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FINAL REPORT

OVERVIEW OF LATEX MODIFIED CONCRETE OVERLAYS

by

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SUMMARY

Twelve bridges with latex modified concrete (LMC) overlays ranging in age from new to 13 years were studied and their general condition found to be good. The half-cell and chloride data were inconclusive because background data were not available for the older overlays, but the data should be useful some 5 to 10 years from now if similar data are collected at that time for comparison. The shear strength of the bond between the LMC overlays and the base concretes was about the same or greater than that of the base concrete, which indicates that good bonds were achieved and have been maintained. The permeability to chloride ions based on the rapid permeability test was an average of 773 coulombs (very low) for a 1.25 in. thick LMC overlay and 4,590 coulombs (high) for the base concretes. The inverse of the ratio of the logarithm of the permeability of the LMC overlay to that of the base concrete was 1.27, which provides a very conservative indication of the relative benefits to be obtained from the LMC overlay as compared to an A4 concrete overlay.

The three sets of cost assumptions developed indicate that an LMC overlay costs 6% to 31% more than an A4 concrete overlay. Considering that the benefit-to-cost ratio ranged from 0.97 to 1.20, it was concluded that for bridges in which the low permeability provided by the LMC overlay is needed, the benefits usually obtained are worth the extra cost when compared to that of an A4 concrete overlay.

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INTRODUCTION

Latex modified concrete (LMC) is a portland cement concrete in which an admixture of latex emulsion is used to replace a portion of the mixing water. This type of concrete has been used on highway bridges over the past 20 years,(1) and was first used on a bridge deck in Virginia in 1969.(2)

The Virginia Department of Highways and Transportation's special provision for LMC overlays requires 3.5 gal. of styrene butadiene latex emulsion (46.5% to 49.0% solids) per bag of cement.(3) Other Department requirements are a minimum cement content of 658 lb./yd.^{3}, a maximum water content of 2.5 gal. per bag of cement, a water-cement ratio (w/c) of 0.35 to 0.40, an air content of 3% to 7%, a slump of 4 to 6 in. when measured 4.5 min. after discharge from the mixer, and a cement, sand, coarse aggregate ratio by weight of 1.0/2.5/2.0. In comparison, the requirements for class A4 concrete used in bridge decks include a minimum cement content of 635 lb./yd.^{3}, a maximum w/c of 0.45 (0.47 from 1966 to 1983), an air content of 5% to 8%, and a slump of 2 to 4 in.(4) Thus, it can be seen that by design the LMC is batched with more cement, less water, less air, and at a higher slump.

As compared with A4 bridge deck concrete, the LMC is reported to be more resistant to the intrusion of chlorides, to have higher tensile, compressive, and flexural strengths, and to provide better freeze-thaw performance.(1) The greater resistance to chloride intrusion is said to be attributable to the lower w/c and a plastic film the latex emulsion produces within the concrete which inhibits the movement of chlorides. The concrete is reported to have a higher strength because the w/c is lower and because the plastic film produces a higher bond strength between the paste and aggregate. Its freeze-thaw performance is said to be superior because the lower permeability helps keep water out of the concrete and because the concrete is more flexible and therefore able to withstand the expansion and contraction forces associated with frost action.(1)

A 1.25 in. thick overlay of LMC is usually installed at a cost of \$20 to \$30/yd.^{2}, exclusive of the cost for traffic control and deck preparation. It is believed that a conventional A4 concrete overlay could be installed for less, but definitive cost data are not available since only two overlays of this type have been constructed in Virginia, both placed in 1974 on one span of each of two new experimental bridges near Berryville. The cost was estimated to be \$15/yd.^{2} as compared to \$24/yd.^{2} for two spans overlaid with LMC and \$32/yd.^{2} for two spans overlaid with concrete containing wire fibers.(5)

In addition, the Department is not certain that it is cost-effective to require that all salt-contaminated concrete be removed from a bridge deck prior to placement of an LMC overlay. In an effort to minimize the lane closure time and the cost of the rehabilitation of a deck, LMC overlays have occasionally been installed without removing all of the salt-contaminated concrete, a practice which does not satisfy the restrictive requirements for federal funds. However, the Federal Register of February 14, 1983, contains proposed changes in the requirements to give the states a greater voice in the selection of materials and procedures for bridge projects that qualify for federal funding.(6) FHWA Docket 83-1 in the Federal Register indicates that the states can qualify for federal funding for a reconstruction method that does not require the removal of all salt-contaminated concrete if, based on considerable experience and a vast quantity of data, the reconstruction method can be demonstrated to be effective. A study of the effectiveness of the LMC overlays that have been installed on salt-contaminated concrete would help establish whether or not this practice can be considered suitable for federal funding and thus can be used to effect economies.

PURPOSE AND SCOPE

The purpose of the research was to determine the cost-effectiveness of LMC overlays. The work included a review of the literature and the experiences of the eight construction districts in the Department. The bridge engineers were contacted to determine the status of LMC overlays in their districts from the standpoint of cost and performance.

Each district bridge engineer provided information on four or more bridges, with the exception of the bridge engineer in Suffolk, who provided information on the only two LMC overlays in the district. The information included the chloride contents and half-cell potentials of the decks prior to the construction of the overlays, the age of the overlays, the cost of the overlays at the time they were constructed, the supplier of the latex and the contractor, and a qualitative assessment of the condition of the overlays. From the information on 39 bridges, 14 bridges were initially selected for study and 2 of these which were representative of an LMC overlay used in new construction were deleted, so that 12 bridges (3 representing new construction) were studied in detail. Because epoxy coated rebars are used in lieu of LMC overlays in new construction, a large sample of LMC overlays used in new construction would not provide valuable information. The 12 bridges were selected to provide information on overlays placed over a 13-year period, including overlays used in both new deck construction and deck repair, and overlays considered to be in excellent condition and ones whose condition was in question because of their appearance or because it was known that they were placed on salt-contaminated concrete.

Since the principal purpose of the use of an LMC overlay is to inhibit the penetration of chloride ions to the reinforcing steel, permeability tests were conducted on 3 cores removed from each of the 12 bridges. Also, since the strength of the bond between the overlay and the base concrete is a factor in service life, 3 other cores were taken from each bridge and subjected to a shear force directed through the bond line. In addition, the chloride (Cl^-) content was determined and the electrical half-cell potentials were measured for the shoulder and travel lane of each bridge, and the data were compared with data collected prior to the placement of the overlays.

These data can be used to quantify the performance of the overlay on the basis of its having prevented the infiltration of chloride, or prevented an increase in half-cell potentials, if additional samples are taken at the same location 5, 10, or more years from now. The data can also be used to determine if it is acceptable practice to place LMC overlays on concrete having Cl^- contents in excess of 2.0 lb./yd.[3].

Since less air is specified for LMC than A4, freeze-thaw specimens were prepared during the construction of three overlays and were tested in accordance with the modified version of Procedure A of ASTM C-666 used at the Research Council.

Benefits in terms of the lower permeability to chloride ions provided by the LMC overlays as compared to that provided by conventional bridge deck concrete were used for a cost-benefit assessment. Because costs could not be obtained from contracts for decks rehabilitated with conventional A4 concrete overlays, it was necessary to use estimates for this assessment.

RESULTS

Data supplied by the district bridge engineers for the 12 bridges selected for study are shown in Table 1. On bridges 1, 2, and 6 the LMC overlays were placed during new construction, and those on bridges 1 and 2 represent older overlays. Bridge 1 has three spans with a 2-in. overlay on each span. Span 1-A has LMC, 1-B has wire fiber concrete, and 1-C has a 2 in. slump portland cement concrete. Unless designated 1-B or 1-C the data refer to span 1-A. Bridge 4 has five spans. Spans A, B, and C were overlaid with LMC and spans 4-D and 4-E were completely replaced with A4 concrete. Unless indicated otherwise, the data refer to spans A, B, and C. The overlays on the other 9 bridges were used in rehabilitation, with those on bridges 3 and 4 being examples of older overlays. The approximate average cost of the 12 bridges was $28/yd.^{2}, exclusive of deck preparation and traffic control.

Permeability

The rapid permeability test developed by the Portland Cement Association (7) was used to measure the permeability to chloride ions of the top 2 in. and the next 2 in. of each of 3 cores removed from each bridge, with the exception that for bridges 10 and 13 it was necessary to cut and test sections from the cores which were approximately 4.5 to 6.5 in. from the top for determining the permeability of the base concrete. This was necessary because on bridge 10 the latex overlay was 4.4 in. thick and on bridge 13 a layer of patching material which exhibited a permeability of 4,140 coulombs separated the overlay from the base concrete. The results of the tests are shown in Figure 1.

The permeability of the top 2 in. was significantly less than the permeability of the conventional A4 base concrete for all bridges. The average permeability of the base concrete was 4,590 coulombs, excluding the value for bridge 10, which was based on only 1 core.

Interpretation of Permeability Test Results

Because the permeability test is fairly new, the interpretation of results is subject to debate. The PCA, which developed the test, recommends assigning qualitative values to the results such as <1,000 coulombs is very low permeability and >4,000 coulombs is high permeability.(7) This method does not lend itself to a benefit-cost assessment of using different materials. With this interpretation, most of the base concretes have a high permeability and the latex overlays a very low permeability. The question arises as to how much one should pay to go from high to very low. A more quantitative method of interpreting the results is needed.

Table 1

Data Obtained From Questionnaire Survey

Bridge No.	Structure No.	Location: Route	Location: District (City or County)	Type Super-structure	Date Overlay Placed	Original Date Constr.	Contractor	Latex	Deck Condition	Cost, $/yd.^{2}
1	B612	Rte. 7, EBL over N&WRR	Staunton (Berryville)	3-50'steel (1 latex)	6/1974	6/1974	Moore Brothers Const. Co.	Dow	Good	24.00
2	1124	Rte. 29, NBL over 29	Lynchburg (Pittsylvania)	Steel 3 span 35', 120',35'	11/1974	11/1974	English Const. Co.	Dow	Good	32.27
3	1030	Rte. 29, NBL over Otter Rr.	Lynchburg (Campbell)	Steel 7 span	5/1975	4/1953	Landford Brothers	Dow	Good	40.00
4	1029	Rte. 29, NBL over So. R.R.	Lynchburg (Campbell)	5 steel spans (3 latex)	5/1970	8/1950	Dow	Dow	Fair	9.00
6		Rte. 301, SBL over Rappahannock River	Fredericksburg (Port Royal)	3 cont.steel spans 122',152',122'	1980	1979	G & C Const. Co.	Dow	Good	38.25
8	2032	Rte. I 81, NBL over 683	Bristol (Smyth)	3 conc. spans 32' to 47'	1982	1964	Ramco	Polysar	Good	35.26
9	2033	Rte. I 81, SBL over 683	Bristol (Smyth)	3 conc. spans 32' to 47'	1982	1964	Ramco	Polysar	Good	29.02
10	2000	Rte. I 81, NBL over Rte. 640	Salem (Roanoke)	3-39' conc. tee beam spans	1983	1962	Whitting Turner	Dow	Good	30.70
11	2900	Rte.I 66, WBL over Bull Run	Culpeper (Fairfax)	3 steel spans	1980	1961	Central Atlantic Wagman	Dow	Good	21.00
12	2024	Rte.I 81, NBL over Narrow Passage Cr.	Staunton (Edinburg)	5-70' prest. I-beams	1979	1966	Central Atlantic	Dow	Good	26.00
13	2000	Rte. I 81, NBL over Rte. 100 and Rte. 11	Salem (Pulaski)	4 steel spans, 55'	1980	1959	Chapin	Dow	Good	21.97
14	1043	Rte. 501 over Banister River	Lynchburg (Halifax)	15-50' steel spans	1979	1958	Lanford Brothers	Dow	Good	32.10

