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A REPORT ON THE CAUSE OF DETERIORATION OF SECTIONS OF FLEXIBLE I 94 PAVEMENT

MICHIGAN DEPARTMENT OF STATE HIGHWAYS AND TRANSPORTATION

TESTING AND RESEARCH DIVISION
RESEARCH LABORATORY SECTION

A REPORT ON THE CAUSE OF DETERIORATION OF SECTIONS OF FLEXIBLE I 94 PAVEMENT

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Testing and Research Division
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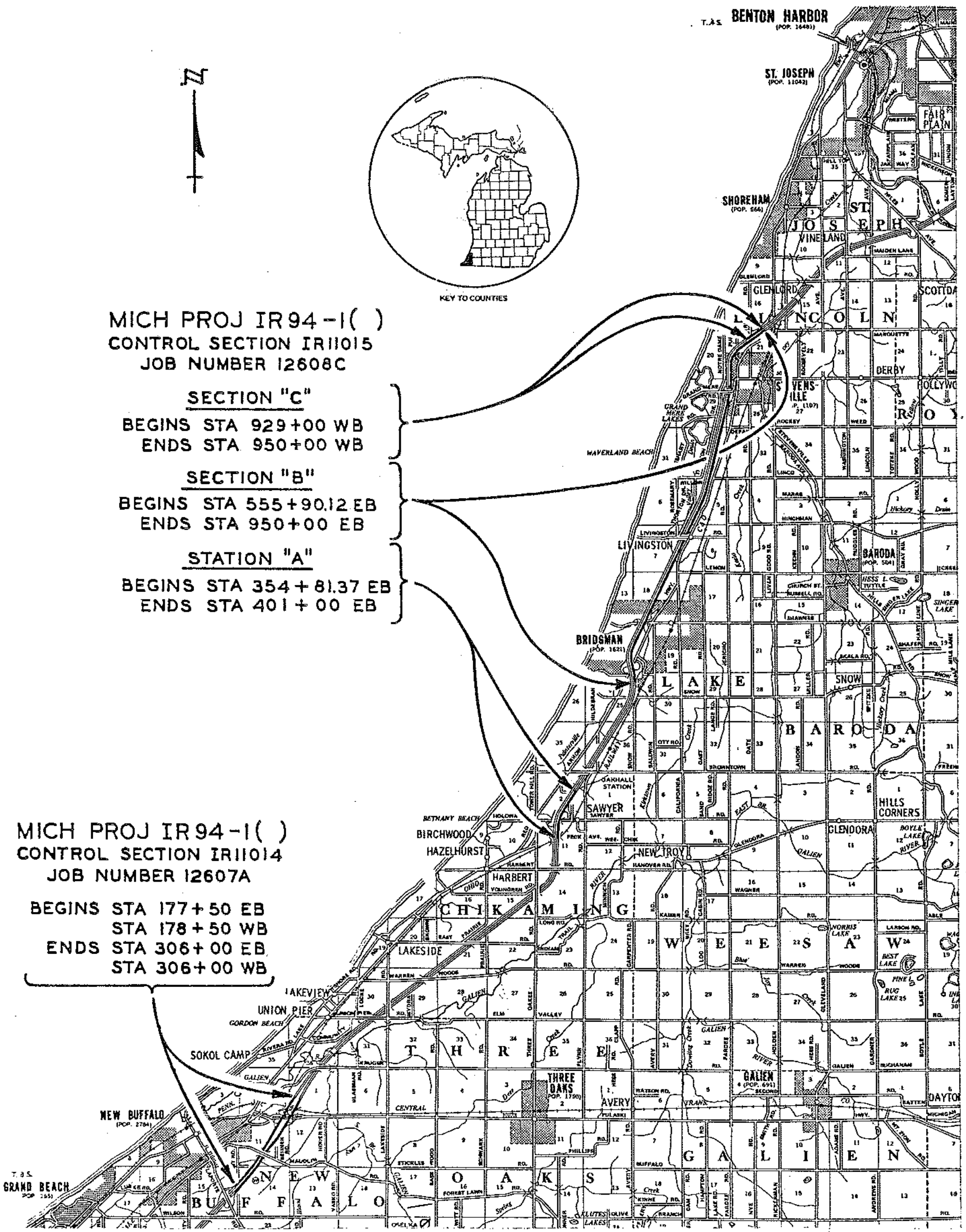


Figure 1. Recommended for reconstruction sections, I 94.

INTRODUCTION

A Grade Inspection of I 94 from Laporte Rd northerly to Puetz Rd was conducted on October 18, 1977 to identify where the surface has deteriorated to the extent that it must be rehabilitated. In a letter to C. J. Zajac from G. T. Luther, dated October 25, 1977, sections recommended for rehabilitation were indicated and are shown in Figure 1. Bituminous recycling was mentioned as a possible method to be included in the rehabilitation. The heavy traffic loading (ADT of 22,500 with 18 percent commercial) on I 94 in contrast with the very light traffic loading of the bituminous section of I 75 is also mentioned, apparently indicating concern that the procedures for crushing the bituminous concrete and using it as additional base thickness may not work on I 94 where base rutting is much more likely. It was also suggested that the eastbound and westbound lanes between Sta. 178+00 and 306+00 be constructed such that one is rehabilitated to include recycling of the bituminous concrete layer and the other is simply resurfaced.

As a result of Mr. Luther's letter K. A. Allemeier requested that the Research Laboratory perform sufficient study of the sections of I 94 indicated in Figure 1 to determine the cause of deterioration of these sections and in particular the cause of rutting.

I 94 was inspected and samples collected on November 9 and 10, and November 21 and 22. The types of failure occurring were identified by the crack formations and surface distortion according to field survey procedures developed by the Research Laboratory. Samples of bituminous concrete, base, subbase, and subgrade were collected for laboratory analysis. Because our newly constructed Research facility is not yet fully operational, not all of the planned testing could be completed in time to be included in this report. The additional data will be summarized later as an addendum to this report. The purpose of these additional data will be to verify conclusions as to the cause of bituminous distress and substantiate recommendations for recycling the bituminous concrete.

Investigative Procedure

The entire section of I 94 flexible pavement was surveyed and three basic forms of surface distress were found; alligator cracking, transverse (thermal) cracking, and longitudinal cracking. The forms of distress show that the bituminous concrete and aggregate base layers--and to a minor extent the subgrade--are, in various combinations, responsible for this distress.

Because of the heavy traffic volume, samples of each pavement layer were collected from only the outside, or traffic lane. Generally, samples representing the right and left wheelpaths (RWP and LWP) and the center of the lane were collected from sites which varied from no signs of distress to those which were very distressed. The thicknesses of each layer were determined in the field to ± 1/8 in. Samples were carefully placed in heavy duty plastic bags. In addition, each test site was cross-sectioned, the rut depths determined, and each site photographed.

Soil samples were tested to determine the following soil properties:

Gradation
Specific gravity
Density (M.D.) using the one-point chart
Permeability
Effective porosity
Particle index of combined + No. 4 material
In-situ water content

The bituminous concrete samples will be tested to determine the following properties:

Layer thicknesses
Asphalt content
Penetration at 77 F
Viscosity in centistokes at 275 F
Percent voids in mineral aggregate
Percent air voids
Aggregate gradation for each layer

Photographs were taken of the bituminous concrete cores since differences from site to site are sometimes visible.

ANALYSIS OF THE CAUSES OF DISTRESS USING FIELD SURVEY METHODS

Transverse Cracking

Transverse cracking, such as that shown in Figure 2, indicates that the bituminous concrete is temperature-sensitive in these areas. This form of cracking tends to develop equi-dimensional blocks since thermal

Figure 2a. Typical example of a crack susceptible bituminous concrete and a good performing base.

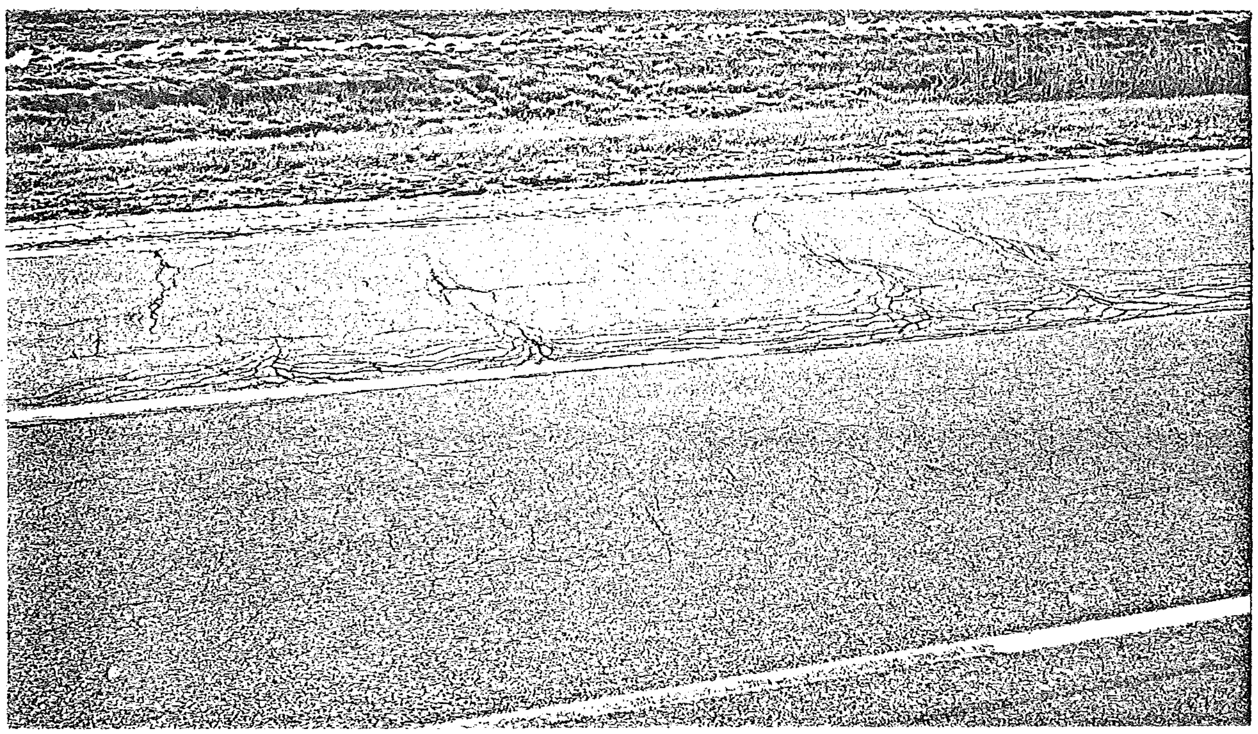


Figure 2b. Typical example of a crack susceptible bituminous concrete and a poor performing base.

Figure 2. Crack susceptible bituminous concrete over good and poor performing bases.

stresses are equi-dimensional (Fig. 2). Thus, longitudinal cracks will normally accompany advanced stages of transverse cracking. The transverse cracks in themselves do not influence riding quality but they do permit the entrance of surface water which can cause softening of the aggregate base and localized failure around each thermal crack. Figure 2a indicates the base in this area is performing very well while the area shown in Figure 2b indicates the base is softening, allowing traffic to develop alligator cracking in the area around both transverse and longitudinal cracks.

Figure 3a depicts an unusual form of transverse cracking which occurred in several areas but was restricted to the traffic lane. The bituminous concrete shows considerable ability to heal and cracking has generally not progressed beyond the right wheelpath. The aggregate base has also shown ability to resist softening in the presence of surface infiltrated water, hence no alligator cracks have formed around the transverse cracks. However, fines from the base are being pumped out onto the pavement surface so as to form transverse depressions which create a very rough riding surface for commercial vehicles. The pumped-out fines are normally quickly removed by the heavy traffic; however, as shown in Figure 3c, they are sometimes visible.

Longitudinal Cracking

Most of the pavement is subject to longitudinal cracking between the inside lane, which was added two years after the other two lanes were constructed, and the center lane. Longitudinal cracking is also frequently found between the center and traffic lanes. Figures 2, 3a, and 4 show typical examples of longitudinal cracking.

Longitudinal cracking occurs for several reasons, the most common of which is differential foundation movements which occur due to the difficult compaction problems associated with adding a lane adjacent to previously constructed pavement. Such cracking could be avoided only by constructing all three lanes at the same time so that the layers are homogeneous and uniformly compacted. In some areas (Figs. 2a, 3a, and 4) the longitudinal cracks are not a significant problem because the base is not softened by surface infiltrated water and so no other distress is associated with it. In Figure 2b the surface infiltrating water has softened the base causing formation of alligator cracking, a serious maintenance problem, and a distorted pavement surface that can be a traffic hazard for vehicles changing lanes.

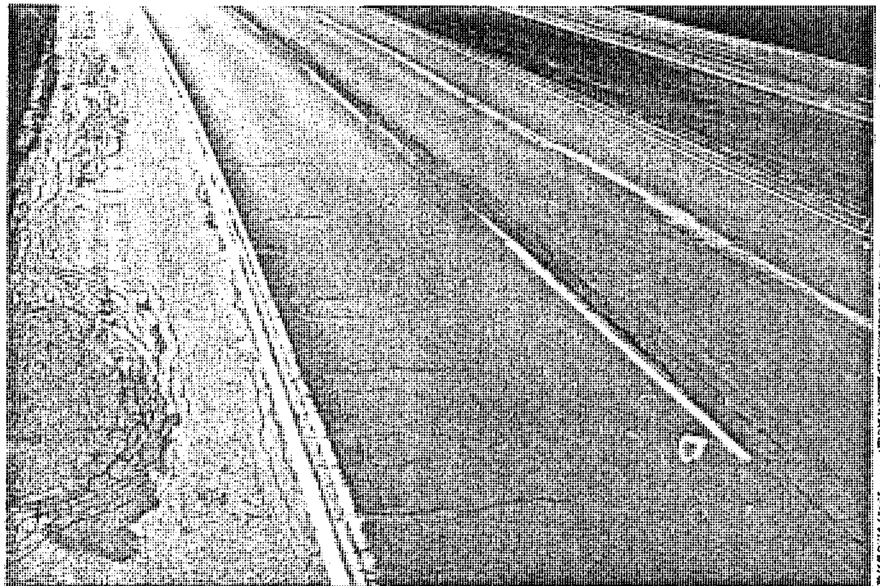


Figure 3a. Typical example of transverse cracking in areas with high bitumen contents.

Figure 3b. Pumping of fines from the base has caused the formation of transverse troughs, the presence of which make the surface particularly rough riding for commercial vehicles.

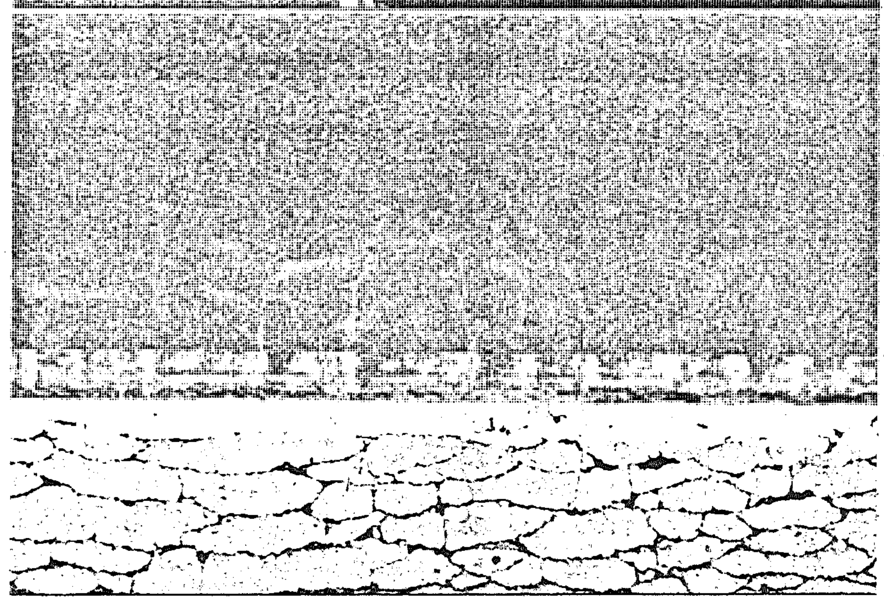


Figure 3c. Pumped fines are visible around cracks for only a short time after the pavement has dried due to its quick removal by traffic.

Figure 3. Typical example of transverse cracking that is occurring in areas where the bitumen content is high and susceptible to transverse cracking.

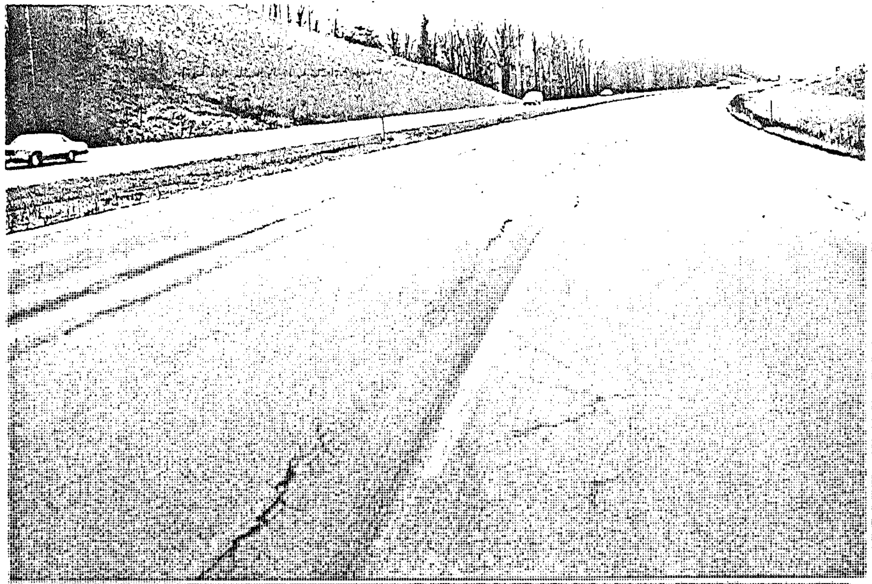


Figure 4a. Longitudinal cracking due to slight settlement of fill to the left of the cracks.

Figure 4b. Note the magnitude of the movement of the center and outside lanes.

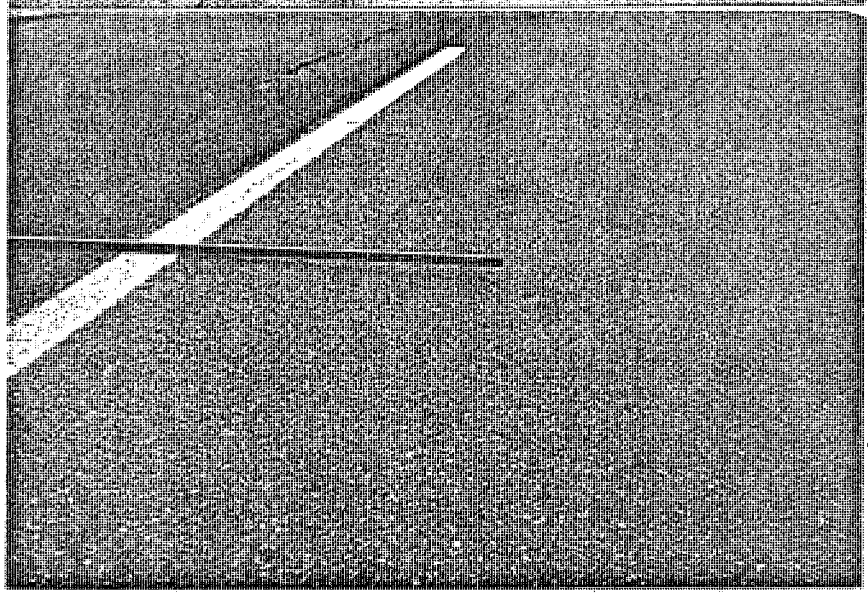


Figure 4c. Close view showing a difference in surface slope of approximately 3/4-in./ft.

Figure 4. Longitudinal cracking associated with movements within the pavements foundation. Note that the surface is generally free of surface cracks, except for the longitudinal cracks, indicating good bituminous concrete performance. The basence of alligator cracks adjacent to the longitudinal cracks indicated good base performance.

Figure 5a. Typical example of very crack susceptible bituminous concrete on a good aggregate base.

Figure 5b. Typical example of a good aggregate base which ruts very little, in spite of the heavily cracked surface.

