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EVALUATION OF SEVERAL BRIDGE DECK PROTECTIVE SYSTEMS

RICHARD M. WEED
AUTHOR

DIVISION OF RESEARCH AND DEMONSTRATION

NEW JERSEY STATE DEPARTMENT OF TRANSPORTATION

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16. Abstract

This report details the installation and evaluation of ten different bridge deck protective systems. These include asbestos-modified asphalt, hot-applied liquid rubberized asphalt, two preformed sheet systems, one roll-on fabric system, latex-modified concrete, high density concrete, epoxy-coated reinforcing steel, galvanized reinforcing steel, and internally-sealed concrete. Most installations involve at least two test decks.

Methods of evaluation included an appraisal by Construction, Maintenance, and Research engineers of the ease of installation of these systems. Apparent effectiveness has been judged by periodic visual monitoring and (for membrane systems only) the gathering of data from moisture sensing electrodes placed on the surface of the bridge deck.

As described in the body of this report, the moisture sensing electrodes did not perform as effectively as expected, providing only very general trends rather than precise information. Also, because the quantity of detected moisture was relatively small, there is some uncertainty whether it represents moisture trapped in the pores of the concrete or water that has permeated the membrane after it was installed. Consequently, the evaluations are based on the impressions of the several engineers who witnessed these installations plus the periodic visual inspections by Research personnel. At this writing, the time in service of the various installations ranged from three to seven years.

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Abstract (Continued)

All are considered tentatively acceptable based on their performance to date although the Department's Design and Maintenance forces have developed distinct preferences based on ease of installation, cost and apparent effectiveness. All systems will continue to be monitored for several years as part of another study.

As a further aid to designers, Appendix VI contains charts useful in making realistic comparisons between less expensive but shorter lived systems and more expensive but longer lived systems. For example, if the cost and expected life of a membrane system (short lived) are known as well as the cost of some more elaborate system, these charts enable the user to determine the expected life required for the more expensive system to be economically equivalent to the membrane system.

NOTICE

The State of New Jersey and the United States Government do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

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The writer wishes to acknowledge the cooperation and assistance of the many individuals in the bureaus of Construction Practices, Structural Design, and Maintenance who furnished much of the information contained in this report. The Bureau of Construction Practices, in particular, provided construction and cost data for several of the systems including all of the data pertaining to internally-sealed concrete.

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1.0 SUMMARY AND CONCLUSIONS

Although all systems tested under this study are considered tentatively acceptable based on their performance to date, both our Design and Maintenance forces have developed distinct preferences based on speed and ease of installation, cost, and apparent effectiveness. For repair of existing decks that are not badly deteriorated, patching followed by a preformed sheet membrane and a bituminous concrete wearing course is preferred. For badly deteriorated decks requiring substantial removal and replacement of concrete, the top surface is scarified and replaced with either latex-modified mortar or high density concrete. For new decks or those requiring complete reconstruction, the top mat of reinforcing steel is usually protected with an epoxy coating and normal structural concrete is used. (Because of its ease of handling, galvanizing had been favored until FHWA Notice N5140.10[1] restricted further use of this system on Federal-aid projects pending more positive proof of its effectiveness.)

It had originally been planned to evaluate the effectiveness of the waterproofing membrane systems by means of moisture sensing electrodes placed beneath the membranes during installation. Although some long-term trends appear to exist, the data gathered in this manner turned out to be considerably less conclusive than was expected, due primarily to the uncertainty of the actual source of the relatively small amounts of moisture that were detected. This is discussed in more detail in Section 5.1.

The moisture sensing electrode data is included in this report because it may be of interest to others who have used this method or who may be considering the use of similar instrumentation. However, for the purposes of this study, the evaluations of the membrane systems rely almost entirely on the collective judgement of the several engineers who witnessed these installations plus the periodic visual inspections by Research personnel.

2.0 BACKGROUND

One of the most serious destructive phenomena in evidence on a large percentage of concrete bridge decks throughout the country is spalling, the breaking away of large chunks of concrete from the deck surface. This is attributed to the corrosion and subsequent expansion of the top mat of reinforcing steel resulting from the penetration of water and deicing chemicals.

In theory, the spalling problem can be solved if a means can be found to prevent the corrosion of the reinforcing steel. The following are possible basic approaches:

A. Prevent corrosive materials from reaching the steel
   1. Waterproof membrane on deck
   2. Protective coating on steel

B. Avoid corrosion by other means
   1. Stainless steel or other special alloys
   2. Cathodic protection

The methods listed under Category "B" were briefly investigated at the beginning of the study and then excluded from further consideration. Although stainless reinforcing steel was commercially available and probably could have solved the spalling problem, its cost was prohibitive. An economic comparison indicated that a bridge deck could be repaired several times at less overall cost than that of an installation using stainless reinforcing steel. Cathodic protection was also considered but was judged by the Department's Design and Maintenance forces to be a more exotic system than was desired for the type of applications expected to be routinely encountered in the future.

It was decided to limit candidate systems to the two general types listed under Category "A", bridge deck waterproofing membranes (or similar barriers) and protective coatings for the reinforcing steel. Further, since this study was initiated largely at the request of our Maintenance forces who needed an effective way to repair a growing backlog of badly spalled decks, it was decided to concentrate on systems which had already shown promise in previous investigations by others. This policy was followed throughout the study except for the last installation which utilized a more highly experimental system (internally-sealed concrete).

In order to provide a thorough and realistic test of the experimental systems, it was decided that they would be installed on actual bridge decks. Test sites selected for this study were decks which were structurally sound but which exhibited extensive surface deterioration. The necessary repairs and surface preparations were made as required for each of the protective systems tested. (Chloride contents and depth of cover over the reinforcing steel were not measured because the Department had not acquired the necessary equipment for this at the time the study was initiated. A depth of cover study was performed on other bridges at a later date and is discussed in Section 6 of this report.)

Since most of New Jersey's main arteries are heavily travelled and subjected to substantial volumes of truck traffic, suitable test bridges were fairly plentiful. It is estimated that all test bridges are on routes having an AADT of 20,000 or more with the percentage of heavy truck traffic ranging from 5% to 15%.

The deicing compound used in this state is a 4:1 mixture of rock salt and calcium chloride but the actual application rate on the test bridges is not known. The standard application rate is 250 to 350 pounds per lane mile but the truck drivers are instructed to turn off the spreader when passing over a bridge deck. However, it is suspected that these instructions are not always followed and, even when they are, it is known that a substantial amount of salt is tracked onto the decks by traffic.

Initially, it was planned to have two test decks for each of the protective systems included in this study. However, as the study progressed, a number of additional bridges were included as part of the FHWA's experimental cost-effective bridge deck reconstruction program. Typically, these installations were made on bridge decks that were badly deteriorated or which contained chloride levels above 2 lbs./c.y., the threshold above which it is believed more economical to remove and replace the entire deck.[2]

3.0 METHODS OF EVALUATION

Since the objective of this study was to identify bridge deck protective systems which could be readily used by the Maintenance Department to repair deteriorated decks, a primary concern was speed and ease of installation. In most cases, it was desired to be able to divert traffic in the morning, complete the repairs during the day, and open the bridge in time for the late afternoon rush hour. Furthermore, from the standpoint of the Maintenance Department, a desirable system would require neither highly trained workmen nor special equipment.

The effectiveness of the systems was evaluated by two methods.

All systems were subjected to periodic visual inspections and, in addition, the waterproofing membranes were evaluated by means of special electrodes placed so as to sense the presence of moisture directly beneath the membranes. The visual inspections were made to observe any obvious physical deterioration while the electrodes made it possible to detect any substantial accumulations of water beneath the membranes.

A third means of evaluation was cost effectiveness. A more costly repair would still be considered of value if it were felt it could substantially extend the useful service life of a bridge deck. Appendix VI presents the development of charts useful in making economic comparisons between substantially different systems.

3.1 MOISTURE SENSING ELECTRODES

A schematic drawing of the moisture sensing electrodes is shown in Figure 3.1. The electrodes consist of thin copper tape, 1/2 inch wide by 10 ft. long by 0.0015 inches thick. The copper tape is first attached to polyethylene tape (duct tape) and then placed on the surface of the bridge deck. Wire leads with waterproof high-temperature insulation are run underneath the bituminous wearing course to a terminal box at one end of the bridge. More extensive information on these instrumentation materials is contained in Appendix I.

Normally, about 10 pairs of these strips were placed on each test deck. Some were placed at specific locations such as close to the curb, near the end of the bridge, or next to any joints. Others were located randomly on the decks, some in the wheelpaths and others between the wheelpaths, and one (control) was usually placed on the approach slab at the end of the bridge where there was to be a bituminous overlay but no membrane. The exact locations of the electrodes are shown in the diagrams in Appendix II.

To determine the existing wetness condition of the concrete surfaces

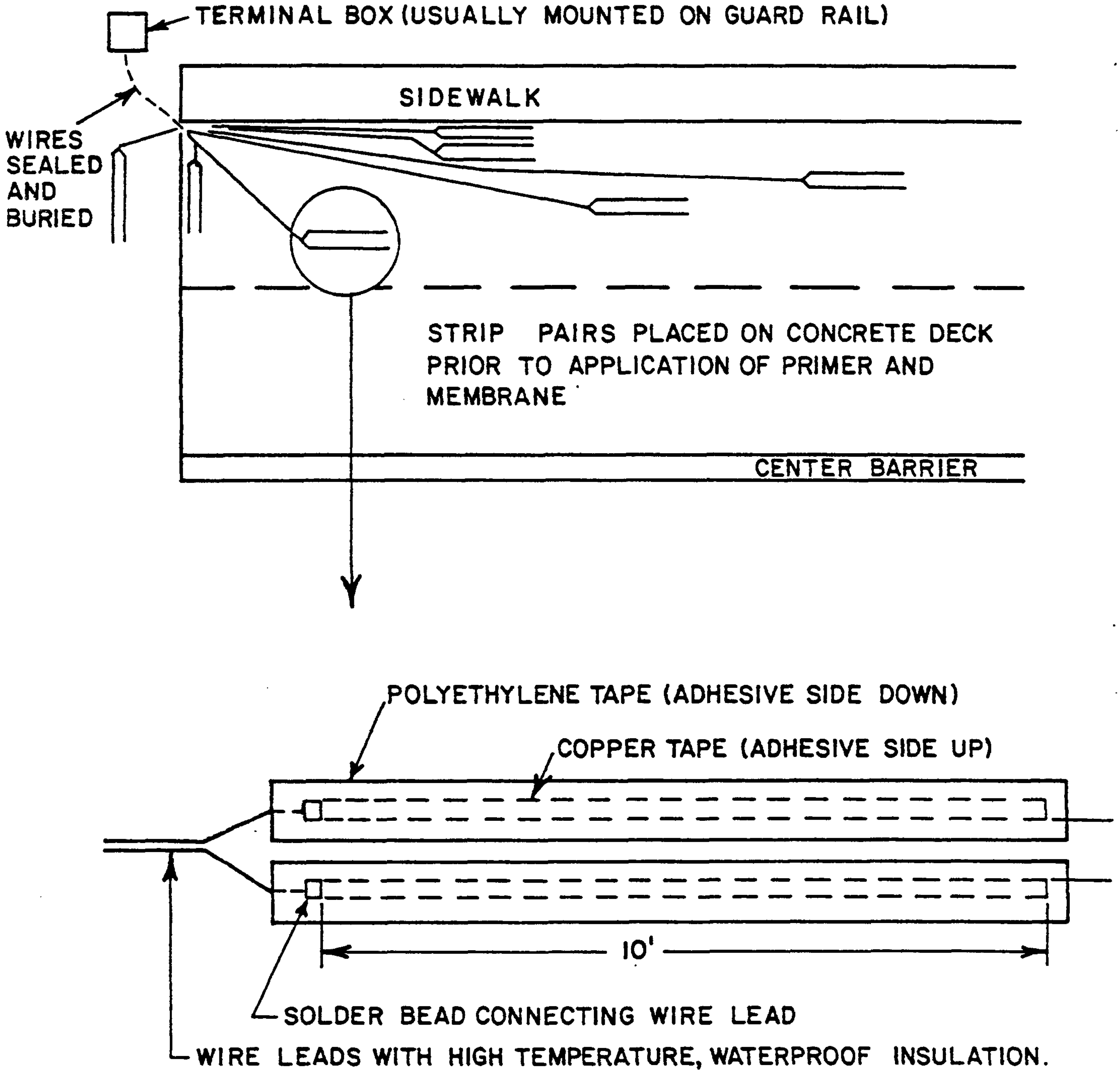


FIGURE 3.1 Schematic diagram of moisture detection system.

upon which the electrodes were placed, electrical resistance readings were taken between the two strips of each pair by means of an ordinary ohm-meter. By instrumenting a test slab and controlling both moisture and salt levels, a series of calibration tests were made. These indicated that completely dry concrete would produce readings of at least 20,000 ohms and as high as several million ohms. Readings in the range from 20,000 ohms down to about 2,000 ohms are considered uncertain as far as the presence of moisture is concerned. Below 2,000 ohms, moisture is almost certainly present and, below approximately 500 ohms, it is believed that both salts and moisture are present. The bridge deck readings for this study were taken on a periodic basis and, on occasion, were taken shortly after a heavy rain in an attempt to detect any leaks in the membranes.

While performing the calibration tests, two unexpected observations were made. When a resistance reading was taken, the ohm-meter often tended to drift for a few seconds before stabilizing. Also, reversing the two leads to the electrodes usually produced a slightly different reading. Therefore, it became standard procedure to allow time for the readings to stabilize and to make both direct and reverse measurements and average the results. All the data recorded in Appendix III were obtained in this manner.

Although the terminal strips were housed in closed aluminum junction boxes which were mounted fairly inconspicuously near the ends of the test bridges, nearly all of them were eventually destroyed by vandals. In most cases, readings were obtained for periods of five years or more although, in some cases, it was less. As a result of the vandalism, all future long-term monitoring will have to be accomplished by means other than the moisture-sensing electrodes. Annual visual observations will be included as part of another study and, if it appears that additional useful information can be obtained, chloride measurements and half cell readings may be taken.

4.0 SYSTEMS UNDER TEST

This section provides general information pertaining to each of the ten systems under test and is summarized in Table 4.1. More additional information including identification of the test bridges is contained in Appendix IV.

4.1 ASBESTOS-MODIFIED ASPHALT SYSTEM

This is a bituminous concrete system which consists of a relatively thin membrane course followed by a thicker wearing course or normal bituminous paving. The membrane mix uses a fine aggregate and a small amount of asbestos fibers (supplied by Johns Manville) to offset the high asphalt content of approximately 15%. The membrane mix is usually put down at a thickness of 1/2 inch to 3/4 inch and, because of its composition, a higher-than-normal placement temperature of 350°F or more is recommended.

Advantages of this system include low cost and the ability to place it on a rough, uneven surface using standard equipment. Disadvantages include the handling of the asbestos fibers at the mixing plant and the requirement of a higher than normal placement temperature. (A subsequent disadvantage is the withdrawal of Johns-Manville from the asbestos-modified-asphalt market in 1976.)

Due to a delay in placing the moisture sensing electrodes, plus the fact that the paver was cold at the start, the material was placed on

TABLE 4.1

SYSTEMS UNDER TEST

SYSTEM	SUPPLIER	NUMBER OF TEST DECKS	DESCRIPTION	APPROXIMATE CURRENT (1978) IN-PLACE COST* ($/S.Y.)
Asbestos Modified Asphalt	Johns-Manville (Supplier of asbestos fiber)	2	Fine aggregate bituminous mix with extra asphalt and asbestos fibers. Covered by wearing course of regular bituminous concrete.	$6 - $7/S.Y. (Includes $1.50/S.Y. cost of 1½" wearing course.)
Hot-Applied Liquid Rubberized Asphalt	Uniroyal	2	Liquid system heated in double jacketed kettle and spread by squeegee. Covered by wearing course of regular asphaltic concrete.	$7.50/S.Y. (Includes $2/S.Y. cost of 2" wearing course.)
Preformed Sheet Membrane	Royston	2	Poll-on sheet membrane placed over tack coat and covered with wearing course of regular asphaltic concrete.	$6.50 - $8.50/S.Y. (Includes $2/S.Y. cost of 2" wearing course.)
Preformed Sheet Membrane	W. R. Grace (Bituthene)	2	Roll-on sheet membrane placed over tack coat and covered with wearing course of regular asphaltic concrete.	$6.50 - $8.50/S.Y. (Includes $2/S.Y. cost of 2" wearing course.)
Fabric and Tack Coat Membrane	Phillips (Petromat)	1	Roll-on fabric placed over heavy tack coat, covered with wearing course of regular asphaltic concrete.	$3.50/S.Y. (Includes $2/S.Y. cost of 2" wearing course.)

