A REVIEW OF BRIDGE DECK PROBLEMS, AND A FINAL REPORT ON THE PERFORMANCE OF SEVERAL BERRIEN COUNTY STRUCTURES THAT WERE WIDENED UNDER TRAFFIC

MICHIGAN RESEARCH LABORATORY SECTION

MICHIGAN DEPARTMENT OF
STATE HIGHWAYS AND TRANSPORTATION

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C. J. Arnold
M. A. Chiunti
K. S. Bancroft

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Testing and Research Division
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Peter B. Fletcher, Chairman; Carl V. Pellonpaa,
Vice-Chairman, Hannes Meyers, Jr., Weston E. Vivian
John P. Woodford, Director
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This report will terminate Research Project 65 F-84 concerning the widening of numerous Berrien County structures on I 94, and will also incorporate relevant information related to bridge deck performance and deterioration. Specific information concerning deterioration of the I 94 structures and the present condition of the widened portions of the decks is included later in the report.

GENERAL SUMMARY OF BRIDGE DECK PROBLEMS AND PERFORMANCE

The following is a summary of points that have been shown to be important; based on analysis of our own research, information from other states, observations made on numerous decks during construction, and evaluation of their performance over many years thereafter.

Concrete Quality

Excess water in the mix appears to be the primary factor in deck deterioration, and along with concrete cover variations comprise the major variables determining the performance of otherwise identical decks. "Excess" in this case means simply a sufficient quantity to separate from the mix, and locally accumulate under the conditions of vibration that exist at the site. Tiny fountains of clear water were observed springing from the surface of one of the I 94 decks during widening under traffic. Vibration of the newly placed deck was severe due to truck traffic on adjacent lanes. This was merely an accelerated case of a phenomenon that also occurs in some new decks where localized accumulation of water, and deck "rippling," result from structural vibrations caused by construction activities. It is well known that relatively small increases in water/cement ratio in the mix can cause large increases in the average permeability of the concrete and the amount of chlorides that can penetrate the deck. (See for instance, "Durability of Concrete Bridge Decks, A Cooperative Study," by several State Highway Departments, FHWA and the Portland Cement Association, 1970.) However, average permeability is not the entire problem. Job conditions can cause extremely high water/cement ratios at selected layers in the decks, causing sieve-like porosity at those locations, and associated concrete strengths that approach zero. Evidence here in Michigan, and in other states, shows that when decks delaminate at an early age, they fail along a built in plane-of-weakness. This "fracture plane" generally follows a horizontal, undulating pattern with the top rebars at the low points of the plane. Examination of fragments shows that the failure plane is porous and very weak, and is bounded above and below by higher quality concrete. A hollow area in an uncracked portion of one of the Berrien County structures was examined. Removal of a layer of high quality concrete above the fracture plane, revealed that the separation had occurred at a plane approximately 1/8-in. thick, that was composed of sand rubble. This plane obviously was the remains of an area that had a very high localized concentration of water when the deck initially set. The tiny fountains of crystal-clear water, noted above, had to originate from a subsurface "lake." Subsequent evaporation of the "lake" would leave a lens, like the one found, so porous and weak it could not long survive the effects of weather and traffic.

Admittedly, the conditions on the widened structures were harsh. The evidence is clear, however, that on construction sites throughout the State similar weakened planes have been formed, though not generally of the severity noted on the widened structures. Typical fracture plane delamination on hundreds of structures testifies to the presence of a weak high water content zone sufficient to eventually precipitate failure.

Coated rebar cannot be expected to completely solve deck failure problems that result from severe planes of weakness, although such decks should last longer than those using bare steel, because the expansive pressures associated with corrosion at the bar would be delayed, reduced, or prevented. However, the deleterious effects of salt, frost, and traffic can be expected to take their toll, if the severely weakened plane exists. Prevention of such action requires the limitation of water content in the mix, insofar as possible. Water reducers and water-reducing retarders should be beneficial in this respect, and it appears that the improved mix designs of recent years should be better than those used in the older structures now decaying.