Figure 5. Typical example of distress in locations where the bituminous concrete is crack susceptible and the aggregate base performs well. Poor bituminous concrete performance is characterized by extensive cracking of the entire pavement surface and only slight, if any, rutting.

Other causes of longitudinal cracking are related to foundation movements in fill sections. In Figure 4a, the left side of the pavement is in a fill section the right side a cut section. The longitudinal cracking to the left of the paint stripe dividing center and traffic lanes is caused by settlement of the fill area. The magnitude of settlement is shown in Figure 4b. The base and bituminous concrete in this area are performing very well as is indicated by an absence of alligator cracking. The longitudinal cracking shown in Figure 4 is apparently caused by lateral movement and settlement of the fill along the superelevated section. In this respect, the dune sands, when not confined, do not provide good support. The result is severely distressed shoulders and an obvious maintenance problem. A thick shoulder section should correct this situation.

Alligator Cracking

Various forms of alligator cracking are occurring along much of the traffic lane. That which occurs on good performing base is illustrated in Figure 5, while that which occurs on bad performing base is illustrated in Figure 6. Generally, bituminous concrete pavements which are susceptible to transverse cracking are also susceptible to fatigue cracking, and those which do not tend to develop transverse cracks also have greater resistance to fatigue cracking. Another variable to consider is the effect of asphalt content which as it increases, up to an optimum value, reduces crack potential of all forms. Therefore, it is possible to vary bituminous concrete quality from excellent, when bitumen content is high and it is not crack susceptible, to very poor, when bitumen content is low and it is highly crack susceptible.

Figure 5 is an example of a poorly performing bituminous concrete since its penchant for cracking is indicated by numerous transverse cracks and increased cracking in the wheelpath area which is the result of combined thermal and fatigue cracking. Good base support is indicated because only slight rutting is occurring. The slight rutting that is occurring is primarily a result of pumping of base fines through the cracks (Fig. 5b).

Figure 6 illustrates a good performing bituminous concrete over a base which tends to soften when wet. The cracking is generally confined to the wheelpaths and rutting is more severe, as shown in Figure 6a, due to a combination of lateral displacement of the base and some pumping of the fines. An example of more severe base problems is shown in Figure 7 where rut depths range between 3/4 and 1-1/4 in. A large percentage of the traffic lane is rutted in this manner. The poor performance of the base

Figure 6a. Typical example of a good bituminous concrete on a poor aggregate base.

Figure 6b. Typical example of the severe rutting that occurs with poor aggregate bases.

Figure 6. Typical example of distress when bituminous concrete has good crack resistance and the aggregate base performs poorly. The saturated base is pumping fines and softening, to a moderate degree, under freeze-thaw conditions. The poor base performance is characterized by deep rutting and alligator cracking which is generally confined to the wheelpaths.

Figure 7a. Typical example of a very poor performing aggregate base.

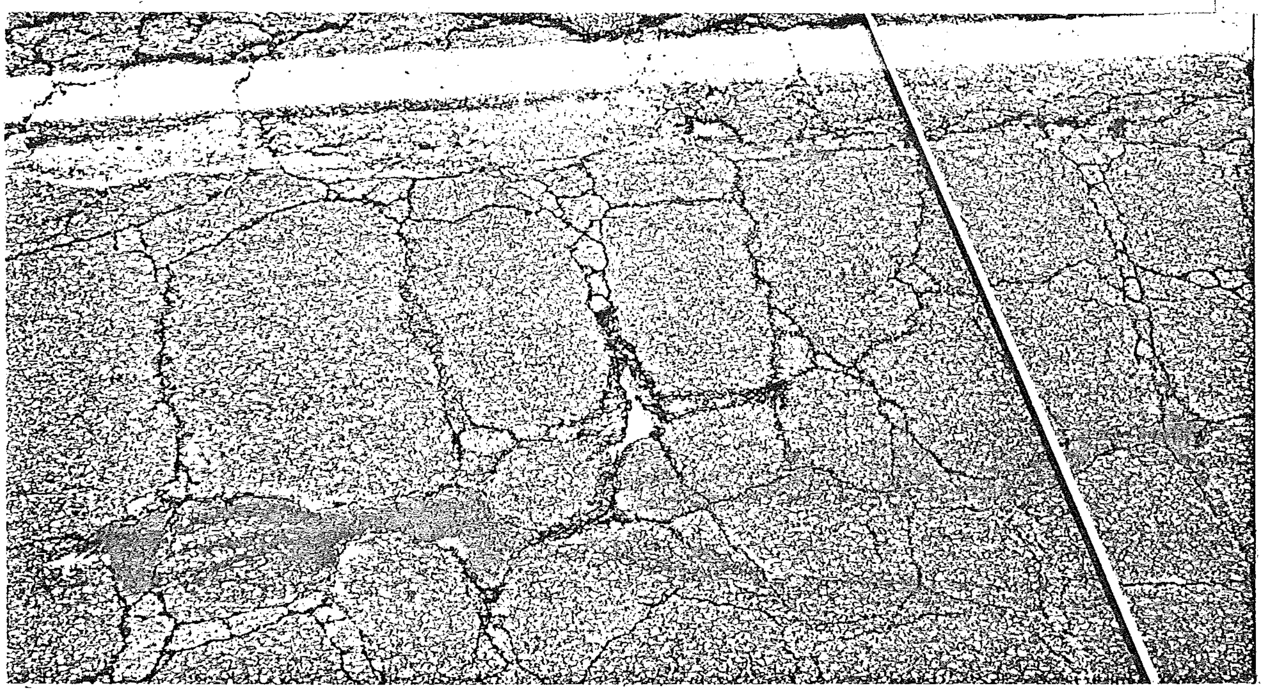


Figure 7b. Although the pavement surface is dry, water in the cracks is unable to penetrate the relatively impervious base.

Figure 7. Example of the performance of crack susceptible bituminous concrete on a poor performing base. The severe alligator cracking and rutting is attributed to pumping of base fines and softening of wet base under freeze-thaw action.

TABLE 1
SUMMARY OF PAVEMENT LAYER PERFORMANCE
CHARACTERISTICS SHOWN IN FIGURES 8 THROUGH 17

Figure Number	Layer Performance Characteristic								
	Bituminous Concrete			Aggregate Base			Subgrade		
	Good	Fair	Poor	Good	Fair	Poor	Good	Fair	Poor
8		X		X			X		
9			X	X			X		
10		X			X		X		
11		X			X		X		
12		X			X			X	
13			X			X	X		
14	X			X			X		
15		X			X		X		
16	X			X			X		
17			X			X	X		

shown in Figure 7 occurs whenever the base is both impervious, permeability is less than 0.5 ft/day, and it is over 90 percent water saturated when gravity drained.

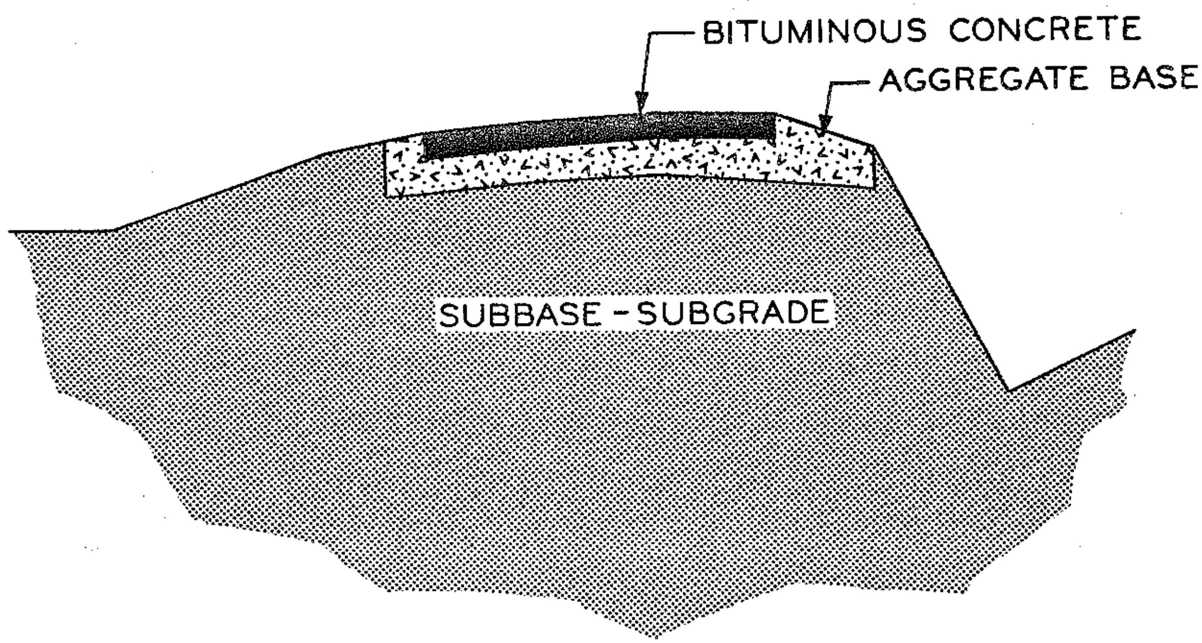
FIELD TEST RESULTS

Figures 8 through 17 summarize the results of the on-site investigations. The cross-sections indicate that the inside and center lane slope to the median which means that surface water, in most cases, will tend to migrate back under the pavement. This condition could be corrected during rehabilitation. Correction would, however, require the addition of considerable quantities of aggregate base material.

The thickness of the base plus select subbase is 1 to 3 in. thinner than the 12 in. design thickness, with the actual average thickness being a little over 10 in. Pumping of fines from the base has reduced its thickness in the wheelpaths as illustrated by results obtained at Sta. 592+00 and 746+00 (Figs. 14 and 17). It was noted that the aggregate base was of higher density and more difficult to dig in those areas where the base was the primary cause of distress. This is attributed to increased coarse aggregate interlock that results as the fines are removed by pumping.

It was also noted that in uncracked areas, cutting bituminous samples was much more difficult than it was for cracked areas. Figures 13a and 16a indicate that comparatively higher asphalt contents exist in uncracked sections of pavement. Tentatively, the excellent performance of the uncracked pavement sections is attributed to higher bitumen content. Bituminous test results are needed to confirm this conclusion. The thickness of the bituminous concrete varies within a range of 4-1/4 to 5 in. which compares well with the 4-1/2 in. design thickness.

Field test findings are summarized in Table 1. These results show that the bituminous concrete is most often giving substandard performance because it is crack susceptible. Once the bituminous concrete cracks, the base performance is usually only fair to poor. The subbase everywhere appears to be performing well. The subgrade is moving in some locations either due to settlement or shear movement, caused by traffic vibrations. However, the subgrade should not cause problems in the rehabilitated pavement of sufficient magnitude to require correction.



Pavement Layer	Thickness, in. RWP
Bituminous Concrete	5
Aggregate Base	10-1/4
Subbase	---
Depth to H_2O	> 7 ft from pavement surface

Rut Depth, in.	
LWP	RWP
0.05	0.075

Figure 8. Cross-section of eastbound I 94 at Station 228+00.

Shallow rutting of RWP.

Core taken from RWP.

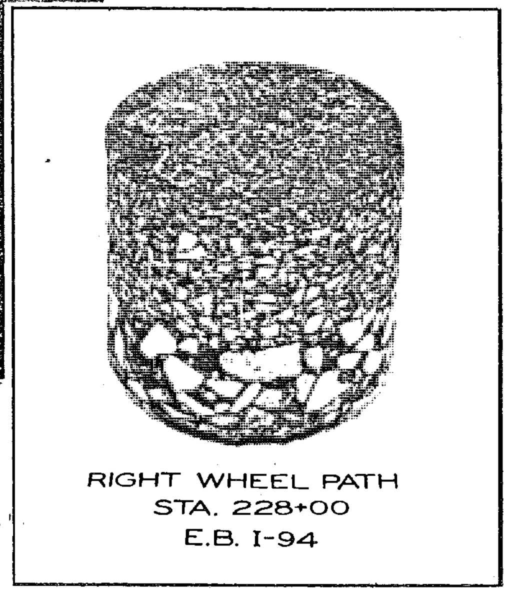
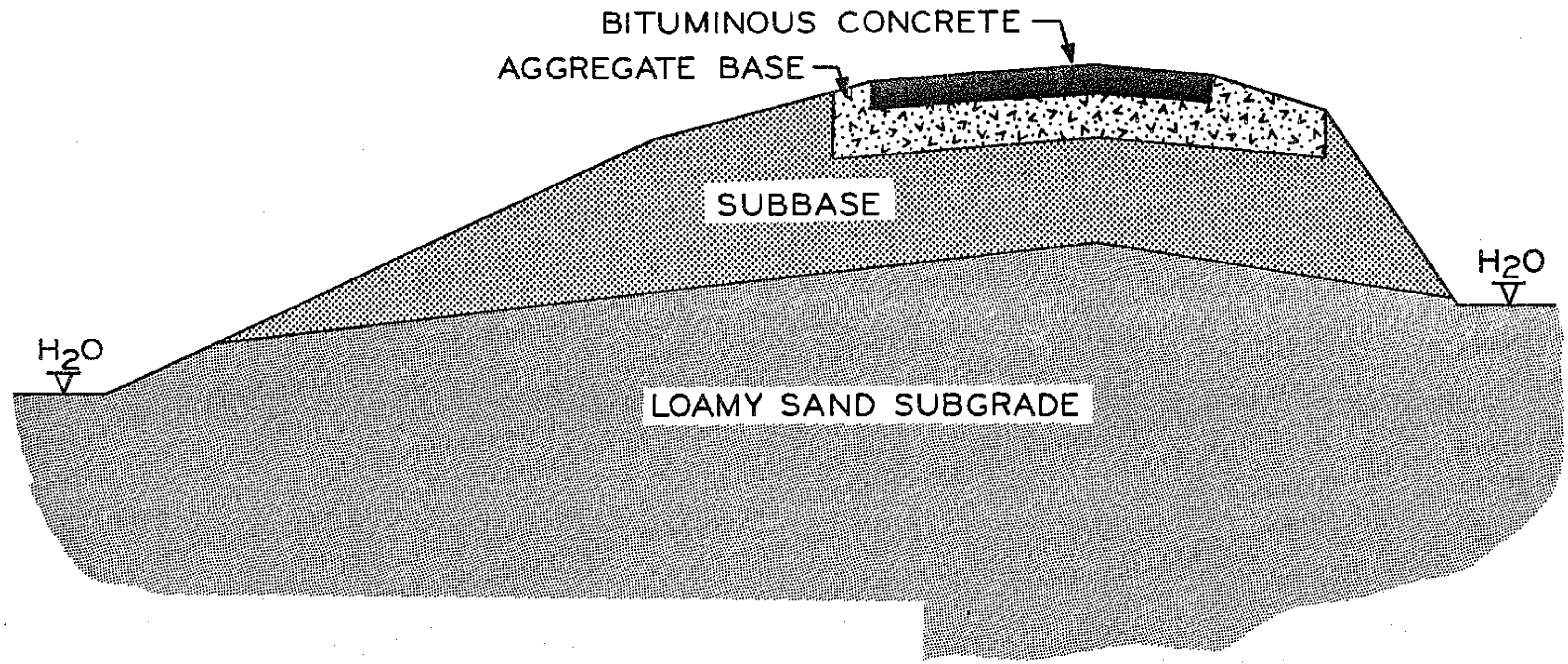


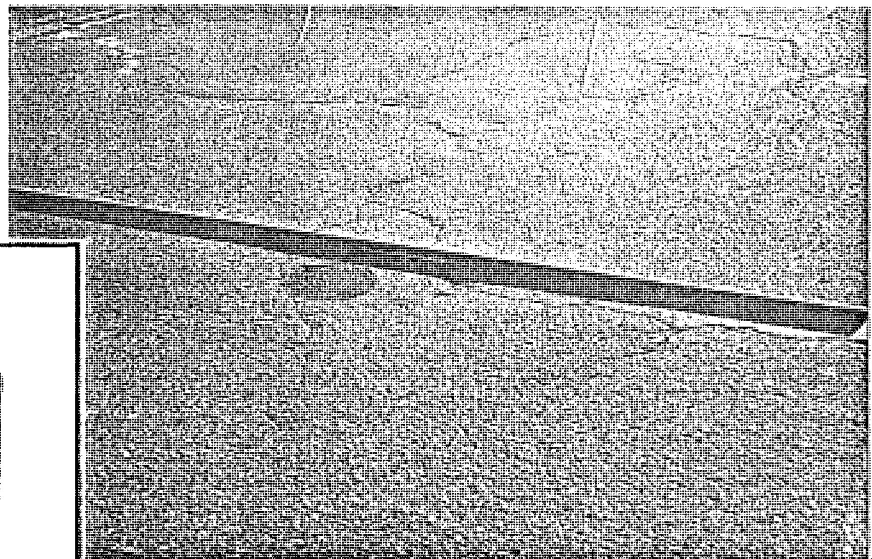
Figure 8a. General view of test area.



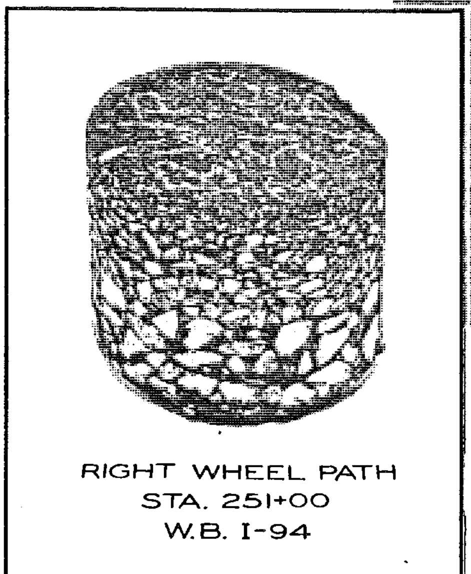
Pavement Layer	Thickness, in. RWP
Bituminous Concrete	4-3/4
Aggregate Base	10-3/4
Subbase	23
Depth to H_2O	48

Rut Depth, in.	
LWP	RWP
0.15	0.08

Figure 9. Cross-section of westbound I 94 at Station 251+00.



No rutting, but slight pumping of base fines.



Core taken from RWP.

