CONTROL AND PREVENTION OF DETERIORATION OF CONCRETE BRIDGE DECKS

MICHIGAN DEPARTMENT OF STATE HIGHWAYS AND TRANSPORTATION

TESTING AND RESEARCH DIVISION
RESEARCH LABORATORY SECTION

CONTROL AND PREVENTION OF DETERIORATION OF CONCRETE BRIDGE DECKS

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The following is a brief summary report of the work performed on the subject Highway Planning and Research project. It is felt that, for reasons to be brought out later, this less detailed summary report is appropriate at this time.

The Problem

The problem statement of this study, as it was originally proposed to be undertaken from 1963 to 1965, was as follows:

> The Purpose of this study is to evaluate current Departmental principles and practices of structural design, construction, and maintenance, as to their effects on various types of deterioration of bridge deck concrete, and to develop methods of minimizing deterioration by improvements in design and construction or changes in maintenance procedures.

At the time the selected structures were being field inspected (1964) the Department began making significant changes in concrete bridge deck design and construction (to be covered later in the report) which would make many of the results of this study out-of-date. Nevertheless, we will attempt to document the Department's design, construction, and maintenance factors as of 1963 through 1965, and also the more recent changes to date.

Due to many changes in personnel and shifts in priorities of the Concrete and Surface Treatments Group, the results of this study were not reported earlier. The contents of this report reflect the views of the author who is responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

Scope of the Study

A complete field inspection was made on a representative number of structures of current (1963) design types to assay the types and degree of disintegration prevalent on concrete bridge decks. Numerous field surveys were made to review the 1963 to 1965 construction sequence of bridge decks with particular emphasis on pouring procedures such as batching, mixing, transportation, placement, consolidation, finishing, and curing of the bridge deck concrete.

An analysis was made of design features then in use on the basic types of structures. This included the concrete mix design as well as other related material factors such as concrete mixtures, aggregate type and gradation, air content, reinforcing steel, structural steel, reinforced concrete girder design, joint design, and drainage design features.

A statistical analysis was made to attempt to correlate the type and degree of disintegration with variables of design, construction, and maintenance to determine those of most significance so that improvements or changes in these areas could be made to minimize structure concrete deterioration.

Objectives

The primary objectives of the detailed field observations and the design and material study were:

1) To establish an itemized field inspection system for all types of structures including ratings of degree of various kinds of deterioration and associated climatic and maintenance data for each structure.

2) To determine all major variables of design, materials, and construction procedures relative to the basic types of structures studied in the field surveys.

3) To correlate statistically the data obtained in the first two objectives so that the most influential variables contributing to concrete deck disintegration may be determined.

4) Based on the above, recommend changes or improvements in design, construction, or maintenance to eliminate or minimize the various types of deterioration.

Research Procedure

The subject of the proposed study had become critically important and nationwide in interest by the early 1960's, particularly in states which had accelerated the use of snow and ice removal salts on highway structures. Problems associated with this study were summarized quite well by F. V. Reagel in his introduction to Highway Research Bulletin 323 (1). There are several papers in this symposium which described visual surveys of bridge deck deterioration in selected states. The Portland Cement Association's random survey and detailed study in five states referred to in Ref. (1) has been completed and described in a series of six reports (2). Their detailed study in Michigan (one of the subject states) was being compiled during the time of this H. P. & R. study. The P.C.A. study in Michigan involved 13 structures of which 11 were postwar, using air-entrained concrete.

A good account of Michigan's experiences in bridge deck construction and resulting durability problems was given in a paper by E. A. Finney (1). Two other papers on bridge construction procedures which offered helpful information toward this study are contained in Highway Research Bulletin 362 (3). A number of good reference papers were also presented in various sessions at the 1963 and 1964 Highway Research Board meetings in Washington, D. C., which described condition surveys of structures and defined variables associated with various construction phases, as well as repair techniques. In particular, Highway Research Record 11 (4) contained a paper by Orrin Riley on the bridge deck problem on the New Jersey Turnpike, and Highway Research Record 61 (5) had two similar papers by A. L. West of the Port of New York Authority, and E. W. Meeker of the Ohio Turnpike Authority. Since the 1963-1965 period of this study there has been a tremendous growth in research and documented reports of the bridge problem (e.g., 6, 7, 8, 9).