SYSTEM	SUPPLIER	NUMBER OF TEST DECKS	DESCRIPTION	APPROXIMATE CURRENT (1978) IN-PLACE COST* ($/S.Y.)
Latex Modified Concrete	Dow	28	This system includes the removal by scarification (or air hammer) of the deteriorated top surface of the bridge deck followed by replacement with latex-modified mortar.	$20 - $50/S.Y. (Depending upon amount of preparatory work required.)
Low-Slump High-Density Concrete (Iowa System)	Various	4	This system is essentially the same as the latex-modified-mortar system except that low-slump high-density concrete is used.	$11 - $35/S.Y. (These figures based on new construction only.)
Epoxy-Coated Reinforcing Steel	Various	2	Protective coating to prevent water and deicing salts from corroding the reinforcing steel. Both upper and lower mats of reinforcing steel were coated for one deck, only the upper mat was coated for the other.	$14/S.Y. for upper mat only, $27/S.Y. for both mats (extra cost due to epoxy coating).
Galvanized Reinforcing Steel	Various	8	Unlike the epoxy coating which prevents corrosion, galvanizing is a sacrifical coating which is believed to reduce the likelihood and severity of spalling. For these installations, both the upper and lower mats were galvanized.	$34 - $50/S.Y. for both upper and lower mats.

SYSTEM	SUPPLIER	NUMBER OF TEST DECKS	DESCRIPTION	APPROXIMATE CURRENT (1978) IN-PLACE COST* ($/S.Y.)
Internally Sealed Concrete	Monsanto (Supplier of wax beads)	2 (Eastbound & Westbound decks of single span bridge)	Wax beads replace a portion of the sand in a non-air-entrained structural concrete mix. After a period of curing, heat is applied to the deck to melt the wax and allow it to flow into the capillaries.	$50/S.Y. (This cost is based upon a relatively small bridge and does not include the cost of the heating equipment borrowed from FHWA. The cost would have been approximately $70/S.Y. with the heating equipment included.)

*NOTE: The cost figures given here represent the total extra cost attributable to the protective system. These are based on a limited number of relatively small installations plus current estimates by the various suppliers and, therefore, must be regarded as approximate.

the first test bridge at a temperature of 325°F or less. As a result, bare gaps occurred in the mat as it was put down by the paver, especially when it was attempted to control the thickness at 1/2 inch. A fairly uniform mat was put down for a short stretch when it was accidentally placed at a thickness of one inch. Because it was cooler than desired, the material in the thinner sections tended to form lumps and required extra effort to rake out to a uniform thickness.

On the second bridge on southbound Route 130 over Route 522, a portion of the material in the last truck was discovered to be insufficiently mixed. Since it was too late to obtain another load, this material was mixed in the paving machine as much as possible after which it appeared to lay down normally. Its subsequent performance seems to indicate that the mixing was adequate.

4.2 HOT-APPLIED LIQUID RUBBERIZED ASPHALT SYSTEM

This material is melted in a special heating kettle, poured onto the bridge deck, spread by squeegees to a thickness of approximately 1/16 inch, covered with cement dust to reduce tackiness and, after 30 - 40 minutes, is covered with a normal bituminous wearing course. The membrane material is a proprietary product manufactured by Uniroyal.

Advantages of this system include the speed with which it can be placed and its apparent ability to bond strongly to both portland cement and bituminous concrete. Disadvantages include the requirement for a comparatively smooth deck surface and the stipulation that it be placed by licensed applicators using special heating equipment.

Due to the roughness of the test decks after extensive repairs had been made, the actual thickness of the poured membrane varied from 1/16 inch to as much as 1/4 inch in isolated spots. This excessive thickness is believed to be the cause of the formation of several "bleed through" spots which appeared after the wearing course was placed. These were gradually worn away by traffic and disappeared in about two weeks.

Some operational problems were experienced with the heating kettle during the treatment of the test deck on Route 46 over the Erie-Lackawanna Railroad. However, judging from its subsequent performance, this did not affect the integrity of the membrane placed on this deck.

4.3 ROYSTON PREFORMED SHEET MEMBRANE

The manufacturer, Royston, markets this product as "Bridge Membrane No. 10." It is a heat modified bituminous resin composition with an inner layer of open weave fiberglass mesh and is normally supplied in four foot long rolls. After the patched bridge deck is swept clean, a special primer is applied with paint rollers. After about one-half hour, the primer is sufficiently dry so that the membrane itself can be rolled on in a slightly overlapping pattern. Edges and joints must be sealed with hand torches after which a bituminous wearing course is applied.

Advantages of this system are the ease and speed with which it can be placed without special equipment or trained personnel and the wide range of temperatures over which it can be applied. A disadvantage is the occasional necessity to repair blisters (pockets of entrapped moisture vapor) prior to the placing of the wearing course. Also, the primer must not be allowed to contact existing bituminous pavement since it has a softening effect.

This membrane is slightly thicker than the Grace material (the other preformed sheet membrane tested in this study). It did not wrinkle as much but it bonded less strongly when first rolled out by hand.

This could be considered an advantage in that it allows the workmen to adjust its position somewhat. Once down, it appeared to be quite secure and was not damaged by the metal tracks of the paver.

About one week after the membrane and wearing course were installed at the Princeton Junction bridge, a small popout of the overlay material was observed. It was discovered that the overlay was much thinner than intended at this point due to an attempt to smooth out some irregularities in the bridge surface. The problem was not felt to be related to the membrane itself and was corrected by adding another thin layer of wearing course over the entire bridge.

Another installation of the Royston material at a later date demonstrated that it could be applied successfully at temperatures substantially below the recommended minimum 50°F. This was a contract job, traffic conditions required that it be done at night, and the schedule was such that it could not be done until early November. As a result, the temperatures were in the low 30's when the membrane was applied. In spite of this, the construction progressed normally and appears to have been satisfactory.

4.4 GRACE PREFORMED SHEET MEMBRANE

The trade name of this product is "Heavy Duty Bituthene" by W. R. Grace and Company. Similar to the Royston membrane, this product is a rubberized-asphalt compound with an embedded woven mesh. It, too, is supplied in rolls and requires a primer to bond it to the bridge deck prior to the application of the wearing course. The edges and seams are sealed with a mastic material instead of the hand torches used with the Royston membrane.

The advantages and disadvantages are essentially the same as those of the Royston system. It is fast and easy to apply with unskilled labor but may require some repair of air pockets before paving. The material is thinner and lighter than the Royston membrane and, therefore, somewhat easier to handle. It was deeply marked but not cut by the steel tracks of the paver.

When the overlay was placed, unexpected reflection cracks occurred at some of the seams (both longitudinal and transverse) immediately behind the paver. However, these appeared to be well sealed by the rolling process and were barely discernible afterwards.

This membrane, like the Royston material, experienced a small popout on the Princeton Junction bridge. As in the other case, this was not attributed to the membrane itself and was corrected by adding another thin layer of wearing course.

This system also was installed at a second location with temperatures in the mid-30's, colder than the minimum of 40°F recommended for this product. The construction proceeded normally and no adverse effects have been observed.

4.5 PETROMAT MEMBRANE

This membrane, manufactured by Phillips Petroleum Company, consists of a non-woven polypropylene fabric which is saturated during installation with either asphalt cement or asphalt emulsion. A heavy seal coat (0.25 to 0.30 gal./s.y.) is placed on the surface to be protected and the Petromat fabric is rolled onto this seal coat while it is still tacky. A conventional hot-mix wearing course is then placed over the fabric, usually without an additional tack coat.

Advantages of this system are speed and ease of installation and very low cost. Since the waterproofing membrane is actually formed in place as it is being installed, a possible disadvantage might be some uncertainty about its overall integrity.

Although it is customary to place the Petromat directly on top of a concrete bridge deck, a slightly different procedure was followed for the NJDOT installation. Because the deck surface was quite rough, the Phillips representative recommended that a thin bituminous course be placed first in order to provide a smooth surface upon which to place the membrane. A fine aggregate mix approximately 1/2 inch thick was placed, followed by the seal coat and the membrane fabric, and a one inch wearing course was placed on top of this. The moisture sensing electrodes were placed directly on the concrete surface as usual.

Due to an insufficient supply of the sealing emulsion, a narrow gap about 18 inches wide next to the center divider in the eastbound lane of the test bridge was not sprayed. This gap extended lengthwise across the entire bridge and received only the bituminous courses without the membrane fabric.

To check the integrity of this membrane, numerous measurements were made with a copper plate resistance measuring device. These indicated that the membrane was completely impermeable. As a check of this procedure, additional readings were taken with the overlay removed and, also, with a small section of the membrane removed. With the overlay removed but the membrane intact, an extremely high resistance continued to be read which indicated impermeability. When a small portion of the exposed membrane was removed, the resistance dropped to nearly zero, confirming that electrical continuity had been achieved for these tests.

4.6 LATEX-MODIFIED CONCRETE

With this system, the top $1\frac{1}{4}$ in. (nominally) of a bridge deck is composed of latex-modified concrete which, because of its relative impermeability, acts as a waterproofing membrane. When used on a new bridge, the latex-modified concrete is added as a second stage of construction. When used to repair an existing deck, the deteriorated surface concrete is first removed with scarifying equipment. Pneumatic hammers are also used to remove isolated sections of defective concrete to whatever depth is necessary.

The latex-modified concrete is mixed on-site in an automatic batching truck (Concrete Mobile) which is part of a special "paving train" designed by Dow Chemical Company and operated under their supervision. This procedure is described in greater detail in Appendix V.

It is believed (but not yet confirmed at this stage of the research) that properly constructed decks of this type would be highly durable and provide many years of maintenance-free service. The primary disadvantage of this system is its high cost which can range anywhere from $20/s.y. to $50/s.y. or more, depending upon the size of the deck and the amount of preparation required. To be considered economically justifiable, this system will have to produce an expected service life considerably longer than that obtained by using conventional membranes. Because of this, it will be some time before its true effectiveness can be assessed.

Since this was a well-established system which had been used in many states throughout the country, it was selected by the Department's Design unit for use on a contract for the major rehabilitation of a series of bridges on one of our older Interstate projects. The material used was Dow SM-100 and, of a total of 24 decks, approximately half developed extensive random cracking. Cores taken from these decks showed that, in some cases, the cracks penetrated to the depth of the steel. Since this could negate the effectiveness of this system and possibly lead to premature failure, Dow was asked to send an inspection team to ascertain the causes and determine what remedial action, if any, should be taken.

After observing the cracked decks and analyzing several cores, the Dow representative proposed the following explanations and recommendations:

1) The core analyses showed that the cement and latex contents were very close to the design values recommended by the manufacturer. Therefore, it was concluded that these factors did not contribute to the cracking problem.

2) The recommended cure of 24 hours of moist condition followed by 72 hours of open air curing is based upon a thin overlay (two inches or less), ambient temperatures above 55°F, and relative humidities below 85% during the air cure period. Due to various circumstances, these conditions were not met. Because the bridges were badly deteriorated, up to six inches of defective concrete was removed at many locations prior to the placement of the latex-modified concrete. Also, most of the construction took place during September and October when the weather was cool and frequently rainy. Therefore, it is possible that the deeper sections of latex concrete did not cure sufficiently to withstand the heavy loads imposed when first opened to traffic.

3) This particular contract called for a mortar mix of latex-modified concrete since it was anticipated that the depth of the overlayment would be relatively thin. For greater

depth, such as those actually encountered on this job, Dow recommends a concrete mix using larger course aggregate.

4) It was the opinion of the Dow representative that the latex-modified concrete will continue to perform as a protective membrane despite the existence of the random cracks. Because the reduced permeability of this material prevails throughout its depth, it is theorized that there will be little lateral migration of water and de-icing salts. Although localized corrosion may occur at isolated points where a crack reaches the steel, it is thought that this will not lead to a generalized spalling condition.

Since no applicable repair for these cracks was readily available, plus the fact that it will be desirable to learn if this condition is truly harmless, it was decided that no repairs would be attempted. These bridges will continue to be monitored for several years in order to make this evaluation.

4.7 LOW-SLUMP HIGH-DENSITY CONCRETE

This system was developed in Iowa and, consequently, is often referred to as the Iowa system[3]. It has been used primarily as a rehabilitation system although, like latex-modified mortar, it can also be used for new construction. The four decks included in this study were existing badly-deteriorated decks which required major reconstruction.

This system utilizes a rich mix (8.75 bags/c.y. compared to 6.7 bags/c.y. for the standard New Jersey mix) and a very low water-cement ratio (approximately 0.33 instead of the typical value of approximately 0.45) to produce a dense layer of concrete which is used for the top two inches of the bridge deck. The concrete was mixed by Concrete Mobiles which experienced difficulty at times in controlling the consistency of the mix. The slump was planned to be maintained at 3/4" ± 1/4" but experience indicated that a range of 1/2" ± 1/2" was more realistically achievable.

Like the latex-modified mortar system, the objective of the Iowa system is to create a relatively impermeable barrier at the top surface of the bridge deck. Based on the few small installations made to date, this system appears to be nearly as expensive as the latex system and will require a lengthy period of evaluation to determine its cost effectiveness.

Two of the four experimental decks developed random cracking similar to (but less severe than) the latex-modified mortar decks. As with the other cracked decks, it is believed that this is a curing problem which emphasizes the critical nature of the curing operation with these special mixes. Long-term monitoring will be conducted to determine whether or not the protective capabilities of this system have been adversely affected.

4.8 EPOXY-COATED REINFORCING STEEL

This system utilizes an epoxy coating to prevent water and de-icing chemicals from contacting and corroding the reinforcing steel. The coating was applied to straight bars which were later bent and cut to obtain the desired configurations. A substantial amount of field touch-up was required to repair the numerous nicks and scrapes occurring during fabrication, shipping, and installation.

The chief advantage of this system is that it should be extremely effective provided that a relatively defect-free coating is achieved. The obvious disadvantage is the effort and expense required to accomplish this. Small "holidays" are not easy to detect and it is unlikely that all defects of this type could be eliminated no matter how thorough an inspection procedure is used. A major unanswered question at this stage concerns just how many defects can be tolerated before the effectiveness of this system is seriously compromised.

According to FHWA guidelines[4], either the top mat of reinforcing steel or both mats may be epoxy-coated. In either case, it is recommended that the chairs and tie-wires be nonmetallic coated although the specifications are not as exacting as those for the reinforcing steel. The upper mat and the parapet steel was coated for both test decks included in this study. For one of the decks (northbound), the lower mat was coated, also. The tie wires were coated but the chairs were galvanized, a slight departure from the recommended procedure.

4.9 GALVANIZED REINFORCING STEEL

This system is basically different from the epoxy coating. Galvanizing is a sacrificial coating which corrodes in place of the material being protected. It is hoped (but not known) that the corrosion products of this reaction will be less harmful to the concrete than those produced by unprotected steel.

Galvanizing is cheaper than epoxy coating and requires considerably less care in shipping and handling. Because of this, many experimental decks were installed throughout the country within a relatively short period of time. The only known drawback is some doubt concerning this system's long term effectiveness as evidenced by the FHWA's discouragement[1] of further experimental installations. This is believed to be a reaction to the unexpectedly strong acceptance of this method on the part of several states plus the failure of laboratory test data to firmly establish the method's effectiveness.

4.10 INTERNALLY SEALED CONCRETE

With this system, developed jointly by the FHWA[5,6] and the Monsanto Company, small wax beads replace a portion of the sand in a non-air-entrained concrete mix. After an initial curing period, heat is applied externally to melt the wax beads in the upper portion of the deck. In theory, the melted wax diffuses into the capillaries and bleed channels of the concrete and forms a waterproof barrier.

This system is more suited for new construction or major rehabilitative work although it conceivably could be used for a resurfacing of moderate thickness. Unlike the other systems investigated in this study, it is extremely experimental and very few installations had been made at the time of this work. The expense of the special heating blankets (furnished by the FHWA) contributed significantly to the high cost of the system (approximately $70/s.y.) and, if this system were to gain wide acceptance, it is reasonable to assume that the cost might be considerably less.

For this installation, two adjacent lanes of a small, box-beam bridge were replaced in separate stages of construction approximately six months apart. The entire deck was removed and replaced with concrete containing wax beads. The work proceeded relatively smoothly although the addition of the wax beads at the construction site and the various measurements that were required slowed down the operation somewhat. The job was further delayed by the use of a concrete conveyor which required frequent repositioning as the work progressed. The slump tests were within specification limits but tended toward the stiff range which is believed to have contributed to some problems in finishing the concrete. Water was added prior to the final finishing in some sections and, in a few isolated spots, caused some of the wax beads to float to the surface.

Since the concrete was placed in colder weather (late fall and spring for the two stages, respectively), it was covered with insulating blankets to keep its temperature above 60°F as recommended for the first seven days of curing. Temperature sensors placed under the insulation indicated that this attempt was not entirely successful for the earlier installation. Temperatures as low as 40°F were recorded with an average of about 50°F. However, the actual internal temperature of the concrete may have been somewhat higher than that recorded by the probes.

