CONCRETE OVERLAYS FOR BRIDGE DECK REPAIR

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Tests were made on portland cement and resinous concrete overlays to determine their suitability as overlays for deteriorated concrete bridge decks. Direct shear strengths of overlays bonded with epoxy, portland cement grout, and latex-modified cement grout were compared with those applied with no bonding agent. Freeze-thaw tests were made to determine durability of bonding agents and of overlay concretes. Load tests were made on 8-ft span beams to determine the stiffening effect of overlays and the effect of repeated loadings on overlaid beams. Durability was studied further by gradually lowering laboratory temperature to 20 F during periods of repeated load applications. Low frequency and low amplitude vibrations were maintained on one beam by cyclic loading during placement and cure of a 1½-in. overlay to simulate vibration due to traffic on a lane adjacent to the one being overlaid. Shear bond strengths ranged from 214 to 668 psi. Epoxy and portland cement grout bonding agents withstood the ASTM C 290 test without failure. Two of three overlays of latex-modified cement concrete came unbonded during the ASTM C 290 test. Latex-modified cement concrete overlay provided better freeze-thaw scale resistance than did other materials. No overlay failed in any way, except for tension cracks, in 2 million cycles of load.

•DEEP scaling and spalling in many concrete bridge decks have advanced to the point were major repairs are necessary to bring the decks back to acceptable levels of performance. The alternative to major repairs is the complete replacement of the deck. The choice between replacement and repair is normally dependent on the extent of deterioration, costs, and user consideration. There are many situations where repair holds a distinct advantage over replacement, and a number of repair methods have been reported (1, 5).

A study that was made to determine suitable overlays for repairing existing deteriorated concrete bridge decks is the subject of this report. The present report concerns materials, bonding methods, and flexural stiffness of relatively thin repair overlays to be applied on existing concrete bridge decks.

Four series of tests, series 1 through 4, were made to provide information from which repair methods might be developed. Information on the portland cement concrete mixes for the test specimens is given in Tables 1 and 2. All overlays, with the exception of F, were made of air-entrained concrete. No air entrainment was used in the grout.

The epoxy mortar overlay was a mixture of epoxy and concrete sand on 15 percent to 85 percent basis by weight. A proprietary product, a mixture of concrete sand and a polyester resin formulation, was used for overlay J.

In series 1, direct shear tests were made to determine the shear bond strength of bonding agents used to bond overlays to base concrete. Freeze-thaw tests were made in series 2 to determine the durability of bonding agents and overlay materials.

In series 3, beam tests were made to determine the effect of overlays and repeated loadings on the stiffness of a reinforced beam and to determine the effect of repeated loads on the bonding agents.

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Repeated load tests were made in series 4 under cold temperature to determine the fatigue characteristics of overlaid beams in freezing environments.

TEST PROGRAM

Series 1

When the overlay was 7 days old, direct shear tests similar to those performed by Felt (5) in pavement overlays were made on the jig-mounted specimens. The shear bond strength was computed as the average shear stress over the interface area.

Series 2

The 3-in. by 3-in. by 16-in. specimens formed by sawing larger slabs were tested for freeze-thaw durability in accordance with ASTM C 290 (6). In this test, the specimens are alternately frozen and thawed in an automatic freeze-thaw cabinet. They are tested for fundamental traverse frequency at intervals not exceeding 30 freeze-thaw cycles.

In other freeze-thaw tests, 1-in. thick overlays were bonded to 10-in. square base slabs. Wells formed by metal rings fixed to the overlays were filled with a 5 percent saltwater solution. The overlays were under ponded saltwater continuously from 22 to $26\frac{1}{2}$ days. About one-half of that time was spent in a freezing chamber and the other half in a thaw chamber.

Series 3

Laboratory beams (Fig. 1) were tested under static and cyclic loads applied at midspan. Load and midspan deflection data were collected just before and just after overlays were placed and cured and at intervals during the cyclic load phase. These data (Table 3) were used to determine the stiffness effect of the overlay and to determine if there was any loss in stiffness brought about by th repeated loadings.

One cyclic load test was made to determine if low amplitude, slow vibration would be harmful to the setting up, bonding, and strength of the overlay concrete that was cast and cured on the vibrating beam. Details of all of the beam tests are as follows.

