EXPERIMENTAL SHORING TO REDUCE
VIBRATION DURING BRIDGE DECK WIDENING
Progress Report: 9-year performance

MICHIGAN
HIGHWAY RESEARCH LABORATORY SECTION

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Progress Report: 9-year performance

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This report covers an evaluation of the performance of deck widening on 110 spans of 19 structures, on I 94 in Berrien County.

Background Information

During the 1965 construction season, work was begun on widening the I 94 structures in Berrien County. The Department specified that traffic be maintained during widening on all except the St. Joseph River bridges, where traffic 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 considerable 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 on-site to observe placement of most of the decks. Initial condition surveys were made on all structures after construction was completed, and surveys have been made each year since then, with the exception of 1972. The most recent survey was made during late October 1974. The method of inspection, as in the past, consists of visual observation of the decks and recording on prepared sketches the type and amount of deterioration. Soundings taken with a hammer on the widened portion of each deck were utilized to find and outline hollow areas.

This report includes data from four surveys made during the past five years. Results are shown in Table 1. The types of deterioration noted are cracks, hollow areas, and fracture plane separations (spalling). 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. It wasn't until the 1970 inspection that the hollow areas and fracture plane separations became prominant enough to record and, as shown in Table 2, they have increased steadily since that time.

TABLE 1

ADDITIONAL DETERIORATION ON BRIDGE DECK WIDENINGS

(Per hundred sq ft of area)

1970

Structure	Supported	Additional Deterioration: Cracks (lin ft)	Hollow Areas (sq ft)	Hollow Areas (Percent Increase)	Fracture Plane Separations (sq ft)	Fracture Plane Separations (Percent Increase)	Total to Date: Cracks (lin ft)	Hollow Areas (sq ft)	Fracture Plane Separations (sq ft)
S01 of 11015 EB	Yes	0.52	0	--	0.72	--	0.52	0	0.72
S02 of 11015 WB	Yes	0	0	--	0.83	--	0	0	0.83
X02 of 11015 EB	No	0	0	--	0	--	0	0	0
X01 of 11015 WB	No	0	0	--	0	--	0	0	0
B01 of 11015 EB	No	0	0	--	0	--	0	0	0
B01 of 11015 WB	No	0.41	0	--	0	--	0.41	0	0
X03 of 11015 EB	No	0	0	--	0	--	0	0	0
X03 of 11015 WB	No	0	0	--	0	--	0	0	0
S10 of 11015 EB	Yes	0	0	--	0.13	--	0	0	0.13
S10 of 11015 WB	Yes	0.81	0	--	0	--	0.81	0	0
S12 of 11015 EB	Yes	0	0	--	0	--	0	0	0
S12 of 11015 WB	Yes	0	0	--	0.05	--	0	0	0.05
S13 of 11015 EB	No	0	0	--	0	--	0	0	0
S13 of 11015 WB	No	0	0	--	0	--	0	0	0
X04 of 11015 EB	No	0	0	--	0	--	0	0	0
X04 of 11015 WB	No	0.99	0	--	0	--	0.99	0	0
S16 of 11015 EB	Yes	0	0	--	0.78	--	0	0	0.78
S16 of 11015 WB	Yes	0	0	--	0	--	0	0	0
S17 of 11015 EB	Yes	0	0	--	1.67	--	0	0	1.67
S17 of 11015 WB	Yes	0	0	--	0	--	0	0	0
X05 of 11015 EB	No	0	0	--	0	--	0	0	0
X05 of 11015 WB	No	0	0	--	0	--	0	0	0
B02 of 11015 EB	No	0	0	--	0	--	0	0	0
B02 of 11015 WB	No	0	0	--	0	--	0	0	0
S21 of 11015 EB	No	0	0	--	0	--	0	0	0
S21 of 11015 WB	No	0	0	--	0	--	0	0	0
B01 of 11016 EB	No	0	0	--	0	--	0	0	0
B01 of 11016 WB	No	0.29	0	--	0	--	0.29	0	0
S01 of 11016 EB	Yes	0	0	--	0	--	0	0	0
S01 of 11016 WB	Yes	0	0	--	0	--	0	0	0
S03 of 11016 EB	Yes	0	0	--	0	--	0	0	0
S03 of 11016 WB	Yes	0.17	0	--	0	--	0.17	0	0
X01 of 11016 EB	No	Bridge Deck Covered with Epoxy Surface Treatment							
X01 of 11016 WB	No	Bridge Deck Covered with Epoxy Surface Treatment							

