Performance Observations on Open-Graded Bituminous Concrete Overlays in Connecticut

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Performance data are presented for open-graded overlays of different ages. The overlays investigated were all placed on Interstate highways that had average daily traffic volumes in excess of 20 000 vehicles/day. Associated with one project was the application of open-graded overlays of varying thickness and support layers. All overlays have exhibited high skid resistance, which has stabilized at skid numbers 40-50, irrespective of lane or traffic volume. Attempts to apply thermoplastic striping were unsuccessful because snowplows tended to remove not only the stripes but also a portion of the underlying pavement to which they adhered. Compared with conventional overlays, there appears to be no advantage gained in terms of resistance to reflective cracking by using open-graded overlays. Air-permeability tests indicate a certain choking of the void structure in open-graded pavements with time. The removal of snow, and especially ice, from open-graded pavements is somewhat more difficult than it is from conventional pavements because of the greater surface area presented for adhesion and the loss of chemical deicers into the void structure. In this respect, greater amounts of deicers are normally required for open-graded pavements than anticipated.

In the 1960s, transportation agencies completed large segments of the Interstate system in the United States. At the end of that decade, the need arose for surfaces with high skid resistance to provide increased safety for the motoring public. Work completed by the National Cooperative Highway Research Program (NCHRP), the Federal Highway Administration (FHWA) (1-4), and several states (5-7) led to the current standards for high-friction pavement surfaces. By the early 1970s, work by the British led FHWA to promulgate Notice HNG-23 (2), which encouraged the use of the open-graded friction course (OGFC). Since then, most states and the asphalt paving industry have used open-graded materials to improve the friction characteristics of pavement surfaces.

Connecticut's first experience with open-graded material was a limited test section placed on a temporary roadway in Groton, Connecticut. The locale was ideally suited to demonstrate the unique high-friction properties of the material, since the test area carried a substantial traffic load around a construction site. The pavement was evaluated for approximately two years. During this period, the section was structurally stable and the skid numbers (SNs) were fairly constant in the range of 45-55 (7). From this work, larger projects evolved; the first was on I-91 south of Hartford (7).

FIRST LARGE-SCALE PROJECT

In June 1975, a two-course overlay was placed on the original concrete pavement on I-91 in the towns of Cromwell, Rocky Hill, and Wethersfield (State Project 33-90). Plans for the project called for a 2-in lift of dense-graded material [Connecticut Department of Transportation (ConnDOT) class 1] topped by a 0.75-in OGFC (ConnDOT class 14) as a safety improvement (Tables 1 and 2). Incorporated into this project were two experimental sections; one was located at the north end of the project in the northbound roadway and the other was at the south end of the project in the southbound roadway.

The primary purpose of this study was to determine the optimum depth of the OGFC and the class-1 layers and their longevity. Each of these sections was divided into three sublots; each sublot received a different treatment. These were as follows:

1. Class-1 material, 1.5 in, topped by 0.75 in of open-graded mix;
2. Open-graded material, 1.5 in placed on the concrete; and
3. Open-graded material, 0.75 in placed on the concrete.

It should be stated here that a class-8 scratch coat was placed on the surface on the concrete as a bonding agent for the overlays over the entire project, including the experimental areas. The class-8 material is a dense sand-asphalt leveling course applied by a skid box. In this case, it served not only as a leveler but also as a primer to improve adhesion between the overlay and the old concrete. Current ConnDOT practice uses an emulsified asphalt tack coat applied at a rate of 0.05 g/yd².

The locations of the six sublots are presented in Figure 1. As is apparent from Figure 1, each of the experimental sublots has a replicate in the opposite roadway. The 25-ft gaps between the variable-depth experimental sections were employed for taper.

ConnDOT design for overlays on jointed-concrete pavements requires saw cuts 0.38 in wide by 0.5 in deep in the overlay over transverse joints to control reflection cracking. It was claimed that OGFC would inhibit this cracking due to its physical properties. To prove or disprove this claim, additional experimental sites were selected within the project to evaluate reflection cracking of the old portland cement concrete joints through the open-graded bituminous overlay. These sections and the treatment afforded them are as follows:

1. Southbound: The first three joints in experimental sublots 1S, 2S, and 3S were sawed in OGFC surface, whereas the last two joints were left unsawed; and
2. Southbound: The first 20 consecutive joints south of the sign "Wethersfield-Rocky Hill Town Line" were sawed in the dense-graded leveling course prior to placement of OGFC and were not sawed through OGFC.

