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EARLY CRACKING OF A BITUMINOUS CONCRETE SECTION OF US 2 LOCATED IN DISTRICT 2

MICHIGAN DEPARTMENT OF TRANSPORTATION

TESTING AND RESEARCH DIVISION
RESEARCH LABORATORY SECTION

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At the request of R. A. Welke, Supervisor of the Bituminous Technical Services Unit, part of Control Section F 210240 of US 2 has been investigated to determine the cause of early cracking. Normally, pavements such as this one are scheduled for reconstruction when 12 to 14 years old; whereas this pavement has been scheduled for reconstruction after only 8 years. The section of US 2 studied extends from Nahma Junction west 9.5 miles (Fig. 1). When the original roadway was reconstructed, some changes in alignment were made and the grade was raised such that the minimum subbase thickness placed on the old pavement is 10 in. and the maximum is 42 in. In addition, the old shoulders were undercut to the bottom of the old concrete pavement and the undercut area backfilled with subbase material. The finished pavement consists of two 12-ft lanes and 9-ft shoulders. The pavement consists of 280 lb/sq yd bituminous aggregate and a 10-in. thick aggregate base. The shoulders consist of 170 lb bituminous aggregate and a 6-in. aggregate base. A brief field study, based on pavement surface distress features, foundation drainage properties, and the pavement's load carrying capacity was conducted to identify the principal causes of early cracking. Recommendations for correcting pavement deficiencies are included in this report.

Field Test Procedures

A visual inspection of the pavement was conducted to identify pavement surface distress features. This procedure, which is outlined in Ref. (1), enables identification of the following causes of distress on the basis of the crack forms present and their associated distress features:

1) Traffic load induced failure,
2) Asphalt durability deficiencies,
3) Non-load related base and subbase deficiencies,
4) Subgrade deficiencies.

On completing the visual survey, 11 test sites were selected and tested to determine the following information:

1) Rut depth,
2) Pavement layer thicknesses,
3) Depth to water table,
4) Base, subbase, and subgrade drainability using procedures outlined in Ref. (2).

The pavement was also load-tested to determine its structural capacity. To do this, a one-mile long site was selected and pavement surface deflection measurements were made using procedures outlined in Ref. (3).

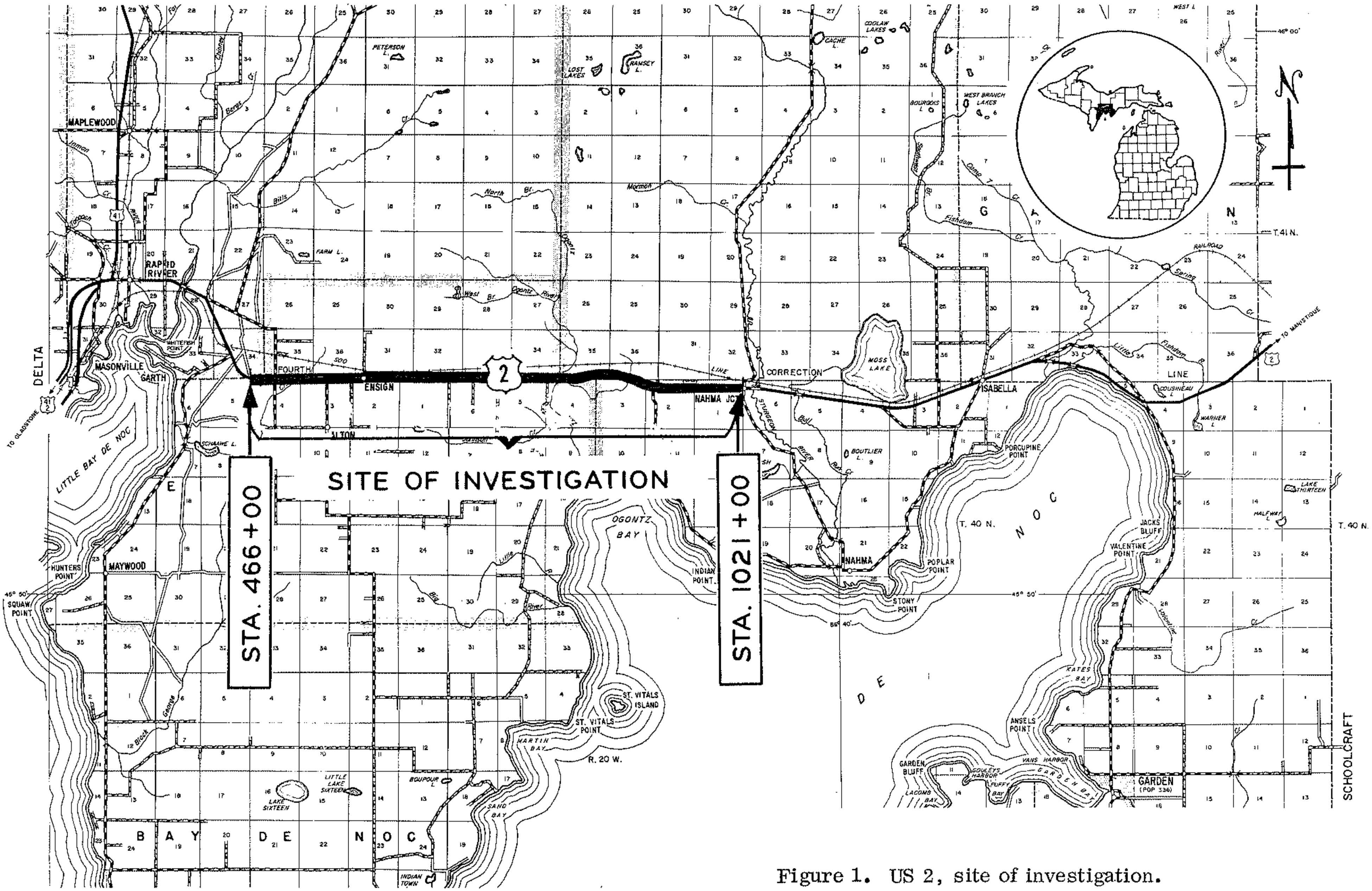

Figure 1. US 2, site of investigation.

The stiffness of each pavement layer was determined on the basis of the magnitude of the measured deflection. The pavement's ability to resist alligator cracking and rutting was determined on the basis of its stiffness, layer thickness, and durability of the bituminous concrete.

Test Results

The results of the visual survey found three basic crack forms present and these indicate the following pavement deficiencies or problems:

1) Transverse cracks - A small to moderate number of transverse cracks are present, indicating the bituminous concrete has low to moderate temperature sensitivity. Therefore, the bituminous concrete generally lacks durability, and will thus be subject to early fatigue cracking.

2) Alligator cracking in the vicinity of transverse and longitudinal cracks and at the pavement's edge (Figs. 2 through 4) - Much of the pavement is subject to this distress form, indicating the base layer is, for much of the roadway, subject to volume change and loss of strength as a result of frost action.

3) A band of alligator cracking occurring between the pavement centerline and the inner wheelpath - The exact cause of this form of cracking could not be definitely established, but it appears to be associated with the area where the two base and subbase layers abut. A scenario of how this form of cracking is believed to have occurred is as follows. Because traffic had to be maintained, this reconstruction was done one lane at a time. Thus, when the new base and subbase layers were placed for the second lane segment, complete consolidation of the longitudinal interface between the base and subbase sections of the first and second lanes was difficult to attain. This left a 'construction joint' area a foot or two to the side of the centerline of the pavement surface and it is an area that is difficult to adequately compact. Under traffic load, this area of the pavement was subject to a small amount of additional consolidation. The differential movement of the surface was enough to cause longitudinal cracks to form in areas of greatest movement. The presence of longitudinal cracks, which admit surface water, combined with the frost susceptible properties of the base, cause seasonal base weakening to occur and resulted in localized alligator cracking as shown in Figure 5.

