

TWO-COURSE BONDED CONCRETE
BRIDGE DECK CONSTRUCTION

Interim Report No. 1
"An Evaluation of the Technique Employed"

by

Samuel S. Tyson
Research Engineer
and
Michael M. Sprinkel
Research Engineer

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

Virginia Highway & Transportation Research Council
(A Cooperative Organization Sponsored Jointly by the Virginia
Department of Highways & Transportation and the University of Virginia)

In Cooperation with the U. S. Department of Transportation
Federal Highway Administration

Charlottesville, Virginia

November 1975

VHTRC 76-R13

SUMMARY

A two-course bonded technique that has evolved from the continuing national and local interest in bridge deck durability was used in June 1974 to construct six bridge decks in Virginia. During the construction, which was the first phase of a five-year study on the construction, condition and performance of two-course decks, detailed observations were made of the activities used to construct the six two-course decks and two conventional single-lift decks, and data concerning the several concretes utilized in the construction of the decks were recorded. Based on comparisons of two-course and single-lift construction techniques the following conclusions are made. An overlay should be placed not sooner than two days after a base layer is placed. Light sandblasting of the base layer removes laitance that might adversely affect the bond between the base layer and overlay. A bonding layer of cement slurry should be broomed onto the base layer not further than 10 feet (3 meters) nor longer than 15 minutes ahead of the overlay placements. The same depth of clear concrete cover above the top reinforcing steel resulted from the two-course construction as from the single-lift technique. Using conventional equipment selected by the contractor, the construction activities proceeded in an orderly and satisfactory manner and coefficients of variation for the time intervals required to install the base layers and the overlays are comparable to values representing excellent control for single-lift construction. Although a 7-yd³ (5.4 m³) truckload of concrete was screeded over 3 1/2 times as much surface area for an overlay as for a conventional single-lift deck, the average duration per truckload between the initial depositing and the completion of the screeding activity on the wearing surface was approximately the same in both the two-course and single-lift techniques. 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, but in terms of project days required for construction the two-course and single-lift techniques are equivalent. The total additional cost of the two-course technique is approximately 5% of the cost of the bridge superstructure.

Three overlay concretes were selected for use as wearing courses on the two-course concrete decks on the basis of their protective qualities. A broad range of handling characteristics is represented by these concretes, which included a latex modified concrete, a high quality PCC, and a wire fiber reinforced concrete. The differences in these wearing course concretes did not significantly affect the placement activities, other than the batching, during their respective installations. In general the decks constructed by the two-course technique are equivalent to those resulting from conventional single-lift construction, however these successfully installed special wearing course concretes offer improved potential for deck performance.

1006

TWO-COURSE BONDED CONCRETE BRIDGE DECK CONSTRUCTION

Interim Report No. 1
"An Evaluation of the Technique Employed"

by

Samuel S. Tyson
and
Michael M. Sprinkel
Research Engineers

INTRODUCTION

The exposed wearing surface on concrete bridge decks is subjected to abrasion from traffic and may simultaneously be affected by any or all of a variety of other stresses such as those from slab action, wheel loads, thermal cycling, hydraulic pressures from frost action, and disruptive products of chemical reactions. Such severe exposure demands concrete of a higher quality than would necessarily be required in the underlying portions of the decks. In addition, specific properties, such as high skid resistance, are needed only in the surface, provided wear can be minimized.

The general problem of concrete deck deterioration was approached in 1961 in a comprehensive program undertaken cooperatively by the Portland Cement Association, the U. S. Bureau of Public Roads, and several state highway departments.⁽¹⁾ As a result of that study and other local research, specifications in Virginia and other states were upgraded with particular emphasis on items such as reduced water to cement ratios, increased air contents, mechanized screeding equipment, and curing methods.^(2, 3, 4) A report on surveys of randomly selected decks in Virginia indicates that these modifications have improved the performance of concrete bridge decks.⁽⁴⁾

The report on the survey of selected decks also indicates a five-fold increase in the use of deicing salts in Virginia, as in other areas, during the period 1953 to 1970. Increased exposure of bridge decks to these deicing chemicals is a matter for concern because the permeability of the concrete cover as well as cracks that may form from a variety of causes allow chlorides to reach the upper reinforcing steel. Concentrations reaching the steel in a given time may be expected to increase with decreased depth of cover, increased water to cement ratio, decreased amounts of consolidation, and by any mechanism that causes cracking.⁽⁵⁾ The resultant corrosion of the steel and disruption of the concrete cover produces distress known as spalling. In this way the cover or wearing surface is rendered unserviceable in a short time relative to the service life of the underlying concrete, assuming timely repairs to the deck are then made. The incidence of spalling is significantly less in Virginia than in other states;⁽⁴⁾ however, where it does occur, it demands difficult and expensive repairs.

TWO-COURSE CONCEPT

One recommendation of the comprehensive PCA-BPR program⁽¹⁾ was for the construction of bonded two-course concrete bridge decks. This recommendation was reiterated by Committee 345 of the American Concrete Institute in its recommended practice for two-course bonded concrete bridge deck construction.⁽⁶⁾ The two-course technique is basically a modification in the construction of a typical structural concrete deck. Instead of casting the full deck depth in a single-lift an initial lift is placed and struck off just above the top reinforcement. After this concrete hardens the remaining depth is cast and in theory the resulting composite structure acts as a monolithic slab. The general characteristics of the two-course deck as constructed in Virginia are depicted in Figure 1.

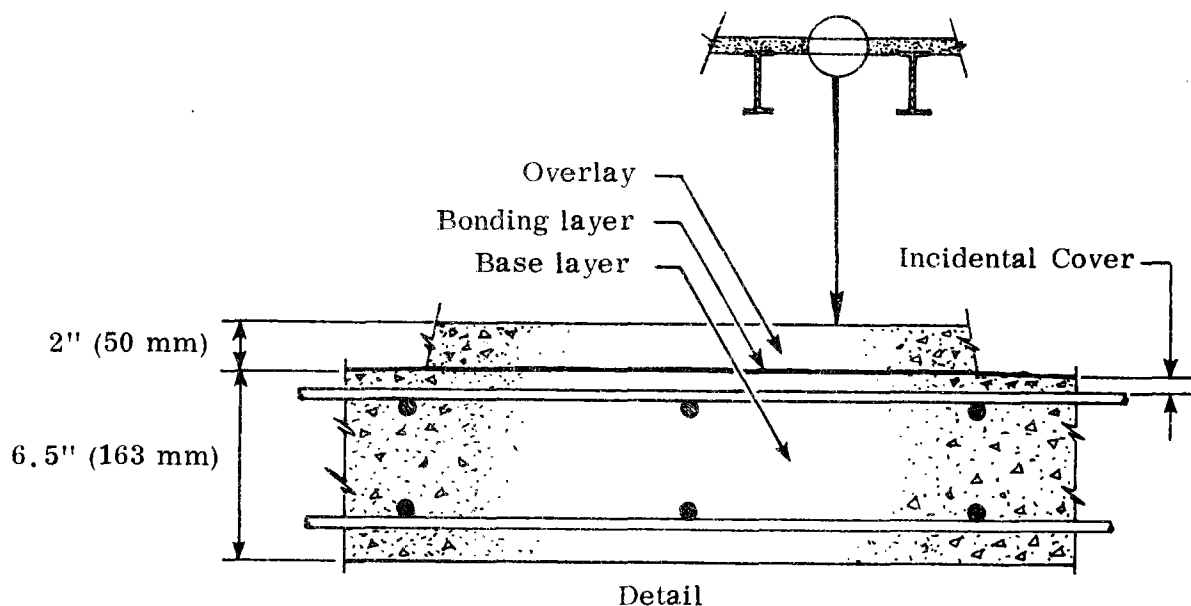


Figure 1. Transverse section of two-course bonded concrete bridge deck.

Advantages of the two-course technique are that it allows the avoidance of certain well-known problems inherent in the single-lift technique,⁽²⁾ and that it provides the opportunity to specify concrete properties that are desirable for the upper portion of the deck but which may be unnecessary (e.g., skid resistant aggregates) and possibly undesirable (e.g., very low slump) for the lower portion.

Despite the problems associated with single-lift construction and the demonstrable need for different materials requirements in the upper and lower deck regions, single lift construction is practiced almost exclusively in the U.S. Some agencies outside of this country routinely apply a two-course technique.⁽⁷⁾

Subsequent to the formal initiation of this study⁽⁸⁾ additional information has become available concerning two-course construction techniques as practiced by other agencies. Summaries of three such techniques as used in Kentucky, Iowa, and Switzerland are presented so that the reader may evaluate within a broad framework the two-course technique employed in the Virginia study.

Kentucky

The Kentucky Department of Transportation constructed a two-course deck 300 feet (91.4 m) long on a continuous composite plate girder bridge structure in 1971.⁽⁹⁾ Even though the two-course concept was employed, the construction technique differed considerably from that used in the Virginia study.

Conventional concrete was placed in one day in the lower half of this 7-1/2 inch (188 mm) thick deck leaving the top layer of reinforcing steel exposed. After 15 days a low slump PCC mix was placed in the upper half of the deck on a bond layer of portland cement grout. This approach was used because of concern for potential settlement and creation of fracture planes.⁽²⁾ Three days were required to complete the upper lift, and each length was screeded longitudinally and compacted with a circular impacting power float. A 2-inch (50 mm) minimum cover was provided over the top reinforcing steel.

The major drawback with the construction technique used in Kentucky appears to be the effort required to place the first lift and the bonding layer below the top reinforcing steel. Also, the same problems experienced in single-lift construction would appear to be encountered in consolidating the concrete around the upper reinforcing steel.

Iowa

The Iowa State Highway Commission has used a low slump concrete to resurface more than 150 bridges since the middle 1960's.⁽¹⁰⁾ This maintenance technique is discussed here because its satisfactory application in Iowa has advanced confidence in such bonded overlays to the stage where, with only minor modifications, they could be considered for use as a construction technique.

The overlay concrete used in the Iowa technique had a specified maximum slump of 1.0 inch (25 mm). A bonding grout consisting of portland cement and sand was broomed onto the base concrete. An oscillating transverse screed with an effective weight of 75 lb/ft² (3.6 k Pa) on the bottom face area is specified. The screed advanced under its own power and consolidated the overlay concrete to 98% of the rodded unit weight. Consolidation of this stiff mix was accomplished by energy from high frequency vibrators mounted rigidly to the screed at five-foot (1.5 m) intervals along its single lane width.

The very high quality of this overlay concrete is indicated by the air content of 6% and water to cement ratio of 0.33 for a cement content of 825 lb/yd³ (490 kg/m³). The performance of decks that may be constructed using this technique should be of vital interest in advancing the technology of two-course bonded construction.

Switzerland

A technique developed in response to a need to rehabilitate and possibly upgrade existing deteriorated bridge decks has been used in Switzerland over the past 15 years. (11) Based on this technique for maintenance, the Swiss have adopted a two-course construction technique which involves the addition of a four-inch (100 mm) reinforced PCC overlay to a full-depth base deck.

The bridge cross section is a reinforced concrete box girder type with partially cantilevered upper roadway flanges. The Swiss have modified their original design section for new construction through reducing the reinforcement by 2% and 40% in the longitudinal and transverse directions, respectively. They have concluded that adequate bond has been achieved between the overlay concrete and the base deck for the two units to be considered as monolithic. A cement paste was used to produce the bond.

PURPOSE

The purpose of this report is to document and evaluate the technique employed for the construction of six two-course bonded bridge decks in Virginia. It deals with the construction activities and fresh concrete properties recorded during the placement of these six decks and two control decks. Concurrently this report presents an evaluation of the placement characteristics of the three overlay concretes selected to serve as the wearing surfaces of the two-course decks.

SCOPE

Some advantages of the two-course concept for bridge deck construction have been presented. Three related, but independent, construction and maintenance techniques employing the two-course concept have also been described. The next three sections of this report are devoted to the background research, the project characteristics, and the pre-construction activities that shaped the technique in Virginia. A detailed description of the construction activities and the concrete control data for the project is then presented and evaluated.

A second report in this study will present information on the condition of the decks at the time of construction and at the ages of one year (when traffic first used the structures) and eighteen months. That report will also include information from tests of hardened concrete specimens fabricated in addition to the standard strength control cylinders at the project site.

A final report detailing the performance of the two-course decks will be prepared after the structures have been in service for five years.

BACKGROUND RESEARCH

Overlay Concretes

On the basis of laboratory and field evaluations three concretes that indicated good potential for successful application with the two-course construction technique were selected to improve the properties of the wearing course portion of the deck. The three concretes were (1) a high quality PCC, (2) a wire fiber reinforced concrete, and (3) a latex modified concrete. Each concrete was applied as an overlay on two decks.

The high quality PCC was selected because improved concrete quality can be more readily controlled for this relatively small volume of concrete. This control may be sufficient to measurably improve the performance of these two decks over that of standard PCC decks. As with the other wearing course concretes, its quality can be expected to be most influenced by the water to cement ratio and by the degree of compaction attained.

Wire fiber reinforced concrete has been applied as a maintenance overlay for bridge decks and pavements in other states. This concrete should not be substantially different from the plain PCC in terms of permeability of the paste. Significant improvements in compressive and flexural strength have been observed with fiber reinforced concrete; however, its most beneficial property for the deck application is fracture toughness. The fibers tend to inhibit cracking and the formation of spalls that may occur in a typical concrete deck. Corrosion of steel fibers that protrude from surfaces of concrete specimens has been observed to take place to a depth of approximately one fiber diameter beneath these surfaces in laboratory trials. Unlike the situation with reinforcing bars, protection seems to stem from the intimate fiber-paste contact. Because the fibers do resist crack formation in the paste, and since the study decks will be simple spans, corrosion of the fibers should not be a problem.

Latex modified concrete is purported to provide desirable strength, durability, flexibility, permeability, and bond properties. This type of concrete has been used in Virginia as a rehabilitative overlay for distressed decks and paving slabs. Also, in recent FHWA research it was suggested as a material with potential for reducing chloride penetration. (5)

Bonding Systems

Numerous references were found to studies pertaining to the bonding of fresh to hardened concrete. However, most of the studies dealt with overlays of concrete pavements instead of bridge deck overlays.

Among the studies dealing primarily with pavement overlays, one was particularly good for several reasons. The study, by Felt, (12) summarized some fundamental factors for guidance when placing bonded concrete overlays as follows: preparation of the base concrete, the quality of the bonding agent and the overlay concrete, and the need for adequate compaction, jointing, and curing of the overlay concrete. That study also reported the good performance of numerous pavement overlays that had been in service for many years. Presented in the report on the study was a procedure for testing pavement cores in shear and the results obtained with the procedure. These results led to quantifiable shear values that could be used to assess the quality of various bonding systems tested in the laboratory.

A similar test apparatus was designed in the laboratory of the Virginia Highway and Transportation Research Council and used to investigate several bonding systems. At the time this activity was being planned an investigation of bonding systems for use in rapid repairs of concrete pavements was also being considered. The systems investigated for bonding the fresh concrete to hardened 6 in. x 7 in. (150 mm x 175 mm) concrete base blocks were:

1. Plain interface;
2. Type II cement slurry ($w/c = 0.33$) with 2% NaCl_2 ;
3. High alumina cement (HAC) slurry ($w/c = 0.33$); and
4. Epoxy resin.

While the NaCl_2 would not be used in bridge deck applications because of its contribution to the corrosion of the reinforcing steel, the relative strengths resulting from these tests were the main point of interest. A typical specimen is shown ready for testing in Figure 2. Strength results from the series of tests are presented in Figure 3. The values may be interpreted on the basis of Felt's conclusions that strengths of 200 psi (1380kPa) or even less may be adequate for good performance, and that strengths exceeding 400 psi (2760kPa) represent excellent bonds. As seen in Figure 3, the 1-day results are in the range of 200 psi (1380kPa), and the average 28-day strengths exceed the 400 psi (2760kPa) level.

A comparison of the strength values at 28 days indicated that only minor differences existed among the four bonding systems. This finding was not surprising since it is the strength of the base or overlay concretes that must limit the shear strength if the bond interface and bond layer are of equal or greater strength.

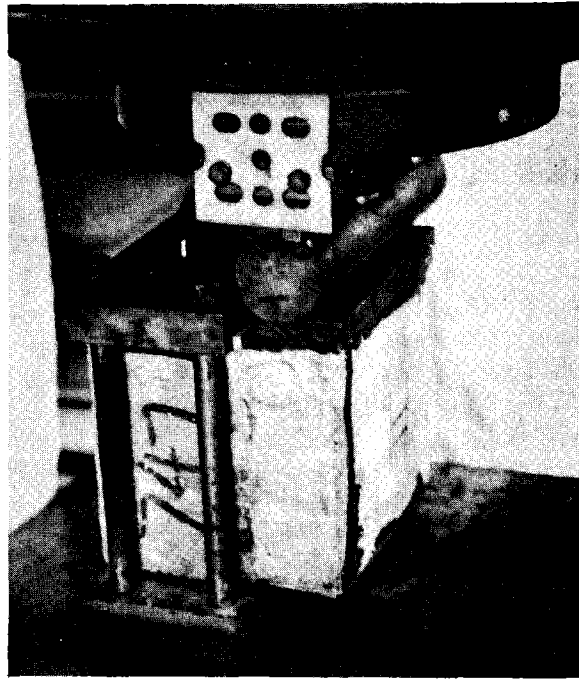


Figure 2. Overlay shear test apparatus and specimen positioned for loading.

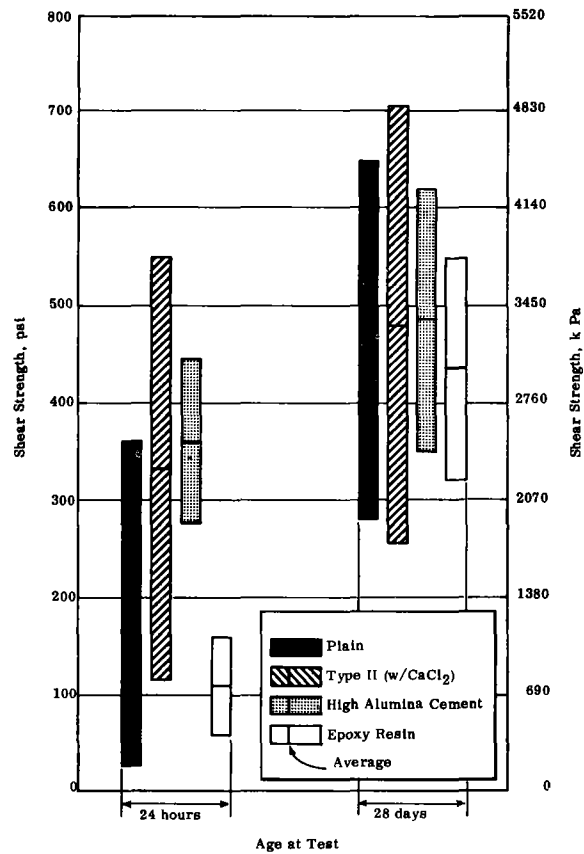


Figure 3. Shear test results for four bonding systems.

The fact that the plain interface performed as well in this test as did the other systems was attributed to the fact that consolidation was performed on a vibratory table in the laboratory and its duration was timed for good control. Conditions in the field were not expected to be so easily controlled, however the surfaces of the base layers were expected to be rougher and therefore produce better bonding potential than the laboratory blocks.

