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STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS

COMPACTION STUDIES OF ASPHALT CONCRETE PAVEMENT AS RELATED TO THE WATER PERMEABILITY TEST

By
Ernest Zube
Supervising Materials and Research E

January 1962

Compaction Studies of Asphaltic Concrete as Related to the Water Permeability Test

By

Ernest Zube*

Synopsis

There appears to be rather widespread agreement that the most stable and durable asphalt concrete pavements are those that are correctly designed and adequately compacted. If the void content in the finished pavement is high, particularly when the voids are interconnected, the entrance of air and water may adversely affect the service life of the pavement mixture. In order to guard against excessive voids in the pavement, many organizations specify some minimum percent relative compaction of the finished pavement, the percentage of relative compaction being measured against some standardized laboratory procedure. These methods are time consuming and it became apparent that a more simple approach to evaluate this property of the pavement was desirable. This paper presents data relating to the void content and water permeability of the pavement as influenced by different rolling procedures and also

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stresses the importance of having newly laid asphaltic pavement subjected to traffic prior to the wet weather season. A simple test method is presented which measures the permeability of the pavement and can be used as an aid during the compaction procedure.

Introduction

In constructing a stable and durable asphalt concrete pavement, two important steps are necessary. First, the mixture must be correctly designed and second, it must be properly compacted. In the design of the mixture such factors as gradation of the aggregate, particle shape characteristics and surface texture, absorption of asphalt by the aggregate, and optimum asphalt content are important considerations. In the laydown operations, temperature of the mix, type of compaction equipment, and air temperature are of paramount importance. If, in the finished pavement the void content is high, particularly when the voids are interconnected, the passage of air and the admittance of water will adversely affect the durability and ultimate life of the pavement mixture. The entrance of air into a permeable pavement contributes to the rapid hardening of the asphalt binder primarily through oxidation and evaporation. This fact has been cited extensively in the literature and needs no further elaboration here. (1)(2)(3). This paper deals primarily with the compaction and its influence on water permeability of asphalt concrete pavements.

The Materials and Research Department of the California Division of Highways has collected over the years a great deal of evidence which leads to a rather conclusive opinion that many asphalt pavement failures are attributable directly to the presence of excessive amounts of water which entered the pavement structure after construction. We have noted that on breaking a chunk of pavement from many failed areas colloidal fines were often found in the intimate part of the mix and particularly in the lower course of the asphalt pavement. This is caused by pumping action resulting from deflection under heavy loads. The infiltration of fines from muddy water into small cracks of the pavement mixture will considerably reduce the cohesion of the mixture and also prevent any possibility of the cracks "healing" under traffic action during summer temperatures.

It is the general assumption that the permeability of the compacted pavement and its durability are more or less proportional to the percentage of air voids. This statement should only be accepted in a general sense. Certain size dimensions of the individual voids, and the lack of interconnection of the voids could easily produce a pavement of relatively high void content and a low permeability. In other words, low density and permeability are not necessarily the same thing. In this case, it is to be expected that the hardening of the bituminous binder will progress at a relatively slow rate. One other important phase of the permeability-void-durability relationship which should be stressed is that the above statements are generally true when the same asphalt and aggregate mixture is used. On the other hand, it should not be overlooked that the source or method of manufacturing the bituminous binder may far overshadow the effects of permeability and air voids as far as durability of the pavement is concerned. (4)(5).

In order to guard against excessive voids of the pavement, many organizations specify some minimum relative compaction of the finished pavement, the percentage of relative compaction being measured against some standardized laboratory compaction or in some cases against theoretical density. In order to determine this relative compaction, it has been necessary to obtain samples of the compacted mixture by either chipping out blocks or obtaining a core. Although both methods have been used with some degree of success, there are definite drawbacks. In breaking out a block, the compacted mixture is very often disturbed, which may lead to erroneous results in the specific gravity determination. When obtaining cores by drilling, water is introduced into the specimen and considerable time is required to dry the core at low temperature. This causes some delay in determining relative compaction results.

After reviewing existing methods, and through our field studies it became evident that if a physical check on compaction during construction was to be possible, a rapid method of measuring relative compaction of pavement mixtures was needed. The purpose of this report is to present our studies as they relate compaction and water permeability of asphaltic concrete pavements, and to discuss the factors that influence the permeability during construction and service life of the pavement. A simple test method is presented which is equally applicable to new or existing pavements.

Test Method

In our preliminary studies, we noted that water poured on a new asphaltic concrete pavement did not readily wet the surface and very little entered the mix. Later studies showed that traffic action, together with the presence of dust on the surface tends to change the interfacial tension relationship, and water will readily enter a permeable surface during the first rains. The problem of devising a test for permeability of the surface was solved by the addition of a small amount of detergent to reduce the surface tension of the water used in the test. On a number of jobs involving a relatively impermeable base, such as cement treated base, the values obtained by this method show good relationship between permeability and the moisture content found in the mix following rains, see Table A.

The test method is detailed in Appendix A. The equipment has been assembled in a compact kit and is readily portable. The general technique was originally developed in connection with Seal Coat Studies (6) and has been in use by this department for the past six years. Briefly, the test is performed by forming a small reservoir by means of a "grease ring" or dam around a previously marked 6" circle on the pavement, Fig. 1A. The ring may be easily placed with a grease gun using ordinary cup grease, or it may be completely formed in one operation by a special gun. The ring grease is sealed to the surface by running the finger around the outside edge of the grease. A special graduated cylinder containing the test solution and equipped with a drain tube is placed beside the ring, and the operator feeds the solution into the area within the ring, starting a stop-watch at the start of flow of the liquid from the graduate, Fig. 1B. The area within the ring is kept moist during a test period of two minutes. The film of liquid in the ring should only be thick enough to present a glistening appearance. In other words, the water is fed in only as fast as it is absorbed by the pavement and the test is conducted under zero pressure. At the end of the two minute period the total solution used is divided by two and the permeability reported in ml/min for a 6" diameter circle. The complete test may be performed in three to five minutes.

Dense graded bituminous surfaces that are covered with an open graded mix* may also be tested by chipping away the open graded mix, just outside of the six inch ring, down to the dense graded surface. The ring of open graded mix removed is about 1/2" to 3/4" wide. This annulus is filled with the

*1/2 thick open graded mix, employing 1/4" maximum aggregate, is being placed extensively in California over newly placed dense graded asphalt concrete.

grease to form the seal, and the permeability is determined through the open graded mix within the area of the ring. We have found it necessary to perform the test in this manner, since removal of all the open graded surface with a chisel within the ring area tends to seal the underlying surface with a glaze of asphalt and results in erroneous readings.

Our present practice is to perform tests successively at intervals of 25' in the wheel tracks and at a point midway between. A total of six readings constitute a "set" for any one area, and the average is then obtained. A series of these sets should be obtained over the length of the job.

On a multi-lane road, one of the important areas for checking should be between the wheel tracks in the passing lane. It has been noted that an initially high permeability of a pavement may be reduced to a satisfactory low value in the wheel tracks by traffic action. However, the between-wheel-track areas may remain relatively unchanged and water may enter here, cross-flow through the pavement, on top of the base, and collect beneath the wheel track areas.

Factors Influencing the Permeability of the Pavement During Construction and Service Life

Our field studies have uncovered a number of variables that influence the permeability of the pavement during construction and its service life.

Some of these variables are:

1. Segregation of mix during placing.
2. Temperature of mix during breakdown rolling.
3. Temperature of mix during pneumatic rolling.
4. Weight of breakdown roller.
5. Tire or contact pressure of pneumatic roller.
6. Ambient temperature during placing of mix.
7. Void content of the compacted mix.
8. Amount of traffic prior to winter rains.

Even though every effort is made to maintain uniform construction procedures, individual permeability test values may be still quite variable.

On one project the variations in a single load of mix were determined by taking readings every five feet in a longitudinal direction and every two feet transversely. This was performed for three separate loads of mix in different test sections. The average values for one load of mix in a transverse and longitudinal direction are shown in Fig. 2. The frequency of values for an individual load in each of three different test sections is shown in Fig. 3. The results indicate an increasing spread of values with increasing permeability, with the spread being greatest for values above the average. It is necessary to obtain a sufficient number of readings to insure a reliable average reading, if it is desired to evaluate compaction by the permeability test.

It should also be pointed out that permeability can not be estimated by visual inspection of the surface appearance, with the possible exception of obvious rock pockets. Fig. 4A and 4B illustrate the large variation in permeabilities for the same general surface texture on a particular project.

The method of placing the mixture may influence the permeability values transversely, across the lane, as shown in Fig. 5. In the normal paving procedure with end dump trucks, the initial permeability is generally higher in the future wheel track areas, probably due to some segregation of the mixture near the edges by the lateral distribution device in the paver. However, this is reversed when the bottom dump method is used. There is apparently a greater amount of segregation in the latter method, and this is manifested by a higher permeability value immediately in back of the pickup or conveyer equipment of the paver.

A major factor is the temperature of the mix at the time of breakdown and pneumatic rolling operations. The results of varying the breakdown temperatures are shown in Table B and Figs. 6 and 7. The change in permeability values for base and surface courses having different gradings and asphalt contents, but rolled with the same equipment are shown in Fig. 6. The reduction in permeability with increase in breakdown temperature is very definite for both types of mixtures. The importance of this factor is further indicated by results shown in Fig. 7. The average permeability value after completion of high temperature breakdown rolling in Section 2 is almost as low as the complete rolling schedule in Section 1 where breakdown temperatures were much lower. These results indicate that the permeability test does provide an indication of the degree of densification during the breakdown rolling operation.

Further reduction in permeability following breakdown compaction may be achieved by pneumatic rolling. Experience has clearly indicated that traffic action is very effective in achieving a "tightening" or "sealing" of the surface and one reason for pneumatic rolling is to obtain this during construction. The requirement for pneumatic tired rolling in the California Division of Highways 1960 Standard Specifications, (Appendix B) was based on evidence that this form of rolling is an effective way to reduce permeability.

Some typical results of permeability-rolling combination studies obtained under our 1954 Specifications are shown in Fig. 8. Although we note an average reduction in permeability with increased rolling, it is not as great as would be expected. Unfortunately, our pneumatic roller tire pressures did not exceed 35#/sq.in. However, on one project we were able to boost the tire pressure up to 50#/sq.in. and a definite reduction of about 150 ml/min. was attained when compared to the 35#/sq.in. tire pressure.

Table C shows more recent permeability values obtained with varying pneumatic contact pressures and varying breakdown and pneumatic rolling temperatures. It appears that the most benefit from pneumatic rolling is obtained when the contact pressures and temperature of the mix are fairly high and when the permeability after breakdown is in the 100 to 400 ml/min. range.

The California Division of Highways has been concerned during the past two paving seasons with the problem of "pick up" and "sticking" of the mix to the tires of the pneumatic roller and has found it necessary on a number of jobs to reduce rolling temperatures in order to avoid this problem and the resulting unsightly appearance of the surface. The addition of small quantities of water soluble oil to the roller water has somewhat alleviated this condition but it seems imperative, that some means be found for preventing this problem with pneumatic rollers if the maximum benefit is to be attained from this method of compaction.

The workability of the mix and degree of compaction will depend not only on field conditions, but also on mix design variables such as asphalt content and aggregate grading. Both will influence the permeability values. The differences between 4.5% and 5.5% asphalt on the same grading are shown in Fig. 9. It is of course realized that the proper asphalt content must be based on consideration of a number of factors and is limited by the stability requirements. In the case of noncritical mixes the asphalt content is limited by necessary safe-guards against possible future "flushing" of excess asphalt to the surface thus providing a skid hazard.

It is logical to assume that the percentage of voids and the relative compaction should be related to the permeability values immediately or shortly after construction. As pointed out earlier, the permeability is greatly influenced by the number of interconnected passageways in the pavement and these will vary depending on factors involved in design and construction. Further, the "sealing" of the surface by pneumatic rolling and traffic action may markedly reduce the permeability measured after the breakdown pass while not materially reducing the total void content of the pavement.

The relation between void content and permeability was measured on a series of jobs by determining the permeability 24 hours after completion of rolling. Cores were then removed from areas of different permeability values and the density and percentage of relative compaction were determined, with 100% relative compaction assigned to a laboratory compacted specimen. Results are shown in Table D and Figs. 10 and 11. The curve for the void-permeability relation indicates that there is no serious change in permeability up to about 10% voids. However, even small increases in void content above this figure show a marked increase in permeability.

A similar relationship is found when the percentage of relative compaction, falls below 94%, Fig. 11.