1971

Structure	Additional Deterioration: Cracks (lin ft)	Hollow Areas (sq ft)	Hollow Areas (Percent Increase)	Fracture Plane Separations (sq ft)	Fracture Plane Separations (Percent Increase)	Total to Date: Cracks (lin ft)	Hollow Areas (sq ft)	Fracture Plane Separations (sq ft)
S01 of 11015 EB	0	1.23	--	0.44	60	0.52	1.23	1.16
S02 of 11015 WB	0	0.32	--	0	--	0	0.32	0.83
X02 of 11015 EB	0	0	--	0	--	0	0	0
X01 of 11015 WB	0.74	0	--	0	--	0.74	0	0
B01 of 11015 EB	0	0.05	--	0	--	0	0.05	0
B01 of 11015 WB	0	0	--	0	--	0.41	0	0
X03 of 11015 EB	0	0.54	--	0	--	0	0.54	0
X03 of 11015 WB	0	5.15	--	0	--	0	5.15	0
S10 of 11015 EB	0	0.81	--	0.27	205	0	0.81	0.40
S10 of 11015 WB	0	0.06	--	0.03	--	0.81	0.06	0.03
S12 of 11015 EB	0	0.78	--	0.07	--	0	0.78	0.07
S12 of 11015 WB	0	0.20	--	0.02	40	0	0.20	0.07
S13 of 11015 EB	1.46	0.05	--	0	--	1.46	0.05	0
S13 of 11015 WB	0	0.05	--	0.02	--	0	0.05	0.02
X04 of 11015 EB	0	0	--	0	--	0	0	0
X04 of 11015 WB	1.48	0	--	0	--	2.47	0	0
S16 of 11015 EB	0.65	1.04	--	0.19	25	0.65	1.04	0.97
S16 of 11015 WB	0	0.84	--	0.06	--	0	0.84	0.06
S17 of 11015 EB	1.78	3.24	--	0	--	1.78	3.24	1.67
S17 of 11015 WB	0	1.30	--	0.75	--	0	1.30	0.75
X05 of 11015 EB	0	0	--	0	--	0	0	0
X05 of 11015 WB	1.43	0.51	--	0.08	--	1.43	0.51	0.08
B02 of 11015 EB	0	0	--	0.06	--	0	0	0.06
B02 of 11015 WB	0	0	--	0	--	0	0	0
S21 of 11015 EB	0	0	--	0	--	0	0	0
S21 of 11015 WB	0	0.04	--	0	--	0	0.04	0
B01 of 11016 EB	0.95	0.23	--	0	--	0.95	0.23	0
B01 of 11016 WB	0	0.15	--	0.04	--	0.29	0.15	0.04
S01 of 11016 EB	0	0.31	--	0	--	0	0.31	0
S01 of 11016 WB	0	0.07	--	0	--	0	0.07	0
S03 of 11016 EB	0.27	0	--	0	--	0.27	0	0
S03 of 11016 WB	0.40	0	--	0.01	--	0.57	0	0.01