After 21 days of curing (including two days of air drying), special electric heating blankets borrowed from the FHWA were placed on the concrete and covered with a thick ($6\frac{1}{2}$ inch) layer of insulation. A carefully monitored heating sequence was then begun which continued for approximately 14 hours before the required melting temperature of 180°F was reached.

Within a few months after construction, cracks began to appear in both of the test decks. The major cracks run longitudinally and coincide very closely with the box beam joints of the bridge. Emanating from the larger cracks are several smaller transverse cracks. Since similar cracks have occasionally been observed in other bridges of this type throughout the state, this problem may not be directly attributable to the use of internally sealed concrete.

In an attempt to determine the seriousness of this problem, cores were taken to measure the depths of the cracks. The cores showed that the larger longitudinal cracks extended to a depth of 4 inches or more while the smaller cracks were usually one inch or less in depth. Although the exact depth of the reinforcing steel was not determined, it is clear that the cracks extend below the level of the top mat of steel at several locations. Like the latex-modified concrete and low-slump high-density concrete which also developed cracks, a long-term monitoring effort will be required to determine the effectiveness of this system.

This installation is described in considerably more detail in a report[7] prepared by personnel of the Bureau of Construction and Compliance Practices.

5.0 TENTATIVE EVALUATIONS OF TEST SYSTEMS

The evaluations are considered tentative because all test decks are presently in good condition and it is not felt that sufficient information has been obtained to classify any of the systems as completely satisfactory or definitely unsatisfactory. Nor has any of the tested systems emerged as clearly superior, although some subjective opinions will be offered to explain why certain systems are favored over others by the construction and maintenance personnel who worked with them.

5.1 MEMBRANE SYSTEMS

A total of five systems (Johns-Manville, Uniroyal, Royston, Grace Bituthene, and Phillips Petromat) are classified as waterproofing membranes and have been evaluated by means of moisture-sensing electrodes. It had been hoped that, over an extended period of time, most of the readings would tend toward one extreme or the other. High resistance readings would indicate the absence of moisture immediately below the membrane and it would be inferred from this that the membrane was effective in keeping both water and de-icing salts away from the deck. At the other extreme, low readings would indicate the entrapment and build-up of water beneath the membrane and result in its being judged unsatisfactory. Unfortunately, many of the readings tended to remain in the "uncertain" zone, even after several years. This indicates the possible presence of a small amount of moisture. A further problem in interpretation is the uncertainty whether this moisture is the result of water leaking through (or around) the membrane or, instead, the result of condensation and upward migration of water vapor trapped in the pores of the concrete. (There does seem to be a tendency for water to enter along the curb line for most of the membranes.)

The moisture readings for several bridges are presented in Appendix III. Because the resistance readings vary from less than 100 ohms to over 10,000,000 ohms, they have been plotted on a log scale in order to compress the range. Two different formats have been used. One format consists of simple histograms of all non-curb line readings without regard to the dates on which the readings were taken. The second format is similar except that a time scale has been added in an attempt to distinguish any long-term trends.

Figure 5.1 illustrates an idealized histogram of resistance readings similar to those observed for several of the test bridges. These histograms tend to be centered in or close to the "uncertain" zone with a fairly large percentage of the readings falling within the "uncertain" zone.

Figure 5.2 is very similar to Figure 5.1 except that the points are also located with respect to the length of time the membrane was in service when the readings were taken. Like Figure 5.1, this plot is

	OHMS		
	LESS THAN 100		
	100 - 158		
	159 - 251	X	
WET	252 - 398	X	
	399 - 631	XX	
	632 - 999	XX	
	1,000 - 1,585	XXXX	
	1,586 - 2,512	XXXXX	
	2,513 - 3,981	XXXXXXX	
UNCERTAIN	3,982 - 6,310	XXXXXXXXX	
	6,311 - 9,999	XXXXXXXXXXX	
	10,000 - 15,849	XXXXXXXXXXXX	
	15,850 - 25,119	XXXXXXXXXXXX	
	25,120 - 39,811	XXXXXXXXXXX	
	39,812 - 63,096	XXXXXXXXX	
	63,097 - 99,999	XXXXXXX	
	100,000 - 158,489	XXXXX	
	158,490 - 251,187	XXXX	
	251,188 - 398,107	XX	
DRY	398,108 - 630,957	XX	
	630,958 - 999,999	X	
	1,000,000 - 1,584,893	X	
	1,584,894 - 2,511,886		
	2,511,887 - 3,981,072		
	3,981,073 - 6,309,573		
	6,309,574 - 9,999,999		
	10,000,000 - AND OVER		

FIGURE 5.1 Typical idealized histogram of all non-curbline resistance readings from moisture sensing electrodes.

	OHMS			1972 1973 1974 1975 1976
	LESS THAN 100			
	100	-	158	
	159	-	251	X
WET	252	-	398	XX
	399	-	631	XX X
	632	-	999	XXX X
	1,000	-	1,585	XX X XXX
	1,586	-	2,512	X XX X XX
	2,513	-	3,981	X X XX X X XXX
UNCERTAIN	3,982	-	6,310	X X XXX XXX X X
	6,311	-	9,999	X XX XX X XXX X
	10,000	-	15,849	XX XXX X XX X
	15,850	-	25,119	X XX XXX X X
	25,120	-	39,811	X X XX X X XXX
	39,812	-	63,096	XX X X X X
	63,097	-	99,999	X X XX X X
	100,000	-	158,489	X X XX X
	158,490	-	251,187	X XX X
	251,188	-	398,107	X XX X
DRY	398,108	-	630,957	XX
	630,958	-	999,999	X XX
	1,000,000	-	1,584,893	
	1,584,894	-	2,511,886	X
	2,511,887	-	3,981,072	
	3,981,073	-	6,309,573	
	6,309,574	-	9,999,999	
	10,000,000	-	AND OVER	

FIGURE 5.2. Typical idealized plot of non-curbline readings from moisture sensing electrodes showing gradual drift toward wetter condition.

idealized to clearly indicate a tendency that was observed on most of the test bridges. On any given date, the readings tend to be scattered but, as the months pass, the range over which they are distributed tends to drift toward the "wet" zone. Although this tendency is noticeable on nearly all of the test decks, it is usually not as pronounced as the idealized presentation shown in Figure 5.2. Because of this, plus the uncertainty of the amount or source of the moisture beneath the membranes, it is not considered appropriate to rate any of these membranes as definitely unsatisfactory at this time. However, it is quite apparent that the decks are not drying out over a period of time and, because of the effect this may have on corrosion activity, there is a need for continued long-term monitoring.

Another fairly consistent tendency was observed. In many cases, the readings from electrodes placed near the curbs tended to be lower than readings from strips near the center portions of the decks, suggesting a greater presence of moisture near the gutter. This may be an indication that it is possible for water to migrate around the edges of a membrane.

In terms of ease of installation, the Maintenance forces who installed the various membranes expressed a definite preference for the rolled-on sheet systems (Royston, Grace, and Petromat). These systems require that the deck surface be smooth but the necessary preparatory work can be scheduled whenever it is convenient over a period of several days prior to the placing of the membrane. In all cases, these installations proceeded quickly and easily using personnel with little or no previous experience.

Next in preference was the Johns-Manville system (asbestos-modified asphaltic concrete). This system has the added advantage that a smooth deck surface is not required but the higher-than-normal placement temperature presents a potential problem. Any unexpected delay could cause the mixture to cool sufficiently to make placement difficult.

The Uniroyal system (hot-applied liquid) also requires a smooth surface and the installation procedure is somewhat more complicated than the others. Both special heating equipment and trained personnel are required which made this system less attractive to the Maintenance unit which normally prefers to use its own equipment and employees.

As a result of these preferences, the subsequent (non-experimental) installations have consisted of either the Royston or Grace membranes. (Because of its similarity, the Protecto-Wrap system is also permitted but no contractor has elected to use it. Although the Petromat system has appeared to perform as well as the other test membranes, it has been under test for a much shorter period of time and has not yet been approved by our Design forces for non-experimental use.)

5.2 LATEX-MODIFIED CONCRETE AND LOW-SLUMP HIGH-DENSITY CONCRETE

These two systems are both very expensive and have been used only for badly deteriorated decks for which the complete removal and replacement of the upper 2 or 3 inches of concrete was warranted. Once the low-slump high-density concrete became available, contractors were permitted to bid on either system and the choice was then determined by the successful bidder. As described in Sections 4.6 and 4.7, both systems require the same type of preparatory work and both have experienced similar cracking problems during curing. Currently, both systems are considered tentatively acceptable and it is expected that additional installations will be made.

5.3 EPOXY-COATED AND GALVANIZED REINFORCING STEEL

Epoxy-coating and galvanizing are systems designed to protect the surface of the reinforcing steel and are used primarily for new construction. Our Design and Construction forces initially preferred galvanizing because of its relatively low cost and ease of handling. However, because of the discouragement by the FHWA[1] of further test installations of galvanized reinforcing steel, this preference has now shifted to the epoxy coating. In our state, this is now the primary system chosen for new construction.

5.4 INTERNALLY-SEALED CONCRETE

This is the only system included in this study that did not have a lengthy history of tests by other agencies. Consequently, it is still regarded as very experimental and no further installations are planned at this time.

6.0 DEPTH OF COVER STUDY

Since the depth of cover of the top mat of reinforcing steel is a major factor in preventing (or at least delaying) the corrosive action of de-icing chemicals, it was decided to conduct a satellite investigation of several bridges located throughout the state. A total of 17 bridges were surveyed by means of a pachometer (nondestructive magnetic testing device) to obtain a large amount of statistical data which could be used to predict the effectiveness of various possible depth of cover specifications.

6.1 BASIC PREMISE

Although the nature of chloride penetration into concrete is such that it is impossible to define a specific depth below which the corrosion of reinforcing steel will not occur, researchers have generally agreed that 2 inches is an effective minimum depth[8,9,10]. The purpose of the satellite study was to determine what specified average or target depth would be necessary to guarantee that nearly all (or some specified large percentage) of the steel would be below the 2 inch minimum depth.

6.2 EVALUATION OF THE PACHOMETER

The pachometer used for this study was a James Model C-4946. It consisted of a hand-held probe which was electrically connected to a battery powered unit provided with a dial gauge. When the size of a reinforcing bar is known, its depth of cover can be determined either (a) directly from the dial or (b) by reading a scale graduated from 0 - 100 and consulting calibration curves furnished with the instrument.

In order to obtain the greatest precision for this study, a variation of the second method was used. As the batteries gradually lost power, it was observed that the calibration curves should be shifted slightly. As a result, it became standard practice to experimentally develop new calibration curves prior to each day's use of the instrument. This was accomplished quickly and easily with a special fixture developed specifically for this purpose.

By having a number of different operators make many replicate readings of the depth of cover in specially prepared control slabs, it was possible to determine the accuracy and precision of this method. The method was found to be accurate with a precision of $\sigma = 0.035$ inches for single readings. This is the equivalent of saying that single measurements are accurate within $\pm 2\sigma = \pm 0.07$ inches or about $\pm 1/16$ inch 95 percent of the time. Consequently, it was judged to be more than suitable for this work.

6.3 DESCRIPTION OF TEST BRIDGES

The 17 test bridges were not a true random selection of all the bridges in the state but were chosen on the basis of certain practical considerations such as accessibility and the ease of diverting traffic while the measurements were being taken. However, an effort was made to include various shapes, sizes, and methods of construction (hand and machine finished). Since the data was to be used to develop a specification applicable to current construction practices, the decks selected were all comparatively new, ranging in age from a few months to about five years.

Of the 17 test decks, nine were built with an earlier depth of cover specification of $1\frac{1}{2}$ inches while the remaining eight had a specified depth of cover of 2 inches. The earlier bridges were mostly hand finished while the newer bridges were largely machine finished. To the extent that it was possible to determine, the reinforcing steel was secured similarly for all the decks. No tolerances were given on the depth of cover specifications and it was the opinion of most of the construction personnel questioned that both specifications were interpreted as minimums.

6.4 ANALYSIS OF DEPTH OF COVER MEASUREMENTS

Depth of cover was measured at approximately 40 systematic (grid) locations on each of the test decks. Histograms for this data from the two sets of bridges are shown in Figures 6.1 and 6.2.

Both distributions exhibit a central tendency with the means falling close to the specification values although, when statistical testa are made, they are found to be significantly different from the specified values. For the earlier bridges (Figure 6.1) the mean depth is greater than the specified depth which is what might be expected if the specified

OVERALL DISTRIBUTION

N = 398
$\bar{X}$ = 1.66"
σ = 0.33"
$\sigma_{\bar{X}}$ = 0.02"

INDIVIDUAL BRIDGE DATA

MEAN (IN.)	STD. DEV. (IN.)
1.75	0.19
1.27	0.23
1.31	0.22
1.88	0.24
1.63	0.27
1.79	0.20
1.72	0.25
1.74	0.27
1.87	0.28

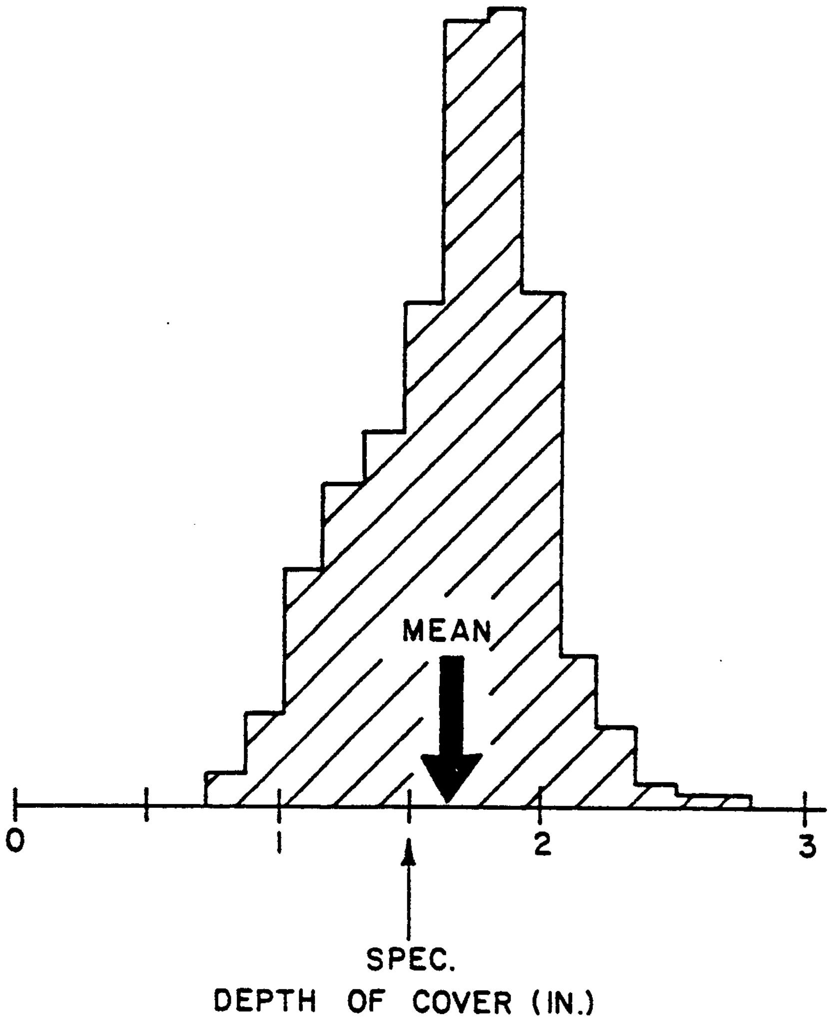


FIGURE 6.1 Depth of cover over top steel of 9 New Jersey decks built with 1.5" specification.