Results of the site investigation are as follows:

1) Pavement layer thickness data are summarized in Table 1. These data indicate that the bituminous concrete thickness averages 2-1/2 in. at

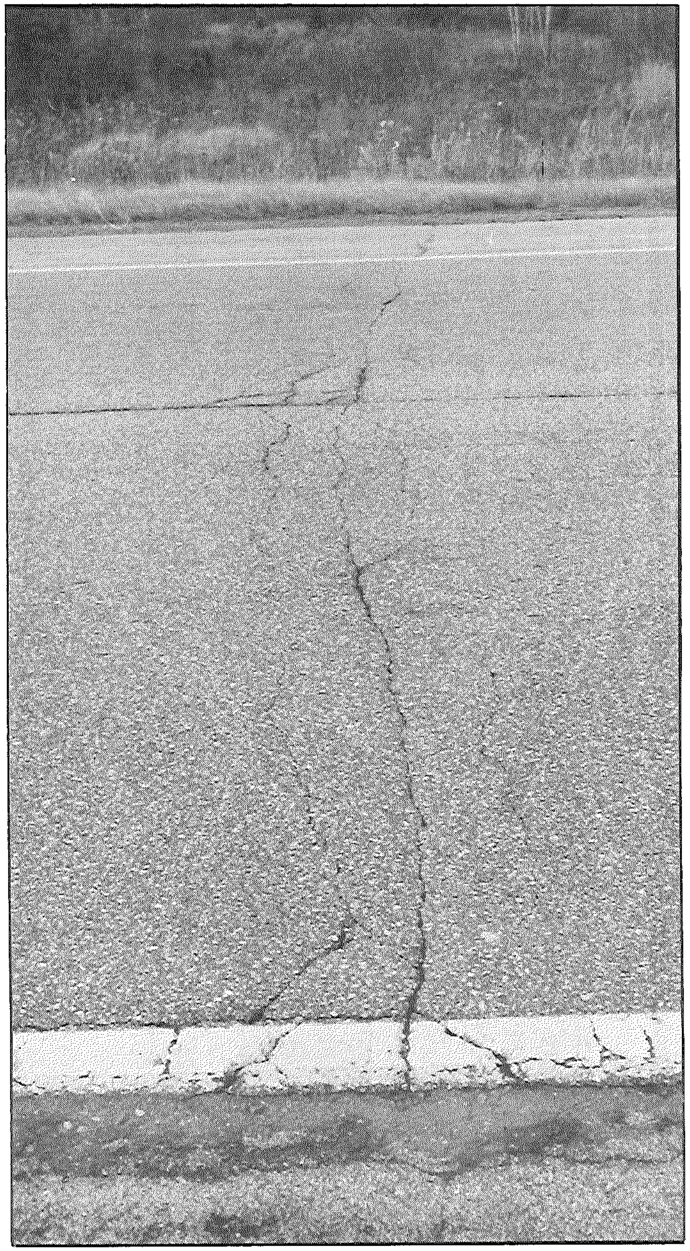

Figure 2. Alligator cracking and depressed pavement surface is associated with transverse cracks and is caused by frost action in the base and loss of base fines during periods of thaw.

Figure 3. Alligator cracking along centerline construction joint caused by frost action in base.

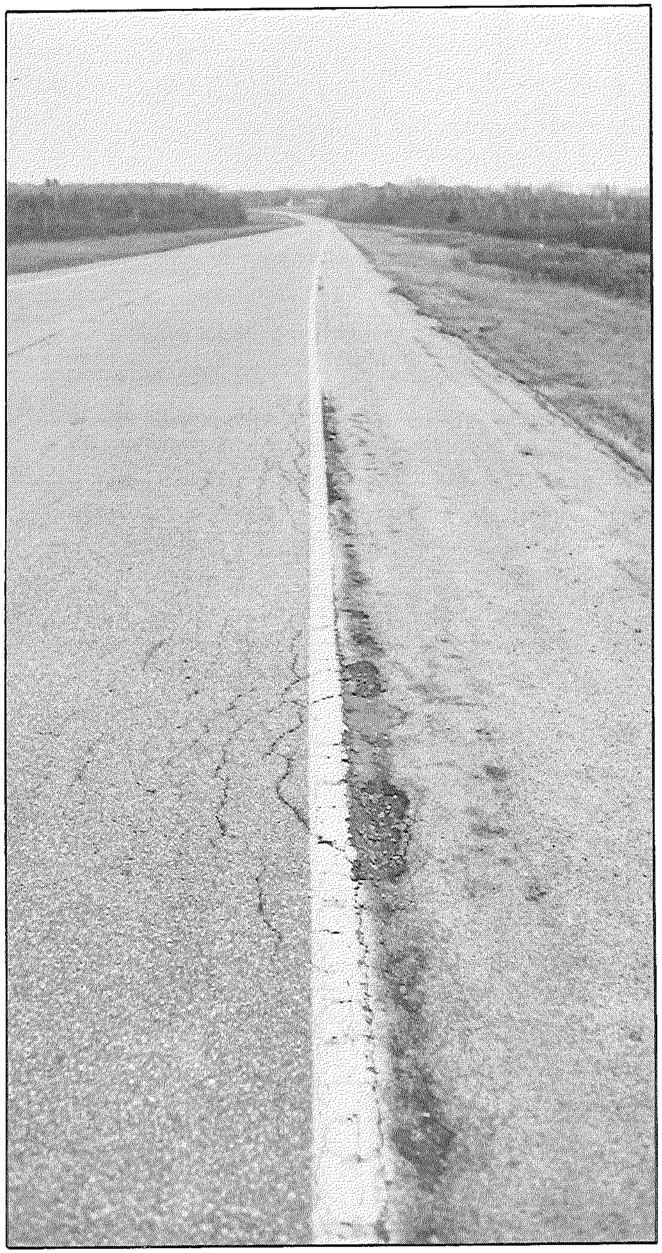

Figure 4. Alligator cracking at pavement edge caused by frost action in base, accompanied by loss of lateral support on thawing.

Figure 5. Alligator cracking between pavement centerline and the inner wheelpath is associated with the foundation construction joint. This distress is believed to be associated with inadequate compaction in the joint area.

