Transportation Research Council, and was financed from state research funds.

The opinions, findings, and conclusions expressed in this paper are ours and are not necessarily those of the sponsoring agencies.

REFERENCES

1. Average Daily Traffic Volumes on Interstate, Arterial and Primary Routes. Virginia Department of Highways and Transportation, 1975.
2. Road and Bridge Specifications. Virginia Department of Highways, 1966.
3. C. Ozyildirim. Durability of Certain Configurations for Providing Skid Resistance on Concrete Pavements. Virginia Highway Research Council, June 1974.
4. An Accident Evaluation of the Effectiveness of Longitudinal Grooving on Virginia's Interstate System. Traffic and Safety Division, Virginia Department of Highways, July 1973.
5. G. B. Sherman and others. Effect of Pavement Grooving on Motorcycle Rideability. Materials and Research Department, California Division of Highways, Nov. 1969.
6. D. F. Noble. Effect of Pavement Texture on Tire-Road Noise. Virginia Highway and Transportation Research Council, July 1975.
7. D. F. Noble. Interior Car Noise Created by Textured Pavement Surfaces. Virginia Highway and Transportation Research Council, Oct. 1975.
8. J. E. Ross and S. M. Law. Texturing of Concrete Pavements. Research and Development Section, Louisiana Department of Highways, Sept. 1976.
9. Road and Bridge Specifications. Virginia Department of Highways and Transportation, 1974.

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Two-Course Construction of an Internally Sealed Concrete Bridge Deck

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A unique form of two-course construction—placement of a 51-mm (2-in) wax-bead concrete overlay on a fresh, conventional-concrete lower course after a 1-h wait period—was used in construction of a bridge deck near Seattle, Washington. Construction and evaluation of test slabs before placement of the deck showed that the direct tensile bond developed between the two courses was as great as the direct tensile strength of the wax-bead concrete. Other test-slab construction and evaluation work showed that the more conventional approach of placing a 51-mm overlay on a 1-d-old hardened lower course (after a water-and-sand blast and grout placement) also resulted in adequate bond. Cores evaluated after construction and heating of the deck confirmed the adequacy of the bond and the complete sealing of the top 13 to 25 mm (0.5 to 1.0 in) of the concrete overlay.

This report describes two-course construction techniques used in the construction of an experimental project undertaken by the Washington State Department of Highways using internally sealed concrete (1). The project required the use of wax beads in the top 51 mm (2 in) of a concrete bridge deck to develop an internally sealed concrete for the protection of the reinforcing steel of the deck. The structure itself—a three-span continuous structure with spans of 22.6, 24, and 22.6 m (74, 80, and 74 ft)—is a railroad overcrossing on I-90 in the western foothills of the Cascade Mountains approximately 48 km (30 miles) east of Seattle. The northern spans of the twin prestressed concrete girder bridges, which received the internally sealed concrete bridge-deck treatment, carry the westbound lanes of traffic. The structure has a 180-mm (7-in) thick, cast-in-place, reinforced concrete roadway slab supported by precast, prestressed concrete girders. The 180-mm-thick concrete deck is comprised of 127 mm (5 in) of Washington State standard structural class AX concrete, and the top 51 mm (2 in) is internally sealed with wax. The structure is 69.5 m (228 ft) in length and has a roadway width of 15.8 m (52 ft) between the concrete curbs. The roadway is on a curve with a radius of 914 m (3000 ft), and the piers are constructed at a skew angle of approximately 47° to the centerline of the roadway. The deck reinforcement consists of No. 6 reinforcing bars spaced 180 mm center to center, both top and bottom. The specified thickness of the concrete cover over the top transverse reinforcing steel is 51 mm.

MATERIALS

The concrete used in this project met Washington State specifications for class AX concrete, which is designed for a compressive strength of 27.6 MPa (4000 lbf/in^2). The sand has a fineness modulus of about 3.2; the grading for Washington State No. 5 coarse aggregate is as follows:

Sieve	Percent Passing by Weight: Minimum	Percent Passing by Weight: Maximum
25 mm (1 in)	100	–
19 mm (¾ in)	80	100
10 mm (⅜ in)	10	40
4.8 mm (No. 4)	0	4

All slab concrete is non-air-entrained because the internal sealing will provide the necessary freeze-thaw protection. This avoids an unnecessary sacrifice of strength that would occur if the concrete contained both wax beads and entrained air.