Michigan specifications, at the time the widened portions of the Berrien County decks were built, called for approximately six sacks of cement/cu yd. Water/cement ratios ranged about 6 gal/sack. More recent specifications require seven sacks of cement/cu yd, 3-1/2 in. maximum slump, water/cement ratios are limited to 5-1/2 gal/sack maximum, and typical values have been 5 to 5-1/4 gal/sack. Water reducers and water-reducing retarders have been used extensively and are now required, and specified cover over rebars has been increased. New specifications call for coated bars, with 3 in. of cover on some decks or 1-1/2 in. of cover plus 1-1/2 in. of low permeability bonded overlay in areas of heavy traffic. These changes should go a long way in improving deck performance.

Rebar Coating

Coated rebar should aid considerably in providing longer lasting bridge decks. Both epoxy coatings and galvanizing are candidates. Theoretical considerations concerning possibilities of galvanic corrosion have caused the FHWA to recommend coating all rebar in the deck rather than just the top mat if galvanizing is used. There is an obvious advantage to having all rebar at the same potential. Michigan now has five experimental structures, approximately four years old, with galvanized rebar in the top mat on half of each deck.

The State of Pennsylvania apparently has the most extensive experience with corrosion-resistant reinforcement. Generally, it appears that they coat all rebar in deck, sidewalks, and railings when galvanizing is specified for a structure. Recent information from that state indicates the following costs for projects through October 1975.

Galvanized Rebar	22,233,000 lb, average cost $.57/lb
Uncoated Rebar	18,139,000 lb, average cost $.43/lb
	Average cost of galvanizing $.14/lb
Epoxy Coated Rebar	6,412,000 lb, average cost $.75/lb
Uncoated Rebar	7,099,000 lb, average cost $.36/lb
	Average cost of epoxy coating $.39/lb

During September, a large number of bridges were let with galvanized bars at an average cost of $.13/lb for galvanizing. The cost of zinc metal was reported to have fallen by $.02/lb.

Three experimental structures let last June in Michigan, were four-span structures with deck reinforcing steel in one span uncoated, one span galvanized, and one span each of two different epoxy coatings. Both the top and bottom mats will be coated on these structures. Bid prices were as follows:

For S13 of 81103 and S02 of 82102:

Epoxy Coated Rebar	168,000 lb	$.50/lb
Galvanized Rebar	36,300 lb	$.40/lb
Uncoated Rebar	877,300 lb	$.27/lb
	Average cost of galvanizing $.13/lb	
	Average cost of epoxy coating $.23/lb	

For S04 of 58152:

Epoxy Coated Rebar	99,000 lb	$.46/lb
Galvanized Rebar	19,900 lb	$.46/lb
Uncoated Rebar	201,200 lb	$.38/lb
	Average cost of either coating $.08/lb	

The prices of coated rebars on our projects undoubtedly were affected to some extent by the experimental nature of the bridges, the relatively small quantities involved, the type of epoxy coatings used, and the method of application.

Recent information concerning performance of galvanized bars has been contradictory, leading to hesistance in further specification of such coatings for deck reinforcement. This Laboratory is currently studying a set of simulated deck sections with galvanized and uncoated bars that have been under heavy salt treatment for six years. Cores have been taken from the specimens and will be analyzed in the near future to examine the condition of the bars and the amount of salt that has penetrated the concrete.

Method of Deck Construction (One or Two Lifts)

Interest has developed recently in the construction of decks with overlays of relatively impermeable concrete. Also, decks with coated top mat and 3-in. minimum specified cover should provide significant increases in performance. There seems to be a considerable difference in the ease of construction between the single and two-lift methods. It appears that the probability of success in constructing the deck as designed is far greater in the case of the single lift method. Probability of shrinkage cracking over the transverse bars decreases very significantly with increasing cover. Also, there is difficulty in properly placing and bonding a thin overlay during hot or windy weather conditions. The so-called "Iowa Method" requires the ultimate in compactive effort to obtain low permeability. If not properly consolidated, it can be more porous than normal deck concrete. Therefore, from a practical point of view, it appears that the single-lift construction will be most satisfactorily done, especially until Michigan contractors gain experience in placing the overlays.