As will be shown later, the permeability of pavements laid during the summer paving season show a marked decrease due to traffic action. This decrease is not accompanied by any pronounced reduction in void content since only the uppermost portion of the surface course is "sealed" by this action. However, pavements laid in the late fall cannot be expected to "seal" prior to winter rains. The void-permeability curve clearly indicates that excessive water may enter the pavement if compaction procedures during construction are not effective in reducing the void content to a safe level.

There is a reduction in permeability during at least the first 24 hours after completion of rolling, Fig. 12. This is best accounted for on the basis of "cold-flow" of the binder since the test section was not subjected to any traffic. It is reasonable to infer that a number of original interconnected passageways are sealed at different points by the slowly continuing movement and adjustment of the asphalt binder.

The importance of traffic action is shown in Fig. 13. This striking reduction in the permeability of all areas of the roadway to a very uniform and low level has been found on a number of jobs paved during the early summer and subjected to traffic during warm weather. In contrast on another job, constructed in December, we found no reduction in the initially high permeability values until the following summer.

During the late fall and winter paving, the lower atmospheric temperatures are a definite handicap in attaining proper compaction. Even elevated mixture temperatures and immediate traffic action will not satisfactorily knead or seal the surface of the pavement to prevent entrance of water. Increasing the mixing temperature may have, in some cases, an immediate effect on the compaction, but at the same time may harden the bituminous binder sufficiently to effect a marked lowering of the service life of the pavement. Table E shows permeabilities obtained during paving operations in September and October-November on the same project. The September permeabilities average about 47 ml/min. against 371 ml/min. for the October-November values.

An interesting illustration of the change in permeability of a pavement laid in the early winter season is shown in Fig. 14. This pavement was laid during low atmospheric temperatures and was not subjected to traffic until the following spring. The pavement was laid over a virtually impermeable cement treated base. In February 1958 after a series of storms we noted an over-all drop in permeability from that found after fog sealing. This was most likely caused by entrance and entrapment of rain water within the pavement and was further confirmed by the gain in permeability values after a period of dry weather. The increase was probably caused by evaporation of pavement moisture. A decrease in permeability values occurred after opening of the pavement to traffic.

The Materials and Research Department of the California Division of Highways has consistently maintained that cold and inclement weather is the most adverse factor affecting success or failure during the placing of any type of bituminous pavement or Seal Coat.

Based on California weather conditions, particularly in the northern part of the State, we have suggested the following tentative schedule for placing bituminous pavements or Seal Coats:

(a) Seal Coat construction using emulsified asphalts should be terminated by September 15th.

(b) Seal Coat construction using cutback asphalts of the rapid curing type may be extended until October 15th.

(c) Asphaltic concrete mixes, both open and dense graded may be placed until December 1st, although a November 15th deadline would be preferable.

Our studies have shown that the normal Fog Seal* will only be effective in sealing a pavement if the original permeability is fairly low. Fig. 15 shows the reduction in permeability by the application of a Fog Seal. (Readings were obtained before and after Fog Sealing at identical spots). We note that the permeability after Fog Sealing tends to parallel the original curve. It is logical to assume that passageways with relatively large diameters will not be sealed by the application of a small amount of asphalt and, therefore, in areas of high permeability no real improvement will be noted.

On the other hand, a Slurry Seal or Screening Seal Coat reduces the water permeability sufficiently and virtually renders the pavement impermeable. (See Table F and Fig. 16). Present data indicate that such seals completely prevent the entrance of surface moisture. Unfortunately, it is very difficult to attain a satisfactory job with either of these types of seal coats during cold or rainy weather although during this paving period newly laid pavements are most in need of some form of sealing.

Tentative Limits for Permeability

We believe that a tentative average water permeability value not exceeding 150 ml/min for a 6" diameter area will be

*Application of 0.05 to 0.10 gal/sq.yd. mixing emulsion diluted one to one with water, on completion of paving operations.

low enough to prevent the entrance of excessive moisture into the pavement from the surface. On the basis of our studies we have concluded that it is not feasible or even advisable in all cases to attempt construction of a completely impermeable asphalt pavement because to do so would in many instances require sacrificing other qualities of importance equal to the water problem. Our objective is to reduce the potential for water infiltration to a minimum through properly designed mixes and practical construction methods. The permeability test is a useful tool in attaining this desirable end result.

It should be pointed out that the figure of 150 ml/min is a relative test figure only and indicates the ability of the newly compacted or existing pavement to accept water. Once the voids in the pavement are filled with water the amount of any additional water admitted depends on the permeability or porosity of the base material.

Conclusions

A simple and rapid test method for measuring the tendency of surface water to enter an asphaltic pavement has been developed.

This test can be used during actual construction to give an indication as to the effectiveness of compaction operations.

The results of field studies clearly indicate that pavements, even of the so-called dense graded mixtures, have been constructed that are quite permeable to the entrance of surface water. This water may contribute to possible failure of the pavement by acting as the agent for transporting base dust and clay fines into the interstices of the pavement mixture, and this action may contribute to the rapid hardening of the binder, especially in the lower part of the pavement.

Field tests indicate that adequate compaction, together with some form of pneumatic rolling, are very important factors in reducing pavement permeability. Also, permeability may continue to decrease immediately after construction and will definitely decrease for pavements laid during the normal paving season when subjected to traffic during the summer months. On the other hand, pavements laid during the late fall or winter must rely on adequate initial compaction since no further decrease in permeability may be expected before the following summer. Bituminous pavements or Seal Coats should not be placed in the late fall or during the winter months.

Fog Seals will decrease the permeability but will not prove effective if the initial permeability is very high. Slurry Seals and Screening Seal Coats effectively reduce the permeability value to a very low figure.

Some of the early studies involving relatively permeable surfaces were conducted on pavements constructed under the 1954 California Standard Specifications. As the result of these studies the 1960 Standard Specifications carry more rigid requirements for temperature control and additional compaction equipment.

The 1960 and 1961 studies on a considerable number of projects show a marked decrease in permeability values and void content of the mix. This of course, should provide better durability for the bituminous binder with a resulting longer service life for the pavement.

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The investigations described herein were conducted under the general direction of Mr. F. N. Hveem, Materials and Research Engineer, California Division of Highways.

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References

1. Ekse, M. and Zia, Z. T., "Field Measurement of Air Permeability for Control of Bituminous Material Construction", Proceedings, Association of Asphalt Paving Technologists, 22 (1953) p 44.

2. McLaughlin, J. F. and Goetz, W. H., "Permeability, Void Content and Durability of Bituminous Concrete", Proceedings, Highway Research Board, 34 (1955) p 274.

3. "Air Permeability of Asphalt Concrete" by T. C. Hein and R. J. Schmidt. Presented at the ASTM Meeting, Atlantic City, June 1961.

4. "Progress Report on the Zaca-Wigmore Experimental Asphalt Test Project", by F. N. Hveem, E. Zube and J. Skog. Presented at the Third Pacific Area National Meeting of ASTM, San Francisco, October 11-16, 1959. Symposium on Road and Paving Materials. ASTM Publication No. 277.

5. "Asphalt Test" by E. Zube, California Highways and Public Works, May-June 1961.

6. "Seal Coats - Laboratory Contribution Toward Better Performance", by E. Zube. Presented at the 37th Annual Meeting of the Highway Research Board, Washington, D.C., January 1958. Published in Highway Research Board Bulletin 215, 1959.

TABLE A

Permeability of Pavement Immediately After Construction
Compared with Moisture Content in Pavement
After Winter Rains.

Permeability Measurement Date	Permeability Ml./Min.	Sample Date for Moisture	Percentage of Moisture Pavement
Dec. 1956	10	March 1957	1.37
	10		1.50
	15		2.50
	35		2.96
	55		3.10
	105		2.69
	112		2.18
	170		3.14
	610		3.37

Average Percentage of Moisture in Paving
Mixture During Construction = 0.2%.

TABLE B

Rolling Studies

Project E

Paving Date	Mix Type	Test Sect. No.	Lane	Course	Type of Rolling	Average Rolling Temp.°F	Ave. 24 Hr. Perm. Ml./Min.
June 1960	2-1/2" Max.	A	Passing	Base	Breakdown, 1 Coverage Finish with Tandem	278 160	227
		B	Travel	Base	Breakdown, 1 Coverage Finish with Tandem	298 168	162
		B-1	Travel	Base	Breakdown, 1 Coverage Pneumatic, 1 Coverage Finish with Tandem	281 176 155	155
		B-2	Travel	Base	Breakdown, 1 Coverage Pneumatic, 3 Coverages Finish with Tandem	289 168 155	135
	3/4" Max.	1	Passing	Surface	Breakdown, 1 Coverage Finish with Tandem	218 163	352
		1-1	Passing	Surface	Breakdown, 1 Coverage Pneumatic, 1 Coverage Finish with Tandem	215 174 138	183
		1-2	Passing	Surface	Breakdown, 1 Coverage Pneumatic, 3 Coverages Finish with Tandem	214 164 142	147
		2	Travel	Surface	Breakdown, 1 Coverage Finish with Tandem	243 160	179
		2-1	Travel	Surface	Breakdown, 1 Coverage Pneumatic, 1 Coverage Finish with Tandem	254 166 152	136
		2-2	Travel	Surface	Breakdown, 1 Coverage Pneumatic, 3 Coverages Finish with Tandem	250 164 139	77

TABLE C

Project	Section	Rolling Pattern	Temperature °F Breakdown	Temperature °F Pneumatic	Temperature °F Finish	Pneumatic Contact Press. #/sq.in. From Bros Chart	Perm. Ml./min. 1-3 Hours After Rolling	Percentage Reduction By Pneumatic Rolling	Remarks
H	1	Breakdown + Finish	187	-	107	-	156	-	
	2	Breakdown + Pneumatic + Finish	220	128	115	68	113	28	Breakdown and Pneumatic temperatures low; Pneumatic contact pressure high.
			220	178	115	68	77	51	Breakdown temperature low; Pneumatic temperature and contact pressure high.
I	1	Breakdown + Finish	278	-	140	-	64	-	
	2	Breakdown + Pneumatic + Finish	263	188	131	62	46	28	Low permeability after breakdown.
J	1	Breakdown + Finish	253	-	130	-	386	-	
	2	Breakdown + Pneumatic + Finish	245	163	130	76	143	63	Breakdown and Pneumatic temperatures high; Pneumatic contact pressure high.
K	1	Breakdown + Finish	235	-	135	-	628	-	
	2	Breakdown + Pneumatic + Finish	235	135	135	34	507	19	Breakdown and Pneumatic temperature low; Pneumatic contact pressure low. Permeability high.
L	1	Breakdown + Finish	250	-	140	-	288	-	
	2	Breakdown + Pneumatic + Finish	250	143	140	39	228	21	Breakdown temperature high; Pneumatic temperature and contact pressure low.
M	1	Breakdown + Finish	243	-	140	-	149	-	
	2	Breakdown + Pneumatic + Finish	255	140	115	64	59	60	Breakdown temperature high. Pneumatic temperature low, and contact pressure high.