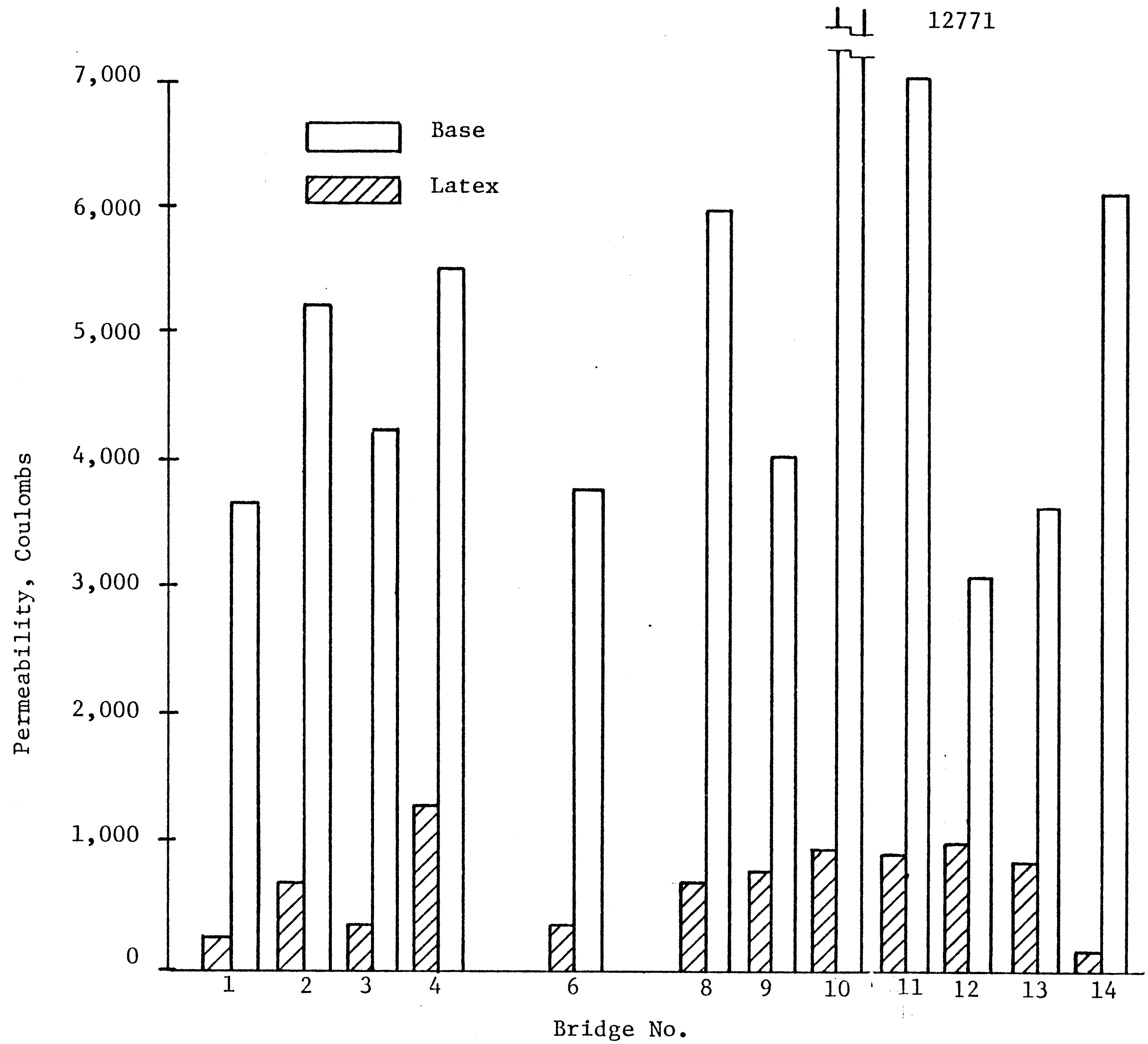

Figure 1. Permeability to chloride ion.

Based on several years of experience with testing concretes of all types from polymer to radiant heat cured, the author believes that the best quantitative interpretation of the data is a geometric one that takes the logarithm of the mean of a number of permeability tests to be equal to the average of the logarithms of the permeability of the individual specimens, or

$$\log_{10} P = \sum_{i=1}^{n} \log_{10} k_i / n,$$

where P = average permeability,

k_i = permeability of i specimen, and

n = number of specimens.

This interpretation is supported by Scheidegger (8), and the average values presented in this report are based on it.

Further support for a geometric interpretation of the data is provided by the results of permeability tests on concretes with two different air contents. Concretes with average air contents of 3.6% and 6.5% exhibited average permeabilities of 9,594 and 13,051 coulombs, respectively. While one would expect the permeability to increase in proportion to the increase in air content, here the permeability increased 36% for a 2.9% increase in air content. On the other hand, if the increase is interpreted in terms of the logarithm of the permeability, then the permeability increased 3.4% for a 2.9% increase in air content, which is reasonable.

Permeability of Base Concrete

The permeability values provide an indication of the differences between the base concretes. One possible explanation for the differences is that the requirements for bridge deck concrete in Virginia have changed over the years, and a significant change was made in 1966. In that year the cement content increased from 588 to 634 lb./yd.^{3}, the w/c was reduced from 0.49 to 0.47, the slump was changed from 0 to 5 in. to 2 to 4 in., the air content went from 3% to 6% to 5% to 8%, and the 28-day strength went from 3,000 to 4,000 psi. The base concretes of bridges 1, 2, 6, and 12 were constructed in 1966 or later and exhibited an average permeability of 3,862 coulombs as compared to 5,068 coulombs for the other older bridges. Although the cause of the improvement in permeability cannot be determined because of the many requirements that were changed, it appears that concrete produced after the 1966 specifications were implemented has a lower permeability on the average than concrete produced prior to that time.

Permeability of Top 2 In.

It is believed that the principal reason for the differences in the permeability of the top 2 in. of the cores is the thickness of the LMC overlay. Figure 2 shows the relationship between permeability and overlay thickness. The best fit of the data shows that for an LMC of 1.25- in. thickness, the average permeability of the top 2 in. is 773 coulombs.

Relative Benefits from Low Permeability

If it is assumed that the principal benefit to be derived from an LMC overlay is lower permeability, then the ratio of benefits for an LMC overlay as compared to the base concrete is the inverse of the ratio of the permeabilities. The average permeability of the base divided by the average permeability of the top 2 in. for an overlay thickness of 1.25 in. yields 4,590/773 = 5.937, which means the LMC overlay is worth 5.9 times more than the base concrete. There are people who will argue that this is the correct interpretation of the benefits. However, based on the arguments cited under interpretation of test results, it is the author's belief that a more accurate interpretation, or at least a conservative one, of benefits is provided by dividing the logarithm of the permeability of the base by the logarithm of the permeability of the top 2 in., which yields a ratio of 1.27. This figure implies that the LMC overlay is worth 27% more than an overlay constructed with concrete similar to the base concrete.

Bond Strength

Three cores were removed from each of the 12 bridges under study and subjected to two shear tests. The shear force was first directed through the bond interface and then through the base concrete to provide indications of their shear strengths. The results of these tests are shown in Figures 3 and 4. Figure 3 shows the shear strength and Figure 4 the location of the failures in the vicinity of the bond interface. No data on the bond interface for bridges 1 and 10 and no data on the strength of the base concrete for bridge 12 are reported because suitable samples were not available for test.

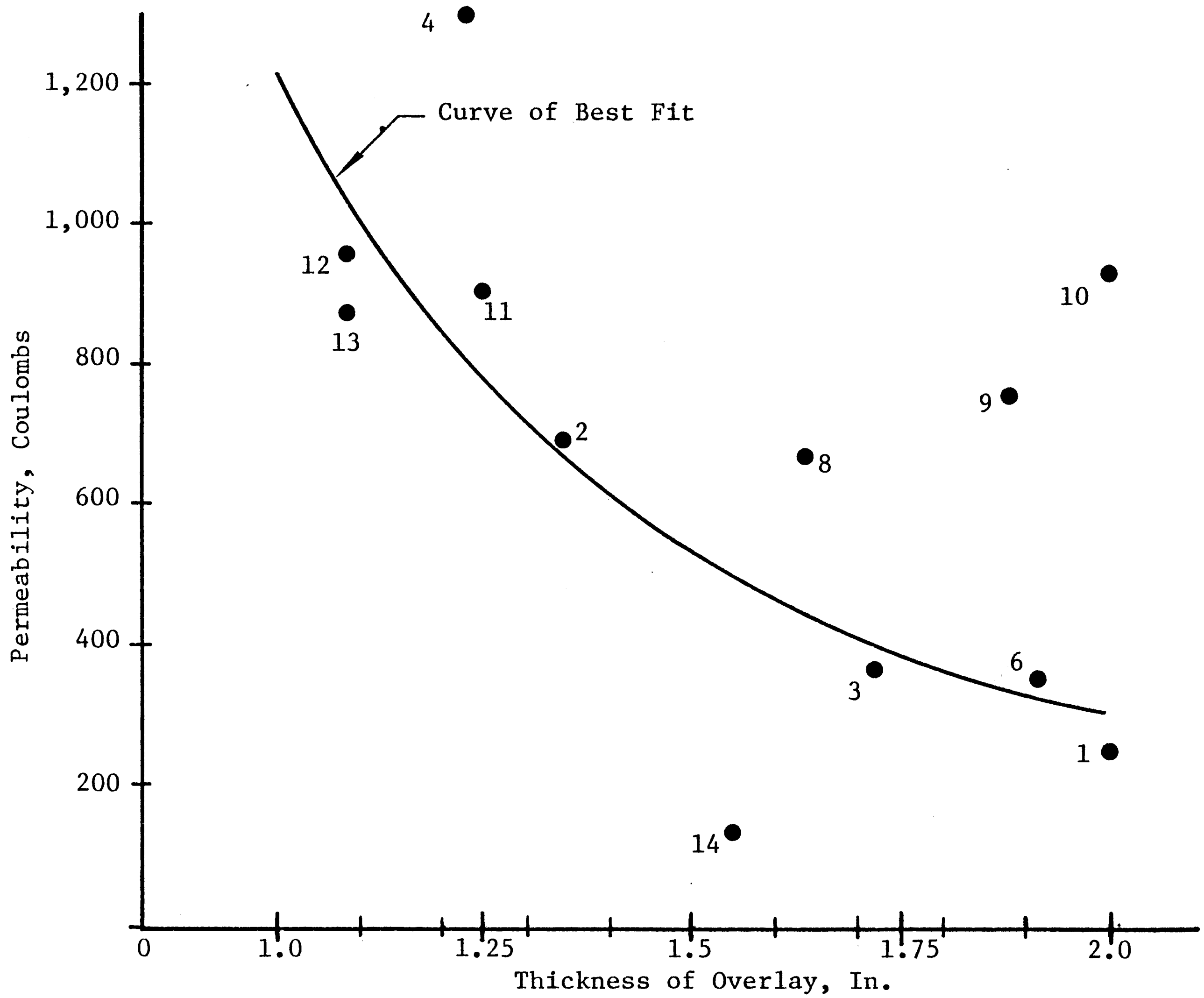

Figure 2. Relationship between permeability and thickness of overlay.

