

## TWO-COURSE BONDED CONCRETE BRIDGE DECK CONSTRUCTION

Interim Report No. 2

Concrete Properties and Deck Condition Prior  
to Opening to Traffic

by

Samuel S. Tyson  
Research Engineer

(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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## SUMMARY

Presented in this report is information concerning the characteristics of the concretes used to construct six experimental two-course bonded bridge decks in Virginia. The quality of the overlay concretes produced under standard specifications supplemented with special contract provisions is described. Recommendations are made concerning the attainment of desired cover depths over the topmost reinforcement and the attainment of adequate consolidation in the overlays.

The several procedures that have been used to compare the condition of the two-course decks with that of conventional, single-lift control decks are discussed, and it is concluded that the two-course decks indicate a greater potential for satisfactory performance. Determinations of future performance will be based on comparisons of data from tests as visual surveys and soundings, chloride analyses, electrical potentials, sonic pulse velocities, and skid resistance of the decks.



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## INTRODUCTION

The two-course bonded technique for concrete bridge deck construction was used in the construction of six bridge decks on the Route 7 Bypass at Berryville, Virginia, in June 1974. A research project was initiated to study the construction, condition, and five-year performance of these decks. The objective of this study is to develop information concerning the two-course technique as it relates to local and national interest in the premature deterioration of concrete bridge decks.

It is believed that from the standpoint of durability and skid resistance two-course construction offers two advantages over normal single-lift construction. The major advantage of the two-course construction technique is that it permits the substitution of special concretes for the wearing course layer that either could not be placed in the reinforced zone of the deck due to insufficient workability, or would not be used for the full deck thickness because of cost considerations. Since these special concretes are accommodated in the original structural design by eliminating essentially all of the normal concrete cover when the base layer is placed, the dead load of the superstructure is unchanged. Special concretes for the wearing surface can be any concrete that is able to withstand the severe environment to which exposed bridge decks are subjected. Overlay concretes should be selected not only on the basis of traditional measures of quality as strength and freeze-thaw durability, but also with consideration for their ability to resist intrusion to the steel of corrosive agents such as chlorides from deicing operations on the deck surface.

In the Virginia study, three concretes were selected for use in the wearing course layers; a high quality (low w/c) portland cement concrete, a wire fiber reinforced concrete, and a latex polymer modified concrete. Each concrete was selected to improve

the resistance of the concrete above the reinforcement to the intrusion of corrosive substances, particularly chlorides. Lower water cement ratios reduce the permeability of the cement paste, with the most significant improvement being realized by not exceeding an 0.4 ratio.<sup>(1)</sup> Fiber reinforcement resists the formation of microcracks which permit accelerated intrusion of deleterious substances, and the polymer modifiers resist such cracking and also occupy a portion of the internal pore structure of the concrete.

The second advantage of the two-course technique stems from the fact that concrete, even after it has been properly consolidated by mechanical vibration, tends to bleed and subside, and the result is a weakened upper zone with possible cracking above the reinforcement. The bleed water is, in fact, part of a large excess of water that is not required by the cement for adequate hydration, but is necessary in the mixture to impart sufficient workability. The bleeding phenomenon occurs in the two-course deck as well, but because the base layer is struck off just above the top level of reinforcement and allowed to harden prior to placement of the overlay, or wearing course, the effects of subsidence are isolated in the base layer.

#### BACKGROUND

The eight decks in this study had a minimum design thickness of 8.5 in. (216 mm) and rested on simply supported steel girders having a center to center spacing of 8.5 ft. (2.5 m). The decks were approximately 50 ft. (15.2 m) in length with a clear roadway width of 38.0 ft. (11.6 m).

The project plan for the six two-course decks is depicted in Figure 1, along with that for the two control decks on nearby structures that were constructed within the same contract by a conventional, single-lift technique. Each of the three special wearing course concretes was applied as an overlay for two of the two-course decks.

The initial report on this study presented the results of an evaluation of the two-course construction technique conducted by comparing it with the single-lift technique typically employed in Virginia.<sup>(2)</sup> In the research then reported, the construction activities were analyzed to determine the relative influence of the two techniques on the times required to batch, deliver, and place the conventional and overlay wearing surface concretes.

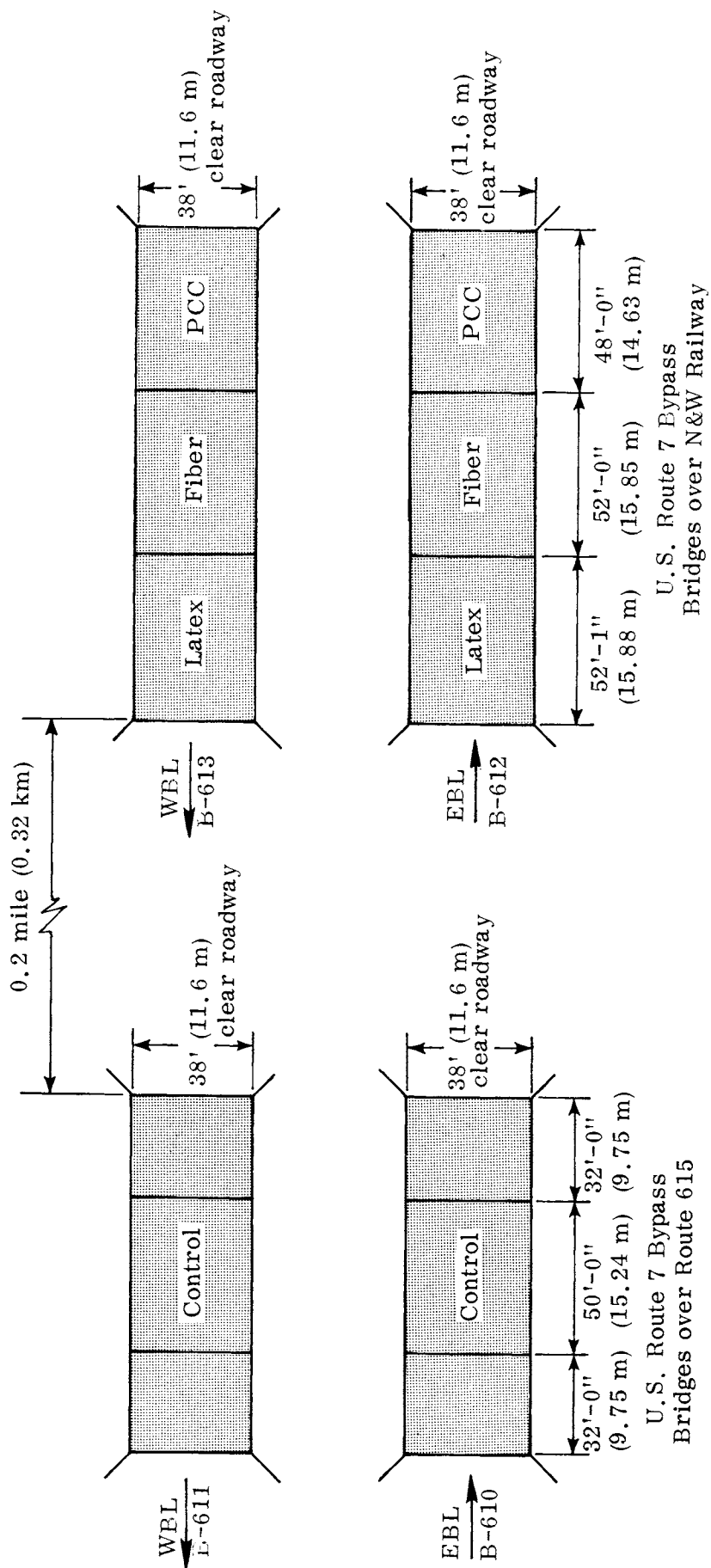


Figure 1. Plan view of bridge structures.

The information presented in that report led to the observations and conclusions presented below.

1. The base layer concrete of the two-course decks was screeded satisfactorily using the transverse screed selected by the contractor for the overlay installations.
2. Light sandblasting of the base layers removed laitance that may have adversely affected the bond between the base layers and overlays.
3. The two-day delay between placement of a base layer and overlay is a desirable period. To avoid excessive drying the bonding layer of cement slurry should be broomed onto the base layer not more than 10 ft. (3 m) ahead of nor longer than 15 minutes prior to the placement of overlay concretes.
4. The overlay concretes of the two-course decks were consolidated and finished satisfactorily using a transverse rotating drum screed with an attached surface vibrator unit.
5. The design strength of 4,000 psi (27.6 M Pa) at 28 days required in the structural concrete decks was exceeded significantly by the overlay concretes, thereby suggesting improved potential for good durability of these air entrained mixes.
6. Clear concrete cover over the topmost reinforcing steel on the two-course decks was determined to be 2.3 in. (58.4 mm) of which 0.3 in. (7.6 mm) was mortar resulting from the base layer construction. This depth of cover is within one standard deviation of the average depth recorded for conventional, single-lift bridge deck construction in Virginia.
7. Time and sequence data indicated a similar, orderly progression of construction activities for the two-course decks and the conventional, single-lift decks.
8. A 7 yd<sup>3</sup> (5.4 m<sup>3</sup>) truckload of concrete was screeded over 3½ times as much surface area for an overlay as for conventional, single-lift decks, however the average duration per truckload between the initial deposit and the completion of the screeding activity on the wearing surface was approximately the same in both the two-course and single-lift techniques.



9. Not including texturing and curing activities, the average man-hours required to install concrete in the separate layers of the two-course decks was 33% greater than for conventional, single-lift decks.
10. In terms of project days required for construction the two-course and single-lift techniques are equivalent.
11. Coefficients of variation for the time intervals required to install each of the overlays and base layers were comparable to values representing excellent control for single-lift construction.
12. The three overlay concretes -- latex modified concrete, high quality PCC, and wire fiber reinforced concrete -- had placement characteristics that were compatible with the equipment and personnel employed in the two-course construction technique.
13. The batching activity was the only installation activity whose duration was significantly affected by differences in the three types of overlay concretes.
14. The total additional cost of the two-course technique was approximately 5% of the cost of the bridge deck superstructure.

The information in that report demonstrated, from an operational standpoint, that the two-course bonded construction technique is a reasonable alternative to conventional, single-lift construction when additional protection of the upper reinforcing steel is warranted. Furthermore, because of the wide range of handling characteristics of the three overlay concretes used, it was suggested that any concrete having similar characteristics plus desirable properties as low permeability, good compressive and bond strengths, and freeze-thaw resistance could be successfully applied in the two-course technique.

#### PURPOSE

The first objective of this report is to present information on characteristics of the concretes in the two-course and control decks in this study; the second is to report findings that indicate initial deck conditions prior to opening to traffic and which will serve as the basis for determinations of future performance for these decks.

