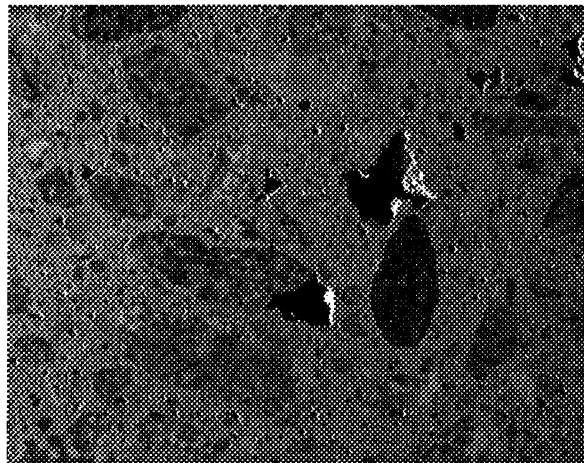


TECHNICAL
ASSISTANCE REPORT

EVALUATION
OF CONSOLIDATION
IN CONCRETE PAVEMENTS



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TECHNICAL ASSISTANCE REPORT

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CONCRETE PAVEMENTS**

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(The opinions, findings, and conclusions expressed in this
report are those of the author and not necessarily
those of the sponsoring agencies.)

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INTRODUCTION

A critical operation in any concrete construction is the consolidation of the freshly mixed plastic concrete into its final form. During the mixing and placing of plastic concrete, large air voids become entrapped in the mortar fraction. These entrapped air voids generally have an irregular shape and are larger than intentionally entrained air voids. All voids reduce the density of the concrete and thus adversely affect some physical properties, such as strength. However, the small entrained air voids provide a very beneficial characteristic: resistance to deterioration from the effects of freezing and thawing and deicing salts. Large entrapped voids provide no such useful benefit.

The purpose of the consolidation operation is to dispel this entrapped air, thus densifying the concrete, while maintaining an entrained air void system adequate to provide resistance to freezing and thawing. Insufficient consolidation of concrete will result in lowered compressive and flexural strengths and adversely affect the ability of reinforcing steel and dowelled joints to transfer load, leading to reduced service life of pavements.¹ Thorough consolidation of concrete does not appear to adversely affect the ability of the entrained air void system to provide protection from the effects of freezing and thawing.^{1,2}

PURPOSE AND SCOPE

Petrographic examinations of specimens from two recently constructed concrete pavements suggested that complete consolidation of the concrete may not have been achieved. Consequently, a quantitative evaluation of the degree of consolidation in these specimens was undertaken. The pavements were of plain, jointed design with dowels for load transfer. Both projects were constructed using slip-form paving machines with spud vibrators.

METHODS

The void content of the concrete was determined on slabs sectioned from the top and bottom half of cores along planes parallel to their axes. The slabs were lapped to provide a smooth, polished finish. Determinations were performed according to ASTM C 457, Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete, Linear Traverse Method,³ with an additional classification by the operator of air voids as either entrained or entrapped. Voids with a dimension in any direction greater than 1 mm or with an irregular shape were counted as entrapped voids, while spherical voids with a maximum diameter less than 1 mm were counted as entrained voids. Although this criterion is admittedly arbitrary, it is generally accepted in practice.^{3,4}

RESULTS

The concrete in both projects was produced using No. 57-size crushed stone as the coarse aggregate. The minimum cementitious material content was 564 lbs/yd³ with a maximum water-cement ratio of 0.49. The specified air content was 6 +/- 2 percent.

The I-64 pavement at Hampton was plain and jointed with a depth of approximately 255 mm (10 in). It was constructed in the summer of 1993 using a slipform paving machine. Load-transfer dowels were preplaced, supported on chairs at mid-depth. Mechanical spud vibrators on the paving machine were set to a constant depth so they would avoid contact with the dowels, and thus did not penetrate below mid-depth of the pavement. Depth check cores broke near mid-depth after being dropped from a height of about 1 meter. Polished slabs from the top and bottom half of the pavement are illustrated in Figures 1 to 5.

