HOT-MIXED MEMBRANE FOR BRIDGE DECK PROTECTION

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A ½ to ¾-in.-thick (12.7 to 19.1-mm) hot-mixed membrane has been evaluated as a protective interlayer on bridge decks in seven states since 1966. Permeability, bonding, and stability under heavy traffic have been satisfactory and equivalent to other effective membrane systems at all locations. Requirements for mixing and placing with standard paving equipment are described. Compared with other membrane systems, the primary advantages of the hot-mixed membrane appear to be low cost, minimal deck preparation, use of standard paving materials and equipment, and ability to withstand heavy traffic for extended periods before there is a need for a wearing course. For one installation on a truck viaduct in Illinois in 1972, stone chips were pressed into the hot-mixed membrane mat to provide a textured surface in place of a wearing course. The hot-mixed membrane has been approved for use by the Illinois Department of Transportation. It is currently being used for bridge deck protection on a number of Interstate highways.

•THIS report discusses cooperative field projects for evaluating performance of an asphalt membrane mix developed by Johns-Manville Research and Development Center (J-M) in 1965. In 1966, small-scale tests were performed at two locations on the New Jersey Turnpike, and in 1967, further testing was done in four states. These tests used sheets of the mix precalendered to ⅛- and ¼-in. (3.2- and 6.4-mm) thickness. Based on the satisfactory performance of these tests, in 1970 and 1971 field trials were initiated by using standard paving machines to place the hot mix directly on bridge decks. The main purpose was to determine the ability of a thin layer of the hot mix to compact to a continuous impermeable layer when it was reheated by a hot asphalt concrete overlay (wearing course) and rolled.

This report concerns the paver-laid applications of the membrane in New Jersey and Pennsylvania, Illinois, Massachusetts, and New York State where more extensive evaluation of the membrane has been done. Results of the original field trials with the membrane mix placed as preformed sheets are included only to give a 7-year performance history of the basic mix.

MIX FORMULATION

The mix consists of standard paving materials: fine-aggregate blends and 60 to 85 penetration asphalt and asbestos fiber (Tables 1 and 2). Aggregate gradation, based on field service tests in 1965, is designed to give minimum thickness. The combined use of asbestos and high asphalt content is based on pavement technology developed since 1960 (3, 4, 5, 6, 7).

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Design and Control

The various membrane mixes placed cover the entire range of specified gradations, asphalt penetrations, and fiber and asphalt contents to evaluate their performance without use of prior laboratory mix design tests or criteria. No laboratory mix design appears to be necessary.

Quality control tests for the J-M hot-mixed membrane can be performed at the batch plant. Marshall tests have been used at several locations in the United States and Canada for quality control.

Production Methods

Standard asphalt paving pug mills were used to produce the membrane mix. Addition of the cold asbestos in sealed polyethylene bags required hot bin aggregate temperatures of 450 F (232 C) minimum to obtain the final membrane mix temperature of 350 F (177 C). A minimum of 30 sec of dry mixing of the aggregates after the addition of the asbestos is necessary to ensure thorough dispersion of the fiber. Wet mixing should continue until aggregates are thoroughly coated. (See appendix 1 for specified procedures.)[1]

Placeability

Factors evaluated that influence placeability include asphalt grade and content, paver type and speed, mix temperature, mat thickness, and ambient temperature. Two objectives in placeability testing were determination of a continuous mat with little or no skipping and a minimum mat thickness. Tearing in the mat is not critical if width of the check cracks is limited to a maximum of $\frac{1}{16}$ in. (1.6 mm). By design, the high asphalt content of the mix produces self-healing of the mat during subsequent reheating and rolling of the wearing course.

Pavers

One of the factors controlling placeability is the paver. The seven mixes (different aggregates and asphalts) placed by different paver models give a general basis for rating respective ability to place the membrane mix. Barber-Greene pavers used at four locations all placed satisfactory mats. These projects included four different models, 60 to 70 and 85 to 100 penetration asphalts, and mix temperatures from 295 to 350 F (146 to 177 C). Barber-Greene pavers have a reputation for being especially suited to place sheet asphalts similar to gradation of the membrane mix.