## SCOPE

The testing program conducted for the research reported here is outlined in Table 1. Determinations of concrete characteristics were made from tests that are specified for routine acceptance of concrete in the field, plus additional tests that provide a broad base for the analysis of concrete characteristics in the eight decks. Table 1 also lists the test procedures that were conducted on the decks approximately one year after construction, which was just prior to the time the roadway was scheduled to be opened for traffic. The results of these tests on the mature bridge decks will be compared with similar test data in the future for evaluations of deck performance.

Table 1

Testing Program for Concretes in Each Overlay, Base Layer and Control Deck

Purpose	Test	Concrete		Number of Specimens or Tests
		Fresh	Hardened	
Concrete Characteristics	Routine Acceptance:			
	Air	X		1/batch
	Slump	X		1/batch
	Temperature	X		1/batch
	Strength		X	4/batch
	Additional:			
	Cement Content		X	2
	Fiber Content*		X	4
	Freeze-Thaw		X	4
	Cover Depth -			
	Probes	X		20
	Pachometer		X	20
	Consolidation -			
	Nuclear	X		20
Rodded Unit Weight	X		4	
Cylinders		X	4	
Cores		X	1	
Acoustic	X		2 (trial slab)	
Deck Evaluations	Visual Survey		X	1
	Soundings		X	1
	Cl <sup>-</sup> Content		X	2
	Electrical Potentials		X	66
	Sonic Pulse		X	44
	Skid Resistance		X*	5/lane

\*Applicable only to wire-fiber reinforced concrete.

## CONCRETE CHARACTERISTICS

In Virginia, bridge deck concrete must attain a design minimum laboratory compressive strength of 4,000 psi (27.6 MPa) at 28 days after the concrete is molded into 6 in. x 12 in. (152 mm x 305 mm) cylinders. Other properties for normal superstructure concrete are listed in Table 2. The only difference between this concrete and the concrete specified for the base layers of the two-course decks can be seen to be the type of fine aggregate. The aggregate from source 1 is a nonpolishing aggregate which is needed for skid resistance on trafficked surfaces but is not needed in the lower structural zone of the deck. Since the aggregate from source 2 was in the proximity of the project, this provision encouraged its utilization in the base layers.

The background information associated with the selection of the three overlay concretes was presented in the initial report from this study.<sup>(2)</sup> Specified properties of these concretes are also listed in Table 2. In order to reduce the water to cement ratios these mixes were proportioned with higher cement factors than that specified for normal superstructure concrete. Additionally, the nonpolishing fine aggregate for these mixes was obtained from source 3, since its void content and the resulting water demand of concrete produced with it could be predicted to be desirably low. The voids contained in the fine aggregates from sources 1, 2, and 3 were 51.2%, 49.5% and 48.9%, respectively, as measured by VTM-5 of the Virginia Test Methods Manual (July 1970).

On this experimental project normal procedures were used by the contractor to satisfy requirements for the concretes in the control decks and in the base layers and overlays of the two-course decks. In subsequent sections of this report the results of routine acceptance testing, based on air contents, slump, temperature, and strength, and other tests of the hardened concretes as cement, void and fiber contents and freeze-thaw resistance are presented to indicate the degree of conformance achieved in the concrete mixtures. These additional tests on the hardened concretes were made using samples cut from cast cylinders as depicted in Figure 2.

Also presented in subsequent sections of this report is information resulting from tests of the fresh and hardened concretes in the control decks and overlay portions of the two-course decks to determine the depths of cover over the top reinforcing steel and the effectiveness of the consolidation provided for these concretes.

Table 2  
Concrete Properties Specified for Eight Bridge Decks in Study

Concrete Specified	Span Identification	Cement Content <sup>3</sup> lb./yd. <sup>3</sup> (kg/m <sup>3</sup> )	Air Content, % Volume	Slump, inches (mm)	Maximum w/c <sup>a</sup>	Nominal Maximum Coarse Aggregate <sup>b</sup> Size, inches (mm)	Fine Aggregate Type
Normal Super- structure	B610, B611 (center spans)	635 (377)	6.5 ± 1.5	3 ± 1 (75 ± 25)	0.47	1 (25)	Natural siliceous (source 1)
Base Layer	B612, B613 (all spans)	635 (377)	6.5 ± 1.5	3 ± 1 (75 ± 25)	0.47	1 (25)	Crushed limestone (source 2)
Latex Modified <sup>c</sup>	B612, B613 (west spans)	658 (390)	4.5 ± 1.5	5 ± 1 (125 ± 25)	0.49	1/2 (13)	Natural siliceous (source 3)
High Quality PC	B612, B613 (center spans)	705 (418)	6 ± 2	2.5 max. (63 max.)	0.41	1/2 (13)	Natural siliceous (source 3)
Wire Fiber <sup>d</sup>	B612, B613 (east spans)	752 (446)	6 ± 2	3 ± 1 (75 ± 25)	0.44	1/2 (13)	Natural siliceous (source 3)

<sup>a</sup> Maximum values calculated from construction records; weight ratio.

<sup>b</sup> Crushed limestone (source 2).

<sup>c</sup> Polymer type-styrene butadiene; 24.5 gallons (92.7 litre), 46.0 - 49.0 % solids.

<sup>d</sup> Steel fibers 1 inch (25 mm) in length by 0.016 inch (0.41 mm) diameter; 160 lb/yd<sup>3</sup> (95 kg/m<sup>3</sup>).

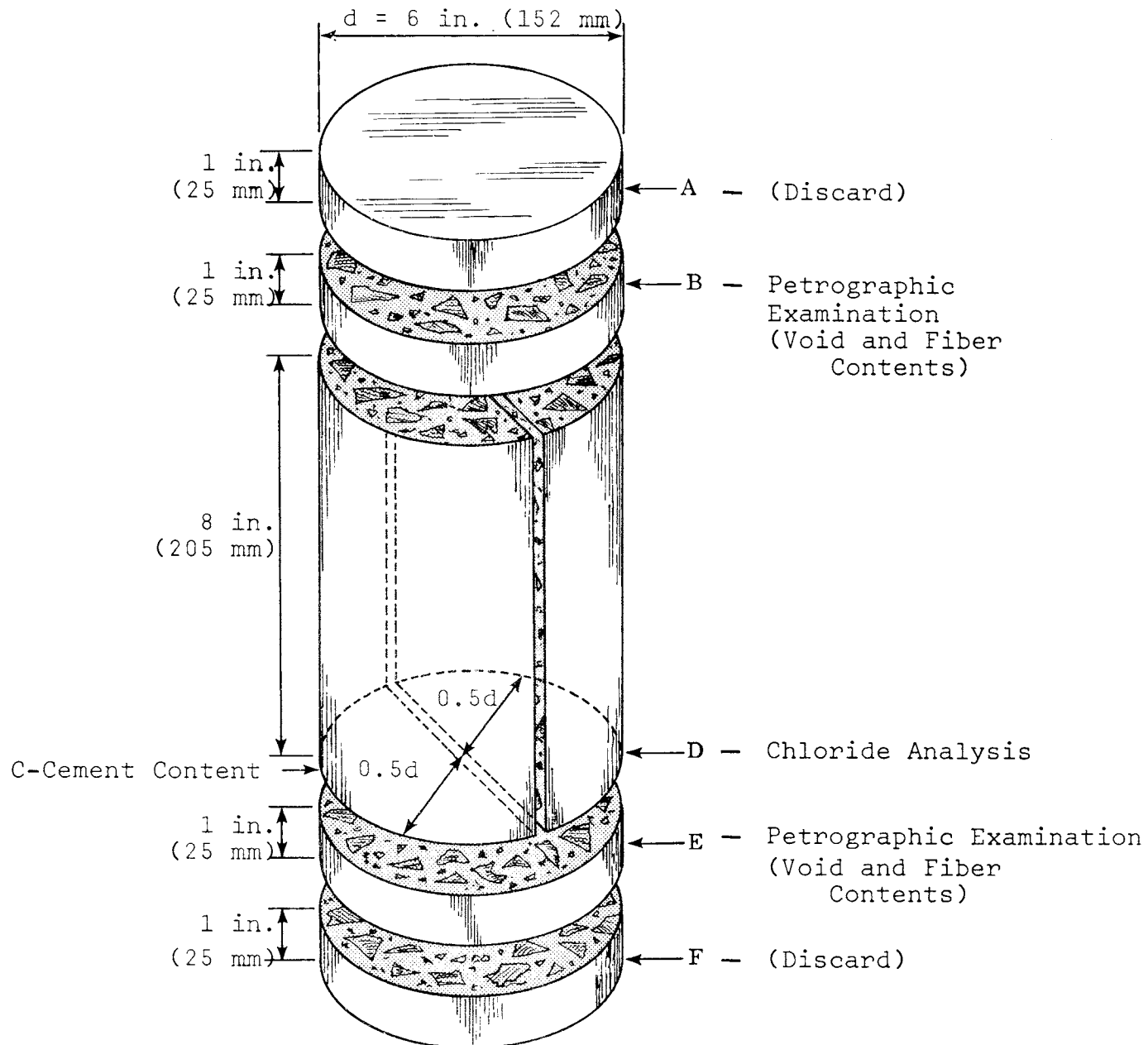


Figure 2. Pattern used to cut cylinders for analysis and examination.

## Acceptance Tests

The properties of the concretes that went into the eight bridge decks of this study are listed in Table 3. The air contents, slumps and concrete temperatures were within normal ranges of variability for each concrete, however the strengths of the normal superstructure concrete used in the single-lift control decks were consistently lower than expected. Strengths for the base layer concrete of the two-course decks exceeded the design minimum in every case, and, as discussed earlier, the only difference in the proportions of the base layer concrete as shown in Table 2 was the allowed substitution of a locally available polishing fine aggregate (source 2) which had a lower void content than that of the nonpolishing fine aggregate (source 1) used in the single-lift decks. The lower strengths of concrete in the single-lift decks were attributed to the higher water demand of the fine aggregate used (source 1).