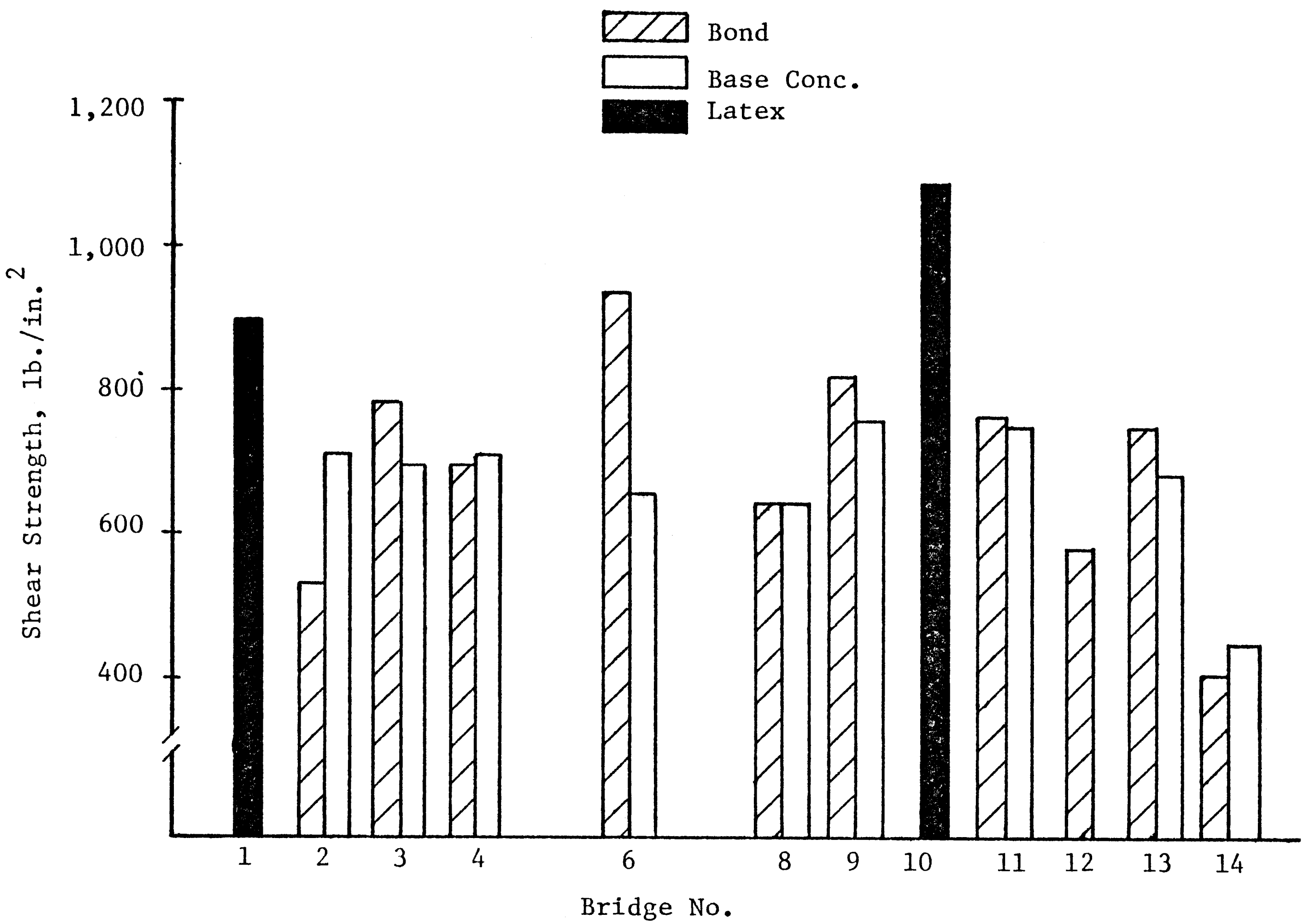

Figure 3. Shear strength.

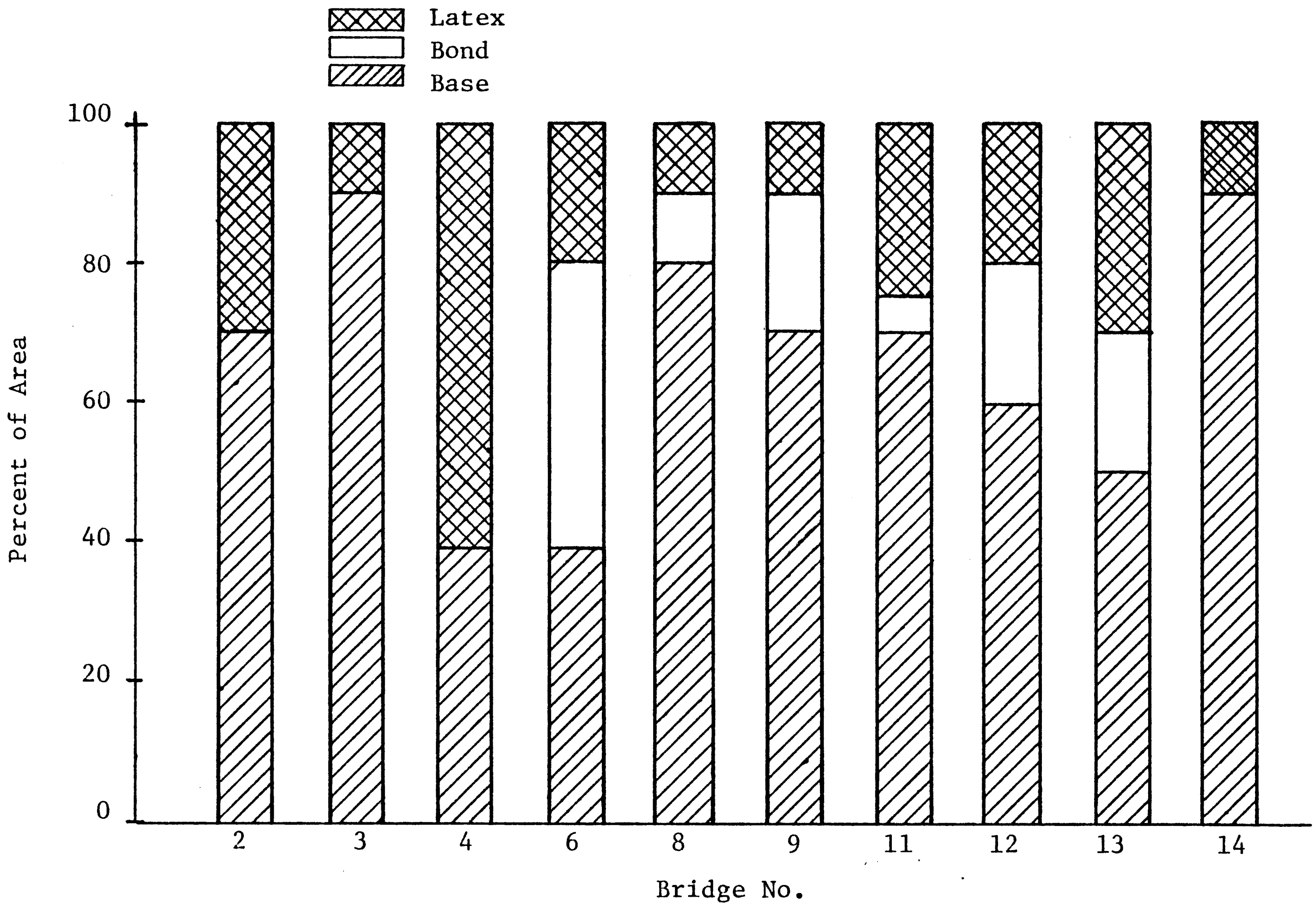

Figure 4. Location of failures in shear tests.

Based on the data in Figure 3 it can be concluded that the shear strength of the LMC is high and the strength of the bond interface is usually as high or higher than that of the base concrete. And from Figure 4 it can be concluded that the majority of failures were in the base concrete, which is reasonable since, as can be seen in Figure 3, the base typically exhibited a lower strength than the bond interface. Also, the base would be subject to surface damage during scarification or, in new construction, to the formation of a weak surface due to the finishing operation and the subsequent bleeding of the concrete. Regardless of the type of overlay that is placed, care should be exercised when preparing the surface of the base concrete to prevent the formation of a weak layer. A petrographic examination of the bond line in cores from bridges 3, 12, and 14 supported the data in Figures 3 and 4, in that considerable damage to the base concrete was noted in the core from bridge 3 and less damage in those from bridges 12 and 14.(9) In summary, it can be concluded that high bond strengths are typically obtained with LMC overlays and that the strengths are maintained over the years. Bridge 4 exhibited a high bond strength after 13 years of service.

Freeze-Thaw Performance

The condition of the 12 bridges provided evidence that scaling due to freezing and thawing had not been a problem. Nevertheless, specimens were prepared during the construction of three overlays and subjected to the Council's freezing and thawing test, which is a modified version of ASTM C666 Procedure A that includes freezing and thawing in a 2% NaCl solution. The results of the tests are shown in Table 2. Prior to testing, the specimens were moist cured for 24 hours and air cured for 3 weeks or more. The standard procedure is to start the test when the specimens are 3 weeks old, but because of problems with the freeze-thaw machine the specimens prepared on 10/27/83 and 11/18/83 were not tested until April 1984.

The specimens prepared on 8/02/83 failed the freeze-thaw test, whereas the other specimens passed it. Since the performance of the overlays has been acceptable, the failures may be attributed to the harshness of the test, the early age at which the test is conducted, or to the preparation of specimens from a sample of unacceptable concrete. The concrete prepared on 8/02 exhibited a lower compressive strength than that prepared on 10/27 and 11/18 and did not satisfy the 4,500 lb./in.^{2} 28-day strength requirements. Possibly more water was batched in the mixture on August 2 than anticipated. On the other hand, the 28-day length change was similar for the concretes, which suggests that the water to cement ratios were similar. It's interesting to note that the 28-day shrinkage for LMC is about twice the 0.025% typically exhibited by A4 concrete.(10)

Table 2

Miscellaneous Information on Specimens Prepared in 1983

Bridge	Contractor	Placement Date	Length Change in 28 Days: Shrinkage, in.	Length Change in 28 Days: %	Compressive Strength at 28 Days, lb./in.^{2}	Weight Loss, %	Freeze-thaw Data: Durability Factor, %	Surface Rating
I-81 SBL over ramp to I-64 EBL	Ramco	8/02/83	0.0063	0.056	4,620*	25.4	31.7	4.55
I-81 SBL over ramp to I-64 EBL	Ramco	8/02/83	0.0047	0.042	4,360	17.5	44.0	4.01
I-81 SBL over Middle River	Central Atlantic	10/27/83	0.0063	0.056	5,085	3.9	91.7	1.31
I-81 NBL over Middle River (str. 2020)	Central Atlantic	11/18/83	0.0049	0.043	5,150	4.4	93.0	0.93

* 1 cylinder

Length change based on average of 2 specimens 3 x 3 x 11 1/4 in.