Two of the three Blaw Knox pavers gave poor mats, one of which can be attributed to low mix temperature. The third Blaw Knox machine gave a good mat with a mix at 345 F (174 C) but required hand-shoveling to help distribute the mix to the end of the auger. The problem appeared to be incomplete distribution of the mix by the auger in front of the screed. This was in part caused by densification of the mix in the truck at the first two locations.

At one location, the Pioneer paver used showed good placeability but only after the mix temperature was raised to 350 F (177 C).

Maximum paver speed for a good mat varied from 10 to 18 ft/min (3 to 5.4 m/min). At higher speeds, the mat showed a tendency to tear, especially at lower mixing temperatures. Keeping the screed heated at or above the mix temperature appeared necessary with all pavers.

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[1] The complete appendixes are available upon request from M. Leman, Johns-Manville AFD, Box 5108, Denver, Colorado 80217.

It is probable that, at temperatures near 350 F (177 C) and by proper machine adjustments, a variety of other paver types and models may prove satisfactory for placing the hot-mixed membrane at the desired $\frac{1}{2}$ to $\frac{5}{8}$-in. (12.7 to 15.9-mm) thickness. [A nominal thickness of $\frac{5}{8}$ to $\frac{3}{4}$ in (15.9 to 19.1 mm) may be necessary to produce a good mat when the deck profile is rough.] The responsibility rests with the contractor.

Mix Temperature

As is apparent from the above discussion, mix temperature is another critical factor in controlling placeability. All but one of the mixes placed at temperatures in the upper range [330 to 350 F (166 to 177 C)] gave good placeability [the exception being a mix at 355 to 375 F (179 to 191 C) placed by a Blaw Knox paver]. Only the Barber-Greene pavers gave good mats in the lower temperature range [295 to 315 F (146 to 157 C)].

Other Factors

Mixes containing more than 15.5 percent asphalt tended to densify in the truck and inhibited placeability by some pavers. The same effect appeared to be caused in one mix by a fines content above the specified 16 percent passing No. 200 mesh. There was no evidence that the variety of aggregate types had a significant effect on placeability.

PERFORMANCE

Impermeability

Field evaluation included four direct procedures for detecting permeation of deicing salts through the membrane. The following methods had previously proved effective in the evaluation of the precompacted membrane sheets placed in 1967 and 1968:

1. Conductive copper foil tapes permanently installed on the concrete deck under the membrane,
2. Inspection of the cracks on the underside of the deck where water leakage had occurred before the membrane was installed,
3. Water permeability tests on cored sections, and
4. Resistivity tests using the California method.

Calibration tests show that electrical resistance between the parallel, disconnected copper foil tapes was inversely proportional to moisture on the concrete surface. The tapes placed several inches (centimeters) apart were capable of distinguishing between water condensed or trapped under the membrane and deicing salt solutions (Figure 1). Resistance values recorded recently suggest that no significant amount of deicing salts have penetrated through the paver-laid membranes since the fall of 1971 (Table 3). This was confirmed by recent inspection of the underside of the structures in Scranton, Philadelphia, and New Jersey. Where efflorescence at cracks indicated previous leakage, no water or dampness is now visible after heavy rainfall, except under walkways and dividers.

Calibration of conductive tapes without covering with a membrane suggests that salt solution reaching only a short section of the tape will give a low resistance reading by a short-circuit effect.

Location of conductive tape (pairs) and resistance readings taken periodically since 1971 on various bridge decks are given in Table 3. Tape readings taken immediately after paving were low at several locations on the New Jersey Turnpike projects, and this indicated penetration of roller water. Readings taken at weekly or monthly intervals thereafter show continuous increase despite heavy rainfall. Apparently the mem-

Table 1. Hot-mixed membrane composition.

Material	Aggregate (percent)	Range (percent)	Total Weight of Preferred Mix (percent)
Aggregate			
Crushed screenings[a]	40 to 60		
Natural sand[a]	40 to 60		
Asphalt, 60 to 85 penetration		14 to 16	14.5[b]
Fiber, Johns-Manville ASBALTIC of equivalent		5 to 6	5[b]

[a]Porous aggregates such as slags and weathered stone are precluded.
[b]Ratio of minimum fiber to asphalt = 0.35.

Table 2. Aggregate gradation of hot-mixed membrane.

