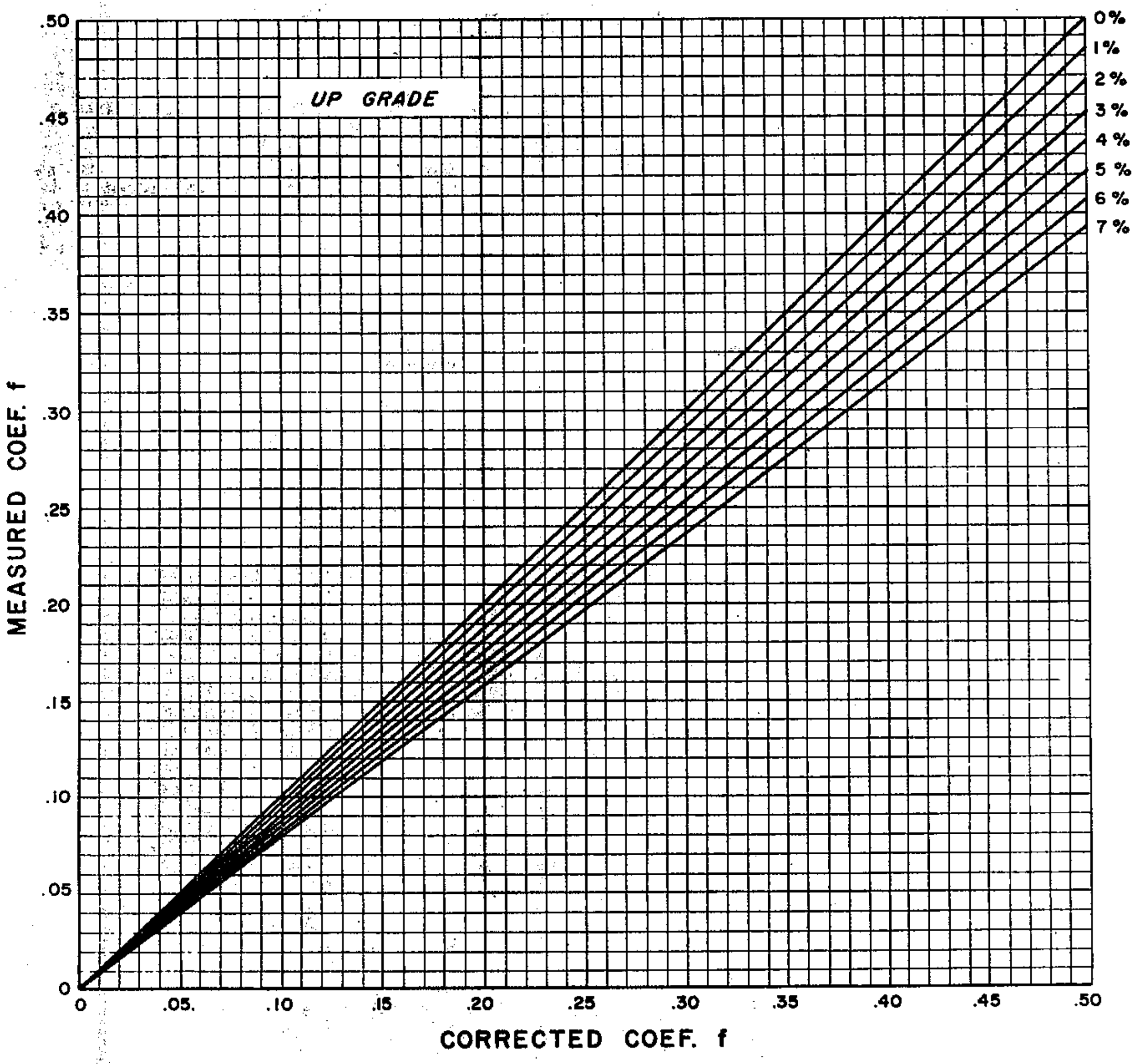


FIGURE VI

COEFFICIENT OF FRICTION CORRECTION CHART FOR MEASUREMENTS MADE ON GRADES