OBSERVATIONS AND TESTS

During the period from June 1975 to September 1978, we performed condition surveys of the experimental and control sections placed on I-91. These inspections were generally conducted twice yearly and included an accounting of longitudinal and transverse cracking, random cracking, durability of line striping, and loss of material. Air-permeability and skid tests have also been conducted, rutting measurements have been obtained at various intervals since placement, and sand-patch and silly-putty tests have been performed once. To increase our data base, we also performed air-permeability, sand-patch, silly-putty, and skid tests and obtained rutting measurements on two open-graded pavements placed on I-95 in July 1977. Here, however, one of these pavements contained a 3/8-in top-size aggregate (Madison) and the other a 1/2-in top-size aggregate.

Table 1. Job-mix formula, 1975 and 1981: sieve analysis.

	Percent Passing by Weight				
			1981 Formula		
	1975 Formula		Class 14		
Sieve Size	Class 14	Class 1	1/2 in	3/8 in	Class 1
1 in					100
3/4 in		95-100	100		90-100
1/2 in		70-100	90-100	100	70-100
3/8 in	100	60-82	-	90-100	60-82
No. 4	30-45	40-65	20-45	20-45	40-65
No. 8	11-20	28-50	5-19	5-19	28-50
No. 50	-	10-26	-	-	6-26
No. 200	0-5	2-8	2-5	2-5	2-8

Table 2. Job-mix formula, 1975 and 1981: other characteristics.

			1981 Formula		
	1975 Formula		Class 14		
Characteristic	Class 14	Class 1	1/2 in	3/8 in	Class 1
Bitumen content (AC-20) (%)	5.0-6.5	5-8	5.5-7.5	5.5-7.5	5-8
Temperature (°F)					
Mix	225-250	265-325	325 max.	325 max.	325 max.
Aggregate	None	280-350	225-250	225-250	280-350
Void content[a] (%)	None	3-6	None	None	3-6
Stability (lbf)	None	1200 min.	None	None	1200 min.
Flow (in)	None	0.08-0.15	None	None	0.08-0.15
Aggregate[b] loss (%)	40 max.	40 max.	40 max.	40 max.	40 max.

[a] Determined from 75-blow Marshall test.
[b] Trap rock (American Association of State Highway and Transportation Officials T96).

SUMMARY OF RESULTS

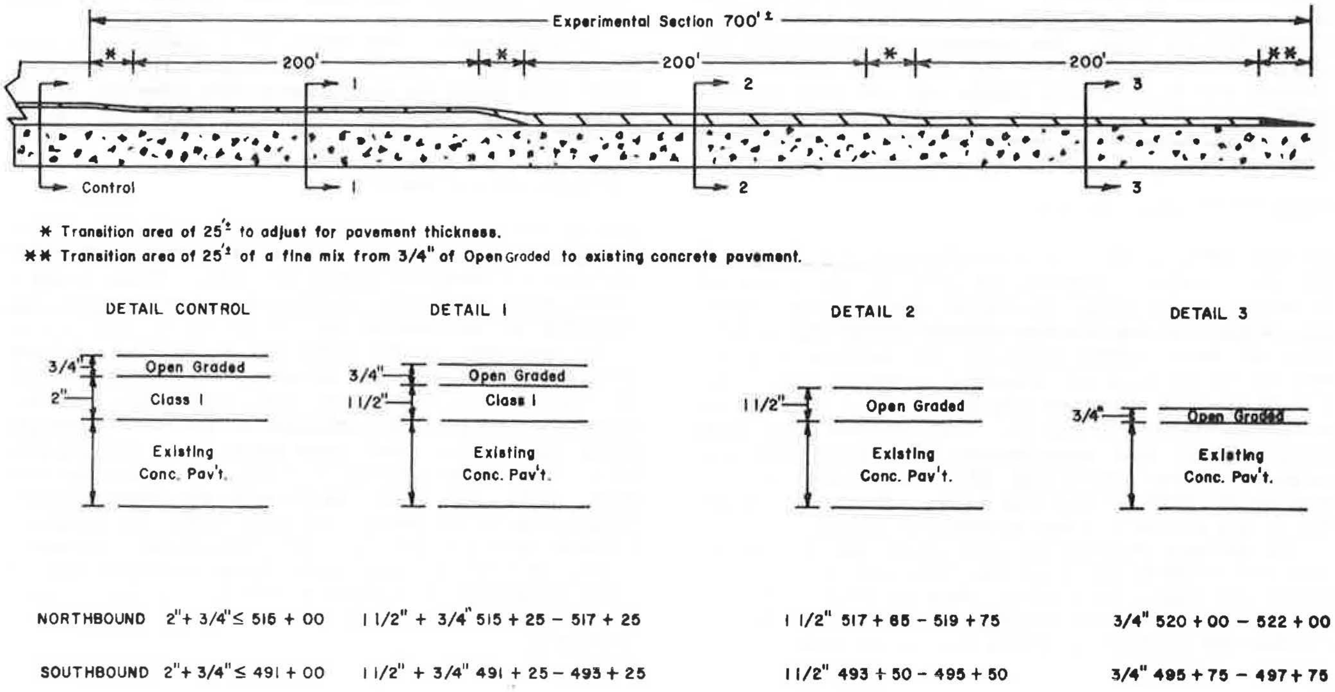
The data obtained from recent surveys and tests conducted on the various open-graded pavements not only reinforce but also complement the conclusions incorporated in an earlier report (6). The following is a summary of our latest findings:

1. OGFC overlays have for the most part performed well, not only in standard pavements (OGFC over 2 in of dense-graded material) but also in two of the three test sections placed on I-91. The test section with the thinnest overlay (0.75 in of open-graded material on concrete) failed in adhesion and lifted off in several large areas. Several smaller areas in the standard sections have also lifted off; one possible explanation for this failure is the inadequacy or poor application of the sand-asphalt scratch coat. Figures 2-13 show typical views of the experimental and control sections on I-91.

The gouge marks shown in Figure 3 and the peeling off of material under the thermoplastic paint (Figure 5) demonstrate the susceptibility of the open-graded material to impact loads or forces exerted by snowplows. Most of the type of damage was sustained early (up to six months after placement), when the asphalt was "young" and had not hardened. The thermoplastic striping originally placed on the open-graded material has since been modified because of the damage sustained by the pavement when the striping peels off under the action of snowplows. We now employ a thermoplastic stripe that has a thinner cross section and tapered ends.

2. The open-graded mat has failed to arrest longitudinal reflective cracking (Figure 2). Transverse reflective cracks have also appeared (Figure 13) where the crack-relief joints have been misaligned or the underlying transverse joints have opened to unusual widths. Spalling is virtually absent or minimal at reflective cracks to date. Of the 20 consecutive unsawed joints in the control section on I-91, 95 percent have reflected through

Figure 1. I-91 safety improvement experimental treatment.



the surface, whereas 100 percent of the unsawed joints in the experimental sections have reflected through.

We have not conducted any condition surveys on the I-95 pavements, but a report from another unit monitoring the surface condition of a whole series of pavements that incorporates both 3/8- and 1/2-in aggregates indicates that the 1/2-in top-size aggregate has superior crack resistance.

3. Although the permeameter tests that we conducted on I-91 and I-95 are by no means statistically valid, they do show a trend toward "choking" of the open-graded surface course and variation in permeability between the centerline and the edge of the shoulder. The results of the permeability tests on I-91 and I-95 are presented in Table 3. The I-95 permeability tests indicate that, initially, the

Figure 2. Propagation of longitudinal cracking beyond previously sealed portions (northbound, control section).

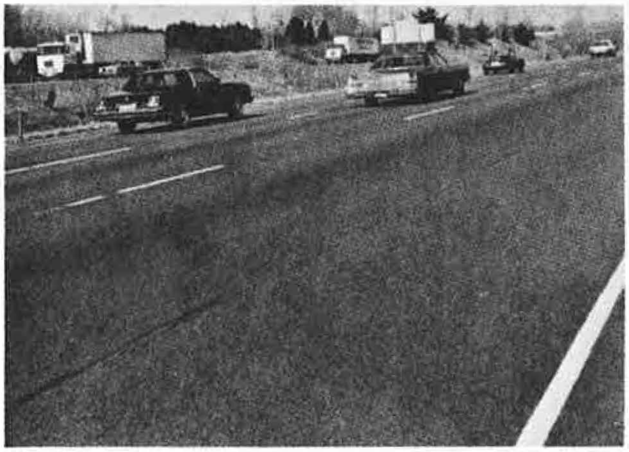


Figure 3. Gouge marks from hard object in surface of open-graded material (southbound, control section).

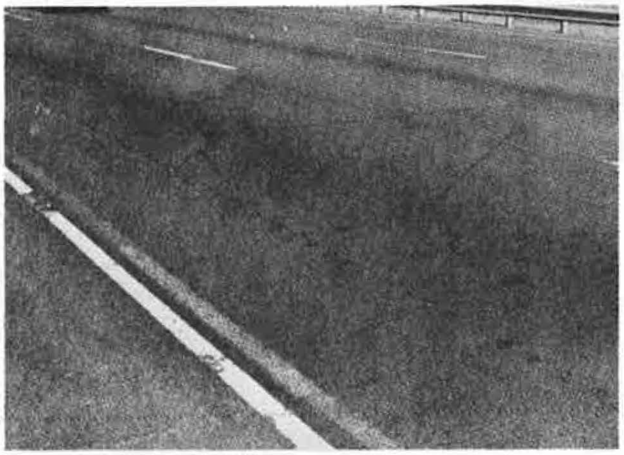


Figure 4. Typical gouge in open-graded surface (southbound, control section).