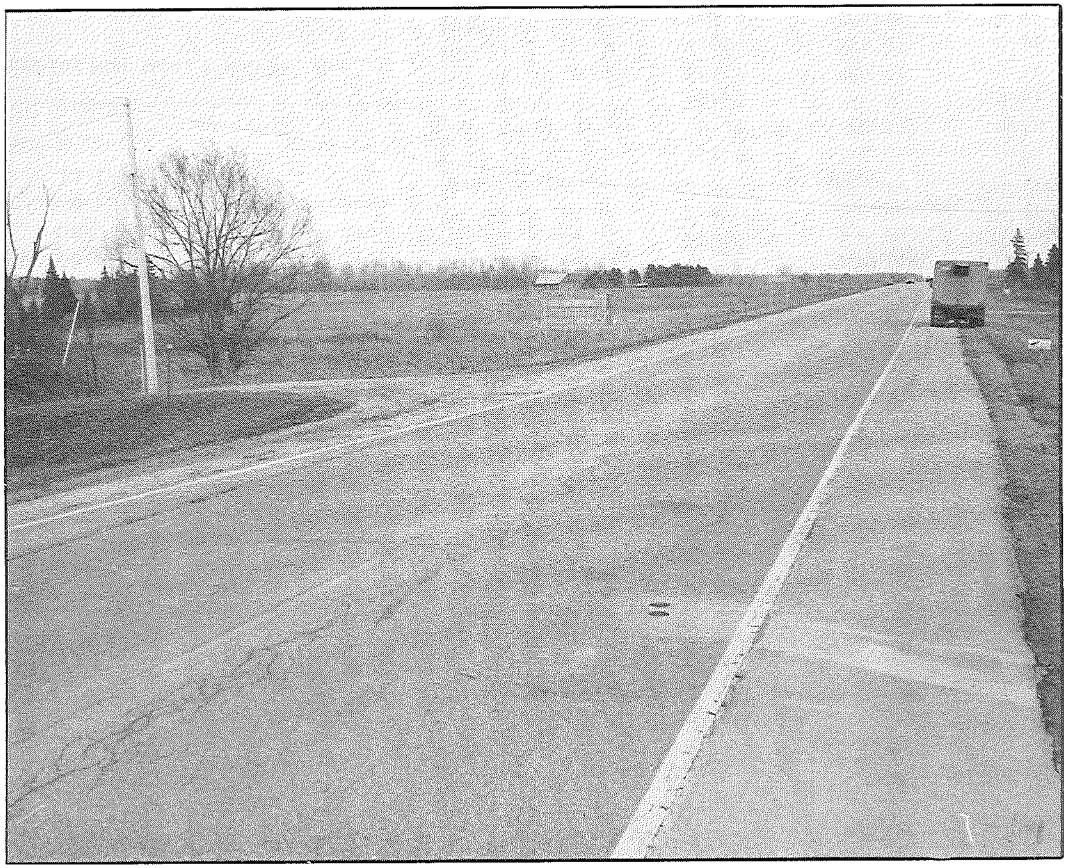

TABLE 1
SUMMARY OF PAVEMENT LAYER THICKNESSES

Site No.	Bituminous Concrete, in.		Base, in.		Subbase, in.[1]		Depth to H_2O, in.
	Lane ℄	Outer Wheelpath	Lane ℄	Outer Wheelpath	Lane ℄	Outer Wheelpath	
1	2	---	9	---	53+	--	60
3	2-3/8	2-3/8	10-5/8	---	22-1/2	--	60
4	2-1/2	2-1/2	11-1/2	---	33-1/2	--	60
6	2-1/2	2-3/4	8-1/2	---	22	--	60
8	2-1/2	2	9-1/2	---	24-1/2	--	60
9	2-3/8	2-1/4	9	---	12-7/8	--	60
10	2-3/4	2-1/2	8-5/8	---	13-3/4	--	60
11	2-3/8 [2]	2-1/2	9 [2]	8-1/2	42	41-1/2	60
12	2-5/8	2-3/8	7-3/8	7-7/8	53+	--	60
14	2-5/8	2-1/8	8-7/8	8-7/8	9-1/4	9-3/4	60
15	2-1/2	2-1/4	7-1/2	7-7/8	14-1/4	15-5/8	60
Average	2-1/2	2-1/3	8-3/16 [3]	8-1/4 [3]			

[1] No non-class II material or subgrade soils found. Except for Site Nos. 1 and 12, the subbase extends to surface of original pavement.

[2] Inner wheelpath.

[3] Average of sites 11 to 15 only.

TABLE 2
SUMMARY OF DENSITY AND DRAINABILITY DATA

	Site No.	Dry Density, lb/cu ft	Permeability, ft/day	Effective Porosity
Base	1	137.1	0.061	0.02
	3	137.1	*	--
	4	137.6	0.195	0.02
	6	138.2	*	--
	8	139.4	*	--
	9	137.4	0.214	0.04
	10	137.6	0.136	0.03
	11	136.5	0.520	0.01
	12	135.5	0.197	0.01
	14	138.7	0.105	0.005
	15	138.0	0.285	0.015
Subbase	1	101.0	36.7	0.08
	3	101.2	23.2	0.13
	4A	105.0	5.5	0.11
	4B	104.2	19.7	0.10
	6	105.4	13.8	0.08
	8	104.4	15.3	0.11
	9	105.3	9.9	0.08
	10	105.5	16.1	0.08
	11	103.5	14.3	0.11
	12	104.9	9.4	0.09
	14	104.0	21.3	0.10
	15	105.3	15.5	0.10

* Samples did not begin to drain in three hours and are essentially impervious.

the center of the lane and about 2-1/3 in. in the outer wheelpath; whereas, no difference is normally found in unrutted pavements. Therefore, the small difference indicates that the bituminous concrete is subject to a minor degree of rutting. The base thickness varied from site to site but no significant differential base thickness was found. Subbase thickness varied considerably due to variability of the grade lift over the original pavement. Where a subgrade was found, the material was, in all cases, granular and would permit vertical drainage.

2) Density and drainability are summarized in Table 2. These data show that the base is moderately dense and essentially impervious. The subbase layer, on the other hand, has good drainability and should be able to drain fast enough so that it will avoid volume change on freezing and, therefore, avoid loss of strength during thaw periods.

3) Rut depth measurements are summarized in Table 3. These results indicate the inner wheelpaths are rutted slightly more than the outer wheelpaths. This means the base is subject to weakening as a result of frost action. Typically, the base increases in volume on freezing and thaw causes lateral displacement as traffic recompacts the wheelpaths. Because more base material accumulates between wheelpaths compared to the edge of the pavement the depth of rutting in the outer wheelpaths is less than that of the inner wheelpaths. This base characteristic, while affecting the performance of the pavement, has no affect on its load carrying capacity.

4) Base and subbase gradations are summarized in Figures 6 through 16. These results show that the base material generally does not meet 22A grading requirements but does meet all 20 series requirements. The subbase does meet all Class II grading requirements.

Results of the load study are summarized in Table 4, and the pavement load capacity data are summarized in Table 5. The deflection data indicate that the closer the original pavement is to the surface of the existing pavement, the less the pavement deflects. The load capacity data indicate the pavement is under-designed for the load it carries. A summary of bituminous content and penetration data is presented in Table 6.

Discussion

The causes of early cracking and distress have been identified and are presented in the following discussion:

Bituminous Concrete Layer - The number of transverse cracks present indicates that the bituminous concrete varies with up to moderate

TABLE 3
SUMMARY OF RUT DEPTH MEASUREMENTS

Site No.	Eastbound, in.		Westbound, in.	
	Outer	Inner	Inner	Outer
1	0.050	0.250	0.150	0.150
3	0.175	0.250	0.175	0.175
4	0.150	0.175	0.200	0.125
6	0.125	0.100	0.125	0.125
8	0.075	0.150	0.250	0.125
9	0.275	0.225	0.225	0.450
10	0.250	0.200	0.200	0.225
11	0.150	0.150	0.250	0.100
12	0.175	0.200	0.250	0.125
14	0.100	0.050	0.200	0.150
15	0.200	0.200	0.175	0.175
Averages	0.150	0.177	0.200	0.175

TABLE 4
SUMMARY OF BENKELMAN BEAM DEFLECTION STUDY
(4,500-lb wheel load, 84 psi tire pressure, pavement temperature 63 F)

Site No.	Deflection					Depth to Original Pavement, in.
	Maximum	1-ft	2-ft	3-ft	4-ft	
1	0.0168	0.0112	0.0058	0.0035	0.0025	63 +
2	0.0154	0.0102	0.0050	0.0033	0.0026	--
3	0.0174	0.0123	0.0068	0.0038	0.0026	--
4	0.0172	0.0120	0.0072	0.0043	0.0027	--
5	0.0157	0.0105	0.0051	0.0028	0.0017	53-1/2
6	0.0162	0.0116	0.0063	0.0033	0.0022	--
7	0.0168	0.0112	0.0058	0.0036	0.0026	--
8	0.0148	0.0106	0.0055	0.0040	0.0033	--
9	0.0159	0.0094	0.0053	0.0045	0.0041	--
10	0.0149	0.0092	0.0049	0.0041	0.0037	25-1/4
$\bar{X}$	0.0161	0.0108	0.0058	0.0037	0.0028	--
S	0.0009	0.0010	0.0008	0.0005	0.0007	--

TABLE 5
SUMMARY OF PAVEMENT LOAD CARRYING CAPACITY DATA

Layer	Modulus, psi	Thickness, in.	Critical Strains		Failure Repetitions	Estimated Pavement Life, years[1]
			Tensile	Compressive		
1	300,000	2.4	0.348×10^{-3}	---	500,000[2]	14.5
2	40,300	8.2	---	---	---	--
3	16,000	∞	---	0.670×10^{-3}	300,000[3]	8.7[4]

[1] Estimated annual traffic load assumed to be 34,500 18 kip EAL's.