Compressive strength based on average of 2 cylinders 4 x 8 in.

Freeze-thaw data based on average of 3 specimens 3 x 4 x 16 in.

Petrographic Data

Table 3 shows the petrographic data obtained from examinations of the cut and finely lapped vertical surfaces of cores obtained from 5 of the 12 bridges in 1983, of cores obtained from bridge 1 in 1974 and cylinders prepared at that time, and of cylinders prepared during the installation of the overlays in 1983.(9)

From the data in Table 3 it can be concluded that the void structure of the latex overlays had not changed over the years. Also, the spacing factor was not and has not been less than the 0.008 in. considered by some to be necessary to provide acceptable freeze-thaw performance. Evidently, the latex emulsion prevents the infiltration of water so that an adequate void structure is not needed.

The cores from bridges 14 and 8 exhibited a large number of coarse voids probably attributable to inadequate consolidation or failure to identify an incident of foaming when measuring the air content by the pressure method.

Although it is difficult to conclude from the data in Tables 2 and 3 that LMC will have acceptable freeze-thaw performance, the data for specimens prepared on 10/27 and 11/18 and the years of satisfactory performance support this conclusion.

Chloride Ion Content

A chloride ion content in excess of 1.3 lb./yd.^{3} at the level of the reinforcing steel can cause corrosion in the presence of oxygen and moisture. Table 4 and Figure 5 show the average chloride ion content in 1983 for the shoulder and travel lane based on one sample from each of three spans of each of the bridges. Where available, data determined by district personnel prior to the installation of the overlays (by Council personnel shortly after the installation of the overlays on bridge 1) are shown. Reasonable estimates of the background chloride that can be attributed to the aggregates are also reported. The depth of the reinforcing steel based on measurements made at the time the 3 samples were taken are also shown in Table 4.

From Table 4 and Figure 5 it can be concluded that there was reasonable agreement between the chloride ion contents determined by district personnel prior to 1983 and those determined by Council personnel in 1983. Also, it can be concluded that there was sufficient chloride in the vicinity of the steel in bridges 3, 4, 8, 9, 11, and 14 to cause corrosion. Insufficient time has passed to conclude whether or not the LMC overlay is preventing the infiltration of chloride ions, and it will be necessary to take samples 5, 10, or more years from now for comparison before conclusions can be drawn.

Table 3

Petrographic Data

Year Latex Placed	Bridge	Specimen	Plastic Air, %	Total Voids, %	Voids <1 mm, %	Specific Surface, in.$^{-1}$	Spacing Factor, in.
1974	1-A	Core	3.3	3.7	1.5	256	0.02150
1974	Berryville, WBL	Core	3.3	3.7	1.3	232	.02383
1974	Average	Core	3.3	3.7	1.4	244	0.02267
1974	1-A	Cylinder	3.2	3.7	2.5	257	0.02154
1974	Berryville, WBL	Cylinder	3.2	4.1	1.9	241	.02183
1974	Berryville, WBL	Cylinder	3.4	4.6	2.0	216	.02316
1974	Average	Cylinder	3.3	4.1	2.1	238	0.02218
1975	3	3CL Core	--	4.46	1.25	181.65	0.028381
1979	12	12 BL Core	--	3.95	1.31	213.56	.025570
1979	14	14 CL Core	--	7.92	2.42	193.80	.01756
1982	8	8 BL Core	--	8.52	3.46	269.72	.011849
1983	10	10 AL Core	--	3.97	1.29	223.59	.02437
	Average			5.76	1.95	216.46	0.02155
1983	8/02/83	Cylinder	3.5	3.17	1.85	298.51	0.020282
1983	8/02/83	Cylinder	3.7	2.74	1.34	254.29	.025452
1983	10/27/83	Cylinder	4.5	4.45	2.66	324.41	.015907
1983	11/18/83	Cylinder	4.6	4.16	2.56	357.78	.014895
	Average		4.1	3.63	0.62	308.75	0.01913

Table 4

Chloride Content Data

Bridge	Year Latex Placed	Thickness Latex, In.	Depth of Top Rebar, In.	Depth CL 1983, In.	Chloride Content, lb./yd.^{3} Due to Aggregate	Prior to Latex	1983	Difference, 1983-Before Latex
1-A	1974	2.0	2.3	2.0	0.3	0.3	0.4	0.1
1-B[a]	1974	2.0	2.3	2.0	0.5	0.5	0.6	0.1
1-C[b]	1974	2.0	2.3	2.0	0.4	0.4	0.9	0.5
2	1974	1.3	3.3	3.1	0.1	0.1	0.1	0.0
3[c]	1975	1.7	3.0	2.9	0.5		1.8	
4[c]	1970	1.2	2.2	2.1	0.1		1.4	
4-D,E[d]	1970	0.0	2.4	2.1	0.1	0.1	0.1	0.0
6	1980	1.9	2.2	2.0	0.0	0.0	0.2	0.2
8	1982	1.6	4.0	2.3	0.4	3.5	3.3	-0.2
9	1982	1.8	3.5	2.3	0.4	1.2[e]	4.5	3.3
10	1983	4.4	3.3	2.3	0.4	3.0	0.4[f]	0.0
11	1980	1.2	3.5	2.3	0.3	4.7	4.6	-0.1
12	1979	1.1	1.8	2.0	0.2	0.3	0.8	0.5
13	1980	1.1	2.5	2.0	0.3	2.4	0.6[g]	0.3
14	1979	1.5	2.7	2.5	0.5	3.6	3.6	-0.6

[a] Wire fiber overlay
[b] High quality 2 in. slump PCC overlay
[c] Chloride data not available prior to latex installation
[d] Entire deck slab was replaced rather than placing latex overlay
[e] All samples taken along edge of parapet
[f] Chloride sample taken from latex concrete used for class II repair
[g] Chloride sample taken from A4 concrete used for class II repair

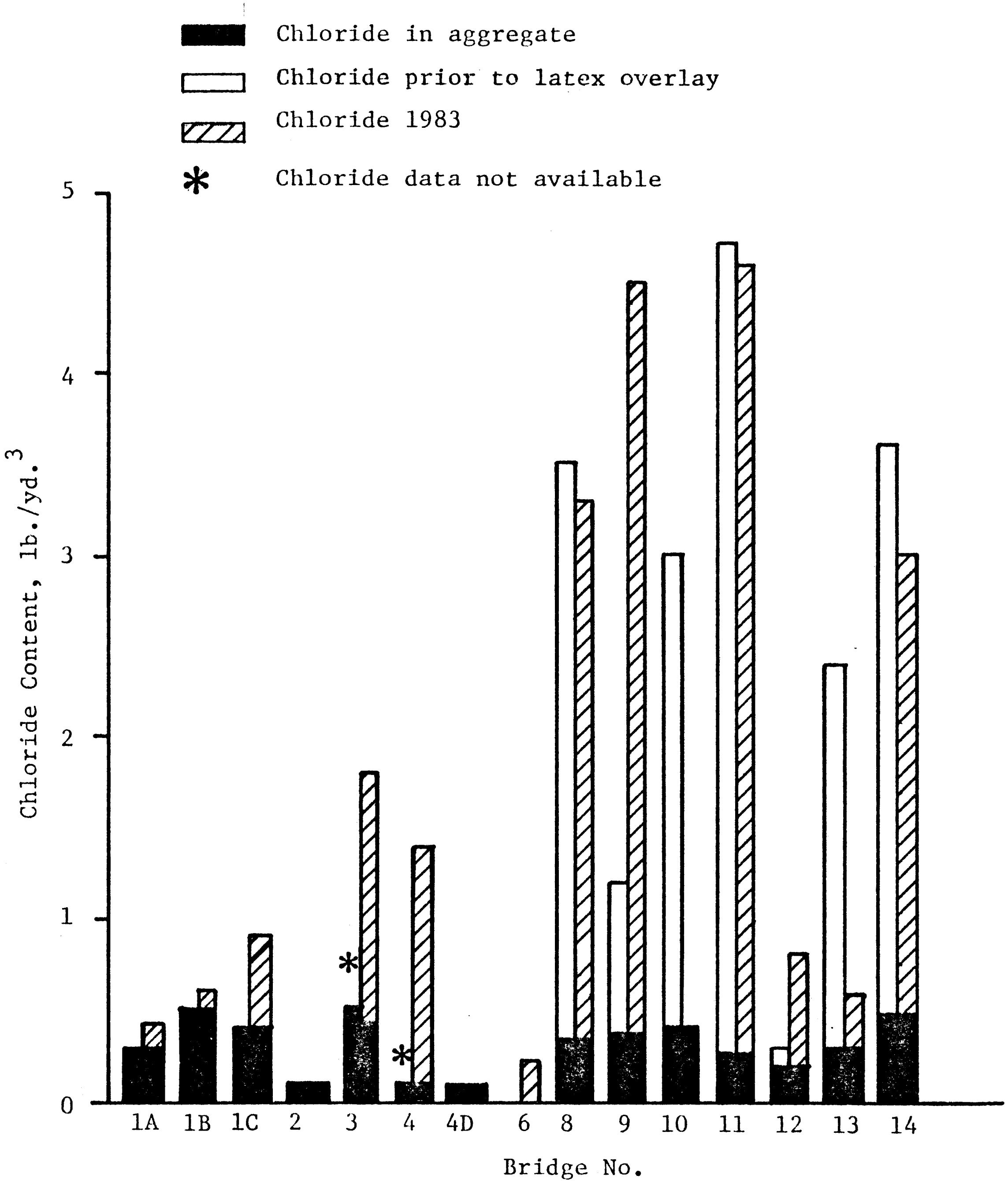

Figure 5. Chloride ion content.

Half-Cell Potential

Copper sulfate half-cell potentials (ASTM C876-77) were measured in 1983 at grid points 5 ft. apart over the shoulder and travel lane of three spans of each bridge and are shown in Figure 6 and Table 5. Also shown are the results of measurements made by district personnel prior to the installation of the overlays (by Council personnel shortly after the installation of the overlays on bridge 1). The data taken prior to 1983 generally agree with the data taken in 1983. The concluding statement for the chloride ion data is also applicable here. It's interesting to note that even on bridges 4, 9, 11, and 13, where there was greater than 95% probability that corrosion was occurring over a large area, the decks were not delaminated or spalled and were providing a satisfactory wearing surface. It's also interesting that for bridges where pre-1983 data were available, the scarification of the deck and installation of the overlay did not significantly change the corrosion potential of the steel.