On the basis of the laboratory test results it was decided that a coating of cement paste would be broomed onto the surface of a base layer just prior to the placement of an overlay to assure a thorough coating of paste, essential for bonding, on the asperities of the base layer surface. For bonding the high quality PCC overlays and the wire fiber reinforced concrete overlays, slurries were specified which were compatible with the overlay concretes. The water-cement ratio for these slurries was not to exceed a maximum of 0.45. A slurry was not specified for the latex modified concrete. The coating of the base layer asperities in this case was to be achieved by brooming small volumes of the overlay concrete onto portions of the deck in such a way that the mortar would be spread thinly and uniformly and the coarse aggregate discarded.

Deck Models

Bridge decks in Virginia are designed to carry traffic on the concrete deck surface. An additional dead load, equivalent to a bituminous overlay 2 inches (50 mm) in depth, is included in the design to allow for future pavement resurfacings which may extend across the bridge structure. Even though the concrete may be assumed to be cracked in design procedures, stresses do exist at any cross section in the concrete and could affect the performance of a bonded overlay. A limited investigation was initiated early in this study to observe the load-deflection and structural soundness characteristics of models of the conventional and two-course decks.⁽¹³⁾ Because strength and freeze and thaw durability had been among the selection criteria for each of the overlay concretes, these properties were known to be adequate.

It had been demonstrated, through testing described in the preceding section of this report, that bonding systems employing a paste layer like that of the overlay concretes could develop strengths in 6 in. x 7 in. (150 mm x 175 mm) shear specimens that would equal or exceed the strength of the base concrete. The effect of some variables that might influence the quality of the bond between the overlay and base courses in a full-size deck were to be simulated in deck models. Further, because the greatest difficulty in the placing of overlays was expected with the wire fiber reinforced concrete, it alone was selected for use in the full-size placing simulations.

A transverse deck strip was selected as the model to be studied. This strip was equivalent to a continuous beam and was designed in two 7-foot (2.13 m) spans due to space limitations in the laboratory. The deck models, or beams, were 8.5 in. deep x 1 ft. wide x 14 ft. long (216 mm x 305 mm x 4.27 m).

Three such beams were constructed. Each beam contained the normal reinforcement to be found in the bridge deck represented (Figure 4). One beam was cast by the conventional single-lift technique, whereas the remaining two were constructed by the two-course technique. An elapsed time of 7 days occurred between the casting of the base concrete and the placing of the overlay concretes. The beams were moist cured for 28 days using burlap and polyethylene coverings.

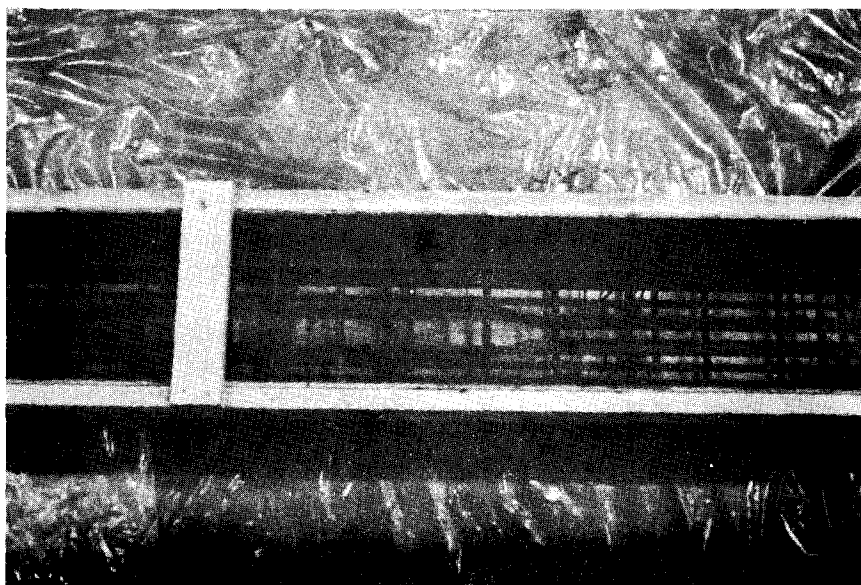


Figure 4. Normal reinforcement pattern used in bridge deck strip models.

Loads and maximum deflections were recorded for each beam with equal concentrated loads applied at the center of the two spans. The data, plotted in Figure 5, indicated that the two beams having the wire fiber reinforced overlays were slightly stiffer than the normally reinforced single-lift beam.

The three beams were then cycled through 200,000 repeated loadings at the design load level. No cracking of the sections was found. Ultrasonic pulse velocities were measured vertically through the two-course beams to detect delaminations of the overlays. Table 1 shows the ultrasonic data taken for one of the two-course beams before and after the loading procedures. These data verified visual observations of a sound bond layer and served as the basis for concluding that the overlays would not delaminate due to normal loading and fatigue considerations.

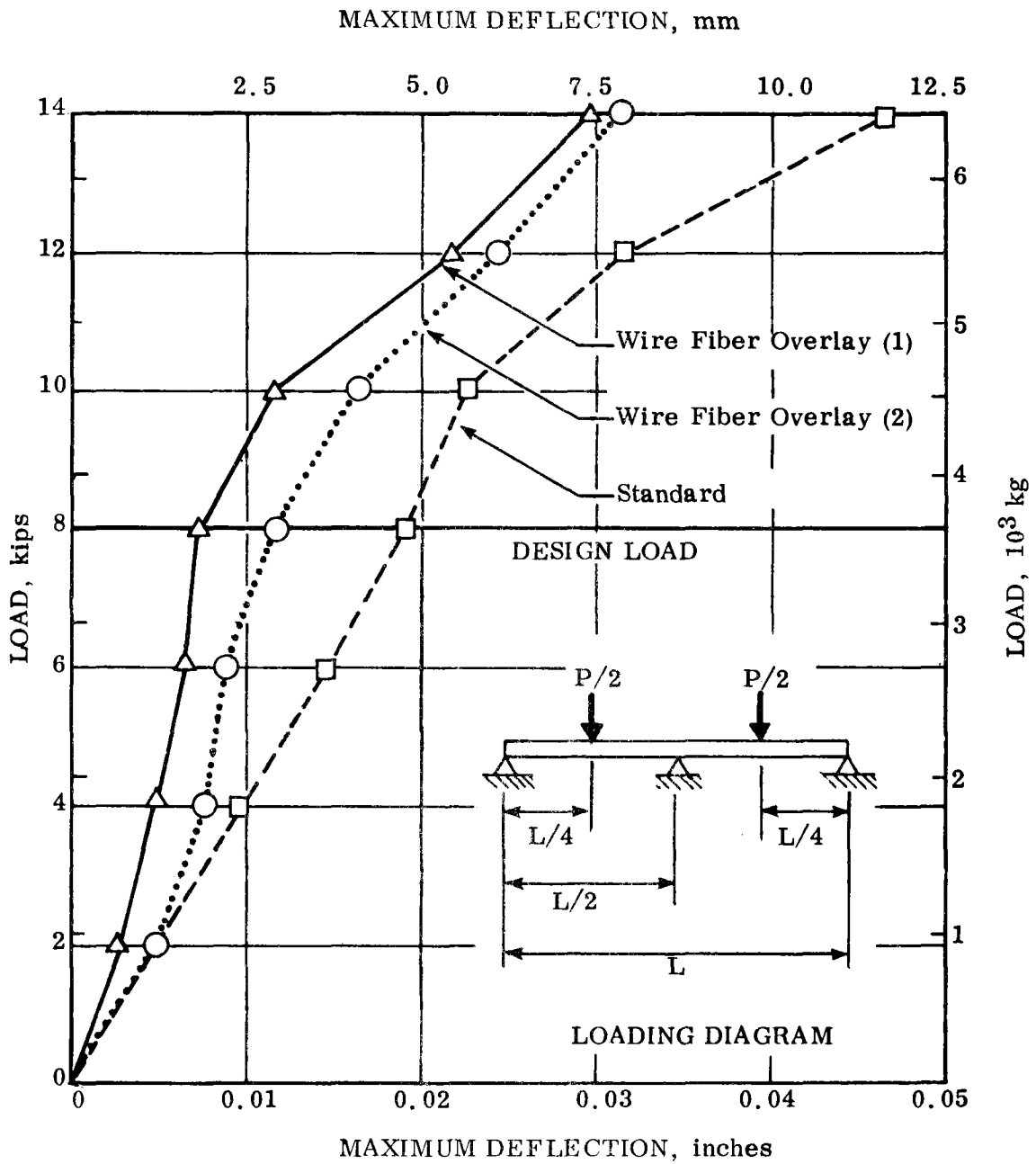


Figure 5. Load versus deflection curves for three bridge deck strip models.

Table 1

Ultrasonic Pulse Measurements for Two-Course Reinforced
Concrete Deck Strip Model

Reading locations along beams, ft. (m)	Ultrasonic Pulse Time ($\times 10^{-6}$ sec)	
	Before Loadings	After Loadings
End support	---	---
1.5 (0.46)	56.1	53.6
2.0 (0.61)	54.0	52.0
2.5 (0.76)	53.0	53.2
3.0 (0.91)	54.4	52.6
3.5 (1.07)	53.4	52.8
4.0 (1.22)	52.0	52.2
4.5 (1.37)	52.4	53.6
5.0 (1.52)	52.8	53.0
5.5 (1.68)	52.8	53.8
6.0 (1.83)	50.2	55.2
6.5 (1.98)	51.4	54.2
Middle support	---	---
7.5 (2.29)	52.0	53.6
8.0 (2.44)	52.6	51.8
8.5 (2.59)	53.6	53.0
9.0 (2.74)	52.2	54.4
9.5 (2.90)	52.0	53.6
10.0 (3.05)	54.2	54.8
10.5 (3.20)	53.6	53.6
11.0 (3.35)	52.6	53.0
11.5 (3.51)	52.8	53.6
12.0 (3.66)	51.8	52.8
12.5 (3.81)	52.0	52.6
End support	---	---

Each beam was finally loaded to failure in the testing rig (Figure 6) and maximum deflections were plotted versus loads in Figure 7. The ultimate strengths of the three beams were found to be essentially equal.

This investigation provided support for the assumption that the two-course construction technique could produce a monolithic deck unit with load-deflection characteristics approximately equal to those resulting from conventional single-lift deck construction and that no modification of the standard bridge deck design was needed for the two-course decks.

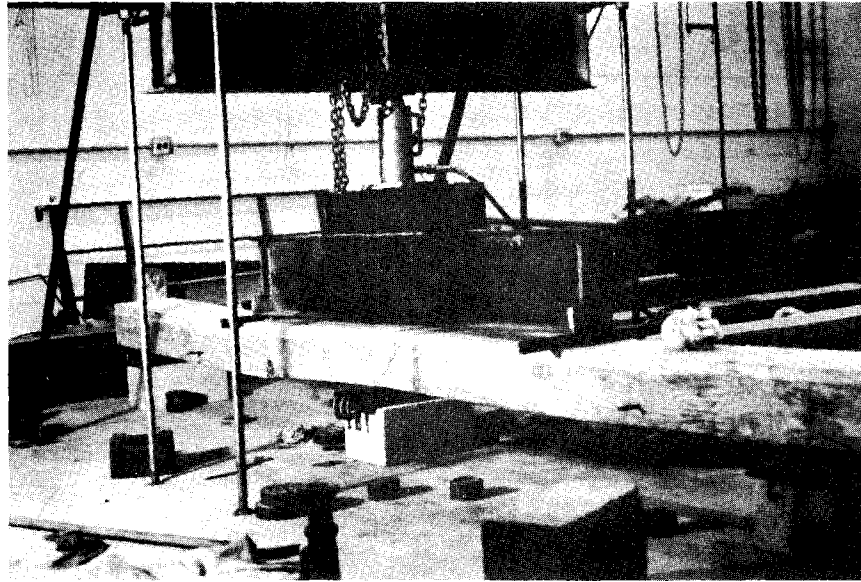


Figure 6. Loading rig for the deck strip models.

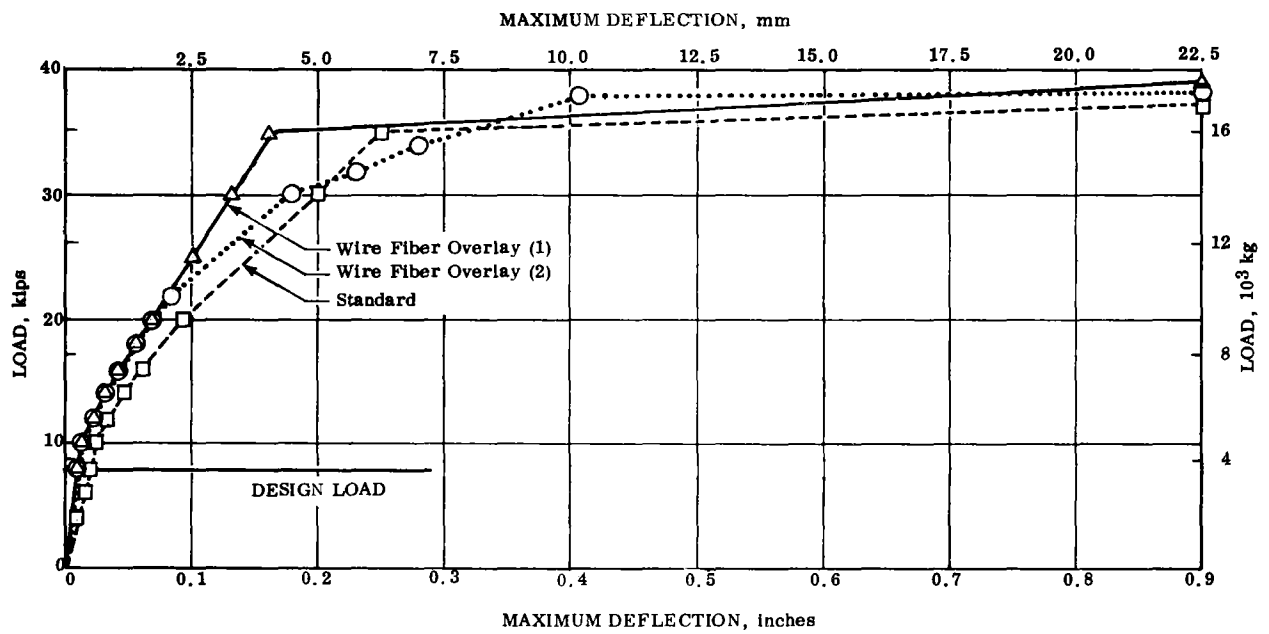


Figure 7. Ultimate strength test results for three bridge deck strip models.

PROJECT CHARACTERISTICS

The two-course bonded technique was specified for the six spans of the two adjacent bridge structures on the Route 7 bypass at Berryville, Virginia. These decks were expected to carry approximately 5,000 vehicles per day and be subjected to periodic salt applications for deicing with as many as 60 freeze-thaw cycles annually. A contract for this construction was awarded in early 1973. At that time two additional decks on the same project were selected to serve as control spans. These two spans were constructed in the conventional single-lift manner.

Comparisons of the single-lift and two-course techniques were facilitated through this site selection because all of the eight spans were nearly identical and were constructed by the same experienced contractor. Each deck had a minimum design thickness of 8-1/2 inches (216 mm) and rested on simply supported steel girders having a center to center spacing of 8-1/2 feet (2.59 m). The decks were approximately 50 feet (15.2 m) long with 38 feet (11.6 m) of clear roadway width.

The relative locations of the study spans along with plan dimensions and other location details are recorded in Figure 8. The numbers preceded by the letter "B" identify the bridge structures as they are designated in the construction contract (State project no. 6007-021-106, C501, B606, B607, B610, B611, B612, B613). The types of wearing courses are indicated on the respective decks in the figure and consist of a latex modified concrete, a high quality PCC, and a wire fiber reinforced concrete.

The general properties of these concretes were discussed earlier. The particular properties of the concrete mixes specified for this project are listed in Table 2. Normal superstructure concrete for bridge decks has a cement content of 635 lb/yd³ (377 kg/m³) and has an allowable w/c of 0.47. Such concrete is required to contain a non-polishing fine aggregate. The natural siliceous sands meeting this requirement were not available in the construction area and were imported from another area. An initial benefit from the two-course construction technique was realized at the time of construction since a locally available crushed limestone was permitted for use in lieu of the siliceous sand for the base layer concrete.

The overlay portions of the two-course decks were required to have a non-polishing fine aggregate. Also it was desired to reduce the w/c for the overlay concretes as much as practicable. Because of its lower void content, and therefore lower water demand, the natural siliceous sand for the overlays had to be obtained from a different source than were the sands for the single-lift decks and the base layers of the two-course decks.

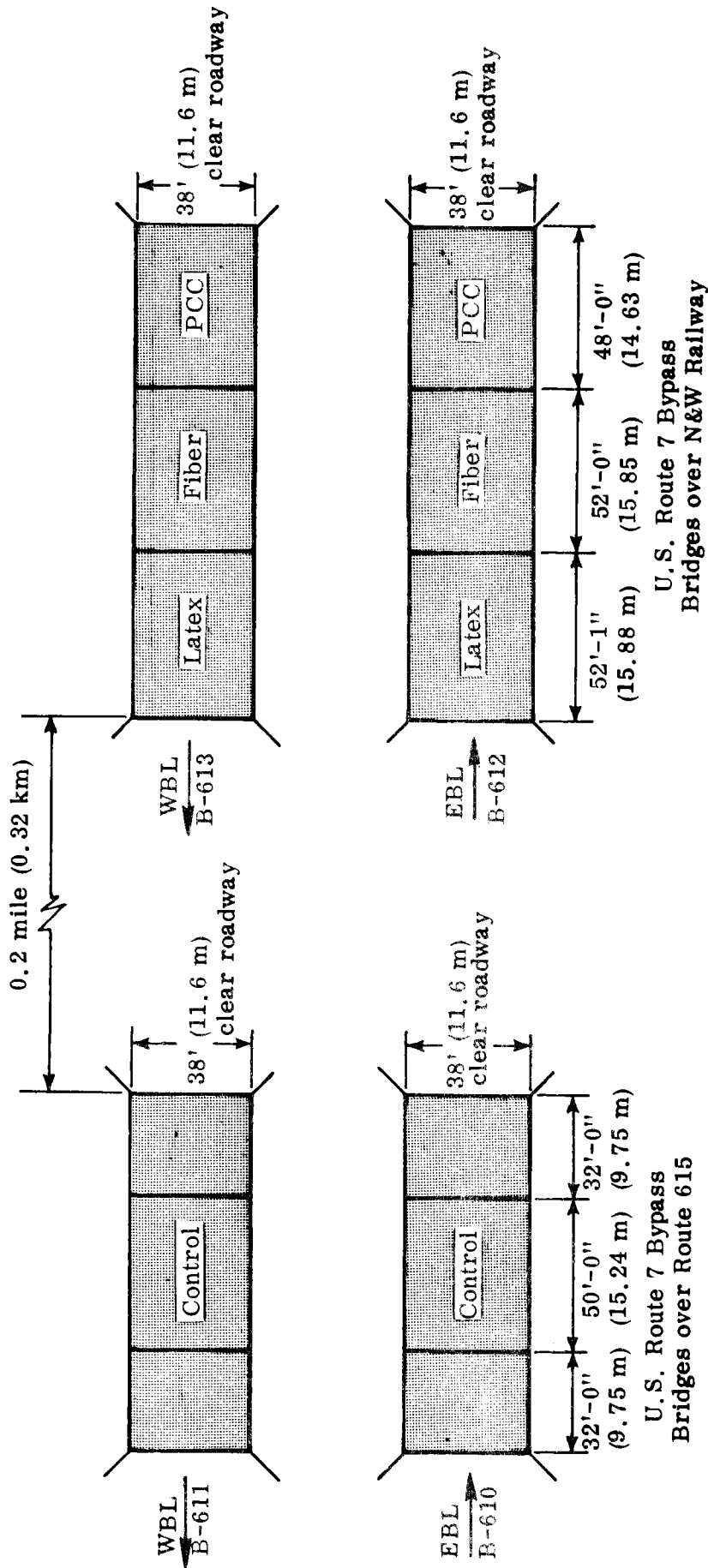


Figure 8. Plan view of bridge structures designated for study.