OVERALL DISTRIBUTION

$N = 314$

$X = 1.84''$

$\sigma = 0.38''$

$\sigma_{\overline{X}} = 0.02''$

INDIVIDUAL BRIDGE DATA

MEAN (IN.)	STD DEV. (IN.)
1.88	0.48
2.04	0.37
2.24	0.21
1.60	0.37
1.98	0.24
1.63	0.30
1.65	0.20
1.72	0.18

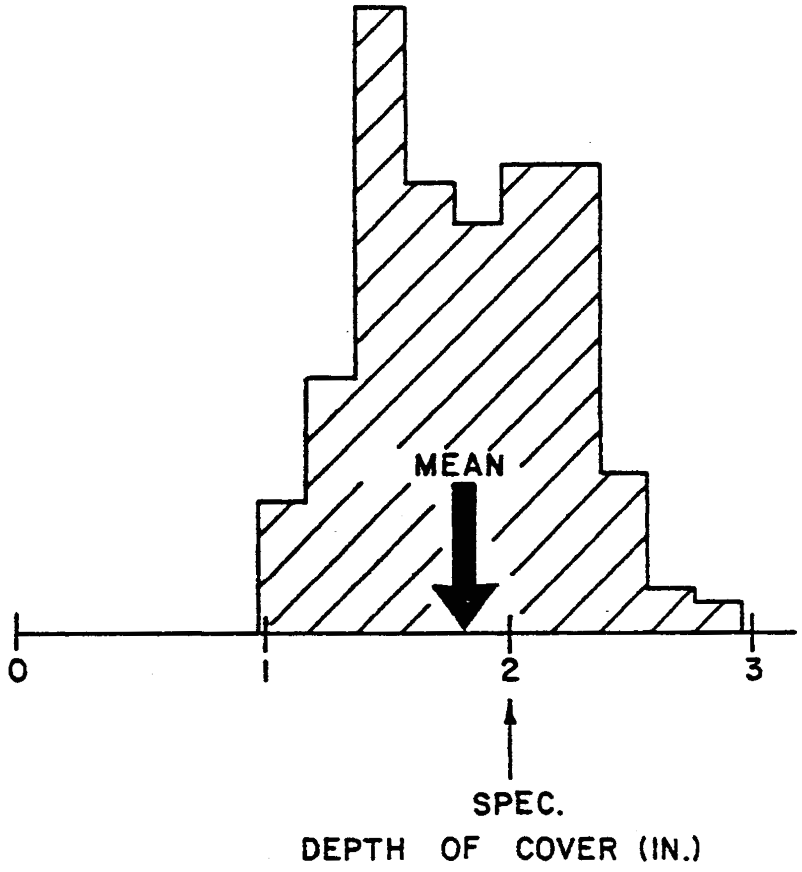


FIGURE 6.2 Depth of cover over top steel of 8 New Jersey bridge decks built with 2" specification.

depth were regarded as a minimum rather than a target value. For the latter bridges (Figure 6.2), however, the opposite situation exists.

When the depth of cover specification was increased from $1\frac{1}{2}$ inches to 2 inches, a corresponding increase in the overall thickness of the deck slab was also made. However, it is not known if the resulting increase in dead load influenced the deflection of the span in a way that would affect the final depth of cover over the top mat of reinforcing steel.

Although it is not clear why these means should depart in opposite directions from the target values, the magnitudes of these departures are not so great that the data cannot be used to develop a useful depth of cover specification. Since there seems to be no obvious benefit to the contractor in setting the steel either too high or too low, it is believed that the departure of the mean from the specified value will be essentially zero, on the average, especially if the specification has equal plus and minus tolerances which are enforced.

Since the histograms are approximately normal, the distribution of depth of cover will be assumed to be normal for purposes of developing the specification. Since the departures of the means from the specified values in Figures 6.1 and 6.2 may reflect a real inability on the part of the contractor to control the mean depth of cover on a given bridge, this will be taken into account by combining these two sets of data rather than simply pooling the standard deviations. In order to establish a common basis, each data value will be coded by subtracting the specified value. This produces an approximately normal distribution with a mean of zero (indicating that, on the average, the depth of cover will be as specified) and a standard deviation of 0.38 inches.

6.5 DEVELOPMENT OF A DEPTH OF COVER SPECIFICATION

This standard deviation, which represents the variability of the depth of cover about the specified value, is approximately 3/8 of an inch and is used to construct the operating characteristic curve shown in Figure 6.3. This curve gives the percentage of steel protected (depth greater than 2 inches) by various possible depth of cover specifications. For example, this curve indicates that a specified depth of cover of $2\frac{1}{2}$ inches would be expected to protect approximately 90 percent of the steel. If it were desired to keep nearly all of the steel below a depth of 2 inches, a specified depth of 3-1/8 inches would be required.

Once a suitable target value has been decided upon, appropriate plus and minus tolerances must be added to complete the specification. Ideally, a statistical survey of the level of top steel for several bridge decks just prior to the placement of concrete would determine what degree of compliance could reasonably be expected. In the absence of such a survey, field experience and engineering judgement must be relied upon. Realizing that the variability of the level of the steel before the pour would be expected to be less than after the pour, and considering the relative ease of correcting steel that is improperly placed, it is suggested that $\pm 1/4$ inch would be a reasonable tolerance for the setting of the steel.

As a direct result of this study, the specification for depth of cover in New Jersey has been increased although in a slightly different form from that recommended here. The previous specification required a minimum depth of cover of 2 inches. This has now been increased to $2\frac{1}{2}$ inches.

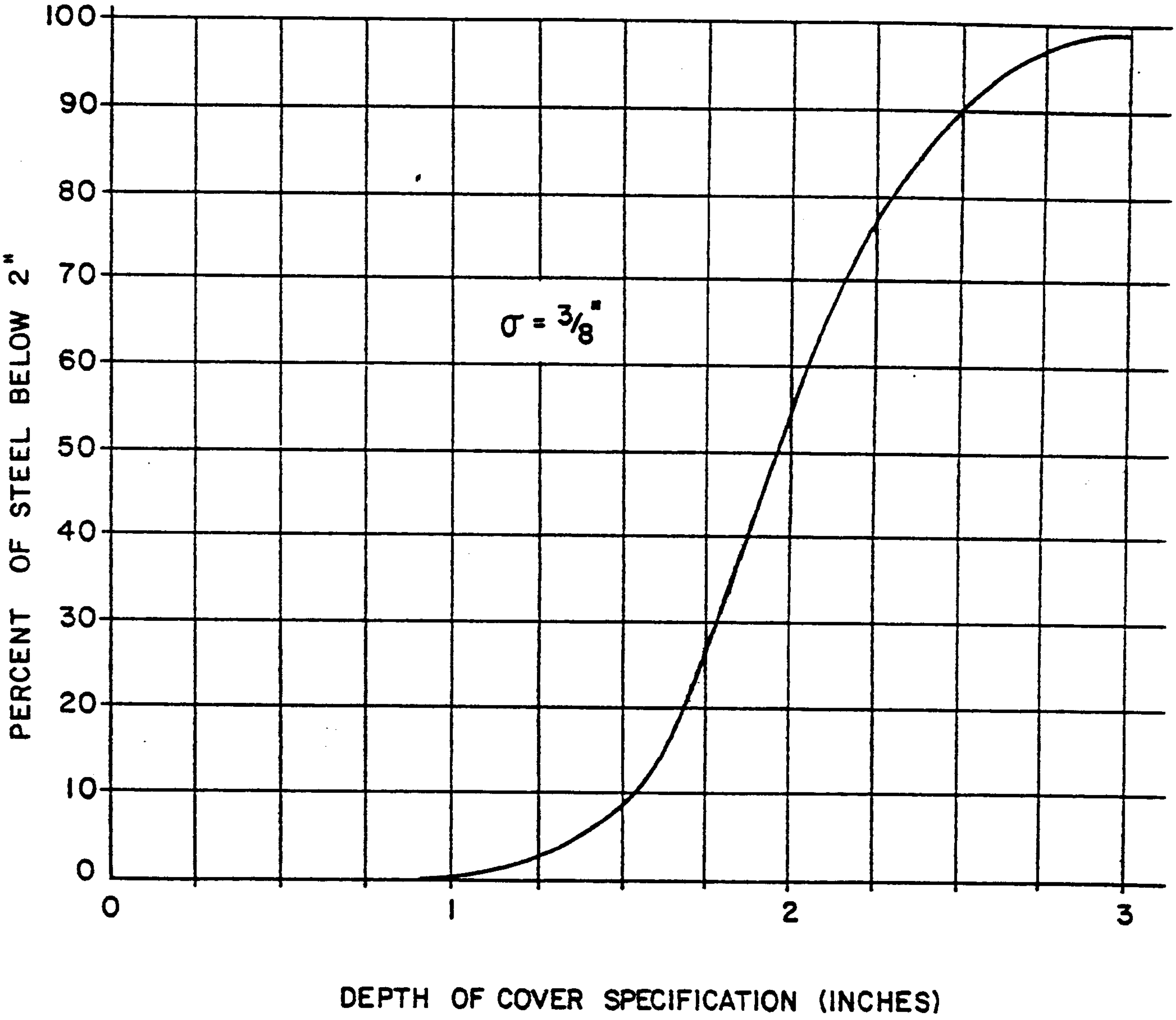


FIGURE 6.3 Operating characteristic curve showing the percentage of steel protected with various possible target values for depth of cover.

7.0 REFERENCES

1. Lindberg, H. A., "Use of Galvanized Rebars in Bridge Decks," FHWA Notice N 5140.10, July 9, 1976.

2. Federal Highway Program Manual, Volume 6, Chapter 7, Section 2, Subsection 7, 1976.

3. Bergren, J. V., "An Evaluation of Concrete Bridge Deck Resurfacing In Iowa," Iowa Department of Transportation, 1975.

4. White, R. O., "NEEP No. 16 - Epoxy Coated Rebars, Summary of Costs and General Comments," FHWA, July 19, 1974, Memorandum.

5. Clear, K. C. and Forster, S. W., "Internally Sealed Concrete: Material Characterization and Heat Treating Studies," Interim Report, March 1977.

6. Federal Highway Administration, "Internally Sealed Concrete," User's Guide, April 1977.

7. Review Team, Bureau of Construction and Compliance Practices, New Jersey Department of Transportation, "In-Depth Inspection of Wax Impregnated Concrete Bridge Decks - Stage I and State II," two reports, 1977.

8. Portland Cement Association, "Durability of Concrete Bridge Decks," 1970.

9. NCHRP Synthesis of Highway Practice No. 4, "Concrete Bridge Deck Durability," 1970.

10. Maloney, M. F., "FHWA Instructional Memorandum 40-6-72," 1972.

APPENDIX I

SPECIFICATIONS FOR MOISTURE SENSING ELECTRODES

Copper Tape

Scotch Brand No. X-1181 copper tape with pressure sensitive conductive adhesive, ½ inch wide by 0.0015 inch thick, obtainable from:

Minnesota Mining & Manufacturing Co.
5698 Rising Sun Avenue
Philadelphia, PA 19120

Polyethylene Tape

No. 357 Nashua polyethylene laminated cotton cloth tape with pressure sensitive adhesive on cloth side, 2 inches wide, obtainable from:

Ridgewood Corporation
58 Fifth Avenue
Hawthorne, NJ 07507

or

Nashua Corporation
Dutch Brand Division
44 Franklin Street
Nashua, NH 03060

Wire Leads

High temperature insulated copper wire, 18 gauge, stranded, 7 strands, tinned, temperature rating 200°C, S.R. Style 3135, obtainable from:

Radix Wire Co.
26260 Lakeland Boulevard
Cleveland, OH 44132

(NOTE: 18 to 25 gauge and 7 to 17 strands acceptable.)

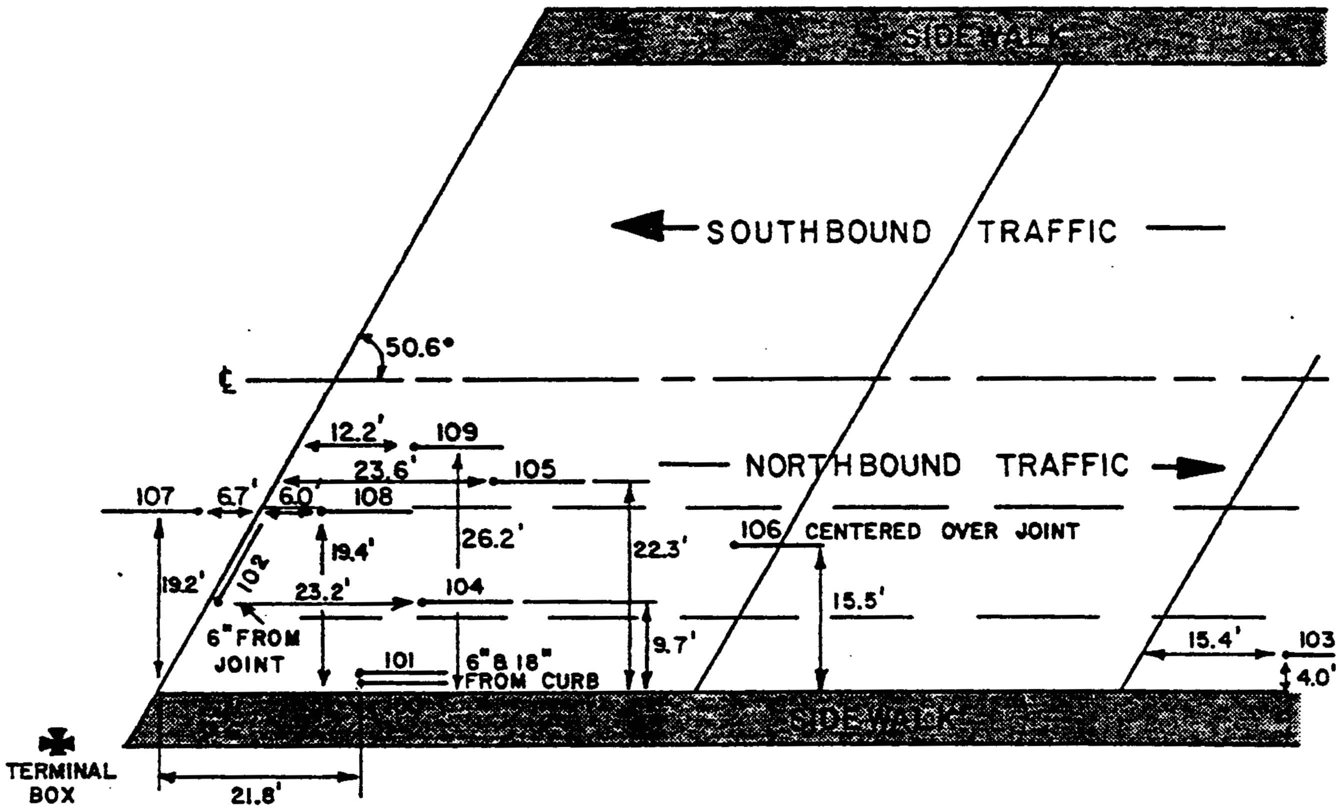
APPENDIX II

MOISTURE SENSING ELECTRODE LOCATIONS

JOHNS - MANVILLE MEMBRANE

Rt. 130 BRIDGE OVER PENNA. R.R.

Bridge # 1227155 Membrane installed 7/12/72

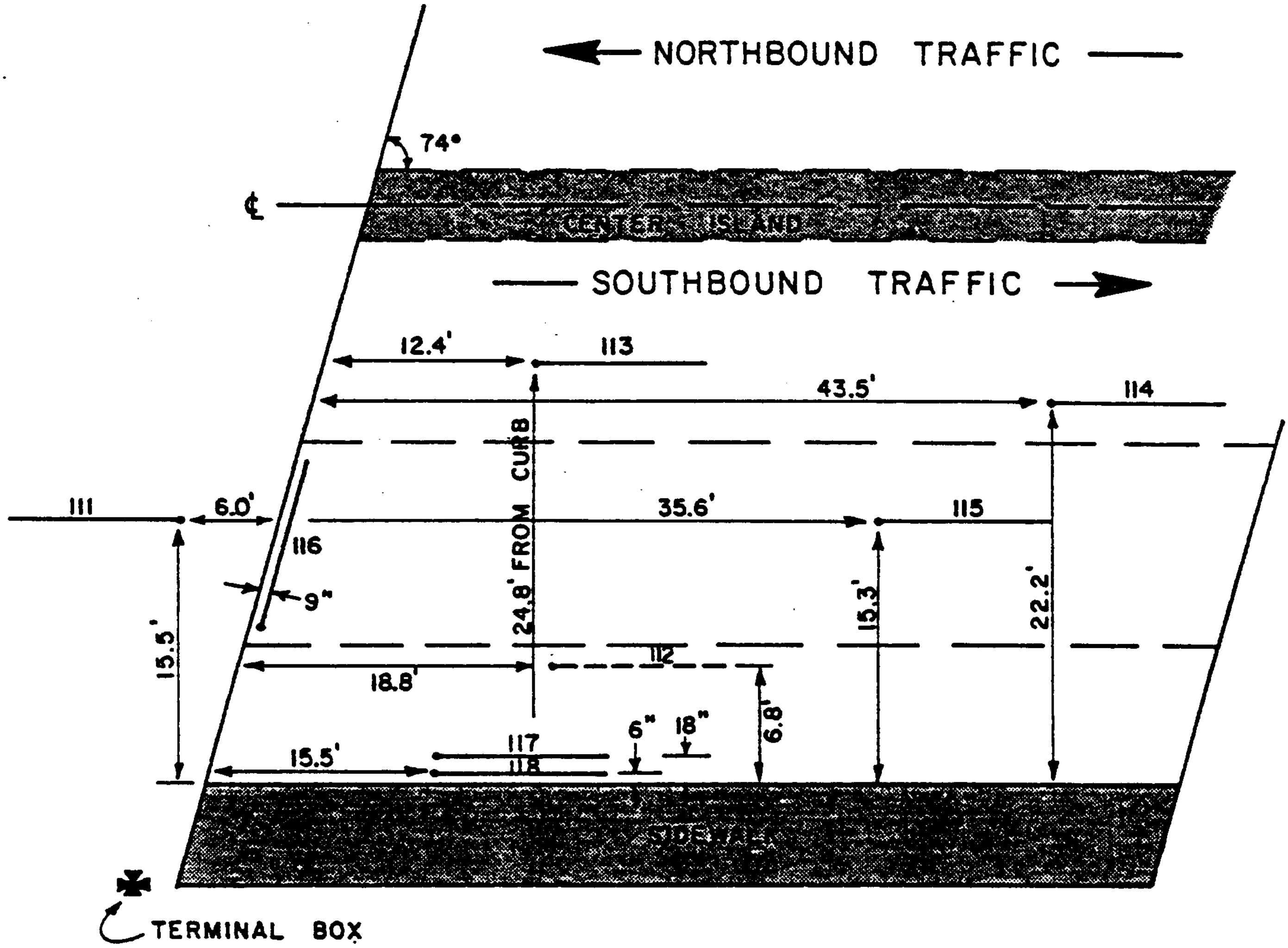


No. 102 Torn during construction — approx. the first 2' is intact.