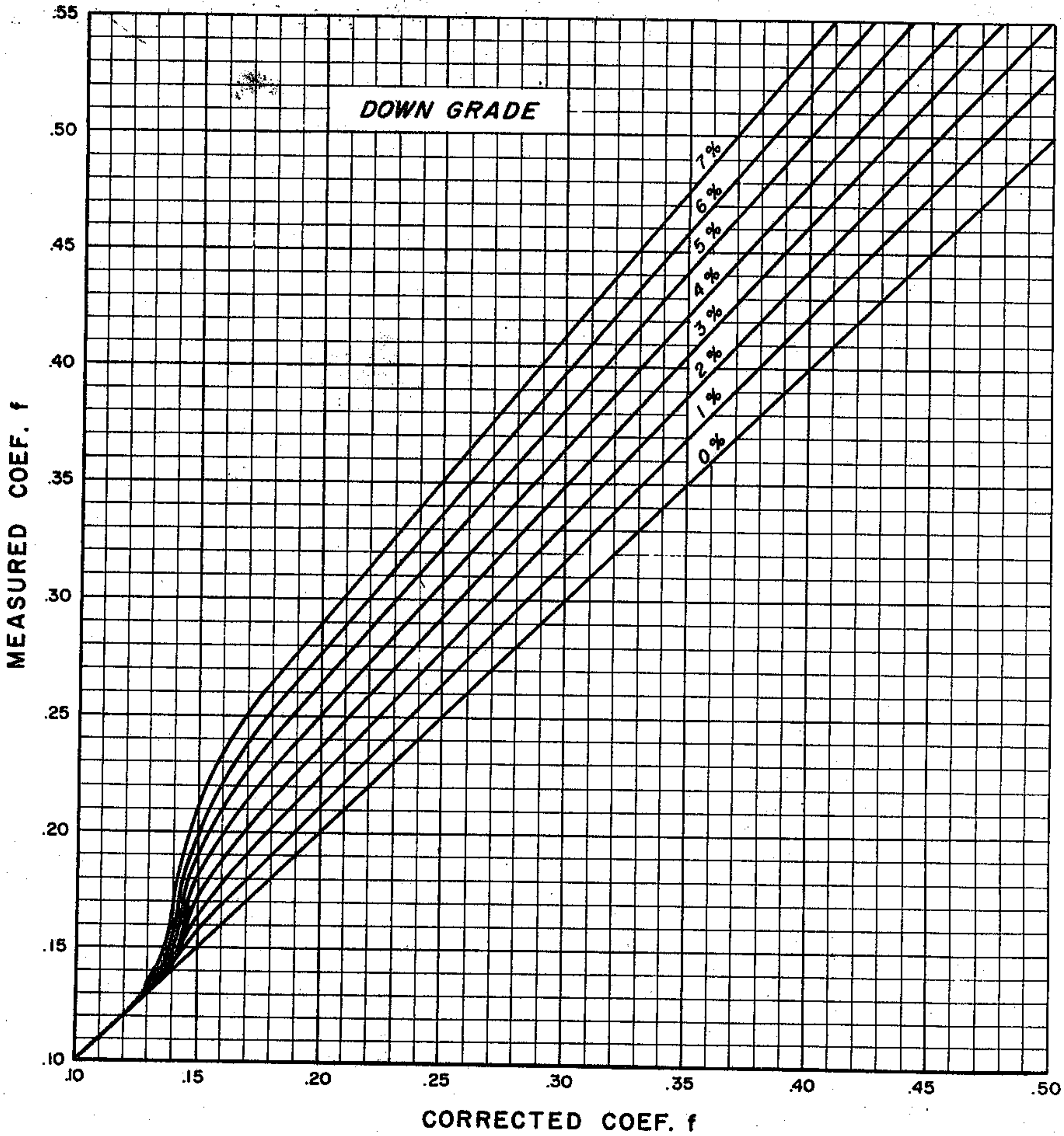


FIGURE VII

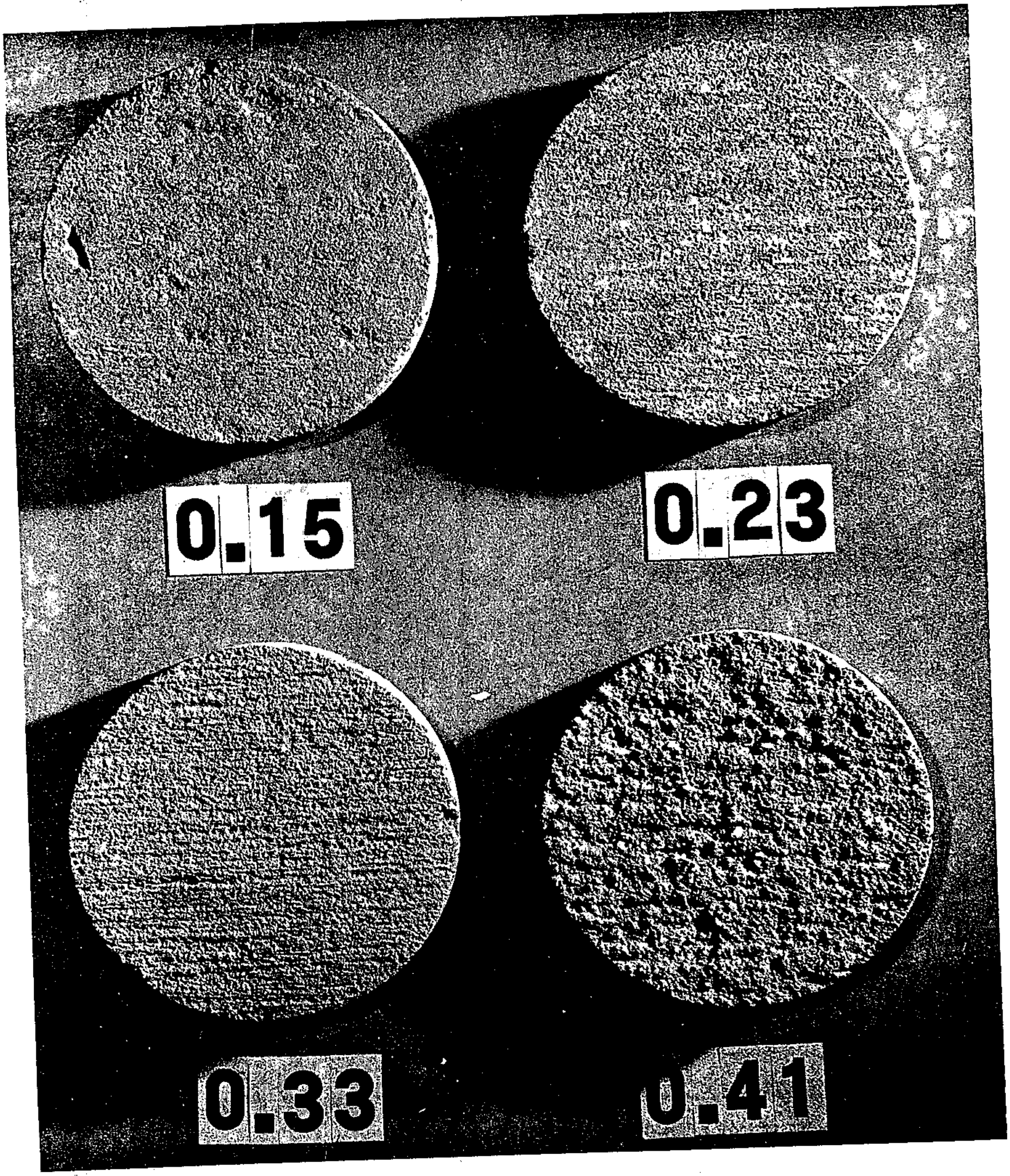


FIGURE VIII