TABLE D

Field Permeability, Void Relationship For a Number of Individual Projects

Project	Type of Mix	Perm. Ml./Min.	% Relative Compaction	% Voids
N	Type A-3/4" Max. 4.5% Asphalt	200 230 510	97.4 97.0 93.5	8.8 9.0 12.3
	Type A-3/4" Max. 5.5% Asphalt	30 70 250 250 550	98.3 97.0 93.2 94.5 92.8	4.5 5.8 9.5 8.2 10.1
G	Type A-3/4" Max. 5.2% Asphalt	15 15 35 35 40 50 55 70 80	98.3 99.6 98.3 100.0 98.3 98.8 97.4 97.4 97.9	5.0 3.5 5.0 3.3 5.0 4.5 5.8 5.8 5.4
O	Type B-3/4" Max. 4.3% Asphalt	150 175 175 195 210 300	96.4 96.0 94.2 93.8 94.2 94.2	9.6 10.0 11.6 12.1 11.6 11.6
H	Type B-3/4" Max. 5.0% Asphalt	55 150 190 265 340 520	95.0 93.3 93.7 91.1 93.4 90.3	8.9 10.6 10.2 12.6 10.1 13.4

TABLE E

Average Permeability Values for a Pavement Constructed During Changing Climatic Conditions

Paving Date	Atmospheric Temperature Range During Paving		Average Permeability Ml./Min.
	Max.	Min.	
Sept.	87	51	47
Oct. Nov.	56	35	371

TABLE F

Reduction in Permeability Values
Following Application of a Slurry Seal

Project Q

Test Condition	Station	New Pvt. Thickness	Permeability - Ml./Min. Shldr.	Travel O.W.T.	Travel B.W.T.	Passing B.W.T.	Passing O.W.T.
New Pvt. immediately after const. Nov. 1957	603+00	2"	310	70	110	270	-
	603+25		-	100	130	140	-
	604+00		260	90	90	320	-
	606+50		230	90	100	270	-
	608+00		400	270	340	320	-
	Ave.		300	124	154	264	
	589+00	3"	-	-	-	700	-
	590+00		-	-	500	480	-
	591+00		-	-	320	440	-
	591+89		-	-	400	500	-
	592+00		-	-	420	490	-
	593+00		-	-	360	-	-
	593+50		-	-	-	500	-
	594+00		-	-	360	350	-
	Ave.		-	-	393	494	-
	596+00	4"	-	-	250	-	-
	597+00		-	-	230	-	-
	598+00		-	-	500	-	-
	599+00		-	-	350	-	-
	600+00		-	-	750	-	-
	601+00		-	-	440	-	-
	Ave.		-	-	420	-	-
New Pvt. plus Slurry Seal immediately after completion Nov. 1957	604+00	2"	-	10	10	10	-
	604+25		-	10	10	10	-
	606+00		-	10	10	10	-
	606+50		-	10	10	10	-
	Ave.		-	10	10	10	-
	593+50	3"	-	10	10	10	-
	593+75		-	10	10	10	-
	Ave.		-	10	10	10	-
	598+00	4"	-	10	10	10	-
	598+25		-	10	10	10	-
	Ave.		-	10	10	10	-
New Pvt. plus Slurry Seal, Feb. 27, 1958 18" rain	604+00	2"	-	-	-	-	-
	604+25		-	-	-	-	-
	606+00		-	10	10	20	10
	606+50		-	5	10	15	10
	Ave.		-	7.5	10	17.5	10
	593+50	3"	-	10	10	20	15
	593+75		-	15	10	10	15
	Ave.		-	12.5	10	15	15
	598+00	4"	-	10	20	20	15
	598+25		-	10	10	10	15
	Ave.		-	10	15	15	15
New Pvt. plus Slurry Seal May 28, 1958	593+50	3"	-	10	10	10	10
	593+75		-	10	15	15	10
	Ave.		-	10	12.5	12.5	10
	606+50	2"	-	10	10	10	-
	606+75		-	5	10	15	-
	Ave.		-	7.5	10	12.5	-

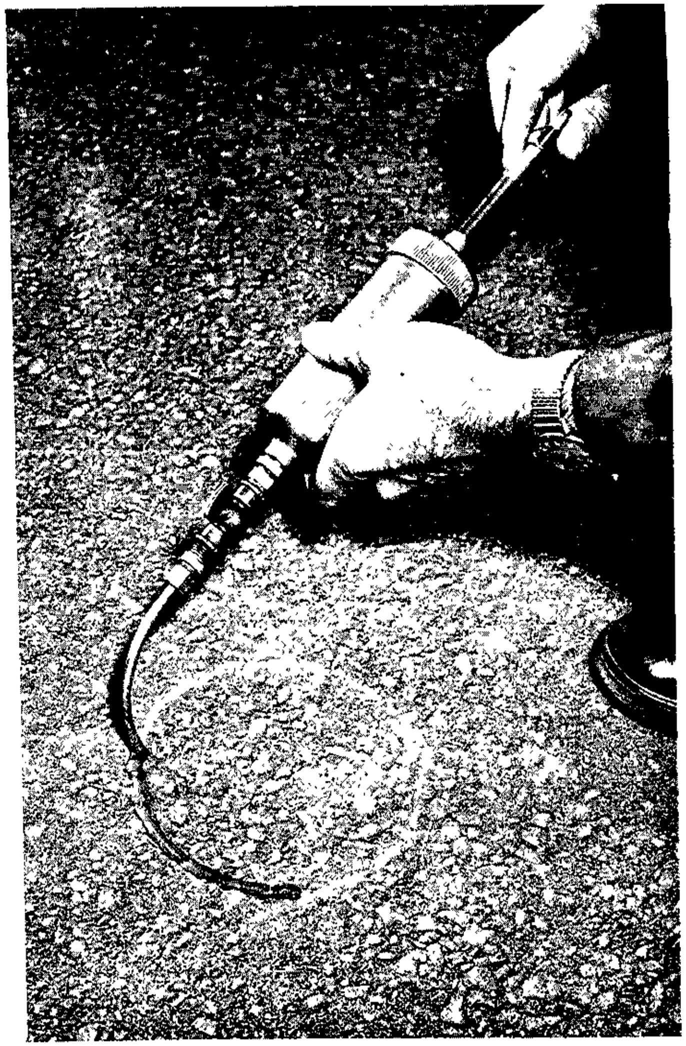


Figure 1A
Forming grease ring

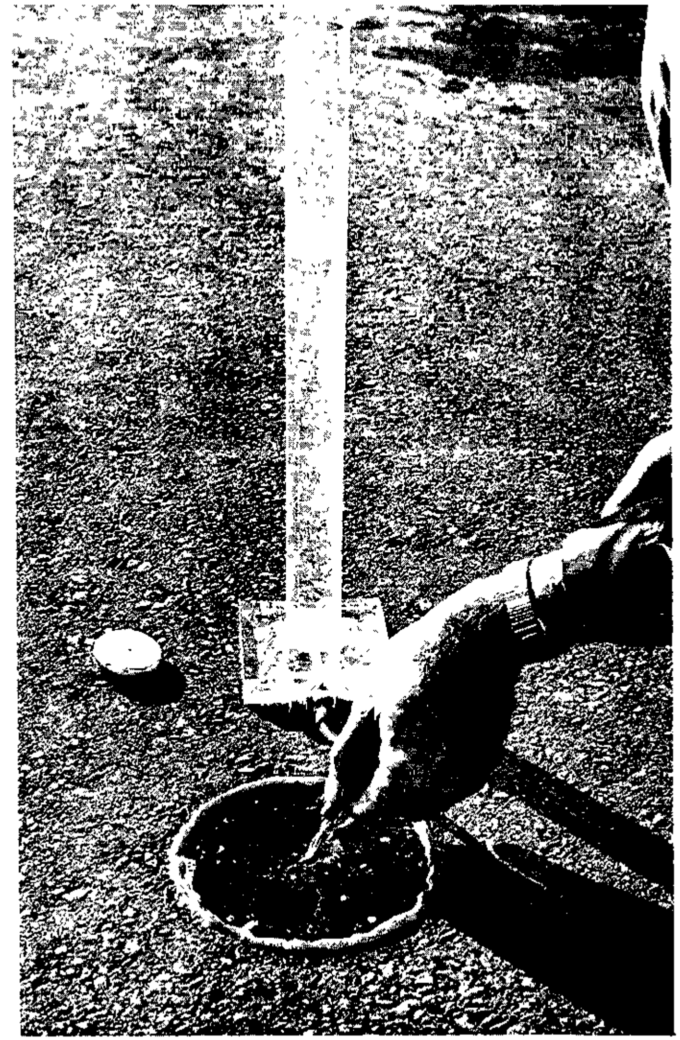
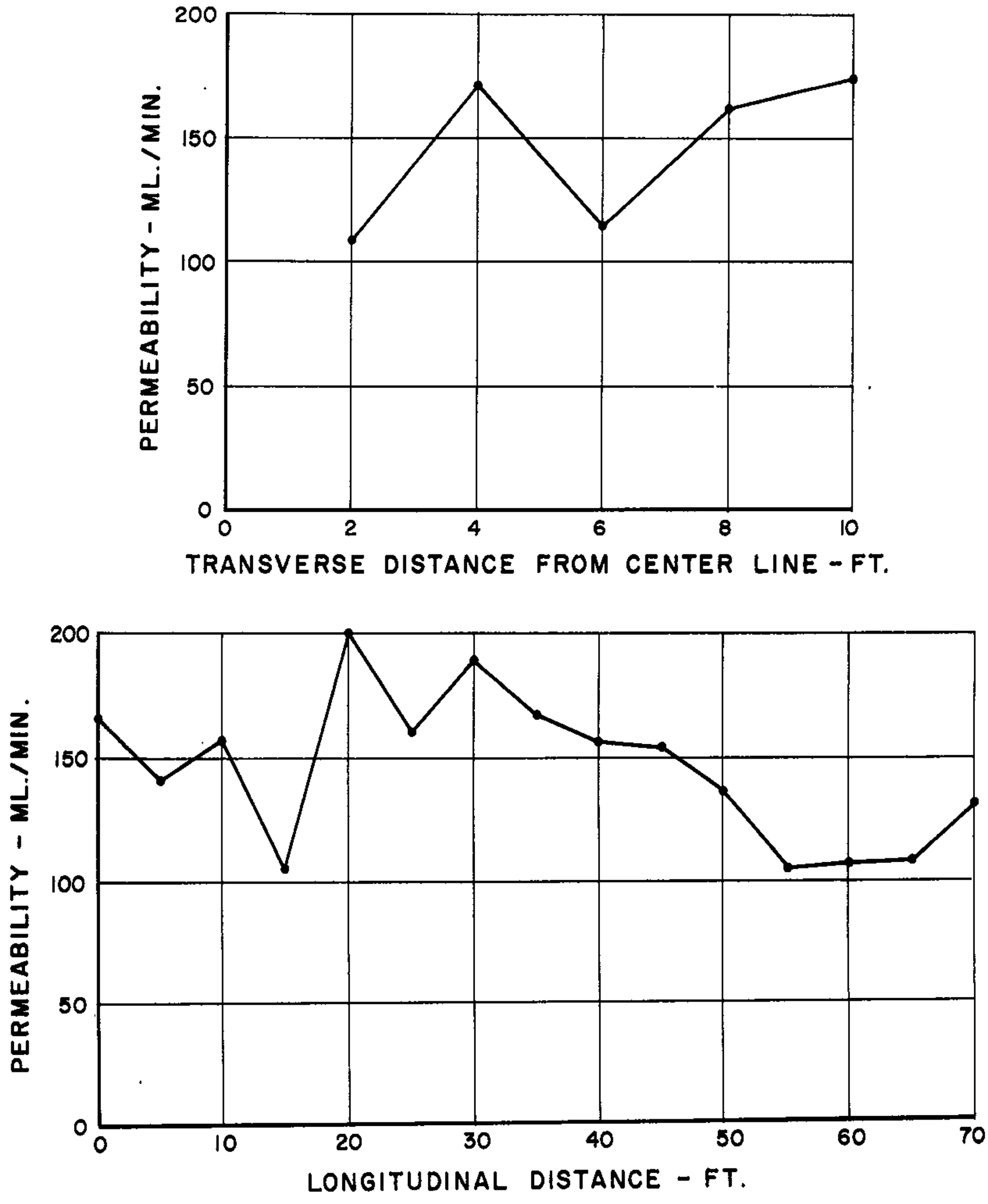