JOHNS - MANVILLE MEMBRANE

Rt. 130 BRIDGE OVER 522

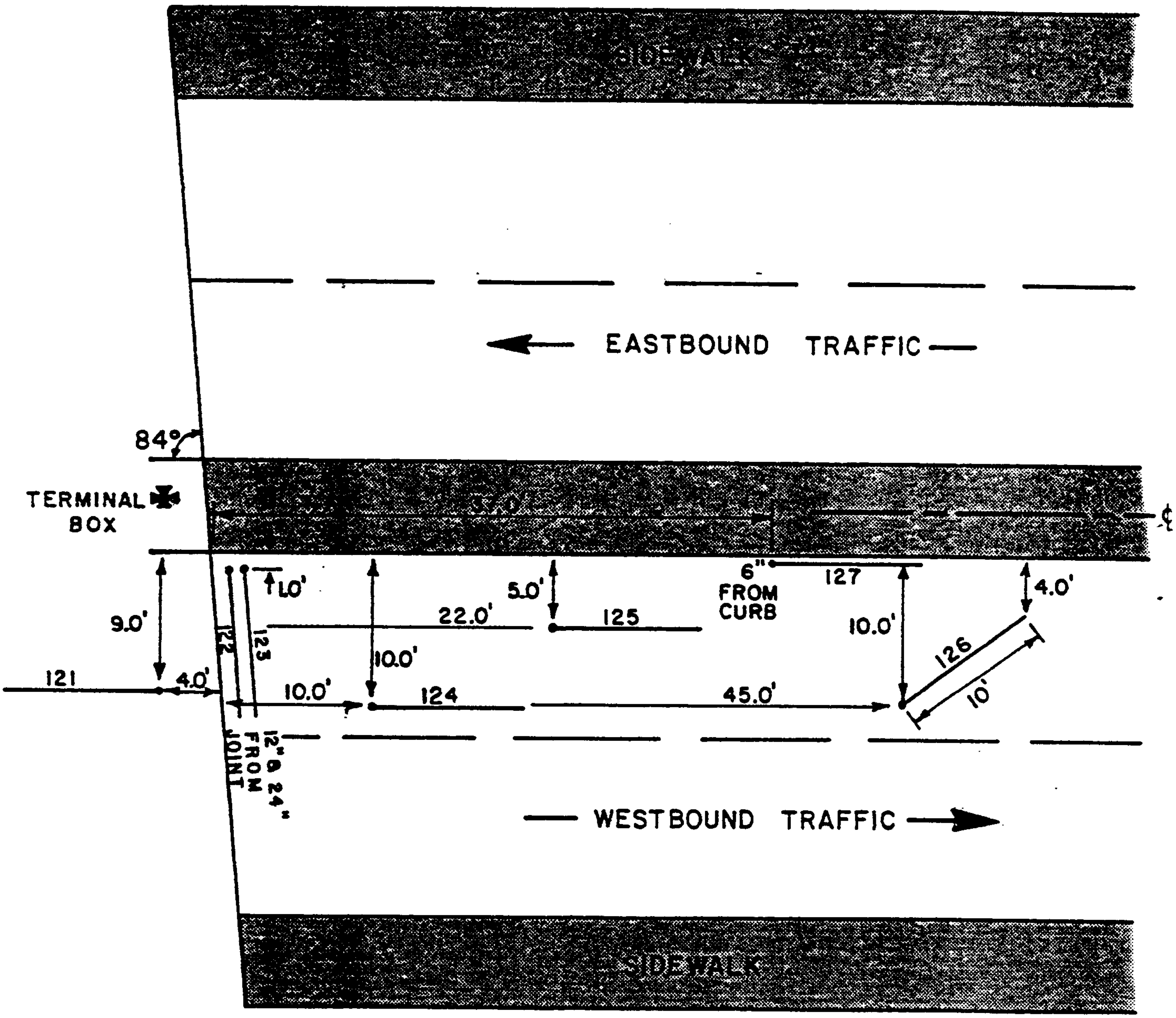
Bridge # 1227156 Membrane installed 7/14/72



UNIROYAL MEMBRANE

Rt. 46 BRIDGE OVER ERIE-LACK. R.R.

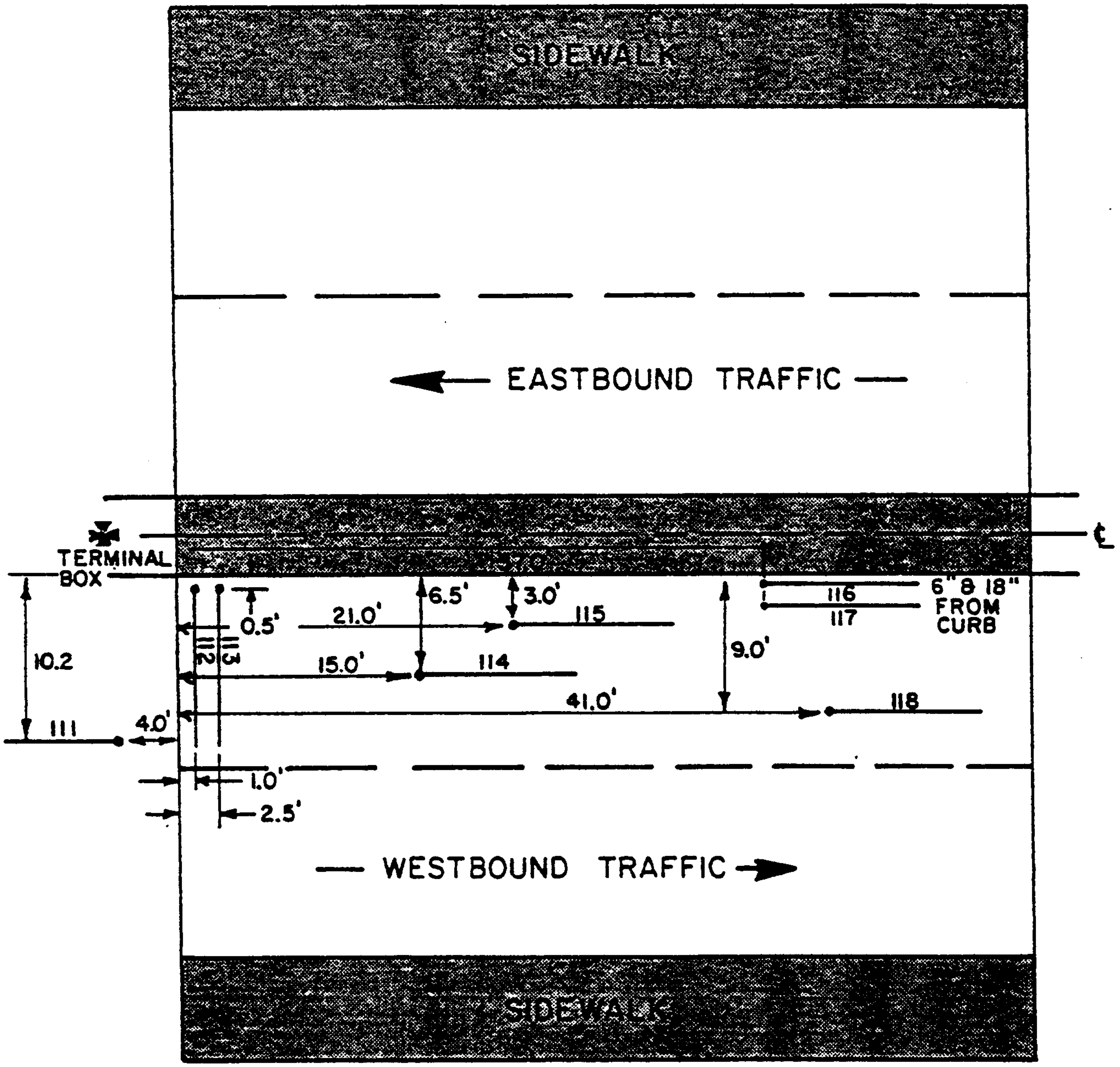
Bridge # 1607156 Membrane * installed 7/19/72



UNIROYAL MEMBRANE

Rt.46 BRIDGE OVER PAULISON AVE.

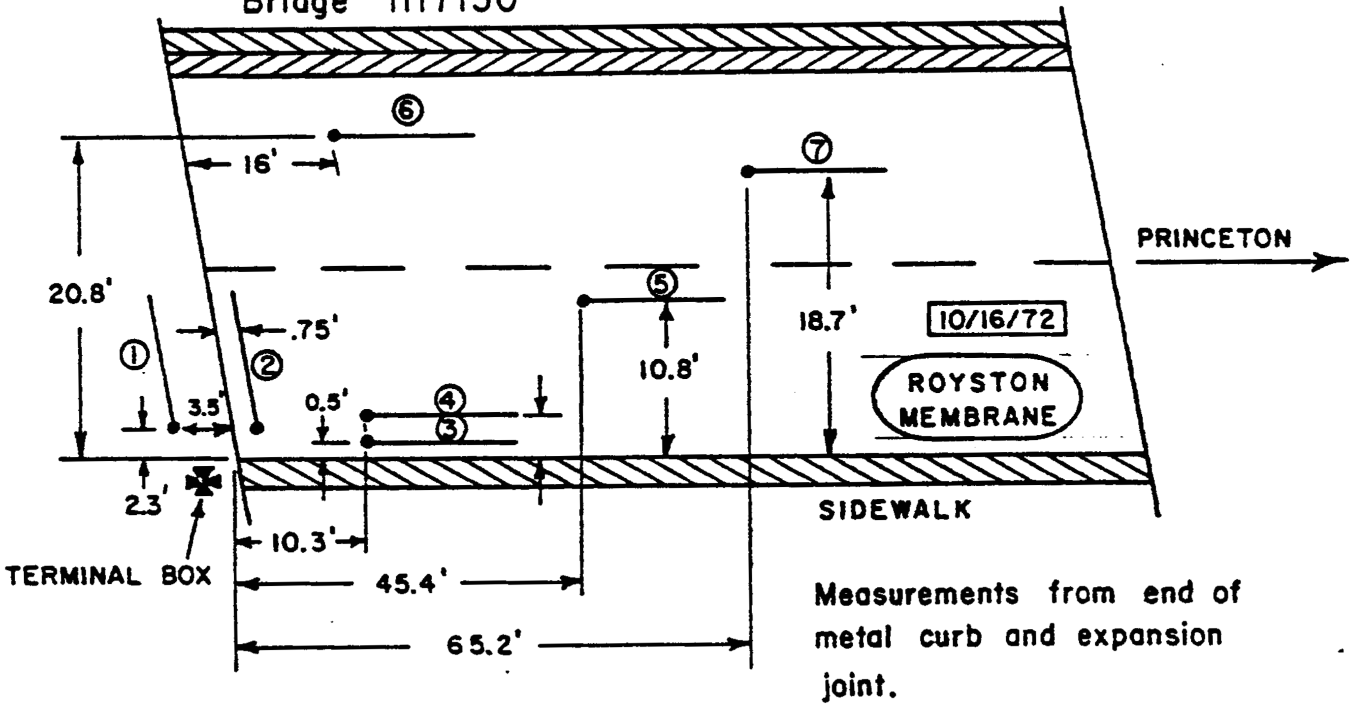
Bridge 1607158 Membrane installed 7/19/72.



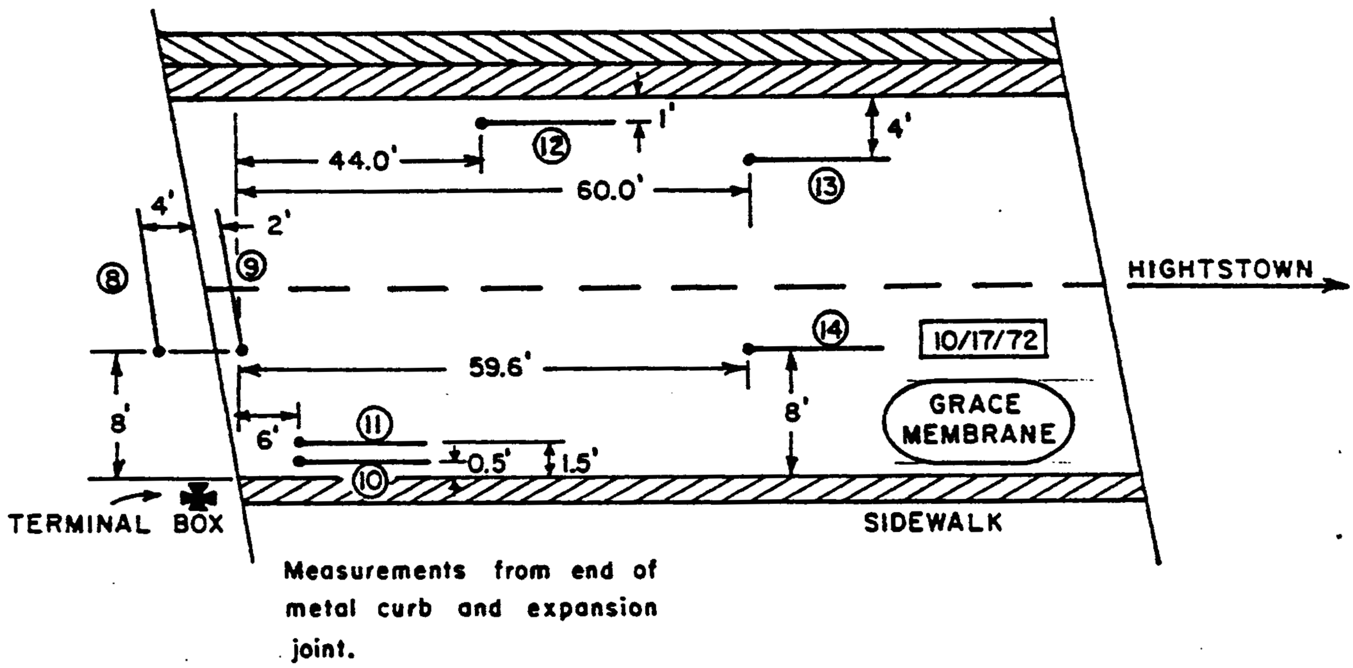
ROYSTON AND GRACE MEMBRANES

PRINCETON JUNCTION BRIDGE W.B. (to PRINCETON)