Static Load-Deflection Tests—The simply supported beam was loaded at midspan to 400 lb in increments of 100 lb after cracking and before the overlay was applied. Midspan deflections were read for each load increment. After the overlay was applied and cured, another load-deflection test was made in the frame used for cyclic loading. The test was identical to the pre-overlay test except that the load was carried to approximately 500 lb, and readings were taken at smaller load increments. A typical plot of the pre-overlay and post-overlay data is shown in Figure 2.

Cyclic Load Tests—The same types of static load-deflection tests were made at intervals of 500,000 load cycles during the repeated load tests. Typical load-deflection plots are shown in Figure 2 at 0 and 2 million cycles for overlay in compression. Cyclic loads were applied by a machine with rotating eccentric weights. The loading device was fixed to the beams at midspan by lugs cast in the beams during fabrication. Power was delivered from an electric motor through flexible shafting to the machine. The loader was operated at the cyclic rate necessary to produce a deflection that, calculated by elastic analysis, would produce 20-ksi tensile stress in the bottom steel of the cracked overlaid beam. The resulting rotational velocity of the eccentric weights, producing the same load on the lifting stroke as on the depressing stroke, was sufficient to overcome the dead weight of the beam and the loader and produce a net upward force.

Overlays Cast and Cured on Vibrating Beams—A 2-in. thick overlay, overlay type D, was cast on a beam while the beam was subjected to 400 load cycles per min by the cyclic loader. The loading was maintained continuously for 48 hours during which time about 1,100,000 load cycles had been applied. It was designed to approximately simulate vibration caused by traffic in one lane while the overlay was placed and partially cured in an adjacent lane. There are situations in which an overlay might be placed under conditions similar to this one (7).

Table 1. Base specimen designs and aggregate gradation.

Specimen (in.)	Coarse Aggregate Gradation	Mix Properties, lb/yd^3				Concrete Properties				Sieve Size	Percent Retained on Each Sieve			
		Gravel	Sand	Cement	Water	Percent Air	Slump (in.)	Cement Factor (sk/yd^3)	Water-Cement (gal/sk)		Grade 1	Grade 2	Grade 3	Grade 4
7 by 7 cubes	4	1,942	1,272	518	273	0.0	3	5.50	6.0	¾ in.	0	Steel fiber	0	20
10 by 16 by 2 slabs	3	1,761	1,323	518	269	5.5	3	5.50	6.0	½ in.	15	Steel wire[a]	5	30
10 by 10 by 2 slabs	3	1,761	1,323	518	269	5.5	3	5.50	6.0	⅜ in.	25	Steel wire[a]	38	30
7 by 8½ by 5 beams	4	1,942	1,272	518	273	0.0	3	5.50	6.0	No. 4	58	Steel wire[a]	57	20
										No. 8	2	Steel wire[a]	0	0

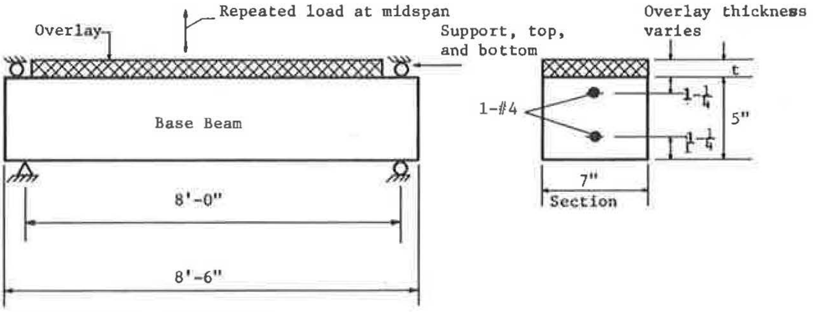
[a] Cut in short lengths (¾ in. by 0.010 in. by 0.022 in.).

Table 2. Overlay designs.