The design and construction of the pavement of the U.S. 460 Bypass at Appomattox was similar to that indicated above for I-64. Polished slabs from the top and bottom half of the pavement are illustrated in Figures 6 to 10. The results of the linear traverse analyses and density measurements are shown in Table 1. Total air content, air content in voids smaller than 1 mm and voids larger than 1 mm in percent as well as the spacing factor are reported. These measurements were made on samples representing either the top half or the bottom half of the pavement.

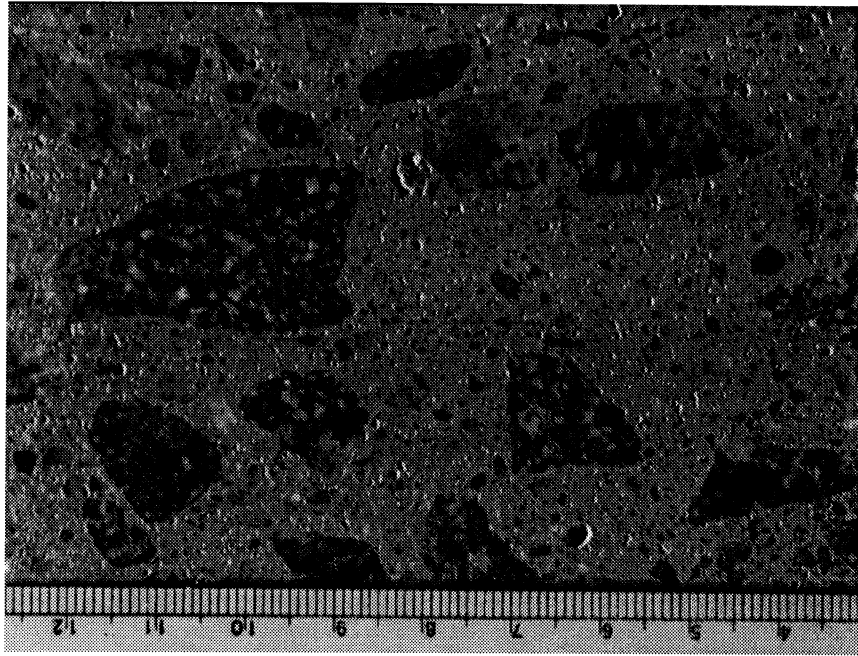


Figure 1. P2190T

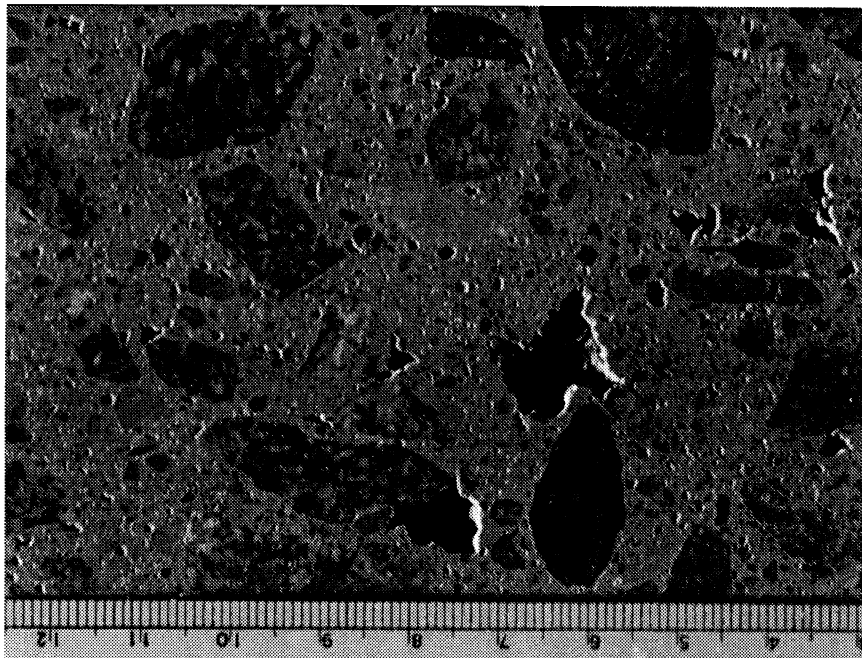


Figure 2. P2190B