Figure 1B
Applying water solution
to pavement surface

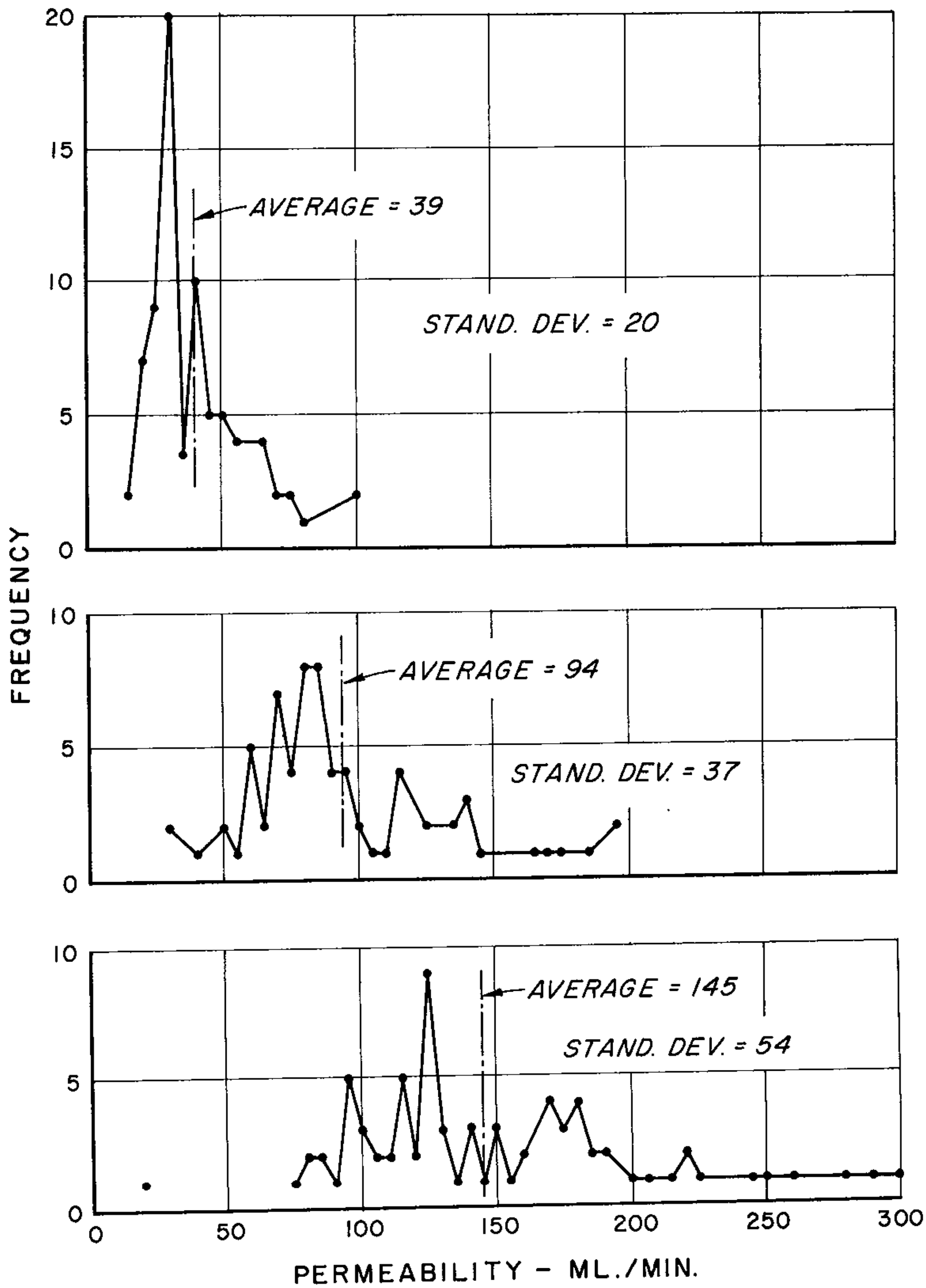
Performing Permeability Test

FIG. 2

VARIATION IN AVERAGE PERMEABILITY AFTER SPREADING AND ROLLING A SINGLE LOAD OF MIX



VARIATION IN PERMEABILITY AFTER SPREADING AND ROLLING A SINGLE LOAD OF MIX FROM THREE TEST SECTIONS ON THE SAME PROJECT



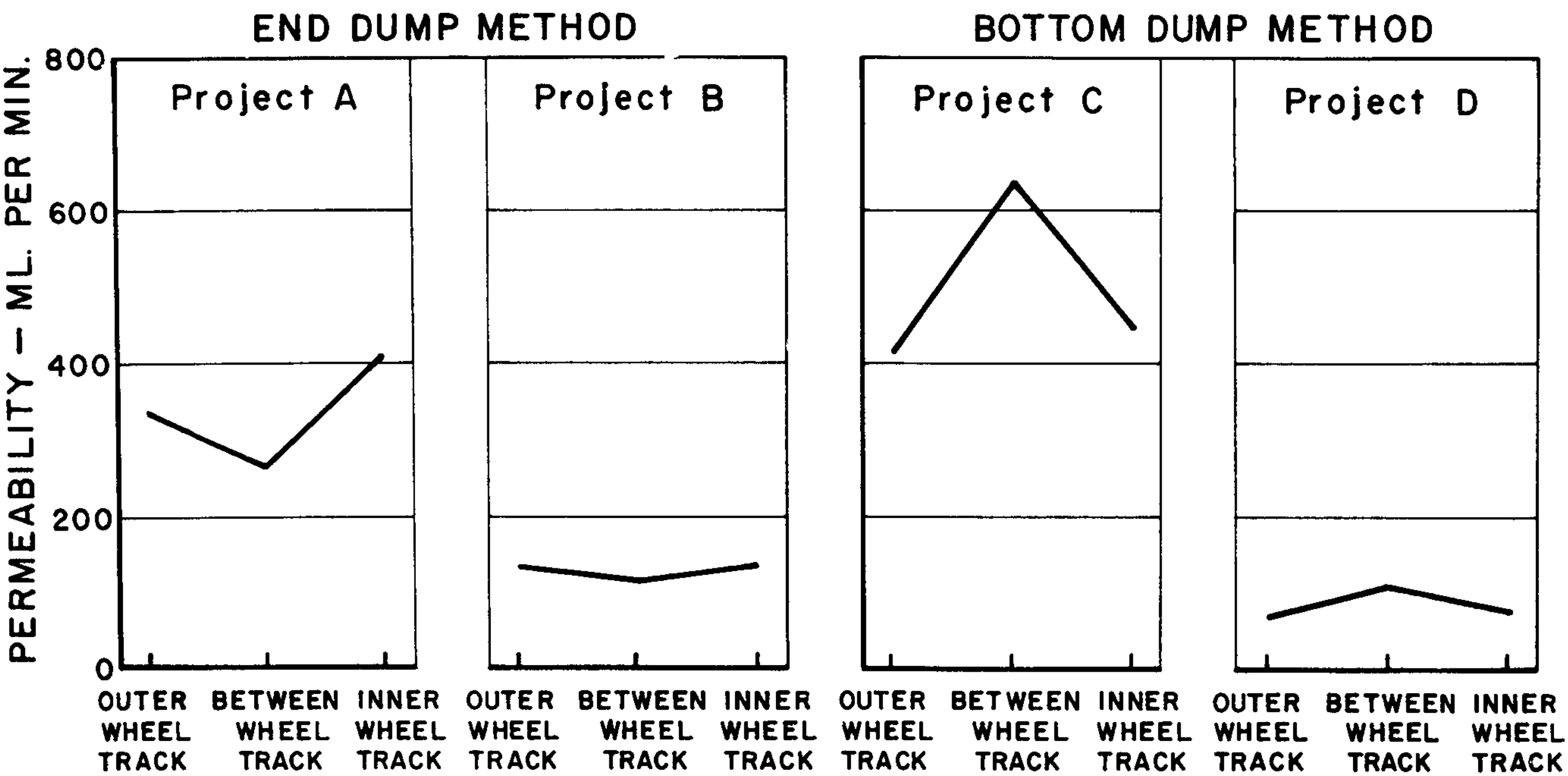
10 ml/min
Fig. 4A

580 ml/min
Fig. 4B

Both Figures from same Project

Permeability-Surface Texture Relation

AVERAGE PERMEABILITY VALUES FOR TWO DIFFERENT PAVING METHODS



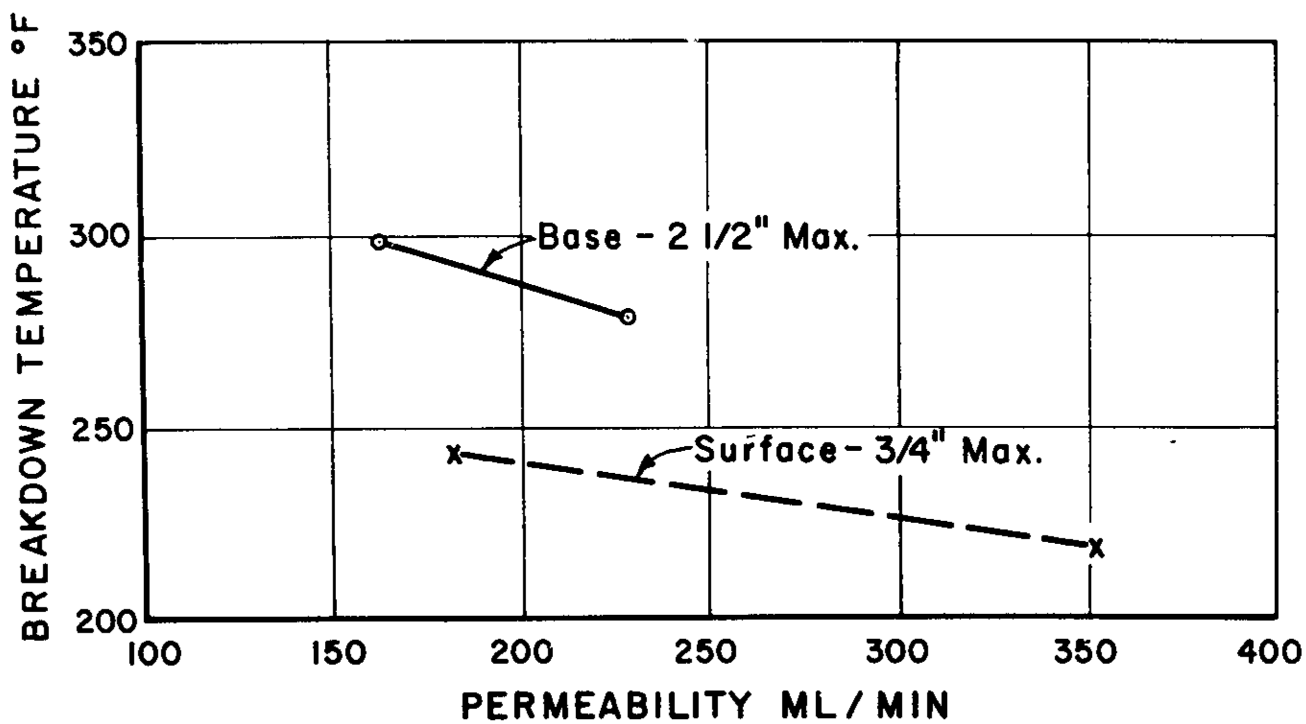
TEST AREA IN TRAVEL LANE

FIG. 5

FIG. 6

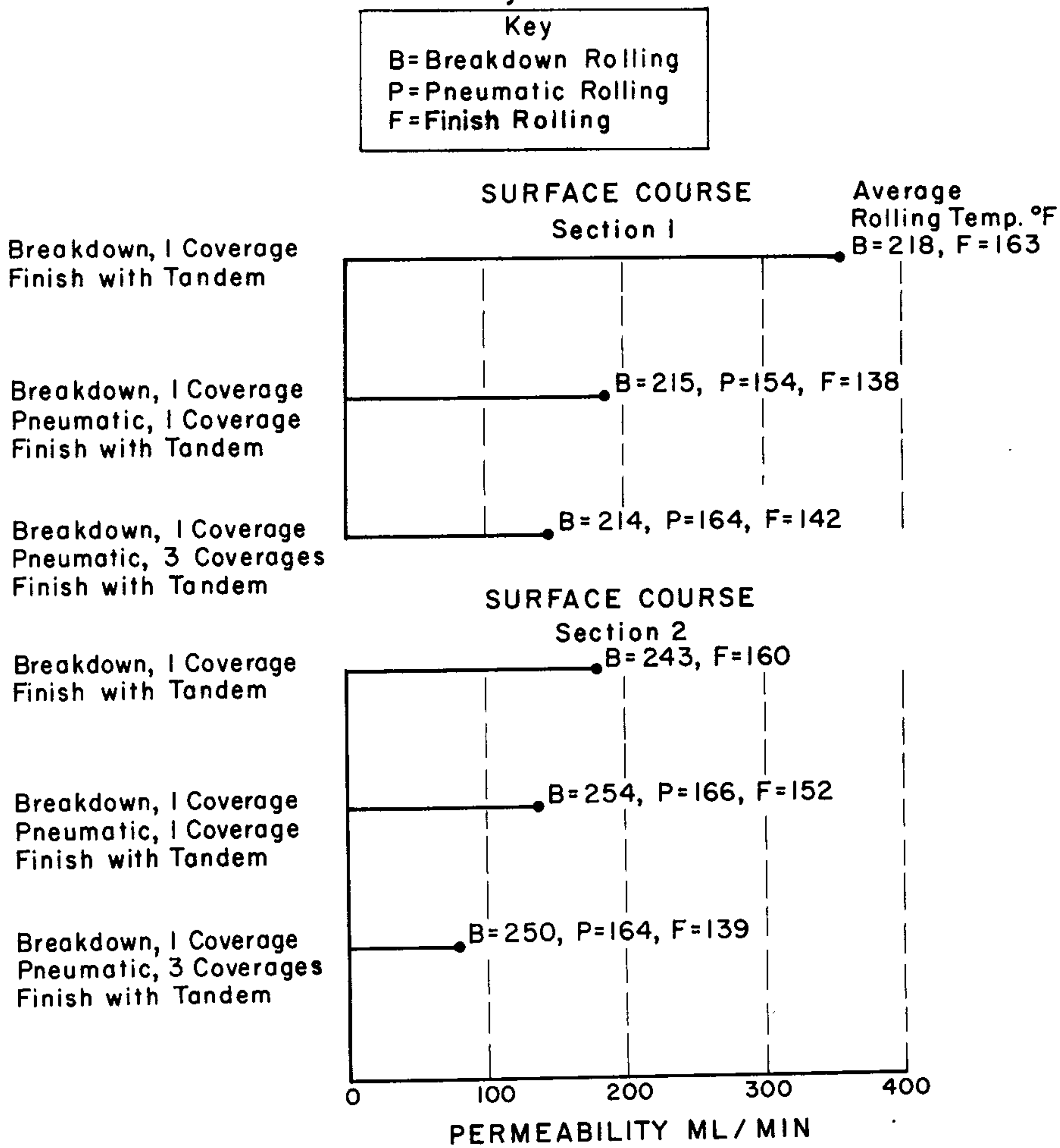
EFFECT OF BREAKDOWN TEMPERATURE ON PERMEABILITY