Table 2
Concrete Properties for Eight Bridge Decks in Study

Concrete Specified	Span Identification	Cement Content, ³ lb./yd. ³ (kg/M ³)	Air Content, % Volume	Slump, inches (mm)	Maximum w/c ^a	Nominal Maximum Coarse Aggregate ^b 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 ^c	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 ^d	B612, B613 (east spans)	752 (446)	6 ± 2	3 ± 1 (75 ± 25)	0.44	1/2 (13)	Natural siliceous (source 3)

^a Maximum values calculated from construction records; weight ratio.

^b Crushed limestone (source 2).

^c Polymer type-styrene butadiene; 24.5 gallons (92.7 litre), 46.0 - 49.0 % solids.

^d Steel fibers 1 inch (25 mm) in length by 0.016 inch (0.41 mm) diameter; 160 lb/yd³ (95 kg/m³).

PRE-CONSTRUCTION ACTIVITIES

The study decks were constructed in May through June of 1974. Just prior to their construction some activities, in addition to those already described, took place. These additional activities actually represented the final steps of the planning process that had been ongoing for several years.

Conferences

A pre-construction conference is routinely held after a contract is awarded so that details of the construction may be discussed. Because of the uniqueness of the two-course technique and the several agencies that were interested and involved with the project in an advisory capacity, an additional conference was held prior to the bridge deck construction.

Among the persons attending the meeting from the Virginia Department of Highways and Transportation were representatives of the Bridge, Construction and Materials Divisions of the Central Office, the Research Council, and the Staunton Construction District. The project contractor and ready mix concrete producer were represented, as were the Portland Cement Association, the Battelle Development Corporation, the Dow Chemical Company, and the Federal Highway Administration. The special contract provisions, included for general reference in Appendix A, reflect the recommendations agreed upon at this meeting.

The sequence of construction for the overlay applications was selected to reduce their impact on construction as much as possible. The latex modified concrete had been used in maintenance work and was considered the most workable of the three wearing course concretes. On this basis the latex modified concrete overlays were placed first, followed by the high quality PCC overlays, which presented fewer batching and handling problems than did the wire fiber reinforced overlays, which were placed last.

Trial Batching

Small trial batches of the high quality PCC and the wire fiber reinforced concretes were prepared in cooperation with the Staunton Construction District and a representative from the ready mixed concrete subcontractor. Minor changes in the mixes, reflecting the properties of the locally available and imported materials to be used, were recommended at that time.

The latex modified concrete was sampled prior to the overlay installations during the calibration of the auger-type continuous mixer, or mobile mixer, its producer utilized. The calibration of this equipment generally followed the procedures included in ASTM Standard C685.

Trial Installations

Trial field installations of the high quality PCC and the wire fiber concretes were made to identify and eliminate any problems that might arise from the contractor's intended procedure in connection with the ready mix operation or as a result of the transverse screed operation.

The trial installations were made on two areas 16 ft. x 24 ft. (4.9 m x 7.3 m) in plan. Base deck concrete with a 4-inch (100-mm) maximum depth was placed on grade, without reinforcement, and cured for 3 days. Normal placements of overlay concretes were then made.

A bonding slurry of cement paste is shown in Figure 9 as it was broomed onto the hardened concrete surface in a thin even layer. Prior to this step the concrete had been maintained in a moist condition without free surface water.

The high quality PCC, as delivered by the ready mix producer, was found to have a slump greater than the maximum allowable of 2-1/2 inches (62.5 mm). Since one reason for the trial placements was to observe the contractor's procedures and the operation of the screeding equipment, the concrete was accepted for placement. The installation went very well, with a planar riding surface being readily attained as shown in Figure 10. Subsequent inspection of the mix data revealed an error in the batching of this mix that involved the addition of extra water. This error was easily corrected after the trial installation but could have caused considerable difficulty if not detected until the day of the actual overlay installation.

Considerable clumping or balling of the wire fibers was seen in the trial installation mix. Concentrations of fibers reduce the effective fiber distribution throughout the mix and present finishing problems as well. Moreover, wire fibers must have intimate contact with the cement paste in order to be protected from corrosion. The fiber balls shown in Figure 11 lacked sufficient mortar to fill their interior portion, thereby suggesting that the balling occurred as a result of the way in which the fibers were added to the mixer drum and not as a result of total mixing time or total drum revolutions.

The procedure for adding the fibers to the mixer drum was modified. With all other components of the concrete mix already in the drum, the drum was rotated at a rate of 13 revolutions per minute while the fibers were being added. By means of a vibrating table and two vibrating chutes, the wire fibers were separated and introduced directly into the concrete without being deflected from the mixer vanes. The successful procedure that was ultimately used for adding the fibers is shown in Figure 12. A sampling of the relatively few fiber balls that occurred after this modification revealed sufficient mortar in their interior portions to coat the fibers, produce a solid mass, and prevent corrosion of the fibers.

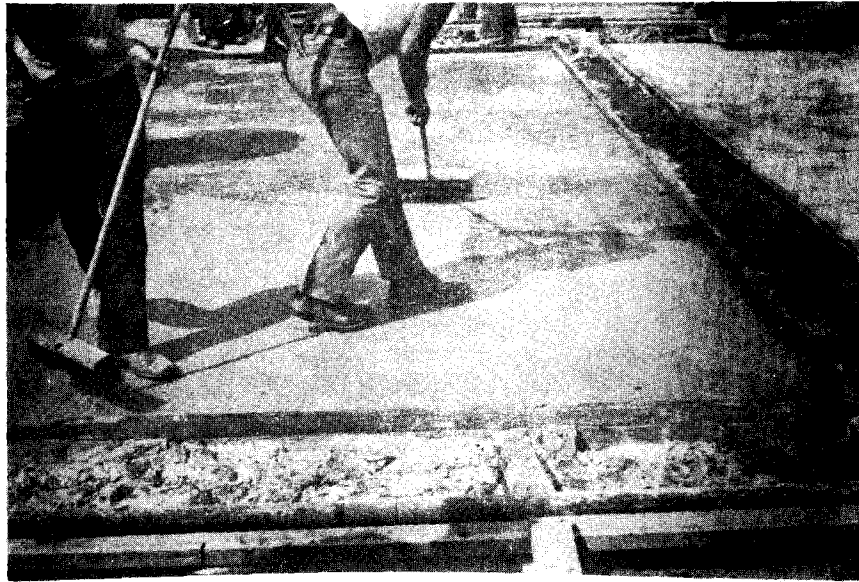


Figure 9. Bonding slurry being broomed for trial overlay installation.

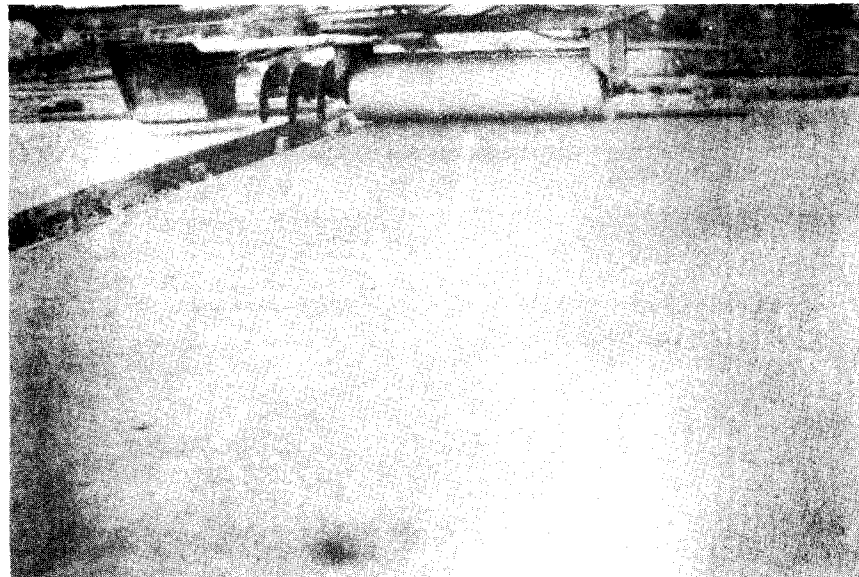
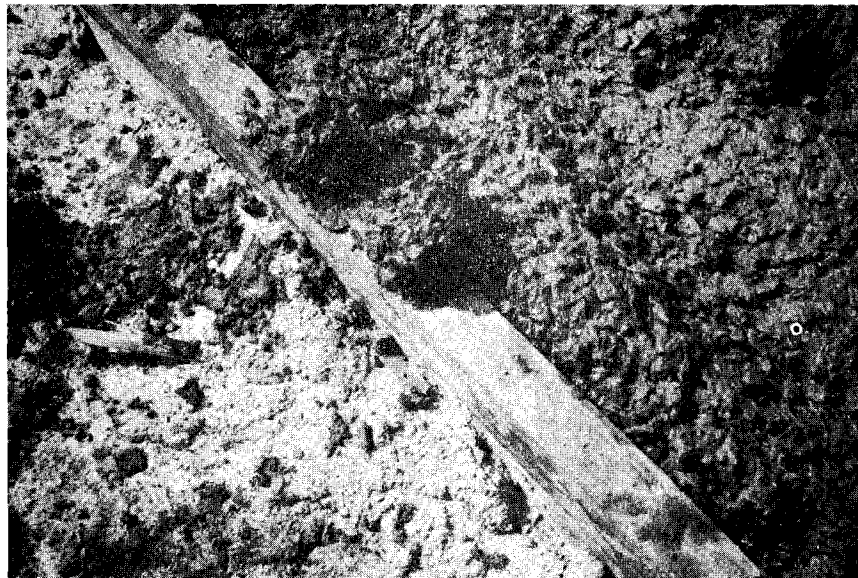


Figure 10. Trial installation of high quality PCC showing acceptable riding surface.

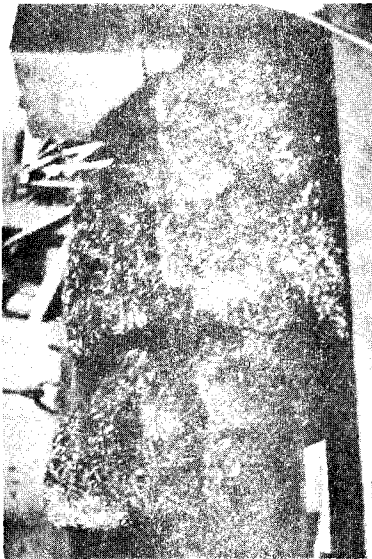


(a) Numerous wire fiber balls in the trial installation mix.

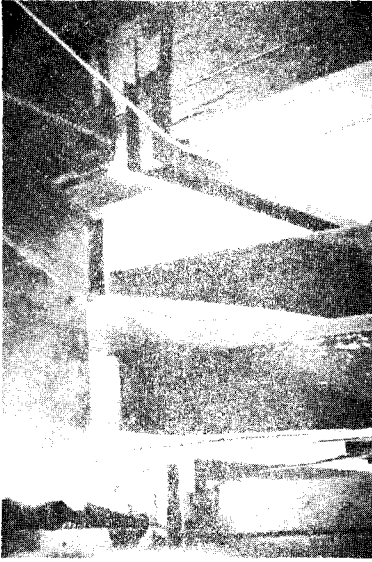


(b) Closer view of fiber balls averaging two inches in diameter.

Figure 11



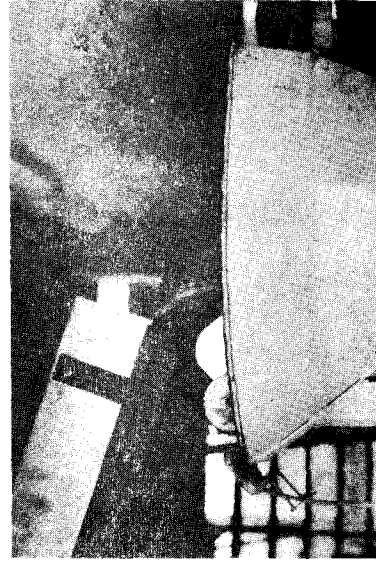
(a) 1" long x 0.016" diameter (25 mm x 0.41 mm) fibers dumped from boxes onto vibrating table.



(b) Vibrating chute below table.



(c) Second vibrating chute being inserted into ready-mix truck drum.



(d) Fibers passing uniformly into mixer.

Figure 12

CONSTRUCTION ACTIVITIES

The procedures associated with the construction of the two control spans and the six experimental spans were observed and documented in detail for the purpose of making a comparison of the single-lift and two-course construction techniques and to note construction events which might influence the performance of the bridge decks. Placement information for the eight deck installations is presented in detail in Appendixes B and C. The strength and durability of concrete are affected by, among other things, the time after batching in which the various placement operations are performed. Therefore the figures and charts shown in Appendix B and Appendix C are illustrated on a per truck basis.

The figures in Appendix B indicate the initial placement to the nearest foot of the concrete from each bucket of each truckload. The bar charts in Appendix C illustrate the sequence of construction activities for each bridge deck. A summary of the construction procedures and a comparison of the eight deck installations based on the details included in Appendix B and Appendix C are presented in subsequent sections of this report.

Screed Equipment and Construction Sequence

The two control spans were constructed by the single-lift technique using a longitudinal oscillating screed that is commonly employed in Virginia for bridge deck construction. This screed rested on supports beyond the ends of the deck and did not impart loads to it.

A transverse vibratory screed was used for the overlay installations. In Figure 10 the essential elements of this screed may be viewed from left to right and include a leading surface vibrating unit for consolidation of the concrete, an auger that moved excess concrete forward, a rotating drum that oscillated transversely over the bridge and finished the deck surface, and a metal float that completed the surface finishing with the exception of texturing.

The transverse screed traveled on rails that were supported on studs in the outermost girders in each span. These studs had to be set prior to construction of the base layer, so the contractor elected to use the transverse screed for the base layer installations as well as for the overlay installations. Internal vibration was used for the base layer construction and the surface vibrator unit of the transverse screed was omitted for these layers.

The sequence of construction for the two-course decks was planned so that two days would elapse between the placement of base layer and overlay concretes on a single deck. This delay period was selected since earlier placement of the overlays entailed a risk not only of creating voids around the upper reinforcing steel but also of causing delaminations from the outset of construction due to the tendency for the bleeding rate of the base layer concrete to exceed the bleeding rates of the denser overlay concretes. Delays exceeding two days would have been acceptable structurally, however the two-day delay was used because at that time light sandblasting was sufficient to easily remove laitance, resulting from bleeding, from the surfaces of the base layers.

Procedure for the Conventional Single-Lift Installations

The procedure used to construct the two single-lift, or conventional, bridge decks are described in the following subsections.

Delivery

The concrete was delivered over a haul distance of approximately 12 miles (19 km) in trucks having a capacity of $8 \frac{1}{2} \text{ yd}^3$ (6.5 m^3). It was discharged into a bucket of $\frac{3}{4} \text{ yd}^3$ (0.6 m^3) capacity for depositing onto the deck. Samples were taken from two randomly selected bucket loads.

Depositing

The concrete was deposited onto the deck using a crane to transport the bucket. The workers used rakes and an internal spud vibrator to consolidate each deposit of concrete into the deck. Manipulation of the concrete was minimal and only 1 to 2 minutes were required to distribute each bucket loads.

Screeding

The oscillating longitudinal screed advanced in the transverse direction following the ongoing depositing operations. The screed was reset and moved over the concrete two or three times on the average to obtain a satisfactory riding surface.

Finishing

Hand finishing was required parallel to and within approximately 2 feet (0.6 m) of the vertical reinforcing steel for the parapets. A monomolecular film was applied liberally at the discretion of the finishers during the operations to retard the loss of moisture through evaporation.

Texturing

After screeding, the deck was textured by pulling a belt longitudinally back and forth over the concrete. A monomolecular film was applied prior to texturing.

Curing

Liquid membrane curing compound was applied by hand-held sprayers from a work bridge after the sheen disappeared from the surface of the concrete.

The time and sequence of the various installation activities for the single-lift type of construction are summarized in Figure 13. The operations proceeded in a reasonably systematic manner and the installations were completed through the texturing stage in approximately 5 1/2 hours after the first truck of concrete was batched.

Procedure for the Six Base Layer Installations

The procedure used to construct the six base layer installations for the two-course technique were similar to those required for the single-lift installations with the exceptions noted in the following paragraphs.

Depositing

On the first base layer the workers, being accustomed to single-lift construction, distributed the concrete too deeply and considerable raking and manipulation were required prior to screeding. However, on the remainder of the decks, the workers usually left very little cover over the top reinforcing steel as they distributed the concrete.

Screeding

The transverse screed rolled and pushed the concrete in the transverse direction as it advanced in the longitudinal direction behind the depositing operations. The concrete was struck off just above the uppermost reinforcing steel. The screed encountered the reinforcing steel on several occasions and had to be adjusted slightly.

Finishing

Hand finishing was required parallel to and within approximately 18 inches (450 mm) of the vertical reinforcing steel for the parapets. Also, some hand finishing was required at each end of the deck.

Texturing

No texturing was necessary on the base layers since they subsequently were to be overlaid.

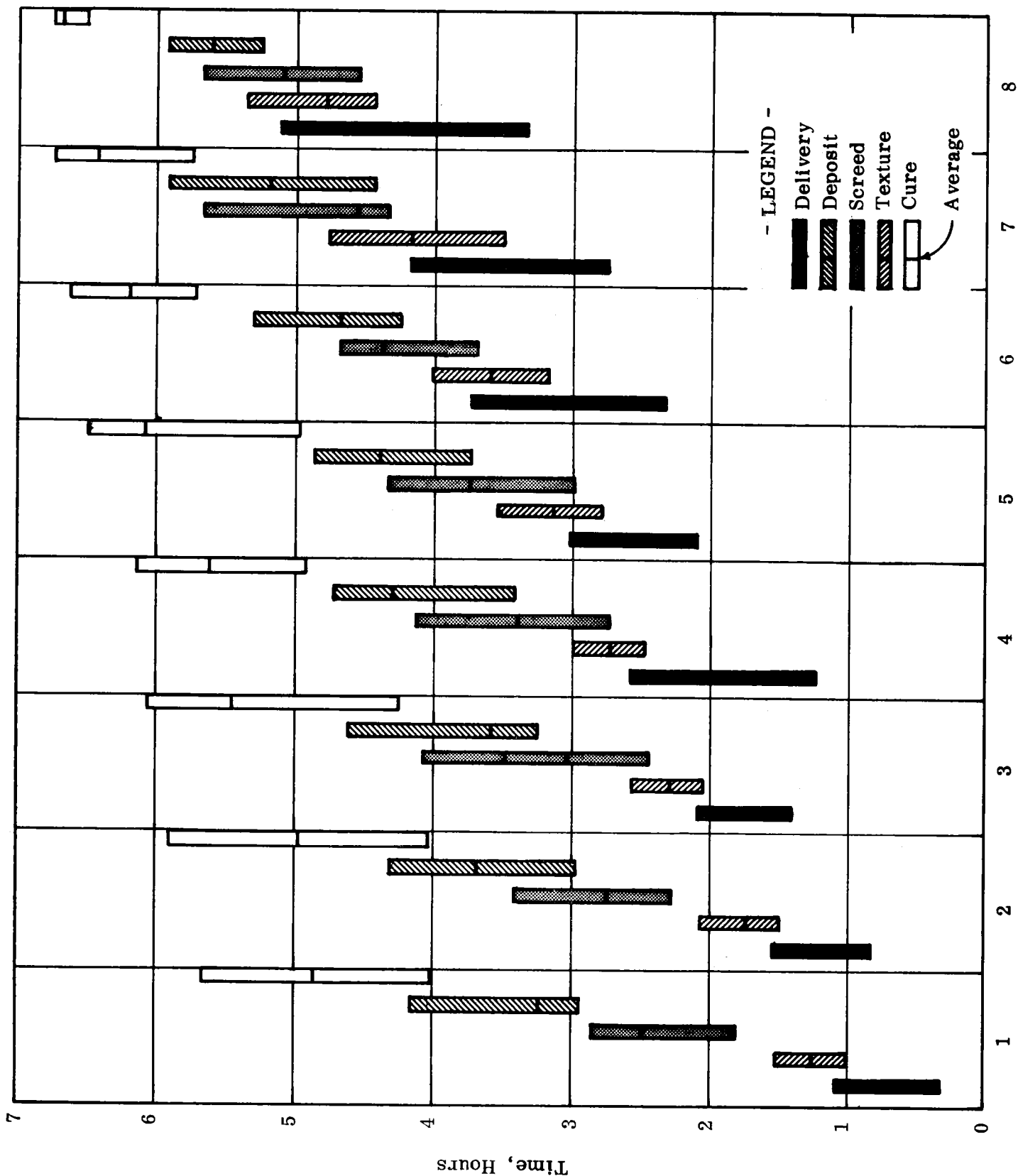


Figure 13. Sequences and total variation in times for single-lift installation activities (average for 2 decks).

