Development of a Bridge Deck Protective System

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The continuing rise in the incidence of concrete bridge deck deterioration and the increasing cost, and patron inconvenience, of making repairs have caused many owning agencies to look for some effective means for protecting bridge decks.

Over the past five years a consulting engineering firm working with several major toll roads has sought to determine the nature and extent of the problem, evaluate numerous protective systems, survey the literature with an eye toward combining new products to offset potential difficulties in the system utilized, and maintain records of the cost of repairing the decks compared with the cost of constructing a protective system.

It was found that cracks in the concrete leading to spalls and eventually to failure were rampant and increasing despite constant, costly repair. One major toll road spent $6 million without arresting the cause of deterioration.

Waterproofing is the key to prevention and coal-tar epoxy resin is the most suitable protective membrane because of its history of satisfactory service, its strength and flexibility, ease of application and cost. But a wearing course is still essential, because no membrane is sufficiently wear-resistant.

The best wearing course is a dense asphaltic concrete (for impermeability) fortified with asbestos (for stability) and modified with latex (for flexibility). Such a wearing course doubles the cost of the system but increases its service life at least fivefold.

The total cost of a protective system is less than half the total cost of repair. Other factors such as design procedures, methods of construction, and skid resistance, are unimpaired.

•IT IS no secret to anyone responsible for maintenance of structures that surface deterioration on concrete bridge decks has become an enormous problem. The extent and similarities of the problem have received extensive attention (1, 2).

The engineering industry has made available, through papers and periodicals, its experience with making repairs, whether conventional (3), using epoxies (4), or other imaginative programs (5). This writer has also reported on bridge deck repair techniques (6).

But surely repair is only half the answer. In the first place, a hole in a bridge deck, whether a surface spall or a complete failure, is at least uncomfortable, if not actually dangerous, on a high-speed roadway. Second, there is the inconvenience of closing lanes to traffic to make the repairs and closing them on toll roads for patrons who have paid for a safe, swift ride. Finally, there is the cost. Between 1958 and 1965 six million dollars was spent on a major toll road solely for the patching and repair of concrete bridge decks.

All such repairs are really an expediency, treating the symptom rather than the disease. The world's best patch is, after all, only a palliative and not a vaccination.

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There is always the likelihood of recurrence, with the added uncertainty about when or where it will happen. Experience in the Northeast has shown that all decks may crack, most of them do, and some of them must. With cracks come spalls, and with spalls come deck failures. So it is manifest that some way must be found either to prevent cracks or to negate their destructive effect. Yet the prevention of cracks surely belongs in the original design and construction, and is not properly a part of maintenance. Therefore, a search was conducted for a superior protective system.

FUNDAMENTAL CONCEPTS

The ideal bridge deck protective system must at least be waterproof, because water is both mechanically and chemically destructive to concrete. It is mechanically destructive because of its power to erode and because of its peculiar property of forming ice crystals which have a greater volume than the liquid. It is chemically destructive because it is rarely pure in an industrial environment and often carries high concentrations of ionic salts used for deicing. Numerous surveys, reports and papers have verified this beyond debate.

An ideal deck protective system should also be wear resistant. It should be capable of resisting abrasion both from traffic and from such punishments as tire chains and snowplow blades (7). Of course, to be effective, the protective system should be better able to resist the same forces that attack the concrete.

In addition, an effective system should be thin to avoid disturbing the design drainage patterns, to prevent the addition of excessive weight to the structure, and to avoid the high attendant costs in reconstructing joints, curbs, and other features which depend on the pavement elevations. It should also be inexpensive and easy to apply outdoors, and it should last for a long time to avoid continued lane closings for repairs every spring.