Table 3

Concrete Properties for Study Decks  
and Weather Data at Time of Placement

Placement Identification	Sample Number	Air Content, % Volume		Slump, Inches	Compressive Strength, psi 7-Day 28-Day	Concrete Temp., °F	Air Temp., °F	Relative Humidity, %	Wind Velocity, mph	
		Pressure	Chace							
Single-Lift B-611 5-15-74	1	7.6	6.0	5.5	2210 3070	81	84	50	5-10	
	2	7.4	6.0	3.2	2490 3710	79	86	46	5-10	
Single-Lift B-610 5-28-74	1	7.1	6.5	3.1	3050 3770	70	58	50	10	
	2	7.3	6.6	3.0	3170 3640	70	64	45	10	
Base Layer B-613 6-4-74	1	4.8	5.0	3.5	3050 4770	78	70	50	0-5	
	2	6.0	5.25	4.7	3290 4350	79	76	45	0-5	
Base Layer B-612 6-5-74	1	5.5	5.75	3.5	3630 4150	81	78	45	0-2	
	2	4.6	5.5	4.9	3430 4620	82	80	40	5-8	
Latex Overlay B-613 6-6-74	1	3.2	1.5	7.5	3270 3860	78	75	65	0-5	
	2	3.4	3.0	5.5	3110 4160	78	80	50	0-5	
Latex Overlay B-612 6-7-74	1	3.4	-	3.2	3610 4420	-	-	75	5-10	
	2	3.2	-	5.0	3730 4380	-	-	75	5-10	
Base Layer B-613 6-18-74	1	4.8	5.0	4.5	3800 5040	82	78	50	5-10	
	2	6.5	5.0	4.2	3470 4550	85	80	45	5-10	
Base Layer B-612 6-18-74	1	6.0	5.0	5.0	3450 4390	85	88	40	5	
	2	7.0	-	5.5	3230 4330	86	80	40	0-4	
PCC Overlay B-613 6-20-74	1	3.3	3.5	2.9	4490 5607	82	80	50	0-5	
	2	4.5	5.0	2.8	4315 4952	79	93	60	0-5	
PCC Overlay B-612 6-20-74	1	5.5	5.0	3.3	3953 4280	80	98	62	5-10	
	2	4.4	3.5	2.7	3930 4616	83	85	60	0-5	
Base Layer B-613 6-25-74	1	5.6	5.0	4.0	3840 5140	78	64	60	0-3	
	2	6.7	5.0	4.8	3785 4850	78	64	60	0-5	
Base Layer B-612 6-25-74	1	6.3	6.0	3.5	3600 4850	79	72	62	0-2	
	2	5.9	5.0	4.0	3860 4850	79	71	61	0-5	
Fiber Overlay B-613 6-27-74	1	4.5	4.5	3.4	5200 5340	84	62	75	0	
	2	5.2	5.0	5.4	4713 4990	80	65	73	0	
Fiber Overlay B-612 6-27-74	1	9.1	8.1	5.5	4263 5310	82	70	70	10+	
	2	9.9	-	5.5	3042 3660	81	74	62	10+	
To convert to:					mm	kPa	°C	°C	—	km/hr.
Multiply by:					25	6.894	(-32)/5/9	(-32)/5/9	—	1.6

Cement Contents

The cement contents specified for the concretes in the control decks and in the base layers and overlays of the two-course decks were shown in Table 2. The proportions of each concrete were monitored during batching and subsequently the cement contents of the hardened concretes were determined from sections of cast cylinders as shown in Figure 2.

A method of selective solution by a methanolic maleic acid was used to determine the cement contents.<sup>(3)</sup> The results of this method are affected by the type and amount of aggregates contained in hardened concretes, and for the concretes in this study the accuracy of the cement determinations was predicted to be within a range of  $\pm 10\%$  of the specified amounts. In Table 4 the differences between the amounts of cement measured by the maleic acid method and the amounts specified for each concrete are expressed as percentages of the specified amounts. The differences are within the predicted range and indicate good control for the concretes.

Table 4  
Cement Contents for the Study Decks

Type/Concrete	a Specified, lb./yd. <sup>3</sup> (kg/m <sup>3</sup> )	b Measured, lb./yd. <sup>3</sup> (kg/m <sup>3</sup> )	(b-a) x 100/a Difference, %
Control	635 (377)	687 (408)	+ 8.2
Base Layer	635 (377)	648 (384)	+ 2.1
Latex	658 (390)	665 (395)	+ 1.0
PCC	705 (418)	728 (432)	+ 3.2
Wire Fiber	752 (446)	683 (405)	- 9.2

Latex and Wire Fiber Concretes

The latex modified concrete was produced at the job site by a mobile mixing unit with a continuous auger-type mixer. This unit was calibrated in general conformance to the requirements of ASTM C685 one day prior to the first latex overlay installation. On the basis of prior experience with this proprietary concrete, further checks of its unique polymer characteristics were not deemed necessary.

The wire fiber reinforced concrete used in this study contained steel fibers that were 1.0 in. (25 mm) in length with a circular cross section having a diameter of 0.016 in. (0.41 mm). The special vibrating table and chutes that were constructed at the batching plant for introducing the fibers to the ready-mix trucks were shown in an earlier report.<sup>(1)</sup> The fiber content specified was 160 lb./yd.<sup>3</sup> (95 kg/m<sup>3</sup>), or 1.2% of the concrete volume. The total fiber addition was easily monitored at the plant since the fibers were received in 40 lb. (18.1 kg) boxed units. Because the uniformity of the fiber dispersion throughout the mix and the random orientation of the fibers within the concrete matrix are important assumptions on which the beneficial aspects of fiber additions are based, a limited investigation of these factors was made. Cast cylinders were prepared from each batch of wire fiber reinforced concrete, and sections for petrographic examination were cut from this hardened concrete as indicated in Figure 2. Information is presented in the following paragraphs concerning the fiber content, distribution, and orientation in these cylinders.

Fiber Content

The wire fiber contents in the cut sections from the cylinders were determined using the linear traverse (Rosiwal) method. The results of this examination are listed in Table 5 for each batch. The measured contents expressed as a percentage of the specified content vary from 83% to 108%.

Table 5

Wire Fiber Contents of Overlay Concrete

Batch No.	Specified Content, % Volume	Measured Content, % Volume	Measured as a % of Specified
1	1.2	1.3	108
2	1.2	1.1	92
3	1.2	1.2	100
4	1.2	1.0	83



### Fiber Distribution

The desired random distribution of the fibers in the mix may not necessarily be indicated by the close agreement between measured and specified fiber contents, because clumping of the fibers during mixing can cause concentrations. By dividing the surface of a cut section into a grid pattern as depicted in Figure 3, and counting the total number of fibers that appeared in each grid section, an assessment of the distribution was made. The grid consisted of 1 in. (25 mm) squares with the fiber counts recorded in the squares. The typical distribution of fibers per 1 in.<sup>2</sup> (645 mm<sup>2</sup>) varied from 15 to 43. A concentration of 160 fibers in one grid section is the result of the clumping, or balling, mentioned earlier. No reduction in durability is anticipated since a microscopic examination of such areas showed them to be filled with a continuous mortar having intimate contact with the fiber surfaces. This condition in test specimens under laboratory conditions has been found to inhibit corrosion, even in the presence of large amounts of chloride ions. Such fiber concentrations would, however, reduce the effectiveness of this reinforcement since fewer fibers than desired can be available in the remaining concrete matrix.

### Fiber Orientation

The fiber inclinations with respect to a horizontal datum plane (0 degrees), were computed from measurements of the elliptical fiber sections in a typical grid section as shown in Figure 4. Their inclinations varied from 15° to 90°, with an average of 51°. This average based on a small sampling reflects a skewed distribution favoring the vertical orientation of fibers due to the rodding involved in the cylinder preparation. The distribution of fiber orientations in the overlays has been assumed to be skewed towards the horizontal due to the screeding operation across the decks.

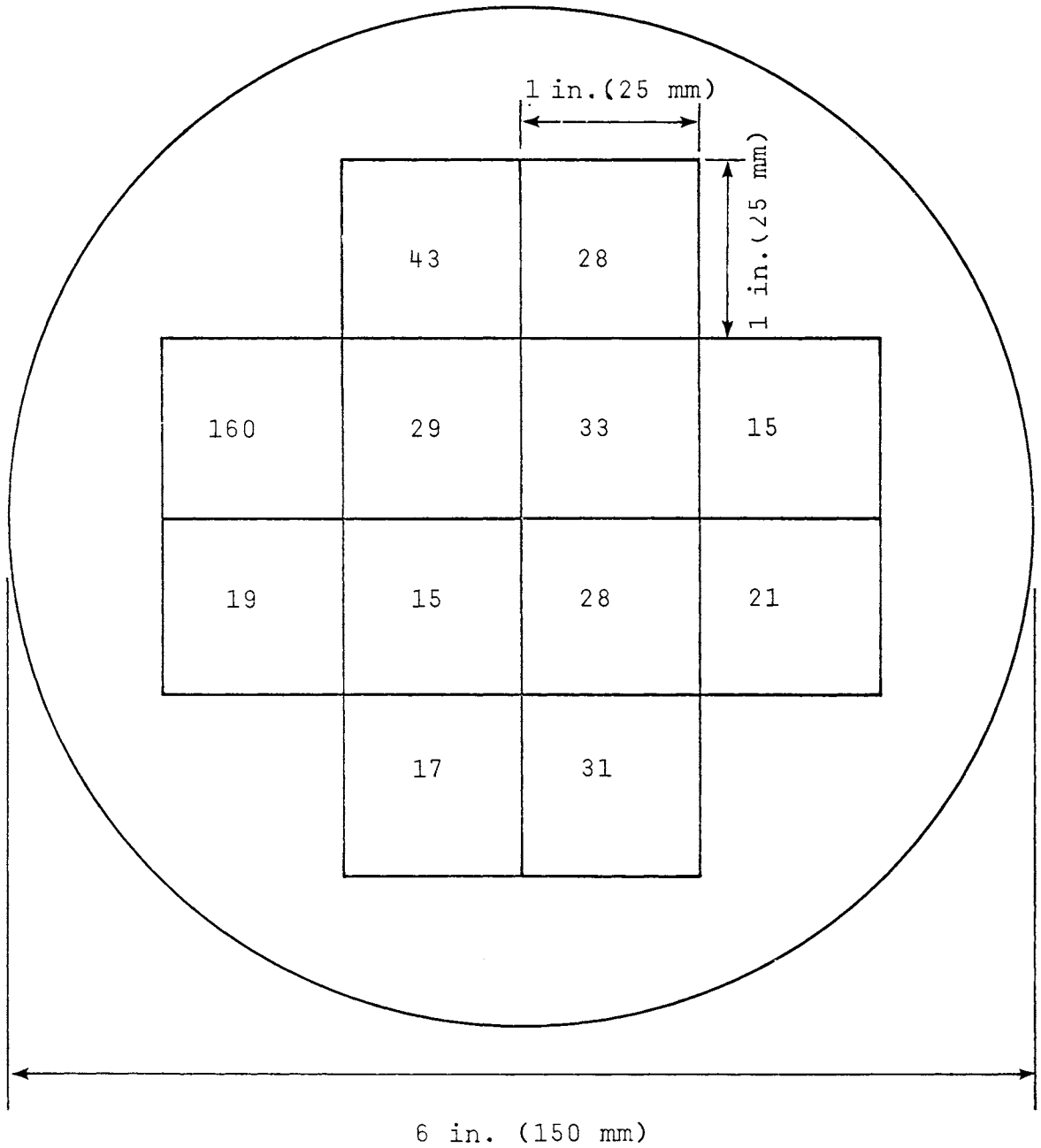


Figure 3. Grid pattern, with fiber counts, used to determine the wire fiber distribution in 6 in. x 12 in. (150 mm x 300 mm) cylindrical concrete specimens.