SPECIFIC INFORMATION ON BERRIEN COUNTY STRUCTURES

Background Information

During the 1965 construction season, work was begun on widening 110 spans of 34 structures on I 94 in Berrien County. The Department specified that traffic be maintained during widening on all except the St. Joseph River bridges, where it was diverted to the opposite roadway. Early in the construction program it became obvious that traffic on the bridges would subject the new deck sections to severe vibration during placement and curing of the concrete. The Construction Division made arrangements to place temporary shoring on some of the structures, and requested that the Research Laboratory make measurements to determine the effectiveness of the shoring in reducing vibration of the newly placed deck sections.

Based on the results of initial experimentation, it was decided that temporary shoring should be placed on 44 of 94 spans to be widened under traffic. The Federal Highway Administration agreed to participate in the cost of shoring as an experimental construction procedure.

Evaluation

Research Laboratory representatives were at the site to observe placement of most of the decks. Initial condition surveys were made on all structures after construction was completed, and yearly surveys have been made since then with the exception of 1972. The method of inspection consisted of visual observation of the decks, and recording estimated crack lengths and square footage of hollow areas and fracture plane separations (spalling) on prepared sketches. With the exception of the 1975 survey, hollow areas were located by taking soundings with a hammer and outlining the hollow areas on the widened portion of the bridge deck. The latest survey taken in mid-October 1975, utilized a delamination detector to locate the hollow areas.

Table 1 gives the data from five surveys made during the past six years. The types of deterioration noted are cracks, hollow areas, and fracture plane separations. The deterioration for each deck is calculated as lin ft per 100 sq ft of widened deck area for cracks, and sq ft per 100 sq ft of widened deck area for the hollow areas and fracture plane separations. The increase in deterioration from the previous inspection is expressed in percent. With the use of the delamination detector, a much

TABLE 1
PROGRESSIVE DETERIORATION OF BRIDGE DECK WIDENINGS
(per hundred sq ft of area)