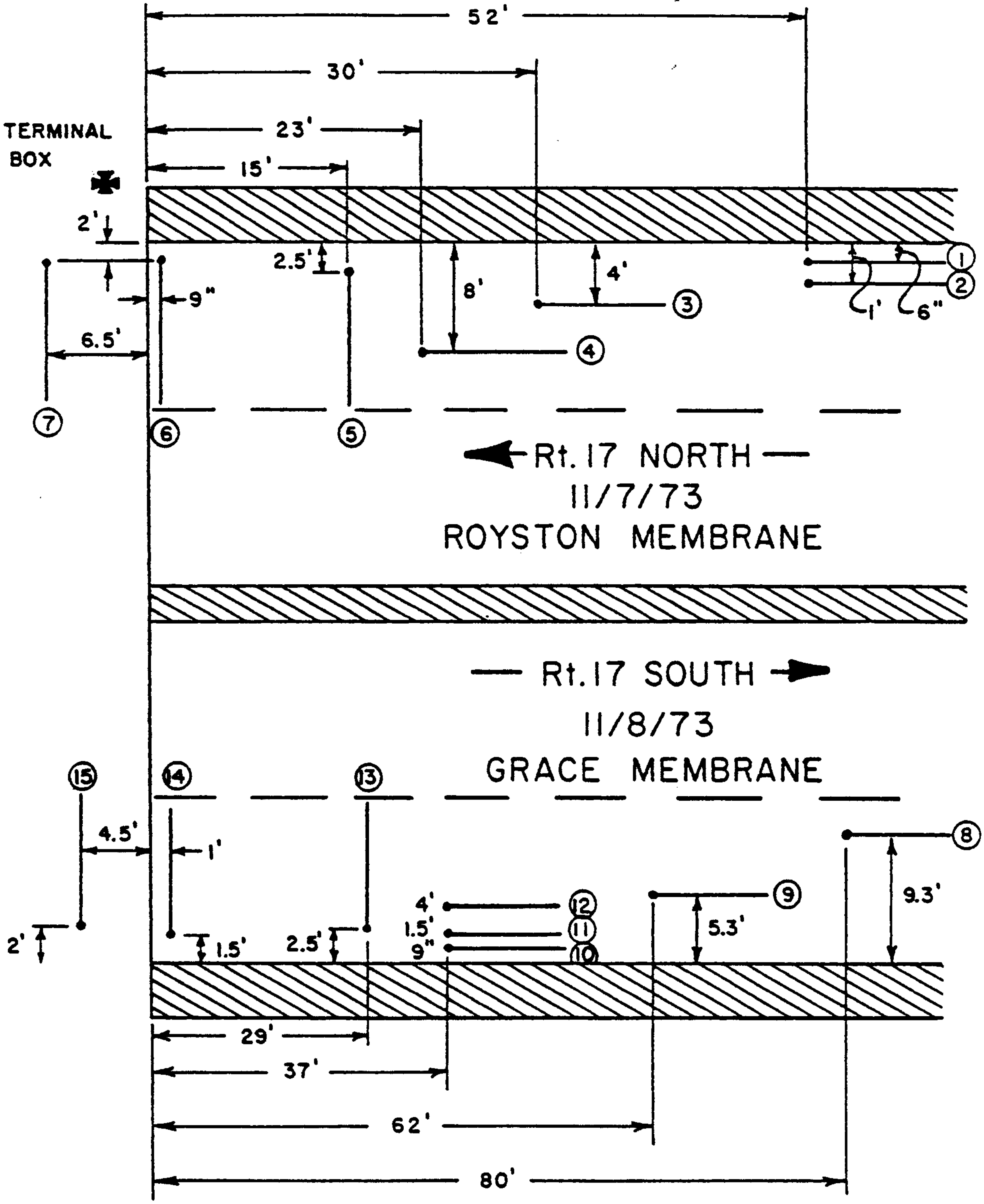
Bridge # 1117150



PRINCETON JUNCTION BRIDGE E.B. (to HIGHTSTOWN)



ROYSTON AND GRACE MEMBRANES



Rt. 17 BRIDGE OVER N.Y.S. & W.R.R.

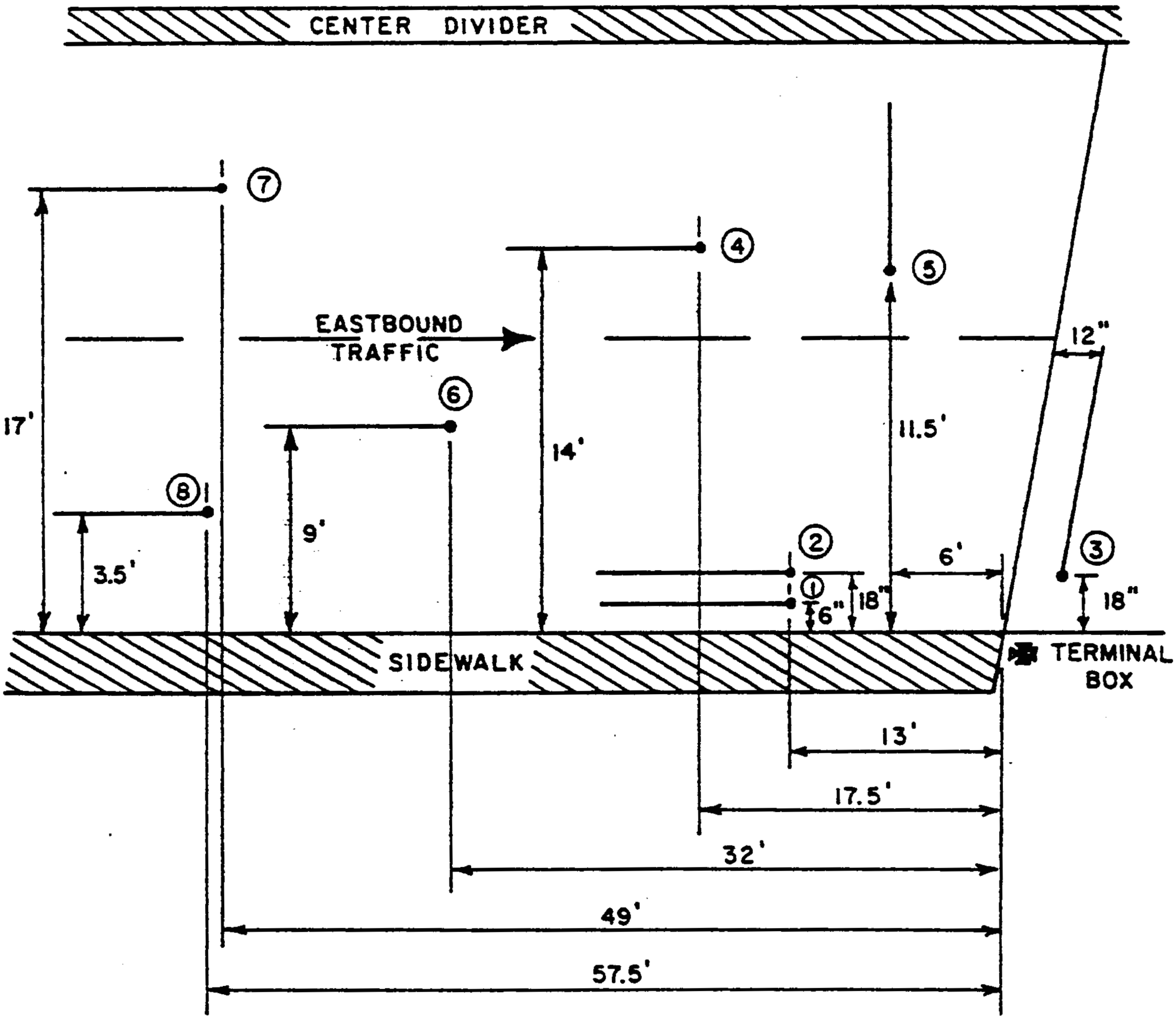
BRIDGE # 0214158

PETROMAT MEMBRANE

Rt. 70 BRIDGE OVER CENTRAL .R.R.

BRIDGE # 1509152

Membrane installed 8/8/75



Wires to No. 7 were severed during placement of the overlay.

APPENDIX III

MOISTURE SENSING ELECTRODE READINGS

HISTOGRAMS AND TREND PLOTS

ROUTE 130 BRIDGE OVER PRR
JOHNS-MANVILLE MEMBRANE

	OHMS			
WET	LESS THAN 100			
	100	-	158	
	159	-	251	X
	252	-	398	XX
	399	-	631	XX
	632	-	999	X
	1,000	-	1,585	XX
UNCERTAIN	1,586	-	2,512	XXXX
	2,513	-	3,981	XXXXXXXXXXX
	3,982	-	6,310	XXXXXXXXXXX
	6,311	-	9,999	XXXXXX
	10,000	-	15,849	XXXXX
DRY	15,850	-	25,119	XXXXXXXXXXX
	25,120	-	39,811	XXXXXXXXXX
	39,812	-	63,096	XXXXX
	63,097	-	99,999	XXXXXX
	100,000	-	158,489	XXX
	158,490	-	251,187	XXXX
	251,188	-	398,107	XXXX
	398,108	-	630,957	X
	630,958	-	999,999	
	1,000,000	-	1,584,893	
	1,584,894	-	2,511,886	
	2,511,887	-	3,981,072	X
	3,981,073	-	6,309,573	
	6,309,574	-	9,999,999	
	10,000,000	-	AND OVER	

Route 130 Bridge over PRR
Johns-Manville Membrane

	OHMS / DATE	07/14/72	08/01/72	08/18/72	08/29/72	09/14/72	09/26/72	10/27/72	11/13/72	12/18/72	02/21/73	10/15/73	12/20/73	03/29/74	06/10/74	08/14/74
	LESS THAN 100															
	100 - 158															
	159 - 251														1	
WET	252 - 398														2	1
	399 - 631															2, 3
	632 - 999															4
	1,000 - 1,585											3				5
	1,586 - 2,512							3				4		2	4	
	2,513 - 3,981								3		3	2, 6	3, 4	1, 3, 4	6	6
UNCERTAIN	3,982 - 6,310	3, 4				3	3				1, 6	1	2, 6	6	3	
	6,311 - 9,999	2						1	1		2, 4				5	
	10,000 - 15,849	6	4	3	3								1			
	15,850 - 25,119	1	3	4	4	6	2, 6	6	6			5	5			
	25,120 - 39,811				2, 6	2	4	4	4	1, 3	5			5		
	39,812 - 63,096		2	2		4			5	6						
	63,097 - 99,999			6		5	5	2, 5	2							
	100,000 - 158,489		6		1					5						
	158,490 - 251,187					1	1			2, 4						
	251,188 - 398,107	5	1	1	5											
DRY	398,108 - 630,957			5												
	630,958 - 999,999															
	1,000,000 - 1,584,893															
	1,584,894 - 2,511,886															
	2,511,887 - 3,981,072		5													
	3,981,073 - 6,309,573															
	6,309,574 - 9,999,999															
	10,000,000 - AND OVER															

(Numbers identify electrode locations)

ROUTE 130 BRIDGE OVER ROUTE 522

JOHNS-MANVILLE MEMBRANE

	OHMS		
WET	LESS THAN 100		
	100 - 158		
	159 - 251		
	252 - 398		
	399 - 631		
	632 - 999		
	1,000 - 1,585		
UNCERTAIN	1,586 - 2,512	XXX
	2,513 - 3,981	XX
	3,982 - 6,310	XX
	6,311 - 9,999	XXX
	10,000 - 15,849	XXXX
DRY	15,850 - 25,119	XXXXXX
	25,120 - 39,811	XXXXX
	39,812 - 63,096	XXXXX
	63,097 - 99,999	XXXXXXXX
	100,000 - 158,489	XXXXXXXXXX
	158,490 - 251,187	XXXXXXXXXXX
	251,188 - 398,107	X
	398,108 - 630,957	XXXXX
	630,958 - 999,999	X
	1,000,000 - 1,584,893	X
	1,584,894 - 2,511,886	X
	2,511,887 - 3,981,072	
	3,981,073 - 6,309,573	
	6,309,574 - 9,999,999	
	10,000,000 - AND OVER	

Route 130 Bridge over Route 522

Johns-Manville Membrane

	OHMS	07/14/72	08/01/72	08/18/72	08/29/72	09/14/72	09/26/72	10/27/72	11/13/72	12/18/72	02/21/73	10/15/73	12/20/73	03/29/74	06/10/74	08/14/74	06/22/75	08/12/76
WET	LESS THAN 100																	
WET	100 - 158																	
WET	159 - 251																	
WET	252 - 398																	
WET	399 - 631																	
WET	632 - 999																	
WET	1,000 - 1,585																	
UNCERTAIN	1,586 - 2,512															4		1 4
UNCERTAIN	2,513 - 3,981																1 4	
UNCERTAIN	3,982 - 6,310														4			3
UNCERTAIN	6,311 - 9,999											4		4				2
UNCERTAIN	10,000 - 15,849														3	2 3	2	
DRY	15,850 - 25,119												2 3 4		1 2			3
DRY	25,120 - 39,811										4	2 3	1			1		
DRY	39,812 - 63,096			2 3		3	3					1						
DRY	63,097 - 99,999		3		3	2	2	3			3			2 3				
DRY	100,000 - 158,489	1	2	1	2			2	3 4	4	2			1				
DRY	158,490 - 251,187	2 3 4	1		1	1	1 4	4	2	3								
DRY	251,188 - 398,107					4												
DRY	398,108 - 630,957			4	4			1		2	1							
DRY	630,958 - 999,999								1									
DRY	1,000,000 - 1,584,893		4															
DRY	1,584,894 - 2,511,886									1								
DRY	2,511,887 - 3,981,072																	
DRY	3,981,073 - 6,309,573																	
DRY	6,309,574 - 9,999,999																	
DRY	10,000,000 - AND OVER																	

(Numbers identify electrode locations)

ROUTE 46 BRIDGE OVER ELRR

UNIROYAL MEMBRANE

	OHMS			
	LESS THAN 100			
	100	-	158	XX
	159	-	251	XXX
WET	252	-	398	XXXX
	399	-	631	XXX
	632	-	999	X
	1,000	-	1,585	XXXXXXXXXX
	1,586	-	2,512	XXXXXXXXXXXXX
	2,513	-	3,981	XXXXXXXXXXX
UNCERTAIN	3,982	-	6,310	XXXXXXXXXXXXXXXXXXX
	6,311	-	9,999	XXXXXXX
	10,000	-	15,849	XXXXXX
	15,850	-	25,119	XXXX
	25,120	-	39,811	XXXXXX
	39,812	-	63,096	XXX
	63,097	-	99,999	X
	100,000	-	158,489	XXX
	158,490	-	251,187	
	251,188	-	398,107	
DRY	398,108	-	630,957	X
	630,958	-	999,999	X
	1,000,000	-	1,584,893	
	1,584,894	-	2,511,886	
	2,511,887	-	3,981,072	
	3,981,073	-	6,309,573	
	6,309,574	-	9,999,999	
	10,000,000	-	AND OVER	

Route 46 Bridge over ELRR
Uniroyal Membrane

	OHMS \ DATE	07/24/72	08/01/72	08/21/72	08/29/72	09/14/72	09/26/72	10/27/72	11/13/72	12/18/72	02/21/73	10/15/73	01/02/74	03/28/74	06/11/74	08/13/74	06/21/75	08/12/76	04/04/77	10/18/77	03/21/78
	LESS THAN 100																				
	100 - 158														4		4				
	159 - 251											4						5			4
WET	252 - 398														5	1	1	1			
	399 - 631											5					5				1
	632 - 999																				5
	1,000 - 1,585						4									4 5		2 3	1 2 5	1 2	
	1,586 - 2,512	3	3				1 5	3 4				1	3	1 4	1	3	3				
	2,513 - 3,981	1		3 5	3 4	4		1 5	4				1	5							
UNCERTAIN	3,982 - 6,310	4 5	1 4 5	1 4	1 5	1 3 5			1 5	4		3							3	5	3
	6,311 - 9,999								3		1 4 5	2								3	2
	10,000 - 15,849									1 3 5	2	3				2	2				
	15,850 - 25,119	2		2	2													4			
	25,120 - 39,811		2			2					3	2		2					4		
	39,812 - 63,096						2	2	2												
	63,097 - 99,999																			4	
	100,000 - 158,489												4 5	3							
	158,490 - 251,187																				
	251,188 - 398,107																				
DRY	398,108 - 630,957												2								
	630,958 - 999,999									2											
	1,000,000 - 1,584,893																				
	1,584,894 - 2,511,886																				
	2,511,887 - 3,981,072																				
	3,981,073 - 6,309,573																				
	6,309,574 - 9,999,999																				
	10,000,000 - AND OVER																				

(Numbers identify electrode locations)

ROUTE 46 BRIDGE OVER PAULISON AVE.