Curing

Once the screeding and hand finishing were complete, the decks were covered with wet burlap and polyethylene.

The time and sequence of the various installation activities for the base layer installations are summarized in Figure 14, where it may be observed that the operations proceeded in a reasonably uniform manner. On the average, these layers were completed through the screeding stage in approximately 4 hours after the first truck of concrete was batched.

Procedure for the Six Overlay Installations

The procedure used to construct the six overlay courses were as described below.

Sandblasting

Prior to the placement of the overlays, the base layers were sandblasted to remove laitance and loose or foreign materials. The sandblasting was light and did not expose aggregate particles. Sandblasting and removal of the sand was usually done the afternoon or morning immediately preceding installation of the overlays. Visual inspection of the decks during this cleaning operation confirmed that sufficient laitance had been present to adversely affect the integrity of the bond between the base layers and overlays.

Cement Slurry

Within 1 hour before the placement of the overlay concretes water was broomed onto the base layers. The intent was to maintain a moist concrete surface without free water.

Prior to depositing the first bucket of PCC or fiber concrete, a cement slurry (w/c = 0.40) was deposited and broomed over the entire deck. No slurry was used with the latex modified concrete, however a portion of this concrete was broomed onto the deck surface ahead of the overlay placement. During each of the six installations some sand was tracked onto the deck by the workers before the overlay was placed. Also, because the slurry had been placed over the entire deck at the beginning of each overlay installation, it was necessary to prevent the slurry from drying on the latter portions of deck before placement of the overlay.

Inspection of the overlay placement information (Appendix B) shows that in order to avoid interruption of the screeding operation the slurry did not need to be applied more than 10 feet (3 m) ahead of the concrete placement. If the application time for the bonding layer had been controlled in this way the time sequences of operations shown in Appendix C indicate a maximum exposure time of approximately 15 minutes. Drying of the slurry through evaporation would therefore not be a problem under most environmental conditions.

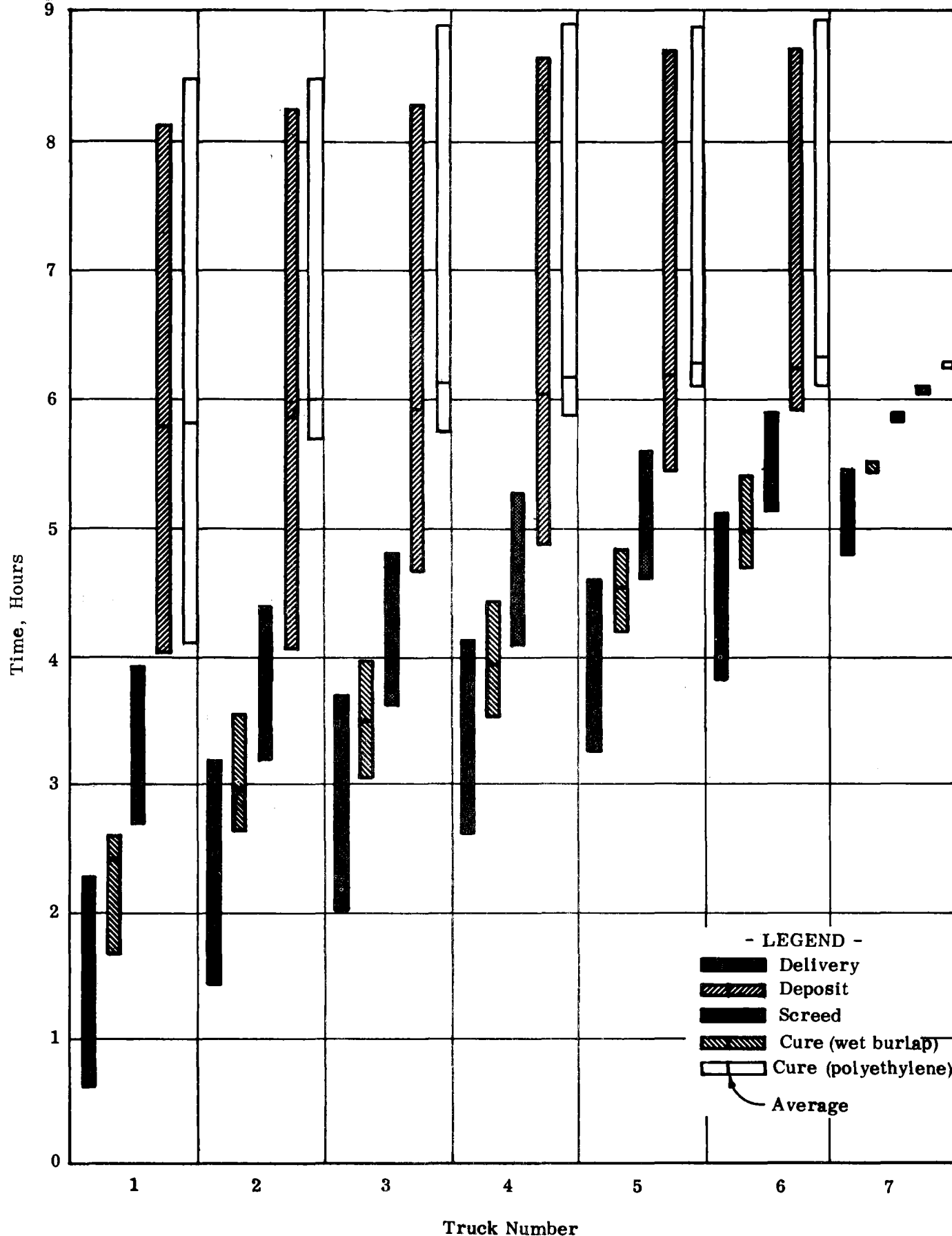


Figure 14. Sequences and total variation in times for base layer installation activities (average for 6 decks).

Delivery

The high quality PCC and fiber reinforced concrete were delivered to the job site in conventional ready-mix trucks as described for the base layer installations. The latex modified concrete was produced at the job site by two mobile mixer trucks which discharged into the $3/4 \text{ yd}^3$ (0.6 m^3) capacity crane bucket.

Depositing

The overlay materials were raked and manipulated a considerable amount as the concretes were deposited somewhat deeper than was necessary. However, an overdepth range of from 1 to 2 inches (25 to 50 mm) in the unconsolidated concrete ahead of the vibrator was found to be desirable. Compared to the ease with which the latex material could be broomed into position, the workers experienced some difficulty in placing the PCC and the fiber concrete. Typical depositing activities are shown in Figure 15, including the handwork required to maintain the overdepth range.

Screeding

The overlays were screeded to provide approximately 2 inches (50 mm) of cover above the reinforcing steel. Also, the screeding operation was begun with the vibrator unit directly over the edge of the deck. From this starting position the transverse screed was moved forward very quickly until the rear edge of the roller was aligned with the edge of the deck, at which time the screeding operation moved forward at a slower speed. As a result, the first 6 feet (1.8 m) of the wearing courses were not vibrated as much as the remainder of the overlays. As with the base layer installations, the roller tended to push the excess concrete and bleed water to one side of the deck and forward. Bleed water was evident during both the latex and fiber overlay installations.

Consolidation of the overlays was accomplished by one or more passes of the vibrator unit, shown in Figure 16, over contiguous transverse strips of the deck surface. The auger pushed most of the excess concrete ahead, and the screed roller smoothed the deck surface while shifting a small roll of surface mortar as shown in Figure 17.

Finishing

The float attached to the rear of the screed roller provided satisfactory finishing for most of the deck prior to texturing (Figure 18). However, as with the base layer installations, hand finishing was required at each end of the deck and along both sides. In most instances the hand finishers worked near the rear wheels of the screed. Little difficulty was encountered in hand finishing this area for the latex overlay, but the internal spud vibrator was used for both the PCC and fiber overlays. A monomolecular film was applied to the PCC overlay, and protruding fiber balls were removed from the wire fiber overlay.

1051



Figure 15. Rapid depositing of overlay concretes (above). Some handwork required ahead of screed to maintain maximum overdepth of approximately 2 inches (below).

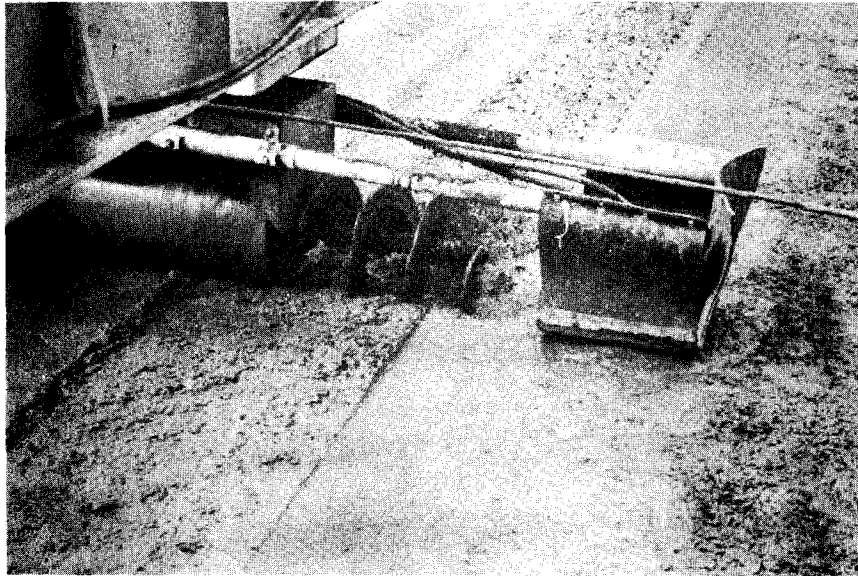


Figure 16. Consolidation of overlay concretes provided by suspended pneumatic vibrator (right).

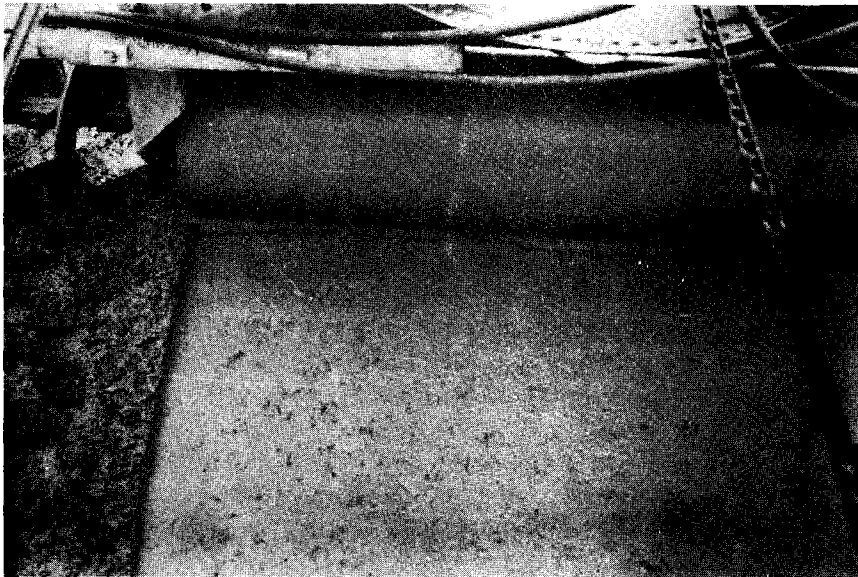


Figure 17. Characteristic roll of mortar preceding the rotating drum of the screed.

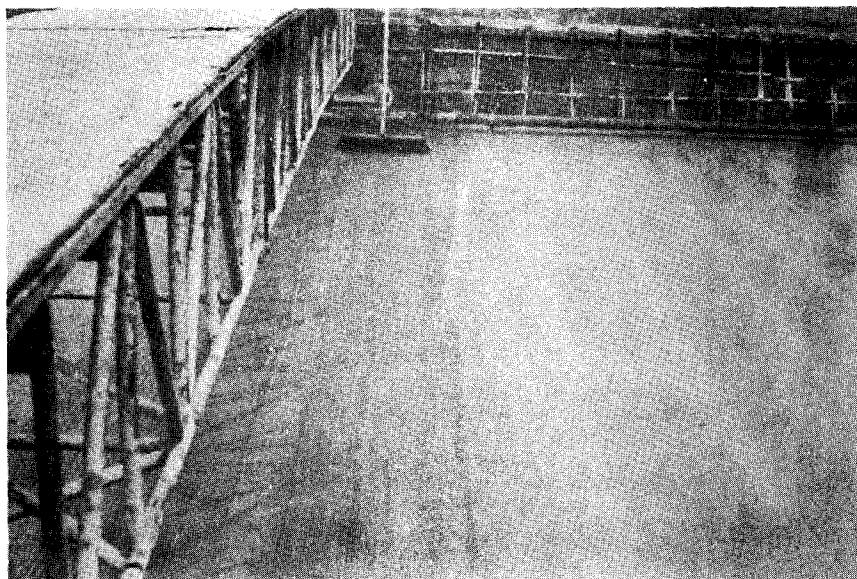
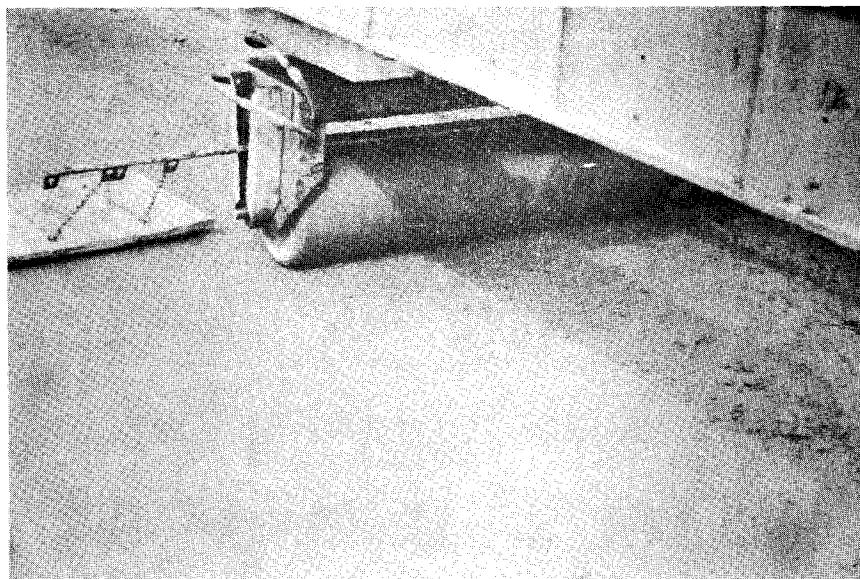


Figure 18. Trailing metal float (above) closes small surface voids to produce a smooth surface for texturing (below).

Texturing

From a work bridge at a suitable distance behind the screed, a broomed texture was applied manually to each of the overlays (Figure 18). A monomolecular film was applied to the surface of the PCC overlay at the discretion of the finishers prior to the brooming of the surface. Numerous minor voids, noted in the surface of the PCC and wire fiber overlays after the finishing operation, were removed by the brooming. An occasional protruding fiber ball interrupted the brooming of the fiber overlay.

Curing

The decks were covered with wet burlap and polyethylene (Figure 19). Particular curing requirements are described in the Virginia Department of Highways & Transportation specifications and in the contract special provisions. The times for and sequences of the various installation activities for the six overlays are summarized in Figure 20. In general, the operations proceeded in a reasonably uniform manner.

Concrete Control

Important aspects of the durability of bridge decks are related to the properties of the fresh concrete and to the ability of the construction technique used to provide the specified depth of protective cover over the reinforcing steel. These topics are discussed in the following sections.

Concrete Properties

The acceptance of concrete for placement in bridge decks involves the measurement of certain properties of fresh concrete at the construction site. The air content, slump and temperature of concrete are measured at the job site and serve as the final criteria for allowing concrete to be placed in the forms. Quality assurance is obtained through the testing of hardened compression cylinders which are fabricated at the site. Table 3 presents data recorded for two independent samples selected randomly from mixes for each base layer, overlay, and control deck installation. These mixes were sufficiently workable for placement in the respective layers, and the air contents and strengths indicated good potential for freeze and thaw durability.

Strength data are contained in Table 3 for 6 in. x 12 in. (152 mm x 305 mm) cylinders that were moist cured and tested at 7 days and later. The design strength of 4,000 psi (27.6 MPa) at 28 days, required in the major structural portion of the decks, was significantly exceeded by that of the overlay concretes. These higher strengths are not necessary for the entire deck structure but suggest improved potential for good durability as desired in the wearing surfaces of the decks.

Weather data included in Table 3 show no unusual conditions during the construction, and it was observed that similar placement conditions existed during construction of the several decks being evaluated.