Sieve Size	Aggregate and Filler Range	Percent Passing Preferred Mix
3/8 in.	100	100
No. 4	98 to 100	98
No. 8 (or No. 10)	80 to 95	93
No. 16	60 to 88	70
No. 30	45 to 75	52
No. 50	28 to 55	35
No. 100	16 to 40	20
No. 200	10 to 16	12

Note: 1 in. = 2.5 cm.

Figure 1. Effect of water and salt solution on electrical resistance between parallel copper tapes before membrane cover.

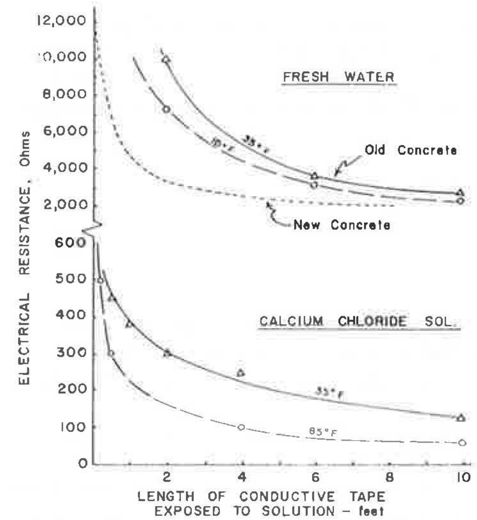

Table 3. Performance evaluation with conductive tapes of U.S. paver-laid membrane.

Location	Authority	Placement Date	Conductive Tapes Under Membrane: Number of Pairs Placed	Electrical Resistance (minimum): Ω	Electrical Resistance (minimum): Date Recorded	Interpretation of Resistance Values
New Jersey Turnpike and bus overpass	New Jersey Turnpike Authority	8/13/71	10	2,000	3/2/72 (connecting wires cut)	No salt penetration
Scranton Expressway, Pennsylvania	Pennsylvania DOT	8/71	3	3,350	3/23/73	No salt penetration
Schuylkill Expressway, Philadelphia	Pennsylvania DOT	10/71	3	2,430	7/25/73 (connecting wires cut)	No salt penetration
Massachusetts Turnpike, Palmer, Massachusetts	Massachusetts Turnpike Authority	8/71	5	5,000	3/10/72	No salt penetration
US-130 and NJ Secondary Route 522	New Jersey DOT	7/12/72	8	3,800	3/29/74	No salt penetration except at curb
US-130 and Pennsylvania Railroad		7/14/72	10	2,075	3/29/74	
Fifth Avenue Bridge over Eisenhower Expressway, Chicago, Illinois	Illinois DOT	6/14/72	1 northbound 1 southbound	1,000 40,000	6/19/74 6/19/74	Trace of salt penetration No salt penetration

brane mat was effectively sealed during rolling of the wearing course, and the entrapped water was gradually absorbed or diffused into the concrete deck.

At locations where the membrane mat was impermeable as placed, the underlying deck was dried by the hot mix and resulted in high resistance readings. As the moisture in the concrete deck normalized and slowly absorbed moisture from the air, resistance decreased but remained at levels that indicate impermeability.

Cores were drilled from the bridge decks on the New Jersey Turnpike and the Schuylkill Expressway for water permeability tests. Results on the turnpike cores (Table 4) show that the membrane was impermeable in each section, including those sections where minimum thickness of the membrane was $^1/_{32}$ in. (0.8 mm). Similar results (normalization of moisture in the deck) were obtained from the expressway cores. On both bridge decks, the wearing course sections were very tight but permeable in all but one core.

The California resistivity test, published after initiation of the hot-mixed membrane field projects, provides a portable method of measuring permeability at any location on the bridge deck. To date, the California procedure has been used to evaluate hot-mixed membrane installations in Ottawa and Chicago.

Tests on the Portage Bridge in Ottawa (Table 5) showed readings ranging from 8 million to 50 million Ω/ft^2 (86 million to 538 million Ω/m^2), well above the 0.5 million Ω/ft^2 (5.3 million Ω/m^2) suggested as the definition of complete impermeability.