1973

Structure	Additional Deterioration: Cracks (lin ft)	Hollow Areas (sq ft)	Hollow Areas (Percent Increase)	Fracture Plane Separations (sq ft)	Fracture Plane Separations (Percent Increase)	Total to Date: Cracks (lin ft)	Hollow Areas (sq ft)	Fracture Plane Separations (sq ft)
S01 of 11015 EB	0	3.90	315	0.44	40	0.52	5.13	1.60
S02 of 11015 WB	0.19	0.51	160	0.19	25	0.19	0.83	1.02
X02 of 11015 EB	0	0.32	--	0.08	--	0	0.32	0.08
X01 of 11015 WB	0.78	0.11	--	0.01	--	1.52	0.11	0.01
B01 of 11015 EB	0.56	0.20	400	0.05	--	0.56	0.25	0.05
B01 of 11015 WB	5.23	0.20	--	0.05	--	5.64	0.20	0.05
X03 of 11015 EB	0	1.27	235	0.12	--	0	1.81	0.12
X03 of 11015 WB	0	1.75	35	0	--	0	6.90	0
S10 of 11015 EB	0	0.67	80	0.27	65	0	1.48	0.67
S10 of 11015 WB	1.30	0.68	115	0	--	2.11	0.74	0.03
S12 of 11015 EB	0	1.43	185	0.20	285	0	2.21	0.27
S12 of 11015 WB	0.78	0.64	320	0	--	0.78	0.84	0.07
S13 of 11015 EB	0.29	0.70	1,400	0	--	1.75	0.75	0
S13 of 11015 WB	0.30	0	--	0	--	0.30	0.05	0.02
X04 of 11015 EB	0	0	--	0	--	0	0	0
X04 of 11015 WB	0	0	--	0	--	2.47	0	0
S16 of 11015 EB	0	1.96	190	0.32	35	0.65	3.00	1.29
S16 of 11015 WB	0	0.84	100	0.81	1,350	0	1.68	0.87
S17 of 11015 EB	0	1.41	45	1.04	60	1.78	4.65	2.71
S17 of 11015 WB	0	0.57	45	0.31	40	0	1.87	1.06
X05 of 11015 EB	0.30	0.10	--	0.06	--	0.30	0.10	0.06
X05 of 11015 WB	1.12	0.88	175	0.03	40	2.55	1.39	0.11
B02 of 11015 EB	0	0	--	0	--	0	0	0.06
B02 of 11015 WB	1.36	0	--	0	--	1.36	0	0
S21 of 11015 EB	0	0	--	0	--	0	0	0
S21 of 11015 WB	0.37	0	--	0	--	0.37	0.04	0
B01 of 11016 EB	0.14	0.14	60	0.02	--	1.09	0.37	0.02
B01 of 11016 WB	1.77	0.41	275	0.11	275	2.06	0.56	0.15
S01 of 11016 EB	0	0	--	0	--	0	0.31	0
S01 of 11016 WB	1.26	0.52	745	0.07	--	1.26	0.59	0.07
S03 of 11016 EB	0.38	0	--	0	--	0.65	0	0
S03 of 11016 WB	1.49	0	--	0.03	300	2.06	0	0.04

1974

Structure	Additional Deterioration: Cracks (lin ft)	Hollow Areas (sq ft)	Hollow Areas (Percent Increase)	Fracture Plane Separations (sq ft)	Fracture Plane Separations (Percent Increase)	Total to Date: Cracks (lin ft)	Hollow Areas (sq ft)	Fracture Plane Separations (sq ft)
S01 of 11015 EB	0	1.58	30	0	--	0.52	6.71	1.60
S02 of 11015 WB	0	0.22	25	0	--	0.19	1.05	1.02
X02 of 11015 EB	0	0	--	0	--	0	0.32	0.08
X01 of 11015 WB	0	0.14	125	0	--	1.52	0.25	0.01
B01 of 11015 EB	0	0	--	0	--	0.56	0.25	0.05
B01 of 11015 WB	0	0	--	0	--	5.64	0.20	0.05
X03 of 11015 EB	0	0	--	0	--	0	1.81	0.12
X03 of 11015 WB	0	0.24	5	0.12	--	0	7.14	0.12
S10 of 11015 EB	0	0.27	20	0	--	0	1.75	0.67
S10 of 11015 WB	0	0.06	10	0.03	100	2.11	0.80	0.06
S12 of 11015 EB	1.02	0.17	10	0.17	65	1.02	2.38	0.44
S12 of 11015 WB	1.11	0.58	70	0	--	1.89	1.42	0.07
S13 of 11015 EB	0	0	--	0	--	1.75	0.75	0
S13 of 11015 WB	0.99	1.16	2,320	0.02	100	1.29	1.21	0.04
X04 of 11015 EB	0	0	--	0	--	0	0	0
X04 of 11015 WB	0	0	--	0	--	2.47	0	0
S16 of 11015 EB	0	5.22	175	0	--	0.65	8.22	1.29
S16 of 11015 WB	0	1.42	85	0.64	75	0	3.10	1.51
S17 of 11015 EB	0	1.04	20	0.36	15	1.78	5.69	3.07
S17 of 11015 WB	0	1.93	105	0.78	75	0	3.80	1.84
X05 of 11015 EB	0	0	--	0	--	0.30	0.10	0.06
X05 of 11015 WB	0.47	0.64	45	0.34	310	3.02	2.03	0.45
B02 of 11015 EB	0	0	--	0	--	0	0	0.06
B02 of 11015 WB	0.45	0.45	--	0	--	1.81	0.45	0
S21 of 11015 EB	0	0	--	0	--	0	0	0
S21 of 11015 WB	0	0.18	450	0	--	0.37	0.22	0
B01 of 11016 EB	0.20	0.05	15	0	--	1.29	0.42	0.02
B01 of 11016 WB	1.43	0.25	45	0	--	2.49	0.81	0.15
S01 of 11016 EB	Resurfaced							
S01 of 11016 WB	Resurfaced							
S03 of 11016 EB	0	0	--	0	--	0.65	0	0
S03 of 11016 WB	0	0	--	0	--	2.06	0	0.04