[2] Assumes the bituminous concrete is not temperature sensitive.

[3] Critical compressive strains are considered to occur on the surface of the subbase since no non-class II material occurs within 5 ft of the pavement surface.

[4] Based on allowable compressive strains for clayey, silty, or loamy subgrades. Actual estimated pavement life, for the good sand subgrade conditions found on US 2, should far exceed 8.7 years.

temperature sensitivity. That is, its tensile strength is too low to resist thermal shrinkage stresses developed in freezing weather, and thermal cracking should increase with time. Because of its moderately low tensile strength it will also be susceptible to early fatigue cracking. The thinning of the bituminous concrete in the outer wheelpath compared to the center of the lane indicates it has only a slight tendency to rut or thin-out near the pavement edge.

TABLE 6
SUMMARY OF BITUMINOUS CONCRETE
PENETRATION AND BITUMEN CONTENT

	Wearing Course		Leveling Course		Combined Course	
	Avg.	Std. Dev.	Avg.	Std. Dev.	Avg.	Std. Dev.
Original penetration	89.6	2.6	89.2	1.9	89.4	---
Recovered penetration						
1. original	49.2	2.9	52.4	5.1	50.5	---
2. present	--	---	--	---	26.3	6.4
Bitumen content						
1. laboratory	6.2	0.2	4.9	0.4	5.7	---
2. field	5.9	0.3	4.8	0.2	5.5	---
3. present	--	---	--	---	5.6	0.7

Base Layer - The principal problem with the base is that most, but not all, of it is subject to frost action. This means that where the base is frost susceptible, freezing causes it to expand, and on thawing, it is unstable until traffic has completed recompaction. This base problem induces alligator cracking, which first occurs along longitudinal and transverse cracks, and the pavement edge where the supply of surface water, needed for volume change, is most abundant. Alligator cracking between the pavement centerline and inner wheelpath is construction related, as noted previously, and should not re-occur in a recycling of the bituminous concrete provided the construction joint area is properly attended to during reconstruction.

Subbase Layer - The subbase layer is adequately drainable and it should have a positive influence on the pavement's long-term performance.

Load Capacity - The pavement is structurally too weak to carry the present commercial traffic load assuming a 20-year design life. According to analysis, failure would occur in two years if the bituminous aggregate were highly crack susceptible and 14 years if it were non-crack susceptible. Since the pavement's crack susceptibility ranges from low to moderate, it is estimated that alligator cracking in the wheelpaths, due to the applied load, should begin when the pavement is about 8 to 10 years old.

Another load capacity problem is that the base has inadequate lateral support during spring thaw periods due, principally, to infiltration of surface water at the pavement/shoulder joint. This results in alligator cracking of the pavement edge and, in more severe cases, short pothole-like depressions are formed.

Recommendations

On the basis of the causes of early cracking and other distress forms found, the following recommendations are offered.

1) Overlaying the existing pavement is not recommended since the temperature sensitive nature of existing bituminous concrete and the seasonally unstable base should prematurely reflect the existing pavement condition. The time needed for reflective cracking to occur would be a function of both the thickness and temperature sensitivity of the overlay. Because of stress concentrations at existing cracks, overlaying will result in earlier cracking than would occur with new or recycled bituminous concrete of the same thickness.

2) It is recommended that the existing bituminous concrete be recycled so that its temperature sensitivity can be corrected by blending with softer bitumen. This should require increasing recovered penetrations to approximately 100. Advantages of recycling are that less virgin materials are needed which, by reduced demand, helps hold their cost down and conserves bitumen for future use.

3) It is recommended that the thickness of the bituminous concrete layer be increased to 5 in. in order to have a design life of 20 or more years. The same design life should be possible with 4 in. of bituminous concrete and full-depth shoulders.

4) It will be beneficial to reduce the base thickness, by as much as 4 to 6 in., in order to reduce the degree of frost heave the reconstructed pavement is subjected to. Therefore, the existing base could be reduced in thickness to supply aggregate for other purposes and yet leave an adequate construction platform.

5) The in-place base material meets 20 series grading requirements. Therefore, in any scheme to recycle the existing bituminous concrete, the base could be used as the source of aggregate for virgin bituminous material.

6) Any rehabilitation scheme should consider full-depth shoulders to improve base confinement and to prevent surface water infiltration at the pavement/shoulder interface. In this respect, specifications should require there be no construction joints between the outside edge of shoulder and the pavement centerline. Other advantages of full-depth shoulders are that they reduce shoulder maintenance costs and facilitate future life cycle renewal.

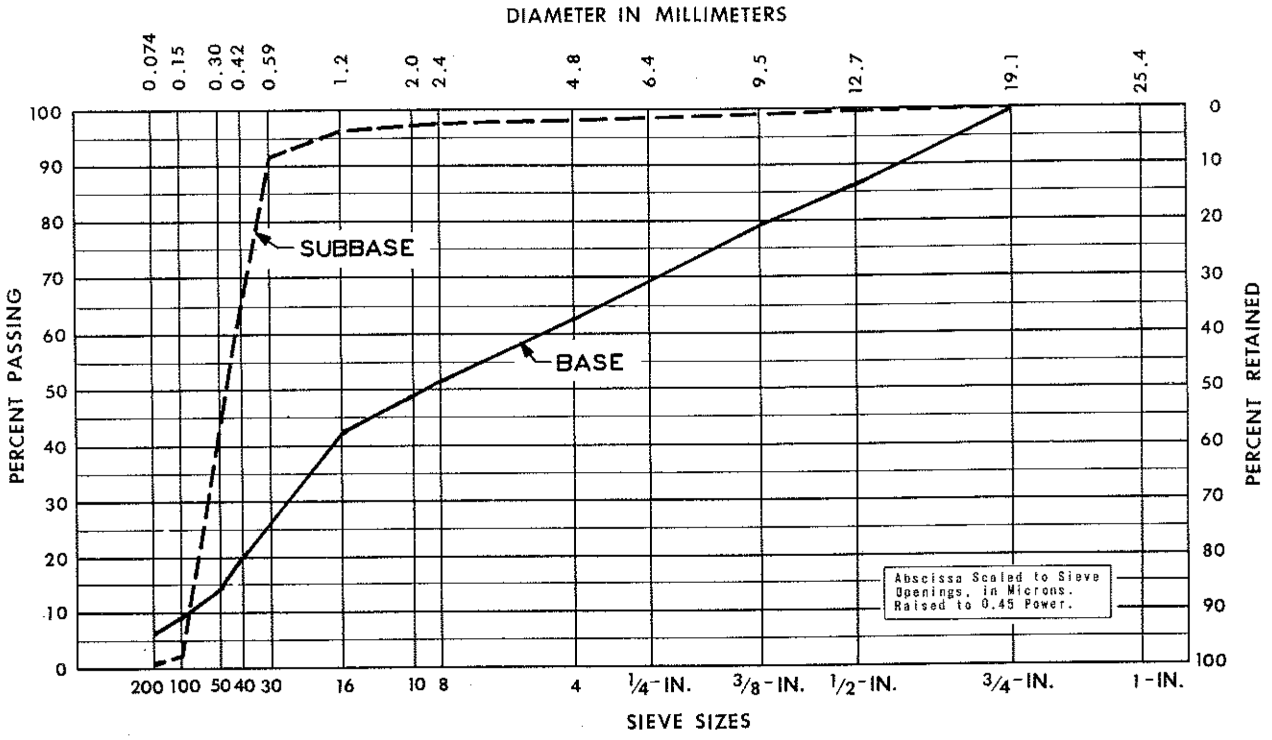

Figure 6. Base and subbase gradation at Site 1, Station 476+00.