Resistivity tests were performed on the Fifth Avenue Bridge (over the Eisenhower Expressway) in Chicago on June 19, 1974. Tests were performed at 5-ft (1.5-m) spacing on 42 areas on the deck: 21 on the outside wheel path of the southbound lane and 21 on the nontrafficked areas of the deck. The readings at each location are given in Table 6. Based on California's criteria for evaluating these measurements, 30 tests were satisfactory [$\geq$500,000 Ω/ft^2 (5 380 000 Ω/m^2)], 7 tests were doubtful [100,000 to 500,000 Ω/ft^2 (1 076 000 to 5 380 000 Ω/m^2)], and 5 were unsatisfactory [$<$100,000 Ω/ft^2 (1 076 000 Ω/m^2)].

Calendered (precompacted) sheets of the same membrane mix installed in 1967 and 1968 show a satisfactory 4 or 5-year performance history. Electrical resistance values measured by using the California method (2) show that the J-M membrane sheets placed on the New Jersey Turnpike in 1967 have remained impermeable. Figure 2 shows crack resistance of the membrane mix under the New York Thruway bridge at Newburgh as of September 1973 (center girder divides the membrane sheet on right from the sealer application on left). Electrical resistance measured by conductive tapes under the membrane sheets in New Jersey and Illinois also demonstrate impermeability. Sheets installed without an overlay in New York, Illinois, New Jersey, Ohio, and Maryland have shown good bonding since 1967. Table 7 gives permeability ratings for conductive tapes under membranes on the Cicero Bridge in Chicago.

Unfortunately, the California calibration criteria do not differentiate between resistance within concrete containing condensed moisture and concrete permeated by deicing salts. Based on calibration of conductive tapes (Figure 1), there should be a different range of values for the two conditions. Future calibration studies may define these ranges. Inspection of the underside of cracked bridge decks should confirm the calibration results.

Stability

The potential effect of membrane thickness on stability under heavy traffic was an important consideration. At several locations excessive thickness of the mat occurred because of poor screed control. For example, at one end of the New Jersey Turnpike ramp, the mat was more than 1 in. (2.5 cm) thick, and in one local area on the Schuylkill Expressway, the mat was more than $1\frac{1}{2}$ in. (3.8 cm) thick. No instability under heavy traffic has occurred at any of these locations with excessive membrane thickness nor in mixes produced with the 85 to 100 penetration asphalt.

The initial assumption that stability would be maintained by the specified fiber concentration has been confirmed to date.

Table 4. Permeability of core sections from bus overpass bridge.

Core Number	Membrane Thickness (in.) Average	Membrane Thickness (in.) Minimum	Permeability[a] (ml/min) Membrane Layer	Permeability[a] (ml/min) Wearing Course[b]
1	3/16	1/16	0	0.07
2	1/8	1/32	0	0.30
3	5/8	3/8	0	0
4	5/8	1/2	0	0.20
5	9/16	7/16	0	0.30
7	13/16	11/16	0	0.20

Note: 1 in. = 2.5 cm. All cores included a layer of portland cement concrete bonded to the membrane. Heating the cores to 160 F (71 C) was required to separate the concrete from the membrane layer.

[a]18-in. (46-cm) head of water.

[b]1½-in. (3.8-cm) nominal thickness of asbestos-asphalt concrete containing 2½ percent ASBALTIC fiber and 7½ percent asphalt.

Table 5. California resistivity test results for hot-mixed membrane on Portage Bridge.

Test	Location: Distance From Hull, Quebec (ft)	Location: Distance From Curb (ft)	Resistivity (1 million Ω/ft²)[a] 1 hour	Resistivity (1 million Ω/ft²)[a] 2 hours
1	5	10	50	50
2	8	5	50	50
3	25	7	50	50
4	33	11	50	20
5	41	6	50	50
6	52	7	50	50
7	67	11	20	12
8	90	5	30	15
9	101	8	15	8
10	115	4	50	50

Note: 1 ft = 0.3 m. 1 Ω/ft² = 10.76 Ω/m². Ground resistance on wetted curb and sidewalks equaled 5,000 Ω. California criteria for impermeability = 0.5 million Ω/ft² (5.4 million Ω/m²).

[a]30-min initial sponge soaking.

Table 6. California resistivity test results for Fifth Avenue Bridge.