Unfortunately, such a product does not exist. There are many materials which can be applied relatively easily in a plastic state and which harden into a thin waterproof membrane. But when dealing in the range of mil thickness, a concrete bridge deck is not a mirror-smooth surface. Any material applied in a liquid state is thinner on hills and thicker in the valleys. Also, most liquid-applied products tend to have a slick surface, so aggregates must be cast into the membrane to provide suitable skid resistance. Any hard, sharp material penetrating through a membrane has the capacity to weaken the membrane. For these reasons, we know of no thin waterproof membrane which can stand up to, for instance, 30,000 axle applications per day for more than two years and still be considered waterproof.

One way around this would be to build up consecutive layers of a polymer material to increase its thickness (8, p. 23). This has been tried but, inevitably, the cost becomes prohibitive.

Thus, the best answer seems to be a thin polymerized type membrane with a suitable wearing course. Even the most carefully controlled and expensive asphaltic wearing courses, put down at a generous thickness and considering all attendant expenses of raised construction joints and inlets, still cost about the same as the membrane itself. But by doubling the cost to provide this wearing course, we increased the life of the system five to tenfold.

Therefore, the following three-step protective system was used: (a) apply a waterproof membrane to the deck, (b) raise the end dams and joints and drainage inlets, (c) place an asphaltic-concrete wearing surface.

INTERLAYER MEMBRANE

There are, no doubt, many products that will serve the purpose of a waterproof membrane (8, pp. 20-26). We have tried four and finally settled on a coal-tar epoxy resin formulation for many reasons. Coal-tar has been used for hundreds of years as a waterproofing material on ships and marine facilities and has proved to be an effective barrier. The epoxy resin gives the added bonus of strength to help bridge the fine cracks and pinholes in the concrete surface. The product was one of the first to be widely test-marketed across the country with satisfactory results (7). Application and distribution equipment has been developed and is competitively available and relatively

Figure 1. Combination mixer and sprayer of epoxy membrane.

Figure 2. Distributor truck conveyor system.

TABLE 1

COST OF COAL-TAR EPOXY RESIN MEMBRANE AND ASPHALTIC CONCRETE

Month	Year	Structure	Unit Price ($)	
			Coal-Tar Epoxy (sq yd)	Asphaltic Concrete[a] (sq yd)
Sept.	1963	Passaic River Bridge	2.00	1.25
Sept.	1963	Oak Island Viaduct	2.00	1.25
April	1964	Blacks Creek Bridge	3.00	0.95
May	1964	Belleville Turnpike	3.00	1.85
May	1964	Hackensack River Bridge	2.40	1.85
Sept.	1964	Southeast Viaduct	2.54	1.75
Oct.	1964	Cranbury Brook Bridge	3.00	1.72
Oct.	1964	Rocky Brook Bridge	3.00	1.90
May	1965	Crafts Creek Bridge	6.00	1.72
Sept.	1965	Newark Bay Bridge	2.90	1.67
Aug.	1966	Rancocas Creek Bridge	3.50	1.98

[a]1½ in. thick.

simple to operate. The cost is at least competitive, and in many cases cheaper, than similar types of membrane materials.

As for methods of construction, the deck surface must first be carefully cleaned, as for any thin-bonded membrane. Acid cleaning is satisfactory but sandblasting is better. The application is made by a combination mixer and sprayer which works much like an ordinary asphalt distributor (Fig. 1). The material is usually put down at the rate of about 2 to 3 lb/sq yd. Then comes the one "touchy" operation, sand application. In planning the work, it should be kept in mind that a coal-tar epoxy resin membrane is really a three component system: the A and B components of the coal-tar epoxy and sand. The sand must, of course, be applied before the epoxy is cured, and this can create a serious access problem when only one lane can be closed to traffic. Fortunately, equipment is now available which spreads the sand simultaneously with the epoxy by means of a conveyor system mounted on the distributor truck (Fig. 2).

The rate of sand application and the selection of sand particle size have also proved more critical than was at first realized. The sand particles should be rounded rather than flat to avoid an interface of particles that might cause capillary action or the drawing up of the epoxy from the concrete surface (9). All the sand should be of a size between a 20 and 40 mesh sieve to provide sufficient voids between particles for the epoxy to be contiguous.