Structure	Supported	1970								1971								1973							
		Additional Deterioration					Total to Date			Additional Deterioration					Total to Date			Additional Deterioration					Total to Date		
		Cracks	Hollow Areas		Fracture Plane Separations		Cracks	Hollow Areas	Fracture Plane Separations	Cracks	Hollow Areas		Fracture Plane Separations		Cracks	Hollow Areas	Fracture Plane Separations	Cracks	Hollow Areas		Fracture Plane Separations		Cracks	Hollow Areas	Fracture Plane Separations
		lin ft	sq ft	Percent Increase	sq ft	Percent Increase	lin ft	sq ft	sq ft	lin ft	sq ft	Percent Increase	sq ft	Percent Increase	lin ft	sq ft	sq ft	lin ft	sq ft	Percent Increase	sq ft	Percent Increase	lin ft	sq ft	sq ft
S01 of 11015 EB	Yes	0.52	0	--	0.72	--	0.52	0	0.72	0	1.23	--	0.44	60	0.52	1.23	1.16	0	3.90	315	0.44	40	0.52	5.13	1.60
S02 of 11015 WB	Yes	0	0	--	0.83	--	0	0	0.83	0	0.32	--	0	--	0	0.32	0.83	0.19	0.51	160	0.19	25	0.19	0.83	1.02
X02 of 11015 EB	No	0	0	--	0	--	0	0	0	0	0	--	0	--	0	0	0	0	0.32	--	0.08	--	0	0.32	0.08
X01 of 11015 WB	No	0	0	--	0	--	0	0	0	0.74	0	--	0	--	0.74	0	0	0.78	0.11	--	0.01	--	1.52	0.11	0.01
B01 of 11015 EB	No	0	0	--	0	--	0	0	0	0	0.05	--	0	--	0	0.05	0	0.56	0.20	400	0.05	--	0.56	0.25	0.05
B01 of 11015 WB	No	0.41	0	--	0	--	0.41	0	0	0	0	--	0	--	0.41	0	0	5.23	0.20	--	0.05	--	5.64	0.20	0.05
X03 of 11015 EB	No	0	0	--	0	--	0	0	0	0	0.54	--	0	--	0	0.54	0	0	1.27	235	0.12	--	0	1.81	0.12
X03 of 11015 WB	No	0	0	--	0	--	0	0	0	0	5.15	--	0	--	0	5.15	0	0	1.75	35	0	--	0	6.90	0
S10 of 11015 EB	Yes	0	0	--	0.13	--	0	0	0.13	0	0.81	--	0.27	205	0	0.81	0.40	0	0.67	80	0.27	65	0	1.48	0.67
S10 of 11015 WB	Yes	0.81	0	--	0	--	0.81	0	0	0	0.06	--	0.03	--	0.81	0.06	0.03	1.30	0.68	115	0.	--	2.11	0.74	0.03
S12 of 11015 EB	Yes	0	0	--	0	--	0	0	0	0	0.78	--	0.07	--	0	0.78	0.07	0	1.43	185	0.20	285	0	2.21	0.27
S12 of 11015 WB	Yes	0	0	--	0.05	--	0	0	0.05	0	0.20	--	0.02	40	0	0.20	0.07	0.78	0.64	320	0	--	0.78	0.84	0.07
S13 of 11015 EB	No	0	0	--	0	--	0	0	0	1.46	0.05	--	0	--	1.46	0.05	0	0.29	0.70	1,400	0	--	1.75	0.75	0