Field Inspection

The selection of the number, type, and location of Michigan structures for the detailed field survey was based on the following factors. All of the structures were post-World War II, constructed with air-entrained concrete. The majority of the structures were built in 1953-54 to compose a 10 year old group at the time of inspection. This age was selected in order to consider bridges having a reasonable exposure to weathering and de-icing chemicals, with the resultant development of deck deterioration to be assessed. A smaller group of structures built in 1958-59 was also inspected to assess the effects after about five years of service. Our basic concrete design was about the same for both age groups, namely; 5.5 or 5.9 sacks of Type 1A cement per cubic yard, depending on slump, and 6A or 6B gravel or crushed limestone, a 1-1/2-in. to No. 4 grading, very similar to ASTM C33, No. 467. The air entrainment range for the projects was 4 to 7 percent. The 5.5 or 5.9 sack mixes were for a 'dry' or 'medium' consistency of about 2-in., or 3 to 5 in. of slump. Most of the deck pours used the latter slump range with 5.9 sacks cement. The design cover for the top transverse steel was 1-1/2 in. to the center of the rebars for all the structures.

The groups of three basic structure types were selected to include samples of those in Michigan highway Districts 1 through 6, with a record of a lower salt usage, and Districts 7, 8, and Metro having a much higher usage. Districts 1 and 2 include Michigan's Upper Peninsula and Districts 3 through 6 include about the northern two-thirds of the Lower Peninsula. Districts 7, 8, and Metro (the latter consisting of four counties in the Detroit Metropolitan area) comprise the southern one-third of the Lower Peninsula (see Fig. 1). Table 1 lists the annual tonnage of sodium chloride (rock salt) used on state trunklines in the various Districts since 1956. The