Plastic Shrinkage Cracks

Figure 7 shows an LMC overlay containing many plastic shrinkage cracks. Of the 12 bridges studied, only bridges 8 and 9 exhibited many shrinkage cracks. A few cracks, probably caused by drying shrinkage or deck movements under traffic, were noted in some of the other bridges but no more were noted than are typical of most A4 concrete bridge decks. These observations agree with data presented by Bishara showing that long-term shrinkage is about the same for LMC as for concrete without latex.(14) Bishara also presented 28-day shrinkage data that agree with the data reported in Table 2 and show that the 28-day shrinkage of LMC is about twice that of A4 concrete.(14)

Plastic shrinkage results from the evaporation of water from the deck surface faster than water can bleed to the surface. When adequate moisture and temperature control is provided to concrete during early stages, plastic shrinkage cracks can be prevented.(15) High concrete temperature, low humidity, high winds, and low ambient temperature promote plastic shrinkage. The American Concrete Institute provides a procedure for measuring the evaporation rate and recommends methods for preventing plastic shrinkage.(16)

LMC is more prone to plastic shrinkage than A4 concrete because it has a lower water-to-cement ratio and, there is, therefore, less free water available to prevent plastic shrinkage. The LMC overlays that do not have plastic shrinkage cracks provide evidence that wet burlap can be applied soon enough after the concrete is placed to prevent plastic shrinkage. Obviously, more care must be taken with LMC overlays than with A4 concrete. The cracks should be prevented because they provide a direct path for the ingress of chlorides.

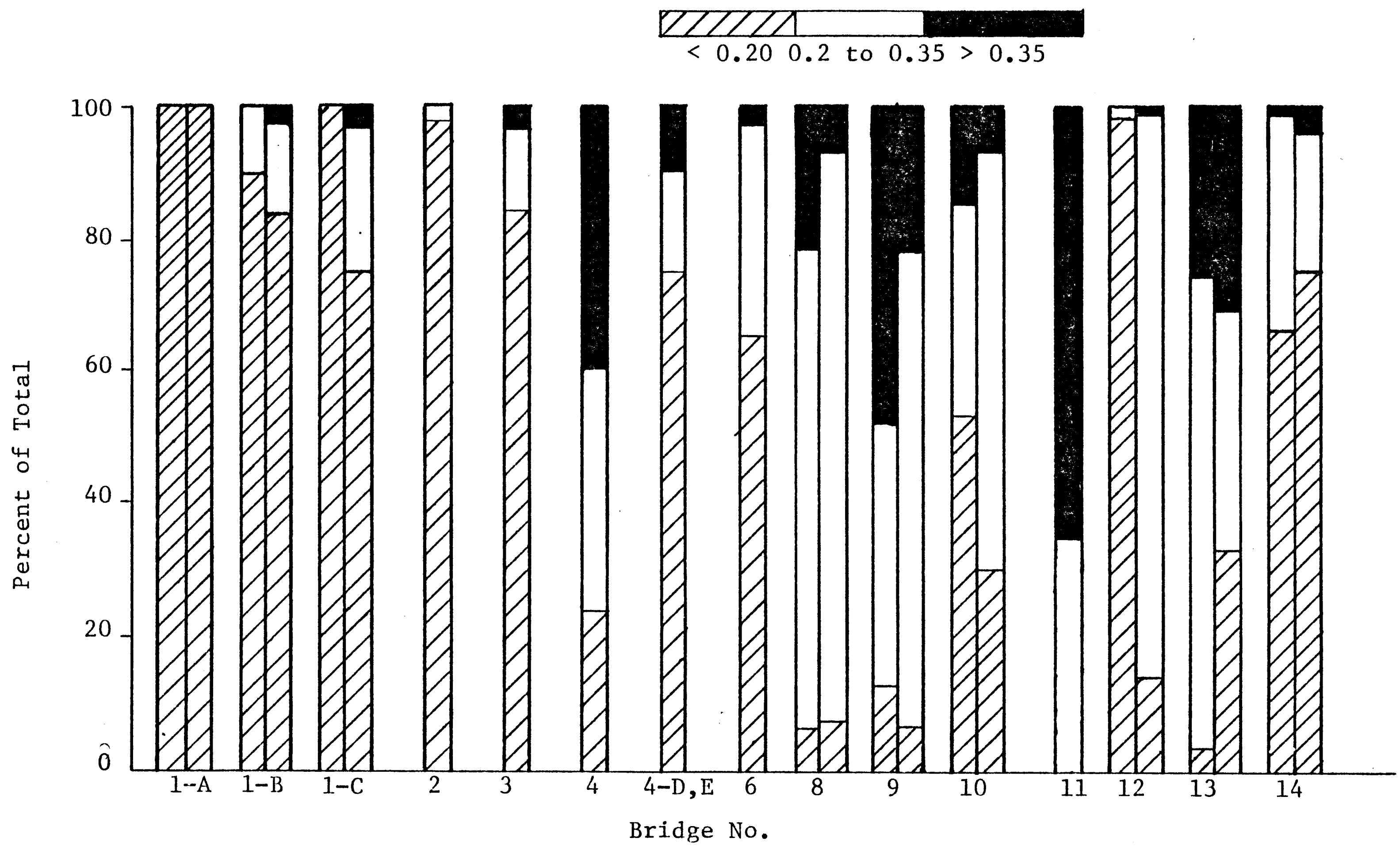

Figure 6. Electrical half-cell potentials.

Table 5

Electrical Half-Cell Potentials, Percentage of Total Number of Readings

Bridge	Year Latex Placed	Year Data Taken	Prior to Latex Range (-Volts CSE) <0.20	Prior to Latex 0.20 to 0.35	Prior to Latex >0.35	1983 Range (-Volts CSE) <0.20	1983 0.20 to 0.35	1983 >0.35
1-A	1974	1975	100	0	0	100	0	0
1-B	1974	1975	90	10	0	84	14	2
1-C	1974	1975	100	0	0	75	22	3
2	1974					98	2	0
3	1975					84	13	3
4	1970					24	36	40
4-D,E	1970					75	15	10
6	1980					65	32	3
8	1982	1981	6	72	22	7	86	7
9	1982	1981	13	39	48	6	71	22
10	1983		53	32	15	30	63	7
11	1980	1979				0	35	65
12	1979	1977	99	1	0	14	85	1
13	1980		3	71	26	33	36	31
14	1979	1977	66	33	1	75	21	4

Figure 7. Plastic shrinkage cracks in LMC overlay.

Cost

When an overlay is placed to rehabilitate a bridge deck, the total cost includes the costs for materials (M), labor (L), deck preparation (DP), and traffic control (TC), or

$$\text{Cost} = M + L + DP + TC.$$

Based on communications with bridge engineers in the Central Office and the districts, the cost for TC is usually \$5 to \$20 per yd.^{2}, but may be higher on bridges carrying very high volumes of traffic. Also, a reasonable value for DP, which consists of the removal of the top 1/2 in. of the deck surface by scarification, is \$9/yd.^{2}.(11)

Based on discussions with bridge engineers in the Central Office and in the districts, a supplier of latex emulsion (12), and a contractor experienced in the installation of LMC overlays (13), it was determined that a typical unit price for LMC is \$600 per/yd.^{3}. Further, it was determined that about one-half, \$300/yd.^{3}, is for installation,

$\$100/yd.^3$ is for the latex emulsion, $\$170/yd.^3$ is for the concrete mobile, and $\$30/yd.^3$ is for cement and aggregates. Typical A4 ready-mix concrete costs $\$60/yd.^3$, delivered. Assuming $\$300/yd.^3$ for labor and a specified minimum thickness of 1.25 in., L is $\$10.42/yd.^2$. The cost of labor should be the same for an LMC overlay and an A4 concrete overlay. If we let T = thickness of overlay (in.), the cost of an LMC overlay is Latex Cost ($\$/yd.^2$) = \$300 x (T/36) + 10.42 + 9 + (5 to 20).

Since cost data were not available for A4 concrete overlays, it was necessary to make assumptions. Three sets of cost assumptions were made and, with one exception, the L, DP, and TC costs were assumed to be the same as for an LMC overlay. For assumption 1, the material costs were $\$60/yd.^3$ x (T/36). Under this assumption, conventional A4 ready-mix is placed in the same thickness as the LMC overlays, which is highly unlikely because A4 ready-mix would probably not be very durable in layers less than 2 in. thick, but the assumption provides a lower limit for the material cost of an A4 overlay.

For assumption 2, the material costs were $\$200/yd.^3$ x (T/36). Under this assumption a concrete mobile or similar special equipment is used and the concrete is the same as LMC except that the latex emulsion is left out. This assumption is probably more realistic than the previous one, and should provide an upper limit for the material cost of an A4 concrete overlay. The assumption is realistic because concrete placed in thin layers should be mixed in small batches, since a large part of a full load of ready-mix would likely loose its workability before it could be placed and finished.

For assumption 3, the material costs were $\$60/yd.^3$ x (2/36). Under this assumption conventional ready-mix is placed in a thickness of 2 in., which has proven satisfactory based on the construction of two overlays in 1974.(5) For assumption 3, the DP costs are increased 50% to $\$13.5/yd.^2$, because it would be necessary to remove more than 0.5 in. of base concrete prior to placing a 2 in. overlay, or it would be necessary to raise the grade of the approaches, which would add to the cost.

The A4 costs for the three sets of assumptions are as follows

1. A4 Cost ($\$/yd.^2$) = 60 x (T/36) + 10.42 + 9 + (5 to 20)

2. A4 Cost ($\$/yd.^2$) = 200 x (T/36) + 10.42 + 9 + (5 to 20)

3. A4 Cost ($\$/yd.^2$) = 60 x (2/36) + 10.42 + 13.5 + (5 to 20)

The latex costs for a 1.25 in. thick overlay divided by the A4 cost for the three sets of assumptions are as follows:

1. 1.31 to 1.20

2. 1.11 to 1.08

3. 1.08 to 1.06

Benefit-Cost Ratio

A benefit-to-cost ratio greater than 1 is needed to justify the construction of an LMC overlay rather than an A4 concrete overlay. Dividing the conservative benefit of 1.27 reported earlier by the costs above gives a benefit-to-cost ratio greater than 1 for all sets of assumptions, except set 1, and a TC of \$5 to \$10/yd.^{2}, which represents an unlikely situation. Figure 8 shows the relationships between the benefit-to-cost ratio and the thickness of the latex overlay for the three sets of assumptions. It is reasonable to conclude from Figure 8 that the use of LMC in a thickness of 1.25 to 2.0 inches is cost-effective relative to an A4 concrete overlay, when the benefits of low permeability provided by the LMC are needed.

ALTERNATIVES TO LMC

Since the principal benefit obtained from an LMC overlay is low permeability, it is desirable to compare its permeability with that of other concretes and bridge deck overlay materials. Table 6 shows the lowest and highest permeability values obtained for single specimens and the average permeability to chloride ions of bridge deck concretes and overlay materials tested at the Virginia Highway & Transportation Research Council during the past 2 years. Figure 9 compares the high and low values for permeability for A5 and A4 concretes and LMC and polymer concrete overlays based on an average of 3 of more specimens.