Overlay	Coarse Aggregate Grade[a]	Mix Properties, lb/yd^3				Concrete Properties				Comment
		Gravel	Sand	Cement	Water	Percent Air	Slump (in.)	Cement Factor (sk/yd^3)	Water-Cement (gal/sk)	
A	1	1,821	1,128	663	301	4.5	2½	7.04	5.13	Plain concrete
B	1	1,846	1,142	664	285	5.0	2½	7.06	5.00	4-gauge welded wire, 3 in. by 3 in., placed on bonding agent
C	2	0	2,390	748	394	9.3	0	7.95	5.95	Coarse aggregate replaced by 261 lb of steel fiber, ¾ in. by 0.010 in. by 0.022 in.
D	1	1,827	1,132	665	309	5.0	4	7.06	5.25	Chem Comp cement used with 4-gauge welded wire, 4 in. by 4 in., at mid height of overlay
E	3	1,531	1,350	607	124	9.2	7	6.45	4.05	Concrete modified with latex additives, 3½ gal per sk, latex was 48 percent solids by weight
F	1	1,846	1,142	664	279	0.0	1¾	7.16	4.75	Not air entrained
G	1	1,846	1,142	664	270	5.0	2	7.04	4.60	Air entrained
H-1	3	1,254	1,568	627	131	5.5	4½	6.67	4.04	Cement A latex-modified grout
H-2	3	1,254	1,568	627	131	6.0	5	6.67	4.04	Cement B latex-modified grout
I[b]										Epoxy, no primer, 15 percent epoxy, 85 percent sand by weight
J[c]										Polyester, primer, 4 lb of resin, 12 ml of catalyst

[a] See Table 1.
[b] Type I consists of 7½ lb of epoxy and 50 lb of concrete sand.
[c] Type J consists of 8¼ lb of resin, 33 ml of catalyst, and 40 lb of sand.

Figure 1. Beam details.



Beam concrete: See Table I

Nominal strength of cylinder at 28 days = 3000 psi

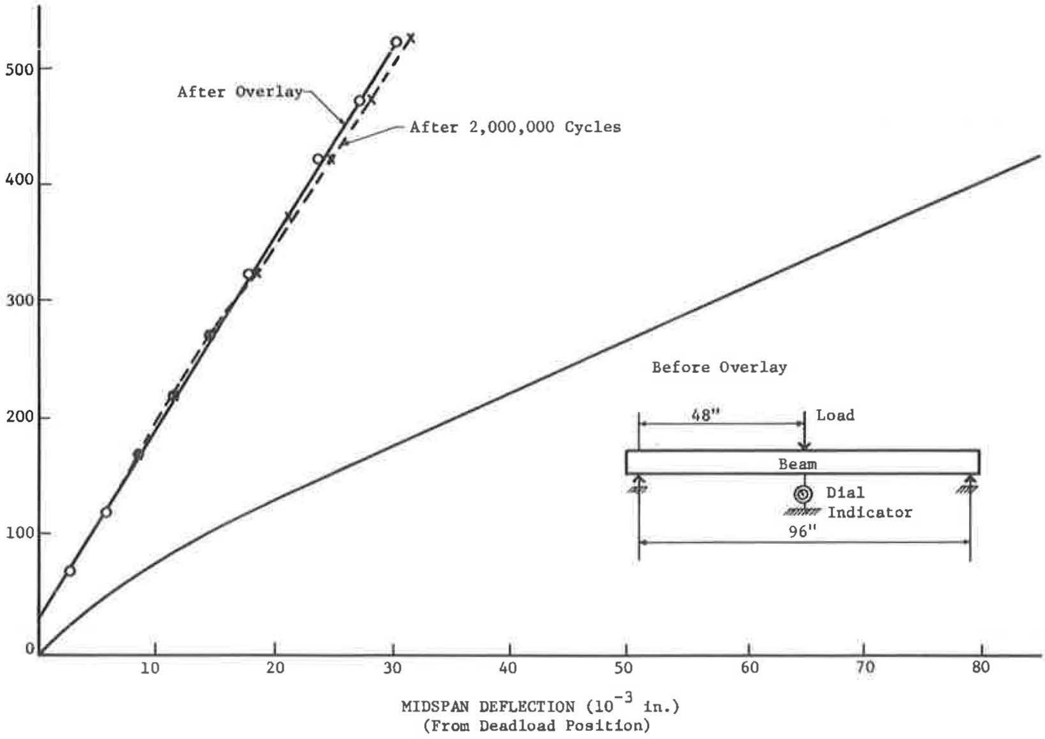
Nominal secant modulus at 1/2 f'_c = 6,000,000 psi

Table 3. Beam schedule and stiffness ratios.