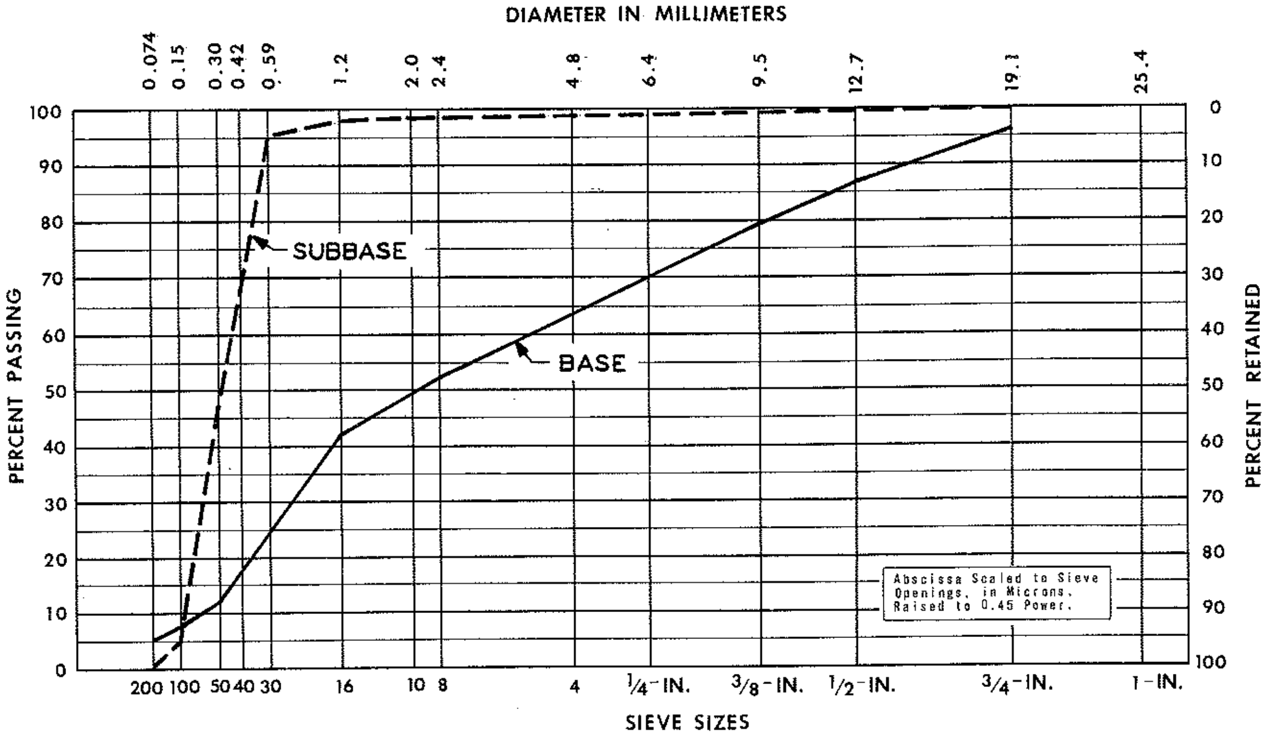

Figure 7. Base and subbase gradation at Site 3, Station 517+00.

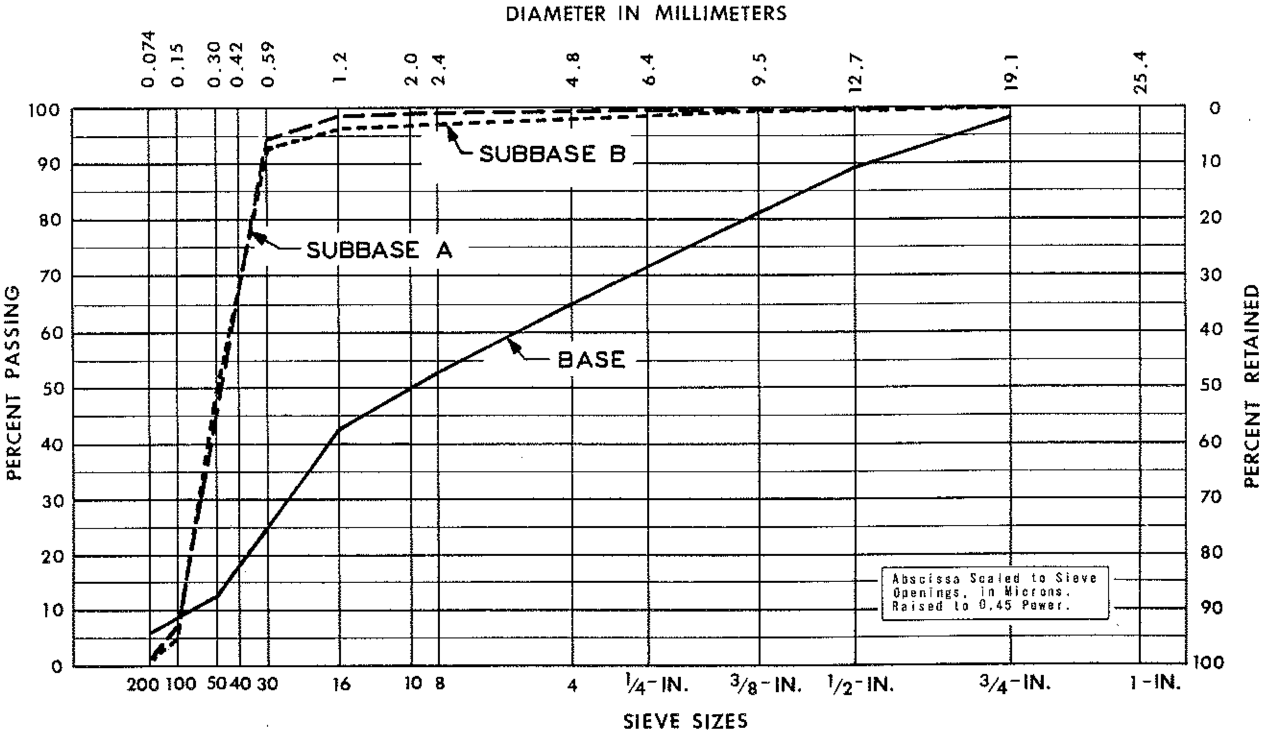

Figure 8. Base and subbase gradation at Site 4, Station 537+00.