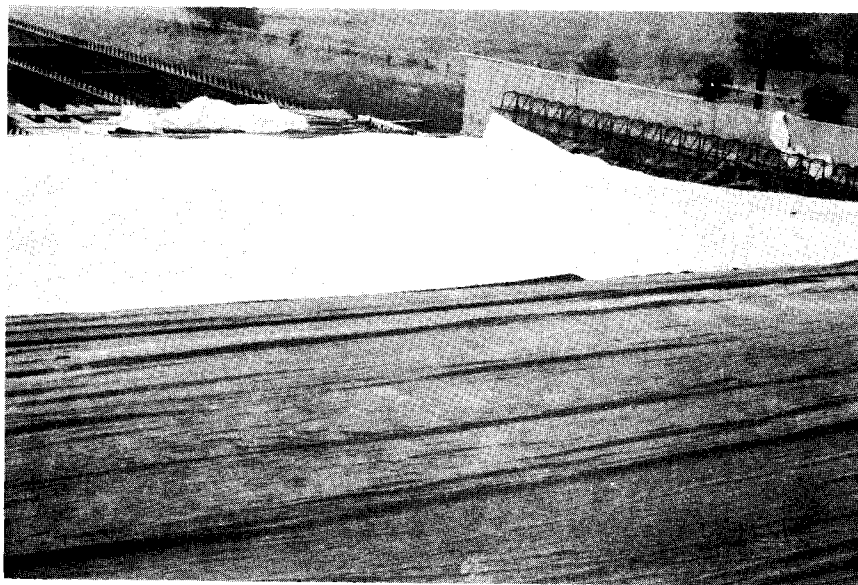
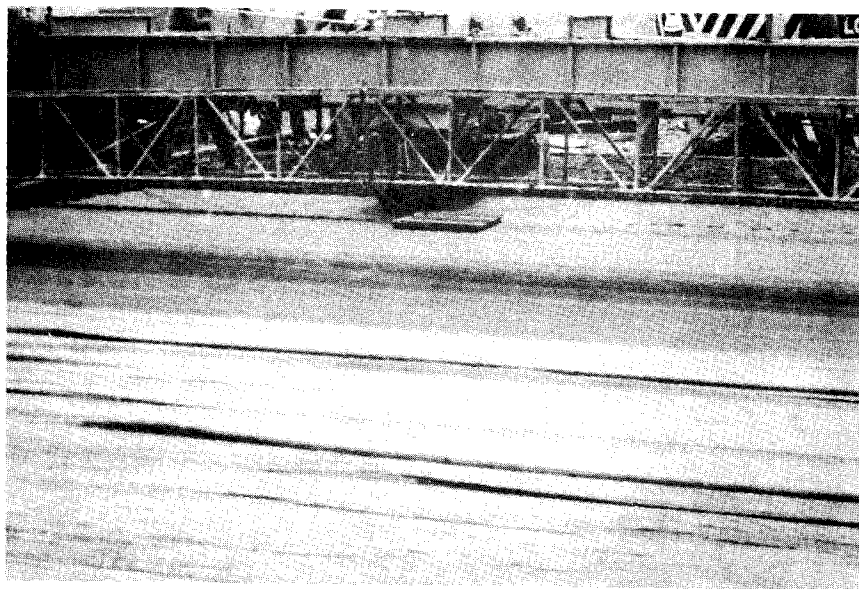


Figure 19. Curing provided by damp burlap (above) with evaporation retarded by white pigmented polyethylene (below).

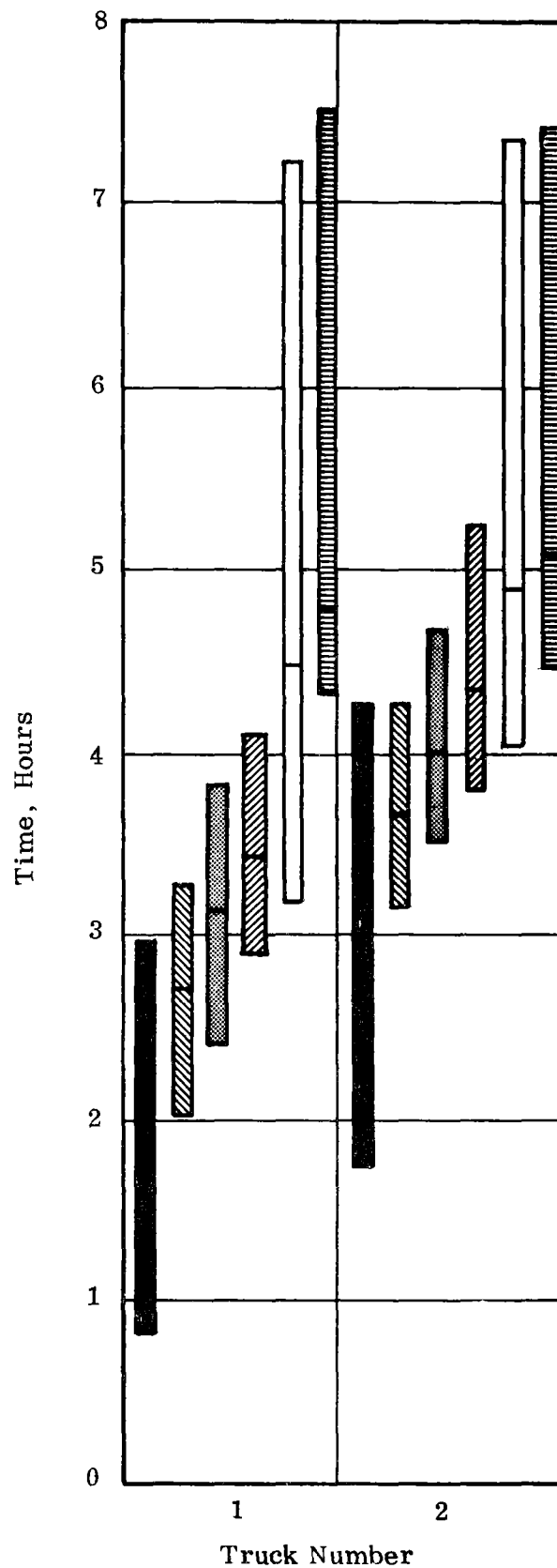
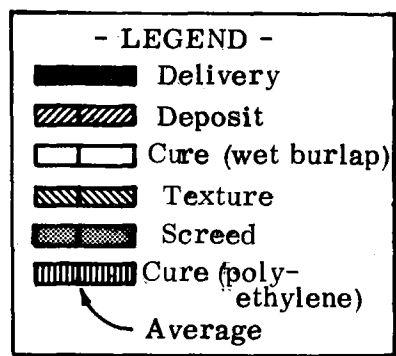


Figure 20. Sequences and total variation in times for overlay installation activities (average for 6 decks).

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	3420 2620	82	80	40	5-8
Latex Overlay B-613 6-6-74	1	3.2	1.5	7.5	3270 3460	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	3200 5020	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	4440 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	3726 4616	83	85	60	0-5
Base Layer B-613 6-25-74	1	5.6	5.0	4.0	3838 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	3599 4850	79	72	62	0-2
	2	5.9	5.0	4.0	3882 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 4940	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

Depth of Cover

Clear concrete cover over the topmost reinforcing steel provides the barrier against intrusion of chlorides and other materials that contribute to corrosion of the steel. A comparison of the thicknesses of these layers in the normal single-lift construction technique and the two-course technique can be made from Figure 21. This figure was derived from depth probes made in the fresh concrete layers.

The average depth of cover is 2.41 inches (61.2 mm) for the single-lift control decks observed in this study. This value agrees closely with the average cover depth of 2.40 inches (61.0 mm) reported by Newlon⁽¹⁴⁾ for 339 deck spans included in a recent report from a study on the performance of concrete in Virginia bridge decks.

The average depth of total cover for the two-course decks is 2.31 inches (58.7 mm), of which 0.31 inch (7.9 mm) resulted from the base layer construction. The magnitude of this total depth is within one standard deviation of the cover depth provided by single-lift construction. The design requirement for the total deck thickness was specified to be a minimum of 8.5 inches (216 mm) yet not to exceed 9.0 inches (229 mm). The averages of total deck thicknesses for the single-lift and two-course techniques were 8.74 inches (222.0 mm) and 8.85 inches (224.8 mm), respectively, with a standard deviation of 0.20 inch (5.1 mm).

Equal deck thicknesses were achieved using the single-lift and the two-course construction techniques. Therefore, any future differences in chloride penetration observed among the eight decks included in this study should be a function of other properties of the hardened concretes.

Discussion

The time and sequence data in Figures 13, 14, and 20 showed the orderly progression of construction activities performed for each truckload of concrete in this study. In Figure 22, these same data are averaged for the single-lift decks and for the two layers of the two-course decks. It may be observed in this figure that the three groups of installation activities progressed in a similar, orderly way.

In the next section of this report, the activities for the overlay installations continue to be discussed without regard to the particular type of overlay concrete involved to illuminate similarities or differences in the two-course and single-lift construction techniques.

Two-Course Versus Conventional Construction

The individual installation activities making up the sequences which were presented in Figure 22 have been adjusted to a common time datum in Figure 23. In this way, several observations regarding the construction activities may more easily be visualized.

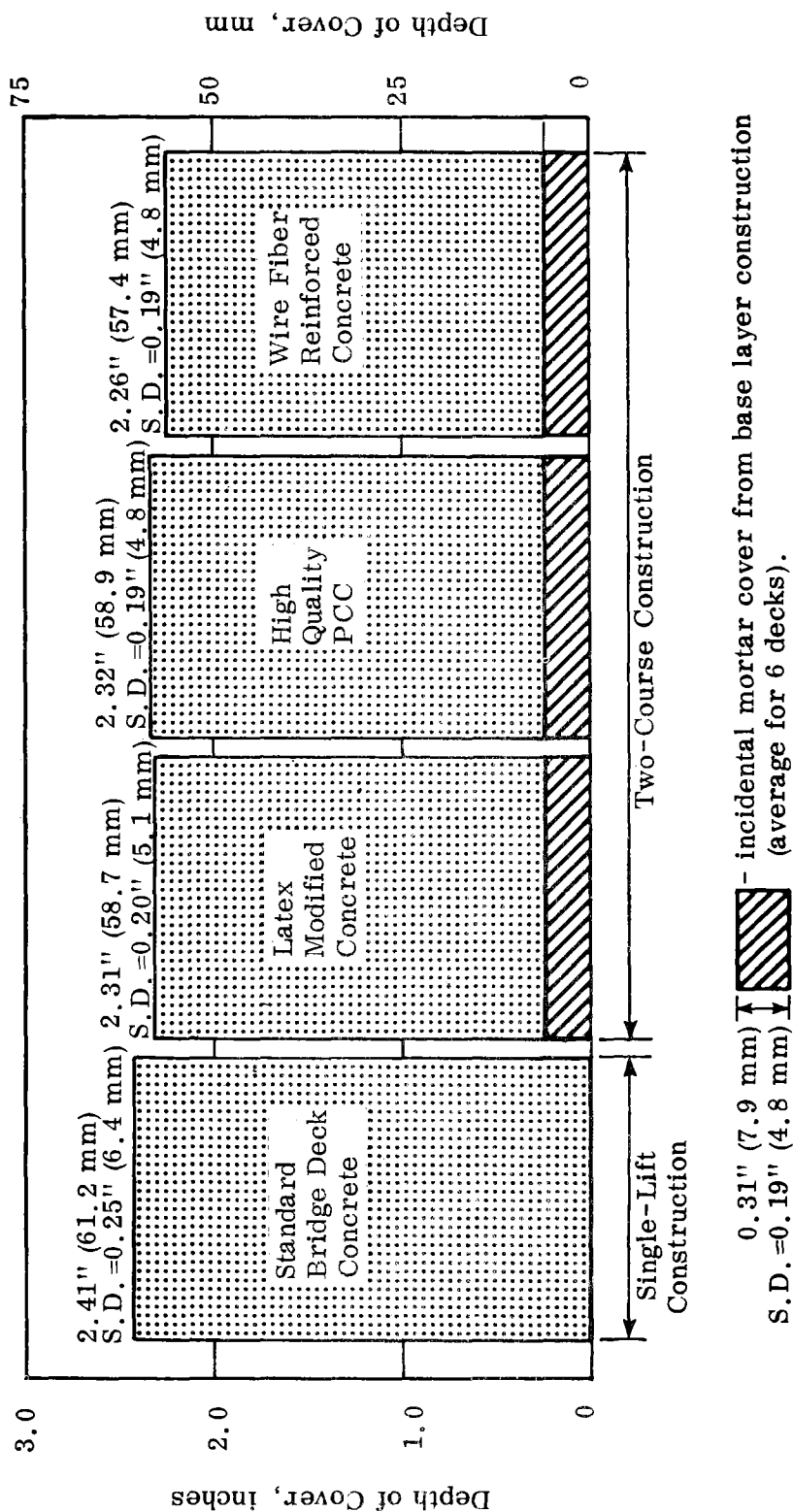


Figure 21. Depth of cover over topmost reinforcing steel for eight study decks.

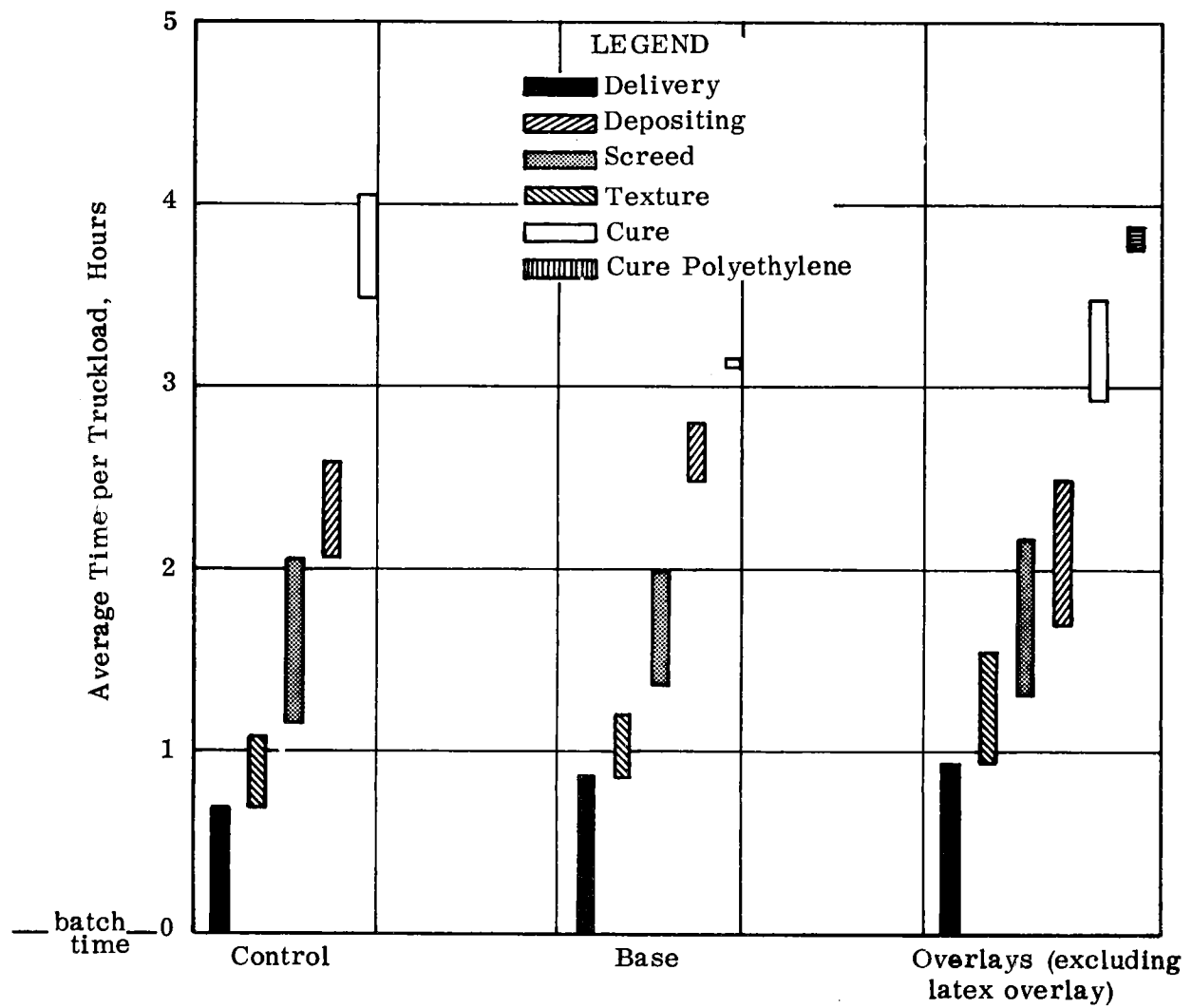


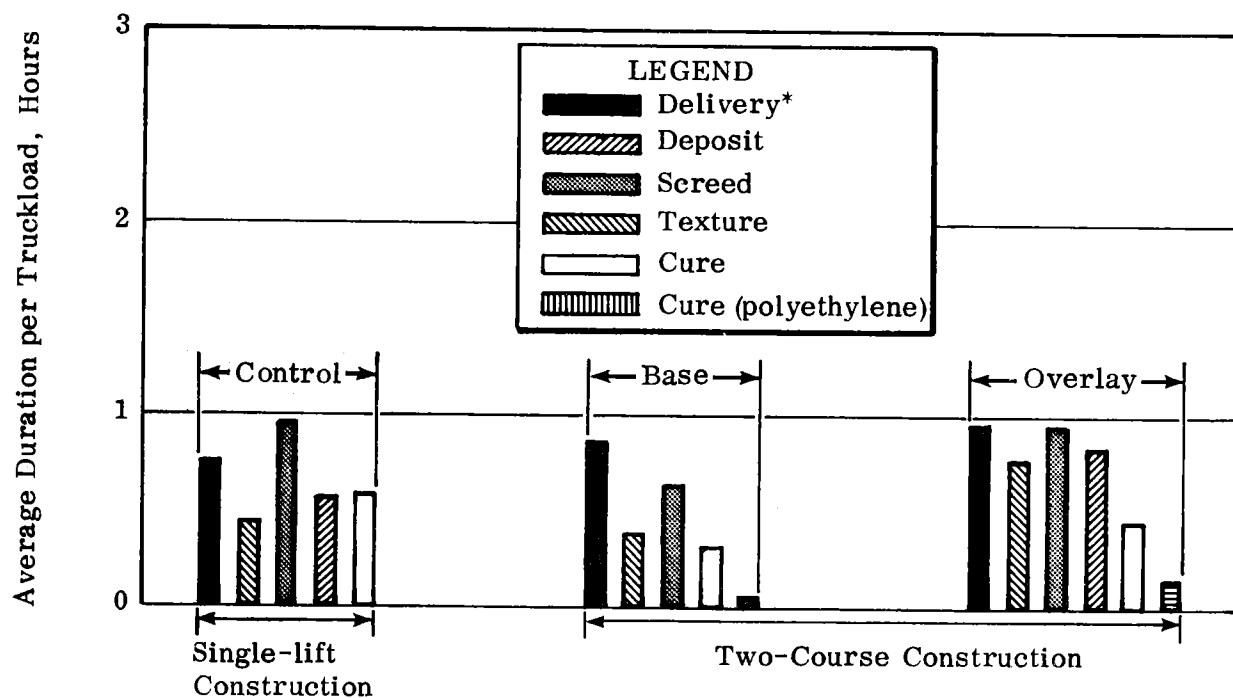
Figure 22. Sequences and average time periods for installation activities.

As shown in Figure 23, somewhat more time was required to deliver and deposit truckloads of concrete for the overlay portions of the two-course decks than for either the base layers or the single-lift decks. Most of the difference in deposit time was caused by the difference in the amount of deck surface area that was covered by each truckload of concrete (Appendix B). Differences in the concretes involved in the study, which will be discussed in the next section of the report, were responsible for part of the differences in deposit time and all of the differences in delivery time.

It is during the time period between the initial depositing of the concrete and the completion of the screeding activity that problems such as excessive drying and reworking can occur. In Appendix B, the placement charts show that seven truckloads of concrete were required for the control decks whereas only two truckloads were needed for the overlay placements. Therefore, a single 7 yd³ (5.4 m³) truckload of concrete was screeded over approximately 3-1/2 times as much surface area during the overlay applications as for the conventional single-lift construction. In Figure 23 it is shown that despite this difference in deck surface area covered per truckload of concrete, the average duration of the screeding activity per truckload was approximately the same in both the two-course and single-lift techniques. Also it was mentioned previously that the average delivery and deposit times were greatest for the overlay installations. Although the greater delivery time is related to the batching procedures, an inspection of Figure 22 shows the overlap in the depositing and screeding operations for the overlay installations, which tends to reduce the time interval between the initial deposit and the completion of the screeding activities for the overlay installations to that required for the single-lift installations. An inspection of Figure 24 confirms the relationship. Therefore, with respect to problems in the concrete mixes that could have an increased tendency to occur with an increase in the time interval between the depositing and the completion of the screeding activities, the two construction techniques are equivalent.