The cost of this membrane ranged from $2.25 to $4.50, with an average price of about $3.00 per sq yd being typical (Table 1). There are three things to watch for in a coal-tar epoxy application: adhesion, pinholing, and blistering. Adhesion is almost always a matter of careful deck cleaning. Pinholing and blistering can be largely controlled by proper sand application.

WEARING COURSE

Inasmuch as some imperfections are bound to occur, it is sensible to design the asphalt wearing course with a thought toward correcting any deficiencies that might exist in the membrane. Ideally, the design of such a wearing course would be dense enough to hold in place the isolated unbonded areas of sealcoat, rich enough to avoid the formation of continuous capillaries which could lead to pinhole imperfections in the sealant, and thick enough to protect the sealing membrane from abrasion and wear.

The addition of asbestos fibers to a well-designed dense mix greatly improves the foregoing characteristics (10). This is brought about by the ability of the asbestos to absorb some of the fatty globules in the asphalt and thereby allow a higher asphalt content without creating surface flushing common to rich mixtures. Furthermore, the fibrous nature of the asbestos tends to bridge the interstices within the matrix of the mix and thus inhibit the formation of continuous capillaries.

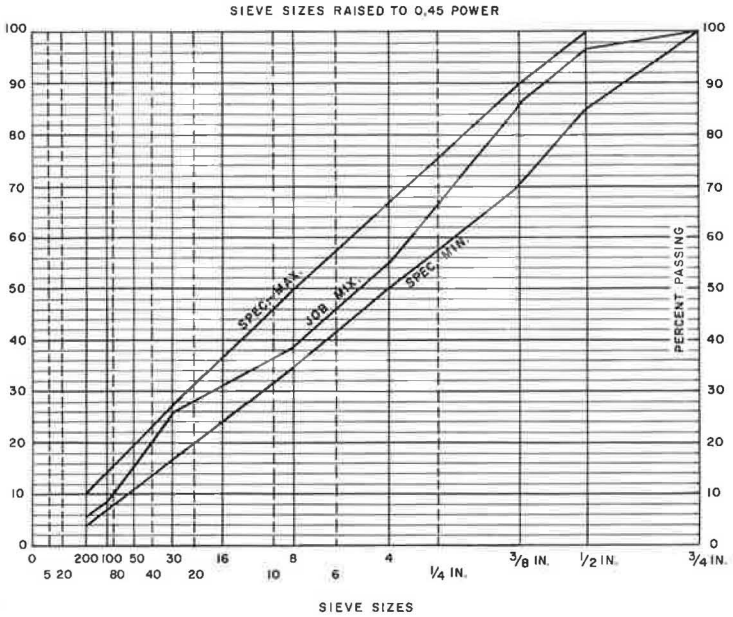

Figure 3. Aggregate gradation chart.

The determination of the most suitable thickness for the wearing course is somewhat arbitrary. We have found it impractical, however, to specify thicknesses of any less than ¾ in. Lesser thicknesses are difficult to bond; reduce the maximum size of aggregate that can be used, thereby reducing stability; and increase the likelihood of damage and wear that would expose the seal coat. However, thicknesses in excess of 1½ in. become uneconomical and present dead-load problems on many structures.

Two things are necessary to insure a dense pavement: well-graded aggregate through all the sieve sizes, and a high asphalt content. A handy way to check for density of the aggregate mix is to plot the aggregate gradation on a chart showing sieve sizes raised to the 0.45 power (11). The curve which falls closest to a straight line is usually the densest mix (Fig. 3). With 2½ percent of asbestos added to the mix, it is possible to increase asphalt content to 8 percent without serious flushing. This combination of densely graded aggregate and 8 percent asphalt content has produced pavements which are virtually impermeable when measured by the California permeability test (12). As an added bonus, asbestos also has the ability to increase the stability of a mix far beyond the normal expectation for such high asphalt contents. Although the reasons for this are beyond the scope of this paper, Spear and Keitzman (13) showed that the addition of 2½ percent asbestos can cause a 90 percent reduction in rutting depth over that which would occur in a similar mix without asbestos.