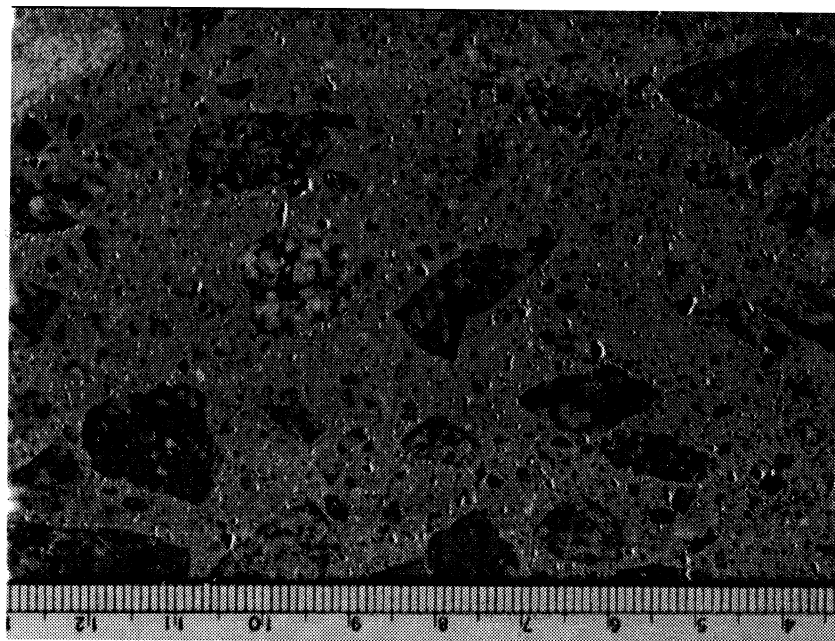


Figure 3. P2191T

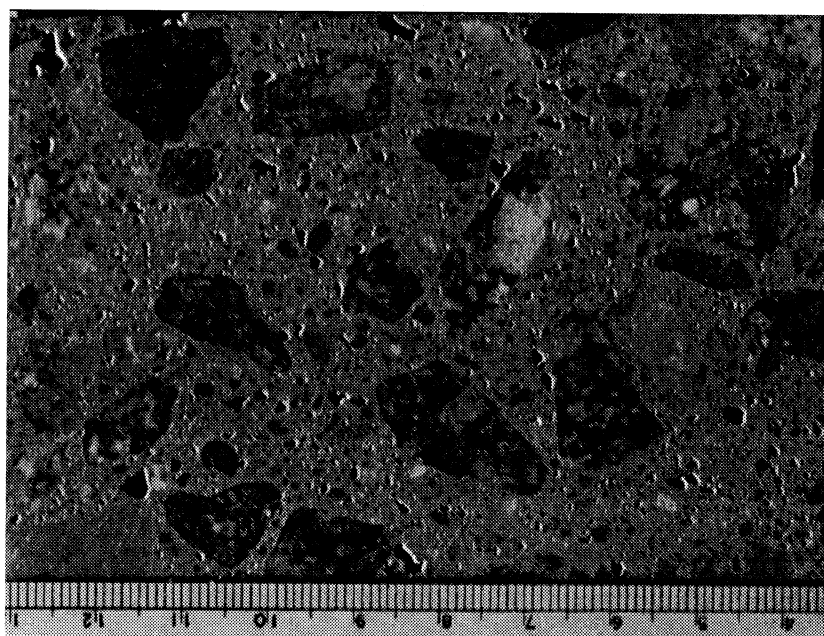


Figure 4. P2191B

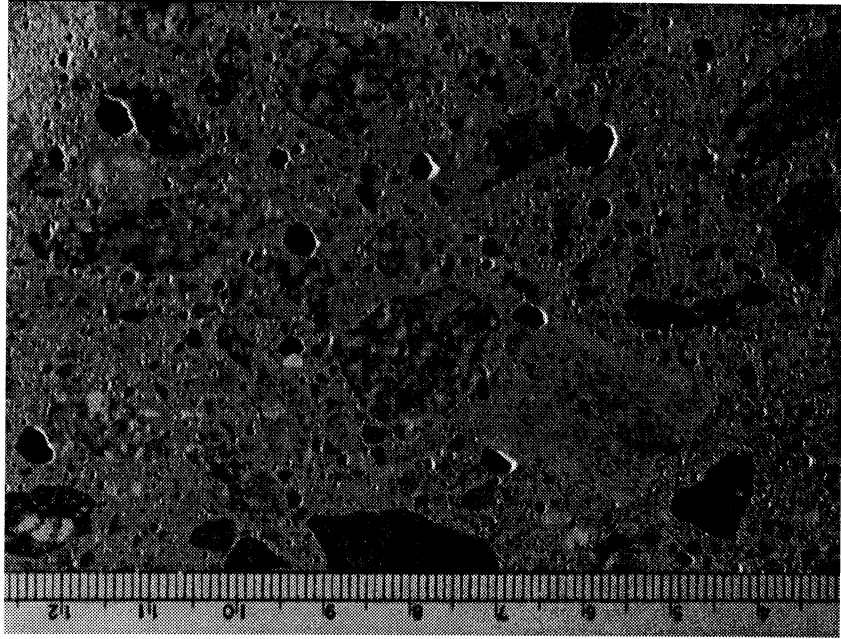


Figure 5. P2180B

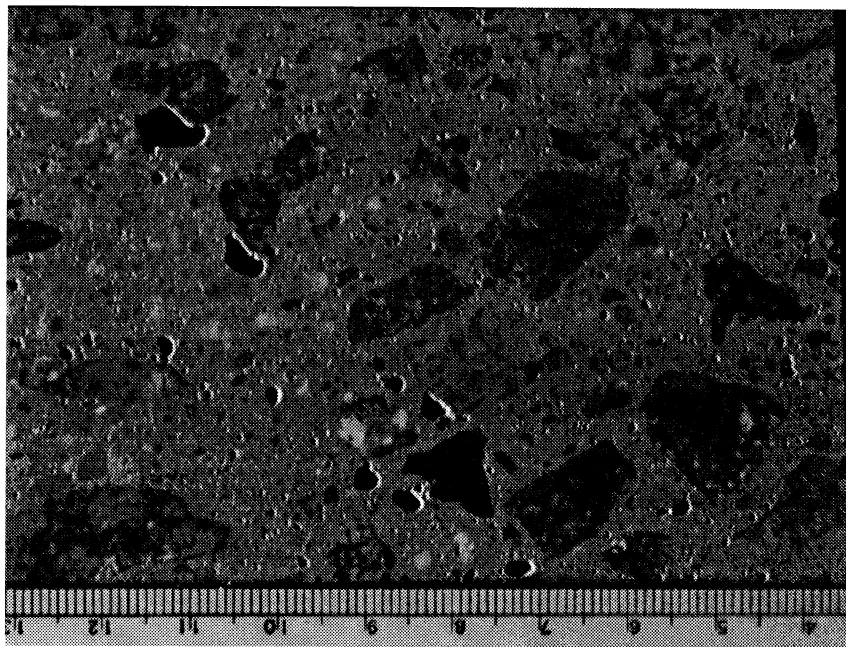


Figure 6. P2181B

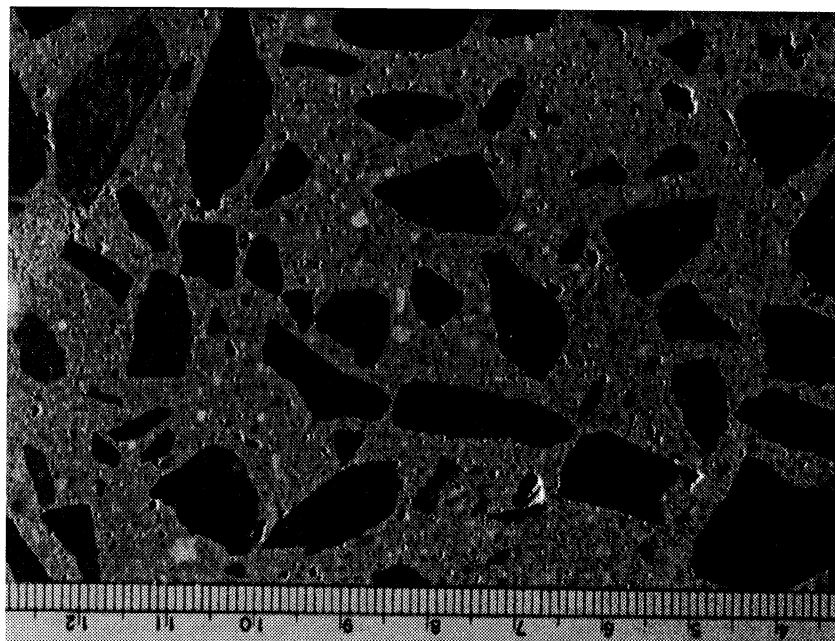


Figure 7. P2192T

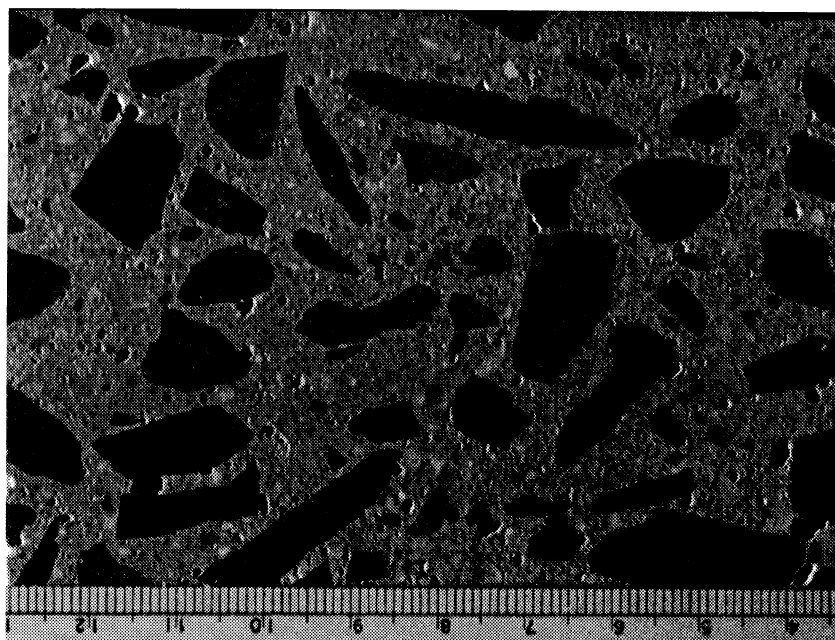


Figure 8. P2192B