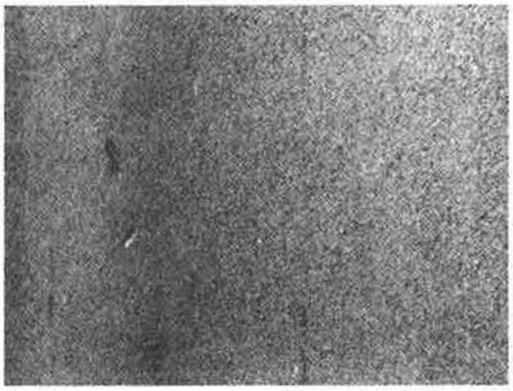


Figure 5. Loss of open-graded material over dense-graded course (southbound, control section).

Figure 6. Open-graded material lost beneath thermoplastic line striping during snowplow operations (southbound, control section).

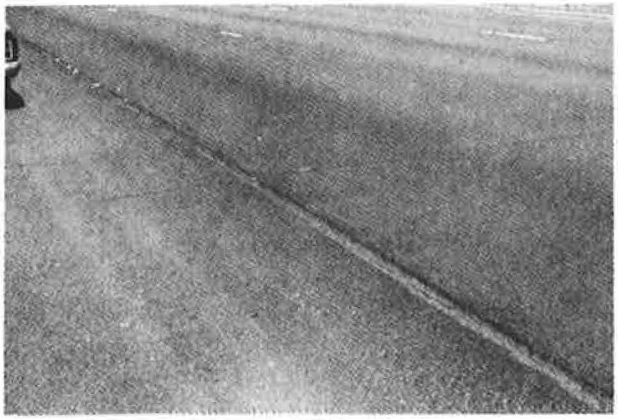
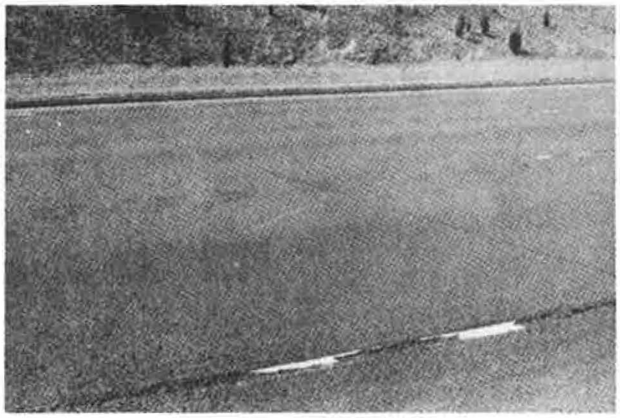


Figure 7. Overview of portion of test section 1N.



pavements (four to nine months) were extremely open and passed considerable volumes of air quite rapidly; this was true even of the shoulder area. At four years, the shoulders of the pavements that had both 3/8- and 1/2-in aggregate became somewhat plugged; the outer lane remained more open, particularly in the pavement that contained the 1/2-in aggregate. The I-91 pavements (all 3/8-in top-size aggregate) all show considerable lessening of voids, not only in the shoulder areas but also in the low-speed lane. Here a pattern is developed in which the middle of the lane yielded a lower permeability than that of the wheel paths. As compared with the three-year tests, the six-year tests showed a surprising improvement in permeability in both the shoulder and the outer lane. This improvement could

Figure 8. Overview of portion of test section 2N.

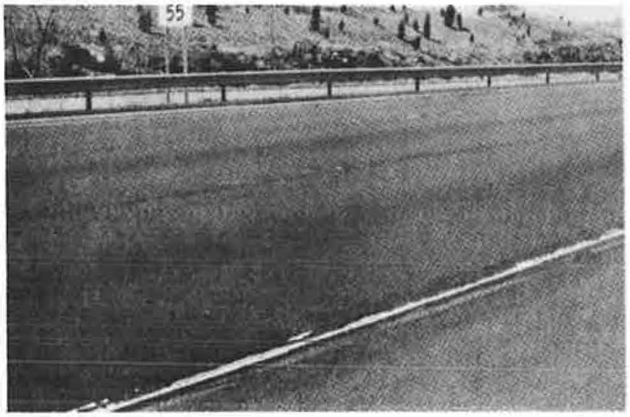


Figure 9. Overview of portion of test section 3N.