PHOTOS OF SURFACE TEXTURES

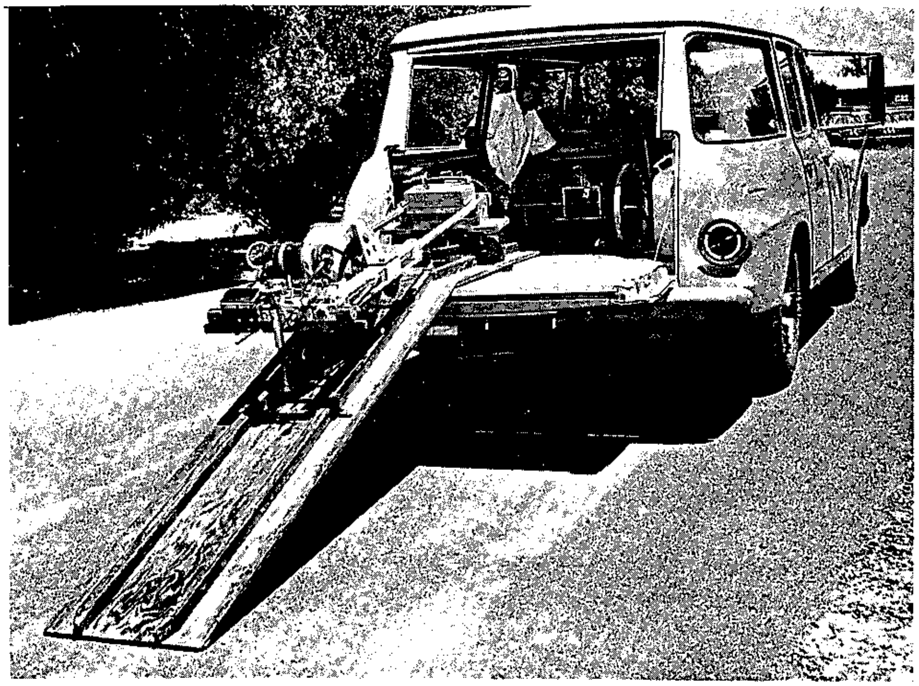


FIGURE IX

APPARATUS BEING PLACED IN VEHICLE