Because of the density of the mix and the absolute necessity to prevent cracking in the overlay, we are also specifying an asphalt modified with rubberized materials. A continuing research program by the British Road Research Laboratory has shown that the addition of rubber considerably reduces the number and severity of cracks in a surfacing material and substantially increases the life of the asphalt when added to a bitumen macadam (14). Research in this country has shown that toughness, tenacity, and ductility are all improved by the addition of neoprene latex to the asphalt cement (17). And recent studies have shown that latex improves asphalt adhesion to aggregate, a property which tends to increase flexibility and decrease brittleness (16). These considerations are important because of the constant repetitive deflections in bridge decks and the density of the surface material. Both conditions may contribute to fatigue of the bituminous concrete mixture and allow the possibility of reflective cracking from

Figure 4. Neoprene-modified, asbestos-additive pavement construction.

Figure 5. Rolling operation.

the deck below. So we have added two varieties of latex to the asphalt-cement to insure retaining the more desirable properties.

In this regard, the relative long-term merits of reclaimed rubber compared with neoprene latex cannot yet be evaluated from our experience. We have used the neoprene for five years and have begun using the reclaimed rubber only this spring.

However, the reclaimed rubber is much cheaper, amounting to only one-third the cost; it is easier to handle as it can be dumped dry directly to the pug mill, whereas neoprene must be specially blended with the asphalt-cement; and it is more uniformly workable because the neoprene with such high asphalt contents sometimes shows a tendency to wave under compaction. Also, the neoprene is currently under limited production.

The methods of construction for the neoprene-modified, asbestos-additive pavement are the same as those used for any asphalt overlay (Fig. 4) with the exception that the mix is somewhat sensitive to rolling temperature. If the mixture is rolled when too hot, a mud wave may develop in front of the roller (Fig. 5). Also, hand-raking should be avoided because this disrupts the careful blending to achieve maximum density. Such an asphalt mix is, of course, expensive. Latex additives add from $0.50 to about $2.50 to the cost of a ton of asphaltic concrete, depending on the type and quantity involved, and the asbestos adds another $1.50. So such a mixture adds about $4.00 per ton to the cost of a conventional asphalt surface course mix. But bridge deck surfacing is usually extremely expensive anyway because of the low production rate that can be realized per day on a short span bridge. On one major turnpike, working under severely restricted conditions, the cost for the total job generally runs to about $20.00 per ton, or about $1.62 per sq yd, which, as noted previously, is about half the cost of the membrane we are trying to protect (see Table 1).