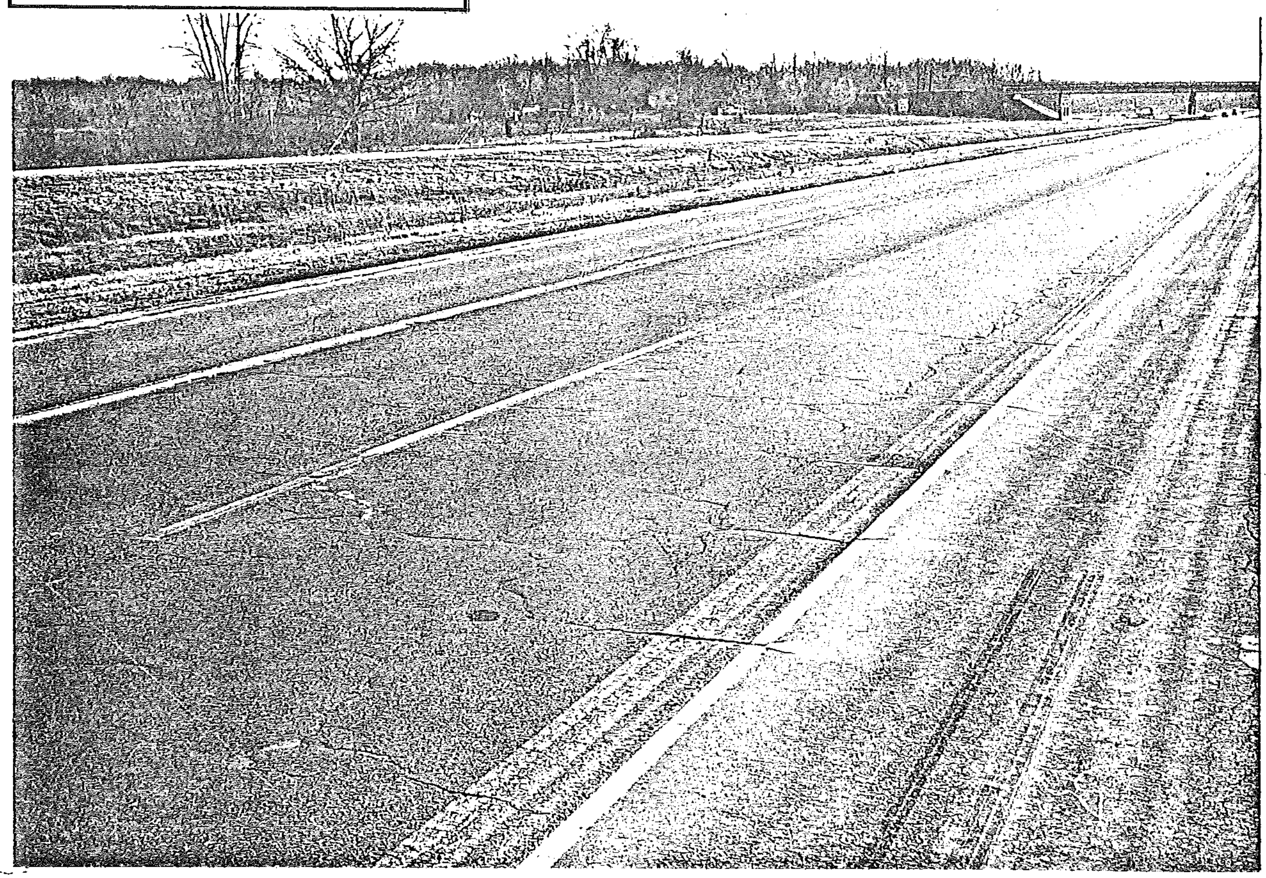
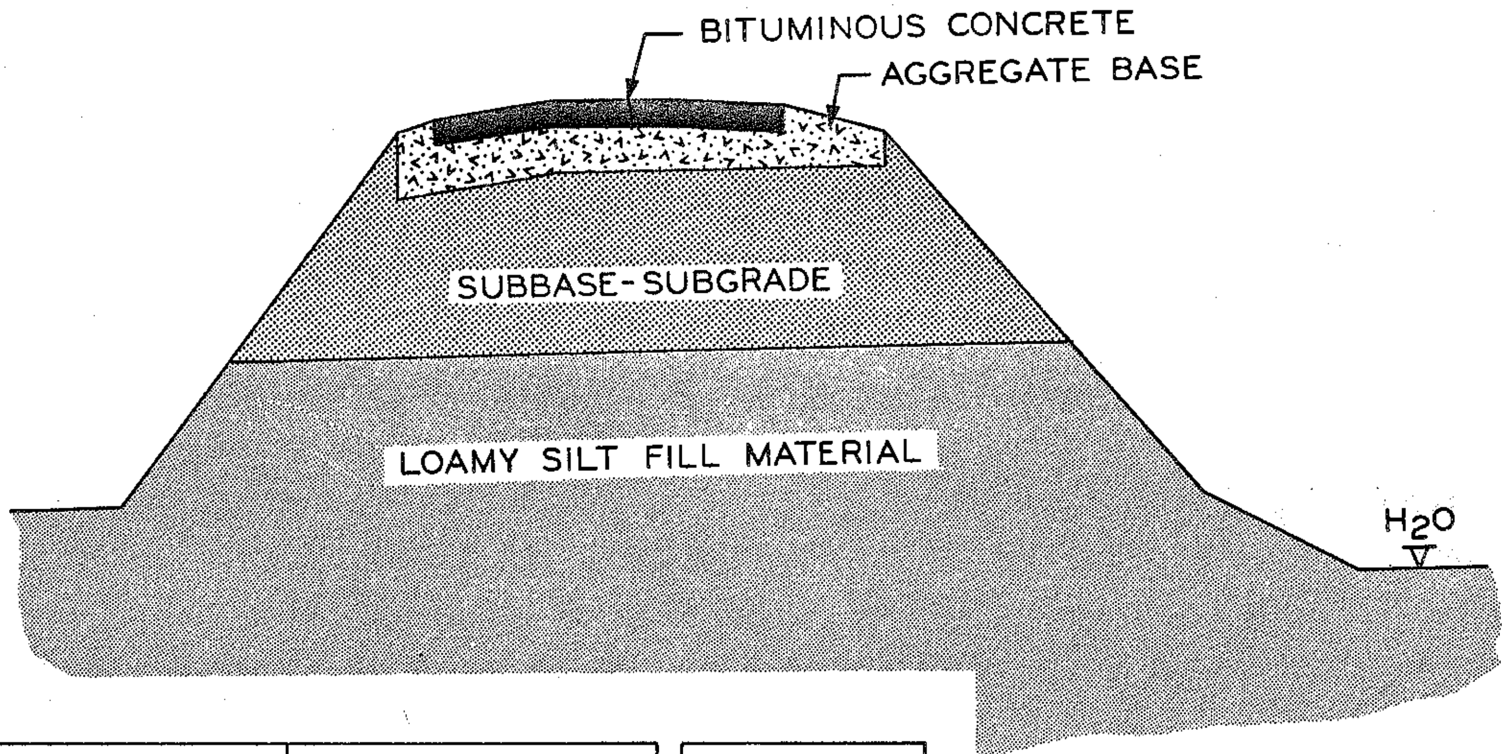


Figure 9a. General view of test area.



Pavement Layer	Thickness, in.			Rut Depth, in.	
	LWP	℄ Lane	RWP	LWP	RWP
Bituminous Concrete	4-1/2	5	4-1/4	0.20	0.35
Aggregate Base	10-1/2	9	8-3/4		
Subbase	36-1/4	38-3/4	38-1/2		
Depth to H_2O	> 7 ft from pavement surface				

Figure 10. Cross-section of eastbound I 94 at Station 254+00.

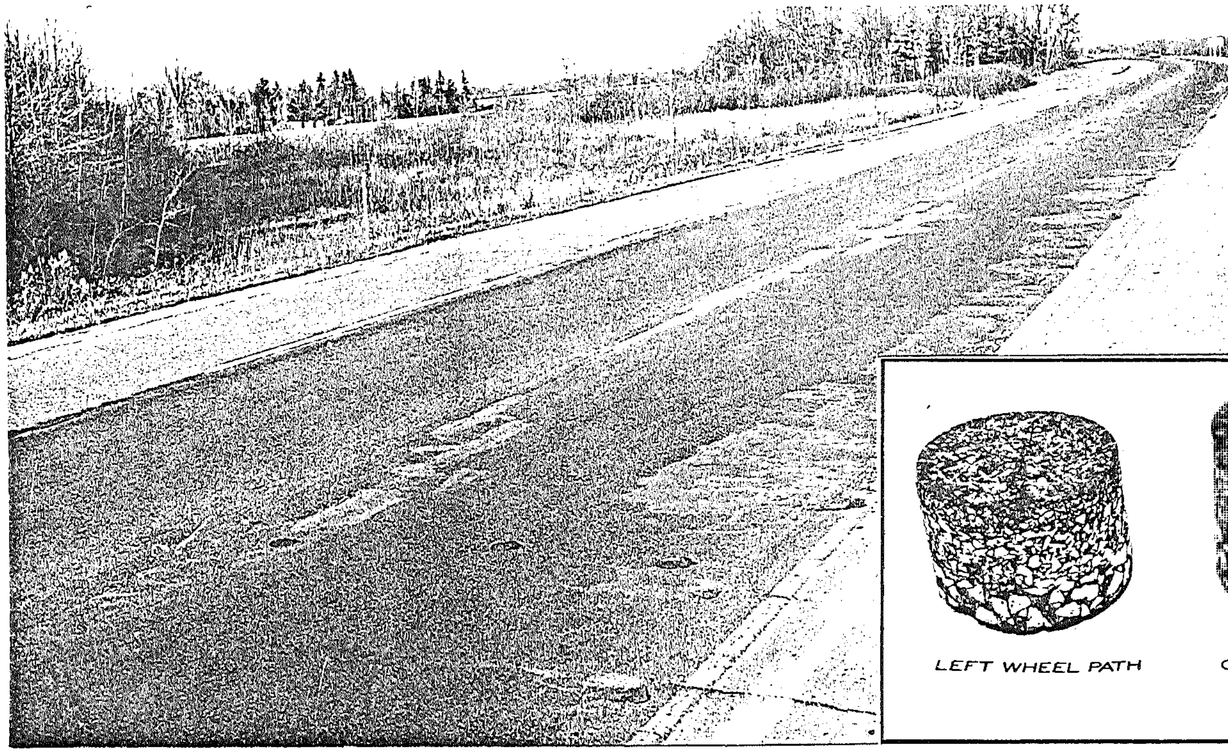
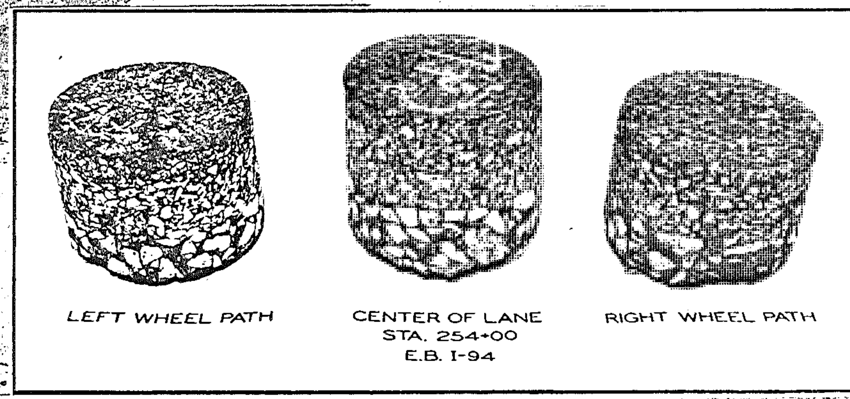
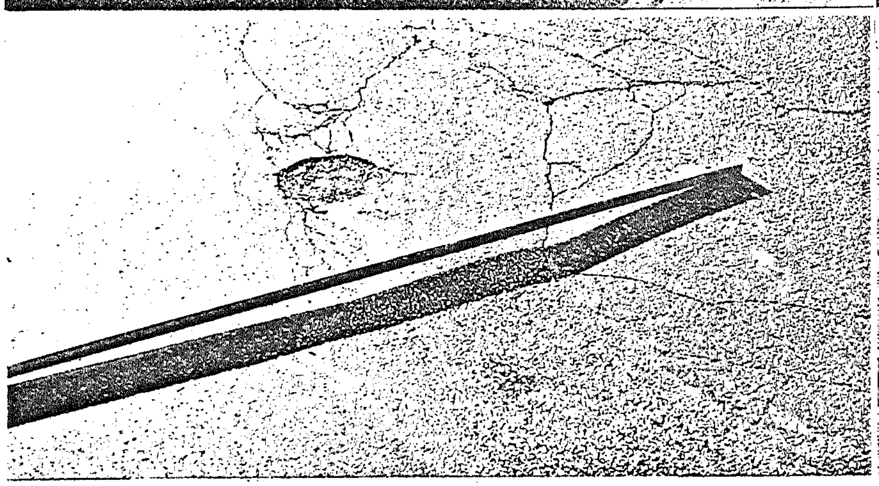


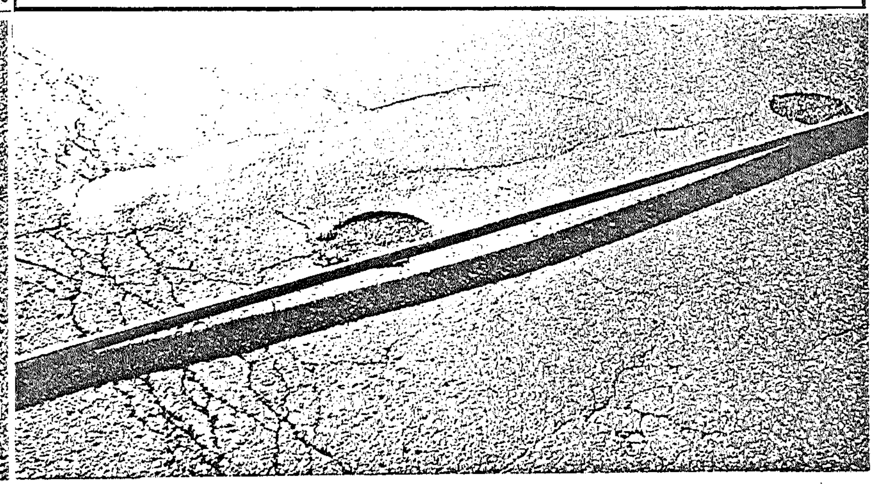
Figure 10a. General view of test area.

Cores taken from test site.

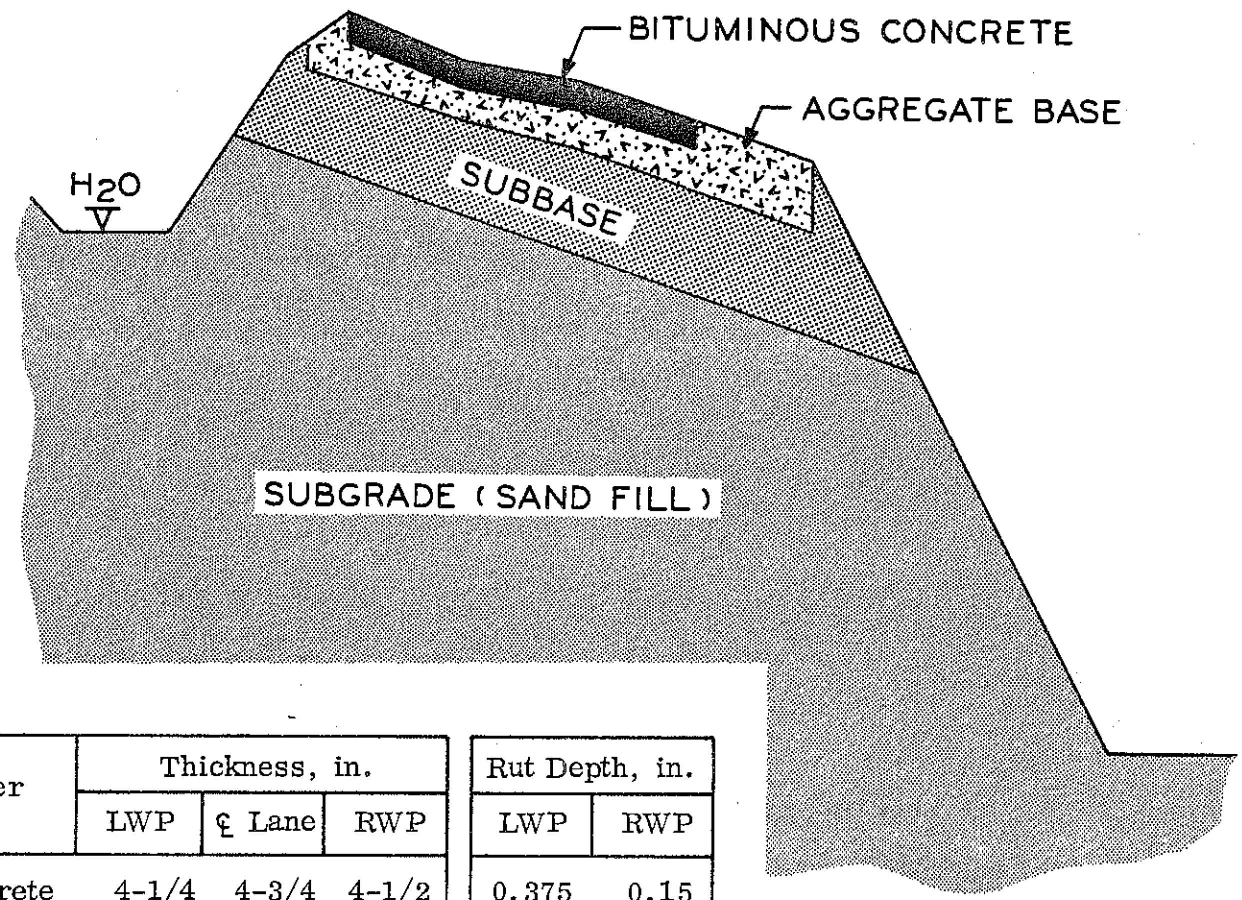




Rutting of LWP.



Rutting of RWP.



Pavement Layer	Thickness, in.		
	LWP	℄ Lane	RWP
Bituminous Concrete	4-1/4	4-3/4	4-1/2
Aggregate Base	10-3/4	10-1/4	9-1/2
Subbase	20	20	20
Depth to H_2O	> 4 ft from pavement surface		

Rut Depth, in.	
LWP	RWP
0.375	0.15

Figure 11. Cross-section of eastbound I 94 at Station 365+00.

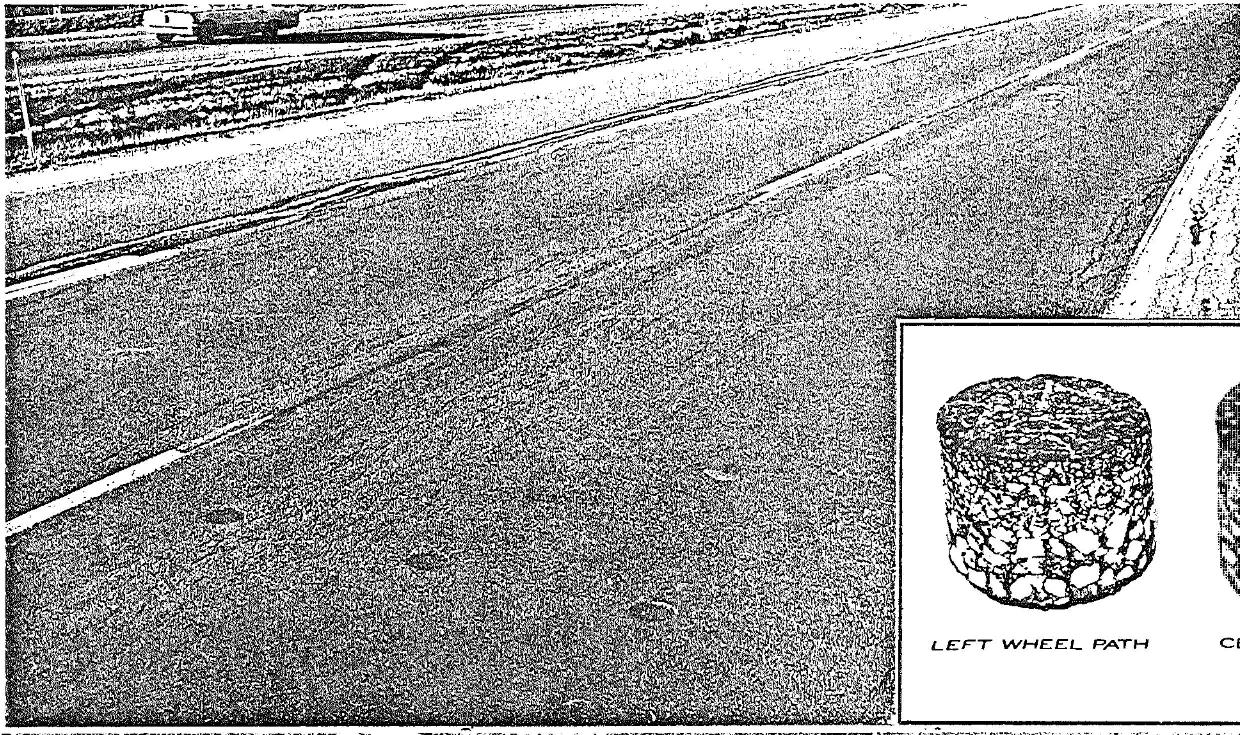
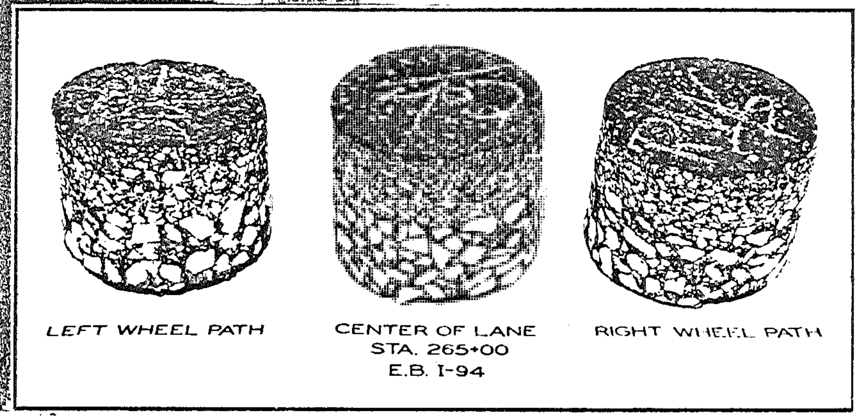
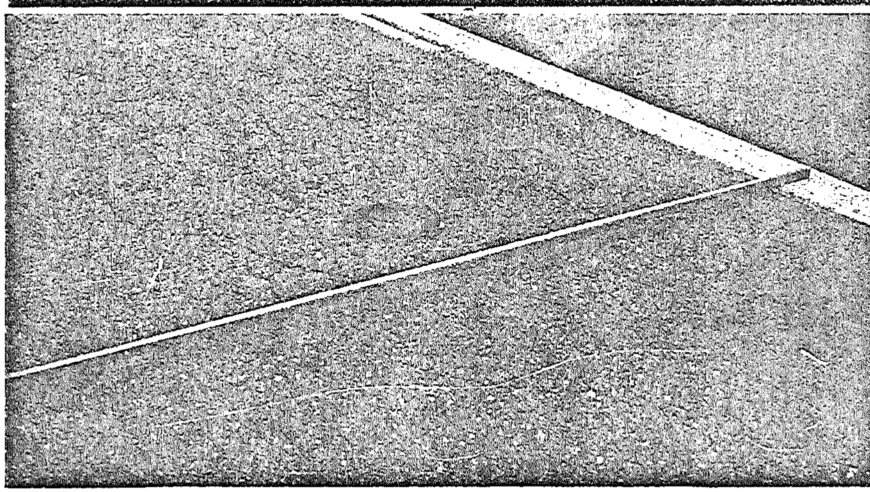


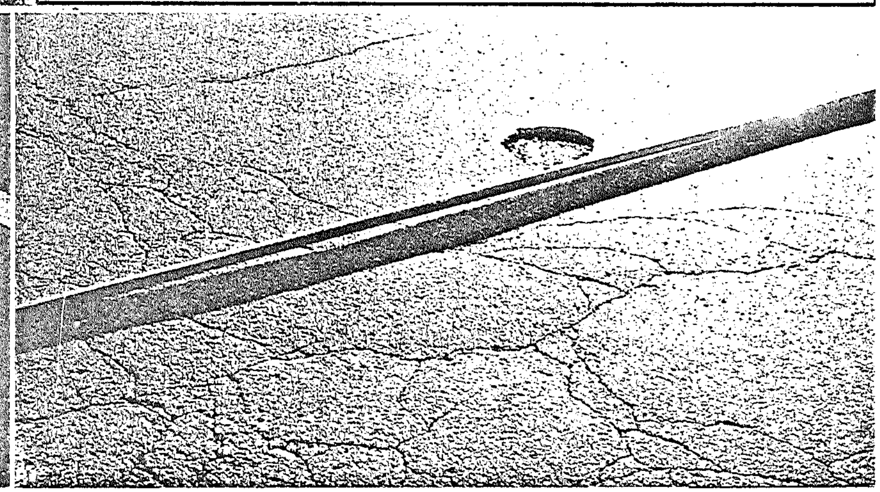
Figure 11a. General view of test area.