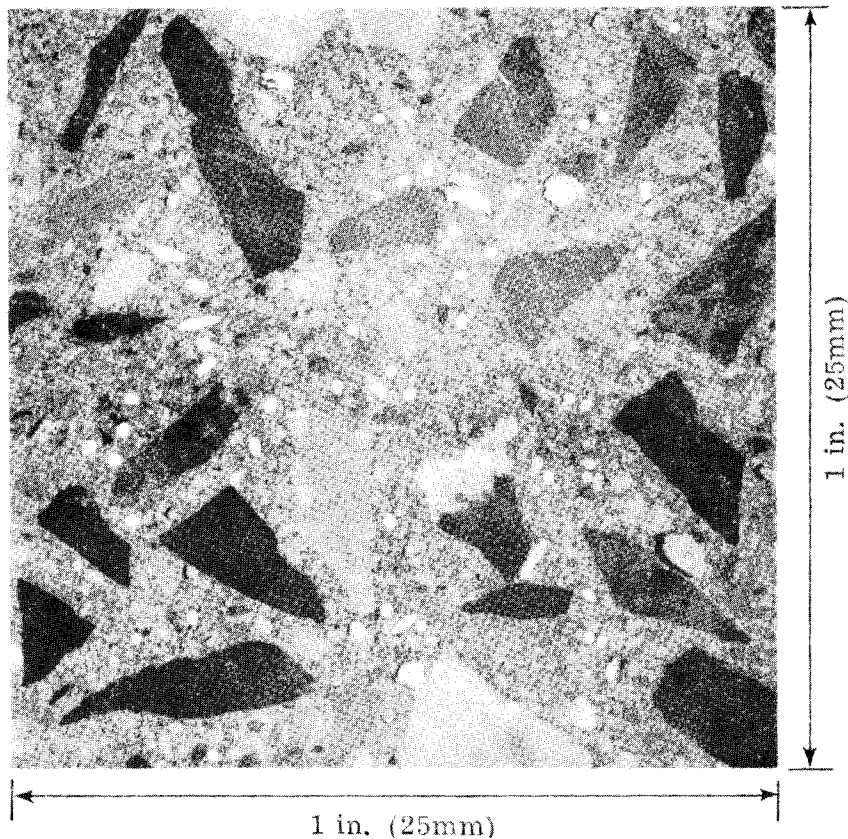


Figure 4. Typical grid section from which the orientations of wire fibers were computed.

#### Freezing and Thawing Tests

The resistance of bridge deck concretes to the effects of freezing and thawing cycles is an important factor influencing long-term performance. Concrete placed in the control decks and in each layer of the two-course decks was sampled randomly and used to fabricate four prismatic test specimens measuring 3 in. x 4 in. x 16 in. (76 mm x 102 mm x 406 mm). The freezing and thawing tests were conducted in accordance with ASTM C666 Procedure A, modified by using a solution of water and 2% Na Cl<sub>2</sub> by weight of the water as the medium surrounding the specimens.

Deterioration of the concrete test specimens takes place in three observable ways as the result of internal stresses that accompany the cycles. The loss of mortar from the surfaces of concrete specimens is recorded on the basis of a visual surface rating system and from continually decreasing specimen weights

recorded throughout the testing period. The visual rating and the weight loss are normally directly related for a particular concrete, with the actual appearance of the concrete surface at progressive stages of deterioration being dependent on the proportions of mortar and aggregates in the concrete. The scale for visual surface ratings is given in Table 6.<sup>(4)</sup> Good performance is indicated by surface ratings less than three and a weight loss not exceeding 7% at the end of 300 cycles of freezing and thawing.

Table 6

## Visual Rating System for Evaluation of Concrete Surfaces

Condition	Surface Appearance
0	No scaling
1	Very slight scaling 1/8 in. (3 mm) maximum depth and no coarse aggregate visible
2	Slight to moderate scaling
3	Moderate scaling — some coarse aggregate visible
4	Moderate to severe scaling

The performance of concretes subjected to freezing and thawing is also evaluated on the basis of dynamic testing for fundamental frequency (ASTM C215). The results of this testing are reported as durability factors (ASTM C666), with the best performance being indicated by high values and 100 being the upper limit. The magnitude of the durability factor is decreased slightly by dimensional changes due to loss of surface mortar, but significant decreases indicate the progression of internal cracking.

The average surface rating, percentage weight loss, and durability factor for each type of concrete are listed in Table 7. Each of the concretes performed well in this test, and this finding assures desirable freezing and thawing characteristics of the concretes as delivered for placement in each of the decks.

Outdoor exposure slabs fabricated with concretes from the project are being subjected to natural freeze-thaw cycles with heavy applications of deicing salts. These slabs, shown in Figure 5 in the Council's outdoor exposure area, are two-course and single-lift deck models having overall dimensions of 2 ft. x 3 ft. x 8.5 in. (0.6 m x 0.9 m x 216 mm) and containing the same reinforcing steel pattern as the structural decks. The deck models have undergone two winters of natural freeze-thaw cycles with no scaling or other indication of deterioration.

Table 7

Average Conditions of Concretes After 300 Cycles  
of Freezing and Thawing

Type Concrete	No. of Specimens	Surface Rating	Weight Loss, %	Durability Factor
Single-lift	8	1.9	2.0	96
Base Layers	24	2.2	1.8	96
Latex Modified	8	2.3	2.8	88
PCC	8	3.0	1.5	100
Wire Fiber	8	1.9	0.6	99

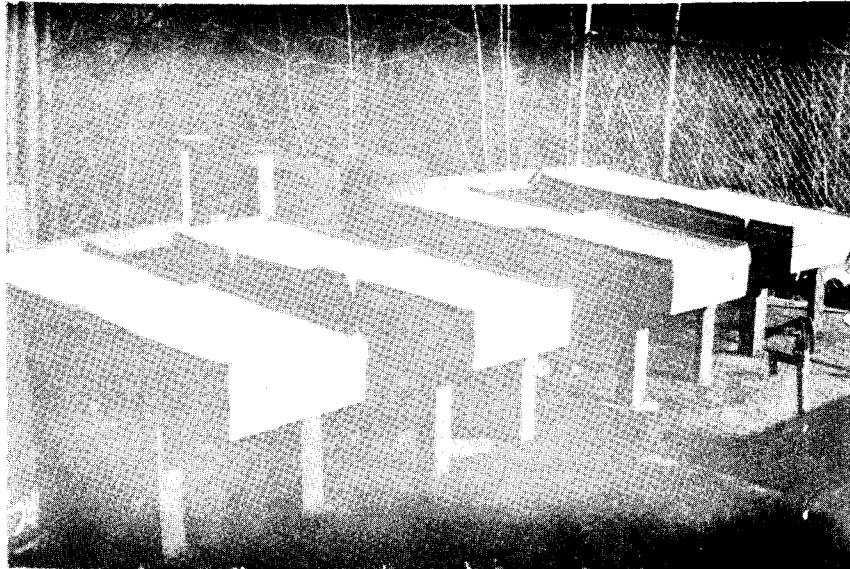


Figure 5. Two-course and single-lift deck models in outdoor exposure area.

Another purpose of these exposure slabs is for determinations of the rates at which the several concretes are infiltrated by chloride ions, and the results of this accelerated exposure testing will be used to suggest the relative protective qualities of these concretes.

### Depth of Cover

The depth of concrete cover over the topmost reinforcing steel of the study decks was determined by direct probes in the fresh concrete during construction and the statistical results from the depth probes are shown in Figure 6. The total depth of cover provided by the two-course technique was found to be equivalent to that provided by conventional, single-lift construction for identical deck designs.

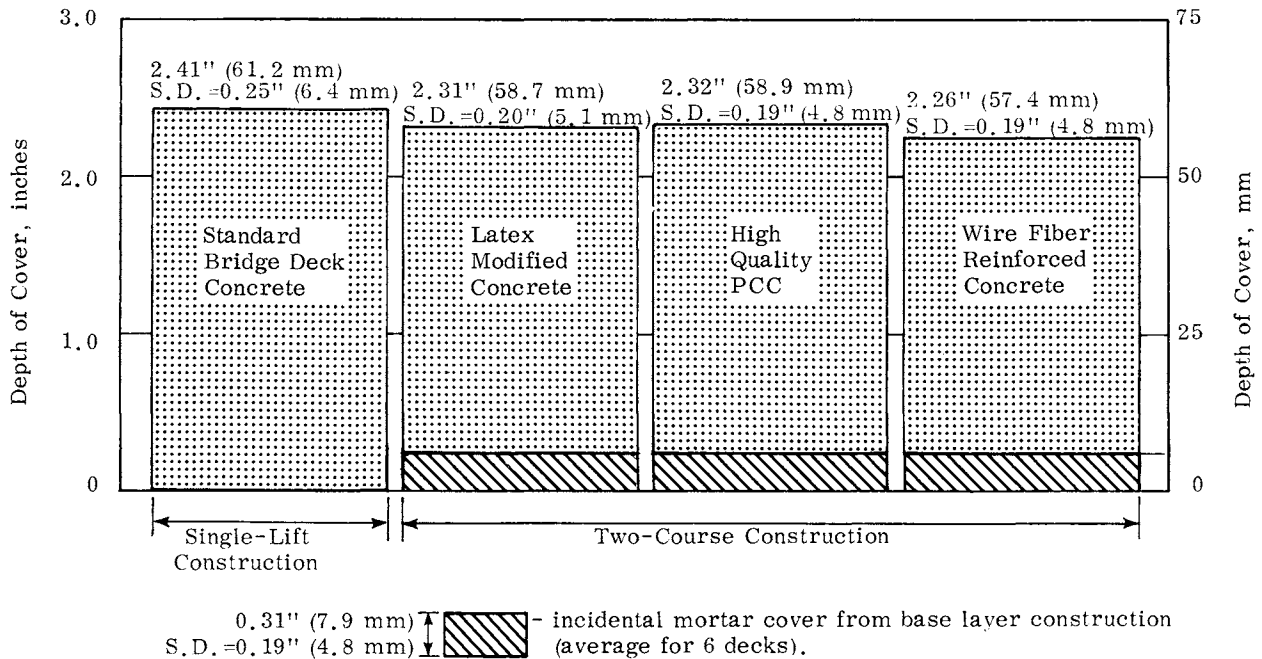


Figure 6. Depth of cover over topmost reinforcing steel for eight study decks.

Concrete cover on existing conventional decks in Virginia has been determined as a part of continuing evaluations of bridge deck construction and performance.<sup>(5)</sup> Such depth data from hardened decks have normally been obtained using the pachometer, so similar readings were made on the study decks. In Table 8 the concrete cover depths from pachometer readings on the hardened study decks are listed along with cover depths initially measured on the same decks by direct probes in the fresh concrete. Each value in Table 8 is the average of 40 measurements on each of the similar decks. The average depths from the two measurement techniques are within one standard deviation of each other and are therefore equivalent. The pachometer could not be used on the wire fiber reinforced concrete to measure depths of cover since the wire fibers at the surface cause uniform readings of zero depth.