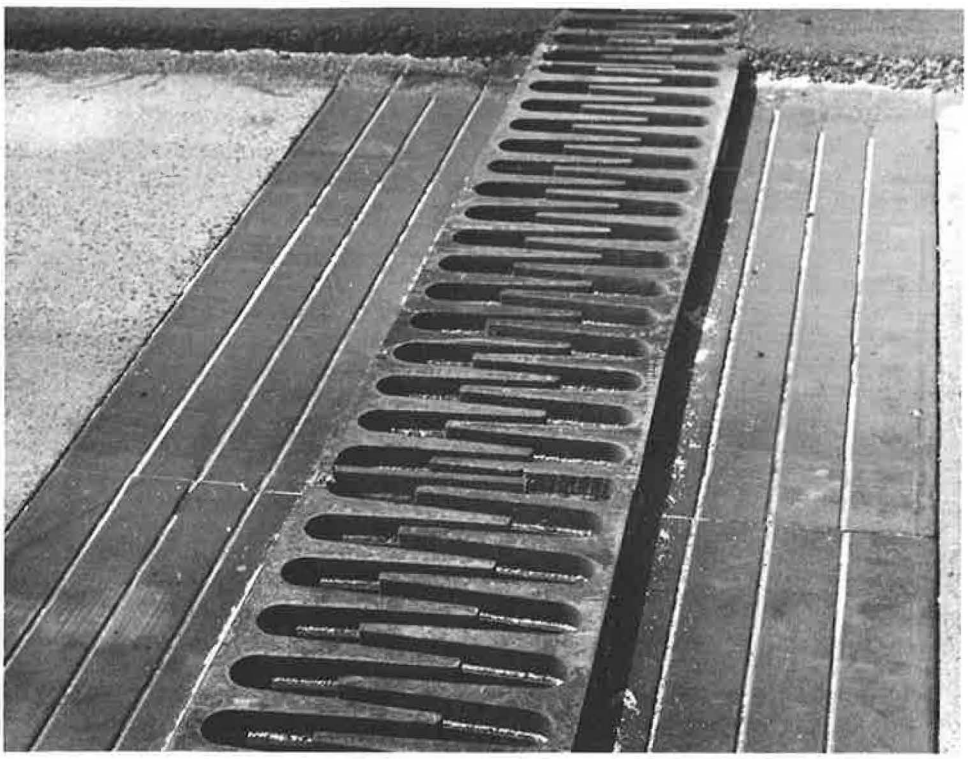

Figure 6. Large finger dam built up 1¼ in.

Figure 7. Welding of bar stock to top of old dam.

EXPANSION JOINTS

There is nothing special about the raising of the end dams and inlets. For the most part, with finger dams a 1½-in. thick steel plate conforming to the configuration of the existing dam is cut out and welded directly to the old dam (Fig. 6). On straight bulb-angled type dams, 1½-in. bar stock is usually welded to the top of the old dam (Fig. 7). Lately, we have also experimented with 1-ft wide epoxy resin dams and with some success. However, I think the steel dams will prove far more durable.

On a few bridges we have experimented with sawn joints only at contraction joints. These were then filled with a hot-poured neoprene-modified joint filler. In at least one instance, nothing at all was placed in the joint. To date, there is no evidence of any failure in the joint edge (Figs. 8 and 9).

SUMMARY

Our procedure is the following.

1. Patch and clean the deck and put down a coal-tar epoxy resin membrane for waterproofing.
2. Raise the expansion dams and inlet covers by 1½ in. to contain the overlay.
3. Place a 1½-in. thick mat of neoprene-modified asphalt-concrete with asbestos added to protect the membrane (Fig. 10).

The results have been most heartening. So far, over the past three years this treatment was used on 3 large bridges, 2 very large viaducts, and about 30 smaller overpasses. The total cost of the protective treatment has so far run to $3,000,000. On each bridge the treatment cost was about equal to the cost of the previous year's

