1158

THE RELATIONSHIP OF AGGREGATE DURABILITY TO CONCRETE PAVEMENT PERFORMANCE, AND THE ASSOCIATED EFFECTS OF BASE DRAINABILITY

MICHIGAN DEPARTMENT OF TRANSPORTATION

TESTING AND RESEARCH DIVISION
RESEARCH LABORATORY SECTION

THE RELATIONSHIP OF AGGREGATE DURABILITY TO CONCRETE PAVEMENT PERFORMANCE, AND THE ASSOCIATED EFFECTS OF BASE DRAINABILITY

C. J. Arnold

Research Laboratory Section
Testing and Research Division
Research Project 73 F-136
Research Report No. R-1158

Lansing, January 1981

The six sections of the experimental pavement on US 10 near Clare, placed without load transfer on bituminous stabilized bases, provide some interesting insights regarding the effects of base drainability on the performance of pavement. Three 1/2-mile sections each, of two opposite types of base were built. One type of base is dense and impervious (bituminous base with 2 percent excess 200 to 250 penetration asphalt, designed to prevent cracking beneath pavement joints). The other is open graded and 'super draining' (Asphalt Treated Porous Material, ATPM; or more recently, Open Graded Drainage Course, OGDC), with permeability in excess of 1,000 ft/day. (See Appendix for details of these sections as well as the other types of pavement that were placed on gravel base.) The concrete mix for all of the experimental sections is nominally the same, with coarse aggregates (6A) from 'Source A' (three different sources are referenced in this report).

This experimental project has subbase drains placed near the pavement-shoulder joint. One of the earliest findings of the project was the unusually large amount of water that penetrated the shoulder-pavement joint, even when the installation was new. The sections with ATPM base are the only sections that have open graded backfill over the subbase drains and the volumes of water reaching these drains after a rainstorm are considerable.

For the impervious bituminous base sections, there is nowhere for the water to go after it penetrates a joint, so the pavement sits in a 'bathtub' environment. Figure 1 shows the way in which water rises from the shoulder. The shoulder-pavement joints have deteriorated more in the non-draining base sections than in the others. Figure 2 shows the upward bubbling of water at the intersection of the transverse and shoulder-pavement joints, due to the coring operation farther out in the lane, demonstrating that the joints act as passageways for water to travel. Although the water in this case is coming from the 'bathtub' below, it is obvious that it could go in the other direction as well, if the 'bathtub' beneath were not full. (In contrast, the core cutting water all drained away on the ATPM base sections, and pails of water poured into the open core holes vanished quickly as well.) It is also obvious from the cores, that water has penetrated considerable distances between the slab and the base. Where faulting has developed, there are voids for passageways as well.

About 3-1/2 years after construction, measurements started to show some isolated indications of joint faulting in the non-draining bituminous base sections. Within the next six months, faulting increased to 3/16 to 1/4 in. on the one eastbound section where the superelevated pavement caused water to pond under the traffic lane, where most of the heavy trucks travel. The westbound section was more flat, or slightly superelevated in

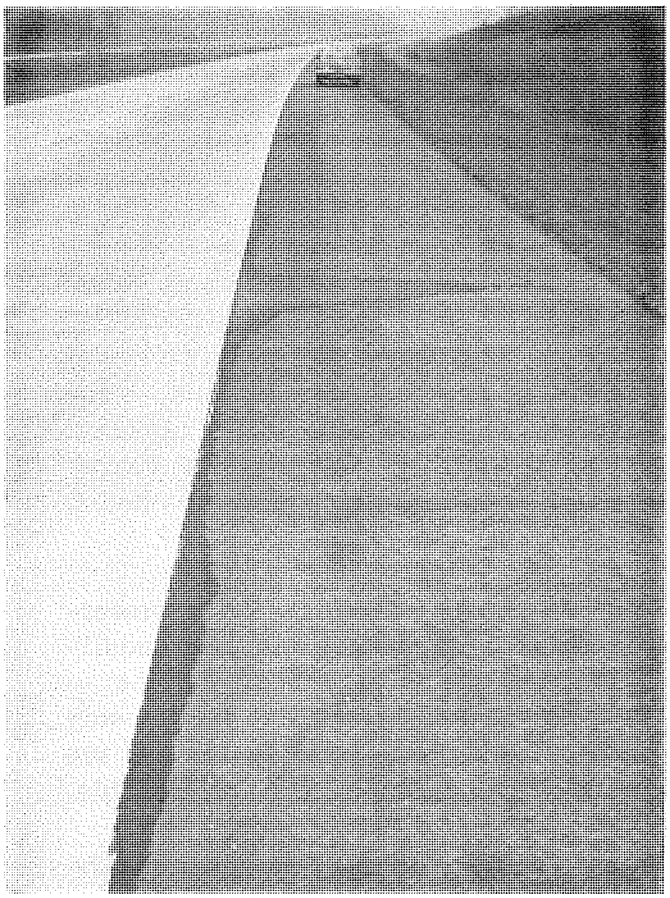


Figure 1. Eastbound superelevated bituminous base section. After rainstorm, water rises through shoulder-pavement joint and drains across surface of shoulder.

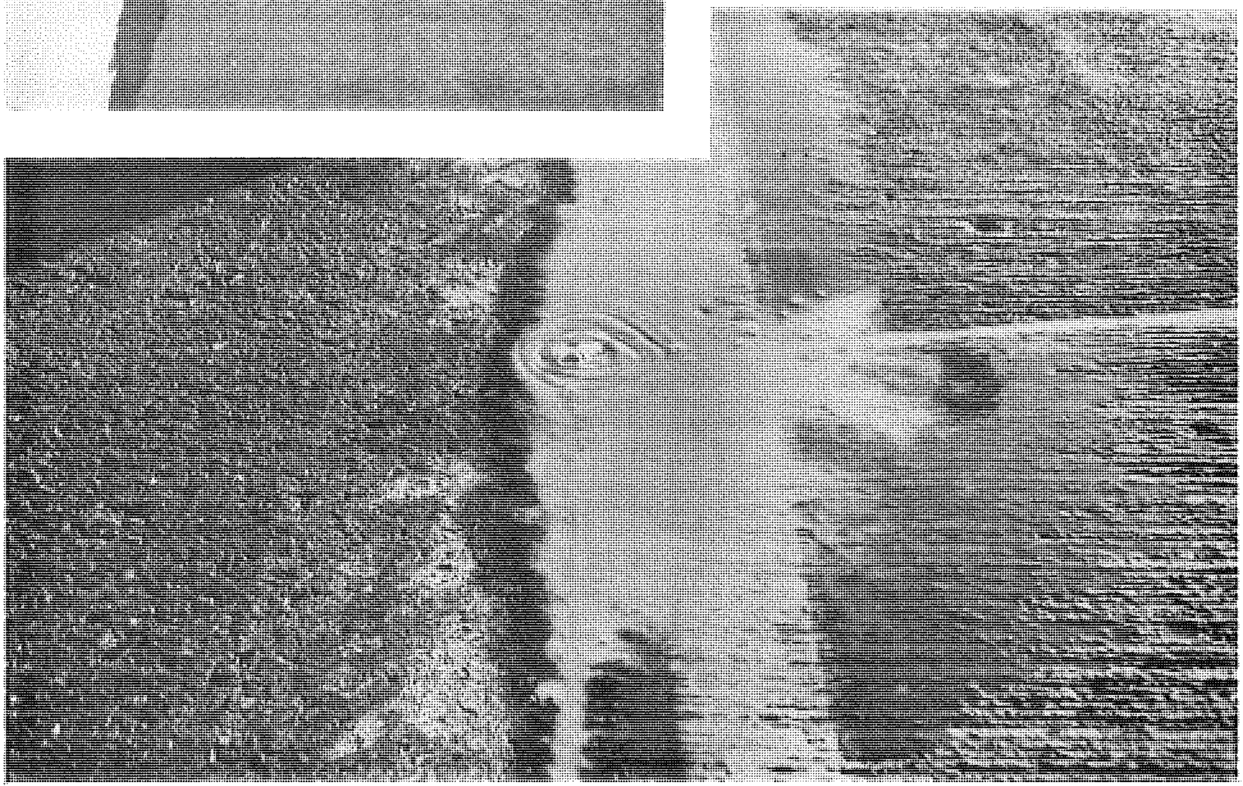


Figure 2. Water from the coring operation bubbling up at intersection of the transverse pavement joint and the longitudinal shoulder-pavement joint, on a non-draining bituminous base section. The core was being cut to the right, out of the picture. This demonstrates the ready pathway for water to penetrate around the edges of the slabs. It also demonstrates that in this particular case of impervious base, water cannot drain away. Conversely, on ATPM base, all core-cutting water disappeared, and pails of water dumped in the core hole quickly vanished.

the opposite direction, keeping the traffic lane drier. All three sections with ATPM base and the six gravel-based sections continued to perform well. Figure 3 shows portions of Rapid Travel Profilometer traces from the faulted bituminous base section and a section with ATPM base. This early information clearly demonstrates the deleterious effects of water in the pavement system.