Table 8

## Depth of Cover for Eight Study Decks

Type of Deck	Cover Depth, in. (mm) Standard Deviation, in. (mm)			
	Pachometer		Direct Probes	
Conventional	2.25	(57.2)	2.41	(61.2)
	0.16	( 4.1)	0.25	( 6.4)
Latex	2.50	(63.5)	2.31	(58.7)
	0.19	( 4.8)	0.20	( 5.1)
PCC	2.23	(56.6)	2.32	(58.9)
	0.21	( 5.3)	0.19	( 4.8)
Wire Fiber	----	-----	2.26	(57.4)
	----	-----	0.19	( 4.8)

Direct probes of the overlay course are desirable during construction when the concrete remains plastic to assure the attainment of specified cover depths while corrections can most easily be made. Also, since the direct probe data correlate closely with conventional pachometer readings, it is not necessary to obtain pachometer readings on two-course decks when making comparisons of cover between two-course and existing conventional decks. On the basis of direct probes of the concrete in the study decks, the six two-course decks were found to have average depth dimensions as shown in the typical transverse section in Figure 7.

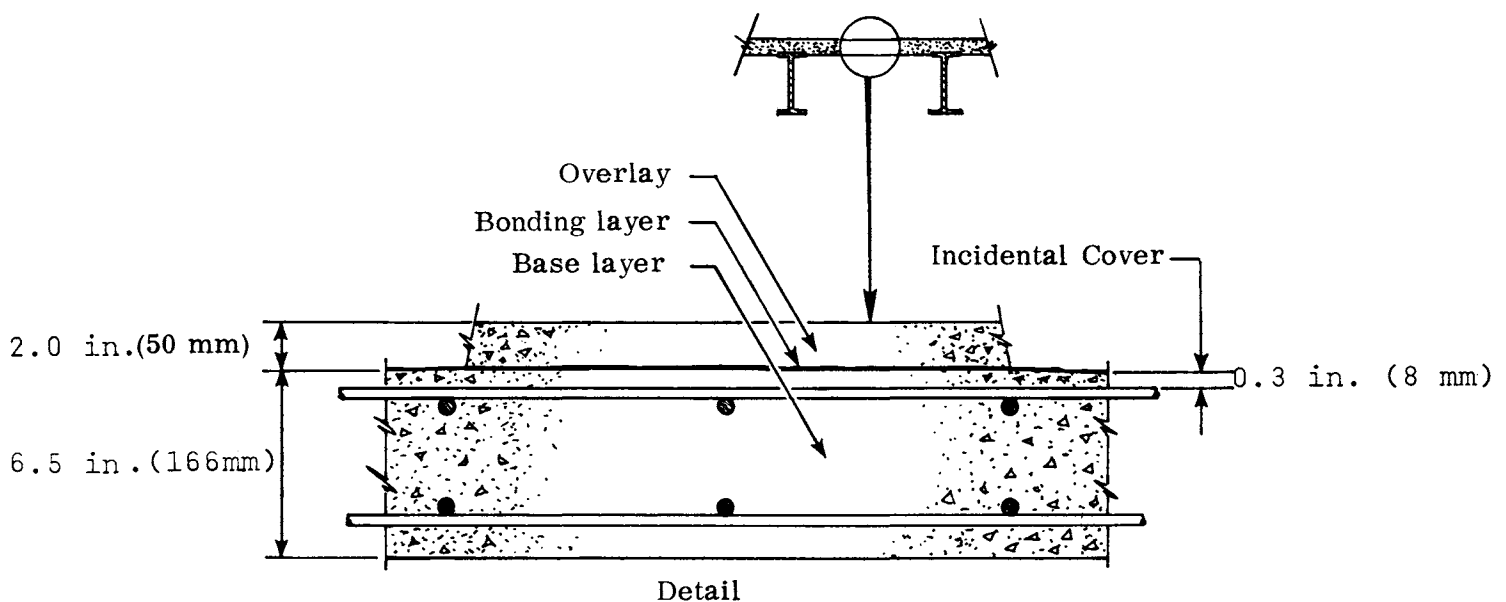


Figure 7. Typical transverse section of two-course bonded concrete bridge decks as constructed in Virginia.

### Consolidation

The base layers of the two-course decks were consolidated in the same manner as were the control decks using internal vibrators, whereas the overlays, due to their relatively shallow 2.0 in. (50 mm) depth, were consolidated with a surface vibrator attached to a transverse oscillating screed. Adequate consolidation of the overlay concretes was needed not only to produce a dense protective cover for the reinforcing steel, but also to provide complete contact at the interface between the overlays and the bonding slurries that were broomed onto the base layers.

Several techniques were used to assess the effectiveness of the consolidation provided for the two-course and single-lift decks. First, the unit weights of the fresh concretes were determined according to ASTM C138 and compared with densities monitored on the decks with a nuclear gage. Next the void systems of the concretes were analyzed from measurements of the air contents of the fresh mixes and void contents of hardened cylinders, depicted in Figure 2, and contrasted with void contents of cores extracted from the hardened decks. Finally, for the two-course decks a qualitative assessment of the compactive effort was made from cores by examining the bond interface between the overlay and base layer concretes. Additionally, an acoustic device was investigated as a means of providing continuous monitoring of the vibrational effort applied to concretes. Each of these techniques is discussed in the following sections.

#### Nuclear Gage

The majority of highway agencies, including the Virginia Department of Highways and Transportation, use nuclear systems for specification control of the moisture and density of soils and aggregates and the density of bituminous concrete.<sup>(6)</sup> Laboratory tests have been performed in Virginia to determine the feasibility of using the nuclear gage for measuring the degree of consolidation of fresh concrete in bridge decks and bridge deck overlays.<sup>(7)</sup> The nuclear gage was used in this study in the backscatter rather than the direct transmission configuration due to the shallow depths of the overlays. It has been found that nuclear gage readings are influenced by variables as depths of the concretes, the time of the measurement after placement, the roughness of the surface, and the location of the steel reinforcement.

In the field the rodded unit weight of each type of fresh concrete was determined by a direct measurement in accordance with ASTM C138. Nuclear density readings were obtained on the surface of the decks immediately following the screeding operation. These



data are summarized in Table 9. The nuclear densities ranged from 97.8% to 104.9% of the rodded unit weights. On the basis of work by the FHWA, (8) it has been reported that densities of  $99 \pm 1\%$  of the rodded unit weight have been monitored with the nuclear gage used in the direct transmission configuration. Additional work is needed to standardize the application of the nuclear gage for the assurance of quality in concrete in various types of field installations, however at this time the results in Table 9 are believed to indicate good control of consolidation in the study decks. Further evaluation of the nuclear gage as a rapid technique for monitoring compaction appears warranted.

Table 9

## Average Concrete Densities

Type of Concrete	Rodded Unit Weight, lb./ft. <sup>3</sup> (kg/m <sup>3</sup> )		Nuclear Density, lb./ft. <sup>3</sup> (kg/m <sup>3</sup> )		Nuclear as a % of Rodded
Single-lift	142.1	(2276)	139.0	(2227)	97.8
Base layer	147.3	(2360)	146.1	(2341)	99.2
Latex	145.7	(2334)	146.3	(2344)	100.4
PCC	146.5	(2347)	150.9	(2417)	103.0
Wire fiber	144.5	(2315)	151.6	(2429)	104.9

Void Contents

The air contents of the fresh concretes were measured using the pressure method (ASTM C231) and were listed earlier in Table 3. The void contents in hardened cylinders were determined from cut sections designated in Figure 2 by the linear traverse (Rosiwal) method (ASTM C457). The relationship between the air contents of the concretes and the void contents for each group of cylinders may be observed in Figure 8, where lines of equality have been superimposed on the five graphs. The void content of one core from each of the decks was also determined by the linear traverse method and these results are plotted on the graphs in Figure 8 for each concrete as the average void content of two cores versus the average air contents of the fresh concretes. Generally, the distribution of plotted values near the line of equality is typical of good field control verified by other research. (9) The most extreme exception to this pattern was for a core from a trial slab of wire fiber reinforced concrete. Its void content, plotted in Figure 8, exceeded 12% due to balling of the wire fibers during mixing.

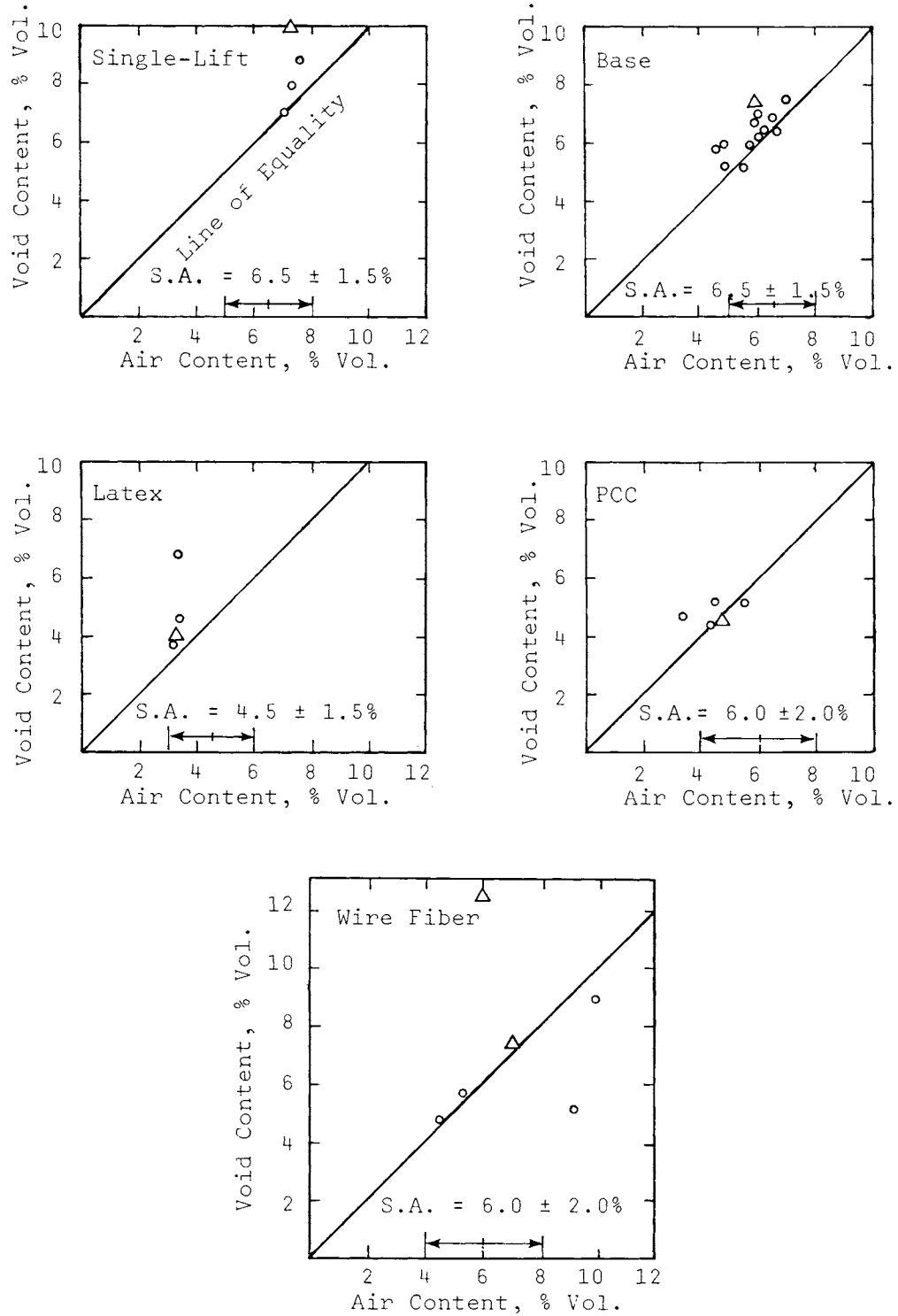


Figure 8. Relationships between air contents of fresh concretes and void contents of hardened concretes from cylinders (o) and cores (Δ). (S.A. indicates specified ranges for air contents.)