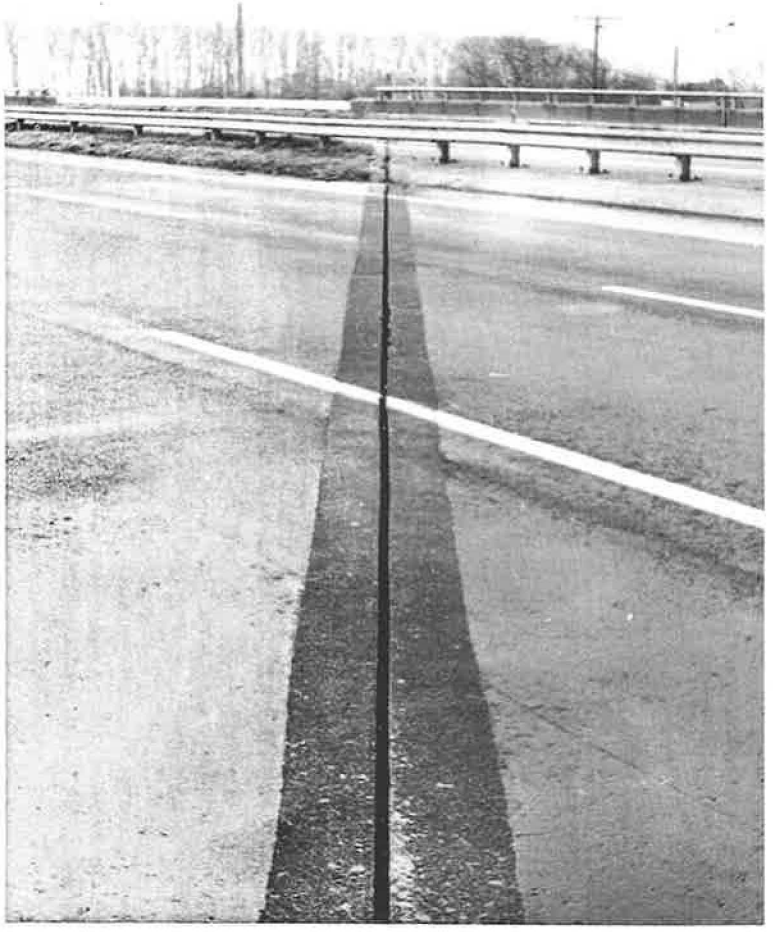

Figure 8.

Figure 9.

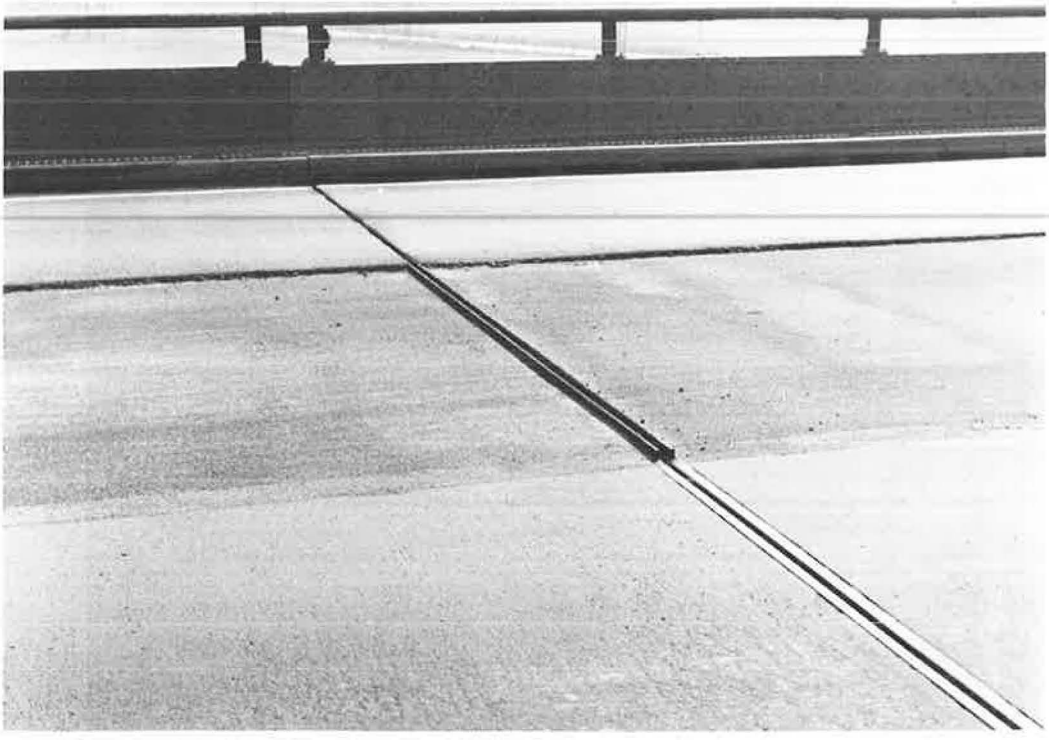

Figure 10. Mat of neoprene-modified asphalt-concrete with asbestos added to protect membrane.