From Table 6 and Figure 9 it is obvious that the highest permeability is found for class A5 concrete cured by radiant heat or steam; therefore, it is desirable to continue the Department policy of applying a protective overlay to this concrete when it is to be subjected to deicing salts. Kuhlmann describes the successful installation in Erie, Pennsylvania, of an LMC overlay on precast box beams to provide protection against chloride ingress.(17)

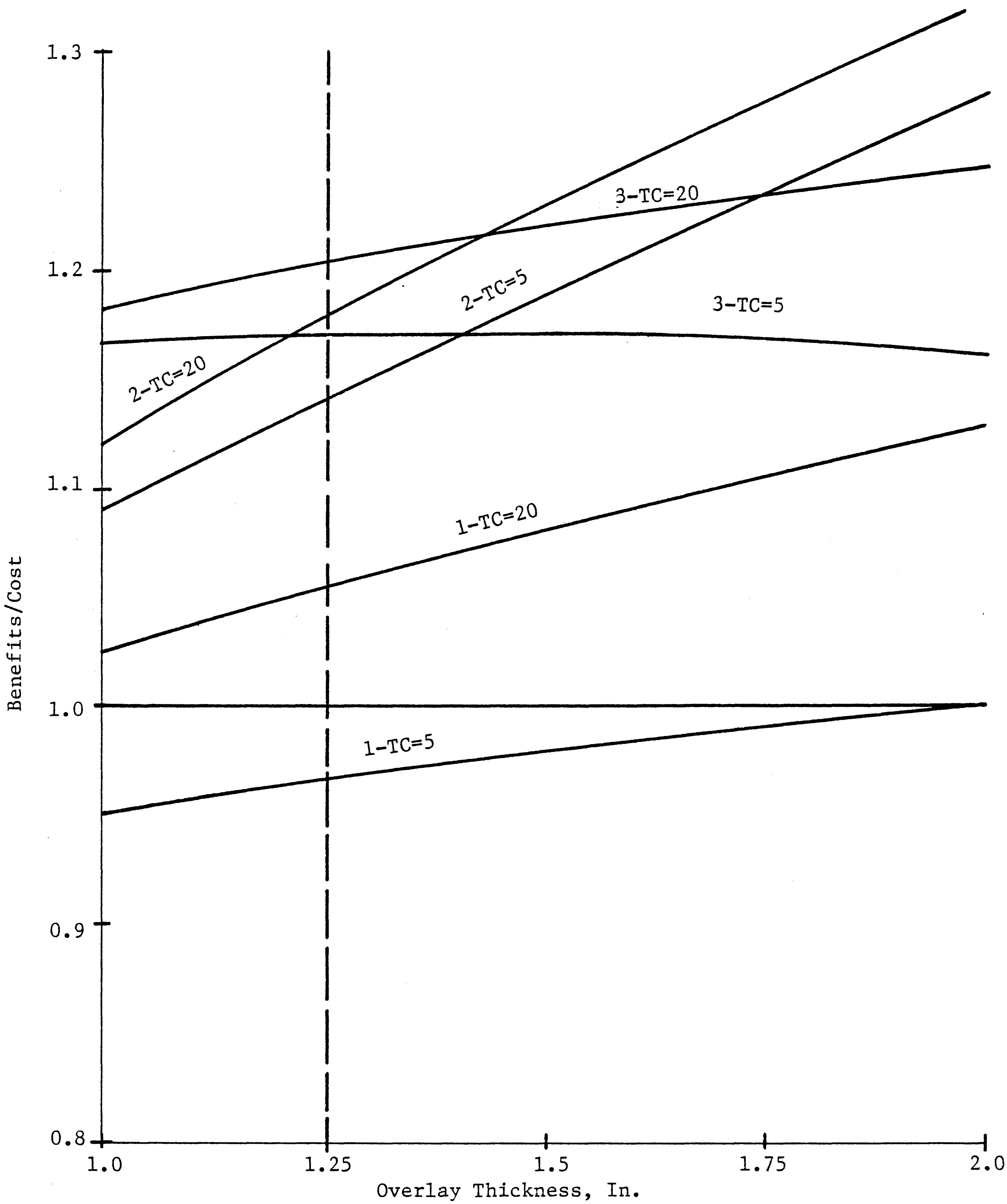

Figure 8. Benefit-to-cost ratio as a function of overlay thickness.

Table 6

Permeability to Chloride Ions of Concretes and Overlay Combinations

Description of Specimen	Permeability, Coulombs		
	Average	High	Low
A5 Conc., Radiant Heat Cure — 150°F, 6.2% air, 3 weeks old	12,690	17,073	9,864
A5 Conc., Steam Cure — 150°F, 7.0% air, 3 and 38 weeks old	11,389	14,344	8,308
A5 Conc., Radiant Heat Cure — 150°F, 6.2% air, 38 weeks old	10,329	13,318	8,352
A5 Conc., Radiant Heat Cure — 150°F, 3.7% air, 3 weeks old	9,409	12,062	6,230
A5 Conc., Radiant Heat Cure — 73°F, also Pavement Repair Conc., 6.4% air, 3 and 38 weeks old	8,402	9,797	7,160
A5 Conc., Radiant Heat Cure — 150°F, 3.7% air, 38 weeks old	7,818	8,836	6,062
A4 Conc., (Base for LB183 overlay, Williamsburg)	6,467	6,974	6,109
A4 Conc., with Wire Fibers	5,388	7,977	3,639
A4 Conc., below Latex Overlays (Before 1966)	5,068	12,771	2,256
A4 Conc., below Latex Overlays	4,590	12,771	2,256
A4 Conc., below Latex Overlays (1966 & Later)	3,862	6,824	2,806
A4 Conc., (Base for 317 Overlay, Swan Creek)	2,786	2,948	2,709
A4 Conc., (Base for LB183 & 90-570 Overlays, Beulah Rd.)	2,214	2,308	2,124
A4 Conc., (Precast Conc. Control Slabs for Polymer Impregnated Concrete Study)	1,893	2,387	1,502
Polymer Overlay (LB183, Beulah Rd., after 300 Thermal Cycles)	1,846	2,442	1,158
LMC — 3 Weeks Age	1,462	1,942	890
A4 Conc., (Control Conc. for HRWR Conc. Study, Norton)	1,406	2,089	1,040
A4 Conc., (2 in. Slump Portland Cement Conc. Overlay, (Berryville)	1,340	1,379	1,303
Polymer Overlay (MMA, Williamsburg, after 1 year)	1,331	1,353	1,309
Polymer Overlay (LB183, Williamsburg, after 1 year)	787	3,607	183
LMC Overlay 1.25 in. Thick	773	2,586	101
Polymer Overlay (LB183, Beulah Rd., after 1 year)	713	859	521
Polymer Overlay (90-570, Beulah Rd., after 300 Thermal Cycles)	609	675	516
Polymer Overlay (317, Swan Creek, after 1 year)	513	675	418
High Range Water Reduced Concrete, Norton	462	935	200
Polymer Impregnated Precast Concrete after 3 years	333	455	292
Polymer Overlay (MMA, Williamsburg, New)	216	257	173
Polymer Overlay (LB183, Williamsburg, New)	62	656	3
Polymer Overlay (LB183, Beulah Road, New)	3	53	1
Polymer Overlay (90-570, Beulah Road, after 1 year)	1	5	0
Polymer Overlay (90-570, Beulah Road, New)	1	2	1
Polymer Overlay (317, Swan Creek, New)	0	0	0

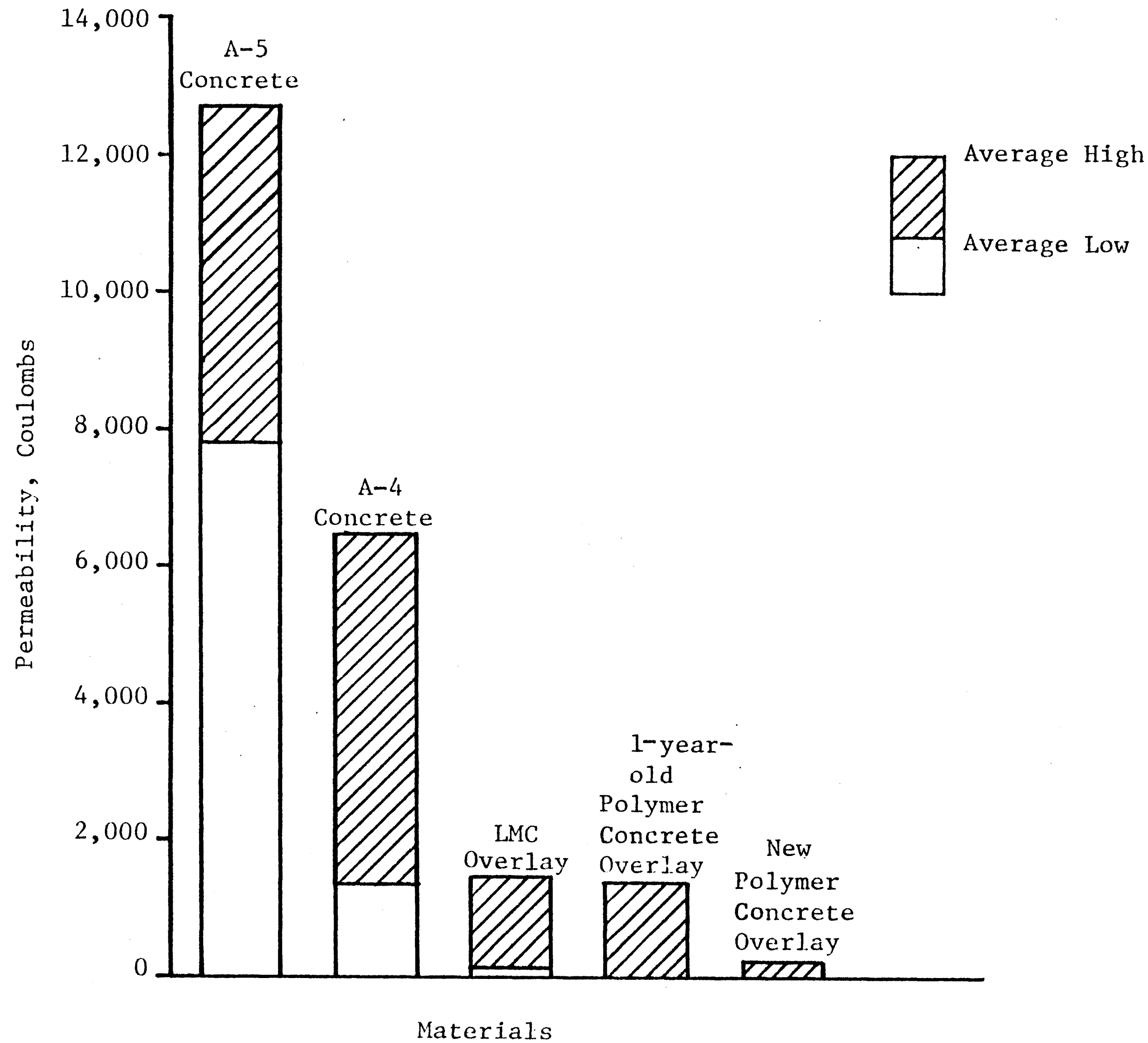

Figure 9. Average permeability to chloride ions of various concretes and overlay combinations.

As indicated by Table 6 and Figure 9, a wide range of permeabilities are exhibited by the class A4 bridge deck concretes. The A4 concrete permeabilities are usually lower than that found for class A5 concrete and that of concrete prepared with 8 bags/yd.[3] of type III cement, which is typical of that used to repair portland cement concrete pavements. The highest A4 concrete permeabilities were exhibited by cores from bridges constructed prior to 1966, but low permeabilities were also exhibited by some of the older concretes such as those in the Beulah Road and Swan Creek bridges. The lowest A4 concrete permeability was exhibited by the cores from the control bridge in Norton. The two experimental bridges in Norton which have high range water reduced (HRWR) concrete overlays exhibited permeabilities which were even lower. In fact, the permeability of the HRWR concrete used at Norton is similar to that exhibited by the bridges overlaid with LMC.