Location	Shoulder	Wheel Path	Location	Shoulder	Wheel Path
0	—[a]	500,000	55	—[a]	—[a]
5	—[a]	200,000	60	—[a]	300,000
10	500,000	120,000	65	—[a]	300,000
15	700,000	70,000	70	—[a]	300,000
20	500,000	85,000	75	—[a]	—[a]
25	—[a]	60,000	80	—[a]	—[a]
30	—[a]	120,000	85	500,000	—[a]
35	—[a]	120,000	90	—[a]	—[a]
40	—[a]	70,000	95	500,000	500,000
45	—[a]	60,000	100	600,000	—[a]
50	600,000	600,000			

Note: All values are in ohms/ft² (1 Ω/ft² = 10.76 Ω/m²).

[a]Infinity.

Figure 2. Preformed membrane sheets.

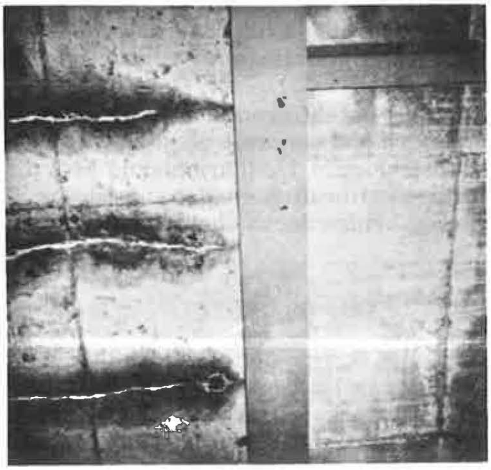

Table 7. Permeability measurements evaluated by conductive tapes under membrane.

Date Placed	Electrical Resistance (Ω) 1-in. Spacing	Electrical Resistance (Ω) 4-in. Spacing
November 1968	4,800	10,000
March 1969	3,000	6,500
June 1969	2,400	4,600
September 1969	1,500	3,800
December 1969	5,200	7,500
April 1970	3,200	3,800
June 1970	6,300	8,100
October 1970	2,200	2,900
April 1971	2,000	1,600
November 1971	4,000	5,000
February 1972	4,500	7,000
June 1974	3,000	4,000

Note: Each tape was rated as impermeable. Wetting of concrete between parallel tapes, 10 ft (3 m) long, installed with 4-in. (10-cm) spacings without a membrane cover, showed resistance readings of 3,200 Ω with fresh water and 40 Ω with a 3 percent solution of NaCl.

The membrane mix was used to resurface a ½-mile-long (805-m) truck viaduct in Decatur, Illinois, in 1972. Because of the structural design of the bridge built in 1926, it was necessary to maintain the overlay thickness at <1 in. (2.5 cm). In place of a wearing course, ⅜-in. (9.5-mm) traprock chips (100 percent retained No. 10 mesh) precoated with 1 percent MC-70 were rolled into the surface of the mat to provide surface texture.

To facilitate complete compaction, a pneumatic roller was used in the final rolling.

Current performance evaluation shows no instability of the membrane mix directly under truck traffic. Inspection of the underside of the deck shows complete impermeability of the membrane overlay. Some chip loss has been noted, but tests by Illinois DOT show that skid resistance provided is sufficient for this situation.

Bonding and Crack Resistance

Bond strength of the membrane mix to the concrete deck appears to be very good. This is confirmed by the 7-year performance of preformed (calendered) sheets of the same mix that were placed both as interlayers and as wearing surfaces in five states.

Electrical resistance values and visual observations at all membrane locations to date demonstrate excellent bonding of the membrane mixes to concrete decks and to the overlying surface courses. This includes locations where very light tack coats were used. Recurring blisters formed in one membrane overlay where a heavy tack coat was used under the membrane mix. The tack coat should be no more than 0.1 gal/yd^2 (4.3 liters/m^2).

At several locations traffic removed all visible tack coat from the deck before the membrane mix was laid. Therefore, the need for any tack coat is questionable.

Blisters often form in the membrane during initial rolling when roller water is entrapped before compaction is completed. These blisters are to be expected and confirm impermeability of the mat. They disappear once the mat cools to ambient temperatures.

Crack resistance of the membrane mix was demonstrated by inspection of open cracks on the underside of the deck. At all locations inspected in March after heavy rainfall, these cracks were dry. Future crack resistance of the membrane will be evaluated at these locations.