S13 of 11015 WB	No	0	0	--	0	--	0	0	0	0	0.05	--	0.02	--	0	0.05	0.02	0.30	0	--	0	--	0.30	0.05	0.02
X04 of 11015 EB	No	0	0	--	0	--	0	0	0	0	0	--	0	--	0	0	0	0	0	--	0	--	0	0	0
X04 of 11015 WB	No	0.99	0	--	0	--	0.99	0	0	1.48	0	--	0	--	2.47	0	0	0	0	--	0	--	2.47	0	0
S16 of 11015 EB	Yes	0	0	--	0.78	--	0	0	0.78	0.65	1.04	--	0.19	25	0.65	1.04	0.97	0	1.96	190	0.32	35	0.65	3.00	1.29
S16 of 11015 WB	Yes	0	0	--	0	--	0	0	0	0	0.84	--	0.06	--	0	0.84	0.06	0	0.84	100	0.81	1,350	0	1.68	0.87
S17 of 11015 EB	Yes	0	0	--	1.67	--	0	0	1.67	1.78	3.24	--	0	--	1.78	3.24	1.67	0	1.41	45	1.04	60	1.78	4.65	2.71
S17 of 11015 WB	Yes	0	0	--	0	--	0	0	0	0	1.30	--	0.75	--	0	1.30	0.75	0	0.57	45	0.31	40	0	1.87	1.06
X05 of 11015 EB	No	0	0	--	0	--	0	0	0	0	0	--	0	--	0	0	0	0.30	0.10	--	0.06	--	0.30	0.10	0.06
X05 of 11015 WB	No	0	0	--	0	--	0	0	0	1.43	0.51	--	0.08	--	1.43	0.51	0.08	1.12	0.88	175	0.03	40	2.55	1.39	0.11
B02 of 11015 EB	No	0	0	--	0	--	0	0	0	0	0	--	0.06	--	0	0	0.06	0	0	--	0	--	0	0	0.06
B02 of 11015 WB	No	0	0	--	0	--	0	0	0	0	0	--	0	--	0	0	0	1.36	0	--	0	--	1.36	0	0
S21 of 11015 EB	No	0	0	--	0	--	0	0	0	0	0	--	0	--	0	0	0	0	0	--	0	--	0	0	0
S21 of 11015 WB	No	0	0	--	0	--	0	0	0	0	0.04	--	0	--	0	0.04	0	0.37	0	--	0	--	0.37	0.04	0
B01 of 11016 EB	No	0	0	--	0	--	0	0	0	0.95	0.23	--	0	--	0.95	0.23	0	0.14	0.14	60	0.02	--	1.09	0.37	0.02
B01 of 11016 WB	No	0.29	0	--	0	--	0.29	0	0	0	0.15	--	0.04	--	0.29	0.15	0.04	1.77	0.41	275	0.11	275	2.06	0.56	0.15
S01 of 11016 EB	Yes	0	0	--	0	--	0	0	0	0	0.31	--	0	--	0	0.31	0	0	0	--	0	--	0	0.31	0
S01 of 11016 WB	Yes	0	0	--	0	--	0	0	0	0	0.07	--	0	--	0	0.07	0	1.26	0.52	745	0.07	--	1.26	0.59	0.07
S03 of 11016 EB	Yes	0	0	--	0	--	0	0	0	0.27	0	--	0	--	0.27	0	0	0.38	0	--	0	--	0.65	0	0
S03 of 11016 WB	Yes	0.17	0	--	0	--	0.17	0	0	0.40	0	--	0.01	--	0.57	0	0.01	1.49	0	--	0.03	300	2.06	0	0.04
X01 of 11016 EB	No	Bridge Deck Covered with Epoxy Surface Treatment																							
X01 of 11016 WB	No	Bridge Deck Covered with Epoxy Surface Treatment																							