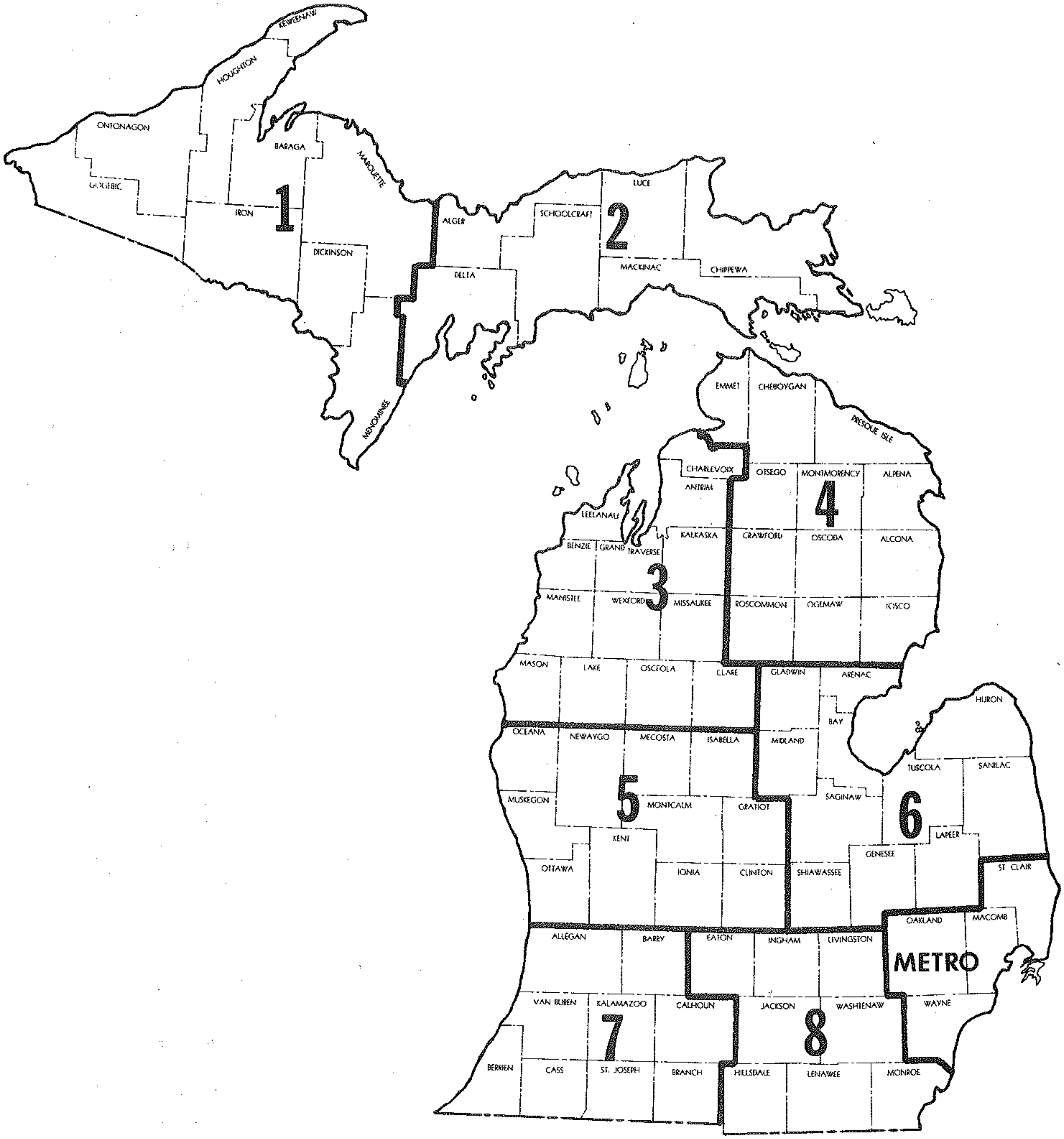

Figure 1. Michigan Districts for trunkline maintenance and salting.

TABLE 1

SUMMARY OF MICHIGAN ROCK SALT USAGE

Average Tons Per Two-Lane Mile by District, by Winter

District No.	Year														
	56-57	60-61	63-64	64-65	65-66	66-67	67-68	68-69	69-70	70-71	71-72	72-73	73-74	74-75	75-76
1	2.6	2.9	9.4	13.9	16.0	15.5	16.8	18.4	19.3	21.4	24.5	26.3	26.4	25.6	23.0
2	2.4	3.6	7.9	10.2	12.0	11.9	15.9	16.0	17.5	16.1	17.4	20.8	24.8	20.9	15.2
3	11.1	8.1	8.2	10.0	8.7	11.0	10.7	12.4	13.7	15.8	17.4	18.2	16.5	19.2	17.8
4	3.2	4.6	8.4	15.7	12.4	18.4	18.8	21.0	21.7	26.1	22.7	19.7	21.7	24.8	19.4
5	4.0	6.1	6.1	13.8	6.1	15.5	13.4	18.3	21.2	27.1	30.2	25.1	18.0	24.7	23.4
6	6.9	8.1	9.4	14.4	10.1	18.6	13.8	16.6	18.7	21.3	26.8	25.1	23.2	23.9	23.9
7	5.5	6.7	15.8	22.2	13.9	30.2	24.5	31.7	29.1	30.8	27.9	28.4	21.4	31.0	22.8
8*	12.3	10.3	14.4	26.4	14.7	32.6	19.0	20.6	20.9	27.2	24.4	28.1	21.2	25.6	19.5
Metro*	37.7	24.9	21.1	50.1	22.4	42.7	35.7	31.8	48.0	51.6	40.0	38.0	40.9	35.1	41.2
Total Tons (x 1,000)	109	96	137	244	153	281	238	265	323	346	335	330	301	334	313

* Figures adjusted from 1956 through 1971 to reflect present four counties in Metro District and addition of Monroe County to District 8.