The construction activities for the base layers of the two-course decks also may be observed in Figure 23. The surfaces of these layers were important since good bond for the overlays was required on them. The average activity durations per truckload of concrete for the base layers was comparable to, and actually somewhat less than, those for the single-lift decks. Concrete properties for developing bond to the overlays were therefore shown to be favorable as a result of the base layer construction procedures.

Various comparisons of the single-lift and two-course construction techniques are possible with the information summarized in the bar charts of Appendix C. Useful information for planning considerations is obtained by computing the average times required to complete the concrete construction activities through the screeding operation for the eight bridge deck installations. These average times for the single-lift, the base layer and the overlay installations were 5-1/2 hours, 4-1/4 hours, and 3 hours respectively. The average total of hours required to install concrete in the three types of two-course decks was therefore 7-1/4 hours, which is 33% greater than the hours required to install conventional single-lift decks. The total man-hours were also 33% greater for the two-course decks since the same crew was employed for all of the decks constructed.



* Delivery time not applicable for latex modified concrete.

Figure 23. Average durations for construction activities.

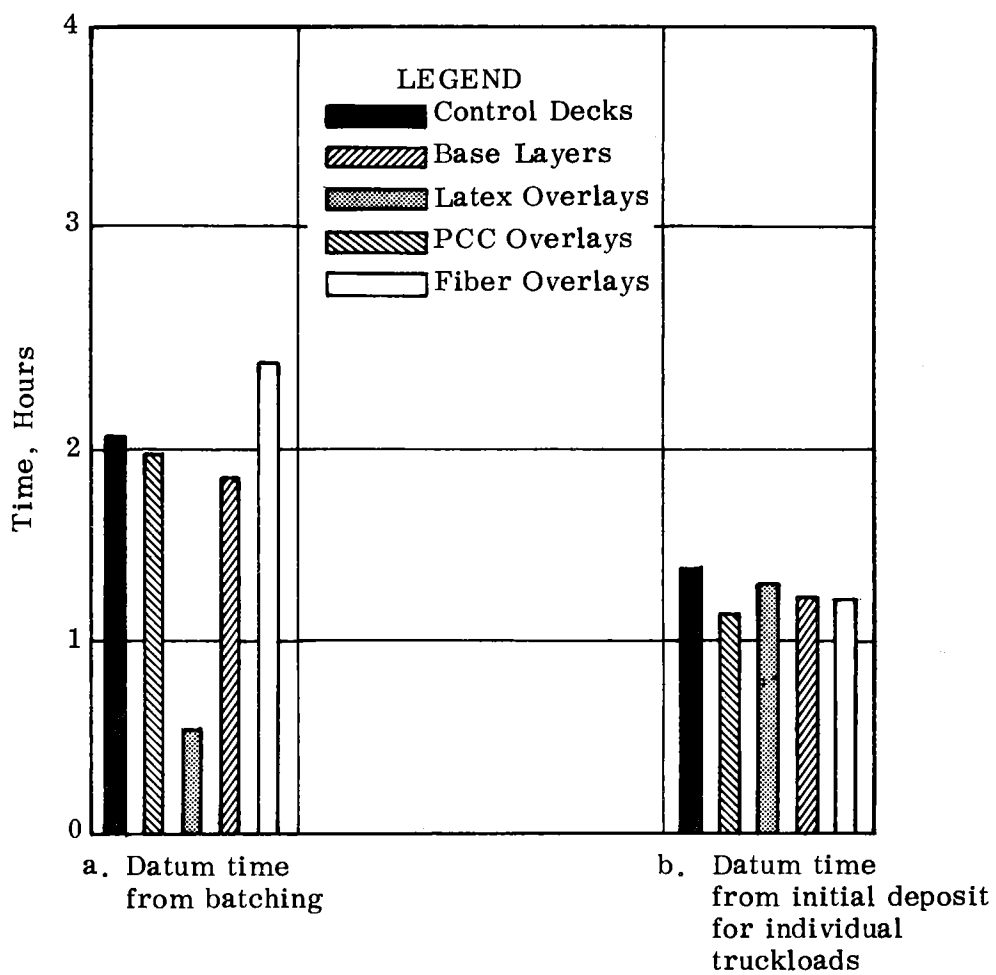


Figure 24. Average times to completion of the screeding activity.

In terms of project days, Appendix C shows that there was no difference between the two techniques. For the final four two-course decks, two base layers were cast per day and subsequent to the hardening two overlays were cast per day. The average was therefore one project day per two-course deck, and similarly the single-lift decks were each constructed in one day.

Comparison of the Three Types of Overlay Installations

The activities for the three types of overlay installations have been discussed as a group for the purpose of drawing comparisons between the two construction techniques. Now some comparisons will be made among the latex modified concrete, high quality PCC and wire fiber reinforced concrete overlay installations. The time at which final screeding is accomplished was discussed in the preceding section as being a critical factor in determining the potential performance of bridge deck concrete. For this reason, the times at which the screeding activity was completed will serve as the basis for comparisons among the three types of overlay installations.

In Table 4 the average and maximum time intervals from the batching operation through the screeding activity for each type of installation is presented. The coefficients of variation for the average time intervals are also tabulated. All of the coefficients are close in magnitude to those for similar data in another study (14) and are believed to represent excellent control for the two-course as well as the single-lift construction. In general, the coefficients are lower for the overlay installations than for the single-lift control decks. This suggests that two-course construction has the potential for producing bridge decks with concrete of more uniform quality. The overlay concretes were also shown earlier in this report to have higher strengths and potentially greater durability than conventional bridge deck concrete. Therefore the concrete in the wearing surfaces of these two-course installations should be characterized as being more uniform in quality and of higher quality than normal superstructure concrete.

The highest coefficient of variation was obtained for the latex modified concrete overlays. This is attributed to the fact that the latex overlays were the first placed by the contractor and were therefore the installations for which the contractor was least familiar with the two-course technique.

The influence of the type of overlay concrete on the construction process may be observed in Figure 24-a. The mean times for completion of the screeding activity for each truckload of concrete were different, primarily because of differences in the batching operations. Addition of steel fibers to the wire fiber reinforced concrete required a special effort, making it the most lengthy batching operation.

In Figure 24-b, the zero reference time for completion of the screeding activity has been computed from the time the first deposit from each truckload of concrete was placed on the decks. It was apparent from observing the six overlay installations that more effort was required to place PCC and wire fiber concrete mixes. However the relative progression of the depositing and screeding activities is as shown in the bar chart in Figure 24-b. A comparison among the several installations indicates that, on the average, operations requiring exposure of concrete on the deck surfaces were of approximately equal duration for all of the truckloads of concrete in the project.

Table 4

Time Interval Information for Periods Between Batching and
Completion of Screeding

Type Construction	Time Interval Average (hours) Maximum (hours)	Coefficient of Variation For Average Time Interval
Control Decks	2.1 2.7	21
Base Decks	2.0 3.4	21
Latex Overlays	0.5 3.4	21
PCC Overlays	1.9 2.5	22
Fiber Overlays	2.5 2.8	11

From the observation made in the preceding paragraph, it may be concluded that the three overlay concretes had placement characteristics that were compatible with the equipment and personnel employed in the two-course construction technique. This, along with the coefficients of variation in Table 4, suggests that the systematic construction procedures observed during these installations are representative of the two-course construction technique. After giving support to the validity of the project data, another conclusion which follows from the information represented in Figure 24-b is that with respect to the placement of a truckload of concrete in a bridge deck, the two-course and single-lift construction techniques are equivalent.

Cost Considerations

The cost of the overlay concretes in place were approximately 15, 24 and 32 dollars per 1 yd² (0.84 m²) for the high quality PCC, latex modified concrete and wire fiber reinforced concrete, respectively. This range of values is probably representative of the costs that can reasonably be anticipated for these and other overlay concretes in the immediate future. An increase of about 5% in the total cost of the bridge deck superstructure is therefore indicated when the two-course technique is specified in lieu of the conventional single-lift construction technique.

Observations and Conclusions

On the basis of information gathered in this study of two-course bonded concrete bridge deck construction, observations and conclusions are made as follows:

1. The base layer concrete of the two-course decks was screeded satisfactorily using the transverse screed selected for the overlay installations. This procedure was selected by the contractor, and the longitudinal screed should prove equally effective.
2. Light sandblasting of the base layers removed laitance that may have adversely affected the bond between the base layers and overlays.
3. To avoid excessive drying the bonding layer of cement slurry should be broomed onto the base layer not more than 10 feet (3 m) ahead of nor longer than 15 minutes prior to the placement of overlay concretes. The two-day delay between placement of a base layer and overlay is the optimum period.
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 inches (58.4 mm) of which 0.3 inch (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 yd³ (5.4 m³) truckload of concrete was screeded over 3 1/2 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 were 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.

RECOMMENDATIONS

1. When additional protection of the upper reinforcing steel is warranted, two-course bonded construction should be considered as a viable alternative to conventional bridge deck construction.
2. Protective concretes should be considered compatible with this two-course construction technique if their handling characteristics from batching through screeding activities are similar to the handling characteristics of any one of the overlay concretes used in this study.

ACKNOWLEDGMENTS

The authors are grateful for the assistance provided by the Staunton Construction District in conducting this study and for the cooperation shown by the contractor on this state funded construction project.

The study of the two-course technique for bridge deck construction is federally funded and is under the general direction of J. H. Dillard, state highway research engineer. The study was initiated through the efforts of H. H. Newlon, Jr., assistant state highway research engineer and head of the Concrete Section.

REFERENCES

1. Durability of Concrete Bridge Decks, PCA-BPR (6 reports: 1965-1970).
2. Concrete Bridge Deck Durability, NCHRP, Synthesis of Highway Practice 4, Highway Research Board, 1970.
3. Newlon, Howard H., Jr., Comparison of Properties of Fresh and Hardened Concrete in Bridge Decks, Virginia Highway Research Council, 1971.
4. Newlon, Howard H., Jr., et al., Bridge Deck Performance in Virginia, Virginia Highway Research Council, Reprint from Highway Research Record #423, Highway Research Board, pp. 58-72, 1973.
5. Clear, K. C., and R. E. Hay, Time-to-Corrosion of Reinforcing Steel in Concrete Slabs, Vol. 1: "Effect of Mix Design and Construction Parameters", FHWA-RD-73-32, Interim Report, April 1973.
6. ACI Committee 345, Proposed ACI Standard: Recommended Practice for Concrete Highway Bridge Deck Construction, Journal of the American Concrete Institute, pp. 381-415, June 1973.
7. Brink, Russell H., Prevention of Bridge Deck Deterioration, In-Depth Study Reports from the World Survey of Current Research and Development on Roads and Road Transport, Conducted by the International Road Federation in Cooperation with the U. S. Department of Transportation, FHWA, pp. 456-474, June 1973.
8. Tyson, S. S., Working Plan, Two-Course Bonded Concrete Bridge Deck Construction, Virginia Highway & Transportation Research Council, March 1974.
9. Rahal, Assaf S., "Bridge Decks Constructed for Increased Durability," Kentucky Department of Transportation, Research Report 402, October 1974.
10. Bergren, Jerry V., and Bernard C. Brown, An Evaluation of Concrete Bridge Deck Resurfacing in Iowa, Iowa State Highway Commission, June 1974.
11. Wilk, W., Stage of Development and Experiences made with Bonded Concrete Bridge Pavements in Switzerland, Unpublished Report, Betonstrassen Ag., Lausanne, Switzerland, 1974.
12. Felt, Earl J., Resurfacing and Patching Concrete Pavements with Bonded Concrete, Proceedings, Transportation Research Board, Vol. 35, pp. 444-469, 1956.
13. Rude, L., Unpublished Report, Load Tests of Bridge Deck Strip Models, Virginia Highway Research Council, 1972.
14. Newlon, H. H., Jr., A Survey to Determine the Impact of Changes in Specifications and Construction Practices on the Performance of Concrete Bridge Decks, Virginia Highway and Transportation Research Council, June 1974.

APPENDIX A

VIRGINIA DEPARTMENT OF HIGHWAYS AND TRANSPORTATION
SPECIAL PROVISION FOR TWO-COURSE BRIDGE DECK CONSTRUCTION

Rev. May 6, 1974

Description - The bridge decks on B612 and B613 shall be of two stage construction. This work shall consist of striking off the first stage deck placement level with the top reinforcement followed by the placement of one of three types of topping. This work shall be performed in accordance with the plans and these specifications.

Stage One construction shall conform to the applicable specifications for bridge decks except as follows:

The use of mechanical screeds will not be required.

The concrete to be overlaid will not require a final finish or texturing operation.

The finishing operations may be terminated following the satisfactory screeding of the surface.

The concrete to be overlaid shall be cured as specified in Section 404; however, liquid membrane shall not be used nor shall the surface be treated with linseed oil.

The requirement for nonpolishing fine aggregate will be waived for the concrete to be overlaid.

Stage Two construction shall conform to the applicable specifications except as hereinafter stated:

Materials - The materials for this work shall conform to the following requirements unless otherwise specified:

- (a) Portland Cement shall conform to Section 216.
- (b) Fine Aggregate shall conform to Section 202.
- (c) Coarse Aggregate shall conform to Section 203.
- (d) Formulated Latex Modifier shall be a non-toxic, film forming, polymeric emulsion to which all stabilizers have been added at the point of manufacture and shall be homogeneous and uniform in composition.

Physical Properties - The latex modifier shall conform to the following requirements:

Polymer Type --- Styrene butadiene

Stabilizers

- (a) Latex --- Nonionic surfactants
- (b) Portland Cement Composition --- Poly dimethyl siloxane

Percent Solids --- 46.0 - 49.0

Weight per gallon (pounds at 25°C) --- 8.4

Color --- White

- (e) Steel Fiber shall have a nominal length of 1 inch and may be of either round or flat configuration.
- (f) Water shall conform to Section 218.

The following mix designs are to be used as guides in establishing trail mixes:

- (a) Latex Modified Concrete per cubic yard
 - Cement 658 pounds
 - Fine Aggregate 1,516 pounds
 - Coarse Aggregate (No. 7) 1,177 pounds
 - Latex 24.5 gallons
 - Water 25.5 gallons
- (b) Steel Fiber Reinforced Concrete per cubic yard
 - Cement 752 pounds
 - Fine Aggregate 1,136 pounds
 - Coarse Aggregate (No. 7) 1,616 pounds
 - Steel Fiber 160 pounds
 - Water 44.1 gallons

An approved water reducing retarding admixture shall be used in the mix in accordance with the manufacturer's recommendation.

- (c) High Quality Portland Cement Concrete per cubic yard
 - Cement 705 pounds
 - Fine Aggregate 1,275 pounds
 - Coarse Aggregate (No. 7) 1,275 pounds
 - Water 37.8 gallons

Physical Properties for Concrete Mixes

- (a) Latex Modified Concrete shall have an air content of 3 to 6% and slump of 4 to 6 inches. Slump determination will not be made prior to 4.5 minutes after discharge. The placement temperature shall be between 55 and 85°F (ambient air temperature).
- (b) Steel Fiber Reinforced Concrete shall have an air content of 6±2% and slump of 2 to 4 inches.
- (c) High Quality Concrete shall have an air content of 6±2% and a maximum allowable slump of 2.5 inches. During mixing and placing, the temperature of the Highway Quality Portland Cement Concrete shall not exceed 80°F.

Equipment shall be in conformance with Section 219.05 and 404.19(f) except that a vibrating screed shall be used for the overlays.

Preparation of Surface - Immediately prior to placement of the overlay, foreign materials detrimental to achieving bond shall be removed by light sand blasting followed by air blast or vacuum. Such sand blasting shall be sufficient to remove all laitance and contamination; however, it will not be necessary to expose the aggregate. Thorough water soaking of the surface for not less than 1 hour prior to placement will be required. All puddles of standing water shall be removed prior to application of bonding slurry.

Handling and Storing Materials shall conform to Section 219.03. In addition, Latex modifier shall be stored and handled in such a manner as to protect it from extreme heat or cold. Latex modifier to be stored shall be kept in suitable enclosures which will protect it from freezing and from prolonged exposure to temperatures in excess of 85°F. Drums of latex modifier if stored in direct sunlight, for a period not to exceed 10 days, shall be covered both top and side with suitable insulating blanket material.

Proportioning of Materials shall conform to Section 219.04 of the Specifications.

Mixing of Materials shall conform to Section 219.12 and 219.13 unless otherwise specified.

* In steel fiber reinforced concrete, the fibers shall be introduced into the mix in such a manner as to preclude any clumping and so as to provide for their even distribution. The order of blending shall be to charge the mixer first with the aggregates followed in order by the steel fibers, approximately 80% water, cement and the remainder of the water.

Placing and Finishing shall conform to Section 404.19(f) unless otherwise specified.

Expansion joints shall be maintained through the overlayment.

(a) High Quality and Steel Fiber Concrete

After the surface has been cleaned and dampened, and immediately before placing the High Quality or Steel Fiber overlayment, a portland cement, slurry, having a water-cement ratio compatible with the overlays shall be brushed onto the wetted prepared surface. Care shall be exercised to insure that all surfaces receive a thorough, even coating and that the rate of progress is limited so that the brushed material does not become dry before it is covered with the overlayment.

Curing shall be in accordance with the specifications.

(b) Latex Modified Concrete

After the surface has been cleaned and dampened with water, the properly mixed Latex Modified Concrete shall be deposited on the placement site where it shall be brushed onto the prepared surface. Care shall be exercised to insure that all surfaces receive a thorough, even coating and that the rate of progress is limited so that the brushed material does not become dry before it is covered with sufficient additional material required for the final grade.

The Latex Modified Concrete shall be promptly covered with a single layer of clean, moist burlap. Care shall be exercised to insure that the burlap is well drained and that it is placed as soon as the surface will support it without deformation. It is the nature of the latex modifier to form a plastic film at the surface upon drying, usually 25 minutes in hot weather. It is the intent of this specification to protect the integrity of the film by prompt covering with moist burlap. An additional curing medium of burlap or polyethylene film shall be placed on the moist burlap approximately one hour later in order to maintain the moist condition for 24 hours after which they shall be removed.

Limitation of Operations - The overlayments shall be placed at the earliest time practicable but in no case earlier than 24 hours nor later than 30 days after placement of first stage. In the event that an overlayment is to be placed prior to the first stage reaching the requirements in Table XVI, provisions shall be made to insure that loads from any equipment are transmitted directly to the girders.

The first stage shall meet the requirements of Table XVI and the overlay shall have been in place 96 hours prior to any traffic being permitted on any of the decks.

Adequate precautions shall be taken to protect freshly placed overlays from sudden or unexpected rain. The Engineer may order removal of any material damaged by rainfall.

The Contractor shall prepare trial batches, of the different overlays, prior to actual use, in order to determine any necessity for minor adjustments in the mix designs and to allow the personnel to become familiar with the mixing and handling of the different materials.

Bridges B612 and B613 shall be used as the overlay bridges. The spans "a" on each bridge shall be overlayed with the Latex Modified Concrete. The spans "b" on each bridge shall be overlayed with the Steel Fiber Reinforced Concrete. The spans "c" on each bridge shall be overlayed with the High Quality Portland Cement Concrete. Consideration will be given to requests to change the preceding sequence.

Method of Measurement - Overlaying of bridge decks will be measured in units of square yards.

Basis of Payment - Overlaying of bridge decks will be paid for at the contract unit price per square yard of the appropriate type. This price shall be full compensation for surface preparation, furnishing all material, equipment and labor necessary to complete the work in accordance with the plans and specifications.