On the Schuylkill Expressway, expansion joints were covered by the membrane and asphalt concrete, and expansion joints were to be installed in the future. In March, cracks were visible in the wearing surface over the expansion joints. The absence of water seepage under the deck at these joints suggests that the membrane interlayer has not cracked to date.

Edge Effects

Potential problems in compaction and bonding adjacent to curbs and appurtenances, typical of many asphalt overlays, were evaluated by placing conductive tapes close to and parallel with the curbs under three of the bridge membranes. Electrical resistance values recorded during and after paving made it possible to check effective compaction as shown by water permeability.

Two of the three tape sets closest [6 or 7 in. (15 or 18 cm)] to the curbs of three bridges in New Jersey showed presence of deicing salts. The remaining eight sets showed no penetration of deicing salts vertically or laterally from the edge based on the tape calibration (Figure 1). This demonstrates the need for special attention to edge protection procedures.

CONCLUSIONS AND RECOMMENDATIONS

1. Performance data to date indicate the hot-mixed membrane provides an excellent impermeable barrier for bridge deck protection.

2. Satisfactory placeability requires a paver capable of placing sheet asphalts at temperatures from 325 to 375 F (163 to 191 C).

3. The membrane mat appears to be self-sealing when covered with the hot-mixed wearing course and rolled. Areas poorly compacted (hand work at curbs) and small cracks (tearing) densify and knit together to form a continuous, watertight interlayer.

4. Bond strength and crack resistance are good at all locations, and no instability has occurred to date. The application in Illinois of the membrane without an overlay allows visual observations of the crack resistance and stability of the hot-mixed membrane.

5. In-place cost of the ½ to ⅝-in.-thick (12.7 to 15.9-mm) membrane mix is estimated to be approximately equal to a standard 1½-in.-thick (38-mm) binder course. The ability of the membrane mat to sustain traffic should minimize traffic control problems and cost.

The membrane hot mix placed by a paver can be placed at ambient temperature as low as is permitted by standard asphalt pavement. The membrane was used on the Schuylkill Expressway in October and on the New York Thruway in November because low ambient temperatures precluded use of other membrane systems that had originally been specified. On the thruway when the ambient temperature was 42 F (5.6 C) the hot-mixed membrane was placed on a 1½-in. (38-mm) wet deck without difficulty.

Another advantage is the ability of the mat to sustain traffic before it is covered with the wearing course. On the Schuylkill Expressway, each membrane section placed at night sustained heavy traffic from 12 to 36 hours before it was covered with asphalt concrete. The traffic had no visible effect on the membrane mat.

Similarly, the thickness of the membrane reduces the possibility of puncturing the membrane by the wearing course or a rough deck surface. The only deck preparation necessary in most cases is replacing structurally unsound sections of the deck.

The following changes are based on the total experience in the hot-mixed membrane projects and should be considered in future contract specifications:

1. The use of 85 to 100 penetration asphalt (at locations where 60 to 85 penetration asphalts are not available) has proved satisfactory. The lower cohesion of mixes made with 85 to 100 penetration asphalt may facilitate placeability.

2. Nominal thickness of the membrane mat should be ⅝ to ¾ in. (15.9 to 19.1 mm) to accommodate bridge decks with rough profiles.

3. The membrane mat should be well sanded (coarse sand) before it is rolled to guard against dry spots on rollers that will stick to and pull up the thin mat.

4. Special sealing procedures should be used along gutters, curbs, and dividers to inhibit lateral migration of deicing salts under the membrane mat through the porous surface of the concrete deck. A paint coating of asphalt emulsion or hot-poured sealer is advisable at these locations.

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DISCUSSION

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This is an excellent paper on the research and development work on the hot-mixed membrane concept that we think is ready to be implemented. We would like to add our recent experience in implementing this research on five bridge rehabilitation projects.

As noted in the paper, the New York State Thruway Authority had participated in the initial development work on the hot-mixed membrane research by Kietzman at Johns-Manville. During the time this paper was being prepared (September 1973 to October 1974) the New York State Thruway Authority implemented this research on two major structures totaling approximately 22 lane miles (35.4 km) or 166,950 yd^2 (139 570 m^2) of deck surface. An additional 1,350 yd^2 (1130 m^2) was placed in 1974 at a contractor's request (substituted for a conventional membrane) to speed up a smaller project. In addition, 18,340 yd^2 (15 222 m^2) will be constructed in 1975, and an experimental bridge rehabilitation project with 6,140 yd^2 (5133 m^2) will be produced based on a modification of our specification.