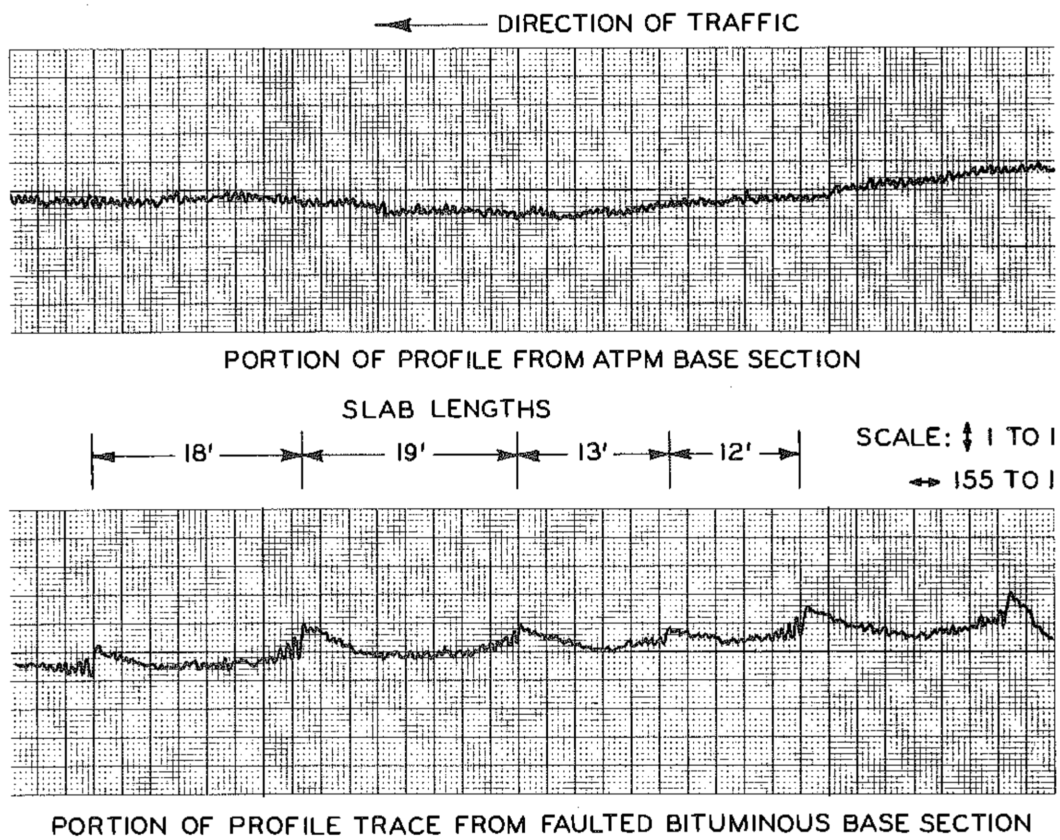
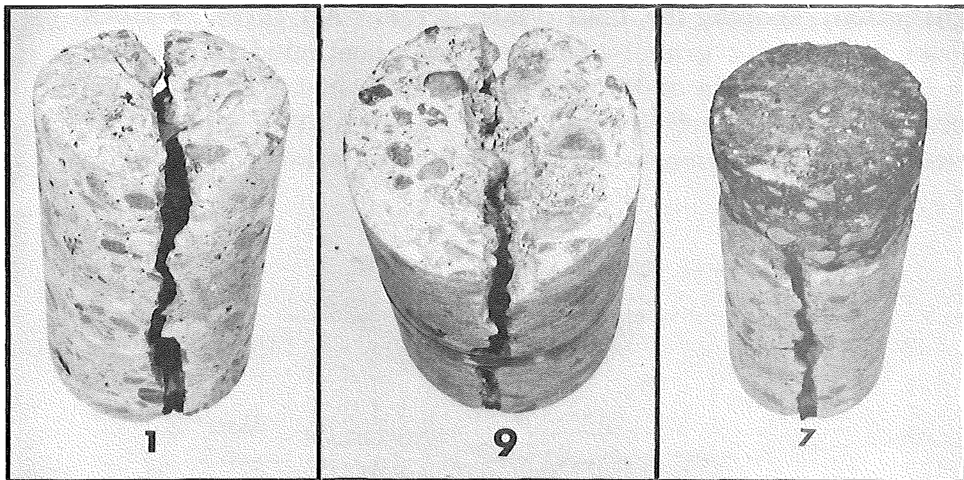


Figure 3. Comparison of profiles: Rapid travel profilometer traces from Clare test road.

Faulting has now increased to as much as 3/4 in. at some locations. Cores were cut through the pavements and bases to determine the source and location of the material being pumped which caused the faults. Figure 4, Core No. 1, (shown upside down) was cut from an unfaulted joint in the bituminous base section on the westbound roadway. It was immediately obvious that serious deterioration is occurring on the joint faces and the bottom of the slab. The bituminous base was not cracked. Figure 4 also shows the faulted transverse joint, the ravelled shoulder-pavement joint, and the core (labeled No. 7) taken from the eastbound section where superelevation causes more ponding of water under the truck lane. Figure 4, Core No. 9 is from a nearby joint in the same section, showing even more



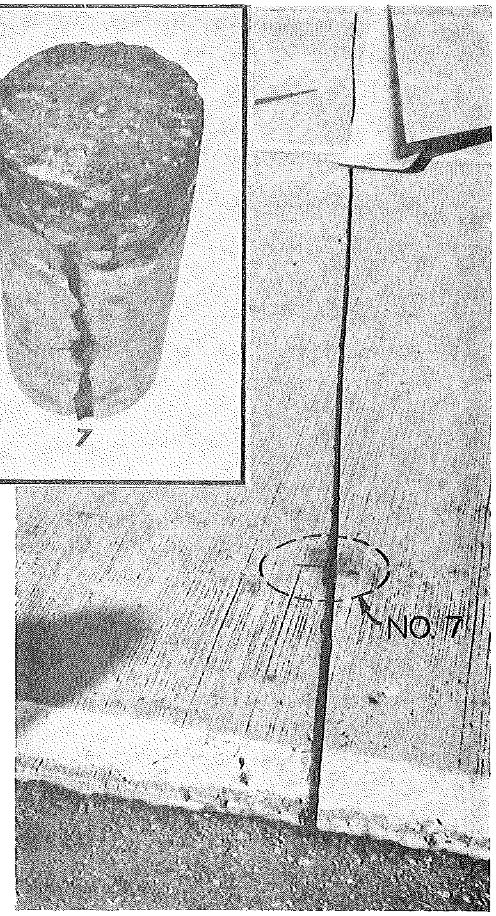


Figure 4. Cores taken from the non-draining bituminous base sections of the Clare Test Rd. The pavement was four years old when sampled. Core No. 1 is from an unfaulted westbound section, the other two are from the faulted eastbound section. All show the same heavy surface deterioration, evidently due to freeze-thaw action while standing in water. The faulted joint shown is the one from which Core No. 7 was taken. Note also the open shoulder-pavement joint.

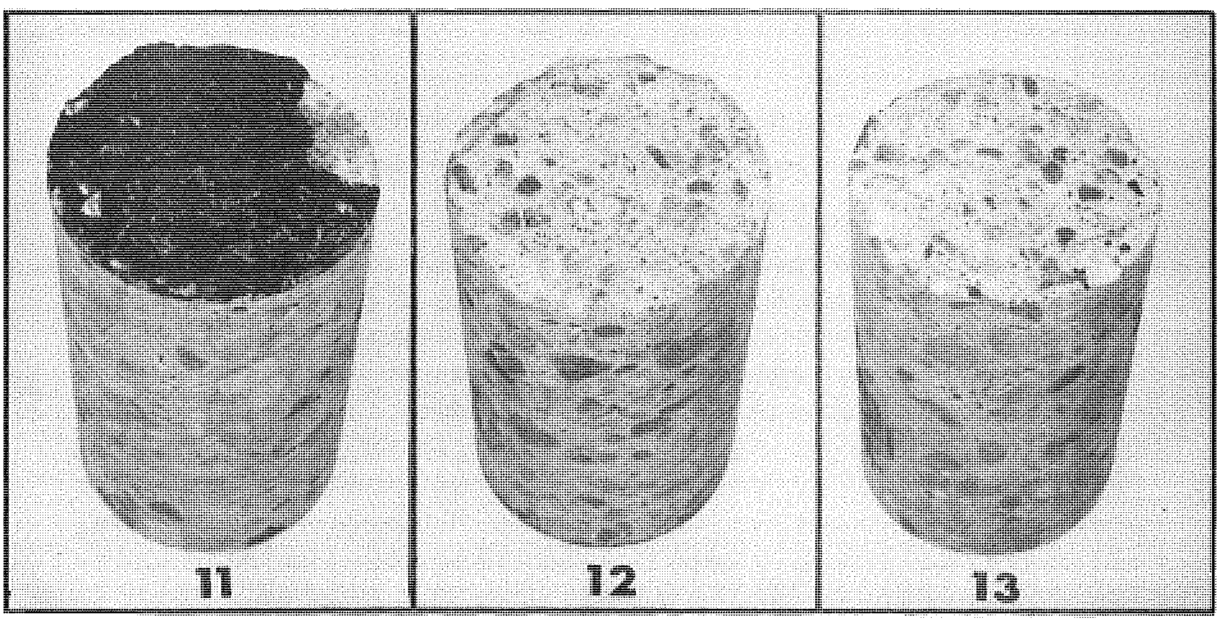


Figure 5. Cores cut from the faulted section to determine condition of the bottom of the slab at locations away from joints. Core No. 11 was cut 9-ft from transverse joint, Core No. 12 at 5-ft, and Core No. 13 at 1-ft.

severe deterioration of the bottom and joint face surfaces. Again, the bituminous base was intact. Here we have the reason for faulting; concrete debris from the deteriorated faces and bottom of the slab, being pumped by truck traffic, because of the captive water between the pavement and base. Figure 5 shows cores removed 1, 5, and 9-ft away from the transverse joint, showing the slab to be bonded to the base only at the 9-ft distance. Figure 6 shows typical pavement surface, concrete and base cores from the ATPM base sections. These sections do not show the concrete deterioration or faulting that was so evident on the non-draining bituminous base.