	Overlay				P/Δ[c] (lb/in.)				
						With Overlay			
Beam Designation[a]	Type[b]	Bonding Agent	Thickness (in.)	Age of Test (days)	Without Overlay A	No Cycles B	2 Million Cycles C	$\frac{B}{A}$	$\frac{C}{A}$
AG-12	A	Grout	2	38	3,810	41,100	37,800	10.7	9.9
AE-12	A	Epoxy	2	38	3,740	25,000	23,500	6.7	6.3
BG-12	B	Grout	2	39	4,450	34,200	29,200	7.7	6.6
BE-12	B	Epoxy	2	32	4,210	18,600	—	4.4	—
CG-12-1	C	Grout	2	10	5,200	36,900	29,200	7.1	5.6
CG-12-2	C	Grout	2	11	4,600	15,800	15,300	3.4	3.3
CE-12	C	Epoxy	2	9	3,150	12,400	11,600	3.9	3.7
DG-12	D	Grout	2	34	5,000	18,800	18,400	3.8	3.7
DE-12	D	Epoxy	2	9	4,700	19,500	16,400	4.1	3.5
EG-12-1	E	LM[d]	2	—	4,550	17,800	16,300	3.9	3.6
EG-12-2	E	LM	2	—	3,980	12,400	11,800	3.1	3.0
AG-11	C	Grout	1½	39	3,880	22,200	20,000	5.7	5.2
AE-11	C	Epoxy	1½	20	5,000	13,300	18,200	2.7	3.6
CG-11	C	Grout	1½	11	3,850	14,400	16,700	3.7	4.3
BG-11-1	B	Grout	1½	9	3,960	7,870	8,450	2.0	2.1
BG-11-2	B	Grout	1½	9	4,080	12,700	10,800	3.1	2.6
CG-11-1	C	Grout	1½	10	3,920	8,640	8,330	2.2	2.1
CG-11-2	C	Grout	1½	10	4,000	9,520	10,100	2.4	2.5
DG-11-1	D	Grout	1½	13	4,830	12,100	12,600	2.5	2.6
DG-11-2	D	Grout	1½	13	3,450	8,930	9,500	2.6	2.7
EG-11-1	E	LM	1½	10	3,670	8,350	8,430	2.3	2.3
DG-11-3	D	Grout	1	10	3,640	9,490	8,090	2.6	2.2
DG-11-4	D	Grout	1	10	3,840	11,100	9,100	2.9	2.4
EP-1	I	None	½	7	4,040	4,430	4,250	1.1	1.1
EP-2	I	None	½	7	5,080	5,650	4,800	1.1	1.0
EP-3	I	None	½	6	4,130	4,590	4,720	1.1	1.1
EP-4	I	None	½	6	3,960	4,380	4,410	1.1	1.1
PL-1	J	Polyester	½	7	3,840	5,150	5,370	1.3	1.4
PL-2	J	Polyester	½	7	3,750	4,090	4,090	1.1	1.1
PL-3	J	Polyester	½	2	2,860	4,680	5,000	1.6	1.8
PL-4	J	Polyester	½	2	2,960	4,190	4,360	1.4	1.5

[a] See Figure 1 for beam dimensions.
[b] See Table 2 for description of overlay materials.
[c] Midspan load/midspan deflection.
[d] Latex-modified cement concrete.

Figure 2. Typical static load-deflection curves.



Series 4

The temperature was gradually lowered in the test chamber from 70 to 20 F during which period the beam underwent cyclic loading. The time-temperature-loading cycle schedule is shown in Figure 3.

A static load-deflection test was made before the overlay was applied and then again after it was applied and cured before cyclic load and temperature cycling began. Room temperature was gradually lowered from 70 to 20 F while load cycling was maintained at approximately 11 cycles per sec. After 500,000 cycles, loading was stopped and the temperature was increased to 70 F. Then, 12 hours after stopping, a static load-deflection test was made.

No continuous record of room temperature was kept of either the descending or the ascending curves, nor were temperatures within the beam measured. The freezing cycle required essentially a 12-hour day to draw the temperature from 70 to 20 F.

The pattern established on the run from 70 to 20 F for the first 500,000 cycles was maintained throughout the 2 million load cycle test. A total of 5 days were required for testing each beam subsequent to application of the overlay. Four of those days were spent in repetitive loading.