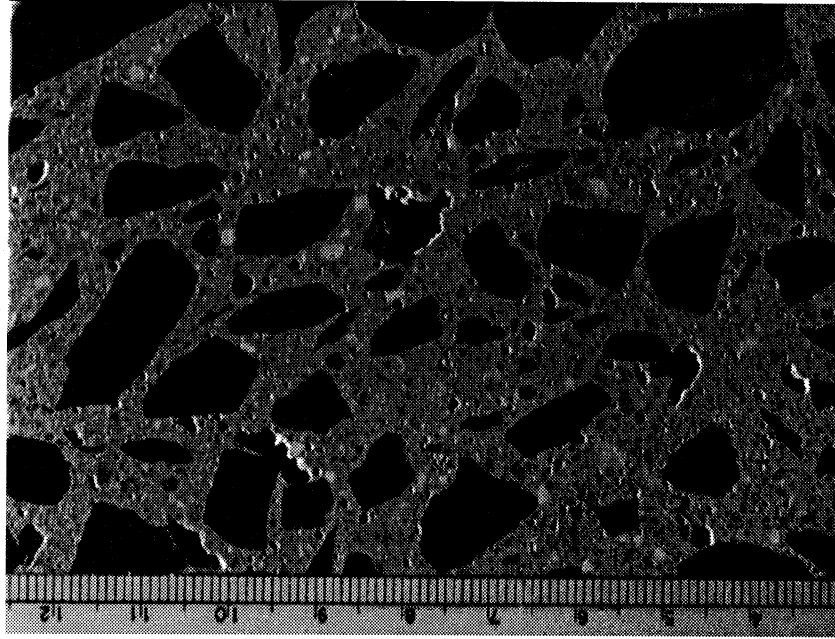


Figure 9. P2193T

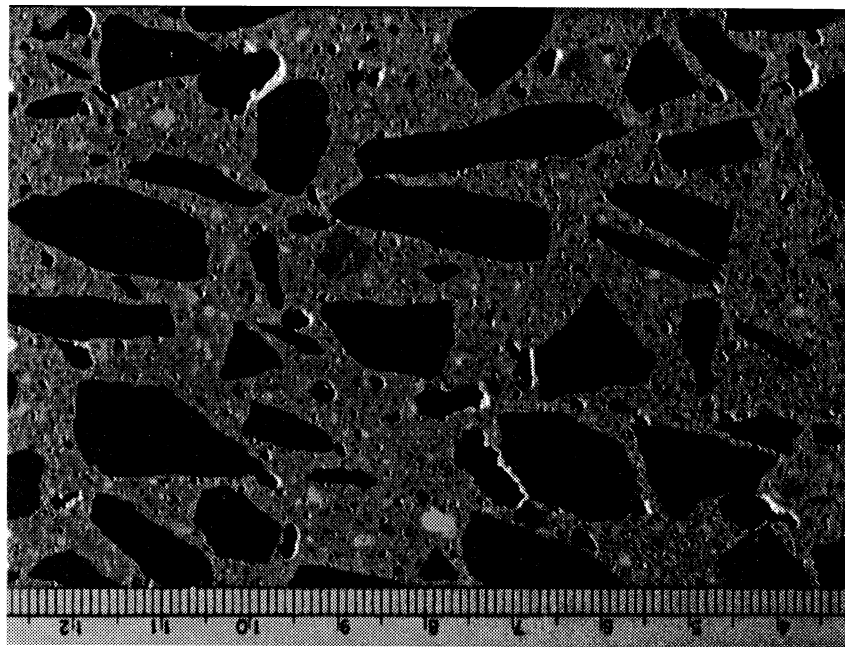


Figure 10. P2193B

Table 1: Results of Air Content and Density Tests

		Air Content %			Spacing Factor (in)	
	Sample	Total	<1 mm	>1 mm		
I-64						
	Top half of pavement:					
	P2190T	6.4	4.9	1.6	0.004	
	P2191T	3.9	2.9	1.0	0.005	
	Bottom half of pavement:					
	P2080B	8.8	5.1	3.6	0.004	
	P2081B	6.8	3.7	3.1	0.006	
	P2190B	10.8	4.4	6.4	0.005	
	P2191B	6.5	3.9	2.7	0.005	
US 460						
	Top half of pavement:					
(12 + 49)	P2192T	4.7	2.5	2.2	0.007	
(39 + 20)	P2193T	7.2	2.9	4.3	0.007	
	Bottom half of pavement:					
(12 + 49)	P2192B	6.1	3.0	3.0	0.006	
(39 + 20)	P2193B	8.5	3.2	5.3	0.007	