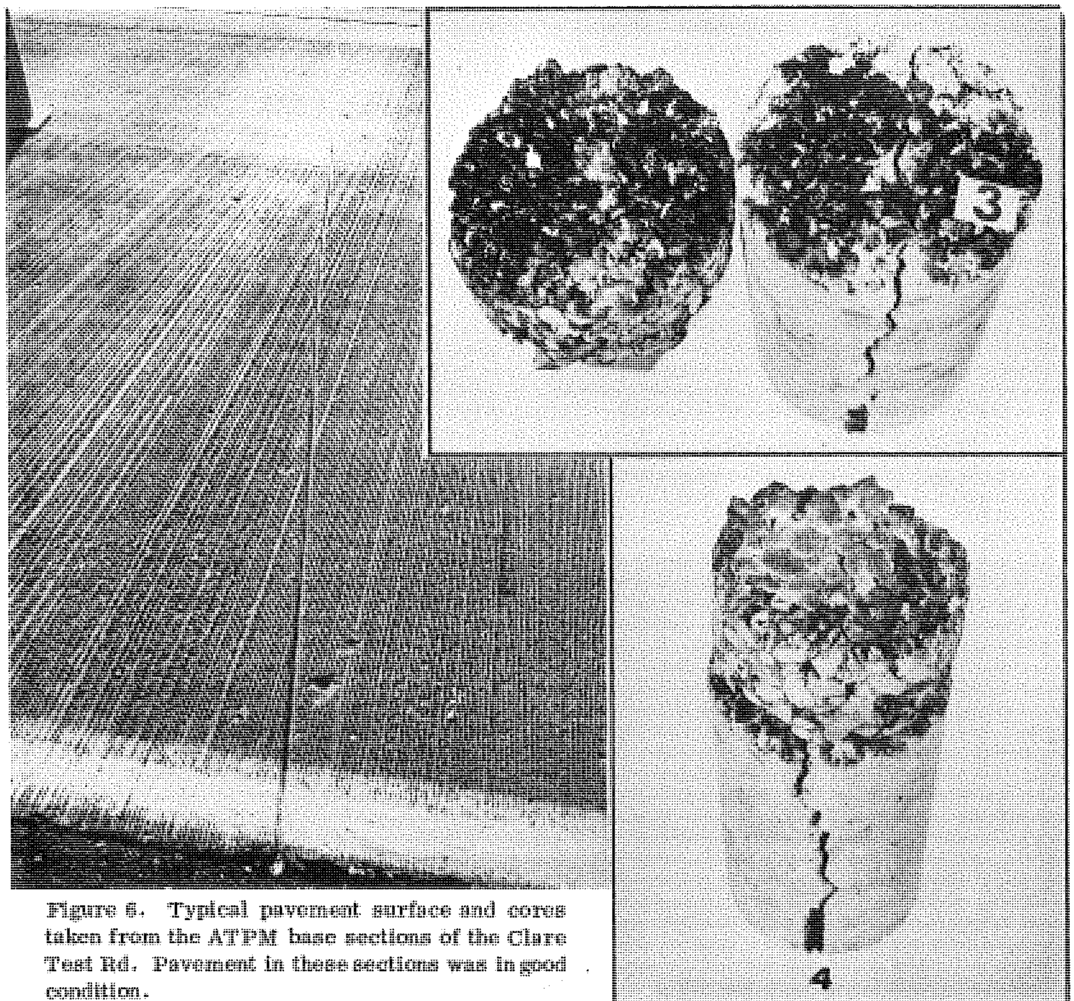


Figure 6. Typical pavement surface and cores taken from the ATPM base sections of the Clare Test Rd. Pavement in these sections was in good condition.

The concrete loss from the cores appears to be typical of heavy scaling, such as often occurs with non-air-entrained concretes. Project records show air checks near this location to be within specified limits, but toward the lower side of tolerance. Preliminary testing of the cores removed from the job indicate an air content below that required to prevent

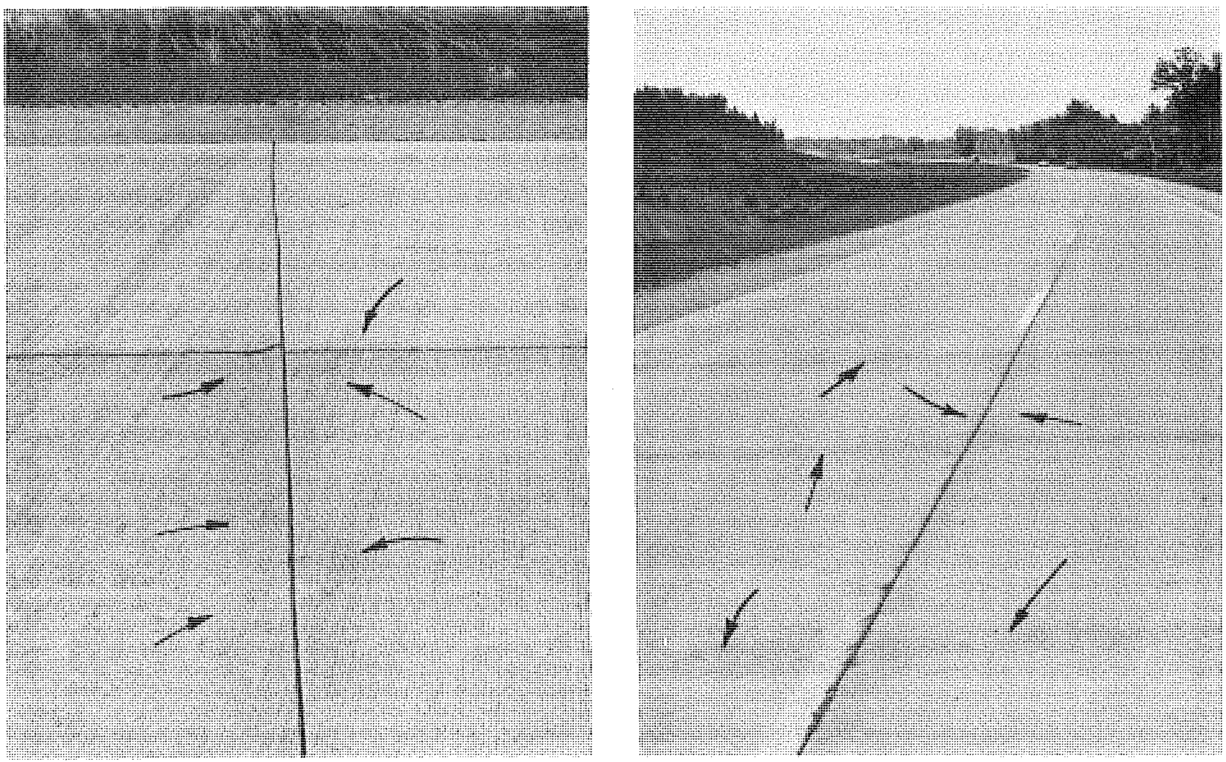


Figure 7. Staining, early stage of D-cracking, showing up on surface of US 10 black base sections at about five years of age All coarse (6A) aggregates from Source A.

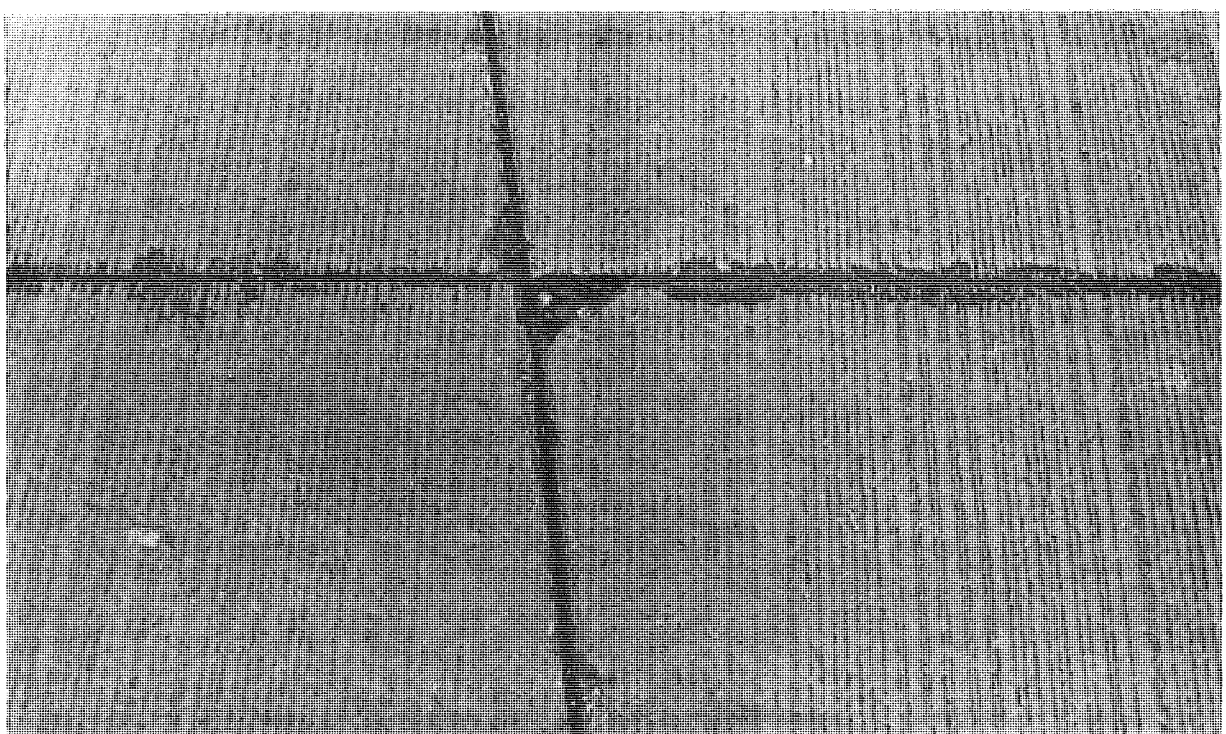


Figure 8. Corner fractures; the beginning of the second stage of deterioration, on the non-draining sections.