<u>Item</u>	<u>Unit</u>
Latex Modified Concrete	Square Yard
Steel Fiber Reinforced Concrete	Square Yard
High Quality Portland Cement Concrete	Square Yard

APPENDIX B

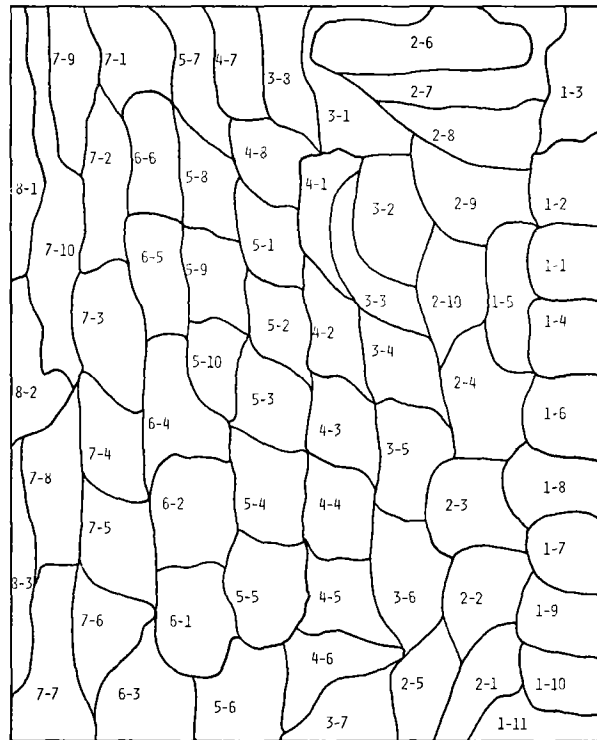
INITIAL PLACEMENT LOCATIONS FOR CONCRETE IN EACH DECK

The locations are accurate to the nearest foot. The numbers in each area indicate respectively the placement sequence for each truck and bucket from each truck. Each figure is oriented so that north is toward the left side of the page.

CONTROL DECKS

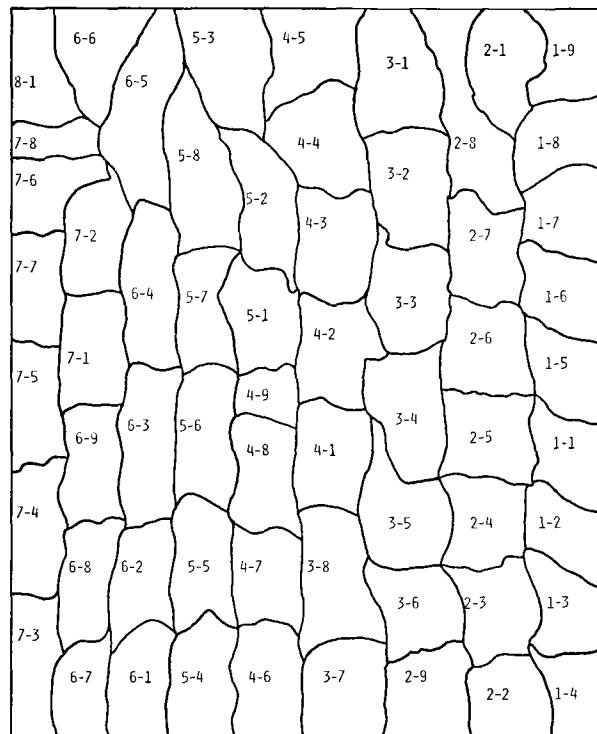
B611 WBL

Date: 5/15/1974



B610 EBL

Date: 6/28/1974



TWO COURSE LATEX DECKS

Base Decks

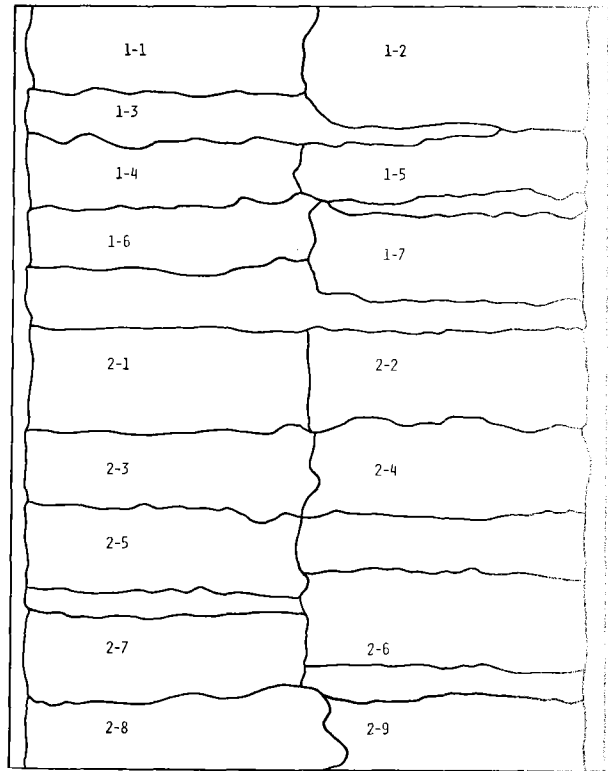
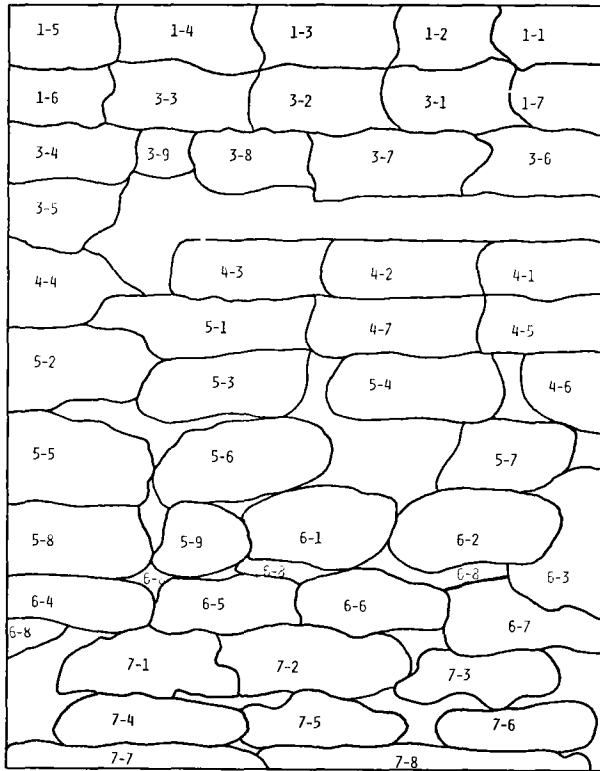
Overlays

B613

WBL

Date: 6/4/1974

Date: 6/6/1974



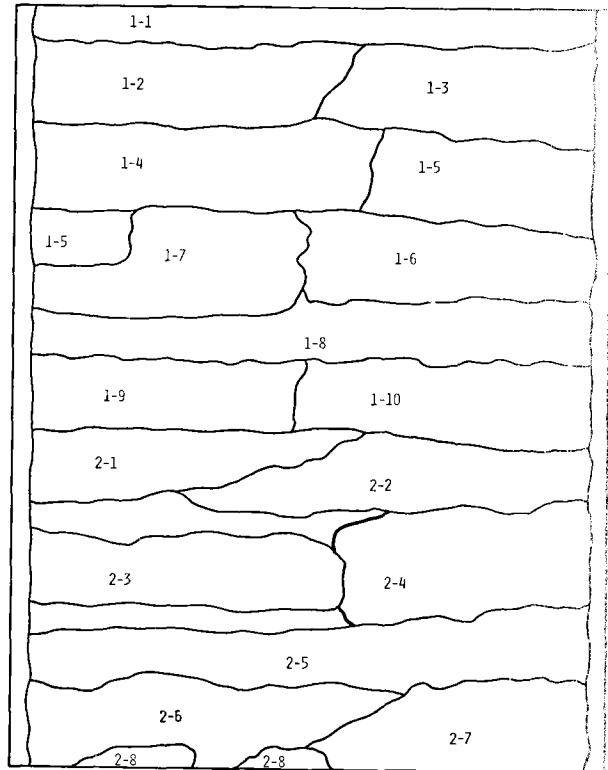
B612

EBL

Date: 6/5/1974

Date: 6/7/1974

Base layer placement not recorded.



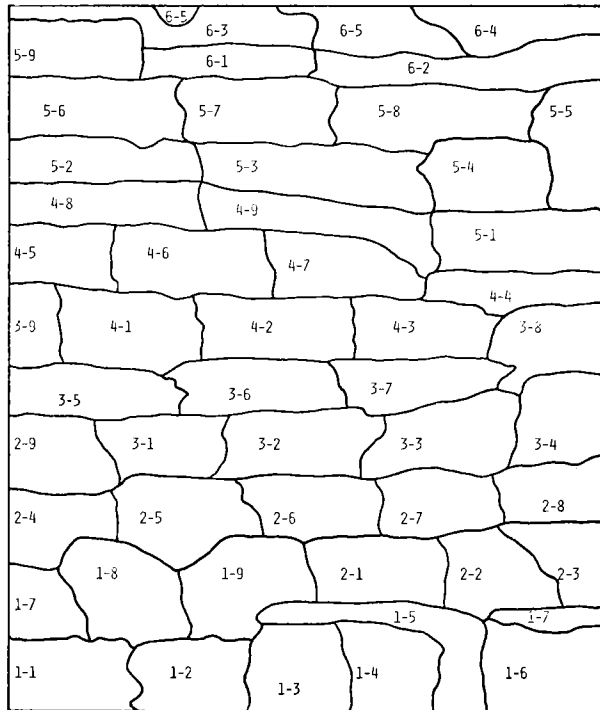
B-3

TWO COURSE PCC DECKS

Base Decks

B613

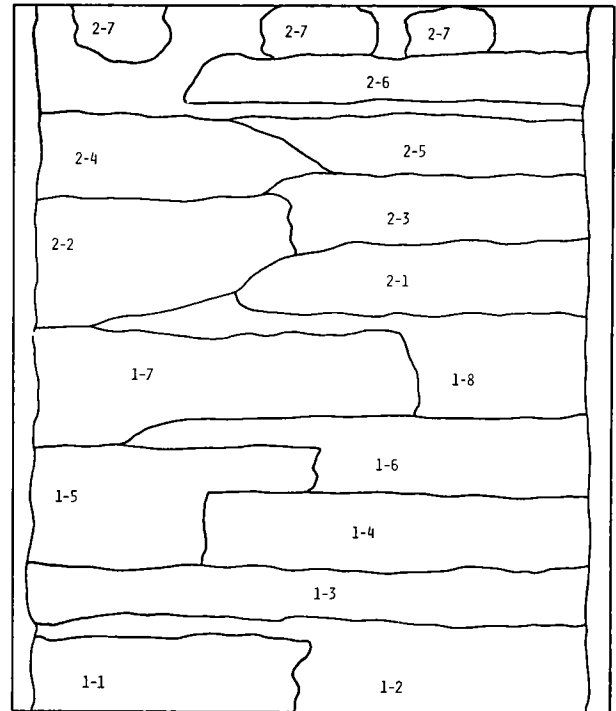
Date: 6/16/1974 a.m.



Overlays

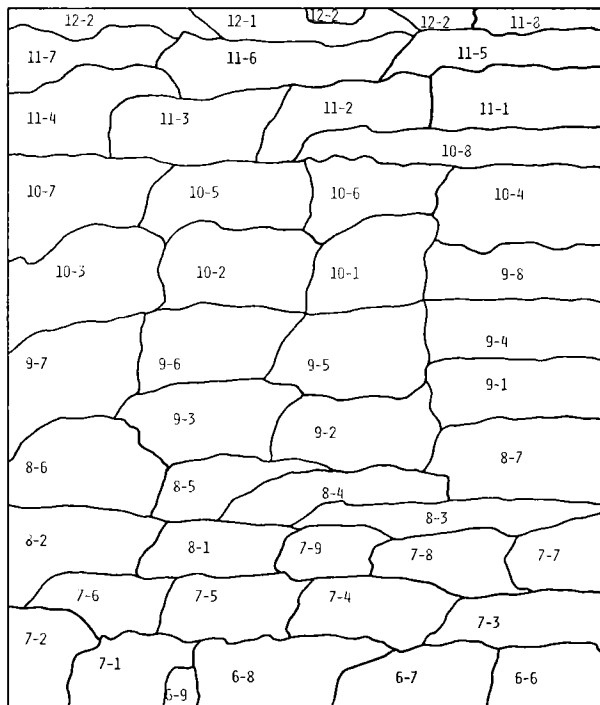
WBL

Date: 6/20/1974 p.m.



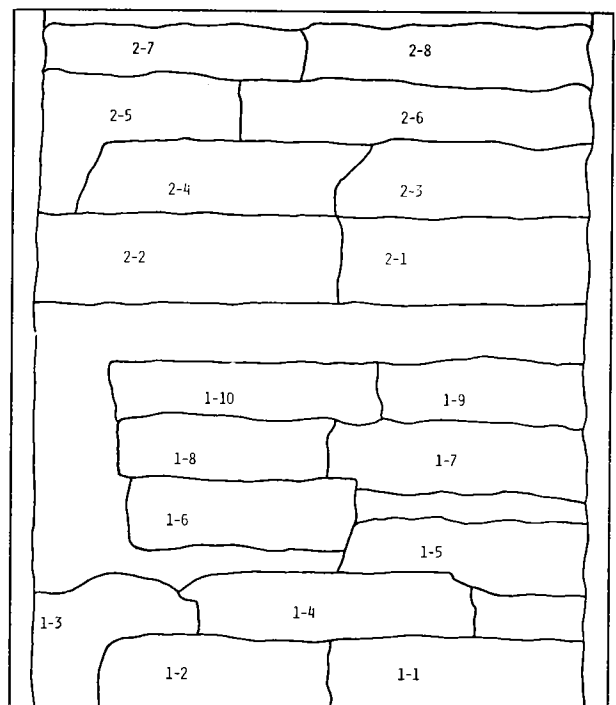
B612

Date: 6/16/1974 p.m.



EBL

Date: 6/20/1974 a.m.



TWO COURSE FIBER DECKS

Base Decks

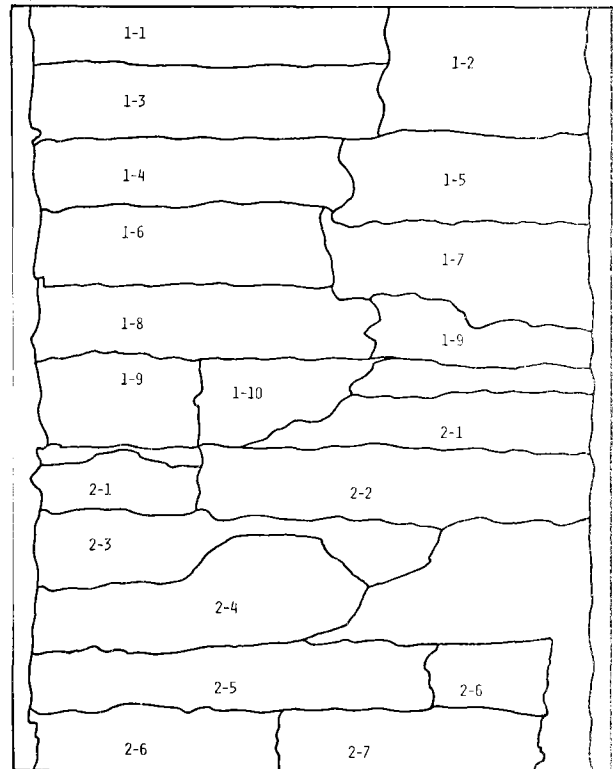
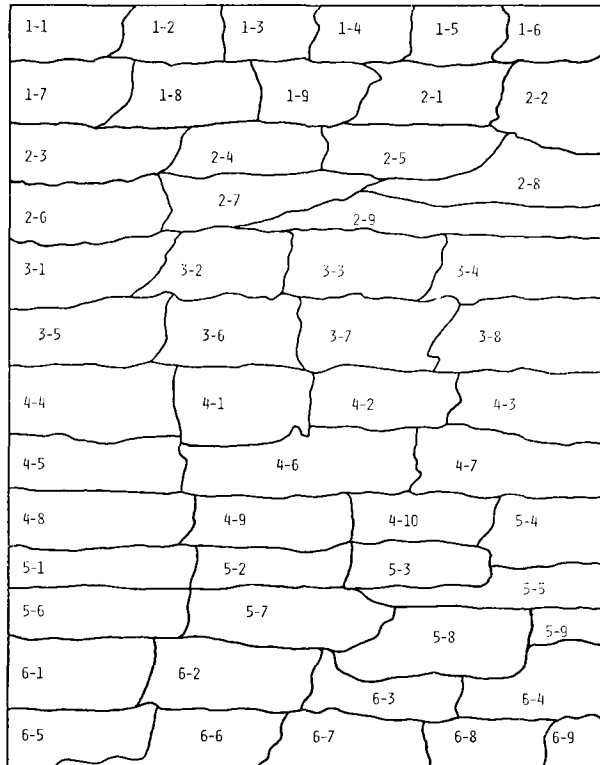
Overlays

B613

WBL

Date: 6/25/1974 a.m.

Date: 6/27/1974 a.m.

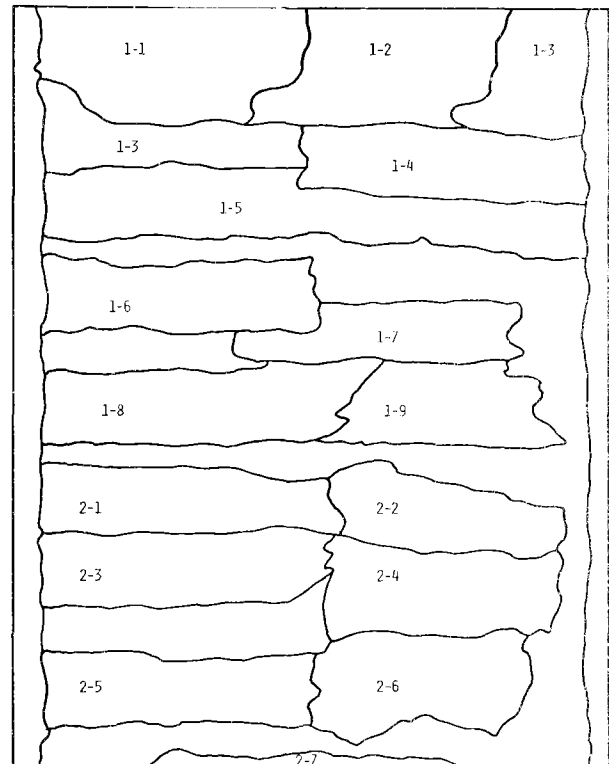
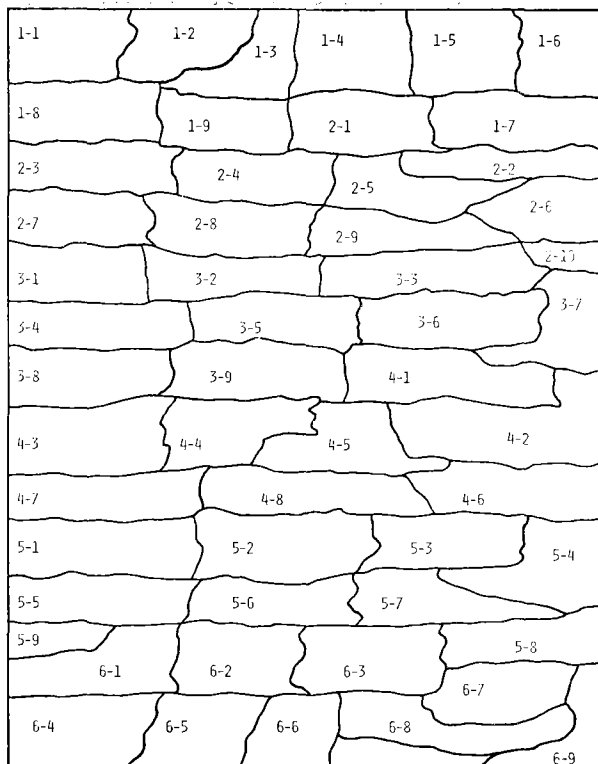


B612

EBL

Date: 6/25/1974 p.m.