DISCUSSION

The air void analyses of the cores from the I-64 project indicate that all specimens possessed an adequate air void system with respect to freezing and thawing (spacing factor <0.008 in). However, a clear difference in the percentage of air in entrapped voids present in the top half of the pavement versus the percentage present in the bottom half is also indicated. In the top half, entrapped voids accounted for about 1.5 percent or less of the volume of the sample. In concrete produced with a No. 57 size coarse aggregate, approximately 1.5 percent entrapped air

is anticipated in adequately consolidated concrete.⁵ A volume of entrapped voids exceeding 2 percent is considered excessive and indicative of failure to achieve adequate consolidation.⁴ In the bottom half of cores the volume of entrapped voids ranged from 2.7 to 6.4 percent.

Similar results were obtained on specimens from the US 460 pavement with respect to void system spacing factors. In all cases, spacing factors indicated resistance to freezing and thawing. Although higher entrapped void contents were found in the bottom of the pavement than in the top, as in the I-64 cases, in the US 460 pavement, both the top and bottom had excessive entrapped void contents ($> 2\%$).

In the case of both pavements, the high entrapped void contents in the bottom half of the pavement indicates that this portion of the concrete received inadequate consolidation. Because the effect of internal vibrators is limited to a "radius of action" about the vibrator,² concrete at some distance from the vibrator will not be densified. This deficiency can primarily be attributed to the method of placement used in which the vibrators were inserted only to a point somewhat above the preplaced dowels (at approximately mid-depth) in the pavement section. Although this method undoubtedly facilitates concrete placement, in these cases thorough consolidation, a fundamental aspect of concrete placement, was not achieved. ACI 309R, "Guide for Consolidation of Concrete,"⁶ recommends that for nonreinforced pavements with a thickness greater than 10 in, internal vibrators be set with the tip about 2 in from the subbase.

In the US 460 pavement, an excessive entrapped void content was also found in the top half indicating a more general problem with consolidation on this project. The poor consolidation may have resulted from one or more factors: insufficient vibrator frequency; one or more malfunctioning vibrators; excessive speed of the paving machine; stiff concrete.

The cores examined in these cases were not from the vicinity of the doweled joints; however, it is reasonable to infer that consolidation in these areas was inadequate as well. Poor consolidation at doweled joint areas may lead to loss of load transfer across joints, which may eventually lead to problems such as faulting, pumping, and surface or bottom spalling, severely reducing the rideability of the pavement.

CONCLUSION

The entrapped void content of concrete in sections of two recently constructed concrete pavements was found to be excessive. In both cases, the entrapped void content of the lower half of the pavement was higher than the upper half. This situation apparently occurred because the vibrators were set to ride above the preplaced dowel assemblages.

In one of the cases, consolidation of the upper half of the pavement was adequate. However, in the other case, the entrapped void content of the upper half of the pavement was also found to be excessive. This situation resulted from one or more factors which caused a diminished densification of the concrete.

Whiting and Tayabi¹ have shown that insufficient consolidation of concrete in pavement adversely affects the compressive strength, leading to reduced service life, as well as the performance of doweled joints. To obtain the maximum performance and serviceability from concrete pavements, adequate consolidation must be achieved during construction.

RECOMMENDATIONS

1. During preplacement conferences and actual construction, emphasize the importance of adequate consolidation of concrete throughout the pavement, especially in the vicinity of dowel assemblages.
2. Consider alternative methods of dowel placement. Pavers with dowel bar inserters are available. It is reported that this type of equipment will be used in pavement construction on I-66 later this year.
3. Investigate methods to evaluate and monitor consolidation during construction. Nuclear gauges are used for this purpose in some states¹ although not all applications have been successful.⁷ Ultrasonic techniques show promise for this application.⁸

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