scaling. However, whatever the basic problem with the mix, it is obvious at this point that this problem is seriously aggravated by the continuing presence of water under the pavement. Close inspection of the pavement surface at four years of age, showed early stages of discoloration and very fine cracking near joints in the non-draining base sections; factors that are typical signs of deterioration commonly referred to as D-cracking. More recent inspections show the staining to be more obvious in the impervious bituminous base sections (Fig. 7), and just beginning in some other sections, including those on ATPM base. Figure 8 shows the type of corner fractures that are starting to occur in the non-draining sections. This is the beginning of the second stage of deterioration, and is progressive. This stage has not yet become evident on the sections with other types of base. The severe surface attack on the joint faces and bottoms of the slabs in the non-draining sections appear to be related to the mortar fraction of the mix rather than to the coarse aggregate. Therefore, it appears that the retention of water, including deicing salts, combined with Michigan's relatively harsh climate, have caused the early onset of two separate types of concrete deterioration in the sections built on non-draining bituminous base. Another look at the pavement surfaces shown in Figures 4 and 6 show the pop-out characteristics normally associated with porous stone contained in the coarse aggregates. This top surface defect appears throughout the project, giving an indication of the presence of non-durable aggregate particles in the mix as well. However, recent work completed by the Portland Cement Association indicates that materials normally classified as soft or non-durable (many of which can be removed by heavy media separation) are not the only ones that cause problems (1, 2, 3, 4). Many heavier types of rock can and do lead to D-cracking. Their results seem to indicate that, at the present time, the only known evaluation that dependably identifies and separates aggregates that D-crack in service and those that do not, is the measured expansion of specimens subjected to severe freezing and thawing.

Investigation and evaluation of the experimental pavements near Clare will continue for several more years. Recommendations have been made and approved by the Department to add edge drains and shoulder-pavement joint seals to the non-draining base sections. However, it is obvious at this time that the longevity of those sections will be less than the more drainable sections of the project.

Some rather interesting and relevant information concerning the performance of aggregates from the same source as those used on the Clare project, but covering a longer period of service, is available from another job in the vicinity. It also provides a contrast, showing the marked improvements that can be obtained by selection of better aggregates, as well

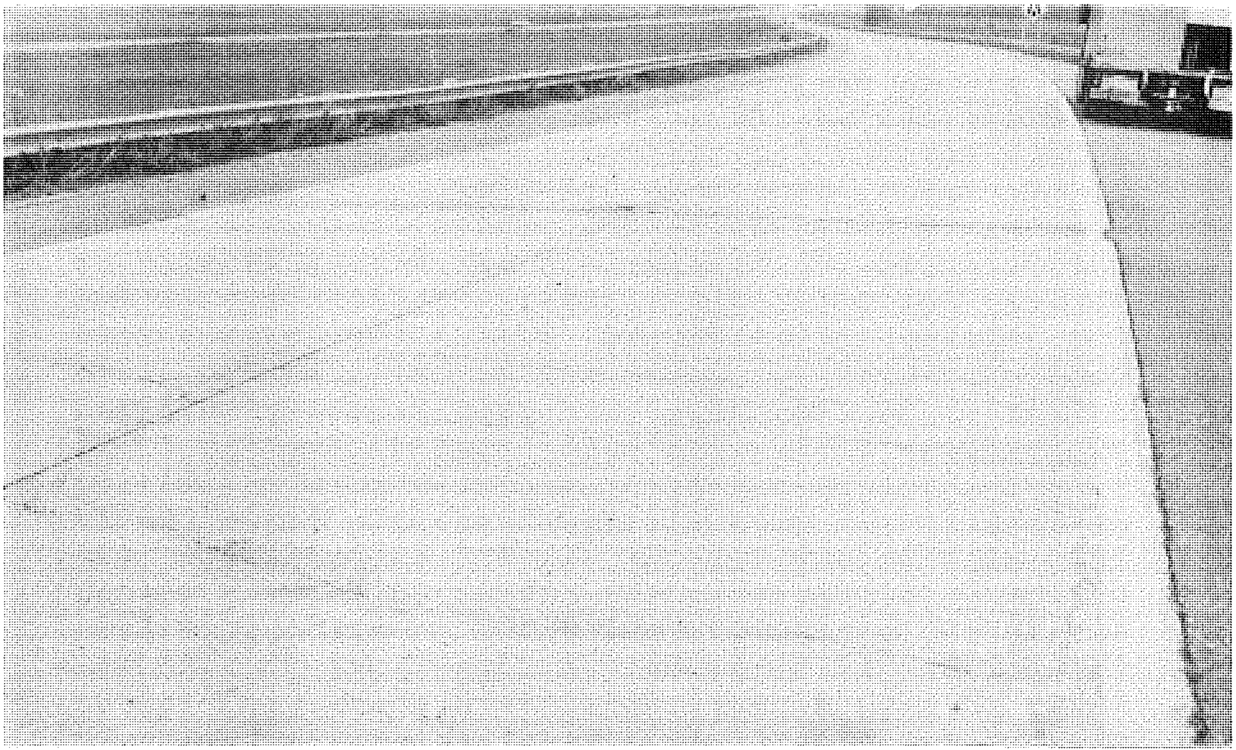
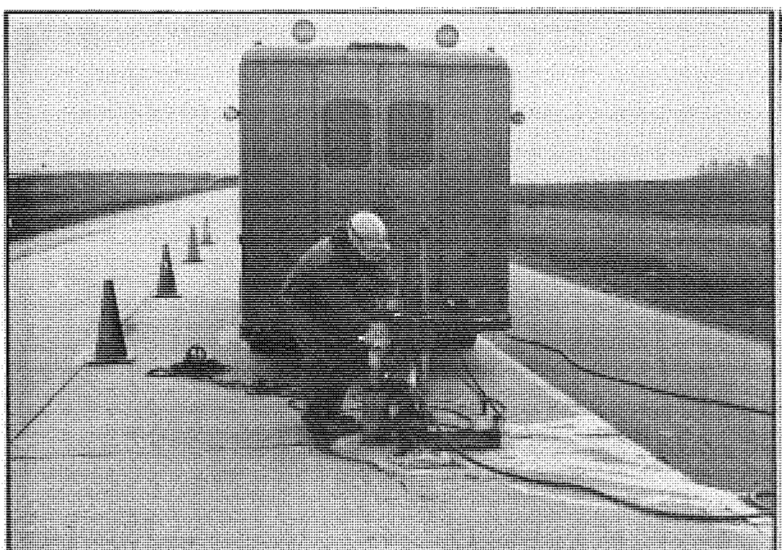


Figure 9. General view of the northbound US 27BR ramp near Mt. Pleasant. Note staining of surfaces near joints and cracks. Pavement was built in 1961, and was 18-1/2 years old when photographed. It has 99-ft slab length; base plates, and poured sealants (4A aggregate from Source C, substituted for high-grade from Source B: 10A from Source A). The nearby ramp shown in the background, contained a premium quality coarse aggregate, and shows no D-cracking at the surface



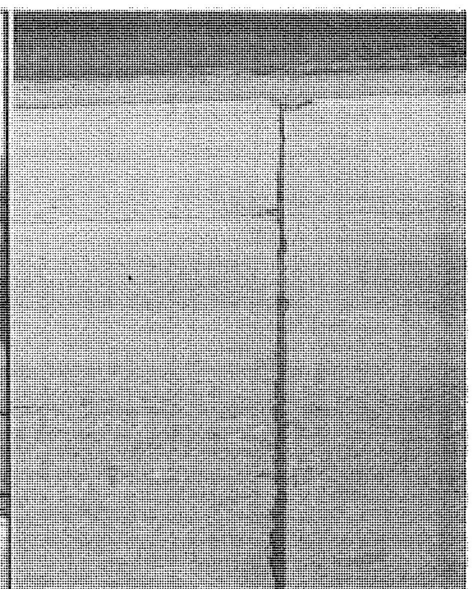


Figure 10. The southbound ramp, constructed one-half year before the northbound, using a blend with higher quality 4A aggregate from Source B, with 10A aggregate from Source A. This pavement shows no D-cracking at the surface (photographed after 19-1/2 years of service).

as the pitfall that lies waiting if the aggregates substituted are not adequately evaluated. The site is on the north and southbound US 27BR ramps at the junction with US 27 south of Mt. Pleasant.

Figure 9 shows a general view of the northbound ramp with the dark staining around cracks and joints, and the typical D-cracking that follows the staining. The pavement was 18-1/2 years old when photographed. Figure 10 shows the adjacent southbound ramp, built with premium quality aggregates in the coarsest (4A) fraction. Finer aggregates were all from the same source. No staining or D-cracking are evident on this pavement after 19-1/2 years of service.