The typical concrete mixes used for the test slabs and the structure are as follows (1 kg = 2.205 lb and 1 L = 0.264 gal):

Item	Standard Class AX Concrete	Class AX Concrete With Wax Beads
Cement, kg	276.6	276.6
Fine aggregate, kg	642.2	496.1
Coarse aggregate, kg	815.4	815.4
Wax beads, kg	–	53.5
Total water, L	113.6	113.6

The maximum amount of water allowed for class AX concrete by Washington State standard specifications is 173 L/m^3 (35 gal/yd^3). The concrete was centrally mixed and delivered.

TEST SLABS

Four test slabs were required to evaluate the various options available for two-course construction and concrete deck heating. These test slabs were each 2.4 m (8 ft) wide by 3.7 m (12 ft) long and had the same deck thickness and reinforcing steel that are called for on the railroad overcrossing structure. Figures 1 and 2 show the test-slab forms and the reinforcing steel.

In September 1975, the test slabs were cast. In all cases, the bottom 12.7 cm (5 in) of concrete was placed first and was vibrated with internal vibrators. The second course of concrete was then placed in the following manner (1 mm = 0.039 in and 1 MPa = 145 lbf/in^2):

Slab	Procedure
1	Bottom 129 mm standard class AX concrete placed; top 51 mm wax-bead concrete placed 1 h later by concrete bucket
2	Same as test slab 1 to construction joint (top 51 mm) Bottom 129 mm standard class AX concrete placed; top 51 mm wax-bead concrete placed next day; surface cleaned by 8.3-MPa waterjet; grout placed
3	Bottom 129 mm standard class AX concrete placed; top 51 mm wax-bead concrete placed next day; entire surface cleaned by 8.3-MPa water-and-sand jet; grout placed
4	Bottom 129 mm wax-bead concrete placed; top 51 mm wax-bead concrete placed same day by concrete pump about 30 min after first pour

The ambient temperature during placement was approximately 18°C (65°F). There was no displacement of the underlying standard concrete during the placement of the top course of wax-bead concrete in slabs 1, 2, or 4 (Figure 3). The finishing of the top course was done

Figure 1. Placement of reinforcement for the four test slabs (test slab 1 in foreground).

Figure 2. Slab reinforcement (deepened sections represent prestressed, precast concrete girders).

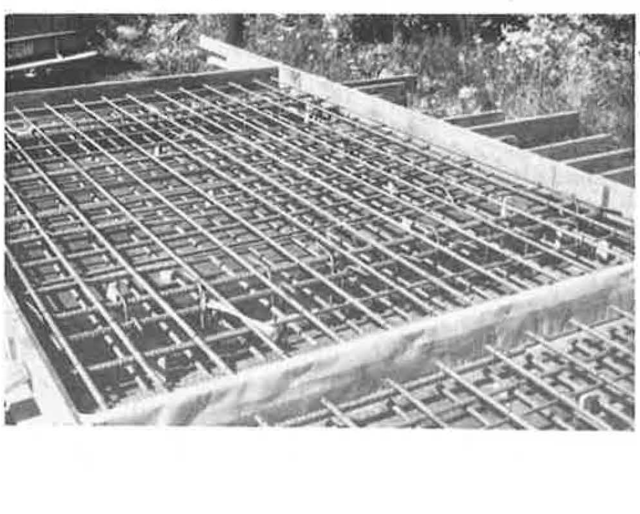


Figure 3. Second (wax-bead) concrete course being deposited at test slab 1 from concrete bucket with no displacement of underlying concrete.