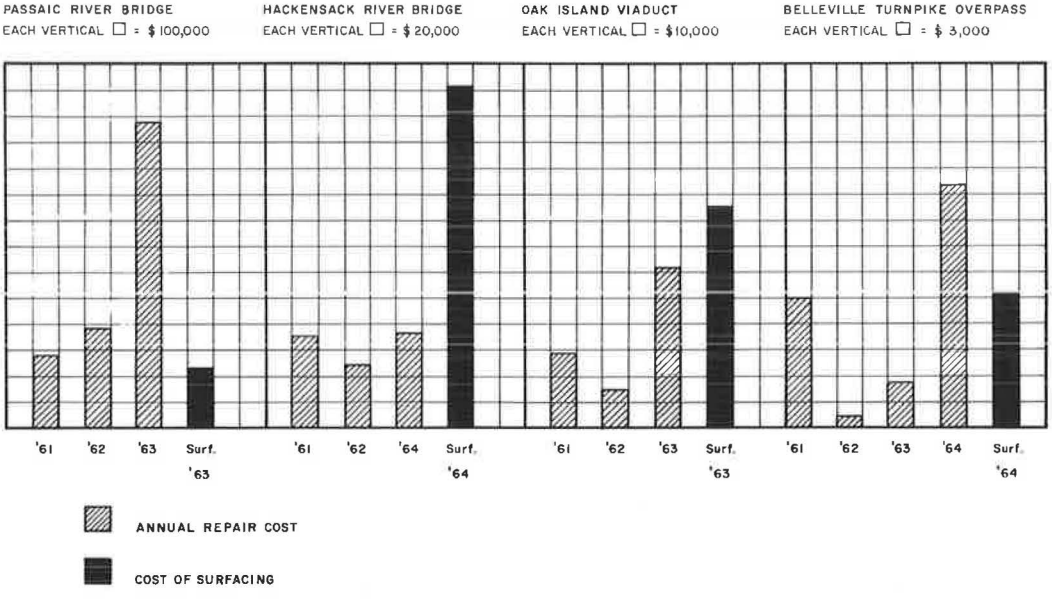

Figure 11. Cost of protective treatment.

TABLE 2

TYPICAL RESULTS OF SKID TEST ON NEW BRIDGE DECK SURFACING—ALLEGHENY AVENUE OVERPASS, NEW JERSEY TURNPIKE

Location	Age	Left Lane		Center Lane		Right Lane	
		f[a]	Skid Length	f	Skid Length	f	Skid Length
Area I + 2.6% grade	49 mo	0.51	48	0.47	51	0.49	58.5
Area II + 2.4% grade	3 mo	0.45	42.5	0.42	56	0.42	59
Area III + 1.8% grade	49 mo	0.43	41	0.40	45.5	0.43	48

[a]f is the coefficient of friction calculated from the following formula: $f = (V^2)/(30D)$, where V = velocity (in all cases corrected from the velocity to 30 mph) and D = total distance traveled from brake application to full stop. All areas were wetted before each test.

repair program on the old concrete deck. Thus, as far as we are concerned, the protective treatment has already paid for itself—$3 million invested to halt a rising $6 million repair bill (Fig. 11).

Furthermore, there is no evidence of cracking in the surface in any of the overlays, nor is there any sign of water leaking through the bridge deck either during, immediately after, or long after a rainfall.

This has been demonstrated rather convincingly by the removal of metal forms. For reasons beyond the scope of this paper, we often use left-in-place corrugated galvanized metal forms to replace a deteriorated bridge deck. Concern was expressed that these forms would prohibit us from evaluating the effectiveness of the surface systems, and some of the forms were removed. Although the forms had been in place for two years, there was no sign of moisture.

Also, because of the high asphalt content used, some clients were fearful of skidding problems. Over the years we have had several areas tested. In all cases the coefficients of friction on the bridge surface were at least as good as those on the roadway approach pavement (Table 2).

The program has been so successful that this method of construction has now been adopted as the standard policy for all new bridges constructed on the New Jersey Turnpike, including the proposed 30-mi widening program and the Delaware Memorial Bridge, and is the recommended procedure for at least three other major clients.

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