This problem was corrected by modifying the procedure for introducing the fibers to the ready mix truck, and the average void content of the two cores from the wire fiber overlays fell close to the line of equality.

### Bond Zone

The bond zones adjacent to the horizontal interface between the base layers and overlays of the two-course decks were examined in 4.0 in. (100 mm) diameter cores. One core was extracted from each of the six decks, cut vertically, and polished. Cores representing each type of overlay concrete — latex modified concrete, PCC and wire fiber reinforced concrete — are shown in Figures 9, 10, and 11. Microscopic examination revealed a uniformly intimate contact interface without voids or cracks between the two concretes in every case. The good condition of the bond zones is indicative of the adequacy of the consolidation effort imparted to the overlay concretes by the surface vibrator.

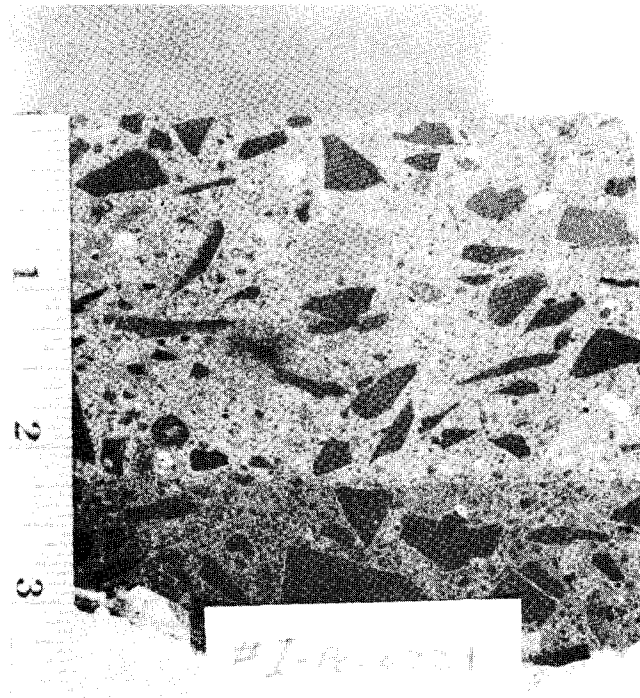


Figure 9. Vertical polished section through 4 in. (100 mm) diameter core showing latex modified concrete, bond layer, and base concrete.

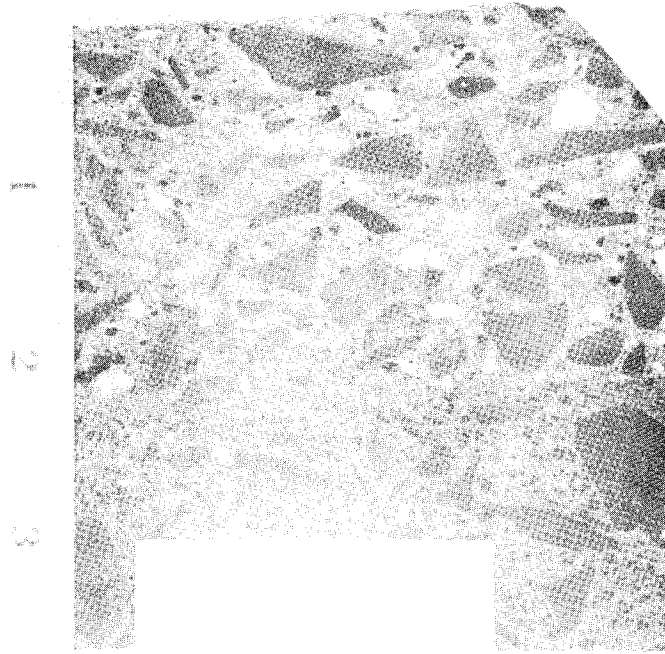


Figure 10. Vertical polished section through 4 in. (100 mm) diameter core showing high quality PCC, bond layer, and base concrete.

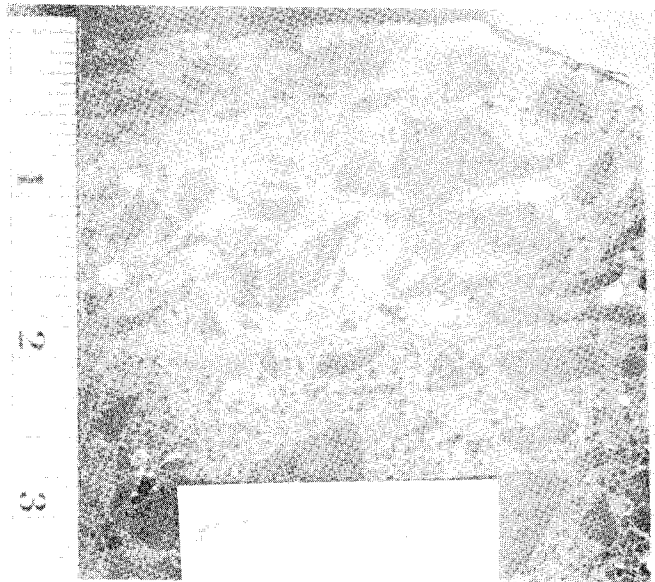


Figure 11. Vertical polished section through 4 in. (100 mm) diameter core showing wire fiber reinforced concrete, bond layer, and base concrete.

## Acoustic Monitoring

In order to explore the possibility of making rapid determinations of concrete densities during placement, an acoustic system that was being developed by the Bayshore Systems Corporation of Springfield, Virginia, was investigated. This system consists of an acoustic receiver that was adapted, after initial laboratory trials, for submersion in fresh concrete. The operation of this system is based on the premise that the acoustic waves generated in a concrete mass by mechanical vibrators and other compaction equipment are attenuated less as the consolidation increases. Therefore, with the surface vibrator at any point on the fresh concrete layer, the strength of the signal received by the passive monitoring system at another point in the concrete layer should reach a maximum value when the maximum concrete density is achieved at the location of the vibrator. The signals received by the system are indicated on a meter calibrated in decibels.

After some initial laboratory testing the acoustic device was used to monitor the vibration of a trial overlay installation of wire fiber reinforced concrete; however, due to funding limitations, the device was not used on the bridge decks in this project. In Figure 12, the 16 ft. x 24 ft. (4.9 m x 7.3 m) area for the trial installation is depicted. A base layer of concrete with a maximum depth of 4 in. (100 mm) was placed on grade and cured for 3 days, at which time the overlay concrete was placed. As shown in Figure 12 the acoustic receiver was located at a fixed position in the 2-in. (50 mm) deep overlay while the surface vibrator traversed the overlay on the transverse screed.

Results of the monitoring for the single vibrator path are shown in Figure 13. The upper curve was plotted with stable, or maximum, meter readings obtained after two passes of the vibrator. The lower curve represents additional readings for the same path but with a different noise filter in the system. These results indicate a good potential for the employment of such equipment for controlling the density of portland cement concrete; however, the equipment will probably need to generate its own standardized acoustic signal rather than to rely on the random and variable signals from construction equipment.

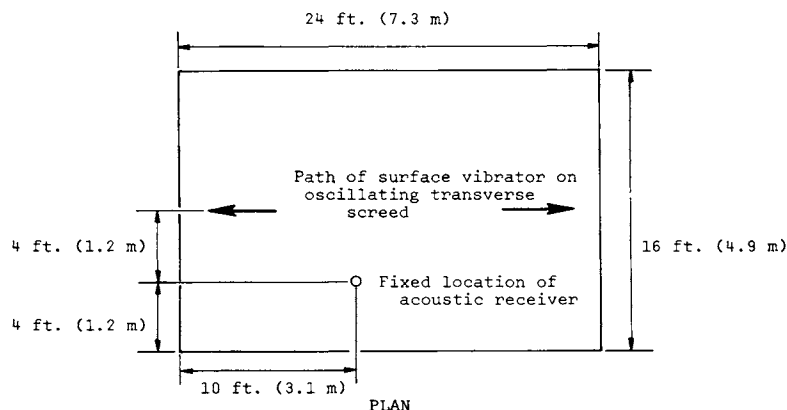


Figure 12. Acoustic monitoring of surface vibrator on a trial slab.