Cores were removed from the northbound ramp in the summer of 1979. Locations of various cores taken are shown in Figure 11. Core No. 11 was taken through the transverse joint, Core Nos. 10 and 12 on the longitudinal joint roughly 1-1/2 and 3 ft from the transverse joint, respectively. Cores 13 and 14 were from the unstained area 4 ft from the transverse joint, and Core 15 was taken from the junction of the stained and unstained areas adjacent to the centerline joint, about 6 ft from the transverse joint. The cores themselves are shown (upside down) in Figure 12. Core 11 from the transverse joint is riddled with cracks and the bottom part of the joint mostly turned to rubble. Core Nos. 10 and 12 from the longitudinal joint have fractures around a badly rusted longitudinal reinforcing wire, and the typical fine D-cracks at the top and bottom, but are basically sound. Core Nos. 13 and 14 from the heart of the slab are sound top to bottom, much as they were when cast. Core No. 15 shows only extremely fine cracking in the dark stained area, and is otherwise sound, indicating the first stages of the progressive deterioration.

The adjacent southbound ramp was paved in the fall of 1960, and is in excellent condition for a 20-year old pavement. Cores from this pavement are shown in Figure 13. The differences between the southbound and northbound ramps are striking, and the appearance tells an obvious tale of differences in materials. The story, derived from project records, follows.

Gravel from Source A was known to have some problems with durability, so blending was proposed to beneficiate those materials for the job. The final situation that developed was that coarse aggregates designated as 4A and 10A (see Table 1 for gradation) were to be mixed 1 to 1 by weight, as then was the custom. The 10A coarse aggregates and the fine aggregates for the entire job were to be from the previously mentioned Source A, the same source as the later Clare job. The 4A aggregates for the job

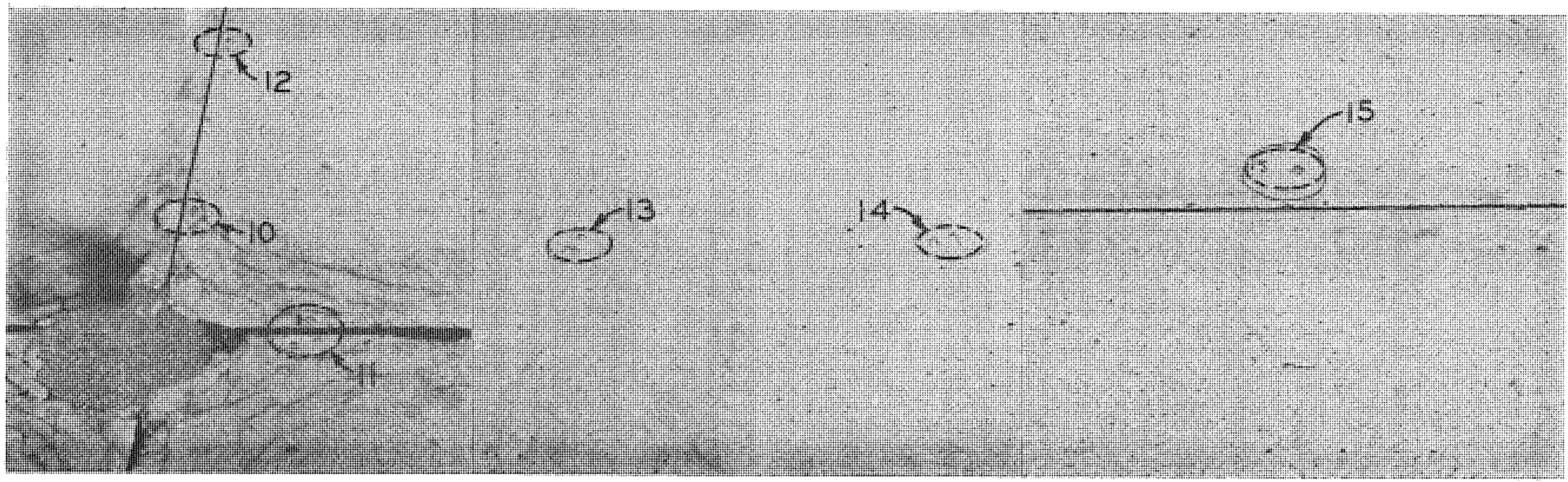


Figure 11. Location of cores removed from the northbound US 27 BR ramp south of Mt. Pleasant.

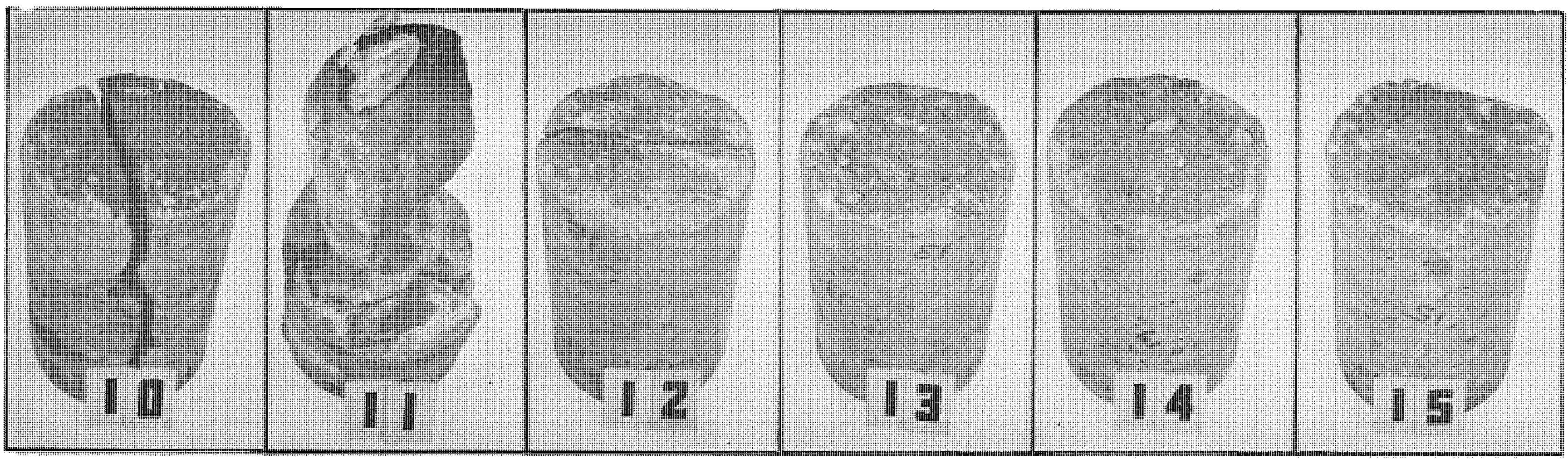


Figure 12. Cores shown here upside down, that were removed from the northbound US 27 BR ramp pavement at the locations indicated in Figure 10. The pavement was built and opened to traffic in the spring of 1961, with 99-ft slab length, poured joint sealants, and base plates under the joints. Pavement age was 18-1/2 years when cored.

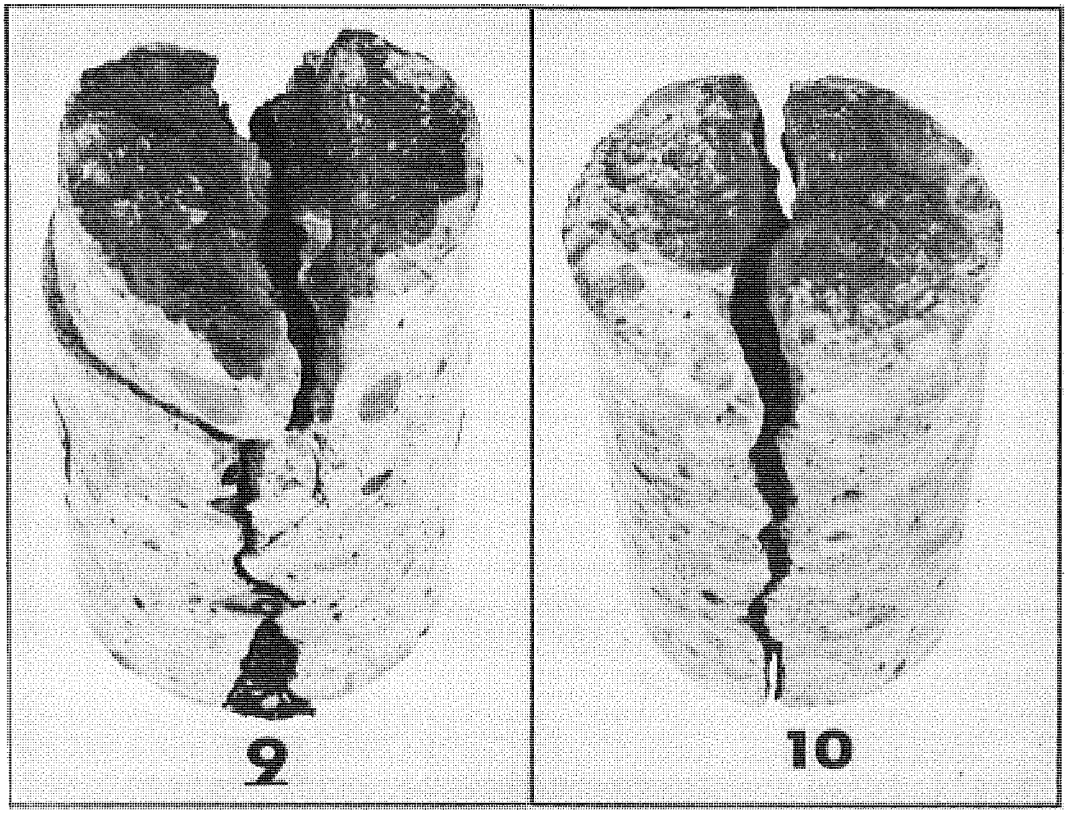


Figure 13. Cores, shown upside down, taken from the southbound ramp shown in Figure 10. Core No. 9, from the transverse joint shows some deterioration at the bottom, that is fairly typical for 'base plate' pavements of this age. Core No. 10 is from the longitudinal joint. The pavement was built and opened to traffic in the fall of 1960 with 99-ft slabs, poured joint sealants, and base plates under the joints. Pavement age was 19-1/2 years when cored.