UNIROYAL MEMBRANE

	OHMS		
	LESS THAN 100		
	100 - 158		
	159 - 251	X	
WET	252 - 398		
	399 - 631	XXXXX	
	632 - 999	XXX	
	1,000 - 1,585	XXXX	
	1,586 - 2,512	XXXXX	
	2,513 - 3,981	XXXXXXXX	
UNCERTAIN	3,982 - 6,310	XXXXXXXXXXXXXX	
	6,311 - 9,999	XXXXXXX	
	10,000 - 15,849	XXXXXXX	
	15,850 - 25,119	XXXX	
	25,120 - 39,811	XXXX	
	39,812 - 63,096	XXXXXXXXX	
	63,097 - 99,999	XXXXXXX	
	100,000 - 158,489	XXXXXX	
	158,490 - 251,187	XXXX	
	251,188 - 398,107	XXXXX	
DRY	398,108 - 630,957	XX	
	630,958 - 999,999	XX	
	1,000,000 - 1,584,893	X	
	1,584,894 - 2,511,886	X	
	2,511,887 - 3,981,072		
	3,981,073 - 6,309,573		
	6,309,574 - 9,999,999		
	10,000,000 - AND OVER		

	OHMS	07/24/72	08/01/72	08/21/72	08/29/72	09/14/72	09/26/72	10/27/72	11/13/72	12/18/72	02/21/73	10/15/73	01/02/74	03/28/74	06/11/74	08/13/74	06/21/75	08/12/76	04/04/77	10/18/77	03/21/78
	LESS THAN 100																				
	100 - 158																				
	159 - 251																	5			
WET	252 - 398																				
	399 - 631															1	1	2	5		1
	632 - 999															4			2	5	
	1,000 - 1,585											1			1			3		2	
	1,586 - 2,512	1												1			2	1			2.
	2,513 - 3,981		1				1						1		2	2 5	4 5				
UNCERTAIN	3,982 - 6,310			1 5	1 5	1		1				2		2	4 5				1 3	1	4
	6,311 - 9,999					5			1			4	2	4						3	5
	10,000 - 15,849		5					5	5		1	5		5							3
	15,850 - 25,119	5								1 5	5										
	25,120 - 39,811						5				4		5				3				
	39,812 - 63,096			2	2		2 4		2 4				4		3	3					
	63,097 - 99,999		2		4	2 4		2 4			2										
	100,000 - 158,489	2 4								4		3						4		4	
	158,490 - 251,187	3		4			3			2									4		
	251,188 - 398,107		4	3	3	3		3													
DRY	398,108 - 630,957		3										3								
	630,958 - 999,999								3		3										
	1,000,000 - 1,584,893													3							
	1,584,894 - 2,511,886									3											
	2,511,887 - 3,981,072																				
	3,981,073 - 6,309,573																				
	6,309,574 - 9,999,999																				
	10,000,000 - AND OVER																				

(Numbers identify electrode locations)

PRINCETON JUNCTION BRIDGE WESTBOUND

ROYSTON MEMBRANE

	OHMS		
	LESS THAN 100		XXXXX
	100 -	158	XX
	159 -	251	XXXXXXXX
WET	252 -	398	XXX
	399 -	631	XXX
	632 -	999	XX
	1,000 -	1,585	XXX
	1,586 -	2,512	XXXXXXXX
	2,513 -	3,981	XXX
UNCERTAIN	3,982 -	6,310	XXXXXXXXX
	6,311 -	9,999	X
	10,000 -	15,849	XX
	15,850 -	25,119	X
	25,120 -	39,811	XXXX
	39,812 -	63,096	XXXX
	63,097 -	99,999	
	100,000 -	158,489	
	158,490 -	251,187	
	251,188 -	398,107	
DRY	398,108 -	630,957	
	630,958 -	999,999	
	1,000,000 -	1,584,893	
	1,584,894 -	2,511,886	
	2,511,887 -	3,981,072	
	3,981,073 -	6,309,573	
	6,309,574 -	9,999,999	
	10,000,000 -	AND OVER	

Princeton Junction Bridge
Westbound
Royston Membrane

	OHMS	10/27/72	11/13/72	12/19/72	02/21/73	10/17/73	12/20/73	03/29/74	06/10/74	08/14/74	06/22/75	08/11/76	04/01/77	10/14/77	03/21/78
	LESS THAN 100								4	4	4	2			4
	100 - 158					4							4		
	159 - 251						4		1 2	2		1	2	1 2	
WET	252 - 398					2				1	1				
	399 - 631				1				3	3					
	632 - 999			1											3
	1,000 - 1,585							4				3			2
	1,586 - 2,512		1		4	1 3	2				2 3		1		
	2,513 - 3,981						1	2 3							
UNCERTAIN	3,982 - 6,310	4	2 4		2 3		3	1				4		3	
	6,311 - 9,999		3												
	10,000 - 15,849	1		4											
	15,850 - 25,119			2											
	25,120 - 39,811			3									3	4	1
	39,812 - 63,096														
	63,097 - 99,999														
	100,000 - 158,489	3													
	158,490 - 251,187														
	251,188 - 398,107	2													
DRY	398,108 - 630,957														
	630,958 - 999,999														
	1,000,000 - 1,584,893														
	1,584,894 - 2,511,886														
	2,511,887 - 3,981,072														
	3,981,073 - 6,309,573														
	6,309,574 - 9,999,999														
	10,000,000 - AND OVER														

(Numbers identify electrode locations)

PRINCETON JUNCTION BRIDGE EASTBOUND

GRACE MEMBRANE

	OHMS			
	LESS THAN		100	XXXXXXXXXXX
	100	-	158	XXXX
	159	-	251	XXXXXX
WET	252	-	398	XXX
	399	-	631	XX
	632	-	999	XXXXX
	1,000	-	1,585	XX
	1,586	-	2,512	XX
	2,513	-	3,981	XXXX
UNCERTAIN	3,982	-	6,310	X
	6,311	-	9,999	XXXX
	10,000	-	15,849	X
	15,850	-	25,119	XXX
	25,120	-	39,811	XX
	39,812	-	63,096	
	63,097	-	99,999	XX
	100,000	-	158,489	
	158,490	-	251,187	
	251,188	-	398,107	
DRY	398,108	-	630,957	
	630,958	-	999,999	
	1,000,000	-	1,584,893	
	1,584,894	-	2,511,886	
	2,511,887	-	3,981,072	
	3,981,073	-	6,309,573	
	6,309,574	-	9,999,999	
	10,000,000	-	AND OVER	XXXX

Princeton Junction Bridge

Eastbound

Grace Membrane

Zone	OHMS	DATE 10/27/72	11/13/72	12/19/72	02/21/73	10/17/73	12/20/73	03/29/74	06/10/74	08/14/74	06/22/75	08/11/76	04/01/77	10/14/77	03/21/78
	LESS THAN 100								1 2	1 2	1 2	1 2	2 3		2
	100 - 158					1		1	3			3			
	159 - 251					2	1			3	3		1		1
WET	252 - 398						2	2						3	
	399 - 631				1										3
	632 - 999				3	3		3						1 2	
	1,000 - 1,585		3				3								
	1,586 - 2,512		1	1											
	2,513 - 3,981	1			2						4	4			
UNCERTAIN	3,982 - 6,310								4						
	6,311 - 9,999			3		4				4					4
	10,000 - 15,849							4							
	15,850 - 25,119		2	2									4		
	25,120 - 39,811	2					4								
	39,812 - 63,096														
	63,097 - 99,999	3												4	
	100,000 - 158,489														
	158,490 - 251,187														
	251,188 - 398,107														
DRY	398,108 - 630,957														
	630,958 - 999,999														
	1,000,000 - 1,584,893														
	1,584,894 - 2,511,886														
	2,511,887 - 3,981,072														
	3,981,073 - 6,309,573														
	6,309,574 - 9,999,999														
	10,000,000 - AND OVER	4	4	4	4										

(Numbers identify electrode locations)

ROUTE 70 BRIDGE OVER CRR

PETROMAT MEMBRANE

	OHMS			
	LESS THAN 100			
	100	-	158	
	159	-	251	
WET	252	-	398	
	399	-	631	
	632	-	999	
	1,000	-	1,585	XXX
	1,586	-	2,512	XXX
	2,513	-	3,981	XXX
UNCERTAIN	3,982	-	6,310	XX
	6,311	-	9,999	X
	10,000	-	15,849	
	15,850	-	25,119	
	25,120	-	39,811	
	39,812	-	63,096	XX
	63,097	-	99,999	XX
	100,000	-	158,489	X
	158,490	-	251,187	X
	251,188	-	398,107	XX
DRY	398,108	-	630,957	XX
	630,958	-	999,999	
	1,000,000	-	1,584,893	
	1,584,894	-	2,511,886	
	2,511,887	-	3,981,072	
	3,981,073	-	6,309,573	
	6,309,574	-	9,999,999	
	10,000,000	-	AND OVER	

Route 70 Bridge over CRR

Petromat Membrane

	OHMS	04/08/76	08/11/76	04/01/77	10/27/77	03/21/78
	LESS THAN 100					
	100 - 158					
	159 - 251					
WET	252 - 398					
	399 - 631					
	632 - 999					
	1,000 - 1,585				3	3 4
	1,586 - 2,512		3 4		4	
	2,513 - 3,981			3		
UNCERTAIN	3,982 - 6,310	3		4		
	6,311 - 9,999	4				
	10,000 - 15,849					
	15,850 - 25,119					
	25,120 - 39,811					
	39,812 - 63,096			2		2
	63,097 - 99,999		2		2	
	100,000 - 158,489					1
	158,490 - 251,187	2				
	251,188 - 398,107			1	1	
DRY	398,108 - 630,957	1	1			
	630,958 - 999,999					
	1,000,000 - 1,584,893					
	1,584,894 - 2,511,886					
	2,511,887 - 3,981,072					
	3,981,073 - 6,309,573					
	6,309,574 - 9,999,999					
	10,000,000 - AND OVER					

(Numbers identify electrode locations)

APPENDIX IV

IDENTIFICATION OF TEST BRIDGES

APPENDIX IV

LIST OF TEST BRIDGES

SYSTEM	PROJECT OR BRIDGE IDENTIFICATION	SYSTEM INSTALLATION DATE	COMMENTS
Johns-Manville Asbestos Modified Asphalt Membrane	Route 130 Structure 1227155 (over Penn. R.R.)	7/12/72	Weather clear and dry, temperature in 80's for both installations. Barber-Greene paver, metal tracks. Mix had 15% asphalt, 6% asbestos. Small amount of material on second bridge (over Route 522) was not completely mixed.
	Route 130 Structure 1227156 (over Route 522)	7/14/72	
Uniroyal Hot Applied Liquid Rubberized Asphalt Membrane	Route 46 Structure 1607156 (over Erie-Lackawanna R.R.)	7/19/72	Installation was made at night, weather was clear and dry with the temperature in the 70's. The outlet valve for the special heating kettle began to clog during the treatment of the second bridge (over Paulison Ave.) but the work was completed satisfactorily.
	Route 46 Structure 1607158 (over Paulison Ave.)		
Royston Rolled-On Preformed Sheet Membrane	Route 64 Westbound Structure 1117150 (to Princeton over Penn. R.R.)	10/16/72	Weather was windy and fairly dry with temperatures in the 50's. A metal-tracked paver was used but did not damage the membrane.
	Route 17 Northbound Structure 0214158 (over N.Y. and Western R.R.)	11/7/73	The weather was dry and cold for this installation, temperature in the 30's.
Phillips Fabric & Tack Coat Membrane (Petromat)	Route 70 Structure 1509152 (over Central R.R.)	8/8/75	Weather was clear and dry with temperatures in the 60's. The installation proceeded smoothly except, due to a shortage of sealer emulsion, an 18 inch wide gap next to the center divider in the eastbound lane received no membrane.

SYSTEM	PROJECT OR BRIDGE IDENTIFICATION	SYSTEM INSTALLATION DATE	COMMENTS
W. R. Grace Rolled-On Preformed Sheet Membrane	Route 64 Eastbound Structure 1117150 (to Hightstown, over Penn. R.R.)	10/17/72	Weather was partly cloudy with temperatures in the 60's. The deck was wet early in the morning but dry before the membrane was installed. The membrane was deeply marked but not cut by the metal-tracked paver. Several vapor bubbles formed under the membrane which had to be punctured and repaired.
	Route 17 Southbound Structure 0214158 (over N.Y. and Western R.R.)	11/8/73	The weather was dry and cold for this installation, temperatures in the 30's.
	Route 46 Structure 0202150 (Homestead Ave.)	1975	
	Route 46 Structure 0202151 (Brinkerhoff Ave.)	1975	
	Route 46-Route 63 Westbound Structure 0202156 (Bergen Blvd.)	1975	
	Route 46 Structure 0202158 (Main St.)	1975	
Dow SM-100 (Renamed Modifier A) Latex Modified Concrete	Route I-80 Rockaway, NJ (Total 24 decks)	1975	Weather was cool and damp for much of this work. Subsequent cracking problems developed. Details are discussed in Section 4.6 of this report.
	Kearny Ave. Bridge Structure M6561001 (over Erie-Lack-awanna R.R.)	11/12/75	Weather was cool with slight amount of rain, did not delay work.
	Dorset Ave. Bridge (Atlantic County)	1976	

SYSTEM	PROJECT OR BRIDGE IDENTIFICATION	SYSTEM INSTALLATION DATE	COMMENTS
Dow SM-100 (Continued)	Route I-287 Northbound (over Littleton Rd.)	1976	
	Route I-287 Northbound (Over Route 46)	1976	
Low-Slump High-Density Concrete (Iowa System)	Mountain Ave. Bridge Somerville, NJ (over Peter's Brook)	5/13/77	These installations were witnessed by personnel from the Bureau of Construction Practices who reported that numerous minor difficulties were encountered and eventually overcome as the construction forces became more familiar with the procedure. Further details are contained in Section 4.7 of this report.
	Pottersville Rd. Bridge Peapack, NJ	6/20/77	
	Lamington Rd. Bridge	7/26/77	
	Pascack Rd. Bridge	8/8/77	
Epoxy Coated Reinforcing Steel	Route I-295 Bridge (over E. State St. Trenton, NJ)	1974	For the northbound deck, all reinforcing steel was coated including the parapet steel. For the southbound deck, the bottom mat was not coated. Tie wires were coated, chairs were galvanized. The epoxy coated bars had many nicks and minor defects which required field touch-up.
Galvanized Reinforcing Steel	Routes 1 & 9 over Route U.S. 22 Structure 0702151	1975 (Express) 1976 (Local)	Both upper and lower mats were galvanized. Tie wires and chairs were not galvanized.
	Route 495 over Routes 1 & 9 Structure 0917150	1976	Both upper and lower mats were galvanized.
	Route 29 over Alexauken Creek Structure 1007153	1976	Both upper and lower mats were galvanized.

SYSTEM	PROJECT OR BRIDGE IDENTIFICATION	SYSTEM INSTALLATION DATE	COMMENTS
Galvanized Reinforcing Steel	Routes 1 & 9 over Route U.S. 21 Structure 0702153	1976	Both upper and lower mats were galvanized.
Internally Sealed Concrete	Heller Parkway Bridge (over Erie-Lackawanna R.R., Newark, NJ) Eastbound	12/6/76	This system is the most experimental of those included in this study. Both installations were witnessed by personnel from the Bureau of Construction Practices who have written a lengthy report[8] describing the work in detail. A brief summary is presented in Section 4.10 of this report.
	Heller Parkway Bridge (over Erie-Lackawanna R.R., Newark, NJ) Westbound	5/12/77	

APPENDIX V

DESCRIPTION OF AN INSTALLATION OF LATEX-MODIFIED CONCRETE

On August 13, 1971, the writer witnessed the resurfacing of a bridge deck with a new system developed by Dow Chemical Company. This experimental bridge is located in Delaware on the off-ramp to southbound Routes 13 & 40 immediately after crossing the Delaware Memorial Bridge.

This particular system is designated SM-100 and consists of a latex modified mortar mix which is claimed to produce concrete which is stronger, more flexible, more impermeable, and more resistant to chemical attack than conventional concrete.

Prior to placing this mix on the deck, the surface of the old concrete is removed by means of a power scarifier to whatever depth is necessary to get down to solid concrete. Usually this is one inch or less, but in spalled areas it is often necessary to go deeper. This frequently requires some hand chipping around and below the reinforcing steel.

After the deteriorated concrete has been removed, the entire deck (and especially any exposed reinforcing steel) is sandblasted to thoroughly clean the scarified surface. If necessary, badly rusted reinforcing bars are replaced.

Just prior to the actual paving, the bridge deck is flushed with water to remove any residual dirt and debris and also to provide a moist surface for proper bonding of the mortar.

The placing of the SM-100 material is accomplished by a "paving train" designed by Dow and operated under their supervision. The "paving train" consists of an automatic batching truck (Concrete Mobile) followed by a finishing machine. An operator continuously deposits the mortar mix from the batching truck directly onto the deck at a uniform rate by swinging the discharge chute back and forth. Laborers then move it with shovels and brooms so that it is spread fairly evenly ahead of the finishing machine which strikes it off smoothly at the desired level. Final finishing operations are done by hand and include "gently" broom finishing. Curing is accomplished by covering with Burlene (burlap faced with polyethelene) within one hour after placement.

A Dow engineer at the job site explained that the "paving train" approach with the automatic batching truck was required to achieve the necessary quality control. Earlier tests by varying procedures in different states had not produced consistent results. He reported that there were now five Dow "paving trains" in operation throughout the country which have made many successful installations, several of them in Michigan.

The Dow literature gives the following mix proportions for the latex modified mortar:

Cement................94 lbs. (1 bag)

Sand..................3.25 cu. ft.

Latex.................3.5 gal.

Water.................As required for water-cement ratio of 0.35 to 0.40.

The Dow engineer stated that the cement factor is quite high, around eight bags per cubic yard. He also said that air content is usually controlled between 6% to 9%. When asked the same question, the foreman on the job mentioned 5% to 7% as the usual range. The Dow specifications simply state "not more than 10% entrained air." The air content of the material being used at the Delaware site was 5½% as determined with an Acme air meter.