RESULTS

Series 1

Bond strengths of concrete overlays applied to sandblasted surfaces of 7-in. cubes using grout, epoxy, latex-modified cement, and polyester were tested. The base concrete mix and cure were constant (although several batches were made), and all batches were not cured at the same time. The failure surface generally followed the interface of overlay and cube with minor migrations, in some cases, into the base material and the overlay. The bond strengths are given in Table 4 as averages of either three or six tests.

A concrete bridge deck carrying service loads is stressed in horizontal shear that varies in intensity with distance from the surface to about middepth of the slab. When the slab carries an overlay, the shear stress at the interface of the overlay and the base slab is dependent on shear at the section and the relative thicknesses of the overlay and slab. A slab supported by beams is considered by AASHO (8) to be adequate in shear if it is designed for moment in accordance with AASHO specifications. A wheel would be carried by a slab strip about 4 ft wide on a bridge with stringers spaced about 8 ft apart. If the wheel were shifted to the edge of the stringer for maximum shear, an H 20 wheel plus impact (about 20 kips, spread over, for example, 3 ft) would cause a shear of 3.9 kips on a 7-in. wide section. By applying the horizontal shear formula $v = VQ/Ib$, to the interface of a 7-in. uncracked slab with a 2-in. overlay for a 3.9-kip load, we find the interface shear to be

$$v = 3{,}900 \times (14 \times 3.5)/(425 \times 7) = 64.2 \text{ psi}$$

This stress, which is only 30 percent of the minimum strength (214 psi) given in Table 4, would be safe for any of the bonds developed in the tests. Earlier overlays having no special bonding agent (9) developed 129 psi, two times the 64.2 psi previously computed.

Results of shear bond tests on overlays applied to concrete that had been treated earlier with waterproofing materials have been reported (10). These tests showed that a concrete overlay applied directly to a surface treated with a linseed oil-kerosene mixture developed a 61-psi bond; after the surface had been sandblasted, the bond was 367 psi. Corresponding values for a surface treated with a tung oil-kerosene mixture were 88 psi and 597 psi.

Specimens F and G were fabricated in the same manner as the earlier group. A through D, to determine if air entrainment affects the shear bond strength of portland cement concrete overlays. The values, the average of six tests, indicate that the air-entrained overlays, specimens G, have essentially the same strength as the concrete without air, specimens F. Both values are lower than the earlier ones in air-entrained specimens A through D, which is attributed to an unknown, and unintentional, difference in material or fabrication.

These tests, and previous ones (9), show consistently that portland cement grout provides superior bonding. It produced higher strength, an average of 541 psi in the 12 specimens (A through D, Table 4), considerably higher than the average bond from other materials in the same test series. Grouted specimens F and G given in Table 4 show that bond strength is not affected by the air entrainment used.

The load cycling of test series 3 and 4 had no noticeable effect on any bonding agent used in the tests. Every bonding agent tested provided far more shear than the 64.2 psi computed for a theoretical shear from a 20-kip truck wheel, but one of them failed the freeze-thaw tests.

Both epoxy and cement grout have been popular as bonding agents for applying concrete overlays to concrete pavements and bridge decks. The tests carried out here show that both of these perform well in the laboratory. The cement grout provided the highest bond strength, and it is easy to apply.

Series 2

All specimens, except two of the overlays E, completed 300 freeze-thaw cycles. Overlay E separated from the base at 183 cycles for one of the exceptions and at 246 cycles for the other one. At 300 cycles, the remaining four specimens of that overlay had deteriorated to the point where the overlay could be pulled away from the slab by hand.

No distress was noted in any other overlay during this test. Table 5 gives the properties and durability of the overlay material. Overlays C, both grout and epoxy bonded, showed no loss in durability factor after the 300 freeze-thaw cycles. The overlay material of these specimens contained 9.2 percent air (Table 2); high air content is characteristic of that material. If the high percentage of air benefited the bond durability of this overlay, it does not appear to have behaved in the same way for the E overlay, which contained essentially the same amount of air as the C overlay. From Table 5, it is evident that all base slab material had almost the same percentage of air.