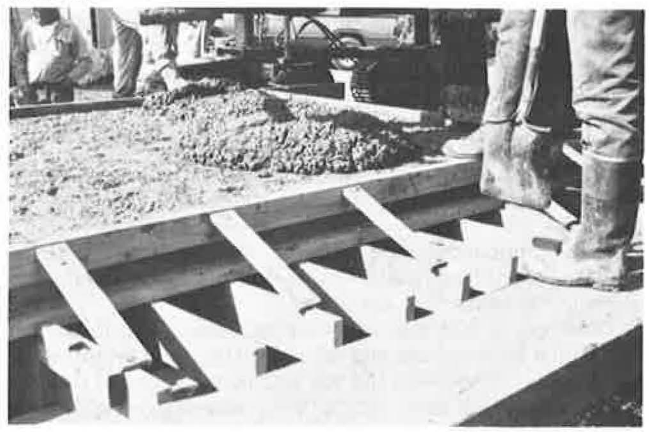
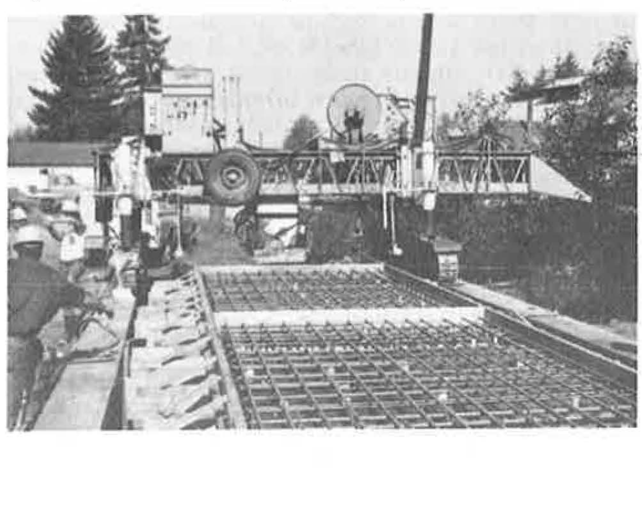


Figure 4. Gomaco 350 finishing machine in position at test slab 1.



by using a Gomaco 350 finishing machine with a vibrating pan for compaction (Figure 4). The finishing machine has twin rollers 123 cm (48 in) long and 20.5 cm (8 in) in diameter, in front of which is a strike-off auger and the vibrating pan (Figures 5 and 6). The effectiveness of the vibrating pan appeared to be reduced by positioning the strike-off auger following it. This was corrected on the bridge deck by placing the vibrating pan between the rollers and the strike-off auger. No attempt was made to smooth or give any special treatment to the surface of the standard concrete (lower course). As shown in Figure 7, a rough surface was achieved through the normal activities of the work crew.

The surface preparation for the second day's placement (half each of slab 2 and slab 3) called for the use of an 8.3-MPa (1200-lbf/in^2) waterjet with a flow of 76 L/min (20 gal/min) and the capability of introducing sand into the jet. The 1.4-m (4.5-ft) unfinished length of test slab 2 was cleaned by using the waterjet without sand. Test slab 3 was cleaned by introducing sand into the waterjet stream. A sand deposit left on the surface of the concrete had to be broomed off before placement of the overlay. The jet also left puddles of water in the depressions of the surface, and these were removed by blotting with burlap. For a larger area, water removal would be accomplished more efficiently by using compressed air. The entire area to be overlaid was coated with a cement-sand slurry (in a 1:1 mixture) that was brushed into the surface (Figure 8).

The overlays on a portion of slab 2 and slab 3 and both lifts of slab 4 were then placed by using a Thompson 102-mm (4-in) piston-type concrete pump (Figure 9). The initial operation involved the placement of the lower course for slab 4 (to the top of the reinforcing steel) and consolidation of the concrete by use of internal vibrators. After the first lift of test slab 4 had been placed, the second lifts for test slabs 2 and 3 were placed. The second lift of test slab 4 was placed last, approximately 30 min after the first lift was placed.

The slabs were covered overnight with plastic sheeting. The next day the plastic sheeting was removed, and the slabs were covered with burlap and kept wet for 10 d. Curing compounds were not used because it was believed that they would inhibit the escape of moisture during the subsequent heating of the slabs.

Test cores 102 mm in diameter were taken from the test slabs both before and after heating to determine the bond strength between the top and bottom lifts of concrete. A design bond strength for two-course construction and the best test method for evaluating bond strength have not been universally established. Furr and Ingram (2) have estimated the horizontal shear at the interface of a 180-mm (7-in) uncracked slab and a 51-mm (2-in) overlay under an AASHTO H20 truck to be 440 kPa (64 lbf/in^2). Work done in England (3) indicated that a bond strength as low as 280 kPa (40 lbf/in^2) may be adequate for an overlay. In this study, it was decided that a direct tensile bond test (Figure 10) would be used and that success of a two-course construction procedure would be indicated by tensile breaks in the concrete rather than at the bond line. In addition, it was believed that the tensile break strength should be in excess of 689 kPa (100 lbf/in^2).