TABLE 1
GRADING REQUIREMENTS FOR COARSE AGGREGATES

Specification Year	Location	No. and Class	Total Percent Passing Sieves of the Sizes Indicated						
			2-1/2 in.	2 in.	1-1/2 in.	1 in.	1/2 in.	3/8 in.	No. 4
1960	Mt. Pleasant	4A	100	95-100	65-90	10-40	0-20	0-5	
1960	Mt. Pleasant	10A			100	95-100	35-65		0-8
Present	Clare	6A			100	95-100	30-60		0-8

were obtained, for the most part, from a high grade quarry, Source B. It is from this mix, using the premium materials in 4A gradation, that the southbound ramp, the southbound US 27 roadway south of there, plus most of the northbound roadway on the project were paved in the fall of 1960. These pavements have given good service. In the spring of 1961, after paving much of the northbound expressway portion of the project, the 4A fraction of the coarse aggregate was changed to Source C, and this mix was used for paving the northbound ramp which exhibited D-cracking. Still later, 4A aggregates from the original marginal Source A were used to complete the remainder of the southbound expressway on the project. These latter pavement sections have experienced D-cracking about as much as the northbound ramp shown in Figures 9 and 11.

This project demonstrates clearly that the original information on Source A was correct, and that the blending of premium grade 4A from Source B provided a pavement that has served well throughout its entire design life, and will continue to provide adequate service for several more years. However, the substitution of 4A from Sources C and A to finish the project resulted in pavements that barely survived their 20-year design life, and which will require a considerable amount of attention during the next few years. It should be noted that Source A was roughly 40 miles from the site, C was about 70 miles, and B was 200 miles by lake freighter plus 40 miles overland. This probably explains, to some extent, the decisions that were made 20 years ago.

Recent research, much of it done by the Portland Cement Association (1, 2, 3, 4), has described test methods that correlate quite well with D-cracking: namely, expansion after 350 cycles of slow freeze-thaw. This research has also shown that D-cracking can be delayed by crushing the coarse aggregate fraction to finer size, and that the fine aggregate fraction is not involved in D-cracking. The results also show that there are considerable differences in the susceptibility of aggregates to treatment by size reduction, and that such treatments of aggregates should not be undertaken without benefit of test results. It should be noted here, that the slow freeze-thaw (two cycles per day) was reported to be more severe than an equal number of the usual faster cycles, as far as D-cracking is concerned. If the faster cycle is to be used for such evaluations, it will have to be calibrated for the specific intent of D-crack sensitivity

It is becoming increasingly evident that Michigan has problem aggregates in many localities, since D-cracking is appearing on many projects of 10 years or more of age, and even at 3-1/2 to 4 years in the case of the US 10 Clare experimental pavements.

It is recommended, therefore, that all possible effort be put into identifying and evaluating sources, and specifying corrective size changes or material substitution where warranted. Also, it is recommended that serious consideration be given to raising the minimum acceptable durability rating by application of the latest principles to adjust the gradation of the coarse aggregate along with other appropriate mix design changes to obtain all practically attainable improvements in longevity of performance. It is also recommended that durability requirements be increased for the more critical applications. Some significant benefits should result from such procedures.

With the present state-of-the-art, the use of aggregate sources (especially of marginal or questionable past performance), for any very large projects should not be approved without benefit of this type of evaluation.

The early results of the experimental installation at Clare, also show clearly the deleterious effects of poor base drainage on concrete pavement performance. Improved drainability for all future base course construction should be pursued.

It is evident that additional data are needed to separate the better performing aggregates from those that cause earlier deterioration. Also, any test that could be developed to identify D-cracking aggregates in less time than the cumbersome long-term freeze-thaw test, would be a real boon to this endeavor. Further research along these lines is definitely needed.

REFERENCES

1. Stark, D. and Klieger, P., "Effect of Maximum Size of Coarse Aggregate on D-Cracking in Concrete Pavements," Portland Cement Association.

2. Stark, D., "Field and Laboratory Studies of the Effect of Subbase Types on the Development of D-Cracking," (RD021.01P), Portland Cement Association, 1974.

3. Stark, D., "Characteristics and Utilization of Coarse Aggregates Associated with D-Cracking," (RD047.01P), Portland Cement Association, 1976.

4. Klieger, P., Stark, D. and Taske, W., "The Influence of Environment and Materials on D-Cracking," (OHIO-DOT-06-78), Portland Cement Association, October 1978.

APPENDIX

LOCATION AND DETAILS OF THE EXPERIMENTAL INSTALLATION ON U.S. 10 NEAR CLARE

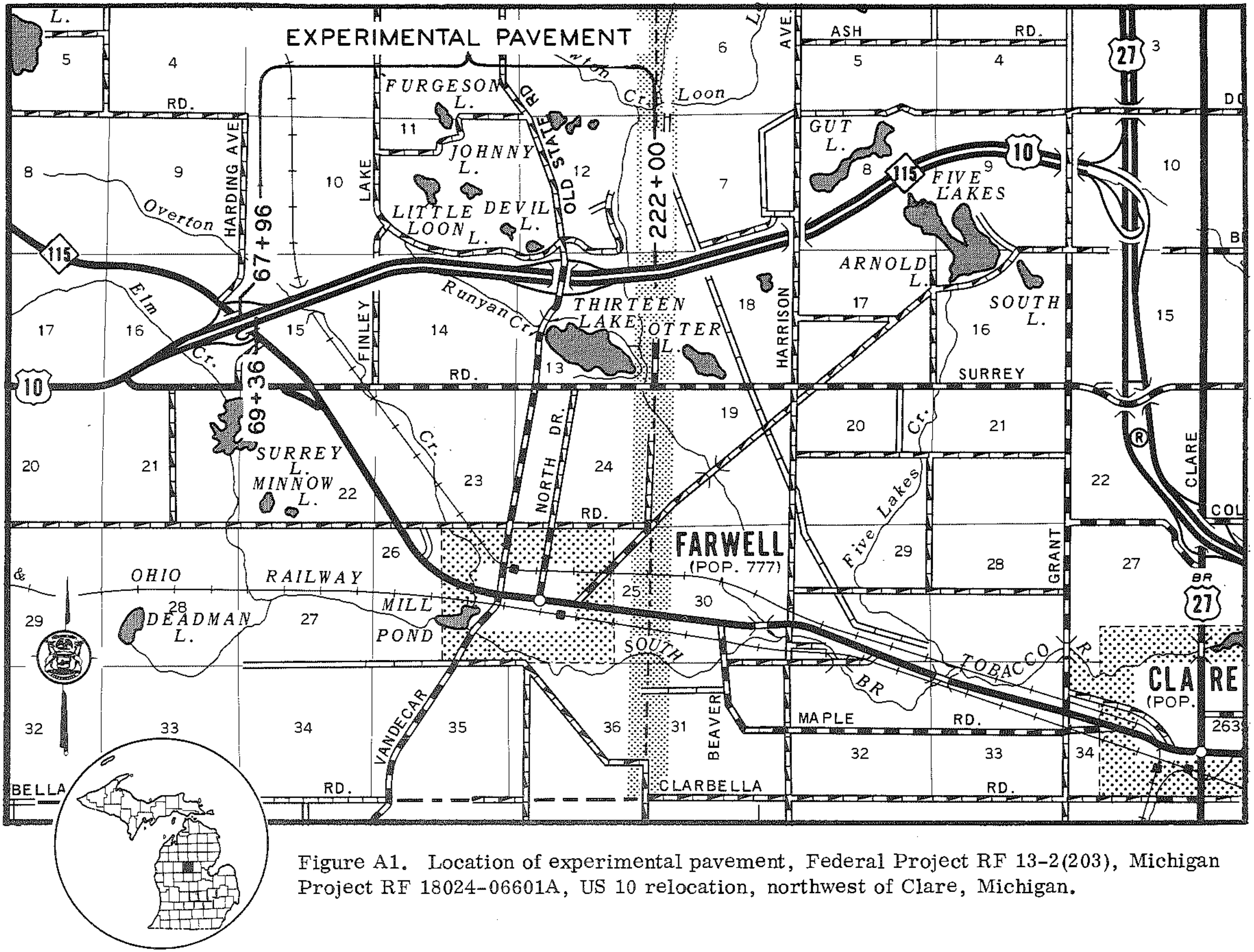
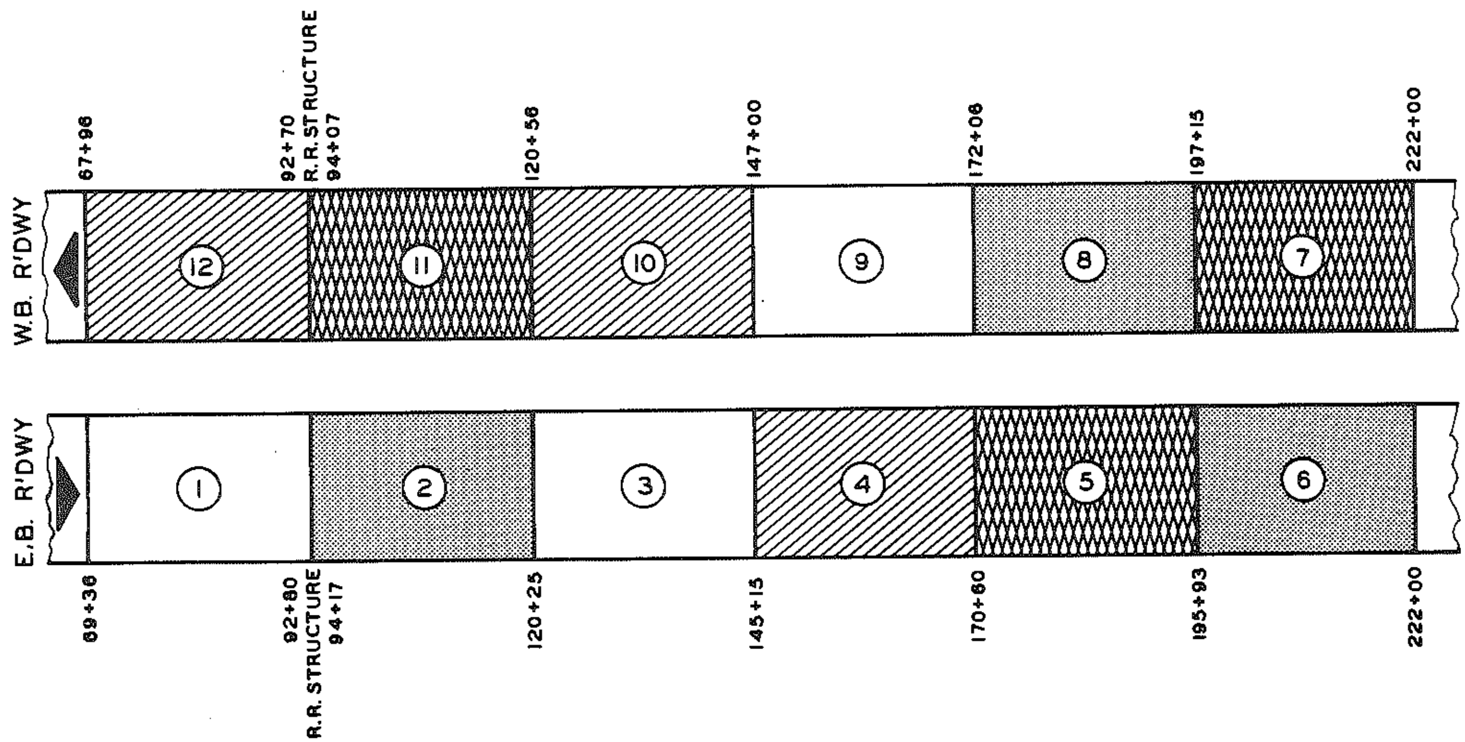
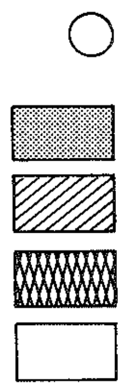