TABLE 1 (Cont.)
PROGRESSIVE DETERIORATION OF BRIDGE DECK WIDENINGS
(per hundred sq ft of area)

Structure	Supported	1974								1975							
		Additional Deterioration					Total to Date			Additional Deterioration					Total To Date		
		Cracks	Hollow Areas		Fracture Plane Separations		Cracks	Hollow Areas	Fracture Plane Separations	Cracks	Hollow Areas*		Fracture Plane Separations		Cracks	Hollow Areas	Fracture Plane Separations
		lin ft	sq ft	Percent Increase	sq ft	Percent Increase	lin ft	sq ft	sq ft	lin ft	sq ft	Percent Increase	sq ft	Percent Increase	lin ft	sq ft	sq ft
S01 of 11015 EB	Yes	0	1.58	30	0	--	0.52	6.71	1.60	0	20.0	300	1.53	95	0.52	26.71	3.13
S02 of 11015 WB	Yes	0	0.22	25	0	--	0.19	1.05	1.02	0	7.0	665	1.09	105	0.19	8.05	2.11
X02 of 11015 EB	No	0	0	--	0	--	0	0.32	0.08	1.52	6.0	1,875	0.12	150	1.52	6.32	0.20
X01 of 11015 WB	No	0	0.14	125	0	--	1.52	0.25	0.01	0	2.0	800	0.08	800	1.52	2.25	0.09
B01 of 11015 EB	No	0	0	--	0	--	0.56	0.25	0.05	0	2.0	800	0	---	0.56	2.25	0.05
B01 of 11015 WB	No	0	0	--	0	--	5.64	0.20	0.05	0	0.4	175	0	---	5.64	0.55	0.05
X03 of 11015 EB	No	0	0	--	0	--	0	1.81	0.12	0.55	8.0	440	0.36	300	0.55	9.81	0.48
X03 of 11015 WB	No	0	0.24	5	0.12	--	0	7.14	0.12	0	17.0	240	1.52	1,265	0	24.14	1.64
S10 of 11015 EB	Yes	0	0.27	20	0	--	0	1.75	0.67	0.34	9.0	515	0.14	20	0.34	10.75	0.81
S10 of 11015 WB	Yes	0	0.06	10	0.03	100	2.11	0.80	0.06	0	2.0	250	0.20	335	2.11	2.80	0.26
S12 of 11015 EB	Yes	1.02	0.17	10	0.17	65	1.02	2.38	0.44	0	12.0	505	0.04	10	1.02	14.38	0.48
S12 of 11015 WB	Yes	1.11	0.58	70	0	--	1.89	1.42	0.07	0.79	6.0	425	0.09	130	2.68	7.42	0.16
S13 of 11015 EB	No	0	0	--	0	--	1.75	0.75	0	0	8.0	1,065	0.06	---	1.75	8.75	0.06
S13 of 11015 WB	No	0.99	1.16	2,320	0.02	100	1.29	1.21	0.04	0	17.0	1,405	0	---	1.29	18.21	0.04
X04 of 11015 EB	No	0	0	--	0	--	0	0	0	0	0	---	0	---	0	0	0
X04 of 11015 WB	No	0	0	--	0	--	2.47	0	0	0	0	---	0	---	2.47	0	0
S16 of 11015 EB	Yes	0	5.22	175	0	--	0.65	8.22	1.29	0	25.0	305	0.07	5	0.65	33.22	1.36
S16 of 11015 WB	Yes	0	1.42	85	0.64	75	0	3.10	1.51	0	24.0	775	0.07	5	0	27.10	1.58
S17 of 11015 EB	Yes	0	1.04	20	0.36	15	1.78	5.69	3.07	0	25.0	440	3.67	120	1.78	30.69	6.74
S17 of 11015 WB	Yes	0	1.93	105	0.78	75	0	3.80	1.84	0	25.0	660	0.84	45	0	28.80	2.68
X05 of 11015 EB	No	0	0	--	0	--	0.30	0.10	0.06	0.14	2.0	2,000	0	---	0.44	2.10	0.06
X05 of 11015 WB	No	0.47	0.64	45	0.34	310	3.02	2.03	0.45	0.72	12.0	590	0.87	195	3.74	14.03	1.32
B02 of 11015 EB	No	0	0	--	0	--	0	0	0.06	0	15.0	---	0	---	0	15.00	0.06
B02 ot 11015 WB	No	0.45	0.45	--	0	--	1.81	0.45	0	0	11.0	2,445	0	---	1.81	11.45	0
S21 of 11015 EB	No	0	0	--	0	--	0	0	0	0	0.2	---	0	---	0	0	0
S21 of 11015 WB	No	0	0.18	450	0	--	0.37	0.22	0	0	0.4	195	0.09	---	0.37	0.65	0
B01 of 11016 EB	No	0.20	0.05	15	0	--	1.29	0.42	0.02	2.10	2.0	475	0.13	650	3.39	2.42	0.15
B01 of 11016 WB	No	1.43	0.25	45	0	--	2.49	0.81	0.15	0	0.8	105	0.09	60	2.49	1.66	0.24
S01 of 11016 EB	Yes	Resurfaced								Resurfaced							
S01 of 11016 WB	Yes	Resurfaced								Resurfaced							
S03 of 11016 EB	Yes	0	0	--	0	--	0.65	0	0	3.85	1.0	---	0	---	4.50	1.00	0
S03 of 11016 WB	Yes	0	0	--	0	--	2.06	0	0.04	0	0.1	---	0	---	2.06	0.08	0.04
X01 of 11016 EB	No																
X01 of 11016 WB	No																

* Delamination detector used.

larger increase in hollow areas was observed during the 1975 survey. Since the delamination detector is a more precise method for locating hollow areas than the hammer soundings, the large increase in hollow areas can be partially attributed to the inaccuracy of the hammer sounding method and thus more accurately indicates actual deterioration of the decks. Even though it wasn't until the 1970 inspection that the hollow areas and fracture plane separations became prominent enough to record, they have increased steadily since that time. As given in Table 2, the hollow areas noted in the 1975 surveys increased 500 percent, and the fracture plane separations increased 90 percent over the 1974 total accumulation. During the years that the surveys were performed, it was noted that an increase in hollow areas was generally followed by an increase in fracture plane separations. This is reasonable, since the formation of hollow areas is one of the initial steps in the formation of a spall.