The cores from the bridges which have new thin (0.5 in.) polymer concrete overlays (LB183,90-570,317,MMA) exhibit lower permeabilities than do the LMC overlays. However, with age, most of the polymer concrete (PC) overlays show increases in permeability, so significant protection is not expected after 10 years. The PC overlays are experimental, they continue to be improved, and they offer promise for bridges which cannot be closed to traffic for sufficient time to install an LMC overlay. Polymer impregnated concrete provides low permeability but is too expensive to be practical.

In summary, permeabilities as low as that provided by a 1.25 in. thick LMC overlay can be obtained with only a 1/2 in. thick PC overlay or with polymer impregnation. Although a PC overlay constructed with resin 90-570 offers potential for a service life in excess of 10 years and is a candidate for competition with LMC, polymer overlays constructed with the other resins deteriorate rapidly and are probably not cost-effective because of the short time they provide low permeability. HRWR concrete overlays and high quality (2-in. slump) portland cement concrete overlays exhibit slightly higher permeabilities than that of the LMC overlays, but are experimental and are subject to placement problems due to the low slump and slump loss. With more experience and with improvements in the mixture proportions and placement techniques, the HRWR concrete and high quality concrete overlays could conceivably compete with LMC overlays. Also, overlays constructed with portland cement concrete and additives such as fly ash, slag, or silica fume may prove to be competitive, but at present LMC overlays provide the most proven cost-effective protection where low permeability is desired.

A nomograph that can be used to determine the present value of a bridge deck protective system is shown in Figure A-1 of the Appendix. The bridge engineer is urged to use the nomograph as described in the Appendix and input data on the cost and service life of LMC overlays and of alternative systems to determine the most cost-effective system for each bridge that is a candidate for rehabilitation.

EXPERIENCE OF OTHERS

Michigan DOT

A survey of 23 LMC deck overlays ranging in age from 7 to 11 years indicated that they were performing quite well.(18) Also, a survey of 4 LMC deck overlays placed on concrete contaminated with more than 4 lb./yd.^{3} of chloride ions were performing satisfactorily after 2 to 5 years of service life.(18)

City of Baltimore

Placement of dual protective systems was stopped when it was concluded that LMC overlays and low slump Iowa concrete overlays were not providing any more protection against the intrusion of chloride ions than could be achieved with the Maryland DOT's standard bridge deck concrete, which was sometimes being removed to place the special concrete overlays.(19)

Indiana DOT

"After 4 years of monitoring for chloride penetration, indications are that latex overlays, when placed on new decks, are effectively preventing the accumulation of chloride to values above the corrosion threshold at the steel level."(20)

Wiss, Janney, Elstner & Associates, Inc.

"All of the specialty concretes had lower permeabilities to the ingress of chloride-laden water than the control structural concrete. In most cases the lower permeability could be attributed to a reduction of the water-cement ratio. However, in the case of styrene-butadine latex, the permeability was considerably lower than the water-cement ratio of the concrete would indicate."(21)

Ohio DOT

"Data on field performance of 132 bridges in Ohio, Michigan, Kentucky, and West Virginia indicate that chloride contents at a given depth are much lower in decks that have latex overlays than in decks that lack such overlays, all other factors being equal. Also, since virtually no scaling was observed on the bridge decks, it is safe to say that latex modified concrete provides adequate freeze-thaw resistance."(14)

Summary

The experiences cited above generally support and agree with the experience in Virginia. Some A4 bridge deck concretes in Virginia have a permeability similar to that of some of the LMC, so the experience noted by Baltimore has also been noted in Virginia on occasions. However, the typical experience in Virginia and the experiences of most others support the conclusion that when the same quality control is applied to both type mixtures, the LMC provides improved protection against chloride intrusion.(22,23)

CONCLUSIONS

1. The average permeability to chloride ions of a 1.25 in. thick LMC overlay was 773 coulombs, which is 17% of the 4,590 coulombs found to be the average permeability of the class A4 base concrete upon which the overlays were placed.

2. A comparison of the logarithms of the permeabilities provides a conservative but better indication of relative benefits, and based on this comparison the LMC overlay is worth 27% more than an A4 concrete overlay.

3. In situations where the lower permeability is needed, the LMC overlay is usually worth its cost, which is estimated to be 6% to 31% more than that of an A4 concrete overlay.

4. The shear strength of the bond between the LMC overlay and the base concrete was typically as good or better than the shear strength of the base concrete, and good bond had been achieved and was maintained over 13 years.

5. LMC overlays have been placed over salt contaminated concrete and steel exhibiting half-cell potentials greater than -0.35 volts CSE

and the performance of these overlays should be checked some 5 to 10 years or more from now to evaluate this practice.

6. The half-cell potential measurements and chloride content determinations will be of value some 5 to 10 years from now, if similar data are collected and compared with the 1983 data.

ACKNOWLEDGEMENTS

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REFERENCES

1. "Lower Lifetime Costs for Parking Structures with Latex Concrete Modifier," Dow Chemical U.S.A., Form No. 173-1089-80, Midland, Michigan.

2. Hilton, M. H., H. N. Walker, and W. T. McKeel, Jr., "Latex Modified Portland Cement Overlays: An Analysis of Samples Removed from Bridge Decks," VHTRC 76-R25, Virginia Highway & Transportation Research Council, Charlottesville, Virginia, November 1975.

3. "Special Provision for Latex Portland Cement Concrete Bridge Deck Repairs and Widening Work," Virginia Department of Highways & Transportation, April 28, 1982.

4. Road and Bridge Specifications, Virginia Department of Highways & Transportation, July 1, 1982, p. 180.

5. Tyson, S. S., and M. M. Sprinkel, "Two-Course Bonded Concrete Bridge Deck Construction, Interim Report No. 1, An Evaluation of the Technique Employed," VHTRC 76-R13, Virginia Highway & Transportation Research Council, Charlottesville, Virginia, November 1975, p. 42.

6. Harrier, D. C., Memorandum to M. M. Sprinkel, April 13, 1983.

7. Whiting, D., "Rapid Determination of the Chloride Permeability of Concrete," Report No. FHWA/RD-81-119, Federal Highway Administration, Washington, D. C., August 1981.

8. Schiedegger, Adrian E., "The Physics of Flow Through Porous Media," 3rd ed., Toronto, Canada, University of Toronto Press, 1974, p. 96.

9. Walker, Hollis N., Memorandum to Michael Sprinkel, April 23, 1984, File 26.4.29.64(84B).

10. Sprinkel, Michael M., "Effective Field Use of High-Range Water Reduced Concrete," Virginia Highway & Transportation Research Council, Charlottesville, Virginia, VHTRC 82-R24, November 1981, p. B-23.

11. Harrier, D. C., Memorandum to M. M. Sprinkel, Oct. 12, 1982, File 29.47.

12. Merolla, Alfred J., Dow Chemical, Richmond, Virginia, January 9, 1984, personal communication.

13. Landford Brothers Company, Inc., Roanoke, Virginia, January 9, 1984, personal communication.

14. Bishara, Alfred G., "Latex-Modified Concrete Bridge Deck Overlays: Field Performance Analysis," Transportation Research Record No. 785, Transportation Research Board, Washington, D. C., 1980.

15. Gebler, Steven, "Predict Evaporation Rate and Reduce Plastic Shrinkage Cracks," Concrete International, April 1983, pp. 19-20.

16. "Standard Practice for Curing Concrete," ACI 308-81, American Concrete Institute, Detroit, Michigan, 1981, 11 pp.

17. Kuhlmann, L. A., "Precast Latex Modified Concrete Overlayment on Box Beams," Dow Chemical Company, Midland, Michigan, August 1983.

18. "Use of Latex Modified Mortar and Concrete in the Restoration of Bridge Structures," and "Experimental Resurfacing of Chloride Contaminated Concrete Bridge Decks with Latex Modified Concrete," Annual Report of Activities of the Michigan Department of Transportation Research Laboratory, MDOT Report No. 359(A), Michigan DOT, 1983.

19. Nickerson, Robert L., and Phillip L. Chiu, "Report Evaluation of Bridge Deck Concrete Overlays," U.S. Department of Transportation, Federal Highway Administration, 1983.

20. Fincher, Howard E., "Evaluation of Chloride Ion Concentration in Bridge Decks with Latex Modified Concrete Overlays," Department of Highway Research & Training Center, West Lafayette, Indiana, June 1981.

21. Perenchio, W. F., and S. L. Marusin, "Short-Term Chloride Penetration into Relatively Impermeable Concretes," Concrete International, April 1983, p. 37.

22. Kuhlmann, L. A., "Latex Modified Concrete for Deck Repair and Rehabilitation," ASCE Specialty Conference on New Materials and Processes for Street, Highway, and Airport Rehabilitation, Fort Worth, Texas, March 1-3, 1983.

23. Reisky de Dubnic, John S., "An Evaluation of the Cost-Effectiveness of Latex Modified Concrete in Bridge Deck Overlays," Thesis in Humanities 402, School of Engineering and Applied Science, University of Virginia, Charlottesville, Virginia, March 27, 1984.

APPENDIX

Nomograph for Determining the Cost Effectiveness of Alternative Bridge Protective Systems.

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Midland, Michigan 48640

COST EFFECTIVENESS
OF
LMC OVERLAYS

The procedure described below uses present value analysis to evaluate and compare protection systems that have different initial costs and different lifetimes. Input for this calculation consists of interest rate, inflation rate, lifetime of the system, and initial cost.

Several decisions need to be made before proceeding. First, values for inflation rate and interest rate need to be assumed. Second, what are the lifetimes (years between installations) of the two systems that are being compared. For the following example 8 years for membranes, and 20 years for LMC were used.

The "planning horizon" can then be calculated. It is simply the lowest number that is wholly divisible by the lifetime of the two systems. For the example, it would be 40 since $40 \div 8 = 5$ and $40 \div 20 = 2$.

The "number of installations" is now known. That is the number of times each protection system would be installed during the planning horizon; 5 for membranes, 2 for LMC, in this example.

Finally, initial cost (or initial investment) needs to be determined. For membranes, \$15/yd^2 was used, for LMC, \$25/yd^2.

With these numbers, present value in \$/yd^2 can be calculated from the attached nomographs. Figure 1 is a layout of the nomograph showing location of the various input factors.

Figure 2 shows the calculation for membranes, which yielded a present value of \$46/yd^2.

Figure 3, the calculation for LMC, yielded a present value of \$37/yd^2, significantly lower than that for membranes.