general trend shows that the annual tonnage of de-icing salts has more than tripled since World War II. For the period of 1952 through 1964, which covers the bridges of this particular study, Districts 1 and 2 salt usage changed from about 4 to 11 percent of the annual total used. For Districts 3 through 6, the annual consumption changed very little, from 31 to 29 percent. In 1964, at the time of the field survey of this study, 58 percent of the road salt was used in the southern one-third of the state. It is of interest to note the increase in salt usage rates from 1963 to date, particularly in the upper 6 Districts. It appears that the total use of salt has essentially leveled off since 1969-70, with the tonnage used the last seven winters running in the 300,000 to 340,000 ton range, depending on the individual year's precipitation. These last few years, there does not appear to be a great difference in the rate of salt usage in Districts 1 through 8, but the rate in the four counties comprising the Metro District is about 1-1/2 to 2 times the other Districts.

The three types of bridge decks that were sampled and inspected were; 1) rolled steel I-beam structures, 2) steel plate girder types, and 3) reinforced concrete T-beams. These included 32 of the rolled beam decks, 11 of the plate girder type, and 10 of the reinforced concrete T-beam type.

Results of the Survey

As mentioned earlier, there have been so many concrete and deck design changes since 1963 that the results of this particular study have been negated. As would be expected, spalling of the concrete cover and transverse cracking over the top reinforcing steel were, by far, the most prevalent types of deterioration discovered. Very little scaling was noted on the decks in general. These have been well described in the P.C.A. detailed study of Michigan bridge decks in their Report No. 2 on the durability of concrete bridge decks in 1965 (2). Tables 2 and 3 list the 53 decks which were surveyed with the included cracking and spalling data. These data represent obsolete deck design factors but are included for general information.

Recent Design Changes

The most significant design changes, which started about 1962, have been in the concrete mix design, concrete clear cover requirements over the top steel, and, more recently, the use of epoxy coated top rebars with either single or two-stage construction.

In 1963, Michigan changed to a smaller coarse aggregate (1-in. maximum), 5 to 8 percent entrained air, and 6.0 sacks of cement per cubic yard of concrete. We began using water reducer-retarders in about 1965 in conjunction with machine finishing. Within the past few years we also started the use of a linseed oil based interim curing compound to be sprayed