The results of the core studies are given in Table 1. All three two-course procedures (overlay on fresh lower course after 1-h delay, overlay on 1-d-old lower course after water blast and grout, and overlay on 1-d-old lower course after water-and-sand blast and grout) were studied. A bond break did not occur in any of the specimens; rather, all breaks occurred in the wax-bead concrete above the bond line. The tensile break strength for cores from the unheated slabs varied from 0.69 to 1.69 MPa (101 to 246 lbf/in^2). All three two-course construction procedures appeared to be acceptable in that bond breaks did not occur. However, the magnitude of the tensile break values indicated that the best procedures were

1. Placing the 51-mm (2-in) wax-bead concrete on the fresh lower course concrete after a 30-min to 1-h delay and
2. Placing a 51-mm wax-bead concrete overlay on a hardened conventional concrete after water-and-sand blasting and following this by placement of a portland cement grout.

The test slabs were heated by using very hot air, electric blankets, and gas-fired infrared and electric infrared techniques. Because the test-slab concrete was saturated by rains, the high-intensity heating systems caused many spalls approximately 19 mm (0.75 in) deep. The slower heating of test slab 4 by use of electric blankets did not cause spalling. Thus, after heating, bond testing could be performed on this slab only. Slab 4 had been constructed by placing a 51-mm overlay on the fresh lower course concrete after a 30- to 45-min delay. The heating process involved placing electric blankets covered with fiberglass insulation on the slab surface. The blankets, shown in Figure 11, received 2 kW/m^2 (190 W/ft^2) of electrical power from a diesel generator, and 5 h of heating were required to achieve a temperature of 85°C (185°F) at the 51-mm depth. The maximum temperature recorded on thermometers placed on the concrete surface under the blankets was 167°C (332°F); the outside air temperature during heating was approximately 4°C (40°F).

The results of bond testing after heating indicate that the bond was not adversely affected by electric-blanket heating. As in the tests conducted before heating, no bond breaks occurred; instead, tensile breaks occurred in the wax-bead concrete.

BRIDGE DECK

The bridge deck was placed on November 11, 1975. The weather was overcast; a light drizzle fell during the late morning and afternoon. The rain was not heavy enough, however, to have an adverse effect on the concrete-placing operation. The temperature was approximately 10°C (60°F).

The results from the test-slab work indicated that the simplest method was to place both concrete courses the same day. The contractor elected to place all concrete by pumping. To avoid confusion and the possibility of a mix-up in the type of concrete being placed, two concrete pumps were used—one for the standard and the other for the wax-bead concrete (Figures 12 and 13). A Bidwell finishing machine was used for the bridge deck, and the vibrating pan was placed between the roller and the strike-off auger (Figure 14). The placement operation for the standard class AX concrete was the same as that used for the test slabs. The class AX concrete was placed in the forms, consolidated by internal vibrators, and struck off to the top of the upper reinforcing steel mat with hand tools. No other finishing was done on the class AX concrete.

The standard class AX concrete was delivered to the project in agitator trucks of 7-m^3 (9-yd^3) capacity; the wax-bead concrete was delivered in 4.9-m^3 (6.4-yd^3) batches in mixer trucks. The odd batch size for the wax-bead concrete was chosen to simplify addition of the wax beads at the bridge site (Figure 15). (After the wax beads were added, the concrete was remixed for 85 drum revolutions.) The first three concrete truck loads ordered were the standard class AX concrete to give the standard concrete placement approximately a 9.1-m (30-ft) lead on the second course of wax-bead concrete. Delivery was scheduled so that two 7-m^3 loads of standard class AX concrete were delivered to the project for every 4.9-m^3 load of wax-bead concrete. The 9.1-m lead the standard concrete had in placement represented, in time, approximately 1 h. During the latter portion of

Figure 5. Gomaco 350 finishing machine in operation with strike-off auger positioned between vibrating pad and rollers.

Figure 6. Rear view of Gomaco 350 machine in operation.

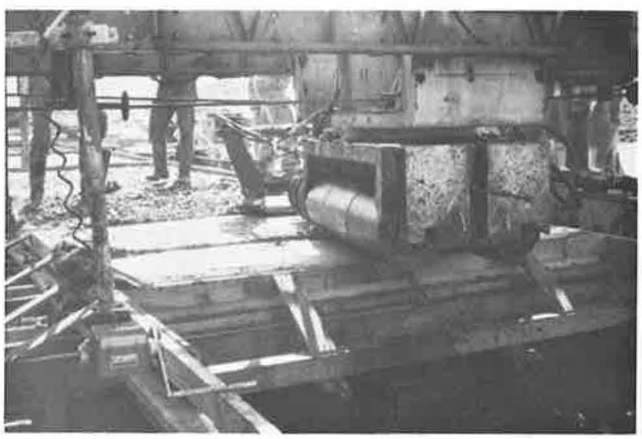


Figure 7. Texture of surface of first concrete course for test slab 3.