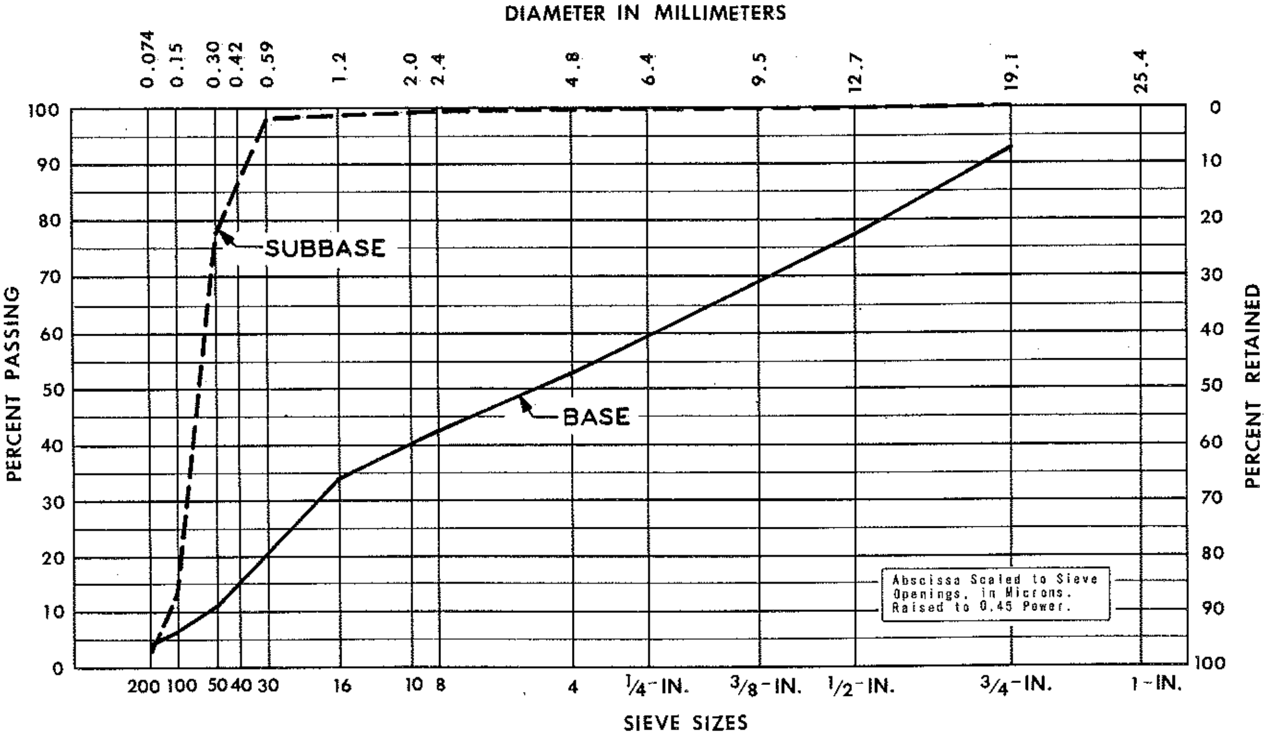

Figure 9. Base and subbase gradation at Site 6, Station 568+00.

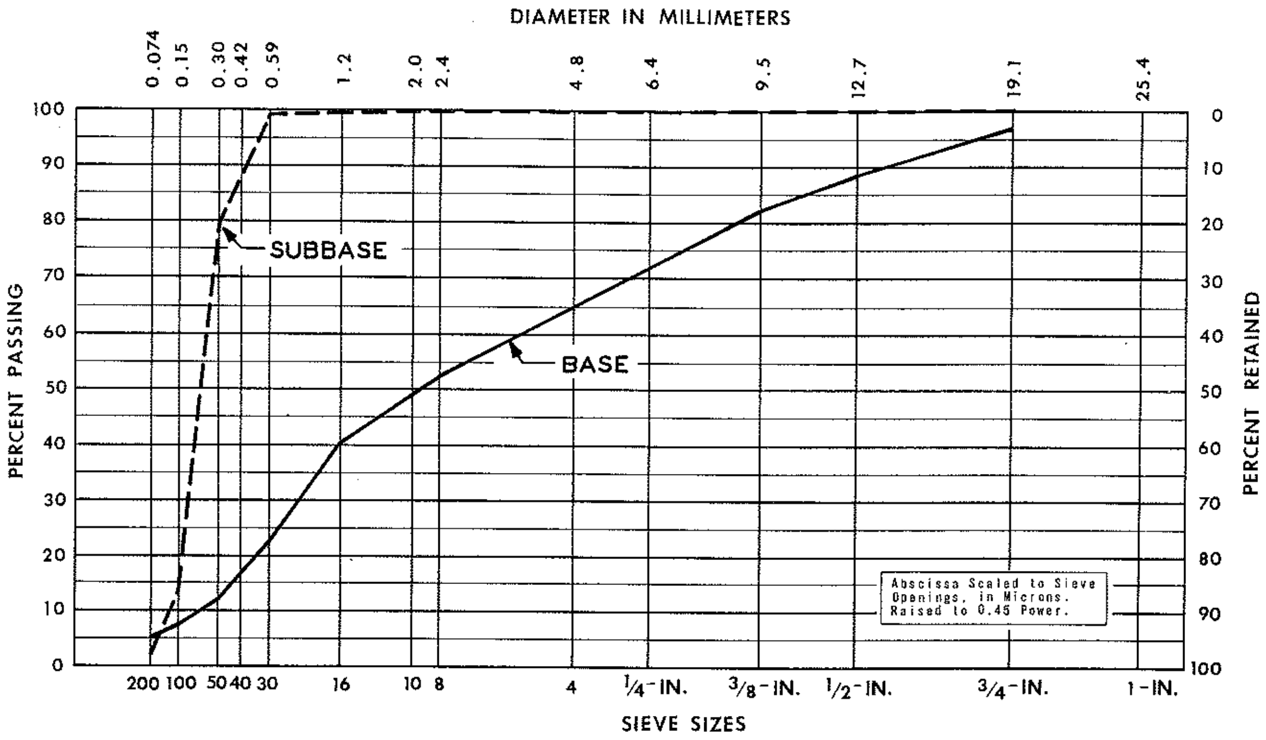

Figure 10. Base and subbase gradation at Site 8, Station 598+00.

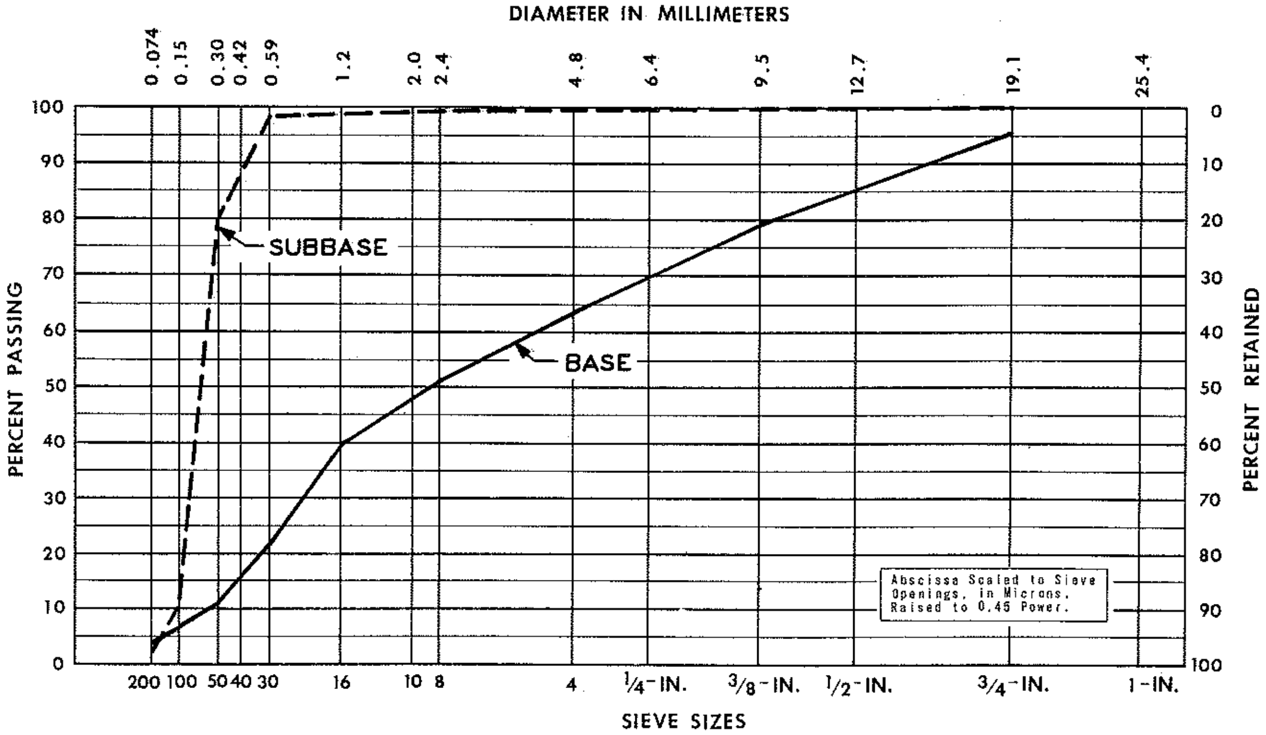

Figure 11. Base and subbase gradation at Site 9, Station 615+00.