Generally, the 1975 survey not only showed an increase in hollow areas but also found that 12 of the 30 structures surveyed had a 50 percent or more increase in fracture plane separations (Table 1), compared to six structures in 1973 and 1974 and two structures in 1971. It should be mentioned that of the 34 original structures, only 30 were still under observation during the 1975 survey. Two structures (X01 of 11016, EB and WB) were covered with an epoxy surface treatment shortly after construction. Two more structures (S03 of 11016, EB and WB) were resurfaced with a latex concrete overlay after the 1973 inspection was performed. Structures S03 of 11016, EB and WB were resurfaced because of extensive deterioration in the original portion of the deck. At this time, there are three additional structures scheduled for overlays for the same reason.

The 1975 survey marks the deck condition ten years after placement. While the recorded amounts of deterioration are somewhat subjective, they do give a general indication of the condition of the widened portions of the decks. On the basis of the 1975 delamination detector data, the visible fracture plane separations represent approximately 10 percent of the total hollow area. Based on the recorded data, field observations, and notes on construction, there appears to be no significant relationship between the amount and type of deterioration, and the presence or absence of shoring. It is evident that other variables, such as concrete quality, cover over the bars, and location and detail of the splice, have more effect on deck performance than does the use of shoring.

Discussion

The following points relevant to deck widening were included in pre-

TABLE 2
TOTAL DETERIORATION OF BRIDGE DECK WIDENINGS
(Based on 30 Deteriorating Structures)

Survey Date	Cracks, lin ft			Hollow Areas, sq ft			Fracture Plane Separations, sq ft		
	Total Increase	Percent Increase	Total Accumulation	Total Increase	Percent Increase	Total Accumulation	Total Increase	Percent Increase	Total Accumulation
1970	320	---	320	Hollow Areas Not Recorded			420	--	420
1971	920	290	1,240	1,700	---	1,700	200	50	620
1973	1,760	140	3,000	1,920	110	3,620	420	70	1,040
1974	570	20	3,570	1,560	40	5,180	250	20	1,290
1975	1,000	30	4,570	26,000*	500	31,180	1,110	90	2,400

* Delamination detector used.

vious reports, and are reprinted for the reader's convenience.

Several problems arise and special considerations are required when widening structures, especially when traffic is not diverted. The following points were noted on the Berrien County jobs.

1) The existing sidewalk, rail, and a portion of the deck must be removed from above the existing fascia beam. Since the fascia may have more camber than the other beams, and in general is not low enough to blend well with the new deck section, a thin slab can result and the reinforcement can extend too near the finished surface in this area. This can result in premature deterioration of the deck. Therefore, the existing fascia should be removed and used as the fascia for the widened section, or reseated lower to avoid the problem.

2) When widening is done on an old structure, new bridge rail will generally be required to meet current specifications. This results in a strange appearance unless the opposite rail is reconstructed to match. Also, on widening the highway, there is good justification for bringing the opposite rail up to current standards. If this is done in the usual way, it requires careful demolition of the sidewalk to avoid damage to the reinforcement and the deck underneath and is a very expensive process. Several of the Berrien County structures were fitted with new parapet rail without the removal of the sidewalk. Epoxy grouts in drilled holes were used to anchor reinforcement into the existing sidewalk and deck. The process gave good results, and reportedly saved about $30,000 on the two projects.

3) Traffic-induced vibration causes rippling of the new deck concrete. This condition is further complicated by grade or superelevation of a structure, and by close proximity of traffic to the freshly placed mix. In some cases it will be necessary to refloat the deck surface several times while the concrete is obtaining its initial set. The Berrien County structures show no ill effects from such refinishing.