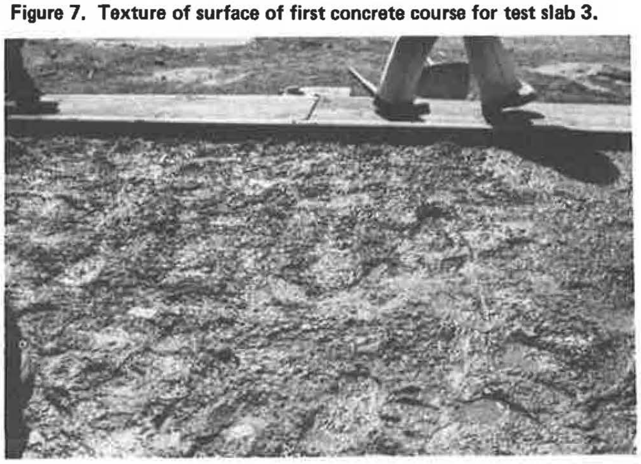


Figure 8. Grout slurry being broomed into concrete surface as a bonding aid.

Figure 9. Thompson 10.2-cm (4-in) piston-type concrete pump placing concrete for test slabs.

Figure 10. Apparatus for testing direct tensile bond.

Table 1. Results of bond testing.

Slab Number	Two-Course Procedure	Direct Tensile Bond (MPa)	Location of Break
1	Wax-bead overlay placed on fresh, conventional concrete after 1-h delay	1.34	1.3 cm above bond line
2	Wax-bead overlay placed on hardened lower course after water blast and portland cement grout	0.69	Slightly above bond line
3	Wax-bead overlay placed on hardened lower course after water-and-sand blast and portland cement grout	1.69	1.3 cm above bond line
4	Wax-bead overlay on fresh, wax-bead lower course after 30- to 45-min delay	1.52	2.5 cm above bond line

Notes: 1 MPa = 145 lbf/in²; 1 cm = 0.39 in.
Only test slab 4 could be tested after heating. Results after electric-blanket heating were the same

Figure 11. Electric blankets on test slab 4.

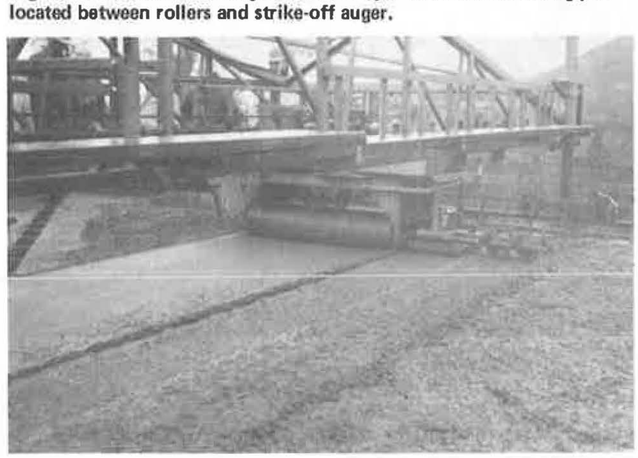
Figure 12. Bridge deck pour in operation: concrete pump in foreground placing standard class AX concrete and pump in background placing wax-bead concrete overlay.

the deck pour, the lead distance was reduced to approximately 4.5 m (15 ft), but there was no evidence of displacement of the standard concrete during the placement of the wax-bead concrete. The deck pour, which was completed in approximately 8 h, required 149 m^3 (195 yd^3) of standard class AX concrete and 61 m^3 (80 yd^3) of wax-bead concrete. The placement of the deck in two courses required an operator for one extra concrete pump and two additional concrete finishers.

The two-course technique of bridge-deck construction was checked by taking cores 51 mm (2 in) in diameter from the bridge deck after it had been heated by an electric-blanket heating system. Cores of this size were used rather than larger cores to minimize the chance of cutting the reinforcing steel. It was realized that the 51-mm cores would not provide as accurate an estimate of actual bond strength [because of the use of 25-mm (1-in) maximum-size aggregate], but the purpose was to determine whether bond breaks occurred rather than to determine the tensile breakstrength of the concrete.

Figure 13. Lower course of conventional concrete being raked off at level of top mat of reinforcing steel after placement and consolidation by internal vibration.