Cores taken from test site.

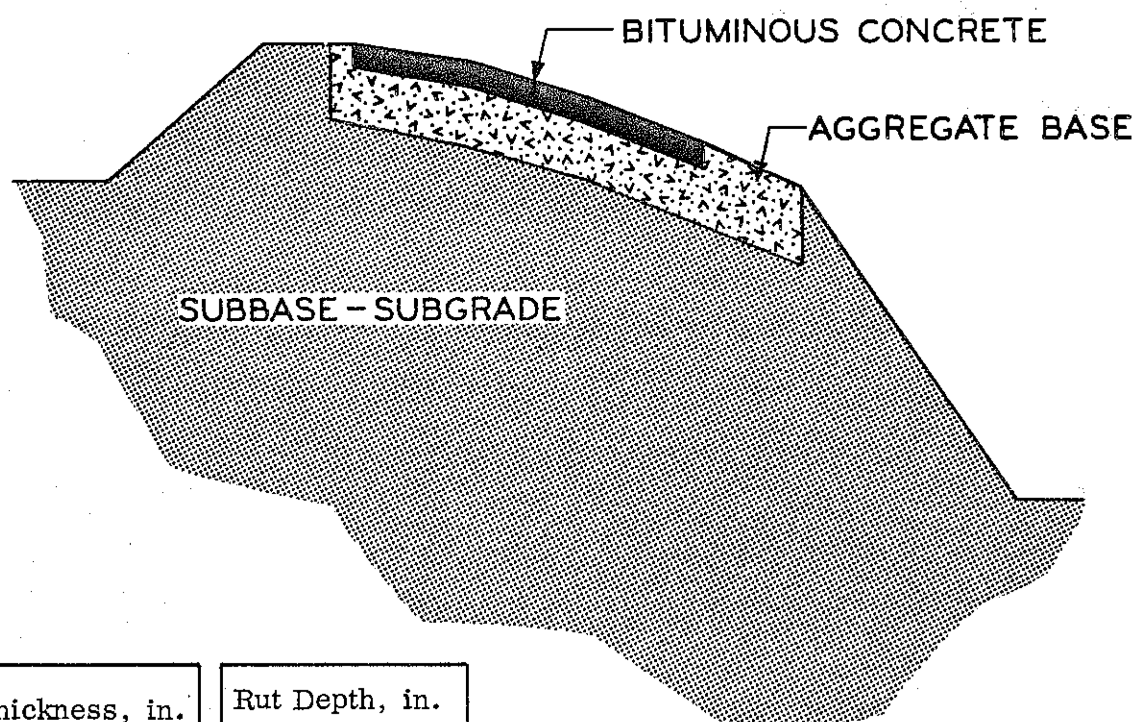




Rutting of LWP.



Rutting of RWP.



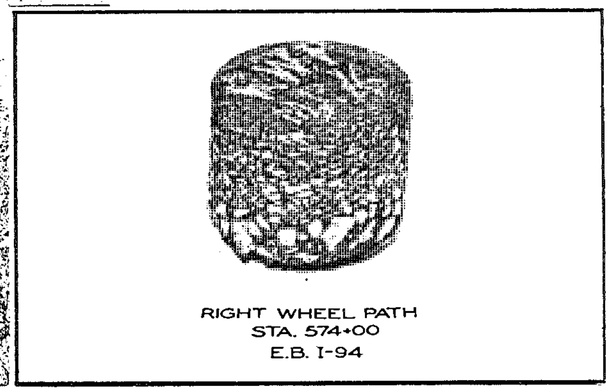
Pavement Layer	Thickness, in. RWP
Bituminous Concrete	4-1/2
Aggregate Base	12-1/2
Subbase	---
Depth to H_2O	> 7 ft from pavement surface

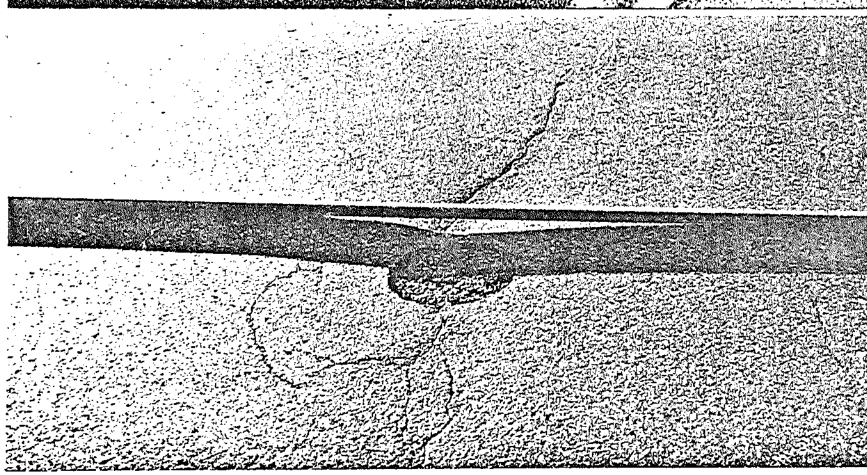
Rut Depth, in.	
LWP	RWP
0.20	0.225

Figure 12. Cross-section of eastbound I 94 at Station 574+00.

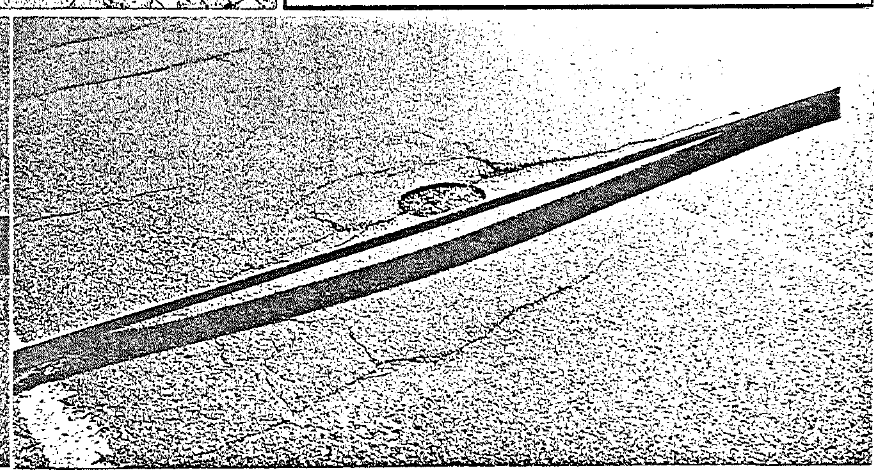
Figure 12a. General view of test area.

Cores taken from RWP.

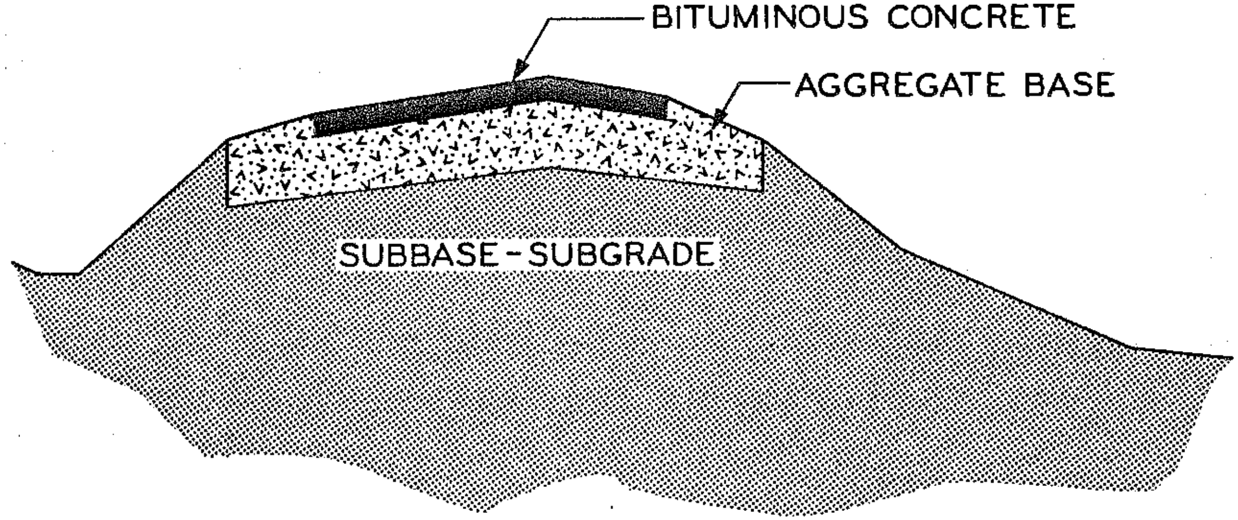




Transverse trough developed by pumping of base fines.



Indicates moderate rutting of the RWP.



Pavement Layer	Thickness, in.		
	LWP	℄ Lane	RWP
Bituminous Concrete	5-1/2	5-1/2	4-3/4
Aggregate Base	11	11-3/4	11
Subbase	---	---	---
Depth to H_2O	---	---	---

Rut Depth, in.	
LWP	RWP
0.275	0.15

Figure 13. Cross-section of westbound I 94 at Station 592+00.

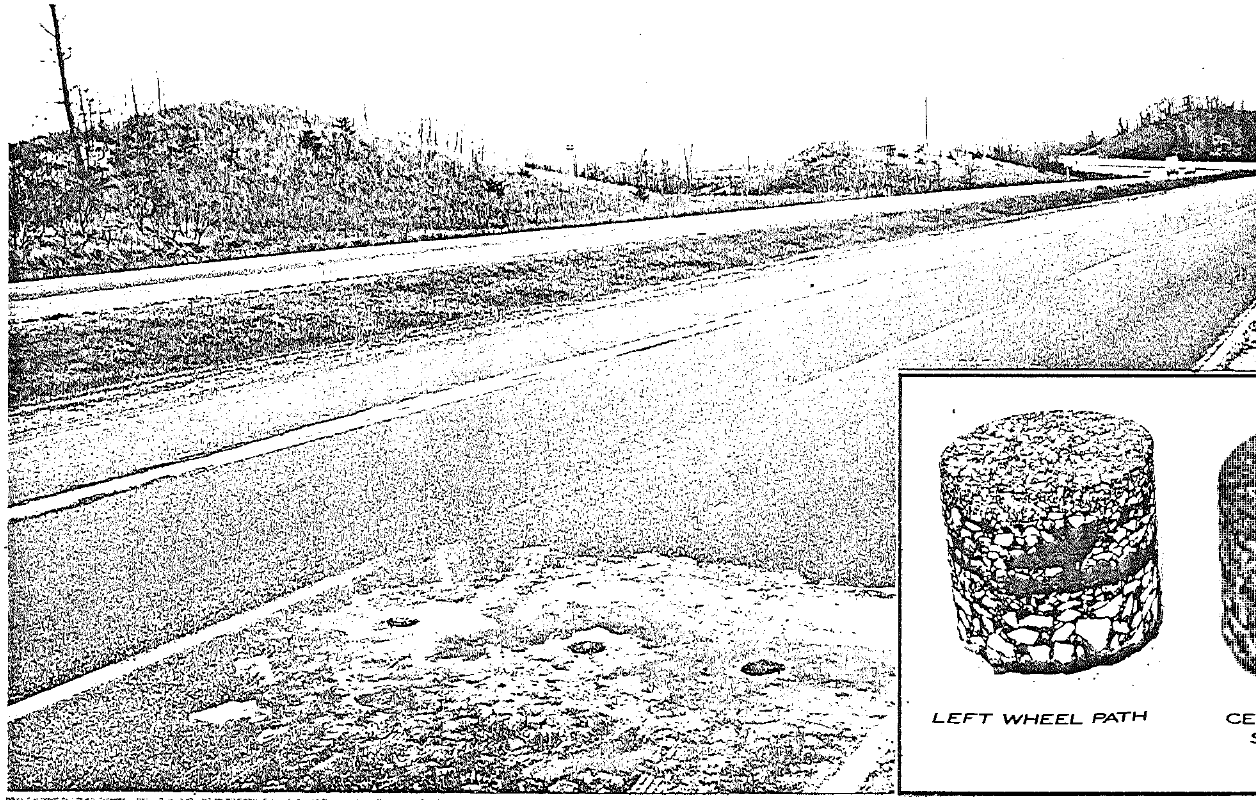
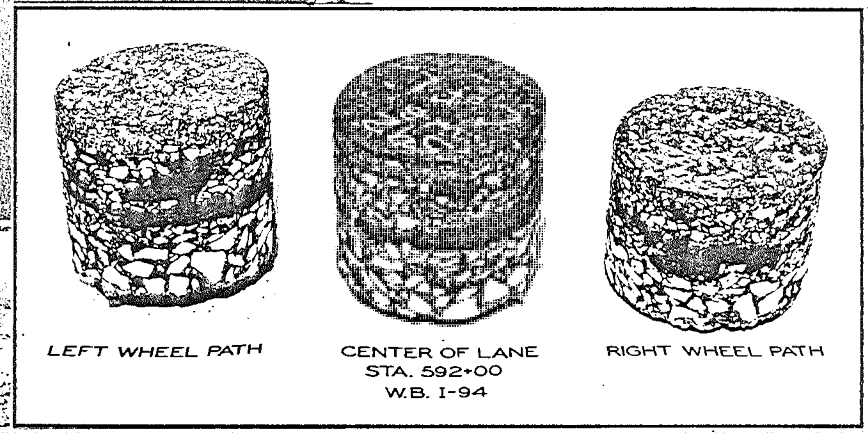
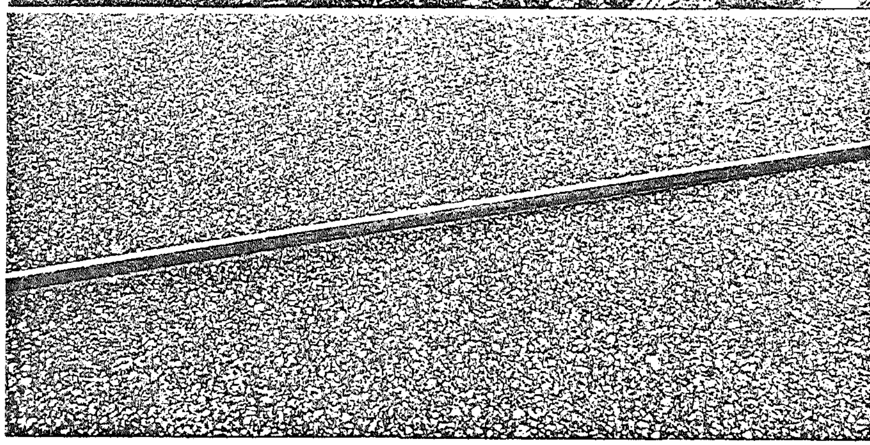


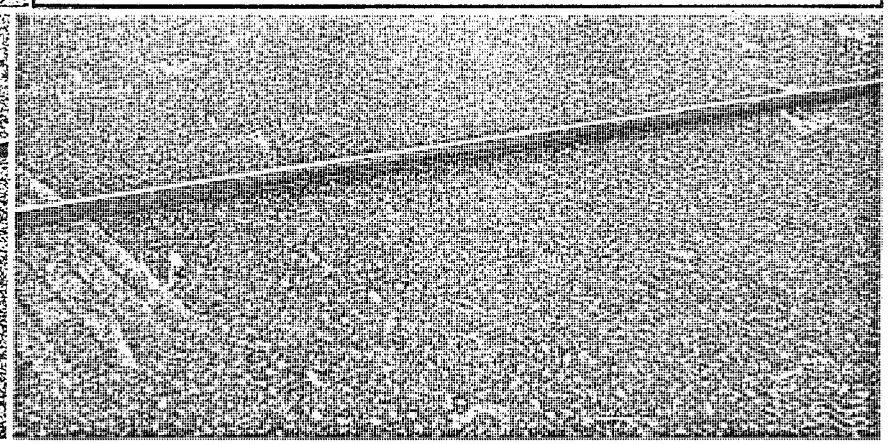
Figure 13a. General view of test area.

Cores taken from test site, note high bitumen content.

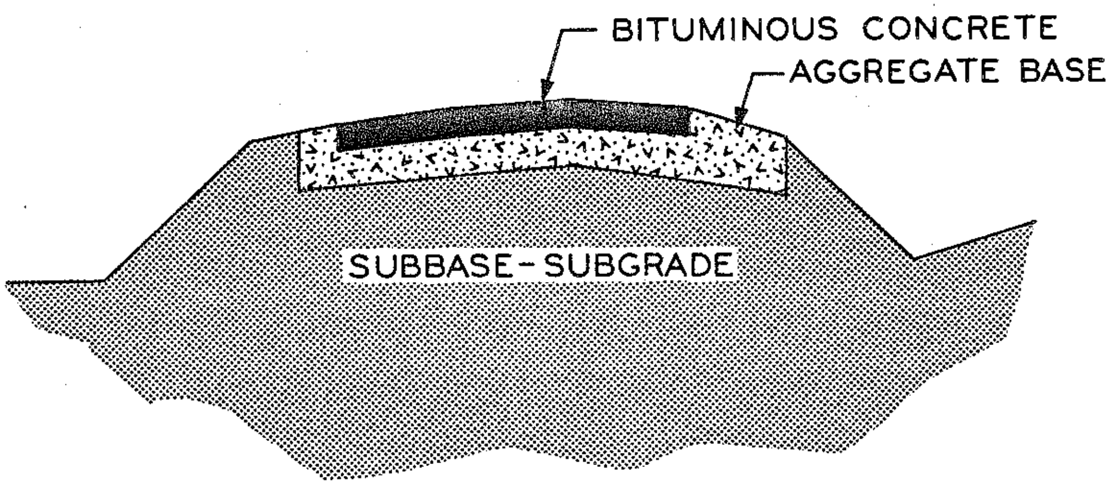




Indicates slight rutting in the LWP.