Figure 10. Overview of portion of test section 1S.

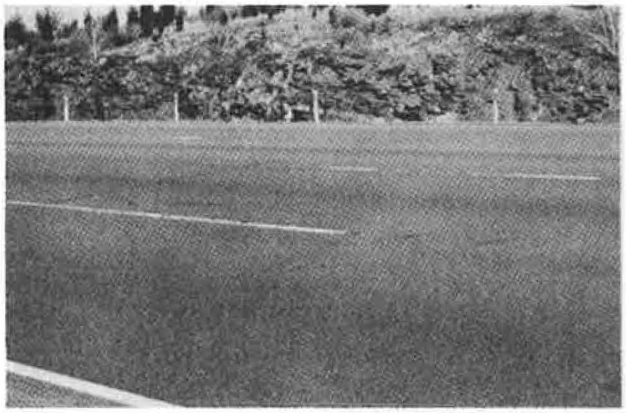


Figure 11. Overview of portion of test section 2S.

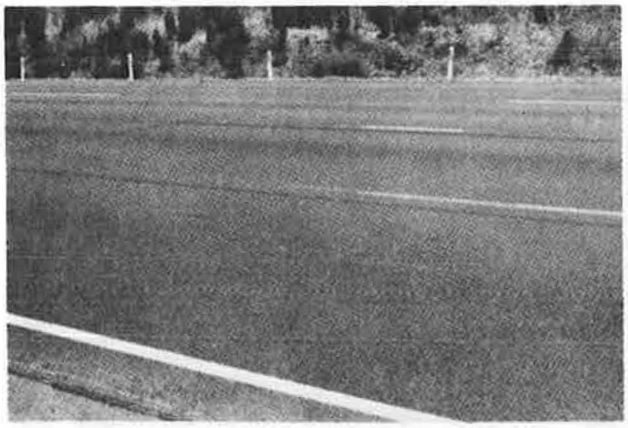


Figure 12. Overview of portion of test section 3S.

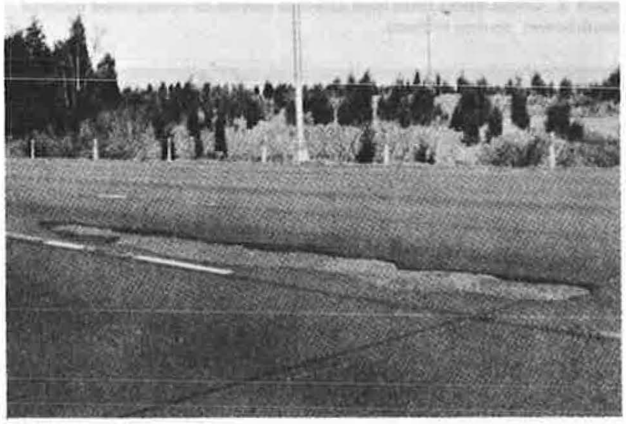
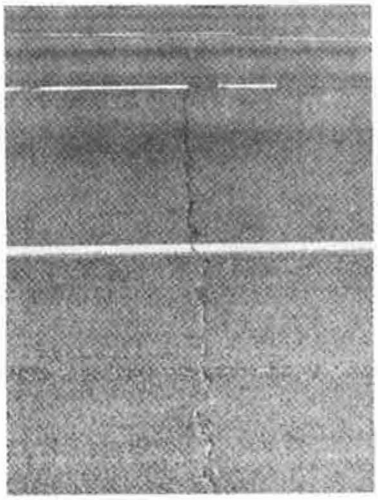


Figure 13. Typical reflection crack over transverse joint in concrete pavement.



be attributed to the extreme lack of snow and ice over the last two winters and, in turn, to a rather sparse application of sand and chemical deicers, which are prime contributors to choking.

4. High SNs have been maintained on all open-graded pavements with normal seasonal variations. Initial tests showed relatively low readings until the asphalt coating had worn away in one to two months and then an increase to a value in the range of SN40-50. The high friction has been maintained over the life of the pavements (up to six years on I-91). Figure 14 shows the history of skid resistance on all travel lanes of the I-91 pavement and the general behavior of the skid resistance of our conventional dense-graded pavements. As can be seen, there is a considerable difference between the SNs of the open-graded and the dense-graded pavements after six years.