TABLE 2
SUMMARY OF DESIGN AND INSPECTION DATA
ROLLED STEEL BEAM STRUCTURES

	Bridge No.	Project No.	District	Location	Year Built	ADT, Avg.	Cement Factor sk/cu yd	Coarse Aggregate Type	No. Spans	Total Length, ft	Deck Width, ft	Transverse Cracks		Spalls	
												Total	No./Span	Total	No./Span
Districts 1-6	1	B01-05011	3	US 31 over Elk River	1953	2,300	5.5	Gravel	3	137.5	46	11	3.8	3	1
	2	S11-25031	6	I 75 under Miller Rd	1954	*	5.9	Limestone	4	172.5	50	9	2.3	9	2.3
	3	B02-26032	6	M 30 over Sugar River	1953	600	5.9	Gravel	3	154.5	28	0	0	2	0.7
	4	B04-52043	1	US 41 over Chocolay River	1954	1,550	5.9	Gravel	2	90	38	0	0	0	0
	5	B02-64013	5	US 31 over Pentwater River	1953	3,700	5.5	Gravel	3	130	42	0	0	9	0
	6	B02-70063	5	WB I 96 over Crockery Creek	1953	3,650	5.5	Gravel	3	150	44	13	4.3	9	3
	7	B01-71021	4	M 68 over Rainy River	1954	900	5.5	Gravel	3	118.3	28	0	0	0	0
	8	B02-73062	6	M 46 over Tittabawassee River	1954	3,500	5.9	Gravel	7	525	2 @ 26	19	1.4	60	4.3
	9	B03-73062	6	M 46 over East Overflow	1953	3,500	5.9	Gravel	3	225	2 @ 26	2	0.3	12	2
	10	B07-75061	2	M 28 over Fox River	1953	800	5.9	Limestone	2	80	38	0	0	0	0
										Average			1.2		1.3
Districts 7-Metro	11	S01-11053	7	US 31 under EB Jean Klock Rd	1953	3,050	5.9	Limestone	3	146.5	28	0	0	0	0
	12	S02-11053	7	US 31 under WB Jean Klock Rd	1953	3,050	5.9	Limestone	3	147	28	3	1	1	0.3
	13	S03-11053	7	US 31 over Grand Blvd.	1953	6,100	5.9	Limestone	3	157	2 @ 26	13	2.2	4	0.7
	14	B01-46082	8	M 50 over Raisin River	1953	3,700	5.9	Limestone	3	145	38	0	0	0	0
	15	B02-58152	8	I 75 over Stony Creek	1954	6,250	5.9	Limestone	3	110	2 @ 30	6	1	7	1.2
	16	B03-58152	8	I 75 over Swan Creek	1954	6,250	5.9	Limestone	3	115	2 @ 40	25	4.2	18	3
	17	B04-58152	8	I 75 over Huron River	1953	6,250	5.9	Limestone	3	185	2 @ 30	14	2.3	4	0.7
	18	S21-77111	M	I 94 under Water St.	1952	*	5.9	Limestone	3	185.7	26	3	1	0	0
	19	X03-77111	M	I 94 over C & O RR	1953	10,000	5.9	Limestone	13	564	32	10	0.8	1	0.1
	20	S24-82023	M	SB US 10 over I 94	1952	31,000	5.9	Limestone	6	297.5	39.5	3	0.5	20	3.3
	21	S27-82023	M	NB US 10 over I 94	1952	31,000	5.9	Limestone	6	297.5	39.5	7	1.2	20	3.3
										Average			1.3		1.2
	22	B01-15051	3	M 32 over Arm of Lake Charlevoix	1958	550	5.9	Gravel	3	145	46	0	0	0	0
	23	B01-16051	4	M 33 over Cheboygan River	1957	1,300	5.9	Gravel	3	200	30	0	0	0	0
	24	B01-49041	2	M 134 over Pine River	1958	600	5.5	Gravel	3	180	30	0	0	0	0
	25	B02-52011	1	M 95 over Trout Falls Creek	1958	700	5.5	Gravel	3	129	30	0	0	0	0
	26	B03-52011	1	M 95 over Michigamme River	1958	700	5.9	Gravel	4	260	30	0	0	0	0

* Information not available.

TABLE 3

SUMMARY OF DESIGN AND INSPECTION DATA

STEEL PLATE GIRDER AND CONCRETE T-BEAM STRUCTURES

	Bridge No.	Project No.	District	Location	Year Built	ADT, Avg.	Cement Factor sk/cu yd	Coarse Aggregate Type	No. Spans	Total Length, ft	Deck Width, ft	Transverse Cracks		Spalls	
												Total	No./Span	Total	No./Span
Steel Plate Girder	27	B01-62031	5	M 37 over Muskegon River	1953	3,150	5.5	Limestone	5	555	2 @ 24	114	11.4	42	4.2
	28	B01-64012	5	US 31 over Pentwater River	1954	3,900	5.5	Gravel	3	268	2 @ 26	11	1.8	3	0.5
									Average				6.6		2.4
	29	B01-11101	7	US 12 over St. Joseph River	1954	4,400	5.9	Limestone	5	480	2 @ 26	48	4.8	46	4.6
	30	S22-82023	M	SB US 10 over I 94 Ramp	1952	31,000	5.9	Limestone	3	232	39.5	26	8.7	25	8.3
	31	S29-82023	M	NB US 10 over I 94 Ramp	1952	31,000	5.9	Limestone	3	224	39.5	17	5.7	28	9.3
									Average				6.4		7.4
	32	B01-66041	1	M 38 over Firesteel River	1958	450	5.5	Gravel	3	240	28	0	0	0	0
	33	B01-34044	5	EB I 95 over Grand River	1958	3,250	5.9	Gravel	4	414	30	84	21	1	0.3
	34	S04-41024	5	Whitneyville Rd. over I 96	1959	light	5.9	Limestone	4	276	26	19	4.8	2	0.5
									Average				8.6		0.3
Reinforced Concrete T-Beam	35	B01-04012	4	M 65 over Thunder Bay River	1953	600	5.5	Gravel	5	203	28	0	0	2	0.4
	36	S01-38101	8	I 94 over Parma Rd.	1953	5,000	5.9	Limestone	3	146	2 @ 44	74	12.3	14	2.3
	37	B01-46062	8	US 223 over Raisin River	1953	6,500	5.9	Gravel	3	150	38	61	20.3	13	4.3
	38	S03-58152	8	Nadeaux Rd. over I 75	1954	local (light)	5.9	Limestone	4	267	26	60	15	4	1
	39	S06-58152	8	Sigler Rd. over I 75	1954	local (light)	5.9	Limestone	4	262	26	6	1.5	1	0.3
	40	S08-58152	8	S. Huron River Drive over I 75	1954	local (light)	5.9	Limestone	4	189	28	78	19.5	6	1.5
	41	S06-81062	8	Stone School Rd. over I 94	1953	local (light)	5.9	Limestone	4	172	26	0	0	0	0
									Average				11.4		1.6
	42	S05-16092	4	M 108 over I 75	1959	*	5.5	Limestone	4	283	26	13	3.3	20	5.0
	43	S03-80024	7	M 40 over I 94	1959	1,900	5.9	Limestone	4	316	48	95	23.8	3	0.8
									Average				13.6		2.9