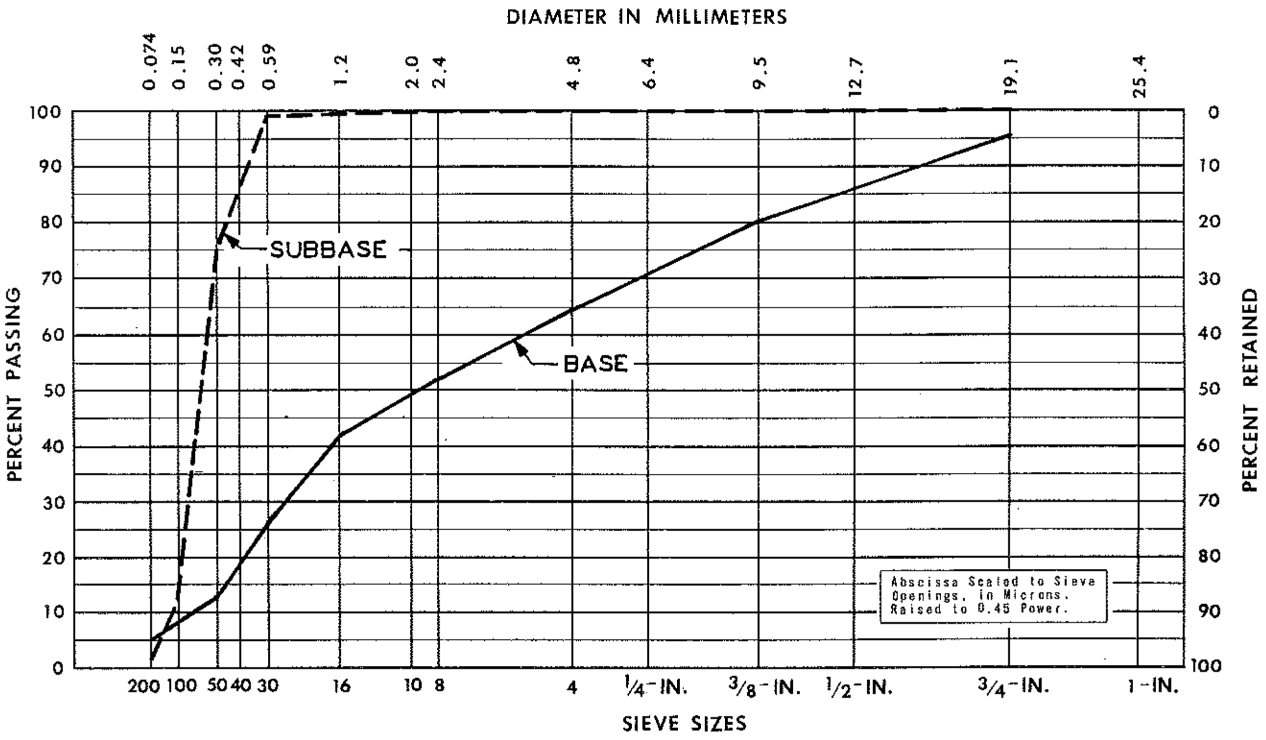

Figure 12. Base and subbase gradation at Site 10, Station 637+00.

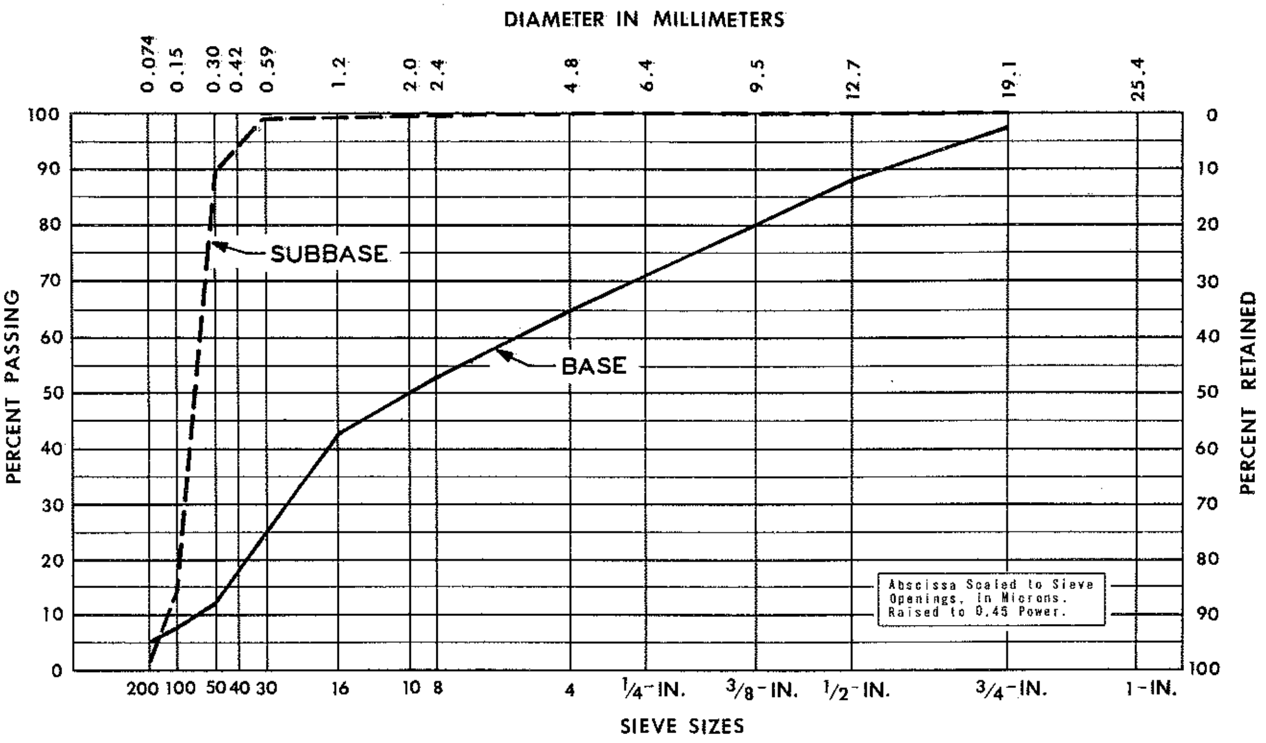

Figure 13. Base and subbase gradation at Site 11, Station 667+00.