5. As compared with the new open-graded material placed on I-95, the 2.5-year-old I-91 pavement exhibited a much shallower texture as determined from sand-patch and silly-putty tests (Table 4). This can probably be related to the clogging of surface voids with foreign materials, which is in turn related to the reduced permeability of the I-91 pavement.

6. Rutting has been minimal in the open-graded surfacing; maximum depths approached 0.25 in after six years of heavy traffic on I-91 and 0.4 in after four years on I-95 (Figures 15 and 16). All sections tested on I-95 showed a definite trend toward wheel-path rutting. The section that contained the 1/2-in aggregate demonstrated what might appear to be shoving of material from the shoulder inward toward the centerline, although the roadway in this section was on tangent. As compared with the 0.75-in open-graded sections on I-91, the thicker 1.5-in section has experienced little rutting, a fact that would attest to the stability of the OGFC material under load.

7. Table 5 presents before and after accident statistics for the I-91 and I-95 projects. The sixth column of Table 5 lists accidents per million vehicles over each section investigated. This figure was arrived at by dividing the total number of reported accidents by the product of the average daily traffic (ADT) derived for the time period in question, the number of days per year, and the number of years in the period. It does not take into account the length of the various sections, since we are primarily interested in the before and after effects over the same sections.

It follows from Table 5 that accidents were reduced by 40 and 29 percent, respectively, in the northbound and southbound roadways. Conversely, accident rates actually increased on the I-95 sections after applications of the open-graded friction courses. The increase was 53 percent with the 3/8-in material, and 16 percent on the 1/2-in material. The fact that from 1972 to 1973 only police-reported accidents and no operator-reported accidents were considered in our accident statistics would tend to bias the results in favor of the "before" period. From 1974 on, all qualifying operatorand police-reported accidents were included in the statistical data; this would result in a greater number of accidents in all "after" periods for each section.

Table 3. Air-permeability tests on open-graded pavements.

		Outer Lane			Shoulder	
Section	Age (years)	Left Wheel Path	Center of Lane	Right Wheel Path	Left Edge	Right Edge
I-95 Eastbound (Madison-Westbrook)						
3/8-in aggregate, 0.75-in OGFC, 2-in dense-graded	0.33	0:14	0:14	0:12	0:14	0:15
	0.75	0:13	0:13	0:10	0:08	0:08
	4^a	0:41	4:15	0:23	6:24	4:23
1/2-in aggregate, 1-in OGFC, 2-in dense-graded	0.33	0:12	0:14	0:12	0:14	0:16
	0.75	0:07	0:07	0:07	0:09	0:08
	4^a	2:25	0:15	0:18	1:09	2:49
I-91 Northbound (Rocky Hill)						
Control (0.75-in OGFC, 2-in dense-graded)	2.5	2:21	8:52	3:15	7:00	3:34
	3	8:44		4:46	34:20	11:32
	6	5:25	6:53	6:53	10:15	6:25
1 N (0.75-in OGFC, 1.5-in dense-graded)	2.5	60	>60	0:50	3:13	3:26
	3	19:16	>60	9:10	12:33	8:26
	6	4:25	5:25	2:15	6:50	5:50
2N (1.5-in OGFC, concrete)	2.5	>60	>60	1:53	11:09	3:23
	3	>60	>60	>60	21:08	11:53
	6	2:09	7:55	1:27	8:20	4:55

Notes: Figures denote time required to pass 1 L of air through 81 cm^2 of pavement surface (min:sec).
Pavements containing 3/8- and 12-in top-size aggregate are located in Madison and Westbrook, respectively.
Depth of open-graded course containing 1/2-in top-size aggregate was 1 in after compaction; current specifications now call for 0.75-in depth, irrespective of aggregate size.

[a] Average of two readings taken 8 ft apart in longitudinal direction.

Figure 14. History of skid resistance on open-graded friction course, I-91, Rocky Hill.

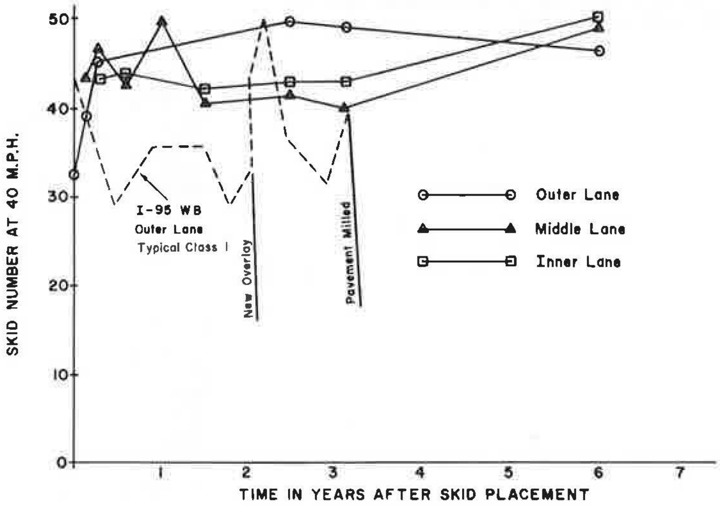


Table 4. Sand-patch and silly-putty test results, Oct. 1977.