4) The face or edge of the existing slab should be coated with epoxy grout immediately prior to placement of the new concrete, to aid in bonding and sealing the construction joint.

5) Steel reinforcement should be tied tightly in place. Steel for the Berrien County structures was tied at every intersection; and the mat was supported at many more locations than would be normal for new bridge construction.

6) Depth of steel at the longitudinal construction joint is fixed by the location of the existing deck steel. Since many older decks have less cover than is presently specified, and low cover is a major factor in deck deterioration, the steel depth should be increased as quickly as possible, near the construction joint.

7) The side-by-side bar splice detail has proven to be a problem in bridge deck performance throughout the state. If other factors are equal, the first location to spall away is directly above the splice. Once this concrete is gone, the net effect is about equivalent to a broken bar. Therefore, it is obvious that special care should be taken to provide extra cover in the region of the splice. Also, a vertical arrangement of the lapped bars should be used instead of the horizontal or side-by-side configuration. Since the splice is important to the structural integrity of the deck, and can also be a deleterious factor in performance of the deck, careful attention to this detail is of utmost importance.

8) If other factors are equal, and bar splice areas are excluded, spalling generally occurs first where cover is least. Since there are plus and minus tolerances on both the beam seat elevations and the camber of beams, it would be wise to design the widened section with beam seats slightly lower than usual. This will help ensure adequate cover over the reinforcement, while maintaining proper slope for drainage of the deck. Construction personnel should set steel toward the lower end of tolerance to increase cover over the bars, especially at the splice.

9) Since ease of placement is important to construction, and low water/cement ratio is required for durability, it would seem reasonable to specify a seven-sack mix with water reducing admixtures for future projects."

It should be emphasized here that the purpose of the seven-sack mix is to obtain lower water/cement ratios and workability, rather than additional strength. Use of water reducers seems to be the only reasonable way to sharply reduce water/cement ratios, while maintaining workability. This seems to be especially critical in deck widenings under traffic, where concrete is subjected to continuing severe vibration during cure, but is equally important for new decks if high durability and performance are to be obtained.

Information gathered on this project and several others indicates that excess water in the mix is a primary cause of many of the problems that plague bridge decks. These problems include shrinkage and associated cracking over rebars, porosity, and formation of a plane-of-weakness that develops fracture plane separation. These conditions are exceptionally troublesome when associated with bar laps or insufficient cover over the reinforcement.

CONCLUSIONS

Ten-year performance of the I 94 deck widenings have shown no advantage gained from temporary shoring. In fact, shored spans show more deterioration, on the average, than unsupported spans.

It is not the intent to recommend prohibition of shoring on all future projects, but rather to indicate that shoring as a general practice to prevent vibration is not warranted by improved performance of the deck. Note that none of the bridges evaluated were of continuous design. Widening such a structure may present additional problems. Structures with girders continuous over piers may require shoring to prevent rotation over the piers. Shoring also may have construction advantages in predetermining the amount of girder deflection due to dead load and construction machinery.

Recent evaluation of the widened portions of the decks with a delamination detector revealed that hollow areas were about 10 times as extensive as spalling.

There is strong evidence of the formation of planes of extremely high water content within the decks, causing high porosity and very low strength at those locations, resulting in fracture plane separation or spalling of the surface.

Hard evidence of the porous plane-of-weakness in bridge decks has existed for several years, but has not received broad acceptance or wide distribution in the highway field. However, it continues to point to the need for strong measures to ensure that excess water is not allowed in concrete for bridge decks. Considerable vibration due to construction activities exists even on new structures, and the countless bridges that suffer from fracture plane separation attest to the remarkable extent to which excess water has collected in the most unfortunate locations. Strong measures are needed to prevent this condition in new decks. Major improvements are possible and every effort should be expended to bring water/cement ratios to the lowest practical level. Our current seven sack mix, 3-1/2-in. maximum slump, and use of water reducers or water reducer-retarders, are certainly steps in the right direction.