Although the history of the cost per square yard for this material has been quite favorable on our larger installations [$1.43 to $4.98/yd^2 ($1.86 to $6.47/m^2)], cost was not a major factor in the decision to use this material. About 70 percent of the volume has been placed at night, and the requirements were that all lanes be open to traffic in the morning. Scheduling and traffic control constraints necessary to maintain income during the rehabilitation work, especially important during the traffic volume declines resulting from the energy crisis, posed such severe materials problems in selecting a membrane system that the most satisfactory course of action was to implement the J-M research rather than to be limited by conventional membrane systems. The biggest roadblock in this process was a deficient technology for the material because it was still in the formulation stage and was not a controlled production item for large-scale projects.

Our main experience to date has been where dead load and curb height have limited the wearing course above the membrane to a nominal 1-in. (2.5-cm) thickness. When only a 1-in. (2.5-cm) submersion was used, it was assumed that the membrane layer was acting structurally as part of the wearing surface, and, therefore, a mix design method was required to formulate a proper mixture. Because of the unusual mastic properties of the mix, a modified Marshall design method was used where the stability is determined at a flow value of 30 units (it normally will not reach a maximum stability). The mixture's stability is sensitive to filler content and sand particle shape. In all cases, where we have formulated the mixture for a minimum Marshall stability of 800 lbf (3560 N) at flow = 30 units, the mixture has required application temperatures from 375 to 425 F (190 to 220 C) to achieve a good quality mat. The mixture has been judged difficult to pave because of its cohesiveness, which gives it a high propensity for tearing. However, in one pass, a ⅜-in.-thick (9.5-mm) and up to 37-ft-wide (11.3-m) membrane has been successfully placed in ambient temperatures down to 35 F (2 C) by our contractors.

High mixing and handling temperatures will have an aging or hardening effect on the asphalt cement. However, by being impervious and protected by a dense asbestos modified wearing course, further aging, oxidation, and hardening are minimized throughout the life of the membrane/pavement system. Therefore, we are not overly concerned with this aspect.

Our results to date indicate that a membrane of acceptable quality (resistance by the California method exceeds 500,000 Ω) has been produced. Mixtures meeting our modified Marshall design method criteria have apparently been sufficiently stable (no noticeable deformation) to withstand traffic loadings unprotected during construction and in service with a 1-in. (2.5-cm) wearing course. In addition to the favorable in-place costs, other benefits include speed of application, less rigorous surface preparation required with this system, and ability of the membrane to withstand traffic during construction. These advantages have substantially reduced contractor occupancy time, traffic control costs, and user cost.

The mix temperature range of 375 to 425 F (190 to 220 C) has caused serious manufacturing engineering problems. During the production of 3500 tons (3 175 000 kg) of the mix for two thruway projects, County Asphalt, Inc. found that automatic temperature sensors and controls in their plant were not designed for the 550 F (288 C) fine-aggregate temperature required to bring the cold filler, cold asbestos, and 350 F (177 C) asphalt cement up to a 400 F (205 C) final mix. Therefore, the plant temperature control had to be controlled manually. Lubrication problems developed in the screens and hot elevators. Until the switch was made to synthetic high-temperature grease, the plant had to be greased twice during each shift (even on that schedule, two sets of screen bearings and one set of hot-elevator bearings were lost). Cooling the dryer down slowly to prevent warping or cracking is strongly suggested. Despite the care taken by County Asphalt, Inc., its dryer did crack at the tire. It should also be noted that, for safety reasons, fuel oil cannot be used as a release agent in the haul trucks. A polymer release agent was used that proved to be satisfactory.

Handling the asbestos fiber has presented no safety problems in projects to date. However, in a project to be completed in the coming year, we encountered resistance from one large asphalt concrete producer to bid on a project in their immediate area because the legal department of their parent organization interpreted that even when the sealed-bag handling method was used (a sealed plastic bag that, when added to the pug mill, melts, releasing the asbestos), the full Occupational Safety and Health Administration asbestos standards would apply. Johns-Manville and most other producers think the full standard does not apply to the sealed bags. This safety aspect is obviously open to interpretation. Because of this problem, future research should explore the use of alternate mix modifiers such as reclaimed rubber or no modifier when the surface course is of sufficient thickness to materially reduce the stresses on the membrane.