Figure 14. Bidwell finishing machine in operation with vibrating pad located between rollers and strike-off auger.



No bond breaks occurred when direct tensile bond tests were performed on four 51-mm-diameter bridge-deck cores; instead, the breaks occurred 25 to 38 mm (1 to 1.5 in) above the bond line in the wax-bead concrete. Thus, the results indicate that the bond between the two layers was stronger than the wax-bead concrete. The direct tensile break strengths varied from 0.76 to 0.97 MPa (110 to 140 lbf/in^2) and averaged 0.83 MPa (121 lbf/in^2). Compressive strength tests on a companion 51-mm core yielded a strength of 35.4 MPa (5130 lbf/in^2), and the tensile splitting strength of another 51-mm deck core was 4.6 MPa (665 lbf/in^2).

Thus, the data indicate that the two-course bridge-deck construction technique of placing a wax-bead over-

Figure 15. Wax beads being added by concrete bucket to already mixed concrete at jobsite.

lay on a fresh concrete lower course within 1 h of lower course placement was successful. In addition, tests on other cores indicated that the top 13 to 25 mm (0.5 to 1 in) of the deck was completely sealed by the wax-bead process.

CONCLUSIONS

The results of this project indicate that a good bond can be developed between two concrete courses (internally sealed and conventional concretes) when both courses are placed in the same operation. The integrity of this bond was not reduced by the temperatures it experienced during the heat treating of the wax-bead concrete, temperatures ranging from 85° to 93°C (185° to 200°F).

When the second concrete course was placed on the test slabs 1 d after the first course was placed, both surface preparation procedures—8.3-MPa (1200-lbf/in^2) water blast and grout and 8.3-MPa water-and-sand blast and grout—proved to be effective. However, the water-and-sand blast and grout procedure yielded higher direct tensile strength of the bond.

Recommended areas of future research on two-course construction are as follows:

1. Further study should be done on the effectiveness of various methods of consolidating the second course of concrete.
2. More research should be performed on the water-blast procedure (minus sand) because it was a simpler and thus less costly procedure than the water-and-sand blast cleaning.

ACKNOWLEDGMENTS

The test-slab and bridge-deck construction described here was accomplished as a joint effort between the Washington State Department of Highways and the Federal Highway Administration. State highway department personnel who contributed significantly to the effort were Jack Launceford, project engineer; Mike Myette, assitant project engineer; and Tom Marshall, assistant materials engineer. The bridge contractor was Lockyear and Sons, and the heating subcontractor was Frank Murry of Lahr Corporation. The electric blankets used to heat the deck were manufactured by Johanson Electrotherm.

REFERENCES

1. G. H. Jenkins and J. M. Butler. Internally Sealed Concrete. Monsanto Research Corp. and Federal Highway Administration, Rept. FHWA-RD-75-20, Jan. 1975.
2. H. Furr and L. Ingram. Concrete Overlays for Bridge Deck Repair. HRB, Highway Research Record 400, 1972, pp. 93-103.
3. G. E. Higgins and C. H. Peters. The Report of Spalled Concrete Surfaces With Thin Concrete Patches: An Experiment on Trunk Road A34 at Stratford. British Road Research Laboratory, Crowthorne, Berkshire, England, R.R.L. Rept. LR217, 1968.

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Two-Course Bonded Concrete Bridge-Deck Construction in Virginia

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Six bridge decks were constructed in Virginia by using the two-course bonded technique. The wearing course layers consisted of a high-quality portland cement concrete, a wire-fiber-reinforced concrete, and a latex-polymer-modified concrete. Analyses of construction activities, labor requirements, and cost are used to demonstrate the viability of two-course construction when additional protection of the upper reinforcing steel is warranted. It is shown that normal cover depths and an adequate degree of consolidation were attained in the two-course decks. The significantly better strength of the overlay concretes, as compared to that of concrete placed on two conventional decks used as controls in the study, underscores the primary purpose of the two-course technique, which is to promote the placement of high-quality protective concretes in the upper cover zone of bridge decks. A basis for assessing the future performance of the decks was provided by evaluating them at the age of 1 year, before they were opened to traffic and before application of deicing salts.

In June 1974, the two-course bonded technique for concrete bridge-deck construction was used in the construction of six bridge decks on the Va-7 bypass over the Norfolk and Western Railway at Berryville, Virginia. A research study was initiated to investigate the construction, the condition, and the 5-year performance of these decks and two control decks constructed nearby on bridges over Va-615. The project plan for the six