NOTE CABLE AND WINCH FOR MOVING SKID TESTER

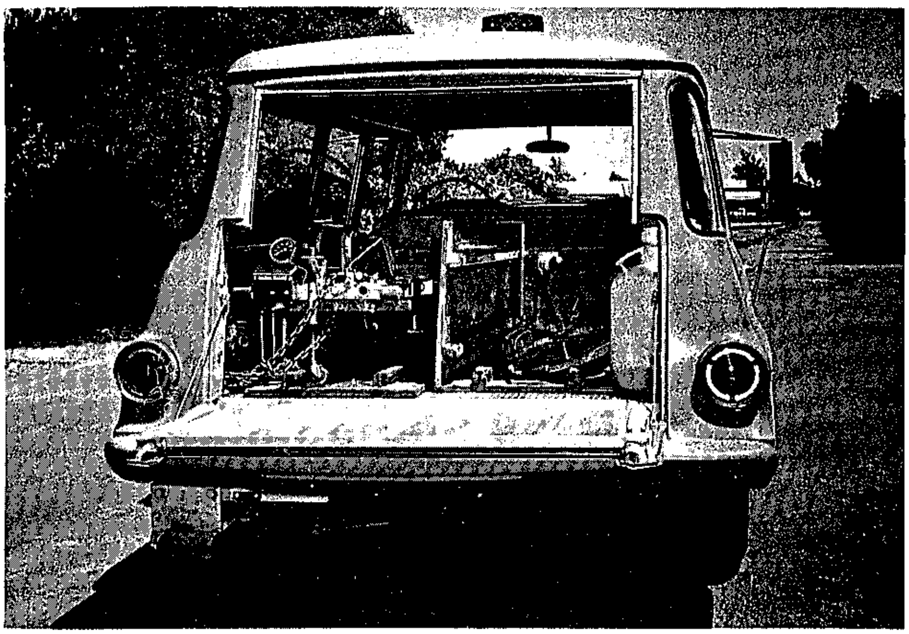


FIGURE X

APPARATUS IN POSITION FOR TRANSPORTATION