Project E

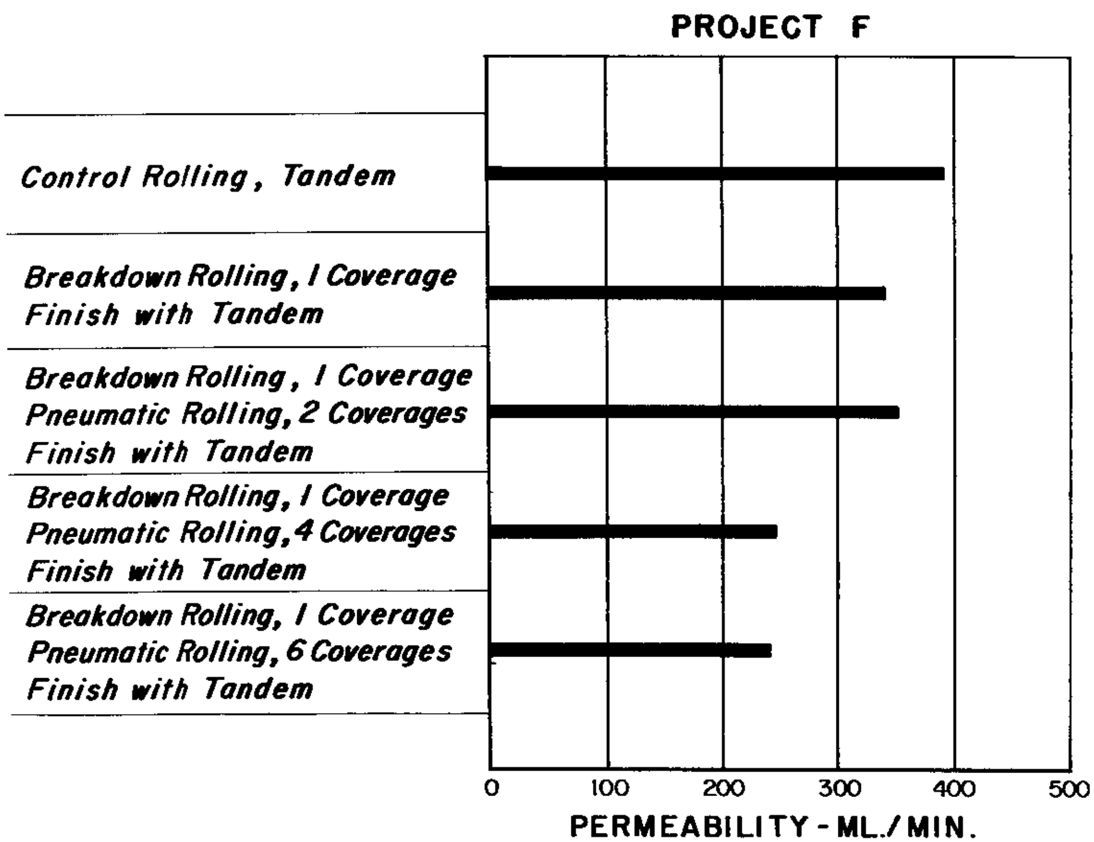


EFFECT OF BREAKDOWN TEMPERATURE ON PERMEABILITY

Project E



EFFECT OF COMPACTION PROCEDURES ON PERMEABILITY VALUES



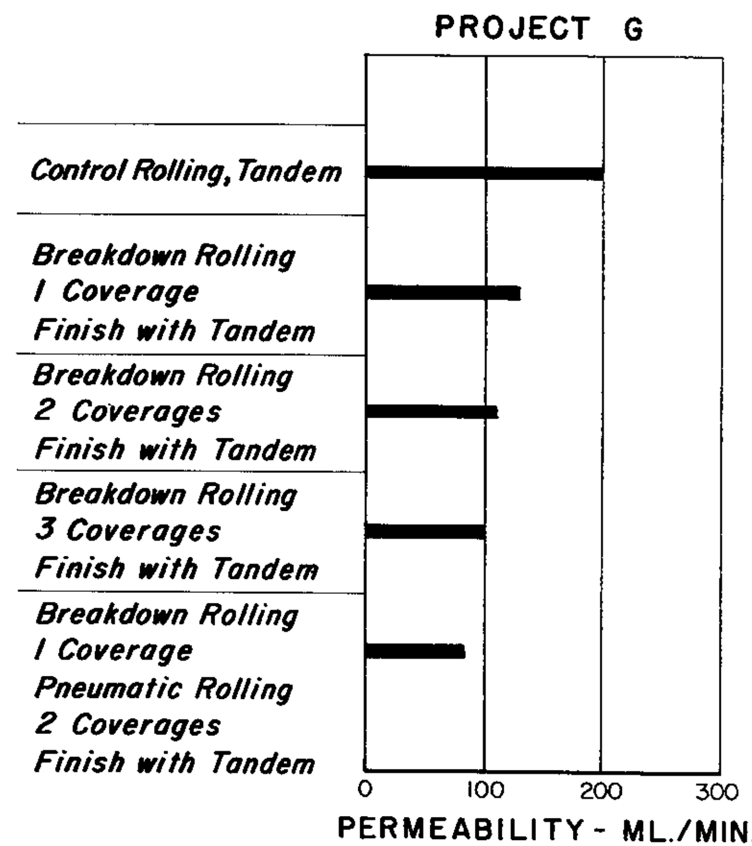


FIG. 8

AVERAGE PERMEABILITY VALUES OF A SECTION CONTAINING DIFFERENT ASPHALT CONTENTS.

PROJECT N

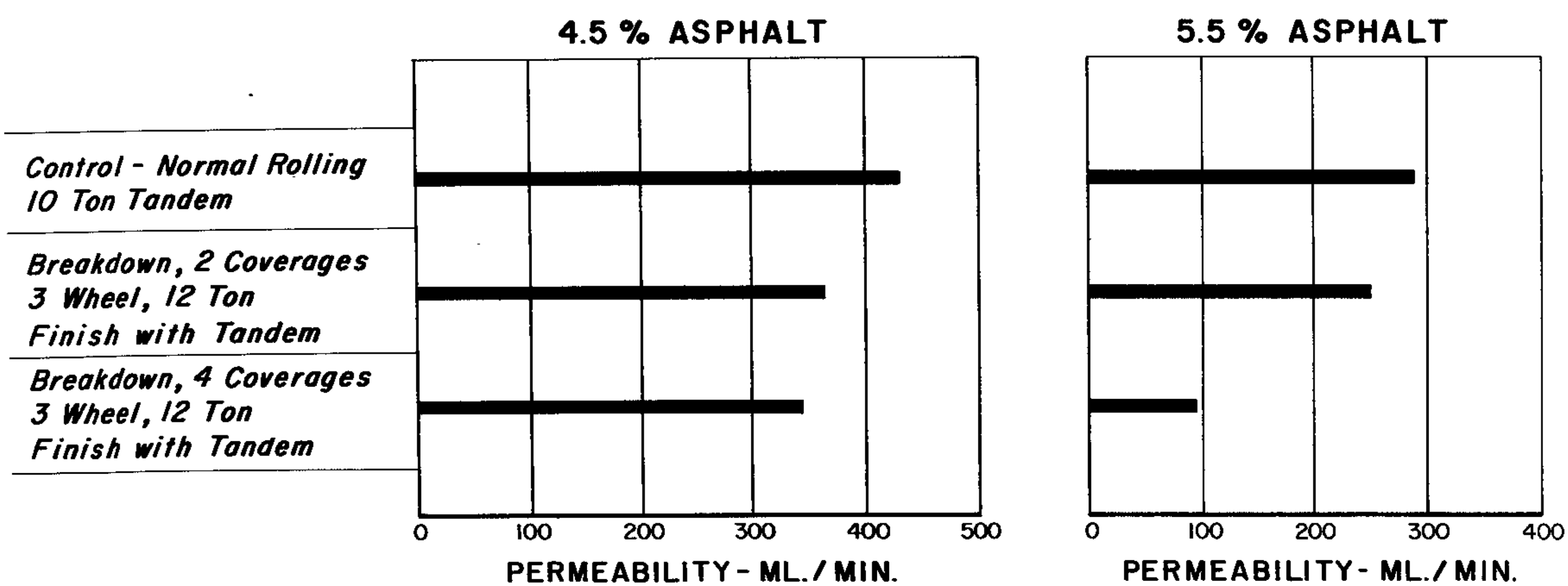
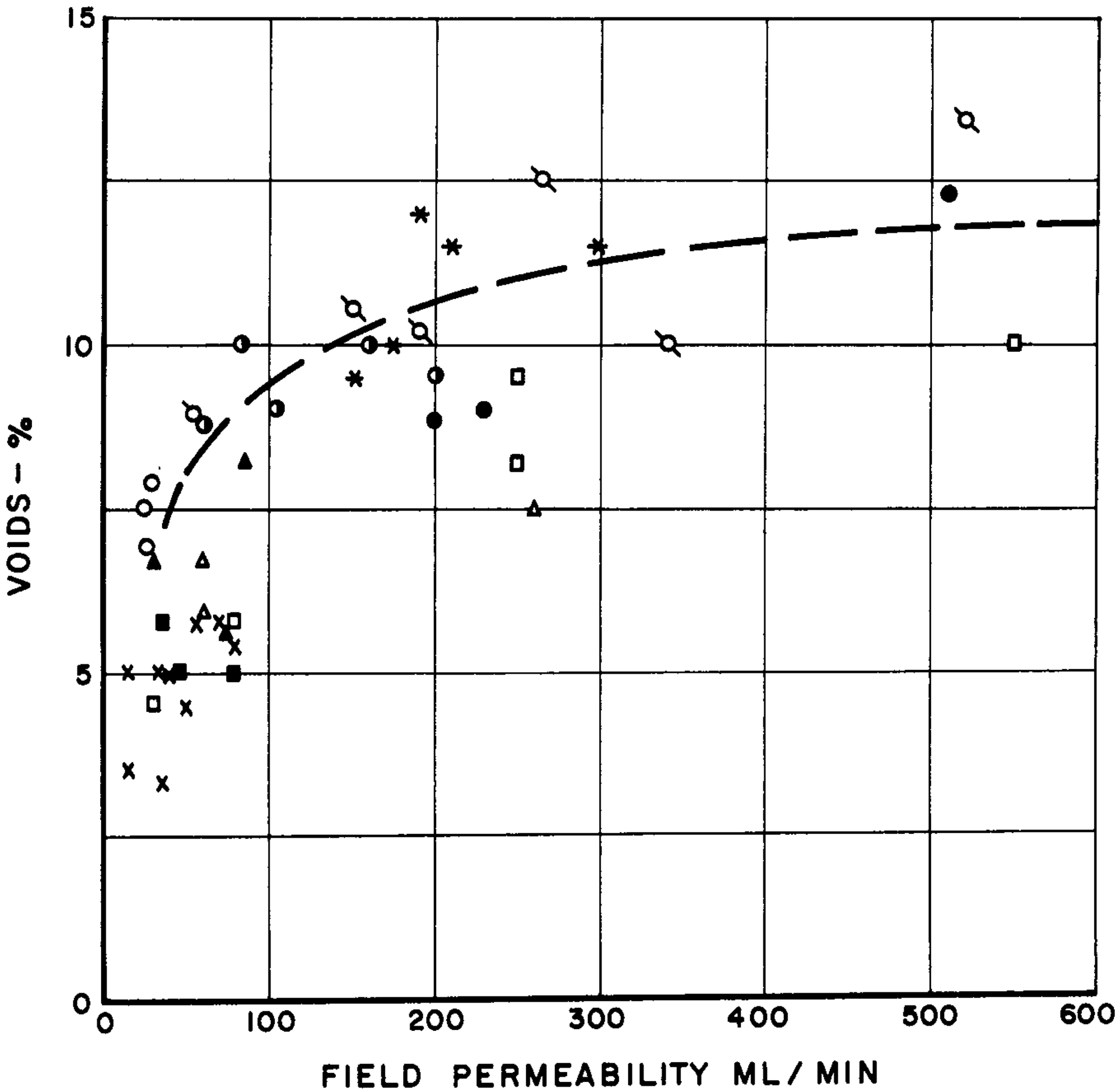
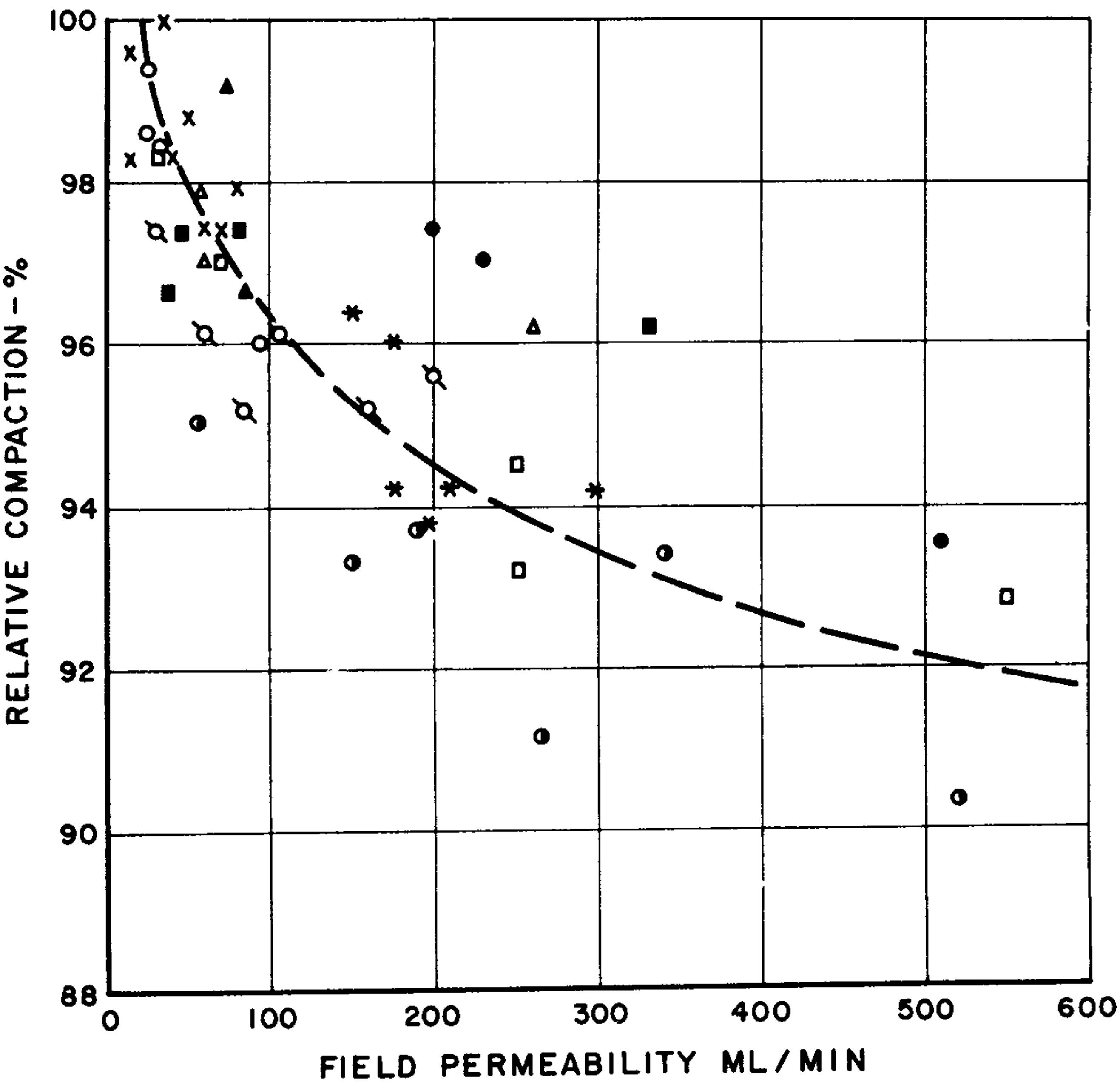