* Information not available.

on the fresh concrete soon after finishing to prevent early shrinkage cracking. Wet burlap cure is then applied the next day for a six-day period. In about 1965, full-width pours were employed which eliminated longitudinal construction joints which proved to be the locus of spalling on many of the surveyed decks.

Our current mix design started in 1973 and uses 7.0 sacks of cement per cubic yard of concrete, maximum 3-1/2-in. slump, maximum 0.49 water-cement ratio, 5 to 8 percent entrained air, a 1-in. maximum coarse aggregate, and requires the use of water reducers or water reducer-retarders. This latter mix is used with either single or two-stage construction. We began using the two-stage deck design this year in all freeway and high traffic area construction. The second stage can be either 1-1/2 in. of latex modified concrete or 2 in. of a rich, low slump mix (Iowa type) with a total clear cover over the top rebar of 3 in. This latter exceeds the recommendations of the FHWA Program Manual (April 5, 1976). Epoxy coated top rebars are also required with these overlays.

Changes in design cover have occurred in several steps beginning in 1962, or just before this study was to start. All of the decks in this study (Tables 2 and 3), and those designed up to 1962, called for a 1-1/2-in. minimum to the center of the top transverse steel. The changes in this top steel cover were to 2 in. in 1962, 2-1/2 in. in 1966, and 2-7/8 in. in 1968 to the center of the rebar. Michigan went to 3 in. of clear cover this year, 1976. In lower traffic areas, single-stage construction is now called for with this 3-in. clear cover and epoxy coated rebars in the top mat.

Conclusions

As has been previously described, this concrete bridge deck study of 1963 through 1965 was concerned with decks having design parameters undergoing changes at the time, and now obsolete. We have seen more changes in the concrete mix and deck design in the last 15 years than, perhaps, the previous 50 years. Our recent changes to 3 in. of clear cover, lower water-cement ratio concrete of less permeability, epoxy coated rebars for the top mat, and thin bonded overlays of low permeability are all steps in the right direction for obtaining long lasting decks exposed to deicing salt usage. It would appear that the continued judicious use of salt will be required to maintain safe winter driving conditions on Michigan's trunklines. Additional new developments in deck protective systems will be forthcoming from research underway by many state and private agencies, as well as the FHWA. Many of these systems were discussed at a recent Research Review Conference in September 1976, at Penn State University. Some of these include galvanized rebars, waterproofing membranes, polymer impregnation, and internally sealed concrete. The economic feasibility of these and other systems will have to be carefully weighed along with performance in light of ever increasing energy costs.

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