TABLE 2
RESULTS OF ADDITIONAL DETERIORATION ON BRIDGE DECK WIDENING
(Based on 30 Deteriorating Structures)

Survey Date	Cracks, lin ft			Hollow Areas, sq ft			Fracture Plane Separation, 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

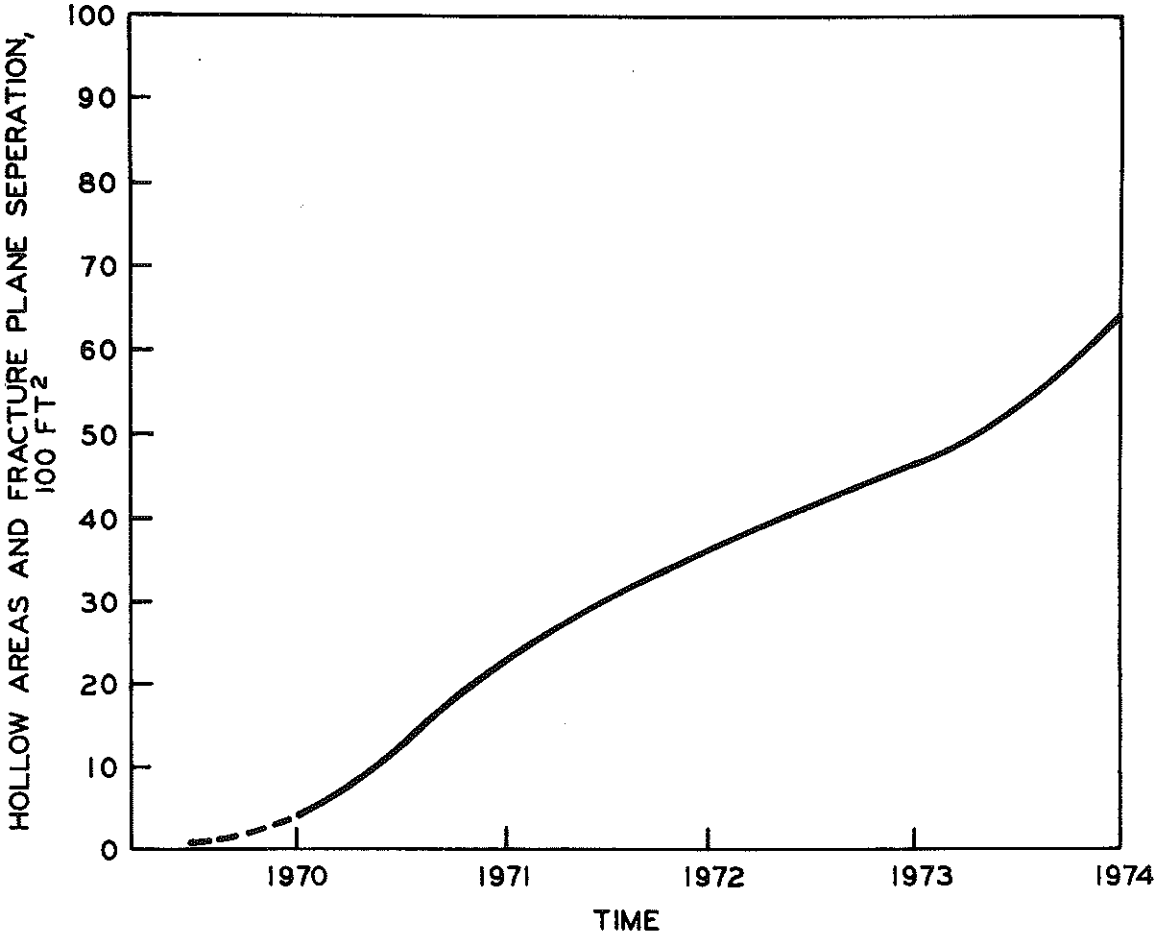

Figure 1. Deterioration vs. time. Summation for 30 structures from Table 2.

Combination of the totals for fracture plane separation and hollow areas from Table 1 shows five structures with more than five percent deterioration on the widened portion of the deck. They are as follows: S01 of 11015 EB, 8.3 percent; X03 of 11015 WB, 7.3 percent; S16 of 11015 EB, 9.5 percent; S17 of 11015 EB, 8.8 percent; and S17 of 11015 WB, 5.6 percent. These five structures averaged 70 percent increase in hollow areas for the two year period 1971-73, and then increased an average of 67 percent more during the following one year. Due to the relatively small amount of cover at the construction joints in some places, and the accelerating effect of side-by-side bars, much of the deteriorated area is in the immediate vicinity of the bar splices adjacent to the construction joints.

Generally, the 1974 survey showed an increase in deterioration on 17 of the 34 structures with the increase in hollow areas being the most dominant. Figure 1 shows the progression of hollow areas and fracture plane deterioration with time. Structures S01 of 11016 WB and EB decks have been resurfaced with a latex concrete overlay since the 1973 inspection. This was due to extensive deterioration of the original deck, which was not included in our surveys of the widened portion.

Discussion

The following points relevant to deck widening were included in the 1971 report, and are reprinted here for those that did not see, or do not have easy reference to, the previous report.

"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, and are included here for future reference.

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, the 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 par. 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. This 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 joints.

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 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 presently is specified, and low cover is a major factor in deck deterioration, the steel depth should be increased as quickly as possible, near the construction joints.