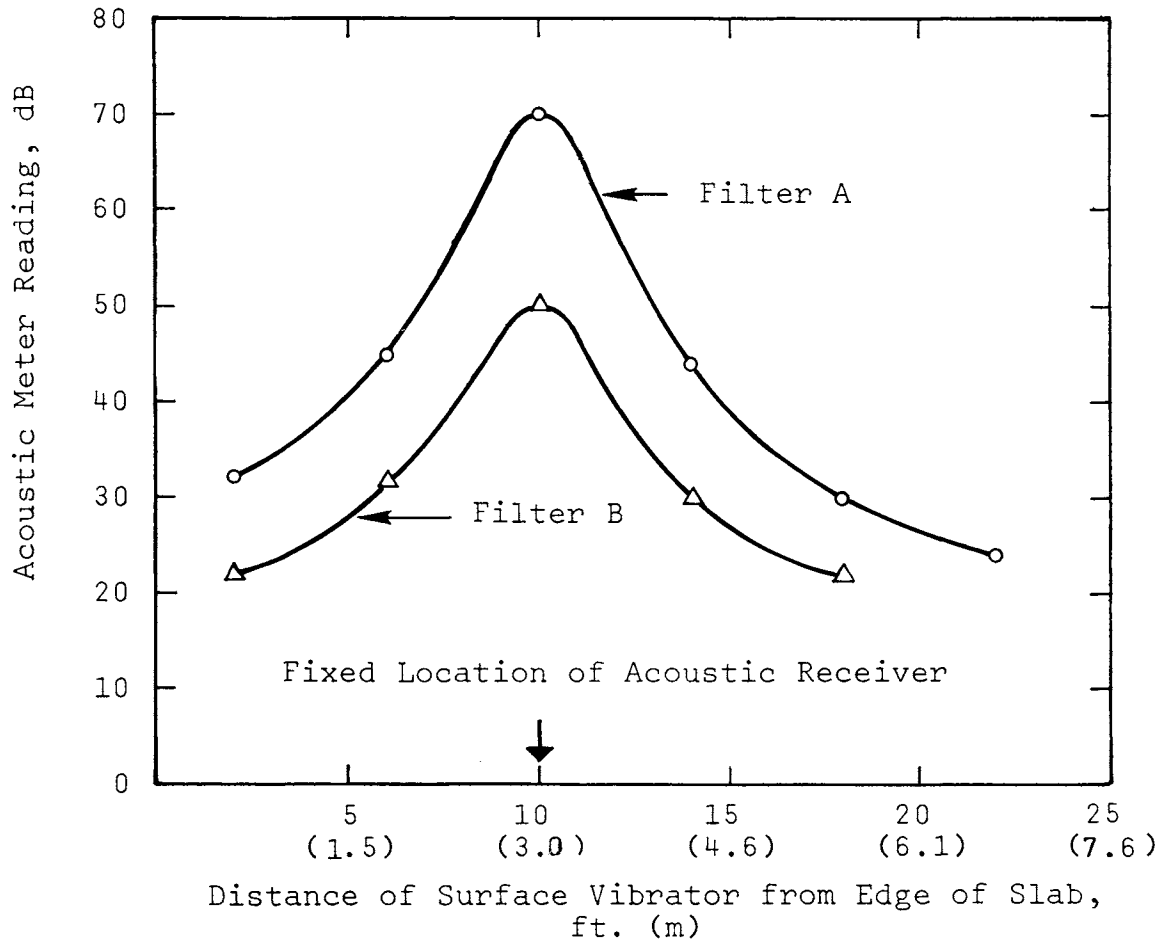


Figure 13. Typical patterns resulting from acoustic monitoring of surface vibrator.

## DECK EVALUATIONS

The study decks were constructed 12 months prior to receiving normal traffic loadings in July 1975, and were therefore 18 months old before deicing operations were required. An analysis of the condition of the mature concrete decks at the age of one year was made both to assess their quality at that time and to establish a datum for future performance evaluations.

The testing program for the deck evaluations was listed in Table 1 and included the performance of visual surveys and soundings on the deck surfaces, determinations of the  $\text{Cl}^-$  ion concentrations in the concretes, electrical potentials of the reinforcing steel, sonic pulse velocities through the decks, and the skid resistance of the deck surfaces. The results of this testing are presented in the following sections.

### Visual Surveys and Soundings

Visual inspection of the two-course and control decks showed no significant defects, the single exception being a 3 in. (75 mm) diameter popout near the railing on one of the latex modified overlays. This was found to have occurred at a screed rail support location over a cylindrical metal insert that should have been removed after the screeding. This defect was isolated and was not indicative of normal practice. Hammer and chain drag soundings at randomly selected locations on the decks produced a ringing sound characteristically emitted by good bridge deck concrete.

### Chloride Contents

An important aspect of future determinations of deck performance will be the degree to which chlorides from deicing chemicals are able to infiltrate the wearing course concretes. The corrosion of reinforcing steel embedded in concrete is dependent on several factors, including the presence of moisture and oxygen and the pH of the concrete; however, active corrosion has been reported to be suspected when the chloride ion ( $\text{Cl}^-$ ) content of a concrete reaches a threshold value of 1.3 lb./yd.<sup>3</sup> (0.77 kg/m<sup>3</sup>).<sup>(8)</sup> Investigations in Virginia and elsewhere of the specific ion electrode titration method for chloride content determinations have shown it to be reproducible and satisfactory,<sup>(10)</sup> and this method was used for the analysis of concretes included in this study.

Chloride analyses of hardened concrete from cylinders (Figure 2) cast at the project yielded unexpected results in that the

chloride contents of the uncontaminated samples were nearly equal in magnitude to that considered to be the chloride content corrosion threshold. Therefore an investigation was conducted to determine the source of these chlorides.<sup>(11)</sup> Samples of aggregates from several quarries in Virginia were tested and found to contain different amounts of  $\text{Cl}^-$  ion as indicated in Table 10. The chloride contents of the aggregates used on the project were thus found to be the source of approximately 85% of the chlorides identified in the concrete cylinders. These chlorides are bound within the aggregates and only minor amounts (3.75%) of the  $\text{Cl}^-$  ions were found to be leached from the project aggregates when soaked in distilled water with the pH adjusted to 12 to simulate the alkaline environment of concrete. Therefore, it is assumed that the chlorides in the project concretes are incapable of contributing to the corrosion process. However, since these chloride ions are measured by the titration method used for the analysis, they should be accounted for in the test results. On the basis of this investigation the true corrosion threshold for these bridge decks will be reached if the total concentrations at the level of the topmost reinforcing steel are determined by use of the titration analysis technique to be as much as 2.0 lb.  $\text{Cl}^-/\text{yd.}^3$  (1.2 kg  $\text{Cl}^-/\text{m}^3$ ) of concrete. This criterion is determined by numerically adding the recognized  $\text{Cl}^-$  corrosion threshold value to the average natural amount, 0.7 lb.  $\text{Cl}^-/\text{yd.}^3$  (0.43 kg  $\text{Cl}^-/\text{m}^3$ ), found to be contributed by the aggregates.

Future evaluations of the bridge decks with respect to the rate of  $\text{Cl}^-$  ion intrusion will be made based on the analyses of concrete samples drilled from the decks. This drilling is performed using a rotary hammer with a 2 in. (50 mm) diameter core bit, and the concrete samples are thus in a pulverized form. Two such samples were taken from each bridge deck and analyzed for comparison to the results obtained from the cut sections of cast cylinders. The results of the analysis of each type of sample representing each concrete are listed in Table 11, where it can be seen that the two sampling techniques cause no significant difference in the test results as the maximum difference between the two is only 0.2 lb.  $\text{Cl}^-/\text{yd.}^3$  (0.11 kg  $\text{Cl}^-/\text{m}^3$ ) of concrete.



Table 10

## Chloride Contents of Some Virginia Aggregates

Aggregate Type	City Near the Source	Cl <sup>-</sup> ion Content as a % of Aggregate Weight
Crushed limestone	Winchester	0.028
Crushed granite	Charlottesville	0.019
Silica gravel	Richmond	0.014
Silica gravel	Fredericksburg	0.012
Crushed limestone	Lexington	0.012
Crushed diabase	Fairfax	0.001

Table 11

## Average Natural Chloride Contents of Bridge Deck Concretes

Type Concrete	Chloride Content, lb. Cl <sup>-</sup> /yd. <sup>3</sup> (kg Cl <sup>-</sup> /m <sup>3</sup> )	
	Cast Cylinder Samples	Deck Samples
Conventional	0.81 (0.48)	0.77 (0.46)
Base Layers	0.99 (0.59)	-----
Latex Modified	0.59 (0.35)	0.71 (0.42)
PCC	0.63 (0.37)	0.75 (0.44)
Wire Fiber	0.70 (0.42)	0.90 (0.53)

Electrical Potentials

A copper-copper sulfate (CSE) half cell was used to determine the electrical potentials of the reinforcing steel in the eight study decks. The magnitude of such readings can be interpreted to indicate the probability of corrosion activity associated with the steel.<sup>(12)</sup> Values from 0.00 to -0.20 volt CSE indicate a greater than 90% probability that no reinforcing steel corrosion is occurring; values in the range of -0.20 to -0.35 volt CSE indicate an uncertainty about the corrosion activity; and values of

-0.35 volt CSE and beyond indicate a greater than 90% probability that corrosion of the reinforcing steel is taking place.

Electrical potential measurements were recorded for 66 points on each deck using a square grid pattern with 51 in. (1.3 m) intervals. The values on each of the six two-course decks were within the 0.00 to -0.20 volt CSE range, which was consistent with the results expected since the one year old decks had not been subjected to traffic and had received no deicing salt applications. Unexpected results were obtained on the two conventional single-lift decks, where the readings were within the range of -0.20 to -0.35 volt CSE.

Because of the anomalous electrical potential values mentioned above, a verification of the data was made two months later after appropriate equipment checks. Additional measurements were taken for the grid points on the southern half of each study deck in the eastbound lane (Figure 1). The values were nearly identical to the initial values and verified the reproducibility of the procedure used. When the second set of measurements was made the decks had been exposed to hot and dry weather conditions, whereas at the time of the initial readings the decks probably had a higher degree of saturation due to the prevailing rainy conditions. Stable meter readings were obtained in both cases. The electrical connection to the reinforcing steel was in all cases made by attachment of a lead to a steel girder. The firm electrical continuity between the girders and reinforcing steel was verified by comparing some of the resultant meter readings with similar readings while the lead was attached to other metal items on the structures. Therefore, at this time the anomalous values for the control decks can be attributed only to the electrical characteristics of the decks as measured in conformance with the recognized test procedure.

### Sonic Pulse Velocities

Sonic test methods have been used for more than three decades to evaluate properties of concrete.<sup>(13)</sup> A standard test method is described in ASTM C597 and consists of measuring the time of travel of a pulse or wave through concrete along a measured path length. The velocity with which a sound wave passes through a concrete mass is affected by several things, one being the concrete mix proportions, and particularly by the type of aggregate it contains. The pulse velocity is also affected by the voids in concrete. Since the wave must bypass the voids to traverse the mass, a longer path length results and a decreased wave velocity will be observed. The wave is most affected by large voids and by cracks, especially cracks whose general plane is perpendicular to the direction in which the wave is traveling. Such cracks cause a reduction in the

observed wave velocity, and if they are present in sufficient size or quantity the propagation of the wave may be fully impeded or its energy may be totally attenuated. The general quality level of concrete has been related to ranges of pulse velocities and these are listed in Table 12.

Table 12  
Ratings for Sonic Pulse Velocities  
Through Concrete

Pulse Velocity, ft./sec. (m/sec.)	Quality
Above 15,000 (4,600)	Excellent
12,000 - 15,000 (3,600 - 4,600)	Good
10,000 - 12,000 (3,000 - 3,600)	Questionable
7,000 - 10,000 (2,100 - 3,000)	Poor
Below 7,000 (2,100)	Very poor

Prior to tests of the field structures, pulse velocities were measured vertically through single-lift and two-course deck models having the same thickness and reinforcement as the structures. Tests of the deck models revealed no significant difference in pulse velocities among the three types of two-course slabs nor between the two-course and single-lift slabs. Also the location of the reinforcing steel relative to the path of the wave had no noticeable influence on the transmission time. These results showed that comparisons of data among the several types of structures in the study would be valid, and that a simple grid pattern could be used for locating test points on the decks without the need for locating the steel reinforcement. From the model testing it was also determined that for a deck thickness of 8.5 in. (216 mm) a range of 1.0 in. (25 mm) was acceptable for the horizontal alignment of the transducers above and below the deck. The average pulse velocity resulting from testing of the several deck models was 14,200 ft./sec. (4,300 m/sec.).