Indicates essentially no rutting in RWP.



Pavement Layer	Thickness, in.		
	LWP	℄ Lane	RWP
Bituminous Concrete	5	5	4-3/4
Aggregate Base	7-3/4	9	9-1/4
Subbase	---	-	---
Depth to H_2O	> 5 ft from pavement surface		

Rut Depth, in.	
LWP	RWP
0.925	0.25

Figure 14. Cross-section of eastbound I 94 at Station 592+00.

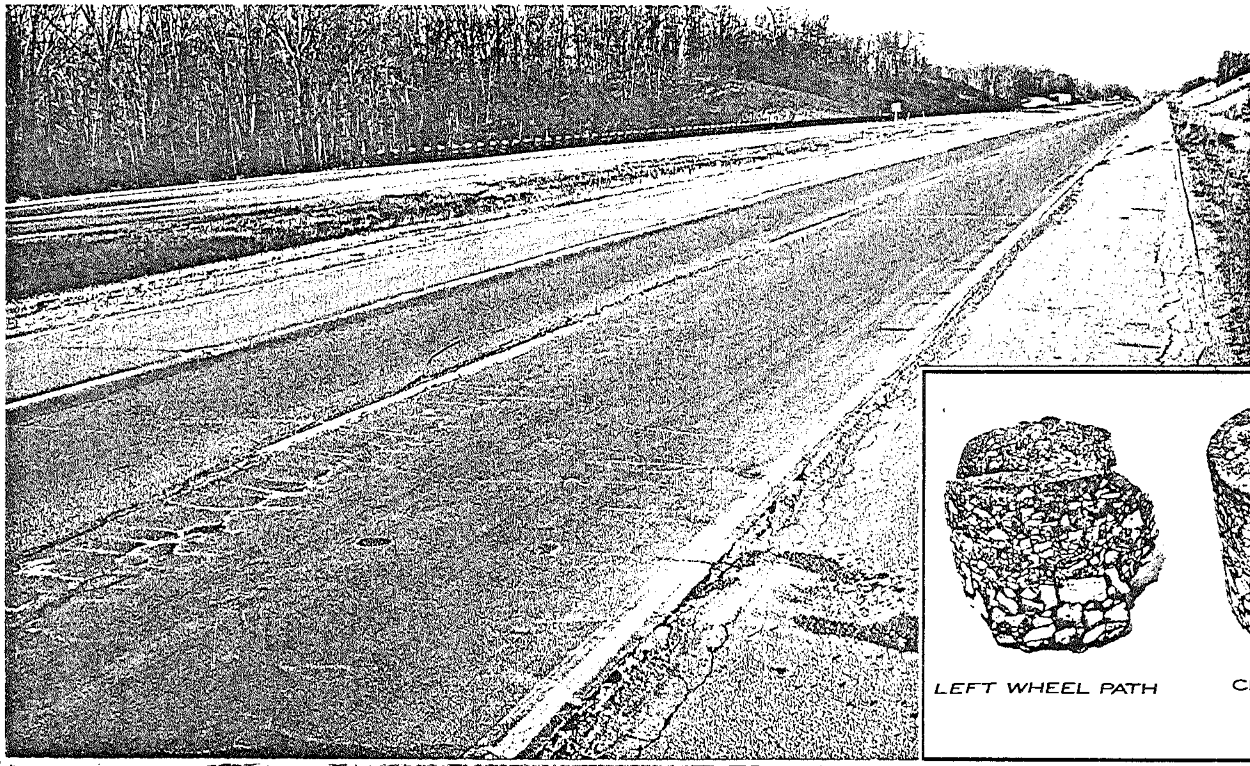
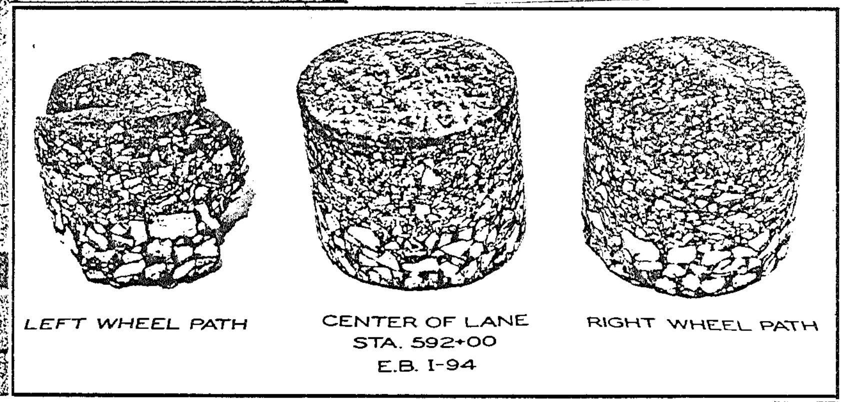
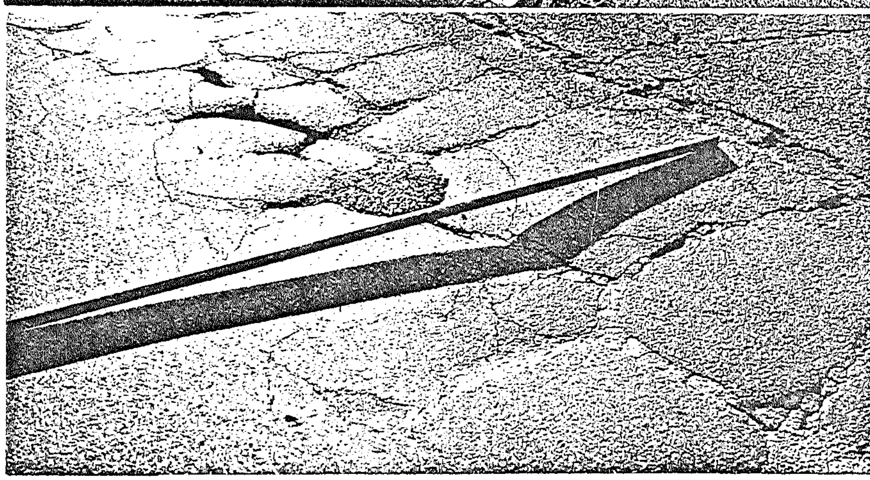


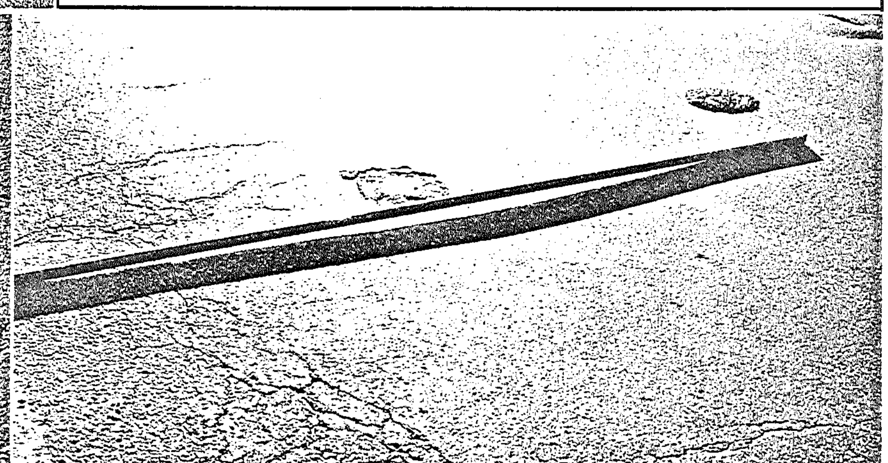
Figure 14a. General view of test area.

Cores taken from test site.

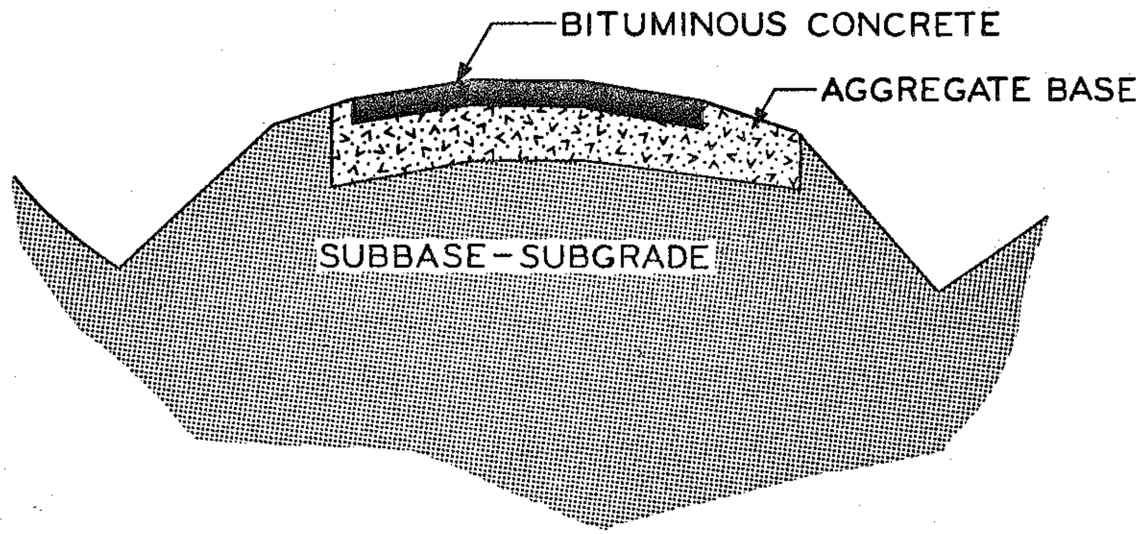




Rutting in the LWP.



Rutting in the RWP.



Pavement Layer	Thickness, in.		
	LWP	℄ Lane	RWP
Bituminous Concrete	5	5	4-3/4
Aggregate Base	10	10	9-1/2
Subbase	--	--	---
Depth to H_2O	> 4 ft from pavement surface		

Rut Depth, in.	
LWP	RWP
0.35	0.70

Figure 15. Cross-section of eastbound I 94 at Station 712+00.

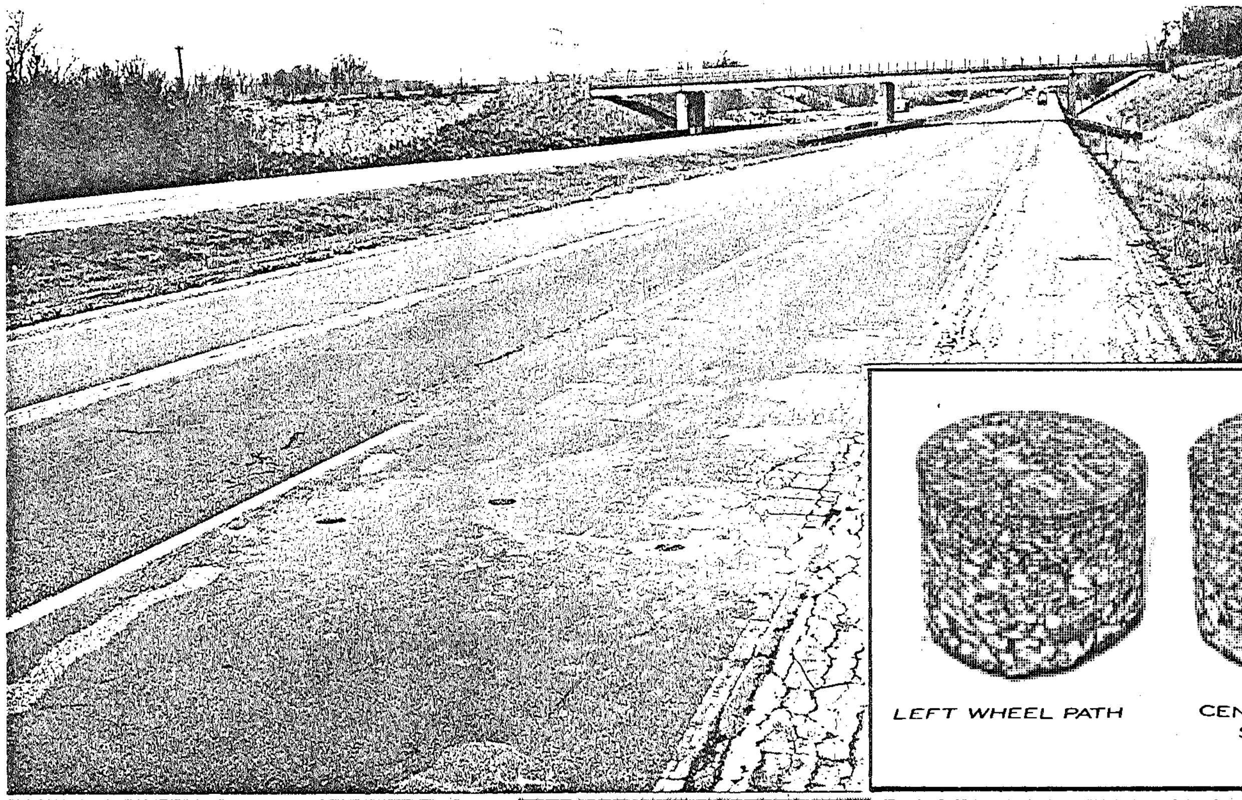
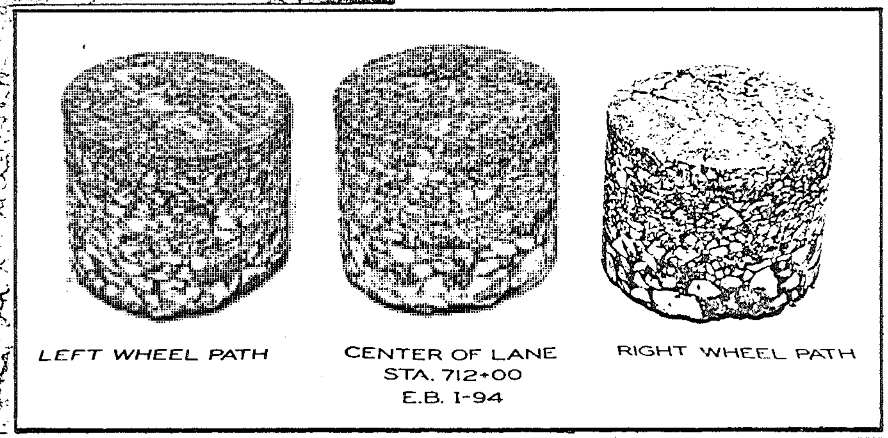
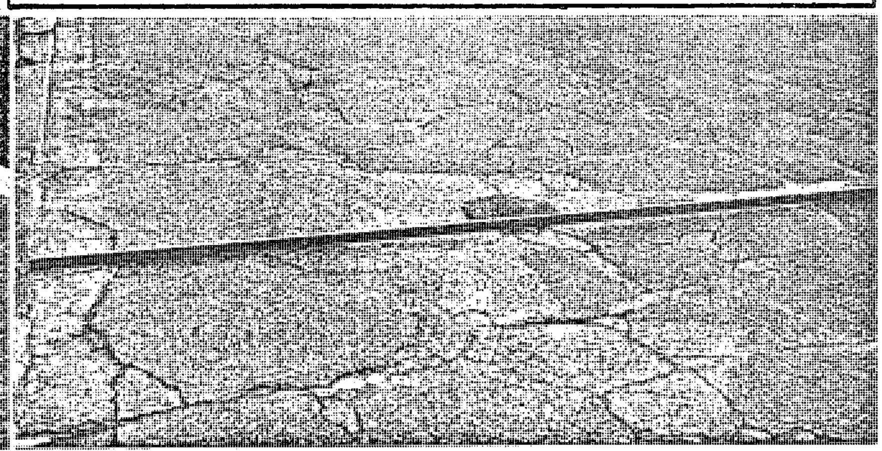


Figure 15a. General view of test area.

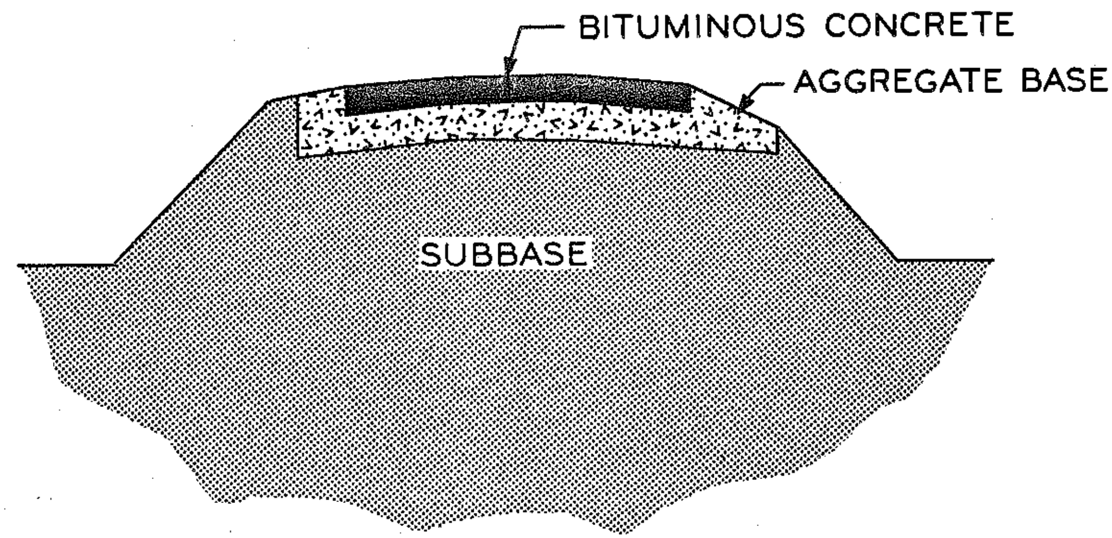
Cores taken from test site.



Rutting of the LWP.



Rutting of the RWP.



Pavement Layer	Thickness, in.		
	LWP	℄ Lane	RWP
Bituminous Concrete	5	5	4-3/4
Aggregate Base	9-3/4	9-1/2	8-3/4
Subbase	---	---	---
Depth to H_2O	> 4 ft from pavement surface		

Rut Depth, in.	
LWP	RWP
0.225	0.275

Figure 16. Cross-section of eastbound I 94 at Station 720+00.