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 insure 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 the plane-of-weakness that develops fracture plane separation. These conditions are exceptionally troublesome when associated with bar laps or insufficient cover over the reinforcement.

The heavy vibration caused by truck traffic during and after placement of the Berrien County decks resulted in an interesting observation. Tiny fountains of crystal clear water, like artesian wells, broke through the surface of the deck. This indicated the existence of reservoirs beneath the surface, where the water had completely disassociated itself from the mix. Such action is direct evidence of formation of a lens of high water gain, which would turn into an extremely weak and porous plane in the finished deck.

During a recent inspection, a hollow area was broken away to determine the condition of the failure surface. A layer of rubble, about 1/8-in. thick, composed mainly of fine aggregates, was found below the sound concrete layer that had been removed. This type of deterioration apparently is caused by action of salt, water, and frost on the porous plane-of-weakness in the deck. Similar deterioration is caused by salt when it is trapped beneath a porous deck overlay, or in joints of concrete pavements.

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 this excess water has collected in the most unfortunate locations. Immediate measures are needed to prevent this condition in new decks. Major improvements are possible at minimal cost and are warranted by all information available. It is strongly recommended that previously stated mix improvements be made, and that additional design cover over rebars be provided to allow more adequate actual coverage when construction variations are considered. Extra cover over bar laps obviously is needed as well.

Conclusions

Nine-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.

Special considerations are required when widening structures. It is not the intent to recommend prohibition of shoring on all future projects, but rather to indicate that shoring as a general practice is not warranted by improved performance of the deck. 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.

Evidence gathered during the evaluation indicates again that improvements in concrete mix and deck design are badly needed.