The 10-in. square specimens with bonded overlays were subjected to two freeze-thaw cycles daily. The appearance of the overlay surfaces at approximately 50 freeze-thaw cycles is shown in Figure 4. The test showed that the bonding agent had no influence on surface deterioration. Figure 4 shows overlay E (with 9.2 percent air) to have much less surface scaling than the 9.3 percent concrete with wire fibers of overlay C.

Although the plain concrete of overlay A shows a little greater durability factor than overlay B, which contained welded wire fabric, no difference could be observed visually. It is evident from Table 5 that neither the grout nor epoxy bonding agent will be troublesome because of freeze-thaw action provided that both are properly placed. All other surfaces, A, B, and D, that contain from 4½ to 5 percent air show moderate surface scaling. Based on results of similar freeze-thaw tests (11, 12), the performances of all specimens in resisting freeze-thaw scaling were satisfactory.

Series 3 and 4

The stiffness tests of series 3 and 4 show that a bonded overlay of 1 to 2 in. of concrete increases the stiffness of 5-in. thick beams from about two to five times prior to overlay. Overlays of ½ in. add little to stiffness, but they would provide protection for the concrete deck and would make the surface smooth for traffic. The cost of resins would permit them to be used for added stiffness only in very limited volume. Therefore, the tests were not designed to provide extensive information on the stiffness of resin materials.

The beam that was overlaid while it was vibrated had a double vibrational amplitude (peak to peak) of 0.044 in. after the overlay was first cast. At an age of 24 hours under continuous vibration, the amplitude had reduced to 0.008 in. under the same load. The test was discontinued after 48 hours, and an inspection showed three tensile cracks near midspan in the overlay. These cracks were formed by the upward load part of the load cycle, which placed the overlay in tension. The concrete at the base of the cracks was inspected by chipping out cracked material, and the overlay was found to be fully and firmly bonded in the area.

Figure 3. Loading cycle temperature and time.

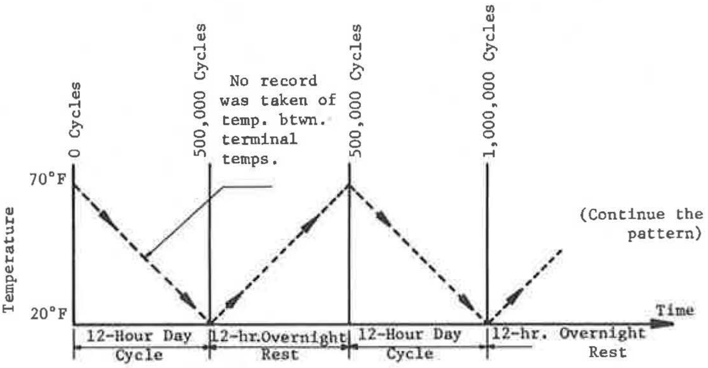


Table 4. Shear strength of overlay bonds.

	Average Bond Shearing Stress, psi					
Overlay[a]	Base Surface Preparation	No Bonding Agent	Grout Bonding Agent	Epoxy Bonding Agent	Other	Comment
A	Sandblast	–	420	462	–	Air-entrained overlay
B	Sandblast	–	555	362	–	Air-entrained overlay
C	Sandblast	–	668	565	–	Air-entrained overlay
D	Sandblast	–	521	402	–	Air-entrained overlay
E	Sandblast	–			382	Latex-modified grout and overlay
F	Sandblast	–	393		–	No air-entrained overlay
G	Sandblast	–	388		–	Air-entrained overlay
H-1	Sandblast	–	–		458	Cement A, latex-modified grout and overlay
H-2	Sandblast	–	–		382	Cement B, latex-modified grout and overlay
I	Sandblast	214	–		–	Epoxy overlay
J	Sandblast	344	–		–	Polyester overlay

Note: The values shown represent the averages of three specimens for each overlay, A through D; six specimens for each of E through I; and four specimens for J. The average bond shearing stresses for overlays A through E were 541 psi with the grout bonding agent and 448 psi with the epoxy bonding agent.

[a] See Table 2 for description of overlay materials.

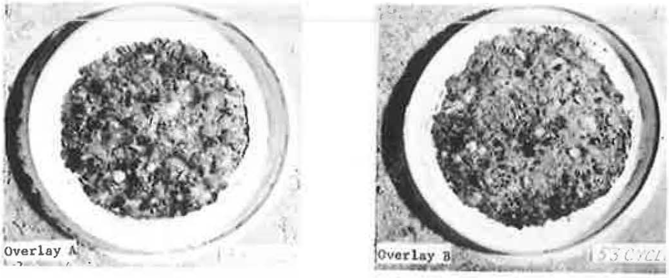
Table 5. Properties and durability factors of overlay concretes.