Section	Sand-Patch Test (avg depth of texture, in)		Silly-Putty Test (avg depth of texture, in)	
	Middle of Outer Lane	Inner Wheel Path of Outer Lane	Middle of Outer Lane	Inner Wheel Path of Outer Lane
I-91 Northbound (Rocky Hill, placed June 1975)				
Control section (0.75-in OGFC, 2-in dense-graded)	0.034	0.044	0.021	0.038
Test section 1N (0.75-in OGFC, 1.5-in dense-graded)	0.037	0.050	0.027	0.045
Test section 2N (1.5-in OGFC)	0.039	0.053	0.030	0.037
Test section 3N (0.75-in OGFC)	0.028	0.039	NA	NA
I-95 Eastbound (Madison-Westbrook, placed July 1977)				
3/8-in top-size aggregate (Madison)	0.095	0.111	0.048	0.054
1/2-in top-size aggregate (Westbrook)	0.114	0.130	0.100	0.098

NA = not available.

ADDITIONAL INFORMATION OBTAINED

In conversations concerning snow and ice control with maintenance foremen in charge of both the I-91 and I-95 sections of open-graded material, it was acknowledged that the open-graded material required special treatment during winter storms. Chloride applications were reported to have been 10 and 30 percent higher on the open-graded sections than on adjacent conventional sections on I-91 and I-95, respectively. Since no salt-use records were maintained strictly for these open-graded sections, these figures are based on the opinions of the foremen involved.

Noise readings obtained by ConnDOT's Environmental Planning Division showed a reduction of 1 dBA in the open-graded section versus comparable readings for our standard pavement section. Obviously, this is not a significant reduction in noise such as has been reported by drivers who travel over open-graded surfaces. The notable reduction in sound perceived by the driver is associated with change in the frequency of sound generated by the course surface texture of the open-graded material.

Figure 15. Cross sections of I-91 in Rocky Hill showing rutting in outer lane of different design sections.

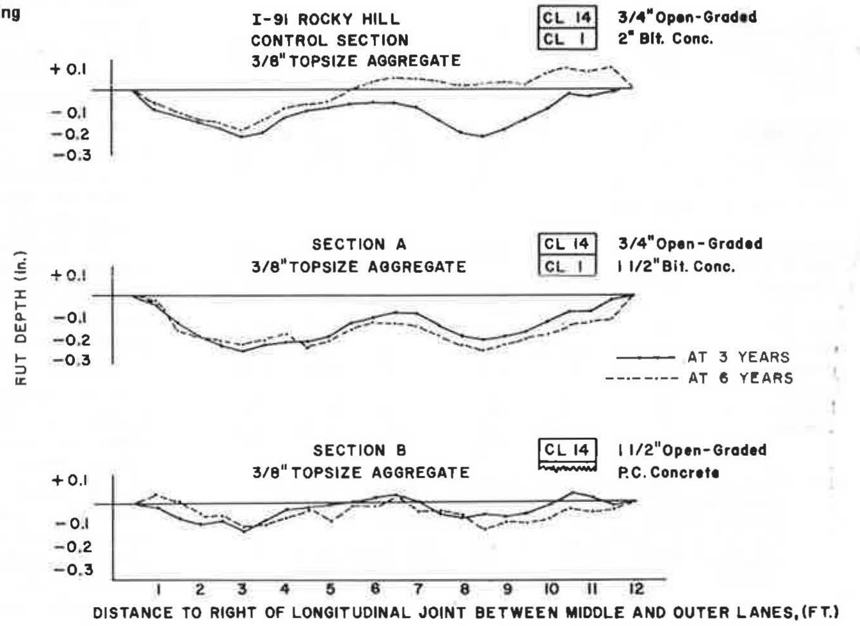


Figure 16. Cross sections of I-95 in Madison and Westbrook that show rutting in outer lane.