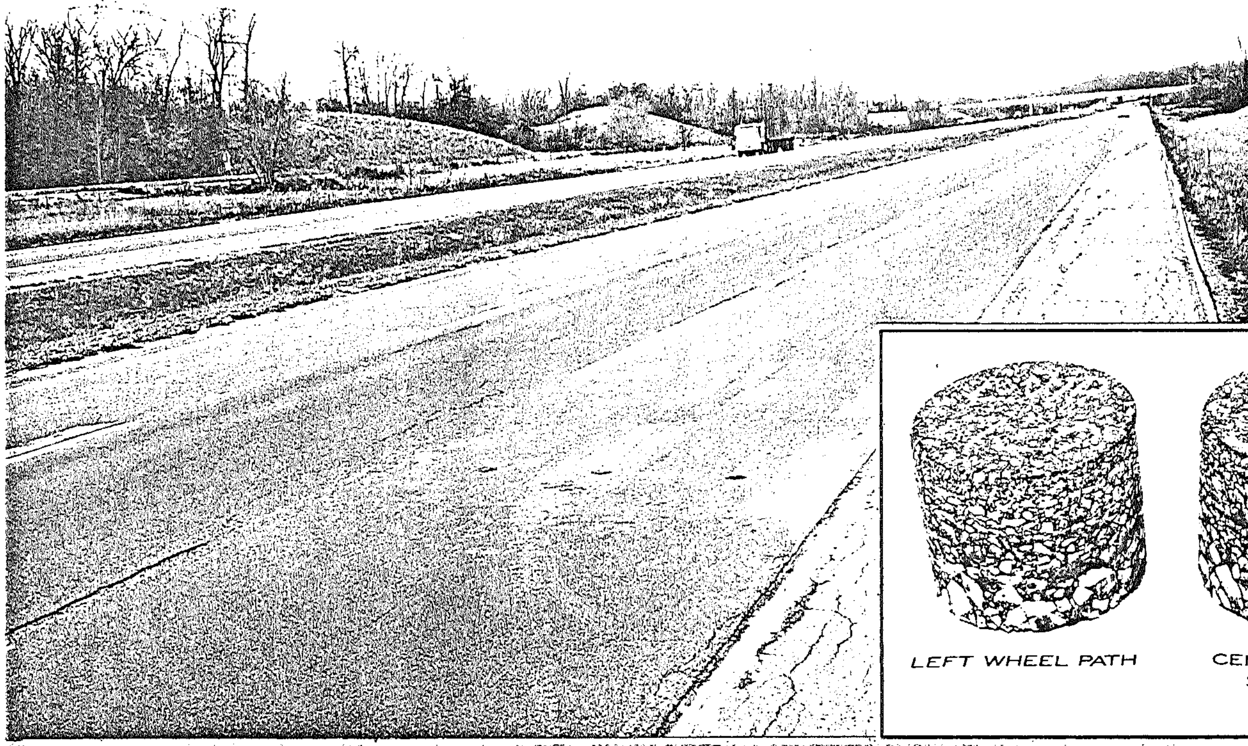
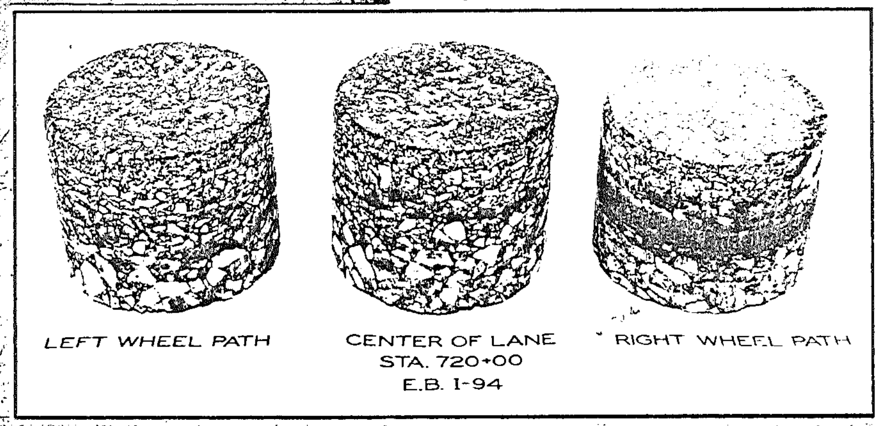
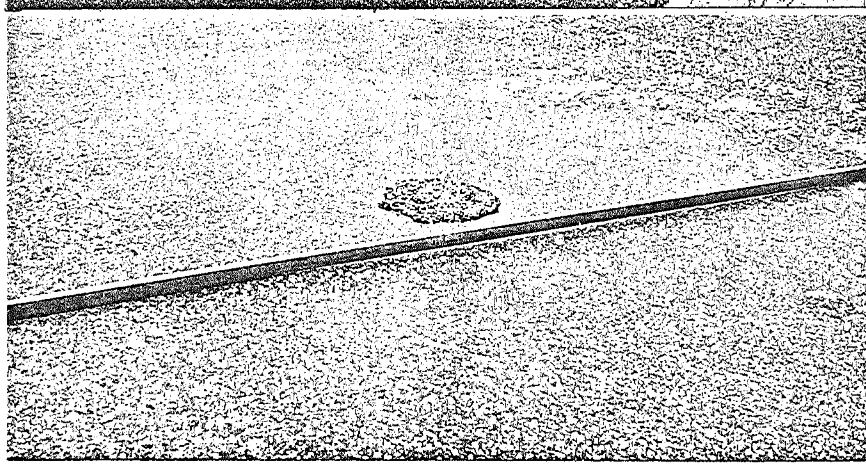


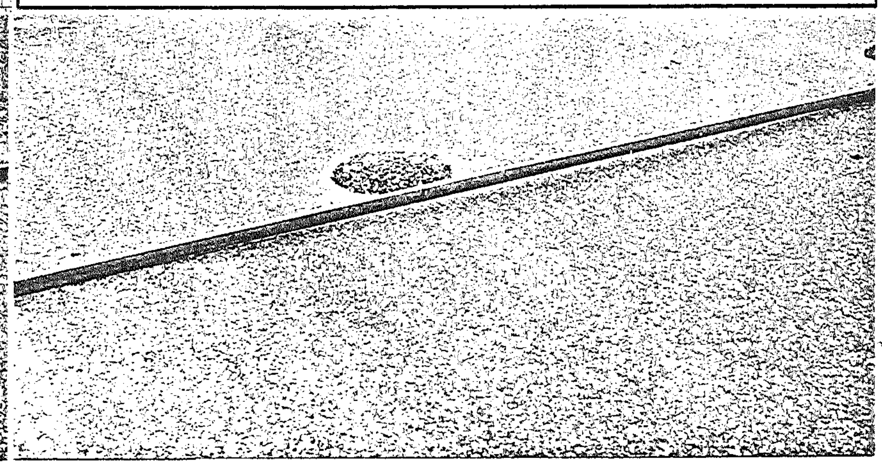
Figure 16a. General view of test area.

Cores taken from test area, note high bitumen content.

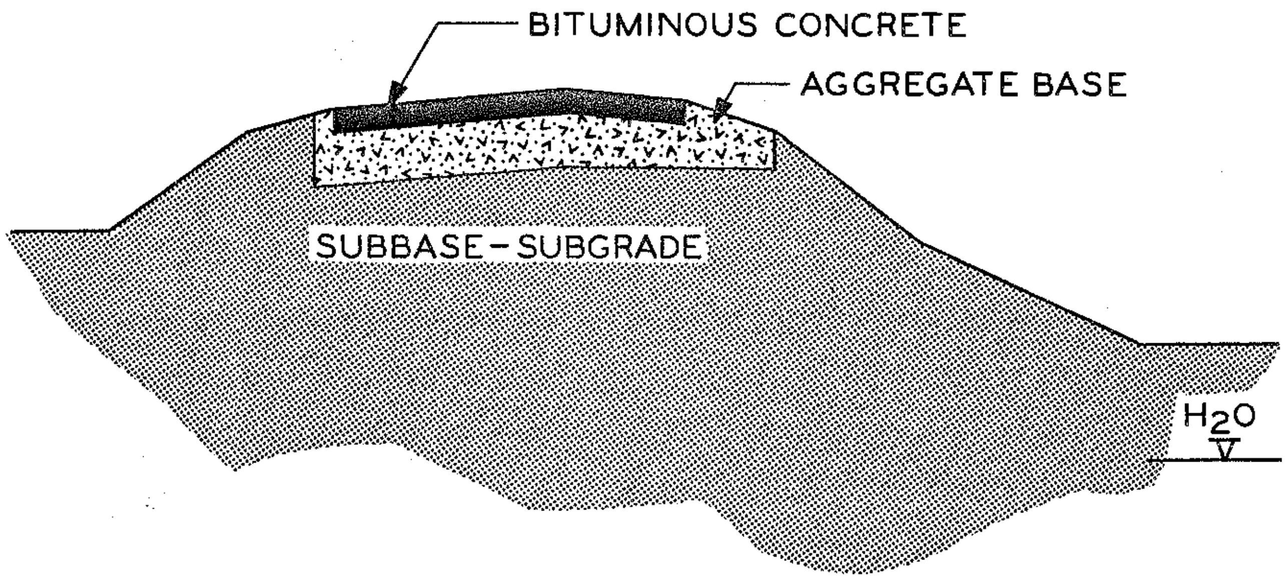




Rutting of LWP.



Rutting of RWP.



Pavement Layer	Thickness, in.		
	LWP	℄ Lane	RWP
Bituminous Concrete	5	5	4-1/2
Aggregate Base	11-1/4	10-1/2	8-1/2
Subbase	---	---	---
Depth to H_2O	> 4 ft from pavement surface		

Rut Depth, in.	
LWP	RWP
0.35	1.15

Figure 17. Cross-section of eastbound I 94 at about Station 746+00.

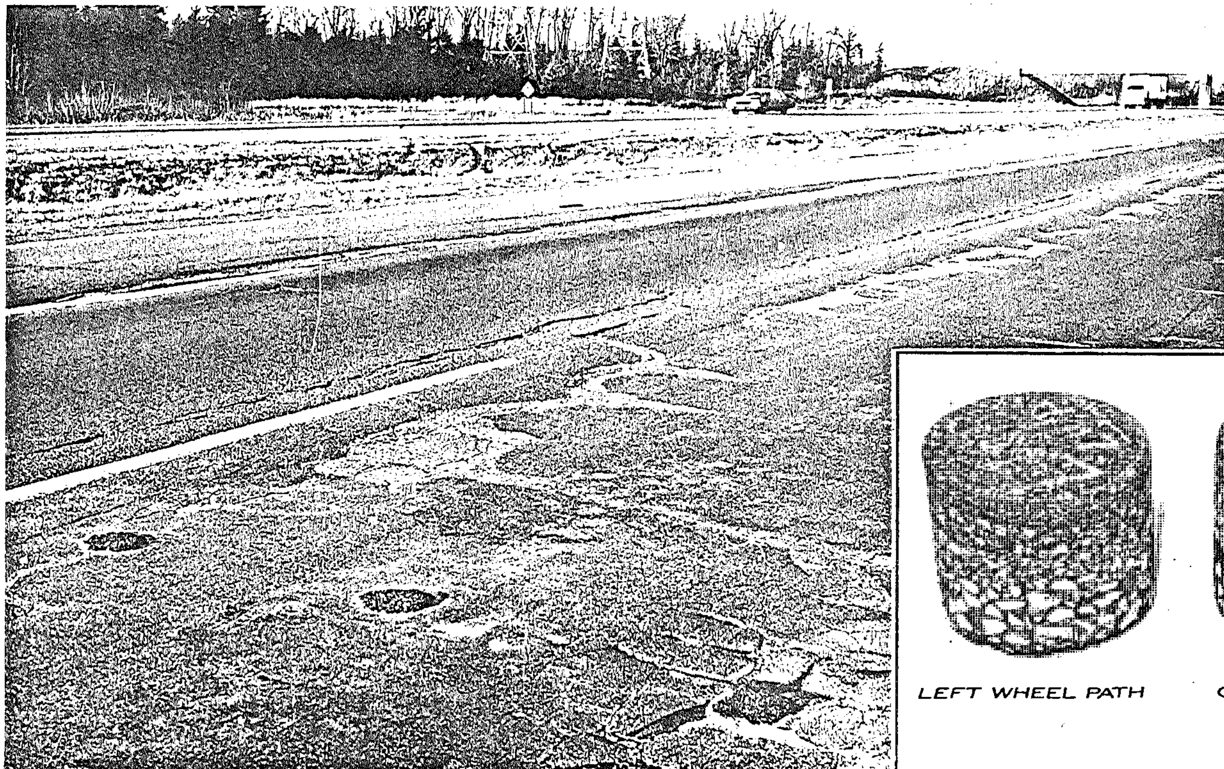
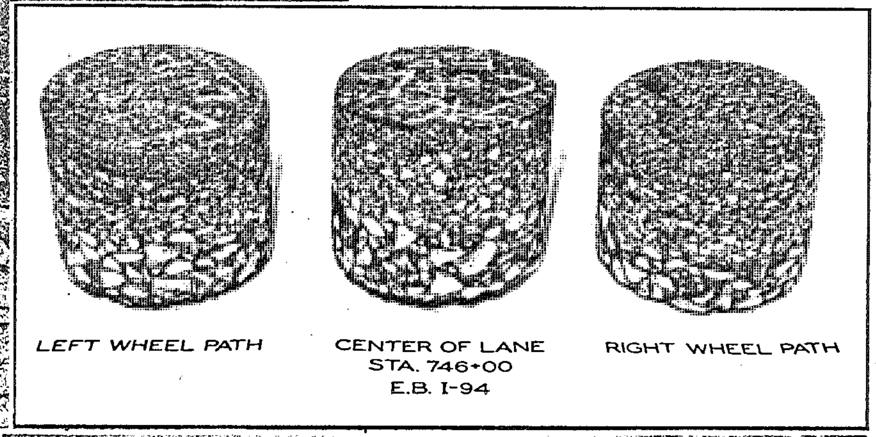
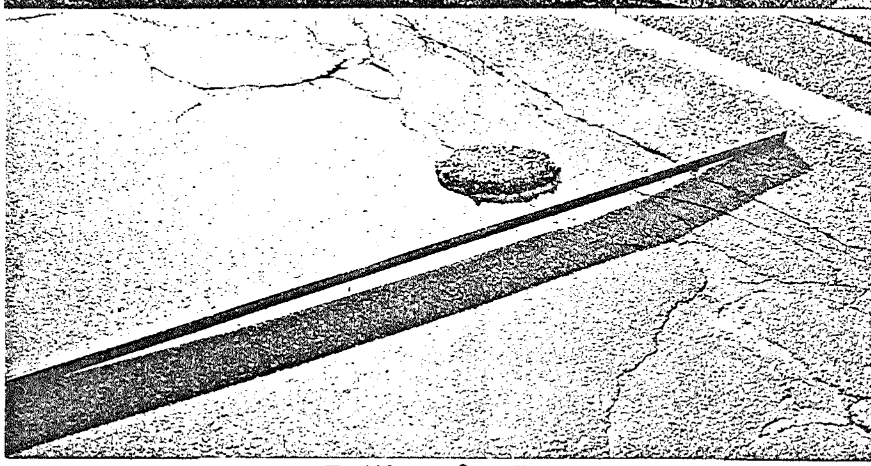


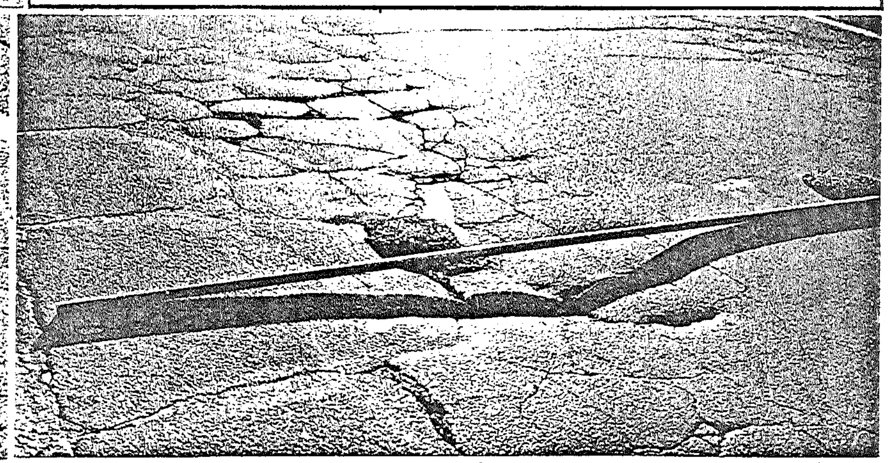
Figure 17a. General view of test area.

Cores taken from test site.





Rutting of LWP.



Rutting of RWP.

TABLE 2
SUMMARY OF LABORATORY TEST RESULTS

Lane	Station	Location	Layer	In-Place Moisture, percent	Maximum Density, lb/cu ft	Permeability Density, lb/cu ft	k,[1] ft/day	$\frac{k}{N_e}$[2]	Drained Moisture, percent	Drained Percent Saturation	Loss By Washing, percent	Particle Index	U, D_{60}/D_{10}
WB	251+00	RWP	Base	3.6	140.8	137.0	0.5	7	5.8	67.2	8.1	--	63
WB	251+00	RWP	Subbase	9.7	109.1	105.8	5.6	70	16.0	77.7	2.1	--	---
WB	251+00	RWP	Subgrade	14.7	114.3	111.3	1	---	--	--	9.6	--	---
EB	228+00	RWP	Base	3.6	139.8	138.7	1.6	27	5.5	67.8	7.3	--	35
EB	228+00	RWP	Subbase	3.8	108.8	105.4	9.4	85	16.0	71.1	2.3	--	---
EB	228+00	RWP	Subgrade	8.8	107.9	106.7	6.4	160	19.3	89.2	4.5	--	---
EB	254+00	RWP	Base	5.0	142.3	138.0	I	---	--	--	7.7	6.4	35
EB	254+00	RWP	Subbase	3.6	107.8	104.7	14.7	210	17.4	81.2	1.7	--	---
EB	254+00	Cen. of lane	Base	3.7	140.0	136.1	I	---	--	--	7.6	6.4	35
EB	254+00	Cen. of lane	Subbase	3.8	108.3	106.5	7.5	94	16.3	77.4	2.1	--	---
EB	254+00	LWP	Base	4.4	140.3	137.3	I	---	--	--	8.3	6.4	45
EB	254+00	LWP	Subbase	4.7	108.4	106.2	1.8	20	16.2	74.4	3.9	--	---
EB	254+00	LWP	Subgrade	15.3	116.3	---	I	---	--	--	76.6	--	---
EB	365+00	RWP	Base	3.4	141.7	139.6	1.3	22	5.8	68.4	7.6	6.1	71
EB	365+00	RWP	Subbase	8.8	111.3	109.2	2.6	24	14.2	69.0	5.0	--	---
EB	365+00	Cen. of lane	Base	3.7	140.0	140.2	I	---	--	--	8.0	8.1	75
EB	365+00	Cen. of lane	Subbase	9.7	110.1	107.9	I	---	--	--	4.0	--	---
EB	365+00	LWP	Base	3.2	143.5	140.3	I	---	--	--	8.2	8.1	100
EB	365+00	LWP	Subbase	11.1	108.5	105.1	6.0	67	17.2	76.3	3.3	--	---
EB	365+00	LWP	Subgrade	13.3	116.1	---	I	---	--	--	75.0	--	---
EB	574+00	RWP	Base	3.6	137.5	139.6	I	---	--	--	9.7	--	78
EB	574+00	RWP	Subbase	2.0	108.5	104.8	33.0	471	19.5	81.7	0.6	--	---
EB	574+00	RWP	Subgrade	3.3	107.9	104.9	17.5	194	16.2	75.6	1.3	--	---
EB	592+00	RWP	Base	5.5	137.2	136.8	0.8	80	7.6	92.5	12.9	8.8	136
EB	592+00	RWP	Subbase	1.9	106.8	107.8	47.3	1577	18.5	91.4	0.9	--	---
EB	592+00	RWP	Subgrade	2.3	106.3	102.7	50.1	501	18.1	74.6	0.2	--	---
EB	592+00	Cen. of lane	Base	4.7	139.2	136.2	1.6	32	5.8	70.2	11.7	8.8	96
EB	592+00	Cen. of lane	Subbase	1.9	107.0	104.2	46.8	520	17.0	75.7	0.3	--	---
EB	592+00	LWP	Base	5.8	139.9	141.9	I	---	--	--	8.9	8.8	80
EB	592+00	LWP	Subbase	2.3	107.9	105.2	56.2	937	17.7	83.1	0.3	--	---
WB	592+00	RWP	Base	4.9	136.5	137.5	I	---	--	--	12.1	7.1	110
WB	592+00	RWP	Subbase	3.5	107.9	105.0	27.7	396	17.4	81.2	1.8	--	---
WB	592+00	Cen. of lane	Base	4.7	133.8	134.4	2.2	55	8.1	82.9	11.6	7.1	126
WB	592+00	Cen. of lane	Subbase	2.4	106.7	104.0	31.8	454	18.7	82.2	0.6	--	---
WB	592+00	LWP	Base	3.9	136.8	138.2	1.0	20	6.3	73.3	9.4	7.1	100
WB	592+00	LWP	Subbase	2.5	106.4	104.7	35.7	1190	19.7	91.9	1.5	--	---
EB	712+00	RWP	Base	4.9	138.0	137.2	I	---	--	--	11.4	9.2	128
EB	712+00	RWP	Subbase	2.5	106.8	104.3	34.2	684	19.3	87.1	0.8	--	---
EB	712+00	Cen. of lane	Base	4.3	139.4	137.0	1.1	37	6.9	84.3	10.3	9.2	98
EB	712+00	Cen. of lane	Subbase	2.3	107.9	106.2	29.9	427	16.3	79.2	1.4	--	---
EB	712+00	LWP	Base	4.4	140.1	137.8	I	---	--	--	10.5	9.2	127
EB	712+00	LWP	Subbase	2.2	108.2	104.4	38.7	553	18.1	81.7	0.7	--	---
EB	720+00	RWP	Base	5.6	138.5	138.5	I	---	--	--	12.2	10.6	146
EB	720+00	RWP	Subbase	2.2	107.9	104.5	39.9	570	17.4	81.2	0.9	--	---
EB	720+00	Cen. of lane	Base	4.6	139.9	136.2	I	---	--	--	11.7	10.6	126
EB	720+00	Cen. of lane	Subbase	1.3	107.3	103.9	40.8	408	16.6	73.0	0.9	--	---
EB	720+00	LWP	Base	3.9	137.8	140.6	I	---	--	--	11.9	10.6	151
EB	720+00	LWP	Subbase	1.2	107.3	105.7	36.2	453	17.4	79.5	0.7	--	---
EB	746+00	RWP	Base	4.5	139.4	135.6	0.7	12	6.5	70.5	10.7	9.0	85
EB	746+00	RWP	Subbase	2.1	108.4	105.4	29.3	266	16.0	71.2	1.0	--	---
EB	746+00	Cen. of lane	Base	4.8	137.9	138.4	I	---	--	--	10.8	9.0	85
EB	746+00	Cen. of lane	Subbase	2.0	107.7	104.2	27.4	228	15.3	69.1	1.7	--	---
EB	746+00	LWP	Base	3.9	139.7	139.5	0.7	35	6.5	85.2	8.5	9.0	60
EB	746+00	LWP	Subbase	2.5	107.6	105.1	27.7	231	16.0	68.9	0.6	--	---

(1) I indicates permeability is less than 0.5 ft/day.
(2) k/N_e greater than 35 indicates generally good drainability and poor drainability if less than 35.