Figure A1. Location of experimental pavement, Federal Project RF 13-2(203), Michigan Project RF 18024-06601A, US 10 relocation, northwest of Clare, Michigan.





Section Number

Type A - Standard pavement; 9 in., reinforced, aggregate base, control sections.

Type B - Experimental pavement; short slab, plain concrete, skewed joints, variable spacing, no load transfer, ATPM base.

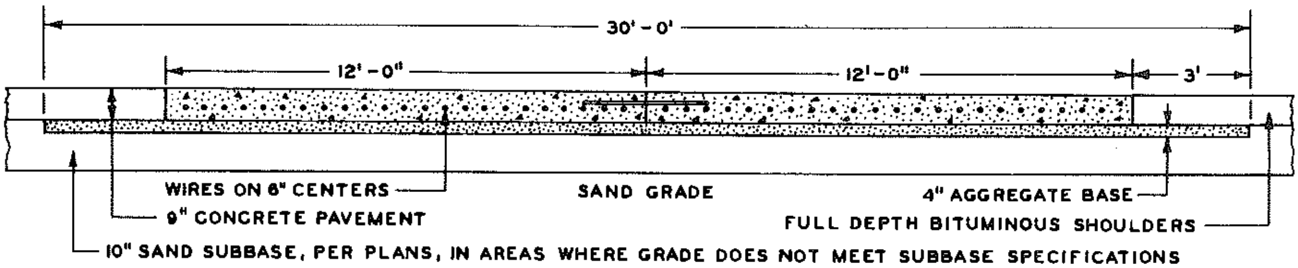
Type C - Experimental pavement; short slab, plain concrete, 90 degree joints, variable spacing, w/load transfer, aggregate base.

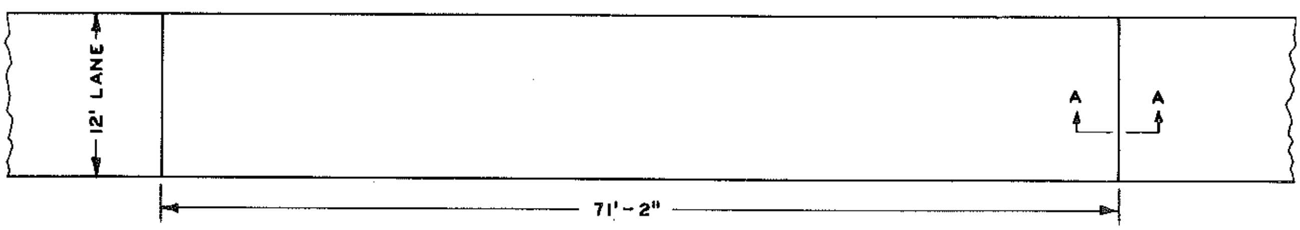
Type D - Experimental pavement; short slab, plain concrete, skewed joints, variable spacing, no load transfer, bituminous base.

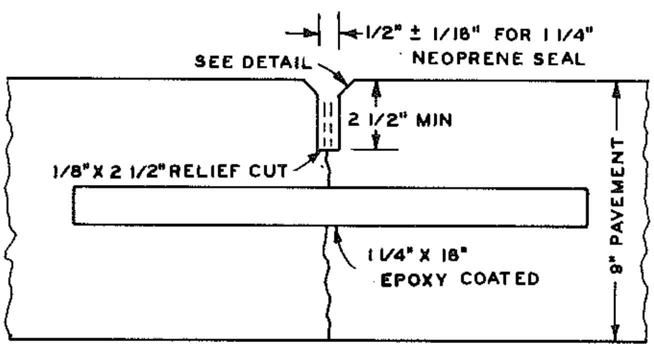
Note: Section limits shown are where pavement base course or slab lengths change. Exact limits of section may vary slightly near the transition areas. Section numbers correspond to sequence in which concrete pavement was placed.

Figure A2. Experimental test section layout, as constructed (US 10 relocation).

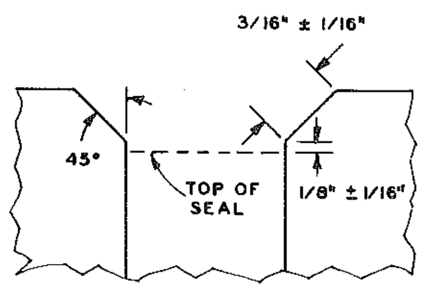
TYPICAL CROSS SECTION







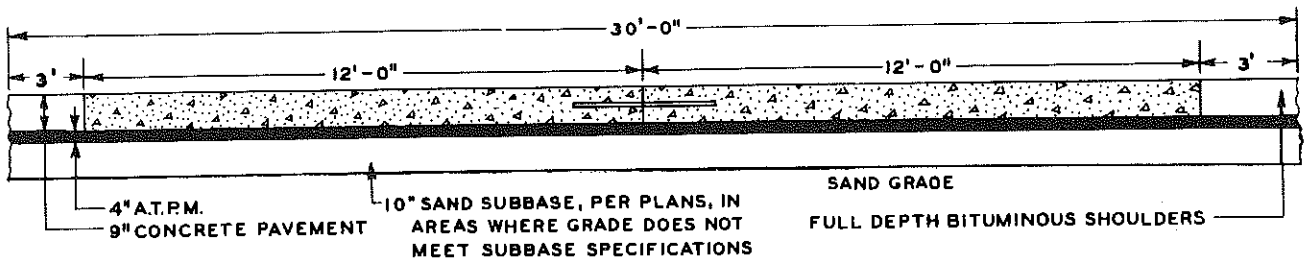
SECTION A - A



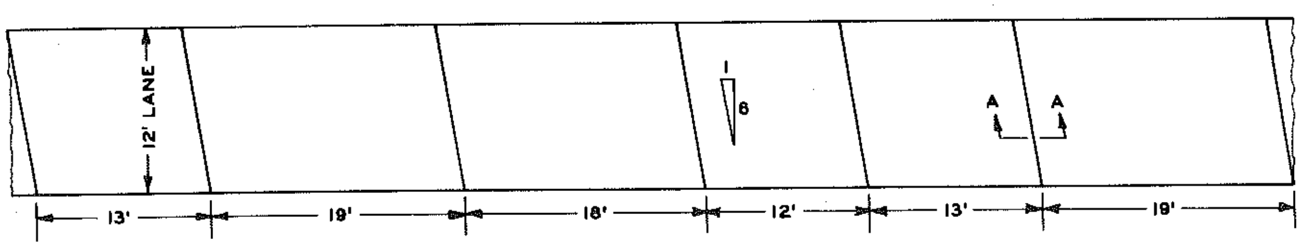
JOINT GROOVE CHAMFER DETAIL

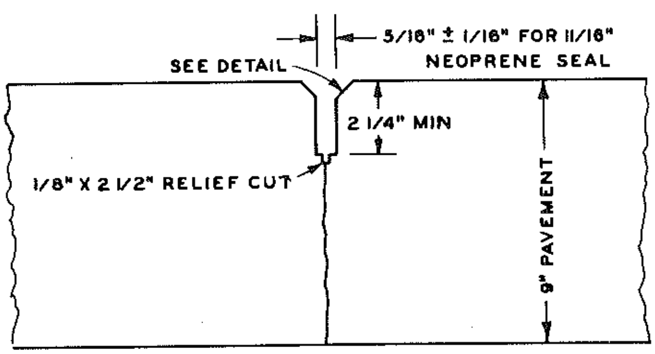
Figure A3. Type A, control section. Nine-inch standard pavement, 71 ft - 2 in. slabs, reinforced, 90-degree, equal spacing with load transfer and neoprene seals.