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Figure 1
Nomograph Layout

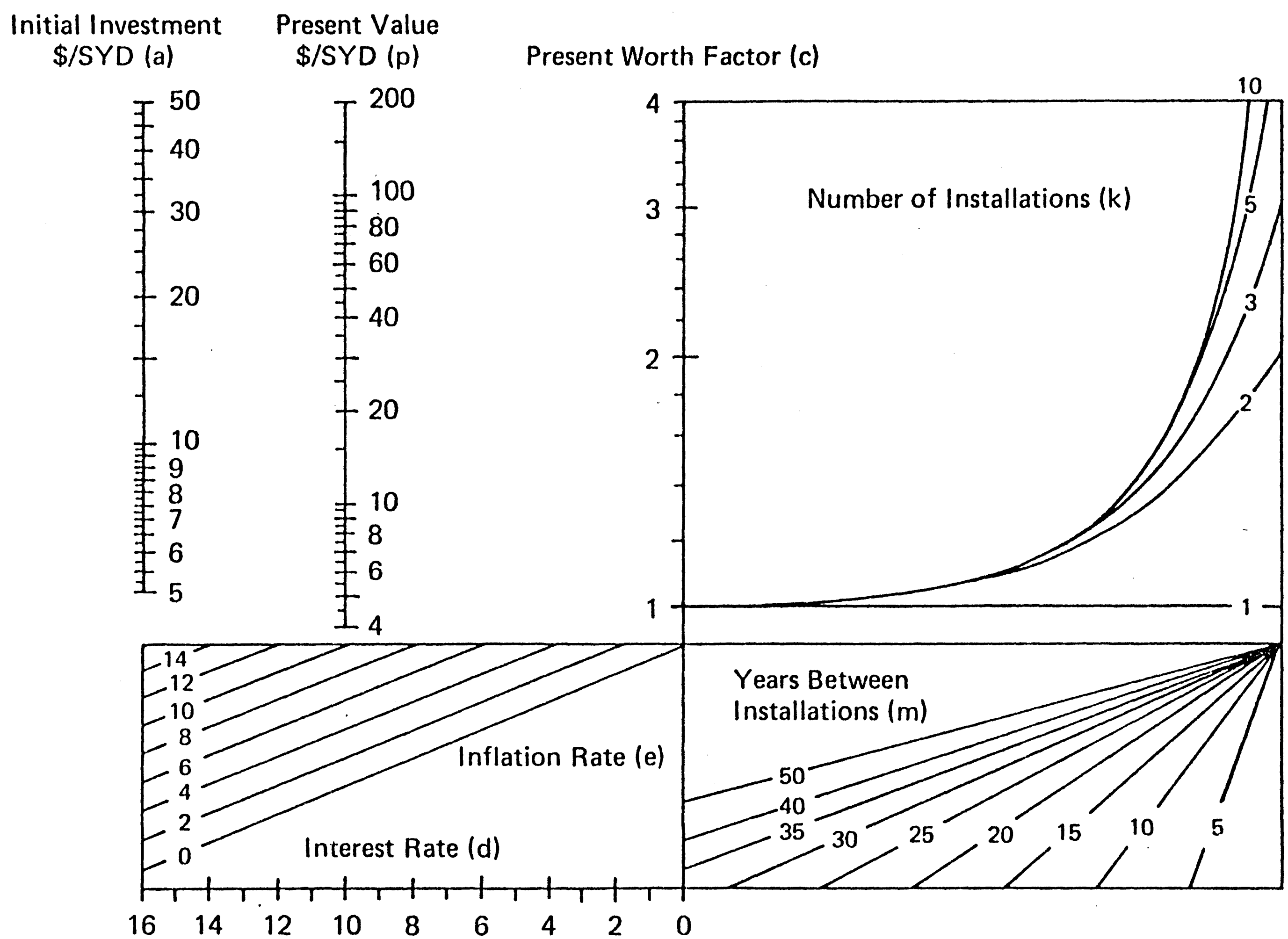


Figure 2
Membrane

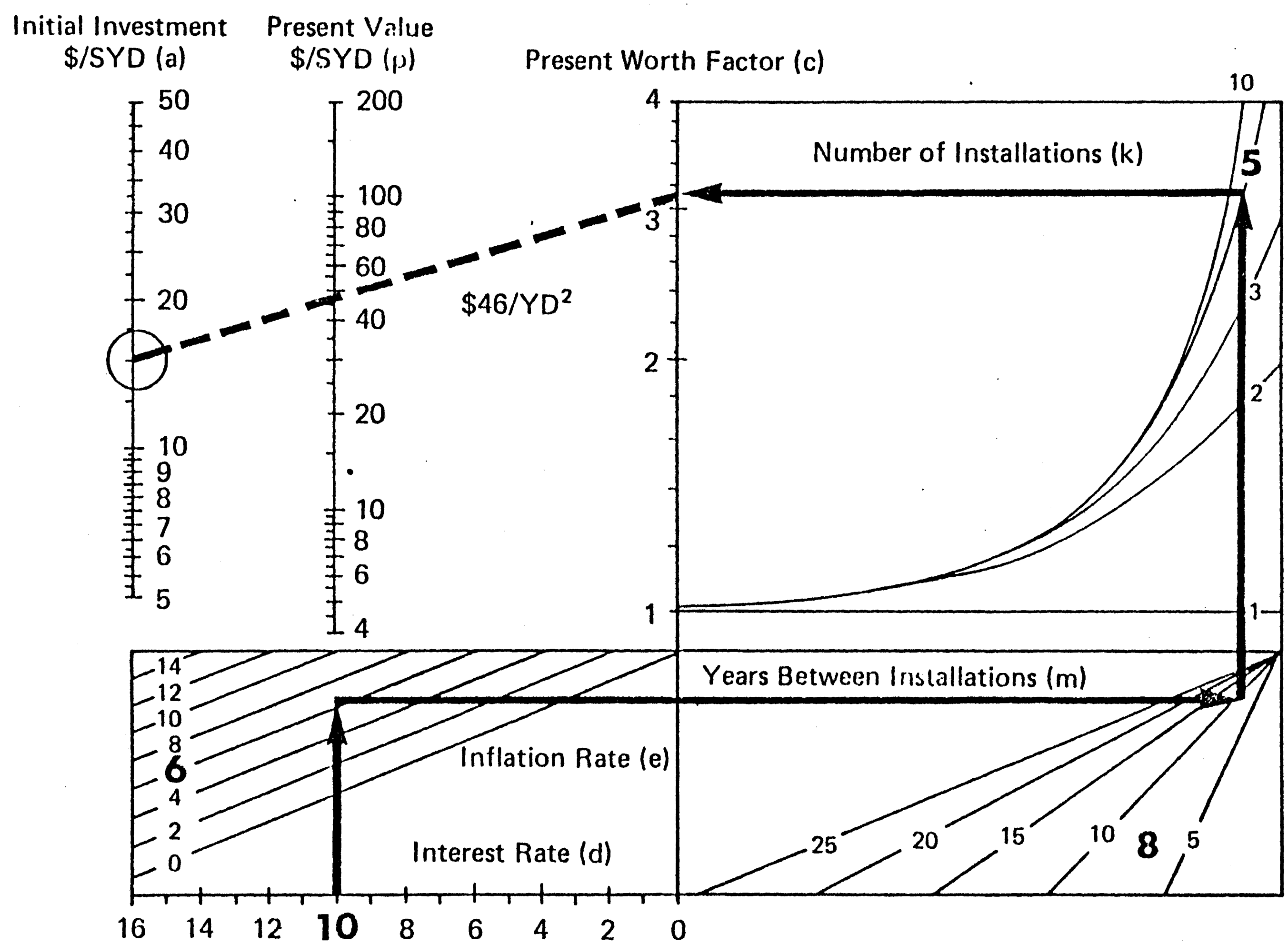
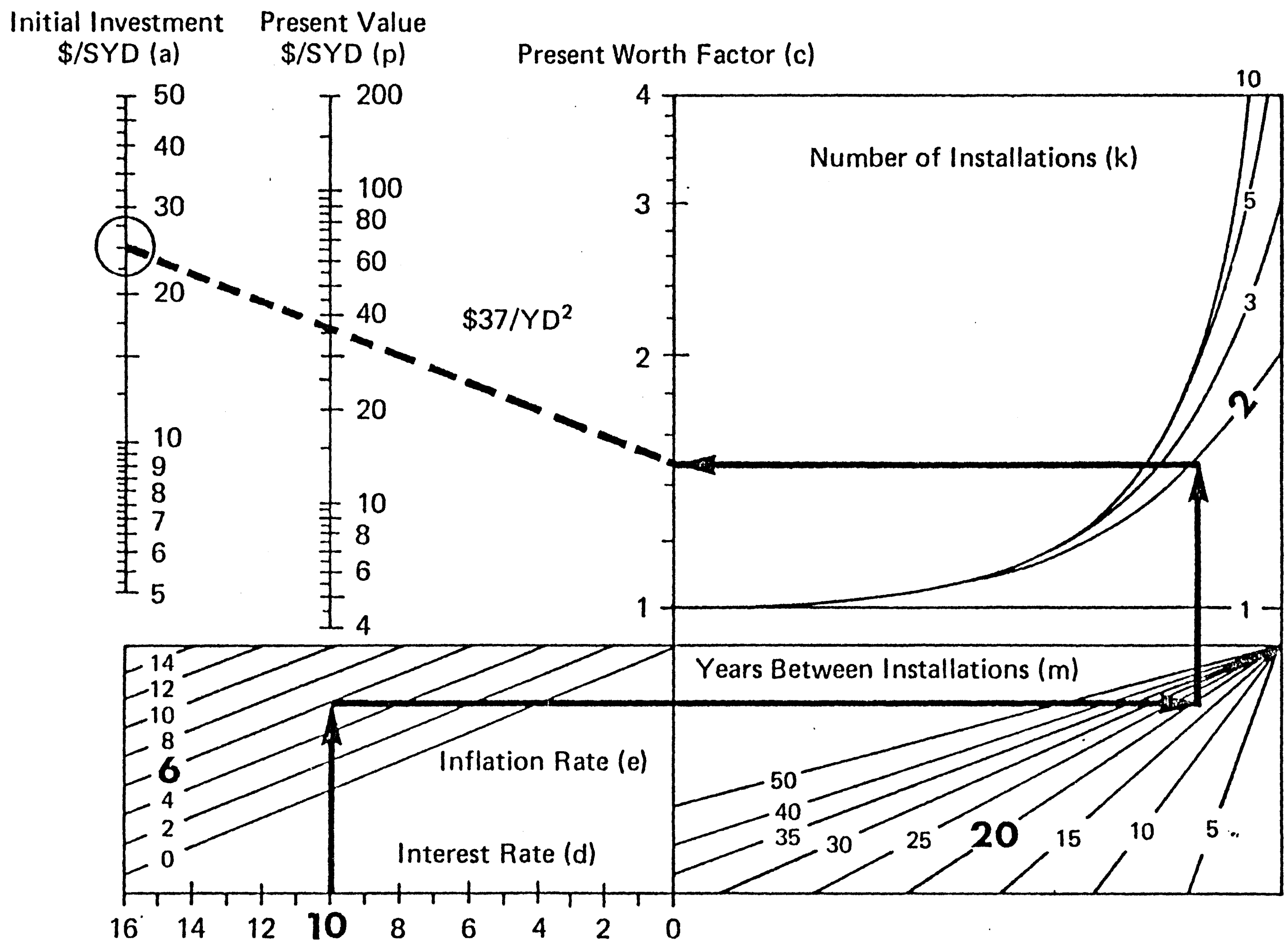


Figure 3
LMC



Initial Investment
$/SYD (a)
Present Value
$/SYD (p)
Present Worth Factor (c)
Number of Installations (k)
$37/YD2
Years Between Installations (m)
Inflation Rate (e)
Interest Rate (d)