The travel times for sonic pulses transmitted vertically from the bottom to the top of the study decks were measured and recorded for a grid of locations as shown in Figure 14. The grid was referenced from brass markers embedded in the upper deck surfaces as shown in Figure 15. Pairs of markers were installed at the ends of each span to permanently reference the locations of the test points between adjacent girders. Corresponding reference marks were located and painted on the underside of the decks by a survey party.



Work beneath the spans was performed on the platform shown in Figure 16. Radio communication between the crew members on the platform and those on the deck surface was maintained for safety and to coordinate the placement of the two transducers for readings. The transmitter and receiver, shown in use in Figures 17 and 18, respectively, were coated periodically with a fluid couplant to provide suitable contact with the concrete for signal transmission. The transmitted and received signals were monitored on a cathode-ray oscilloscope as shown in Figure 18. A hand portable 110-volt generator was used to supply power for the system. The results of the sonic testing are in Table 13, where the 44 measurements from each deck are presented as average pulse velocities and standard deviations. The relative quality of concrete in the two-course decks appears to be better than that of concrete in the single-lift decks, as would be expected from the differences in compressive strengths previously discussed.

Future sonic evaluations of the study decks will consider any significant decrease in the average pulse velocity for each deck, since such a change could indicate deterioration of the concrete due to corrosion induced spalling or from other mechanisms.

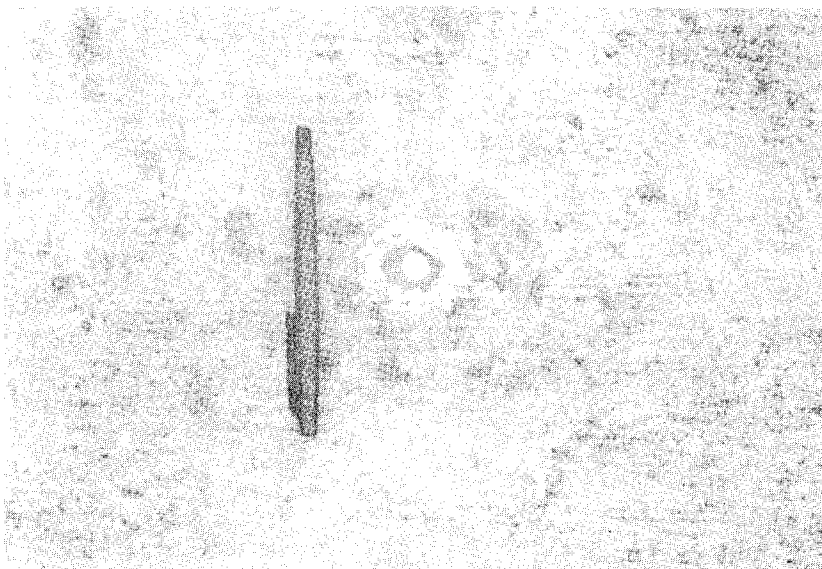


Figure 15. Brass reference marker embedded in bridge deck.

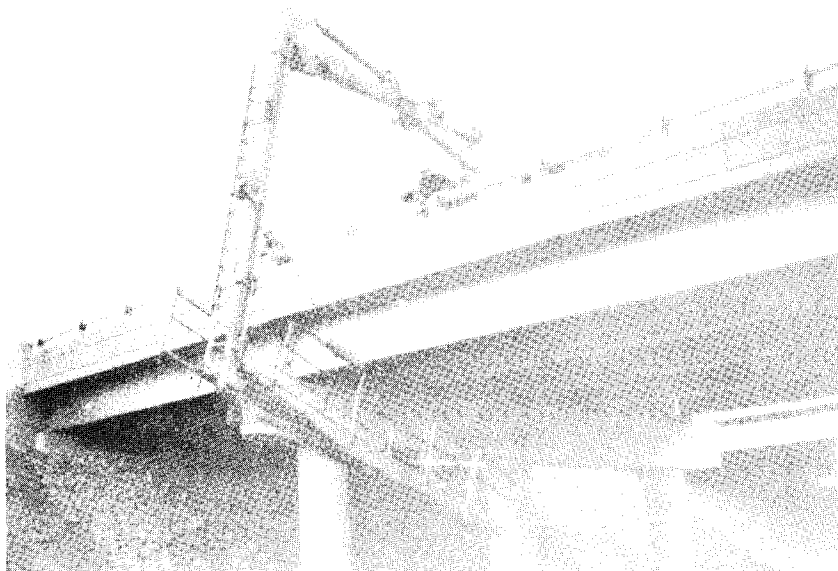


Figure 16. Work platform extending beneath deck.



Figure 17. Sonic transmitter held against bottom surface of deck.



Figure 18. Sonic receiver and monitoring equipment.

Table 13

Sonic Pulse Data for Study Decks

Deck (Lanes)	Average Pulse Velocity,		Standard Deviation,	
	ft./sec.	(m/sec.)	ft./sec.	(m/sec.)
Single-lift (EBL)	10,440	(3,180)	1,360	(410)
Single-lift (WBL)	9,850	(3,000)	1,510	(460)
Latex (EBL)	12,920	(3,940)	1,040	(320)
Latex (WBL)	12,400	(3,780)	790	(240)
PCC (EBL)	12,520	(3,820)	810	(250)
PCC (WBL)	13,500	(4,110)	640	(190)
Wire Fiber (EBL)	13,230	(4,030)	470	(140)
Wire Fiber (WBL)	11,610	(3,540)	2,070	(630)

Skid Resistance

In Virginia the safety of highway traffic has for many years been guarded by constructing and maintaining pavement and bridge deck surfaces that provide adequate skid resistance. The minimum value for stopping distance numbers (SDN) has been determined to be 40 on the basis of a skid test method using an automobile on wet pavement. In recent years the skid trailer has come into use as a safer and more convenient method for evaluating skid resistance. Skid numbers resulting from this test have been correlated with those from the method that used the automobile, and the equivalent numbers are reported as predicted stopping distance numbers (PSDN).

The PSDN's for the travel and passing lanes of the study spans were derived from an average of five measurements using the skid trailer in accordance with the procedures of ASTM E274. In Table 14 the PSDN for each lane of all study decks is seen to be greater than 60, which is excellent. The skid resistance of the decks will be evaluated again at appropriate times.

Table 14

Skid Resistance of Study Decks

Surface Type	Lane	Skid Trailer Data		PSDN
		Range	Average	
Control Concrete	EBTL	52-60	56	61
	EBPL	57-62	59	64
	WBTL	54-57	56	61
	WBPL	57-60	58	63
Latex Modified Concrete	EBTL	57-64	62	66
	EBPL	62-64	64	67
	WBTL	54-62	60	64
	WBPL	57-62	61	65
High Quality PCC	EBTL	54-62	60	64
	EBPL	60-62	62	66
	WBTL	54-64	62	66
	WBPL	60-64	62	66
Wire Fiber Reinforced Concrete	EBTL	60-62	61	65
	EBPL	62-64	63	66
	WBTL	54-64	61	65
	WBPL	60-62	61	65



## CONCLUSIONS

An investigation of the characteristics of the concretes used in two-course bridge deck construction in Virginia was carried out and, on the basis of information presented in this report, the following observations and conclusions were made.

1. The strengths, cement contents, and void systems of concrete cylinders cast from batches of the base layer and overlay concretes were analyzed and found to be within ranges that are indicative of good quality concretes. The relative quality of the conventional concrete was judged to be inferior, and some batches did not meet the stated specifications.
2. Prismatic specimens fabricated from batches of the overlay concretes were subjected to accelerated freezing and thawing in an NaCl<sub>2</sub> solution, and the results indicated excellent potential for long-term durability of the field installations.
3. Depth of cover readings obtained on the hardened two-course decks, using the pachometer, were found to be equivalent to depths from direct probes made in the fresh concretes during construction, with the exception of the steel fiber reinforced concrete, which produced zero depth readings with the pachometer and the depth of cover determinations by either technique may be compared directly to data for existing conventional decks.
4. Limited experimentation on this project with an acoustic monitoring device has demonstrated the potential of such a device to assure the continuous and uniform functioning of vibratory equipment that is essential for producing adequately consolidated, well bonded overlays. The presently available equipment would require modification and additional development.
5. The nuclear gage was used to check the degree of consolidation of the fresh overlay concretes and a reasonable range for specification control appears to be 100% ± 5% of the standard rodded unit weight of the fresh concretes.
6. Examinations of cores from the hardened two-course decks not only verified the adequacy of consolidation within the overlay concretes but also revealed the good condition of the bond interface between the overlays and the base layer concretes.

One year after construction, just prior to the opening of the roadway to traffic, several techniques were used to evaluate the condition of the six two-course decks and two single-lift control decks. Observations and conclusions that resulted from these activities are listed below.

1. Visual inspections and soundings of the two-course and single-lift decks indicated uniformly good quality concrete.
2. Chloride ions, attributable to the aggregates, were identified in the bridge deck concretes. Varying amounts of inert  $\text{Cl}^-$  are found in Virginia aggregates, and in the study decks the adjusted corrosion threshold will be 0.7 lb.  $\text{Cl}^-/\text{yd.}^3$  (0.43  $\text{kg}/\text{m}^3$ ) higher than the  $\text{Cl}^-$  concentration at which active corrosion may normally be indicated.
3. The range of electrical potential readings on the two-course decks indicated a greater than 90% probability that no reinforcing steel corrosion was occurring, whereas on the single-lift control decks the range of readings indicated uncertainty about corrosion activity.
4. Sonic pulses transmitted through the decks resulted in ratings that indicated a better condition of the two-course decks relative to that of the conventional single-lift decks.
5. Skid resistances of the two-course decks and control decks were determined to be excellent.

#### RECOMMENDATIONS

1. The production of good quality overlay concretes was accomplished through the use of standard specifications supplemented by special contract provisions, and the use of such specifications should be continued where two-course construction is warranted.
2. For decks as those in this study, a reasonable statement pertaining to the specification of cover over the topmost reinforcing steel would be: "The total cover over the topmost steel shall consist of not more than 0.3 in. (8 mm) of mortar cover resulting from the base layer construction and not less than 2.0 in. (51 mm) of the subsequently applied overlay concrete."

3. The nuclear gage currently available within the Virginia Department of Highways and Transportation should be used in a program of continuing gage evaluation to provide specification control of the density of fresh concrete in two-course bridge deck overlays.
4. The results of the analysis of data from visual surveys and physical testing of the bridge deck concretes can be interpreted at this time to indicate a greater potential for satisfactory performance of the two-course decks than for the single-lift decks.
5. The actual relative performance of the two-course and single-lift decks should be established by annual surveys of their condition.



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