FIG. 9

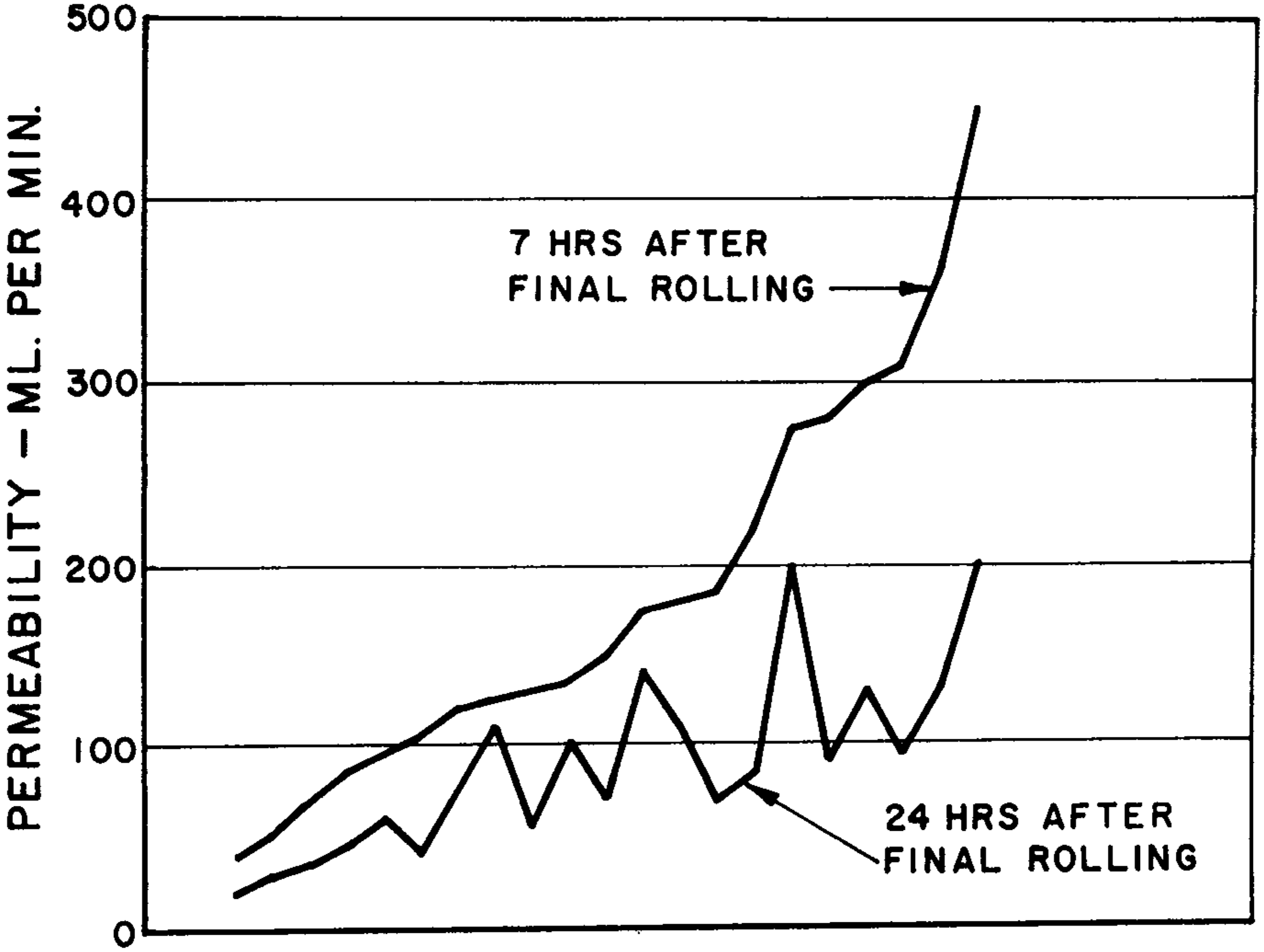
PERMEABILITY — VOIDS RELATION FOR TEN DIFFERENT PROJECTS



PERMEABILITY-RELATIVE COMPACTION RELATION FOR TEN DIFFERENT PROJECTS

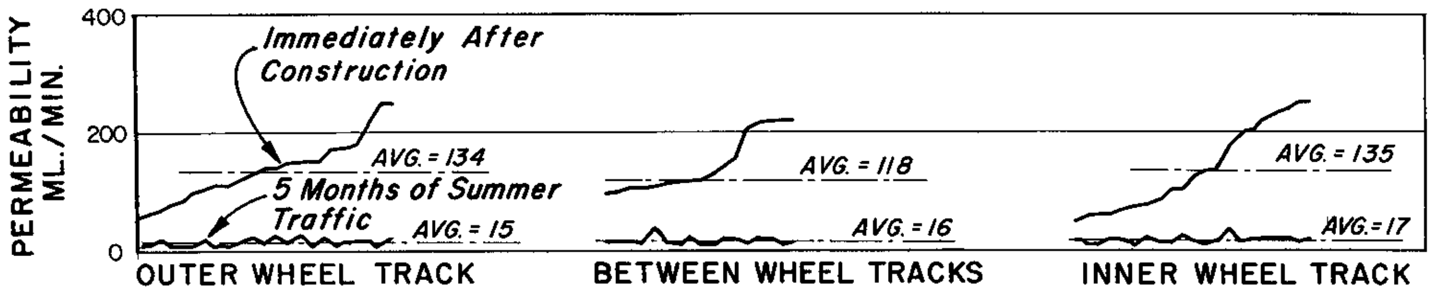


CHANGE IN PERMEABILITY VALUES FOLLOWING FINAL ROLLING. NO TRAFFIC PROJECT G

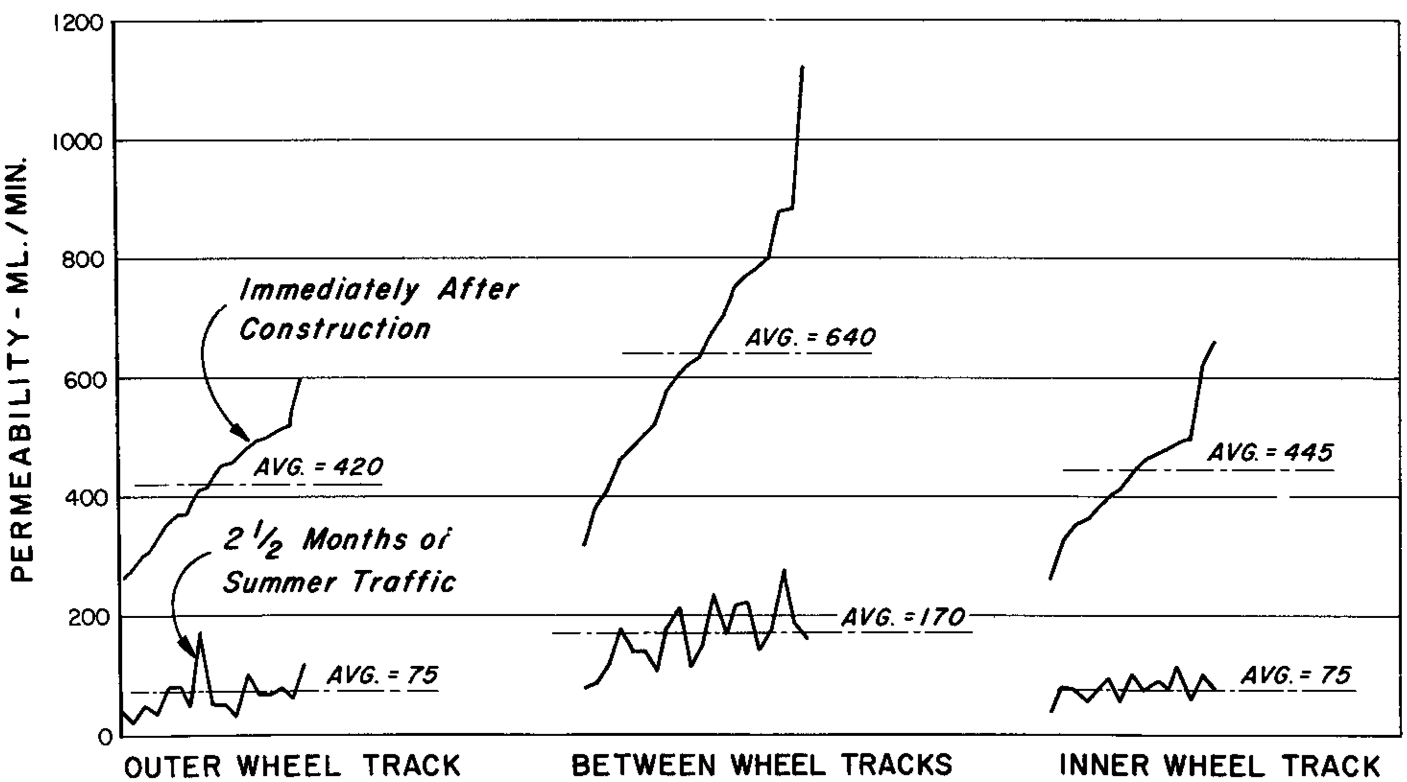


CHANGE IN PERMEABILITY VALUES AFTER SUMMER TRAFFIC

TRAVEL LANE



PROJECT G



PROJECT P

FIG. 13

CHANGE IN PERMEABILITY VALUES CAUSED BY INCREASE AND DECREASE OF PAVEMENT MOISTURE AND TRAFFIC COMPACTION

PROJECT N

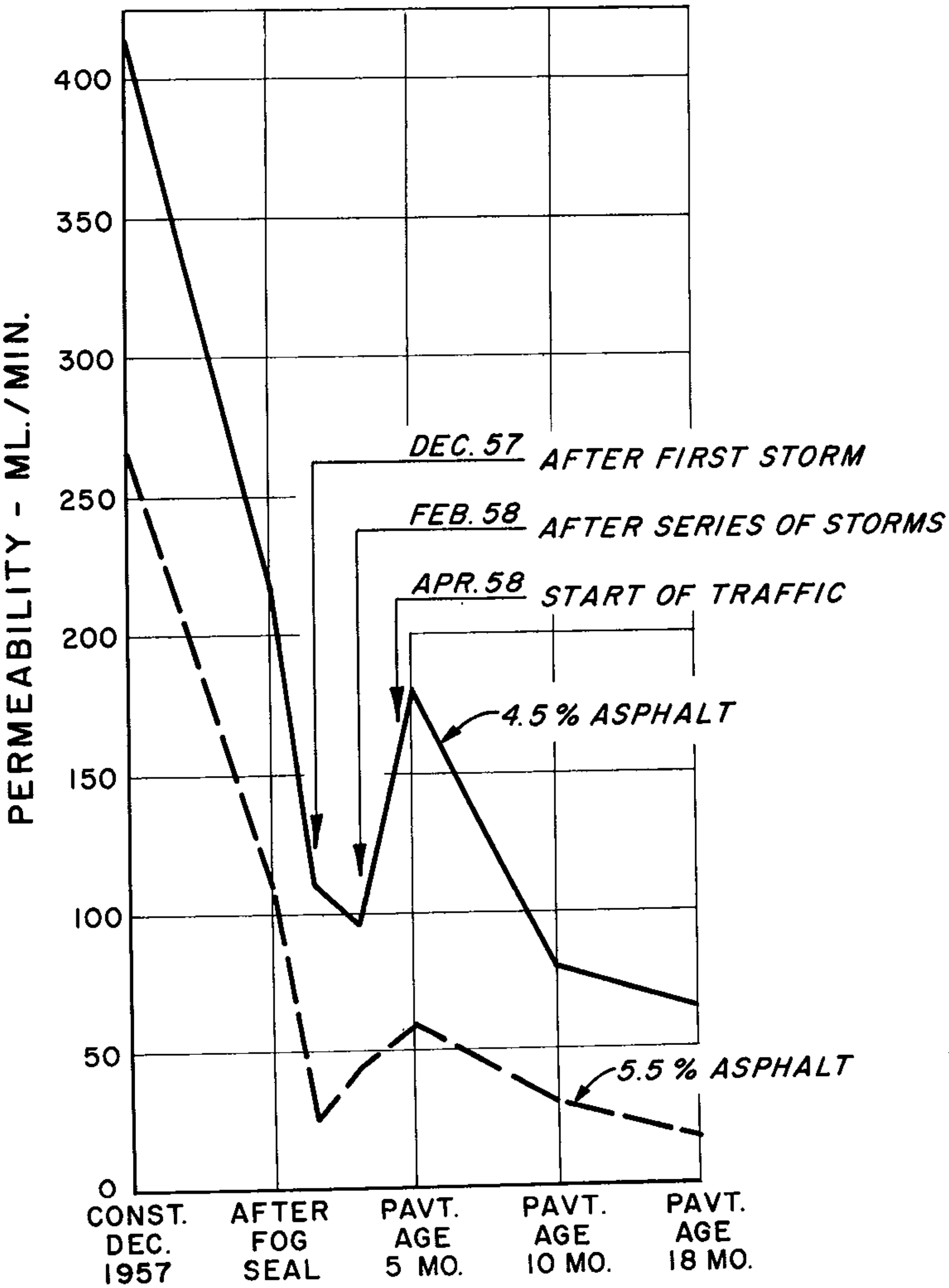