LABORATORY TEST RESULTS

Laboratory analysis of base, subbase, and subgrade samples collected from I 94 test sites are summarized in Table 2, and gradations summarized in Figures 18 to 25. In general, these data show that the base is very densely graded and impervious, the subbase is clean well-drained sand, and the subgrade is typically clean well-drained sand. Three test sites had loamy silt subgrades which had no detrimental influence on the pavements' performance.

All bases tested have a loss-by-washing content in excess of 7 percent and many are in the 11 to 12 percent range. Figures 18 to 25 show that they also have very dense gradations. These two characteristics combine to give a base which is generally extremely stable when less than 90 percent water saturated. However, when over 90 percent water saturated, and subject to freeze-thaw action, volume change and softening (loss of strength) occurs. The volume change is responsible for some of the wheelpath rutting, while softening is responsible for the alligator cracking.

In areas where the bituminous concrete is not crack susceptible, such as at Sta. 720+00 (EB) the high fines content of the base gravel has not detrimentally influenced pavement performance; i.e., the pavement is not rutted or cracked. In adjacent areas with the same base material, Sta. 712+00 and 746+00, the crack susceptible bituminous concrete has cracked, admitted water to the base, and has initiated rutting and softening with its associated alligator cracking of the bituminous concrete.

In other areas such as Sta. 251+00 (WB) and 228+00 (EB) the base is performing well while the bituminous concrete is not. Although base fines contents in these areas are relatively lower than for the other bases, they are still high and could detrimentally influence future performance where heavier traffic loads must be carried.

Some of the base is exhibiting severe degradation characteristics. In reviewing gradations for Sta. 592+00 (EB and WB) and to a lesser extent Sta. 746+00 (EB) it will be noted that the left wheelpath base samples are finer than are the right wheelpath samples. This has caused an increased rutting of the left wheelpath compared to the right (Figs. 13, 14, and 17). The left wheelpath does receive a greater total number of load repetitions than does the right because of the lane changes made by the heavy truck traffic. Normally, the right wheelpath ruts more because of the lower lateral support hence lower stability in the right wheelpath. The tendency to degrade could be alleviated by bituminous stabilization.

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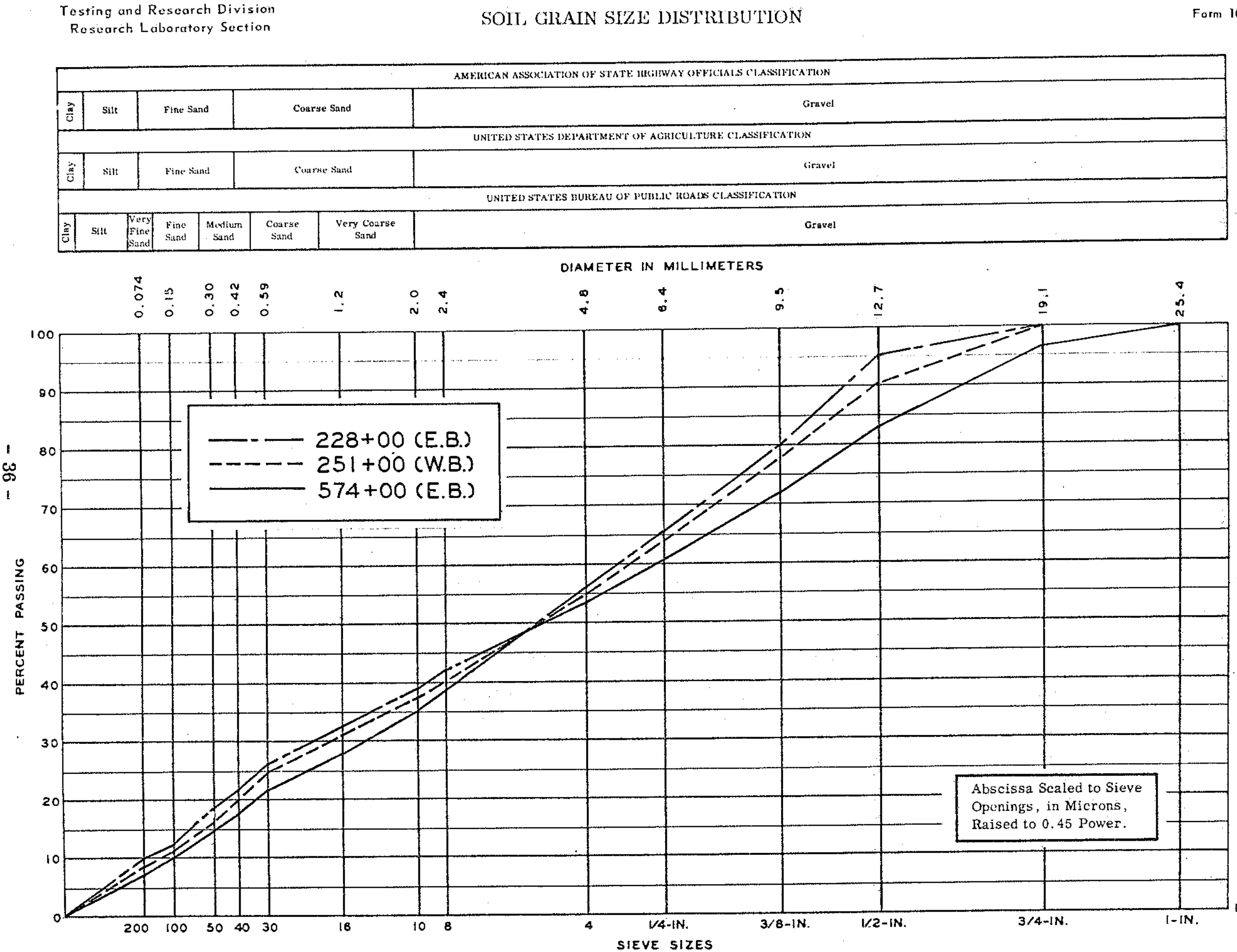

Figure 18. Gradation of base course samples from Stations 228+00 (EB), 251+00 (WB), and 574+00 (EB).

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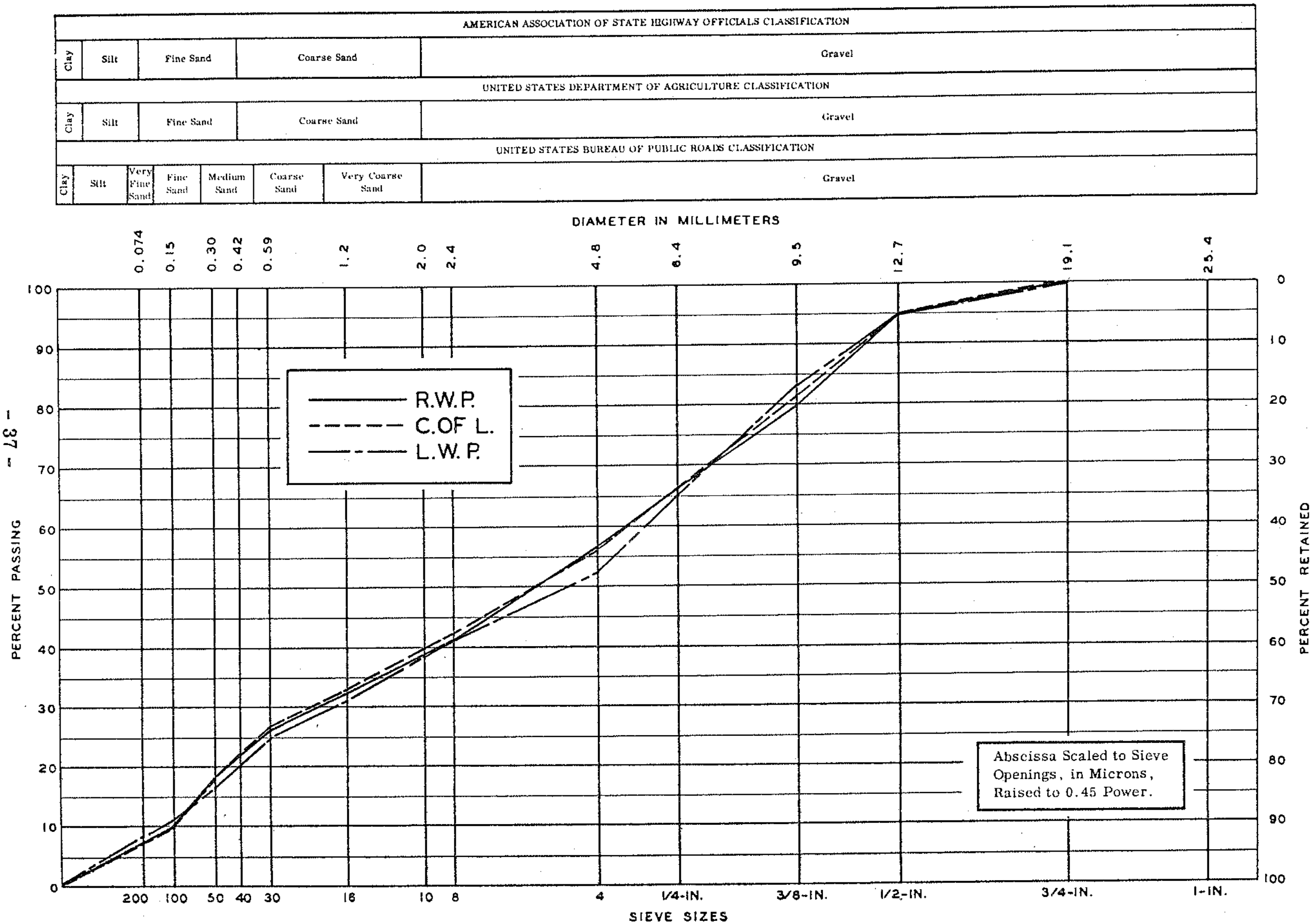

Figure 19. Gradation of base samples from Station 254+00 (EB).

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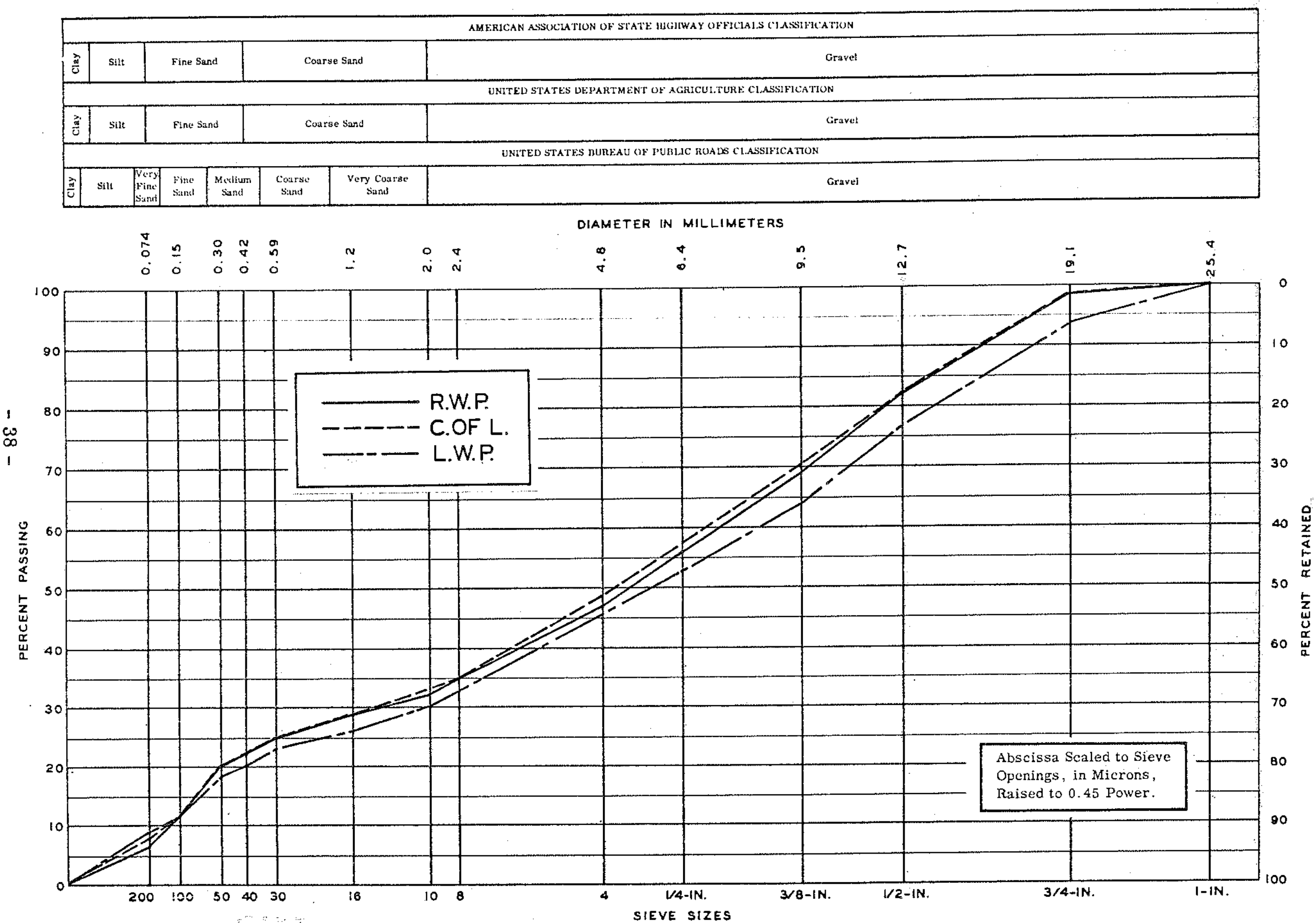

Figure 20. Gradation of base samples from Station 365+00 (EB).

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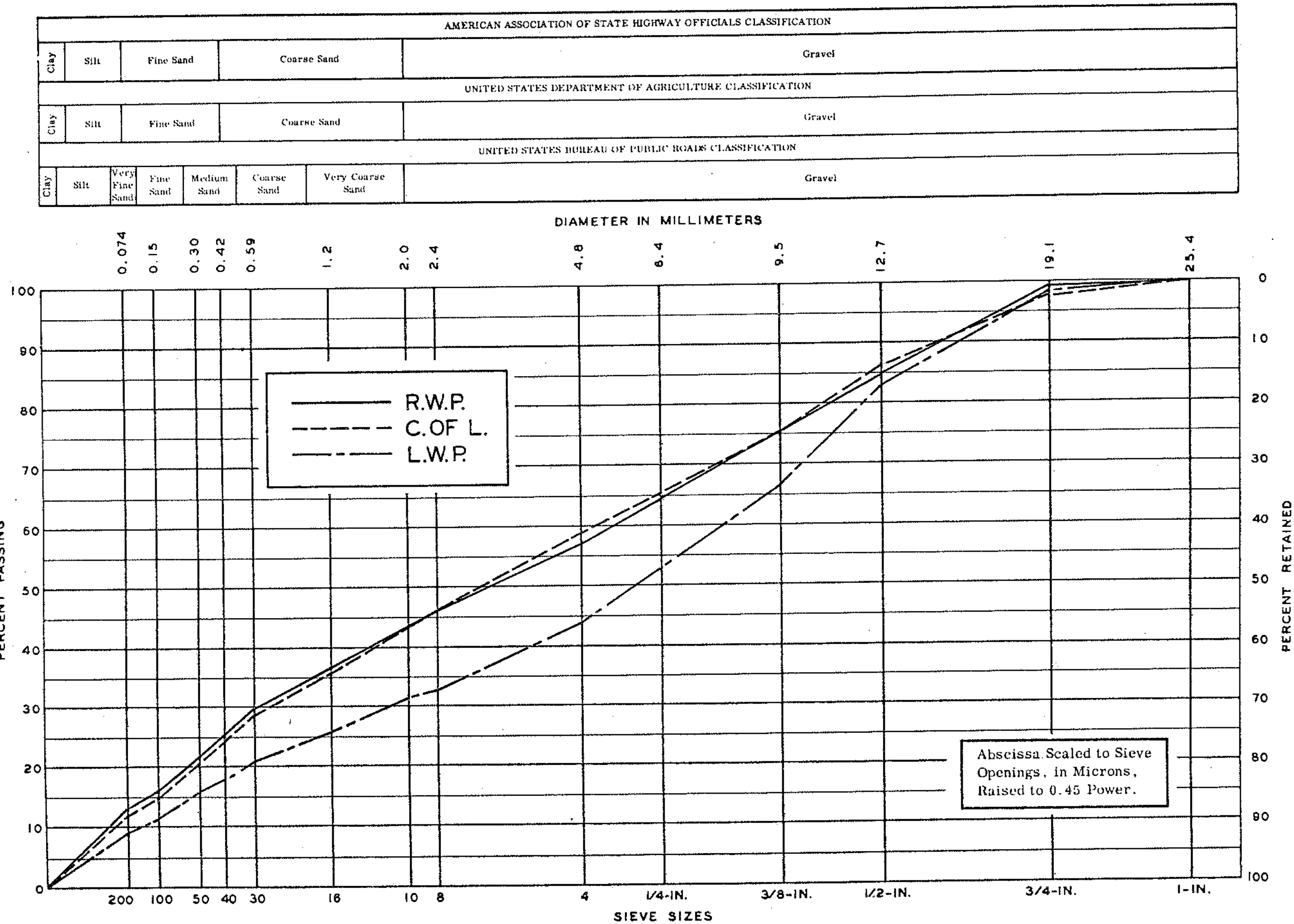

Figure 21. Gradation of samples from Station 592+00 (EB).