Our implementation of the hot-mixed membrane has led us to slightly different conclusions than those presented by the authors. This is because our main experience to date has focused on design, which limited the wearing course above the membrane to a nominal 1 in. (2.5 cm), and because we took an engineering approach rather than a research approach to the material. However, we feel our work can be applied to the more general use and should be taken into account in future applications. We find we differ with the authors on four main points:

1. Our results indicate that the hot-mixed membrane should be laboratory designed to conform to the requirements of the installation. Many trial mixes produced in the laboratory, which conform on paper to the J-M guide specifications, have been deficient in void content and stability or both. If one of these deficient mixes were placed on a deck and were subjected to 30,000 vehicles the next day, the contractor, agency, and public would not benefit.
2. Although this material could be produced in most conventional asphalt concrete

plants, it is definitely a special handling material and cannot be sandwiched into normal plant production at a convenient moment of the day. For applications for which the mixture design dictates high handling temperatures, special techniques must be used in the manufacture of the material.

3. Most late model paving machines are of the same basic design; therefore, there appears to be no reason to prefer one manufacturer over the others. The membrane is very difficult to pave because of its cohesive nature. It is important that the paver be in perfect adjustment (which will preclude the use of worn, outdated equipment) and that it be operated by an experienced paving crew in strict accordance with recognized good paving practices.

4. We have experienced no pickup problems where water was used as a release agent on the steel wheel roller and question the insistence on the use of a sand broadcast during compaction. However, if traffic is to be put on the membrane during construction, sand must be used to deslick the membrane surface.

AUTHORS' CLOSURE

The work by the New York Thruway Authority engineers is certainly noteworthy. Although their design procedures might be desirable for their special situation, we think that, for normal membrane use, their procedures would unnecessarily complicate production and placement of the hot-mixed membrane.

In 1971, a hot-mixed membrane that did comply with the J-M specifications was placed on the thruway. It was placed at a temperature of 350 F (177 C) and showed good placeability at ½-in. (12.7-mm) mat thickness. The thruway engineers' subsequent design of a membrane mix for the Tappan Zee Bridge in 1972 was based on the premise that Marshall stability would be a prerequisite for satisfactory performance when a 1-in.-thick (2.5-cm) overlying wearing course was used. Their final Marshall design mix with 100 percent angular aggregate (stone screenings) and 50 to 60 penetration asphalt was a predictable result of the original premise. The initial problems in placing this mix with a Blaw Knox paver and the necessity of raising mix temperature as high as 425 F (220 C) are not surprising, based on our initial experience in Massachusetts and New Jersey.

In 1961, the American Oil Company demonstrated the ability of short asbestos fibers to prevent rutting of asphalt pavements at high asphalt contents (50 percent above normal) (3). Field tests confirmed this independence of high asphalt content. The initial asbestos-asphalt membrane evaluation involved placing preformed sheets of the membrane (same formula as used subsequently in hot-mixed applications) on concrete decks without an overlay to observe bonding and wear resistance under direct heavy traffic. Since 1966 and 1967 when these sheets were placed (at six locations in six states), no evidence of instability has been observed.

Since 1969, no instability has been reported in the hot-mixed membrane interlayer placed at more than 20 locations; this interlayer was made of local mat thickness exceeding 1 in. (2.5 cm) and 85 to 100 penetration asphalt in many places. If and when the future performance of the J-M membrane shows signs of instability, laboratory mix design tests may be justified. Currently, we prefer to avoid the problems encountered by the New York Thruway Authority and the special requirements by which it has achieved a workable system.

As pointed out to us by contractors in Massachusetts and New Jersey, some paving machines have been designed specifically for rapid placement of granular asphalt concrete, and some of these pavers are not capable of spreading thin layers of fine-aggregate mixes in front of the screed. If true, this should be considered by each contractor in placing the membrane mix. By keeping the mix formula open for on-the-job changes (within the specified ranges), placement of membrane mixes since 1970 has, at most locations, proved to be satisfactory at reasonable mix temperature. This includes mixes placed with Blaw Knox pavers (e.g., on the Scranton Expressway).