TYPICAL CROSS SECTION

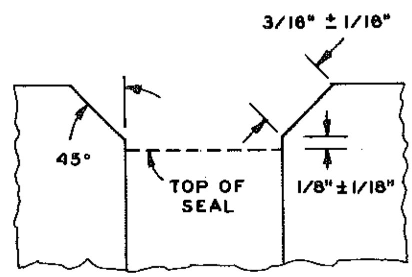


Note: Asphalt for bituminous base to be 200-250 penetration grade.





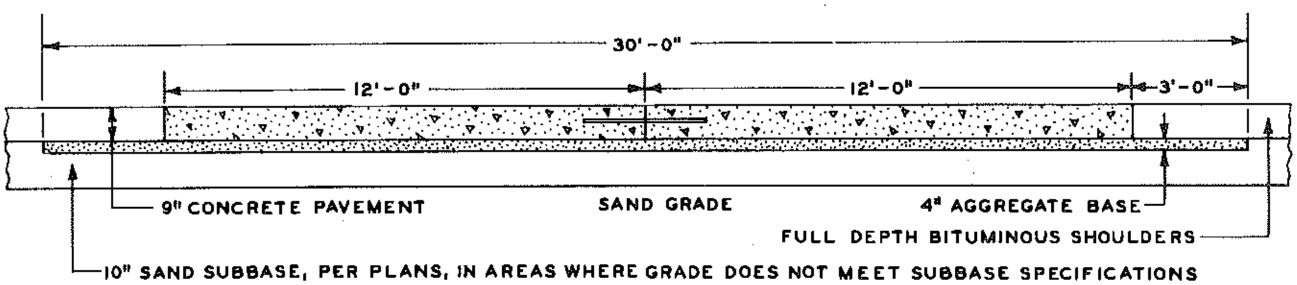
SECTION A-A

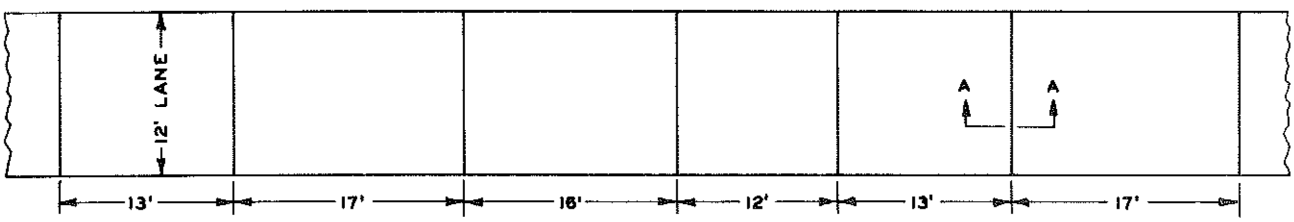


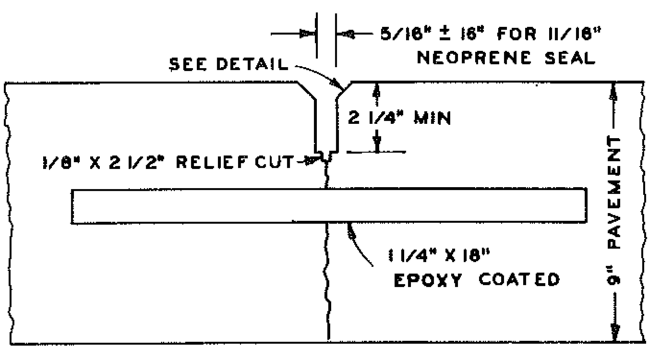
JOINT GROOVE CHAMFER DETAIL

Figure A4. Type B, short slab, plain concrete, skewed joints, variable spacing, no load transfer, porous base, neoprene seal.

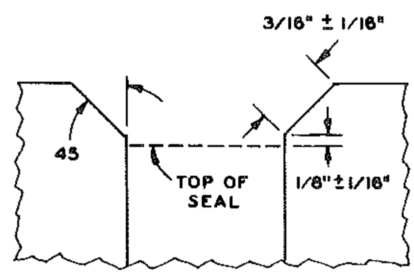
TYPICAL CROSS SECTION







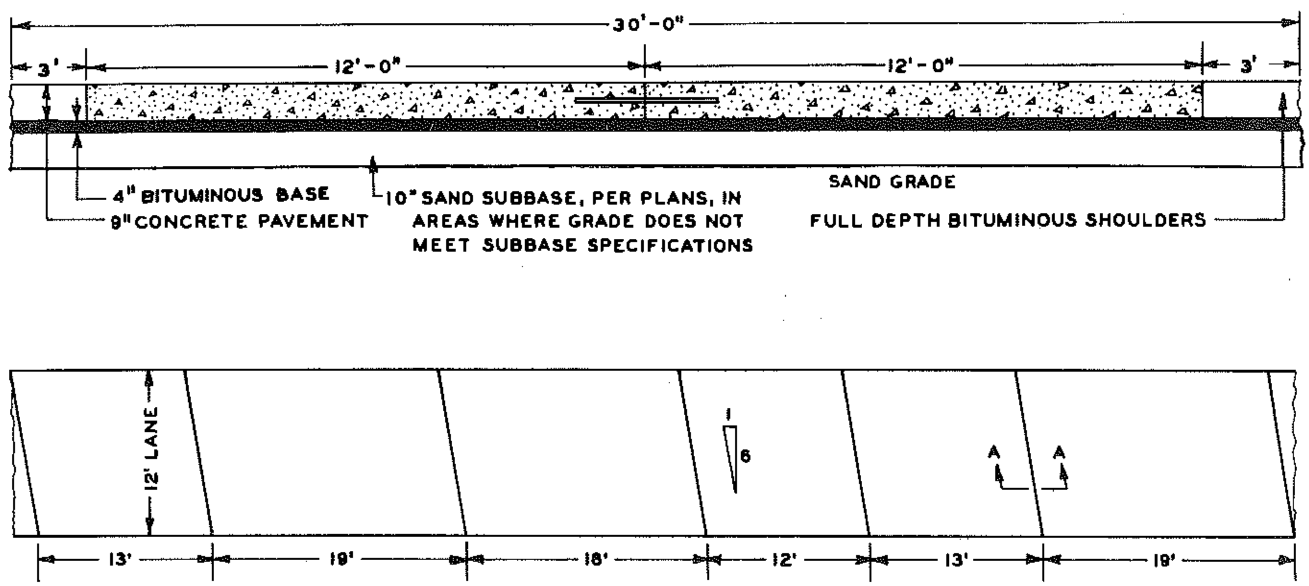
SECTION A-A

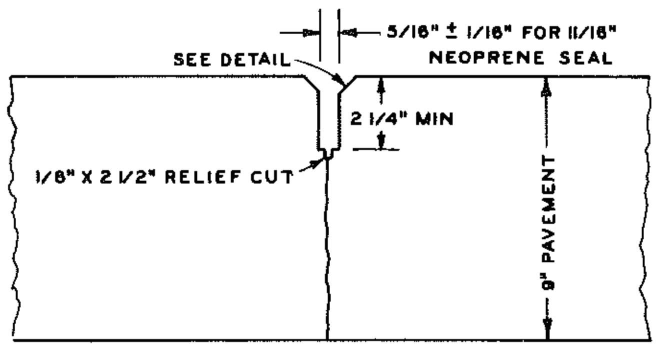


JOINT GROOVE CHAMFER DETAIL

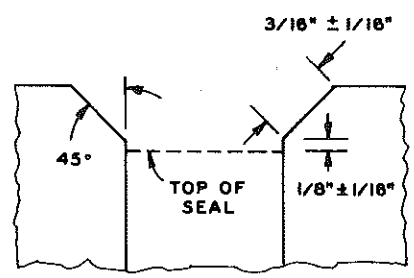
Figure A5. Type C, short slab, plain concrete, 90-degree joints, variable spacing, with load transfer and neoprene seals.

TYPICAL CROSS SECTION





SECTION A-A



JOINT GROOVE CHAMFER DETAIL

Figure A6. Type D, short slab, plain concrete, skewed joints, variable spacing, no load transfer, bituminous base and neoprene seals.