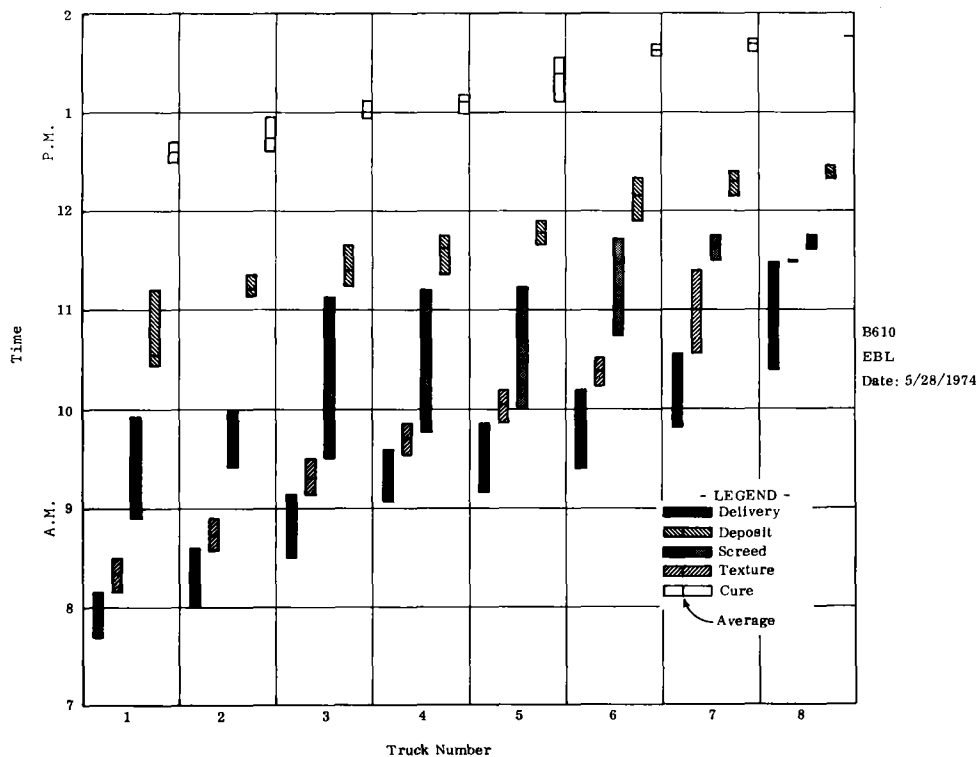
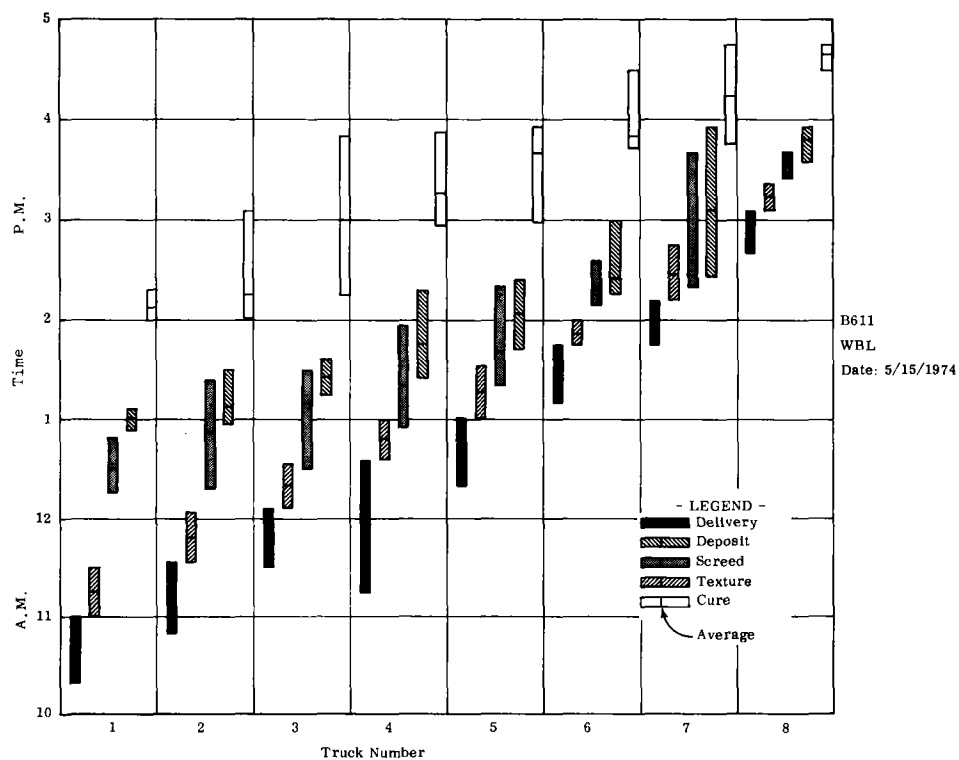
Date: 6/27/1974 p.m.



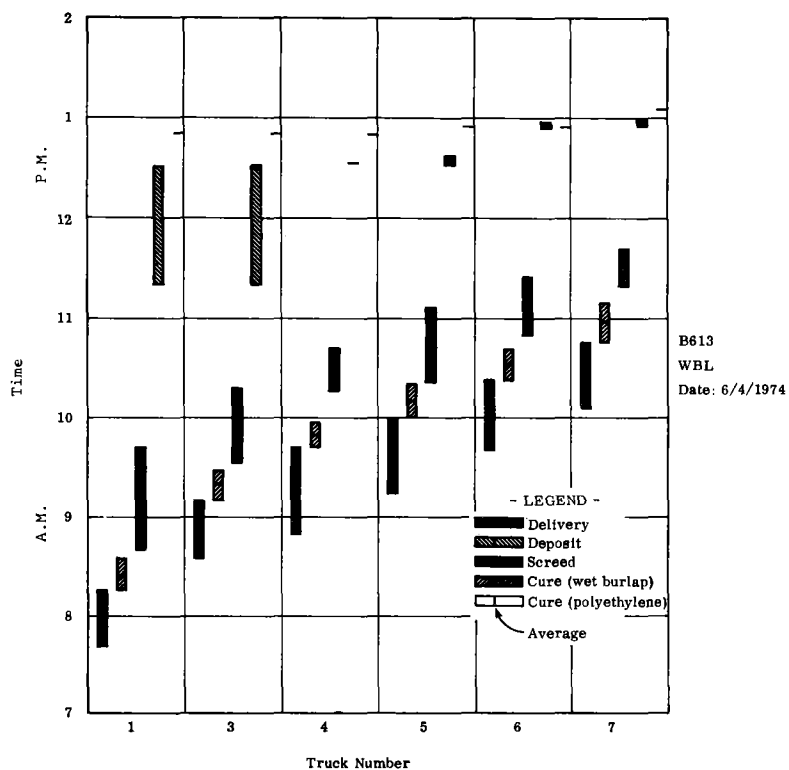
APPENDIX C

INSTALLATION SEQUENCE FOR THE EIGHT BRIDGE DECKS

CONTROL DECKS



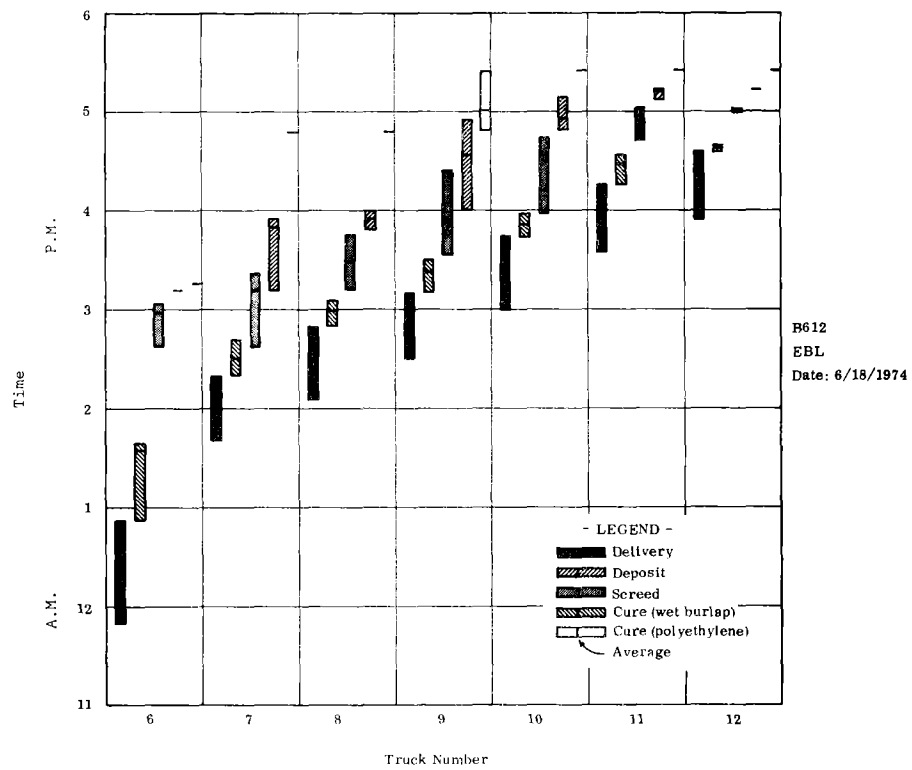
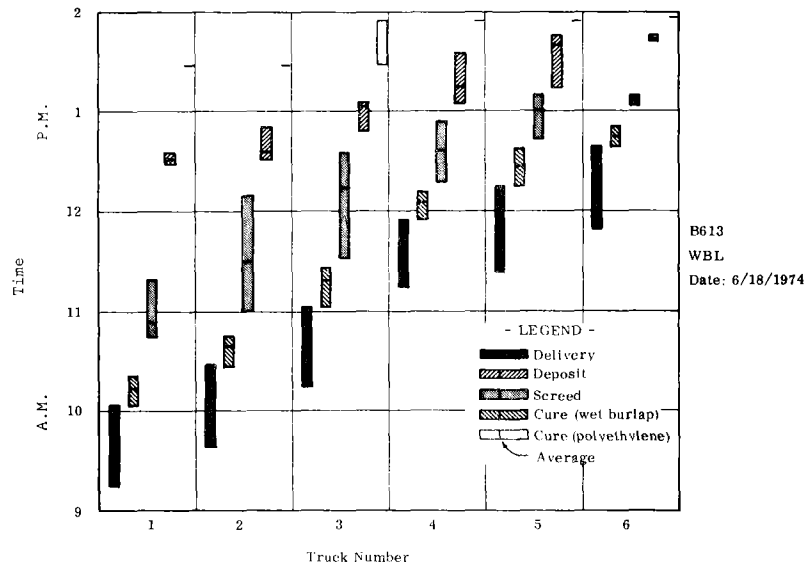
LATEX BASE DECKS



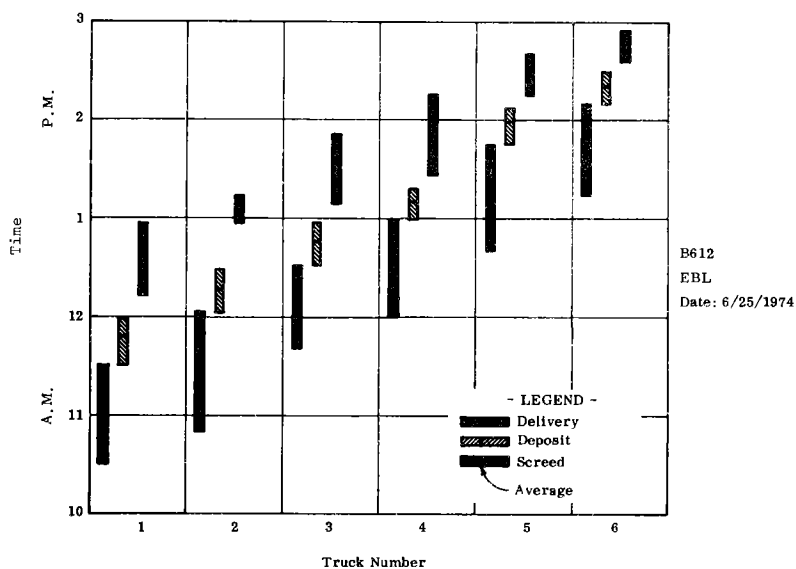
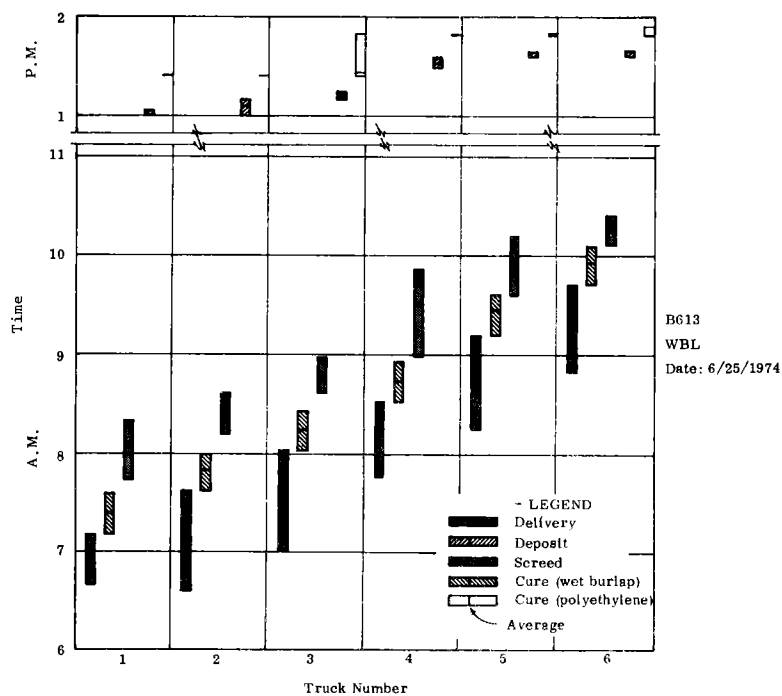
Information Not Recorded

B612
EBL
Date: 6/5/1974

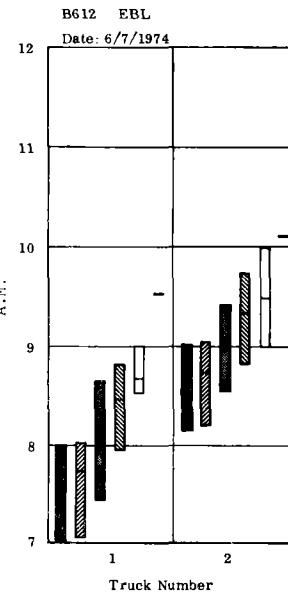
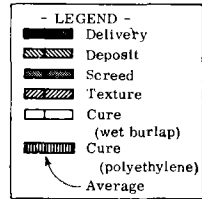
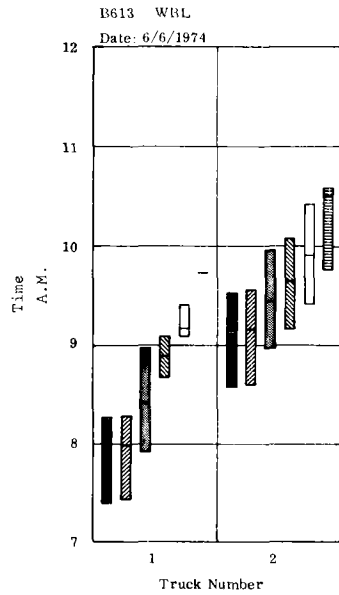
PCC BASE DECKS



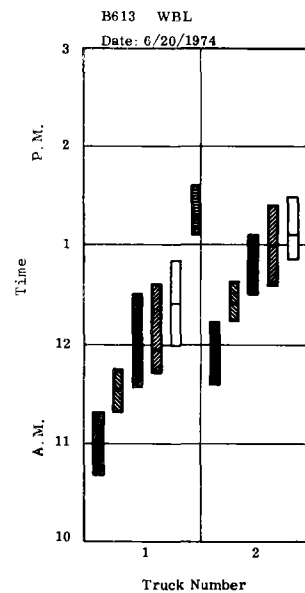
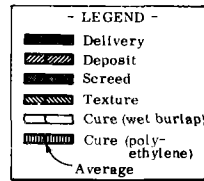
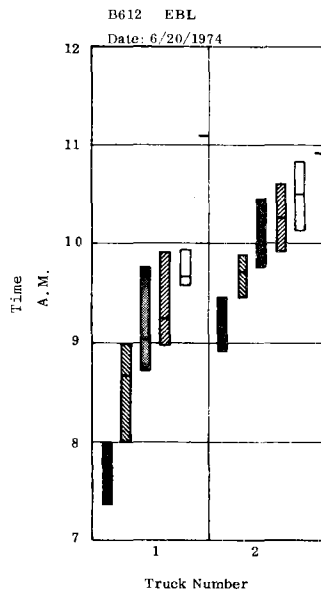
FIBER BASE DECKS



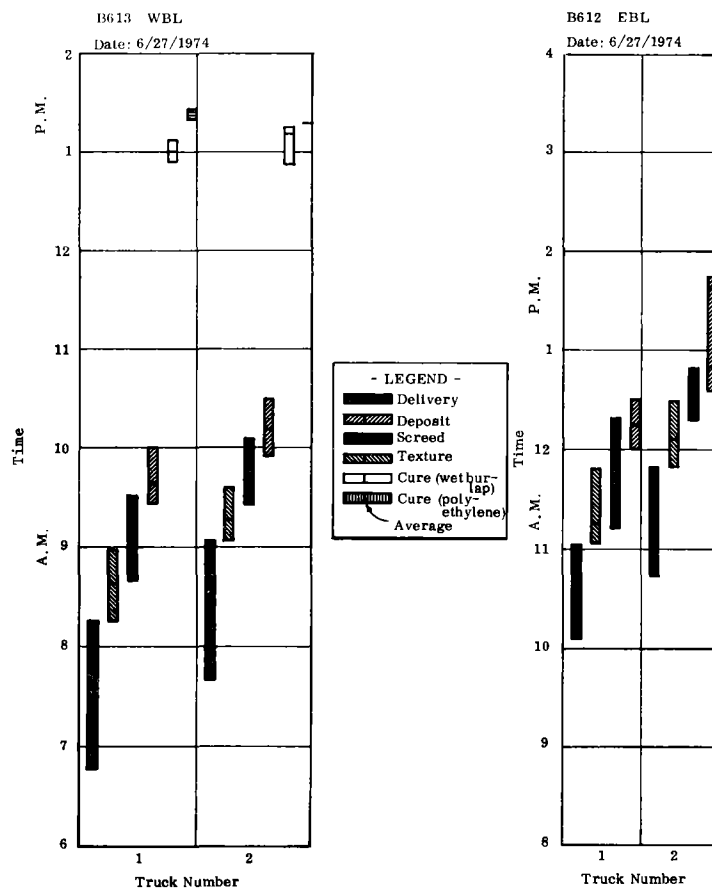
LATEX OVERLAYS



PCC OVERLAYS



FIBER OVERLAYS



1131