This particular job was originally scheduled to begin at 6 a.m., apparently because the material is heat sensitive and may set up too fast. The weather forecast changed, cooler temperatures were predicted, and the work was rescheduled to start at the usual time. The paving was nearly complete by noon at which time the air temperature was approximately 80°. The mortar mix itself was at a temperature of 70° when placed and rose to 73° after one hour.

APPENDIX VI

DEVELOPMENT OF ECONOMIC EQUIVALENCE CHARTS

BACKGROUND

A very expensive protective system may be more cost effective than a less expensive system provided it has a correspondingly longer expected life. In order to compare drastically different systems, it is necessary to evaluate them on some common basis. Assuming that the systems are essentially equivalent from a performance standpoint throughout their useful lives, the most logical basis of comparison is an economic one.

When first installed, the less expensive system has a clear economic advantage since it provides equivalent protection at a much lower cost. However, because the less expensive system has a shorter useful life, it must be replaced periodically. This extra expense may outweigh the initial economic advantage and, depending upon the frequency of replacement, the more expensive system may turn out to be the more cost beneficial one in the long run.

BASIC ECONOMIC CONCEPT

For convenience, the less expensive system will be referred to as System 1 and the more expensive system as System 2. In making the economic comparison, the total value at any time of System 1 must include the growth (at compound interest) of the amount of money saved by not selecting System 2. However, the periodic cost (including inflation) of replacing System 1 must be paid for from this principal and, under most normal conditions, the principal will eventually be depleted in this manner. Consequently, after a specific length of time, the value of System 1 will become zero. If the useful life of System 2 were to be exactly equal to this length of time, the two systems would be considered to be equivalent from an economic standpoint. Therefore, the required life for

System 2 to be equivalent to System 1 is the length of time it takes for the total value of System 1 to be reduced to zero.

DEVELOPMENT OF EQUATIONS

In order to pursue this approach, it will be useful to develop an expression for the total value of System 1 as a function of time. Two preliminary steps are required. First, since interest rates are often quoted as compounded on some periodic basis of less than a year, it will be convenient to convert these rates to an equivalent yearly rate. For example, suppose the interest rate were 12 percent per year compounded semi-annually. This means the principal earns six percent for six months yielding $1.06 on the dollar. This amount then earns six percent for the remaining six months yielding 1.06 x $1.06 or $1.1236 or a net gain of 12.36 percent for the year. Because state agencies are usually exempt from paying income tax, no further adjustment of this figure is required for this analysis. Any interest rate can be converted to an equivalent yearly interest rate by the following general equation:

$$R_y = 100 \left[\left(1 + \frac{R_c}{100n}\right)^n - 1 \right] \tag{1}$$

in which

R_y = equivalent yearly interest rate

R_c = compound interest rate

n = yearly frequency of compounding

Secondly, it will be necessary to develop an expression for the book value (current worth) of an installed system as a function of time. There are several recognized methods of depreciation in existence (straight-line, declining-balance, sum-of-digits) and the method selected is usually strongly influenced by income tax considerations. However, since income tax is not a factor in this analysis, a simple modification of the straight-line method will be used. It will be assumed that the book value of an existing system will be the fraction of remaining life multiplied by the current (inflated) cost of installing an identical new system. This leads to the following general expression:

$$B = \left[\frac{L-t}{L}\right] C \left[1 + \frac{r}{100}\right]^t \qquad (2)$$

in which

B = book value

L = expected life of system

t = time (years) that system has been in place

C = initial cost of system

r = inflation rate (percent per year)

It is now possible to write an expression giving the total value of System 1 as a function of time:

$$V_1 = (C_2 - C_1)\left[1 + \frac{R}{100}\right]^t + \left[\frac{L_1-t}{L_1}\right]C_1\left[1 + \frac{r}{100}\right]^t \qquad (3)$$

in which $0 \leq t \leq L_1$ and

V_1 = value of System 1 at time t

C_1 = initial cost of System 1

C_2 = initial cost of System 2

R = yearly interest rate

r = yearly inflation rate

t = time (years) that System 1 has been in place

L_1 = expected life (years) of System 1

The first term on the right represents the growth of the original principal ($C_2 - C_1$) while the second term represents the declining book value of the installed system. It should be noted that this equation is directly applicable only up to time $t = L_1$. At this point, the principal must be reduced by the cost of the next generation of System 1 and t is again allowed to range from zero to L_1. The successive application of this approach is plotted in Figure VI-1 in which the total value of System 1 reaches zero at about the fourth year of the fourth generation, a total time of 19 years. For this example, System 2 must have an expected life of $L_2 = 19$ years to be equivalent to System 1.

DEVELOPMENT OF EQUIVALENCE CHARTS

Because this procedure is somewhat tedious to carry out with a hand calculator, a computer program was written which made it possible to execute these steps quickly and easily. Tests with this program demonstrated that the procedure is sensitive to the ratio of C_2 to C_1 rather than actual values and, within practical limits, to the difference between the interest and inflation rates. Consequently, it was possible to develop the generalized equivalence charts shown in Figures VI-2 and VI-3. Two charts are presented, one for $L_1 = 5$ and one for $L_1 = 10$, because the procedure is somewhat sensitive to this parameter. For values of L_1 only slightly different from these values, interpolation or extrapolation from these two charts is reasonably accurate.

EXAMPLE #1

The answer obtained graphically in Figure VI-1 can be derived directly from the equivalence charts. Since $L_1 = 5$, the chart in Figure VI-2 will be used. The entry parameters are the cost ratio $C_2/C_1 = 30/10 = 3.0$ and the difference between the interest and inflation rates of $R - r = 12 - 8 = 4.0$. The point on the chart corresponding to these coordinates falls about 4/5 of the way between the 15 and 20 year required life lines. Therefore, the answer is $L_2 = 19$ years, the same as that obtained graphically in Figure VI-1.

EXAMPLE #2

Suppose the ratio $C_2/C_1 = 30/10 = 3.0$, the difference $R - r = 13 - 10 = 3.0$, and $L_1 = 7$. Since Figures VI-2 and VI-3 are for $L_1 = 5$ and $L_1 = 10$,

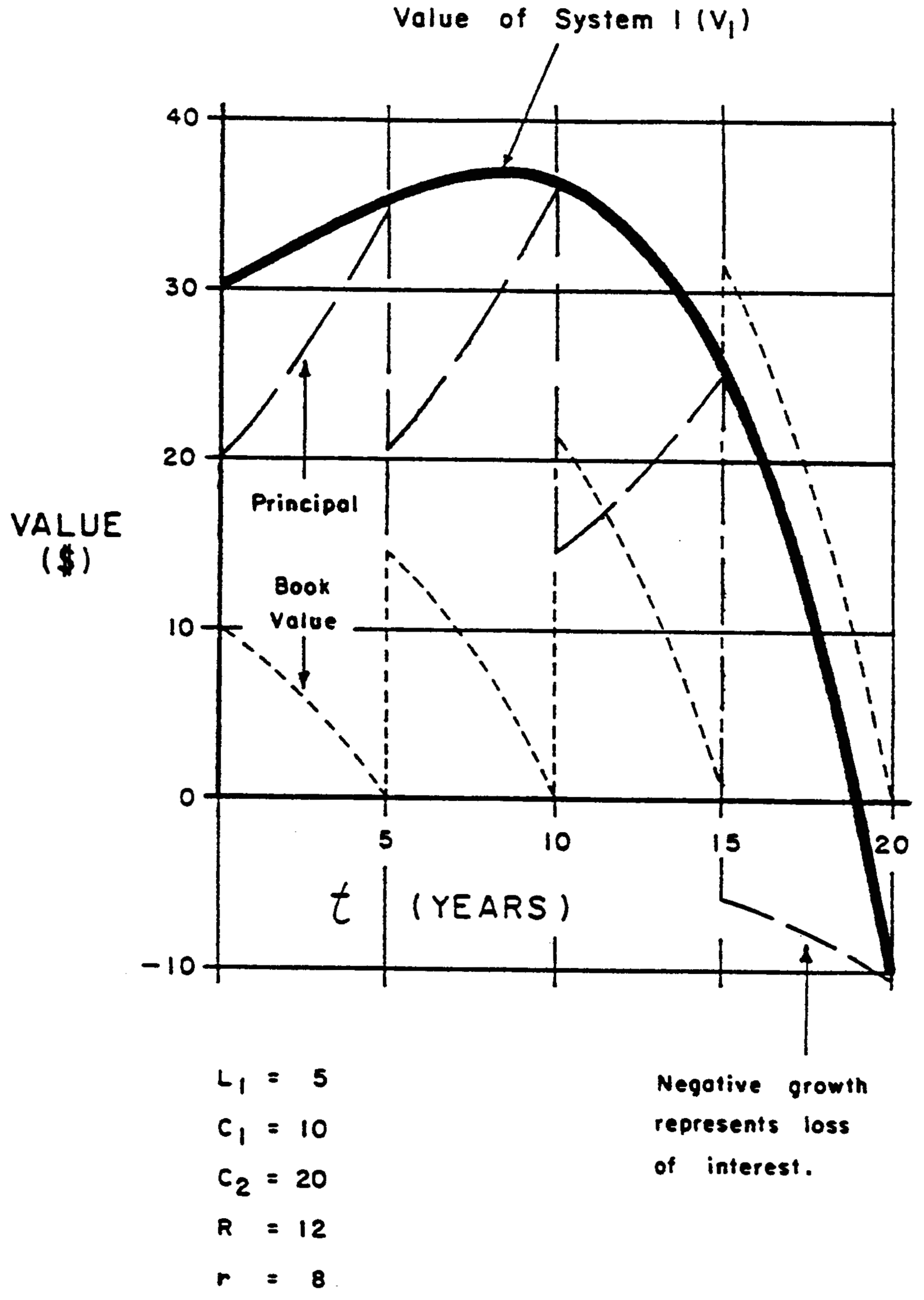


FIGURE VI - 1. - Illustration of method for determining the required life of System 2.

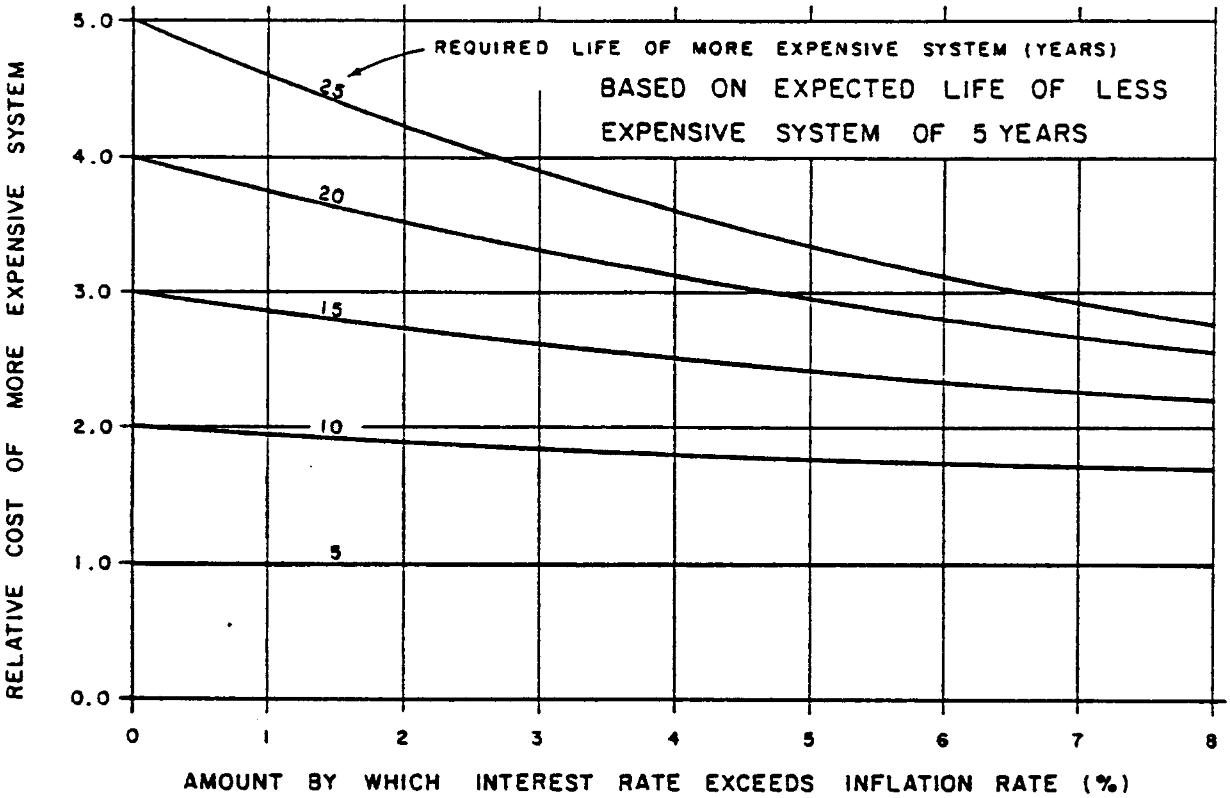


FIGURE VI - 2. Equivalence chart for L_1 = 5 years.

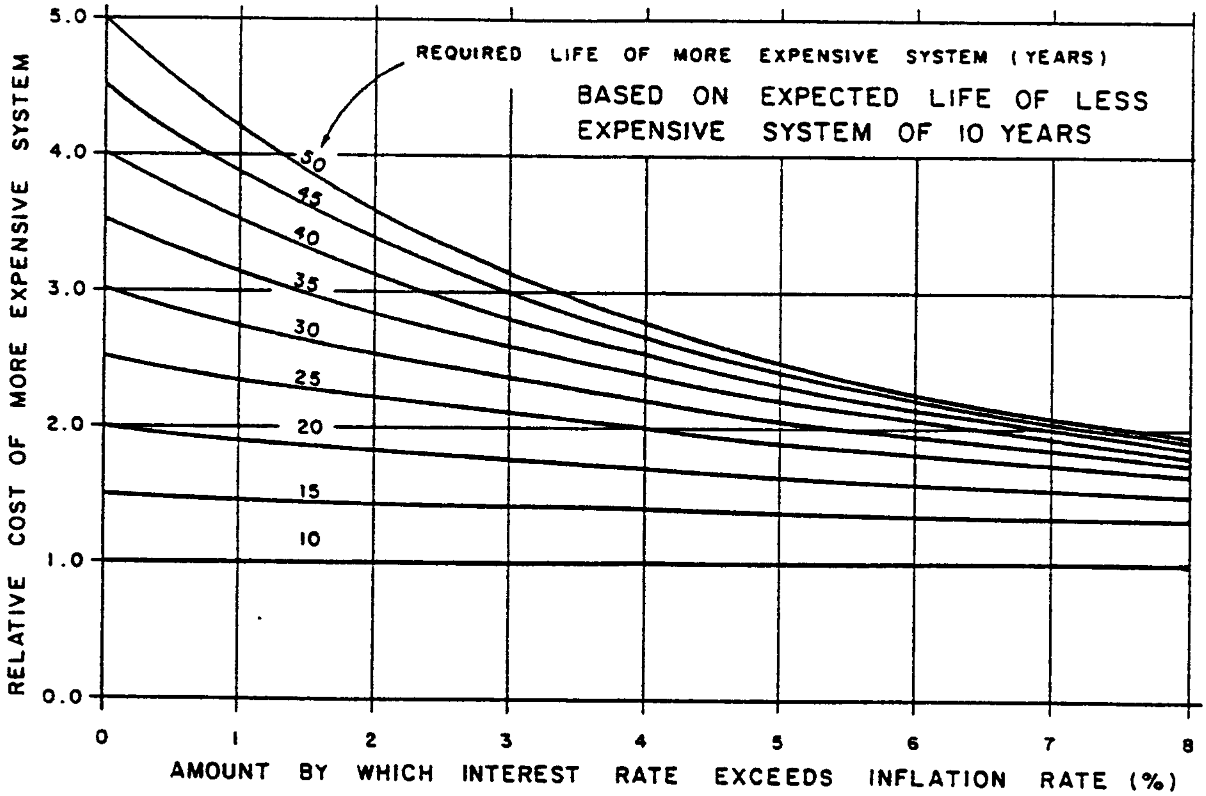


FIGURE VI - 3. Equivalence chart for L_1 = 10 years.

it will be necessary to read a value from each chart and then interpolate between them. The values in the following table were obtained in this manner:

L_1	L_2 FROM EQUIVALENCE CHARTS	L_2 FROM COMPUTATIONAL PROCEDURE
5	18	18
7	29*	27
10	45	45

* BY INTERPOLATION

The values in the third column are provided to check the reliability of this procedure. It can be seen that the charts provide the correct values of L_2 at $L_1 = 5$ and $L_1 = 10$. At $L_1 = 7$, the value of $L_2 = 29$ obtained by interpolation is slightly overestimated but is still accurate enough for most practical purposes.