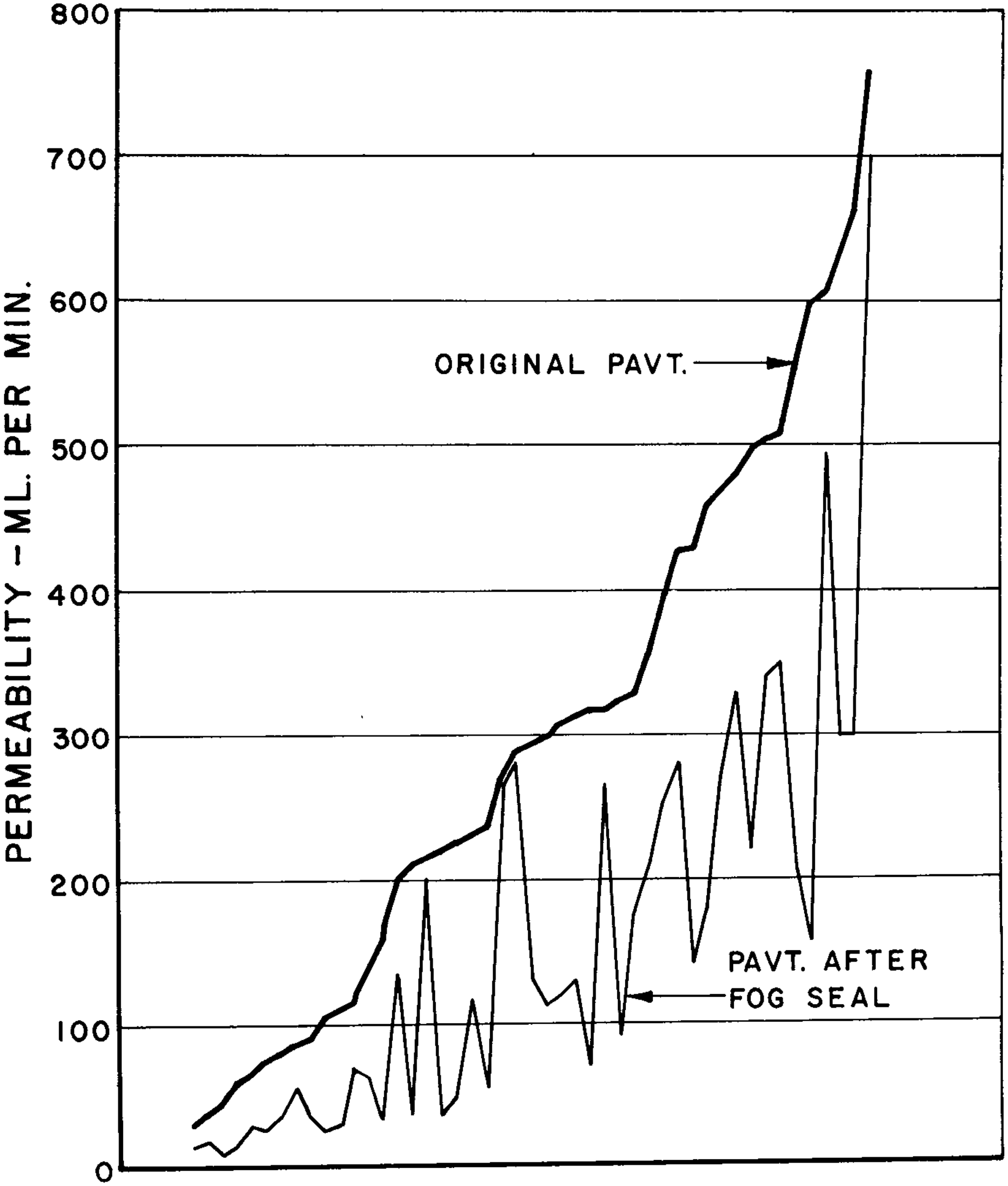


FIG. 15

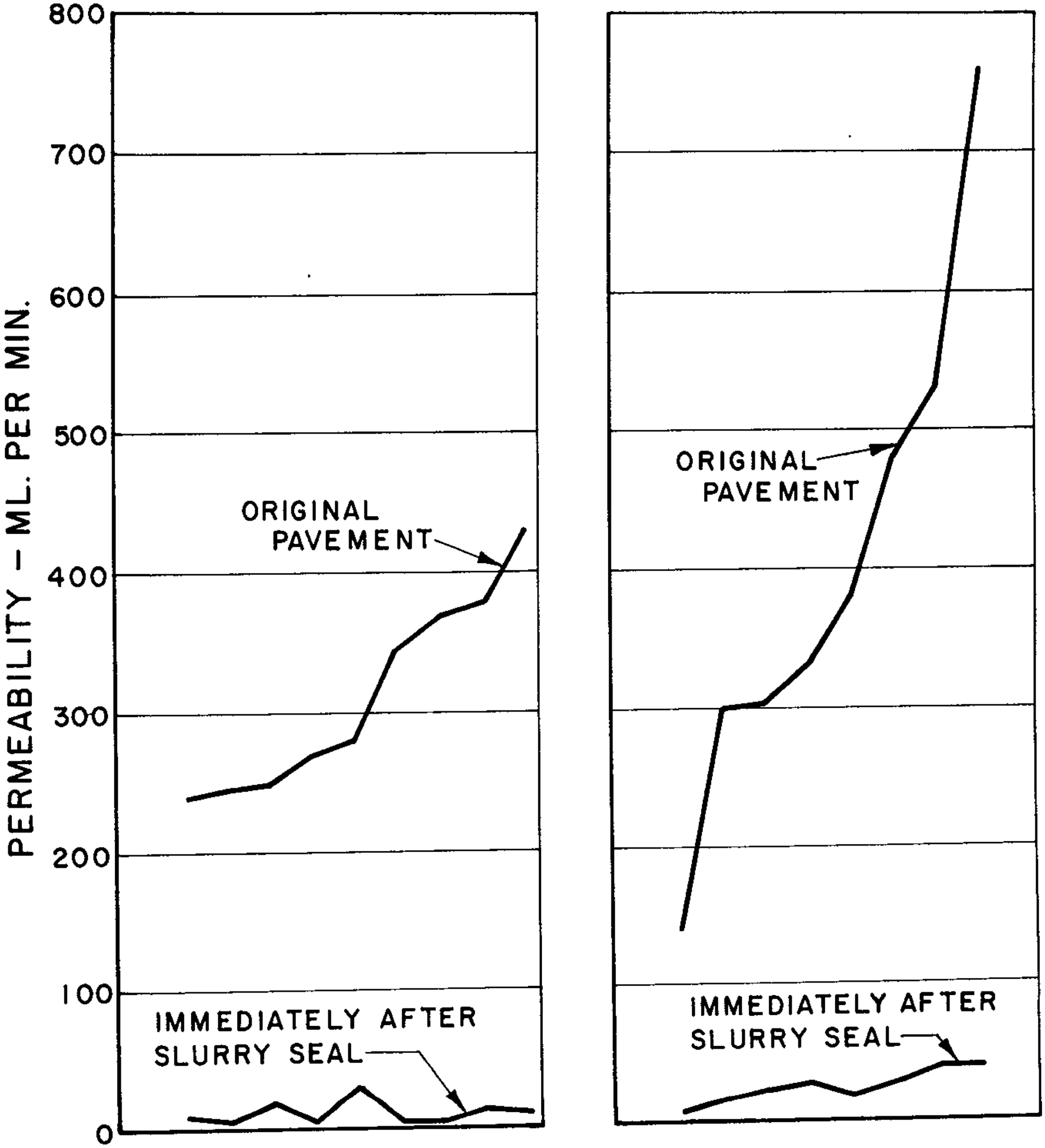
CHANGE IN PERMEABILITY VALUES AFTER APPLICATION OF A FOG SEAL

PROJECT N



REDUCTION IN PERMEABILITY VALUES FOLLOWING APPLICATION OF A SLURRY SEAL COAT

PROJECT Q



APPENDIX A

Test Method No. Calif. 341-A
January, 1960
(6 pages)

State of California
Department of Public Works
Division of Highways

MATERIALS AND RESEARCH DEPARTMENT

METHOD OF TEST FOR MEASURING THE PERMEABILITY OF BITUMINOUS PAVEMENTS

Scope:

This method describes the procedure for determining the relative permeability of bituminous pavements.