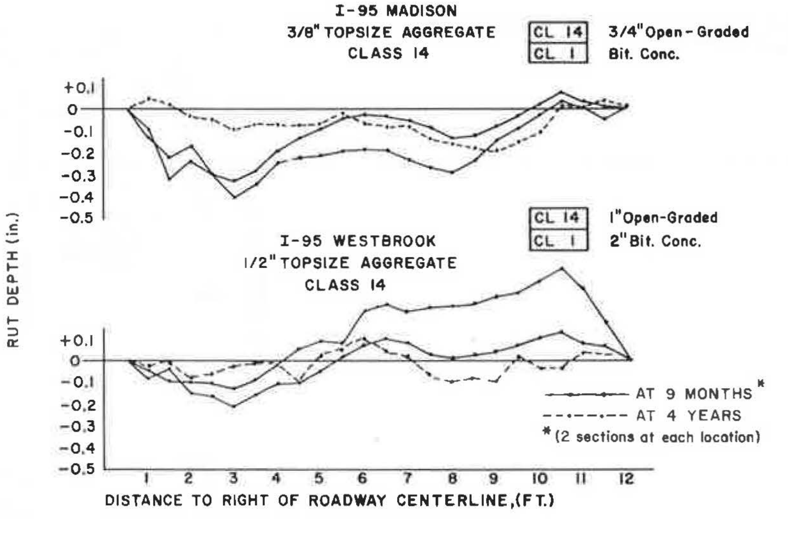


Table 5. Accident statistics for various roadways with open-graded applications.

Condition	Section	Total Accidents	Period (years)	ADT	Accidents per Million Vehicles	SN and Date
No overlay	NB I-91 (before)	69	2.5	24 500	3.09	38.7, 1974
	NB I-91 (after)	98	5	29 400	1.83	47.3, 1980
No overlay	SB I-91 (before)	98	2.5	27 000	3.98	38.5, 1975
	SB I-91 (after)	165	5	32 100	2.82	47.3, 1980
3/8-in OGFC	EB I-95 (before)	124	5 + 7 months	13 800	4.409	35.0, 1975
	EB I-95 (after)	104	2 + 10 months	14 900	6.750	47.7, 1981
1/2-in OGFC	EB I-95 (before)	69	5 + 7 months	13 600	2.490	35.0, 1975
	EB I-95 (after)	43	2 + 10 months	14 400	2.887	48.2, 1981

CONCLUSIONS

Based on the above discussion, the following general conclusions can be drawn. As a skid-resistant surface under heavy traffic, OGFCs have performed well in Connecticut for periods of up to six years. Compared with other ConnDOT mixes used for overlays, OGFC appears to be equal in terms of resistance to reflective cracking. The lateral-internal-drainage characteristics of OGFC have been shown to decrease with time. This decrease is primarily attributed to the use of winter deicing chemicals and abrasives. Due to the short lengths of the three test sections on I-91, no conclusive statements can be made regarding the effect of layer thicknesses on the performance of OGFC mats. In this connection, however, it should be pointed out that the standard ConnDOT design consisting of 0.75-in OGFC on a 2-in dense-graded surface has performed well to date.

ACKNOWLEDGMENT

The project reported in this paper was carried out with the cooperation of the Federal Highway Administration, U.S. Department of Transportation. The contents of this report reflect my views and I am responsible for the facts and accuracy of the data presented here. The contents do not necessarily reflect the official views or policies of the Connecticut Department of Transportation or of the Federal Highway Administration. The report does not constitute a standard, specification, or regulation.

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Effects of Baghouse Fines and Mineral Fillers on Properties of Asphalt Mixes

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The objective of this study was to determine the effects of baghouse fines on asphalt mixes. The analysis included Marshall tests on mixes that had various ratios of filler to baghouse fines. Other tests to study these effects included stability loss, viscosity, penetration, shear-modulus, and softening point. The results of the study indicated that baghouse fines can greatly affect the properties of the mix, such as the optimum asphalt content, stability, and stability loss. Asphalt mortars that used different ratios of filler to baghouse fines exhibited varied viscosity and penetration. Stability loss, which is a main factor in the design of local mixes, was decreased drastically by the inclusion of baghouse fines. One factor that controls the effect of baghouse fines on asphalt mixes was the percentage of carbon. It is anticipated that the results of this study will be of great help in the improvement of mix properties by incorporating baghouse fines.

Pavement systems in the Eastern Province of the Kingdom of Saudi Arabia are exposed to a multitude of severe environmental factors, mainly the high temperature and the high humidity. Roads usually show excessive failures at an early stage of pavement life. Other factors that contribute to the early failure are the extremely heavy axle loads applied to the roads of this province. There is currently no enforcement of the maximum loads permitted on an axle or of the tire pressures. Another major contributor to failure is the low quality of local materials used for highway construction. For ex-