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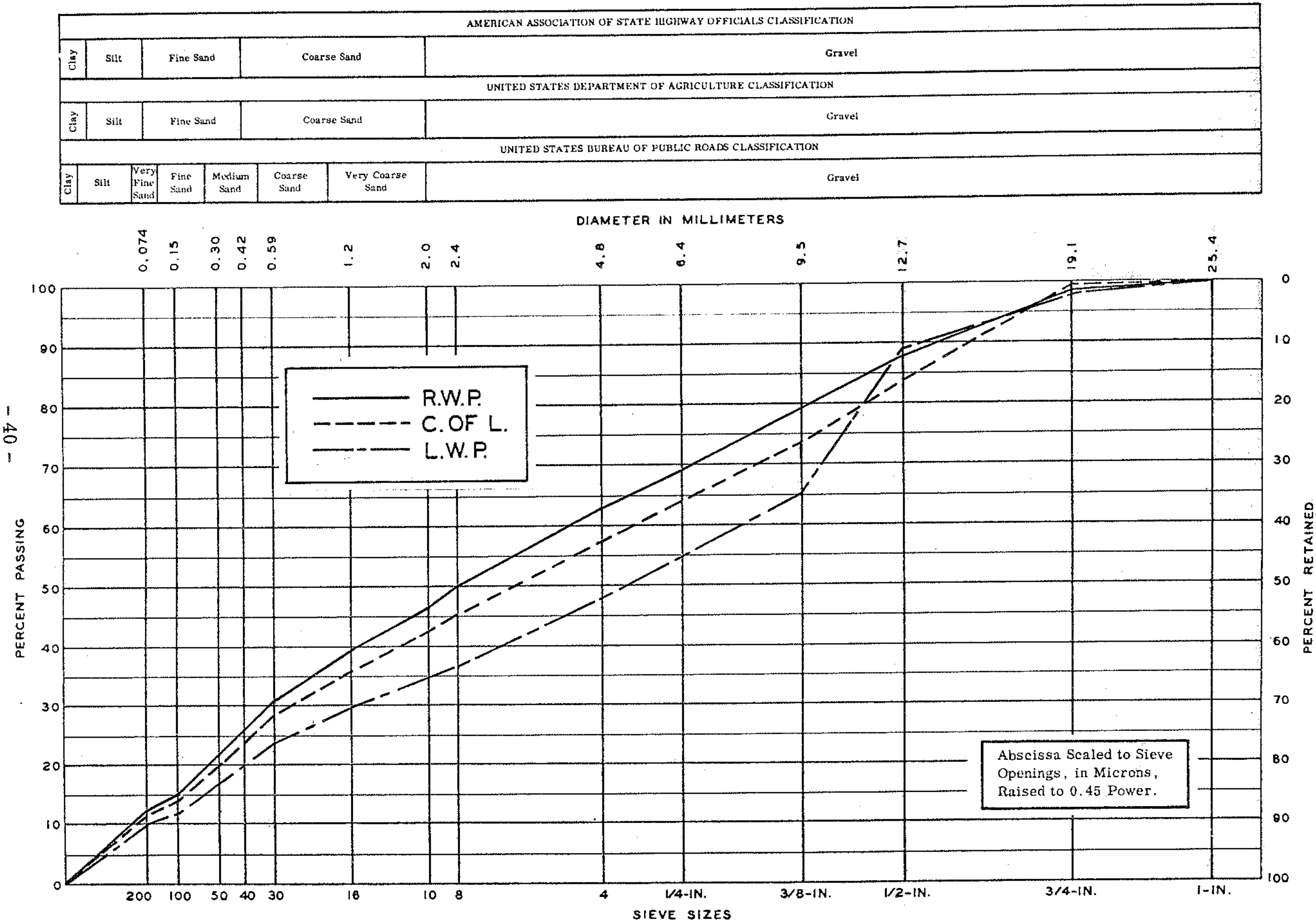

Figure 22. Gradation of samples from Station 592+00 (WB).

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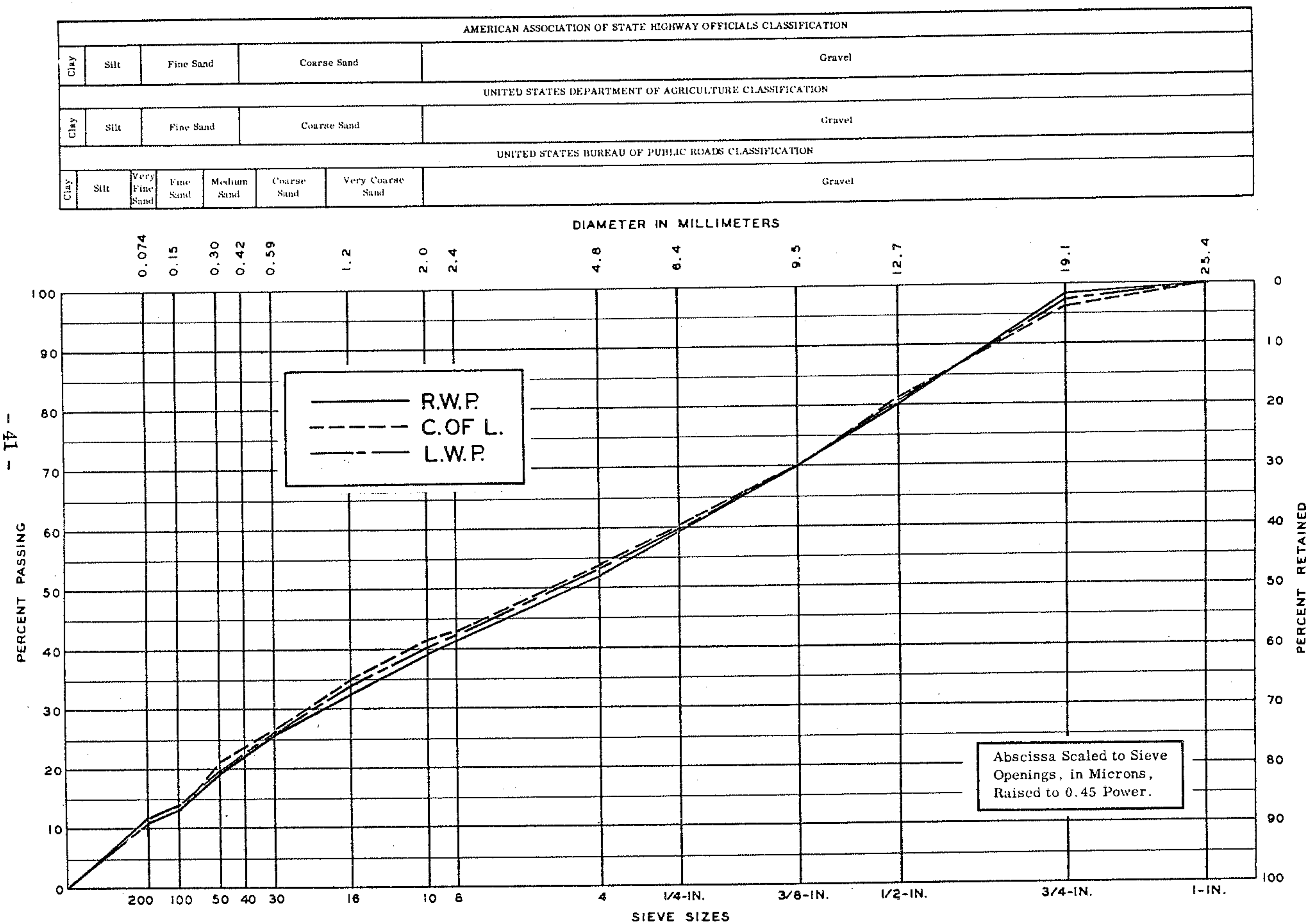

Figure 23. Gradation of base samples from Station 712+00 (EB).

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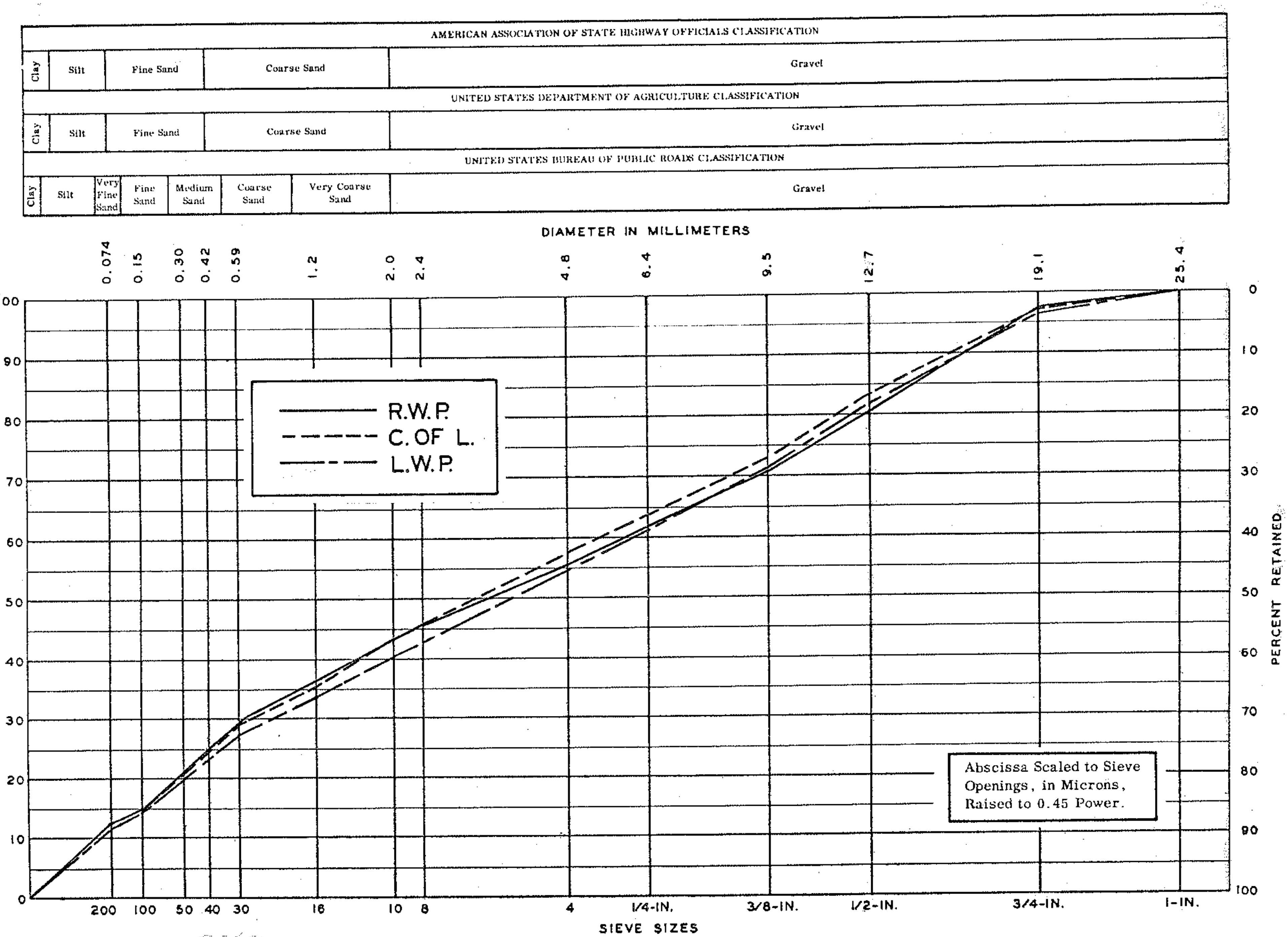

Figure 24. Gradation of base samples from Station 720+00 (EB).

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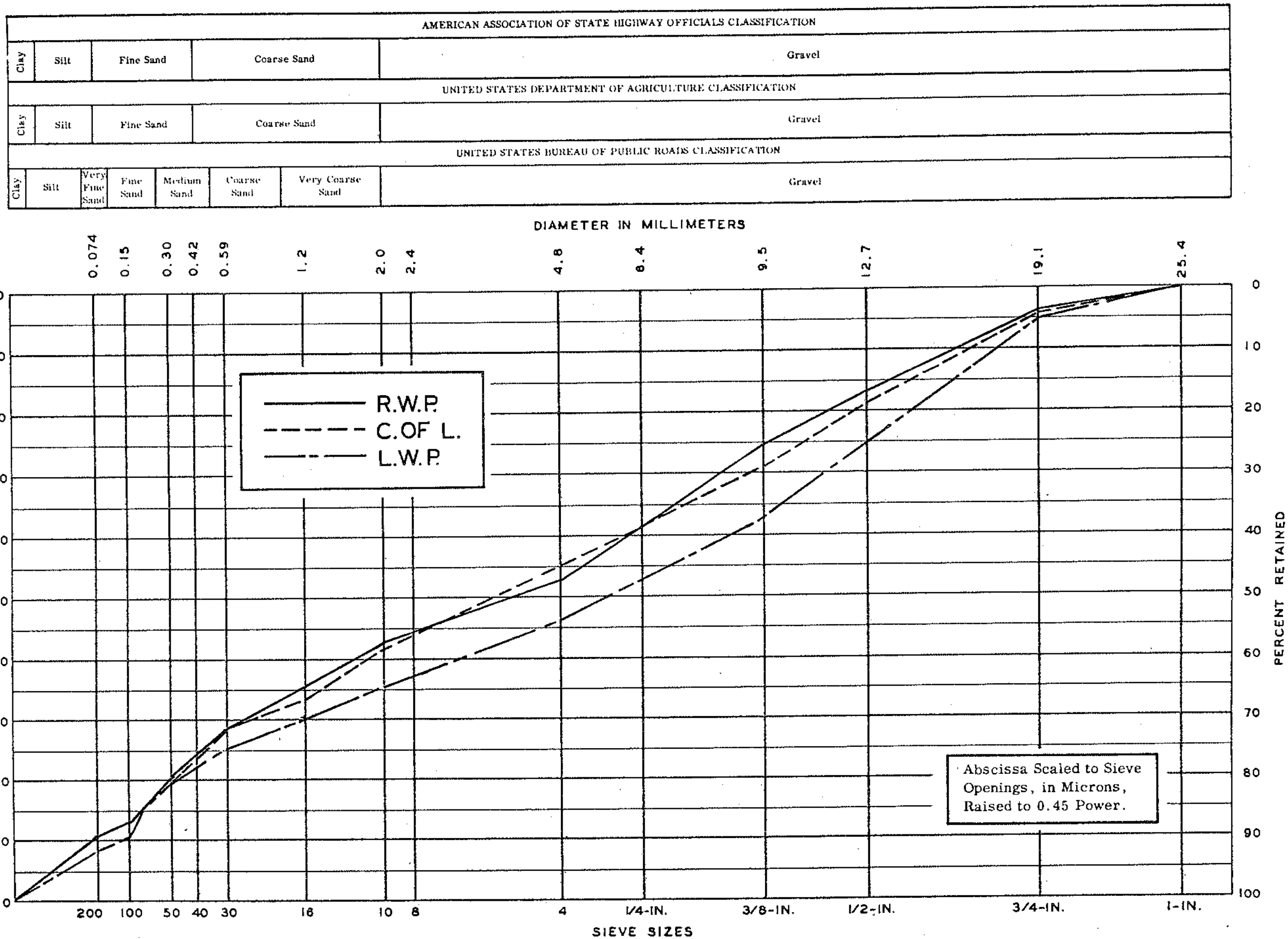

Figure 25. Gradation of base samples from Station 746+00 (EB).

It was not possible to compact the laboratory permeability samples to as high a density as exists in the field. Therefore, reported permeabilities are higher and drained percent saturation lower than that which exists in the field. This means the base gravel actually has greater water holding capacity than the data indicate. In addition, the base gradations, although densely graded, have in most cases excess fines. The combination of high moisture retention and excess fines is responsible for the bases' pumping characteristics.

The particle index data show that most of the coarse aggregate is moderately angular. This should help achieve good base stability, and there is no question but that the base should be upgraded so that if the bituminous concrete surface should crack, the base will not accelerate deterioration. This could be done by stripping off the bituminous concrete and stabilizing the base in-place with the addition of either asphalt cement or slow cure SC asphalts. Because the base is so densely graded, its void volume is close to the volume of asphalt cement normally added (3 to 6 percent by weight). This condition can cause the base to be susceptible to rutting if the mixture is inadequately compacted. Compaction is aided if SC asphalts are used; therefore, it is recommended that the base be stabilized with an SC asphalt using procedures such as those used to build oil aggregate pavements (1940 Standard Specification 4.07).

The test results indicate that the subbase, with only one or two exceptions, is super drainable and doing an outstanding job of keeping water away from the base. It is very likely that the base performance would not be so good had the subbase materials not been so drainable. No corrective measures appear to be necessary for either subbase or subgrade layers. However, subbase drainability in Control Section IR 11014 should be checked during construction. If inadequately drained areas are found, subbase drains could be added at that time.

DISCUSSION

Field and laboratory investigations of sections of I 94 selected for rehabilitation indicate that the pavement has performed reasonably well, but it is underdesigned for a 20 year life cycle. The pavement is roughly 14 years old, and presently carries over 650,000 equivalent 18-kip axle loads annually. The observed distress indicates no major pavement deficiencies exist. The most common cause of distress is related to the crack susceptibility of the bituminous concrete. Indications are that the crack susceptibility is the result of low asphalt content or temperature sensitive asphalt, or both. Where asphalt content is high, the pavement is smooth, uncracked, and only slightly rutted.

Where the bituminous concrete has cracked, the aggregate base has generally not performed well. Had the base not been susceptible to pumping and softening when wet, the pavement would have a better riding quality than it now has, the reason being that pavement roughness is more closely related to base, than to bituminous concrete performance. On the other hand, had the bituminous concrete been less crack susceptible, the crack-free surface would have significantly increased the pavement's life.

Bituminous concrete mixes cannot be designed so that they will not crack. However, the number of load repetitions required to cause cracking can be greatly increased by increasing bitumen content to an optimum level, using bitumens that are more crack resistant, and by reducing tensile stresses in the bitumen. The aggregate base can be made such that it will not pump or soften by eliminating the fines content (minus 30 material) and by bituminous stabilization.

The method of rehabilitation selected for I 94 will depend on how many years its second life cycle is to last. Present technology is such that a life cycle as long as 20 years is possible, but this would require removing the existing bituminous concrete surface; bituminous stabilization of the base; recycling the existing bituminous concrete, i.e., putting it through a hot mix plant, adding bitumen and latex or appropriate viscosity improvers to reduce crack susceptibility; and, resurfacing with a 3 to 4-in. mat for a total bituminous concrete thickness of about 8 in. The resurfacing of existing I 94 with a 3 to 4-in. mat should last between 5 and 10 years before reflective cracking, pumping, and softening of the base make the riding quality poor enough to again require rehabilitation. However, the addition of 3 to 4-in. of asphalt for a 5 to 10 year life cycle builds up the pavement thickness at two to four times the rate of rehabilitation for a 20 year or more life cycle. Another disadvantage of short life cycles is that the pavement is in poor riding condition for a longer period of time. Assuming all pavements are resurfaced within a year after their serviceability has fallen below acceptable limits a 5-year life cycle pavement will be performing poorly for a duration four times that of a pavement whose life cycle is 20 years.

The only apparent advantage to resurfacing I 94 would be lower initial cost. However, resurfacing will clearly compound future rehabilitation problems, have a poorer average serviceability, and a higher total cost.

SUMMARY AND CONCLUSIONS

I 94 was inspected, samples were taken and a determination was made as to the causes of existing distress. No gross layer deficiencies exist;

however, the bituminous concrete is crack susceptible over most of the area to be rehabilitated and the base layer generally does not perform well once the pavement surface cracks. In uncracked sections, the base usually performs well; however, some areas were found to have bases that were degrading and could cause future problems.

Most of the existing pavement surface has been distorted and is in need of correction in order to achieve proper surface drainage and superelevation. Correction would require adding additional materials to the base.

Resurfacing is not recommended because the base and bituminous concrete properties are such that a 3 to 4-in. cap would give satisfactory service for between 5 and 10 years, at which time rehabilitation would be a more difficult problem. The crack susceptible characteristics of the bituminous concrete can be corrected through hot mix plant recycling by increasing its asphalt content slightly or adding viscosity improvers or latex or both. The recycled bituminous concrete, with its crack susceptibility corrected, should increase the life of the pavement over that obtained for its first life cycle. However, the traffic loading is increasing at a rapid rate so that the deteriorating effects of the traffic will be greater than in the past. It is therefore recommended that the total bituminous concrete thickness be increased by about 3 in. or to a total thickness of 8 in.

The aggregate base softens when wet and is subject to freeze-thaw actions, and pumps fines when saturated with surface infiltrated water. This has caused most of the rutting noted in the pavement surface. However, the subbase in most areas is super drainable and this helps enhance base performance. In addition, the base is degrading in some areas and this can, in time, seriously reduce its performance. Since in some areas the base will soften and pump should the pavement surface crack, and since it is degrading, some corrective measures are necessary to ensure that it will not significantly reduce the rehabilitated pavement life. In this respect, it is recommended that the bituminous concrete layer be removed for hot mix plant recycling so that the base can be bituminous-stabilized to a depth of at least 4 in. with SC asphalts using a construction technique similar to those used to construct oil aggregate pavements (1940 Standard Specfication 4.07).

About two years after the flexible pavement portion of I 94 was constructed, a third lane was added. Because of the construction difficulties associated with adding a lane to an existing pavement, longitudinal cracking occurs at the construction joint for the entire length of this portion of

I 94. In areas where the base performance is poor, the longitudinal cracking is a safety hazard. To avoid construction joint cracking of the rehabilitated pavement, all three lanes should be reconstructed at the same time. This would enable the contractor to correct the surface grade, construct a pavement that will not have a built-in point of weakness and distress, and at the same time be safer for the contractor during construction. It will also be safer for the public since the pavement can be reconstructed to have proper surface drainage and superelevation, hence improving skid properties and vehicle control. Also, the surface distortion (a traffic hazard) that would occur by constructing the passing and center lanes separate from the traffic lane would be eliminated.