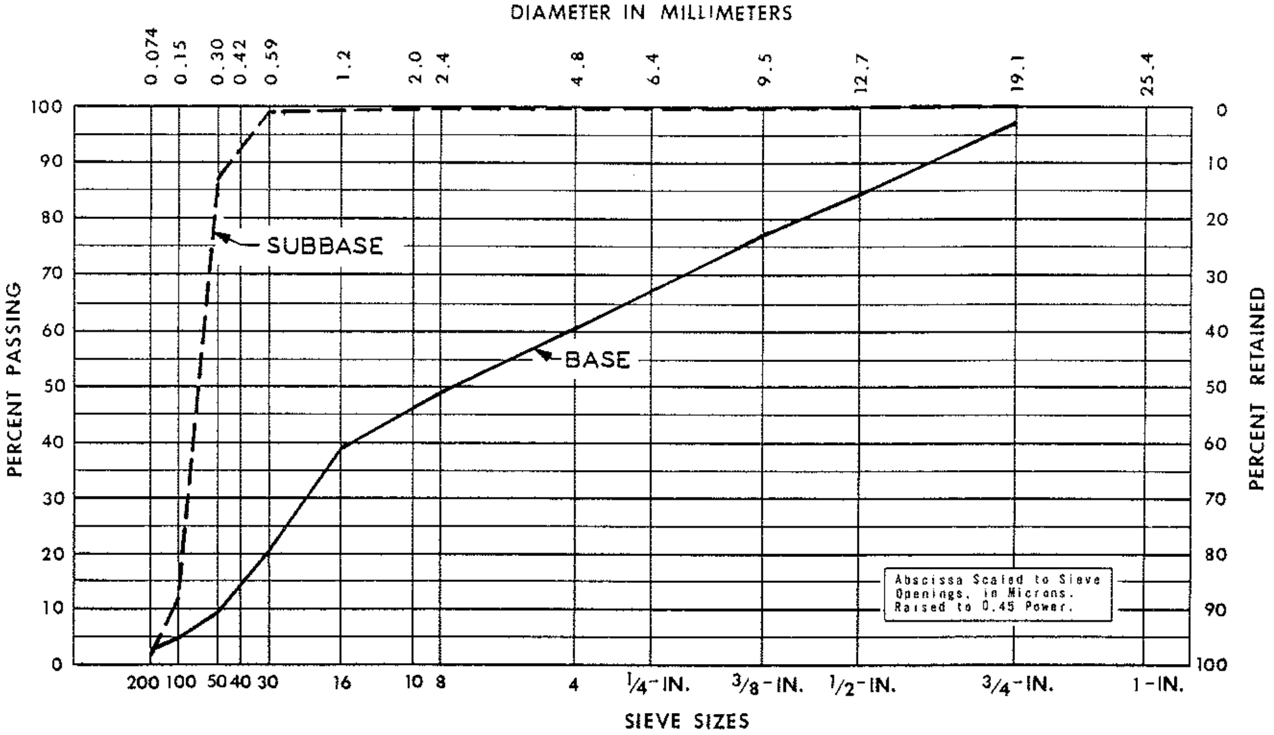

Figure 14. Base and subbase gradation at Site 12, Station 696+00.

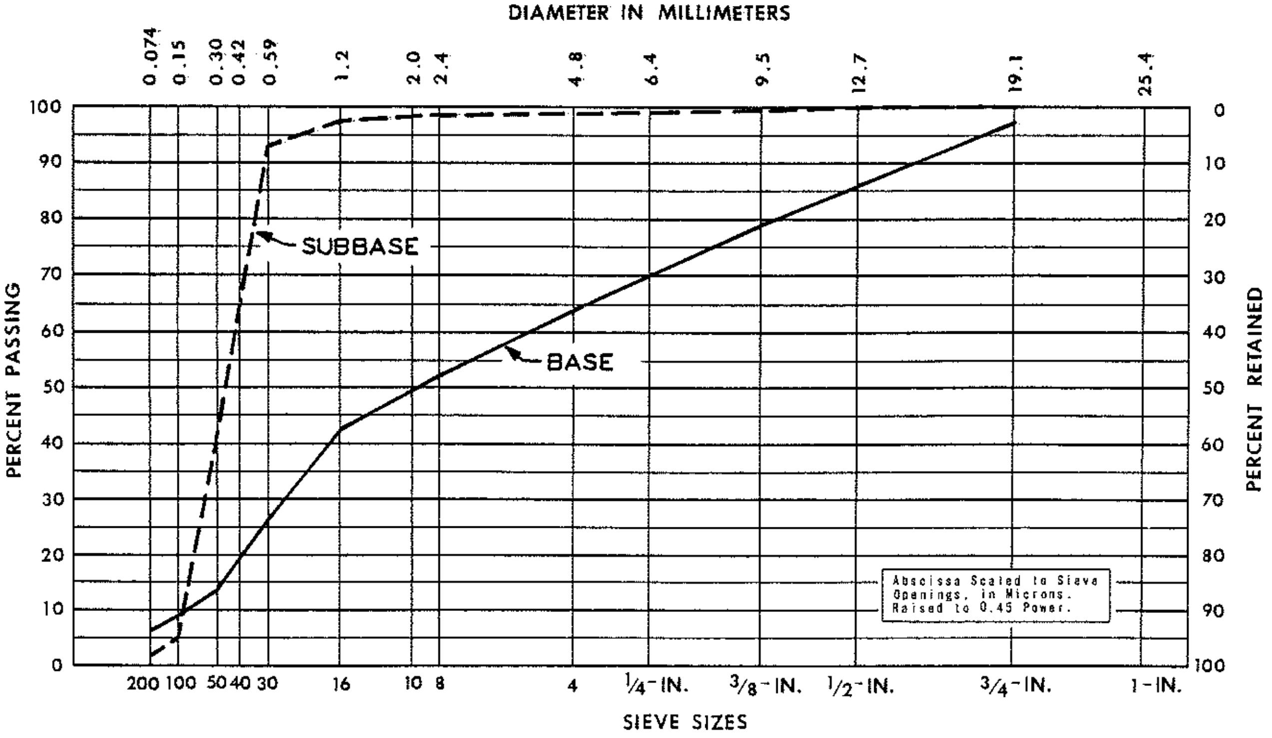

Figure 15. Base and subbase gradation at Site 14, Station 788+00.

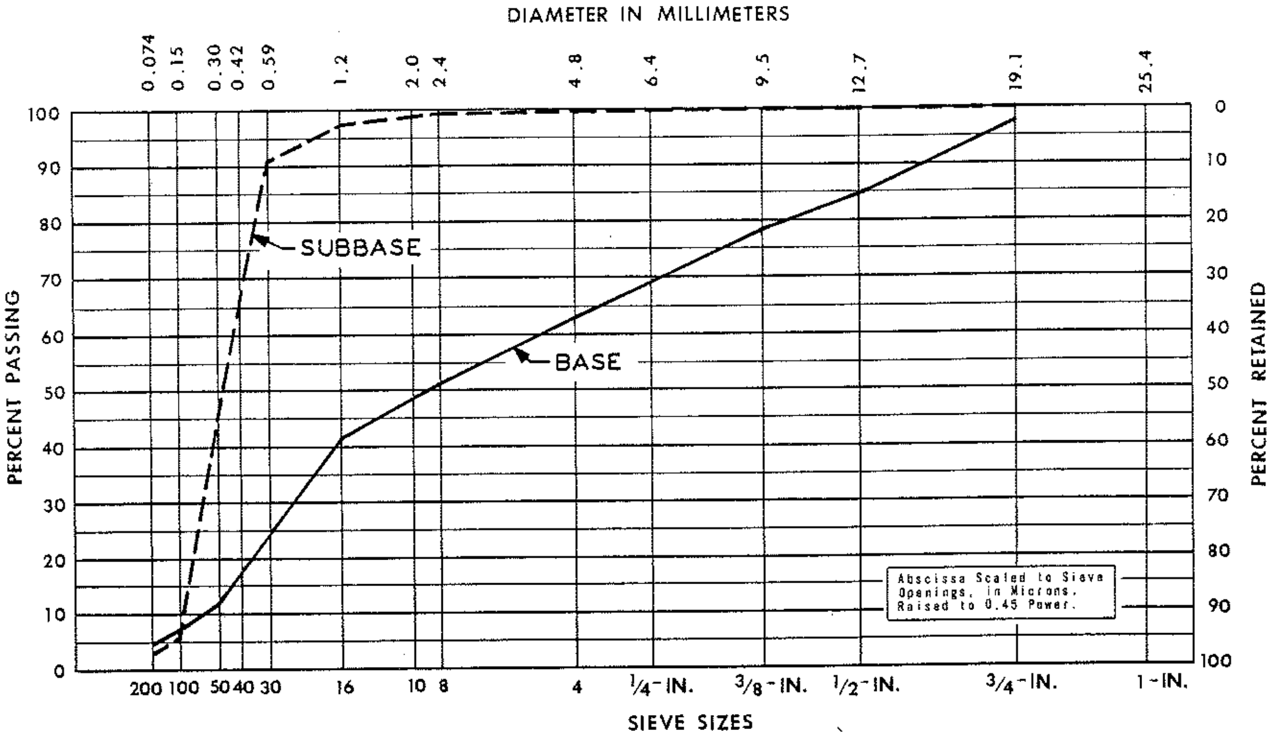

Figure 16. Base and subbase gradation at Site 15, Station 827+00.

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3. Kruse, C. G. and Skok, E. L., Jr., "Flexible Pavement Evaluation with the Benkelman Beam," State of Minnesota Department of Transportation, Investigation No. 603, 1968.