Procedure:

A. Apparatus

1. 1 - 250 Ml special plastic graduated cylinder with valve.
2. 1 - 500 Ml special plastic graduated cylinder with valve.
3. 1 - 250 Ml Polyethylene graduated cylinder.
4. 1 - 500 Ml Polyethylene graduated cylinder.
5. 1 - Calking gun with a 5 inch piece of ¼-inch copper tubing with cap.
6. 1 - gal. Polyethylene bottle with handle and pouring spout.
7. 2 - 1 gal. friction top cans, one containing medium weight chassis grease.
8. 1 - Polyethylene funnel 4½-inch diameter top.
9. 1 - Stop watch with 60 second dial.
10. 1 - Aluminum template, 6-inch diameter with handle.
11. 2 - pieces yellow lumber crayon.
12. 1 - 6 foot folding Zig Zag Ruler.
13. 1 - 5-inch trowel.
14. 1 - 8-inch spatula.
15. 1 - 100 Ml glass graduated cylinder.
16. 1 - 1 qt. Polyethylene bottle for Aerosol Concentrate.

17. 1 - 5 gal. Polyethylene Carboy container for storage of test solution.
    The above items are furnished in a kit box.
18. 1 - 2 pound hammer.
19. 1 - 1 inch wide steel chisel.
20. 1 - Face shield.

B. Materials

1. Medium weight chassis grease. One gallon is furnished with kit.
2. Wetting agent known as Aerosol OT 75% liquid. 1 quart is furnished with kit.
3. Supply of distilled water.
4. Supply of Premix Patching Material.

C. Preparation of Test Solution

Prepare test solution by mixing 95 ml. of Aerosol OT 75% liquid per 5 gallons of distilled water.

D. Method for Filling Calking Gun with Grease

1. Remove front cover of calking gun by turning counter clockwise.
2. Turn handle at rear of calking gun one half turn so that notched teeth on the rod are in an upward position and pull handle all the way out.
3. Fill gun with grease by using spatula and work as many air bubbles out of the grease as possible with the spatula.
4. Replace front cover and turn rear handle so that the notched teeth are in a downward position.
5. Pump calking gun handle until grease extrudes from copper tubing.
6. Always store calking gun in test kit with notches in an upward position and cap on copper tubing tip; this will prevent grease from being extruded from the gun during storage.

E. Test Procedure

The procedure for Dense Graded Asphalt Concrete Pavements and Various Types of Seal Coats is as follows:

1. With the crayon and template, draw a 6 inch diameter circle on the pavement.

2. Extrude grease from the calking gun on the circle. The diameter of the grease on the ring should be about ¼ of an inch; see Figure I.

3. Run the finger around the outside edge of the grease ring, pushing a small amount of grease into the pavement. This will form a sealed reservoir for the test solution.

4. Fill the special plastic graduated cylinder and Polyethylene graduated cylinder with the test solution. The Polyethylene cylinder is used for refilling the special cylinder when more solution is needed during test.

   Note: In areas where the permeability of the pavement is below 250 ml/min. the 250 ml. graduated cylinders shall be used. The 500 ml. graduated cylinders are used in areas where the permeability of the pavement is greater than 250 ml./min.

5. Release valve at base of special plastic graduated cylinder, start stop watch and run solution from the special plastic graduated cylinder onto the area within the grease ring, keeping this area covered constantly with the solution for two minutes; see Figure II. Refill the special plastic cylinder from the polyethylene graduate if more solution is needed during test.

   Note: At the end of the test the pavement in the grease ring should have an unflooded wet appearance.

6. At the end of the 2 minute test period, determine the total amount of solution used.

7. Pick up grease with trowel and place in gallon can. Do not mix used grease with the new grease furnished with kit.

The procedure for pavements surfaced with Open Graded Asphalt Concrete is as follows:

1. With the crayon and template, draw a 6 inch diameter circle on the pavement.

2. Put on a face shield.

3. Use the hammer and chisel to chip away the open graded surfacing from around the 6 inch diameter circle forming a trough around the permeability test area; see Figure III. The trough around the ring shall be about 1 inch wide and shall extend into the dense graded portion of the pavement about ¼-inch.

4. Use trowel to fill trough with chassis grease. The grease shall extend above the surface of the test area about ¼-inch; see Figure IV. This will form a sealed reservoir for the test solution.

5. The test is then run in the normal manner as previously described; see Figure V.

6. After test is completed remove grease, fill trough with Pre-mix patching material and compact with hammer; see Figure VI.

F. Calculations

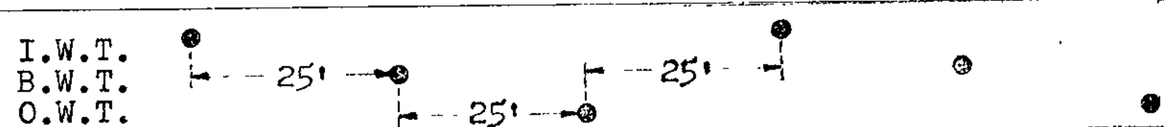
Divide the total quantity of solution used during the test period by two and record the relative permeability in mls/min.

G. Hazards

1. The operator should always wear a suitable face shield when chipping open graded mix in preparation for the test.

H. Tentative Procedure for New Pavements

1. The following tentative procedure is recommended for obtaining an average permeability result on a given section of new pavement. In any travel lane, determine the permeability at 25 foot intervals in the outer wheel track, inner wheel track and between the wheel tracks for a total of six readings. A diagram is shown below:



The six readings should be averaged to obtain the reading for the test area. This procedure should then be repeated at intervals of approximately 1000 feet.

2. In mountainous areas the above noted plan may have to be modified in order to provide a relatively flat area for testing.

3. When permeability studies are required after traffic action, it is advisable to test the passing lane in order to obtain the best indication of the relative permeability of the pavement.

4. When the test is performed on an open graded surface, about 30 ml./min. of solution will be held by the open graded mix, even though no solution is entering the dense graded mixture. Therefore, a reading in this range would not be indicative of any movement into the dense graded pavement.

REFERENCE
A California Method

End of Text on Calif. 341-A

PROCEDURE FOR DENSE GRADED ASPHALT CONCRETE PAVEMENTS AND VARIOUS TYPES OF SEAL COATS

FIGURE I

Forming grease ring.

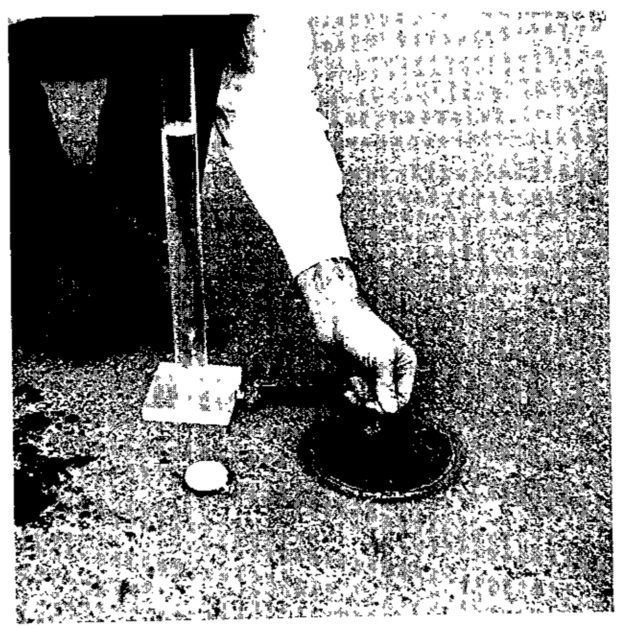


FIGURE II

Applying test solution to pavement surface.

PROCEDURE FOR PAVEMENTS SURFACED WITH AN OPEN GRADED MIXTURE

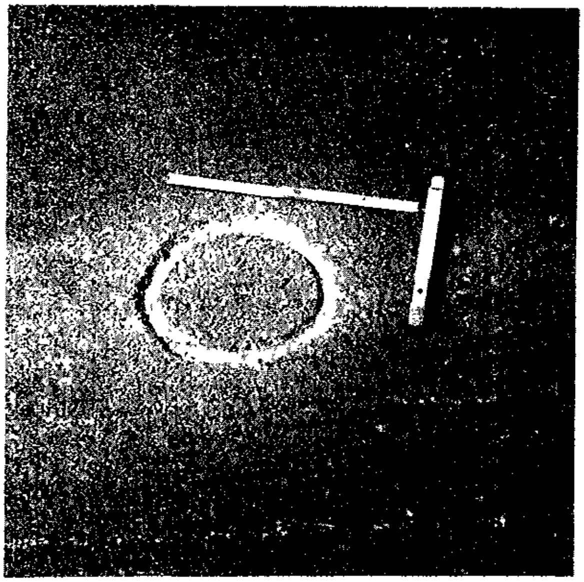


FIGURE III

Trough formed by removal of open graded mix. Note: Intact open graded mix within 6" diameter test area.

FIGURE IV

Grease ring formed around test area.

FIGURE V

Applying test solution to open graded surface within 6" diameter test area.

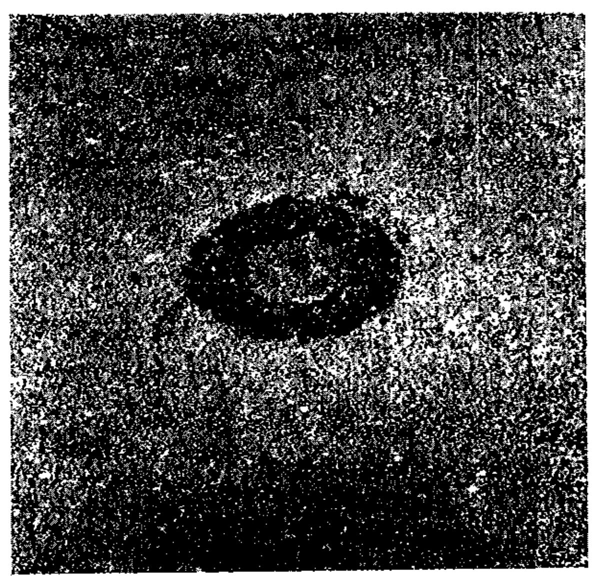


FIGURE VI

Trough area filled with Premix patching material

APPENDIX B

Compaction Requirements for Asphaltic Concrete Excerpts from California Standard Specifications, January 1960

The Contractor will be required to furnish a minimum of one 12 ton 3-wheel roller or tandem roller, one pneumatic-tired roller, and one 8 ton 2-axle tandem roller for each asphalt paver. All mixtures, except open graded mixture, shall be spread at a temperature of not less than 225°F. and all initial rolling or tamping shall be performed when the temperature of the mixture is such that the sum of the air temperature plus the temperature of the mixture is between 300°F. and 375°F. Initial or breakdown rolling shall consist of one complete coverage of asphalt mixtures and shall be performed with a tandem or a 3-wheel roller. Such rollers shall weigh not less than 12 tons.

Rolling shall commence at the lower edge and shall progress toward the highest portion. Under no circumstances shall the center be rolled first. Rolling shall be performed with the drive wheel of the tandem roller forward with respect to the direction of spreading operations, unless otherwise permitted.

The initial or breakdown rolling shall be followed by additional rolling consisting of 3 complete coverages with a pneumatic-tired roller while the temperature of the mixture is at or above 150°F.

The final rolling of the uppermost layer of asphalt concrete or the top of the layer immediately below a layer of Open Graded asphalt concrete shall be performed with an 8-ton 2-axle tandem roller.