	10- by 16- by 2-in. Slabs			1-in. Overlays			
Overlay[a]	Percent Air	Cement Factor (sk/yd^3)	Water-Cement (gal/sk)	Percent Air	Cement Factor (sk/yd^3)	Water-Cement (gal/sk)	Durability Factor (ASTM C 290) of Overlayed System (average of 3)
AG	5.0	5.55	6.13	5.0	7.06	5.0	84.0
AE	5.0	5.55	6.13	5.0	7.06	5.0	85.5
BG	5.0	5.55	6.13	5.0	7.06	5.0	80.0
BE	5.0	5.55	6.13	5.0	7.06	5.0	82.5
CG	5.3	5.55	5.84	9.3	7.95	5.95	100.0
CE	5.3	5.55	5.84	9.3	7.95	5.95	100.0
DG	5.5	5.46	6.17	5.0	7.06	5.25	96.5
DE	5.5	5.46	6.17	5.0	7.06	5.25	87.8
EN	5.8	5.51	5.86	9.2	6.45	4.05	74.5[b]

[a] In the designation, the first letter refers to the overlay type given in Table 2; the second letters are G for grout, E for epoxy, and N for none.

[b] Total of six specimens cast. Because two overlays separated from specimens during freeze-thaw tests, durability factor is average of remaining four specimens.

Figure 4. Typical overlays after freeze-thaw action under ponded saltwater.



a) Overlay A - 53 Cycles (4-1/2% Air).

b) Overlay B - 53 Cycles (5% Air).

c) Overlay C - 50 Cycles (9.3% Air).

d) Overlay D - 44 Cycles (5.0% Air).

e) Overlay E - 51 Cycles (9.2% Air).

Table 6. Cold beam test.

	Overlay			
Beam	Type	Thickness (in.)	S_w/S_D	S_f/S_w
FT-1	1½	Grout	3.4	1.0
FT-2	1½	Grout	3.1	0.9
FT-3	1½	Grout	2.4	0.9
FT-4	1½	Grout	3.5	0.9

Notes: Beam dimensions are given in Figure 1. Each beam was subjected to 2 million load repetitions. S = stiffness and deflection of midspan/load at midspan; S_D = S prior to overlay; S_w = S subsequent to overlay prior to cycling; and S_f = S subsequent to overlay and cycling.

Vibrational amplitudes before and after the overlay material (beam DG12) was cured are as follows.

Amplitude (in.)		Amplitude/Span	
Initial	Final	Initial	Final
0.044	0.008	0.00046	0.0000835

The ratio of final amplitude to initial (plastic overlay) amplitude is 5.5. The ratio of amplitude to span, 0.00046 before the overlay stiffened, corresponds to a deflection of 0.33 in. for a beam spanning 60 ft. Under controlled traffic, it is not likely that this much deflection would occur in a lane being overlayed.

Two 6-in. diameter cylinder molds mounted on the vibrating beam were filled with the overlay concrete and vibrated with the beam as the cylinders cured. Two similar cylinders were made by standard procedures and cured on the floor near the vibrating materials. The cylinders were tested after 48 hours, and those that were mounted on the vibrating beam showed considerably higher strength than those cast and cured in the normal way.

Beams were tested to determine if the cycling of both load and temperature would adversely affect the overlay and its bonding agent. Careful visual inspection of each beam at the time of its static loading revealed no failure or distress of any kind. The load-deflection ratios given in Table 6 show that the beams were greatly stiffened by the addition of the overlay and that subsequent cycling of load and temperature reduced the stiffness by about 10 percent.

Good performance of the concrete overlay bonded with grout is shown in all four of the test series. The materials require proper treatment if good results are to be expected. But the treatment required is not difficult, and workmen are familiar with the materials and the treatment.

CONCLUSIONS

The following can be concluded from the tests discussed in this paper.

1. Portland cement concrete overlays from 1 to 2 in. thick bonded to a base concrete slab with either portland cement grout or epoxy resin are capable of developing shear bond strength far in excess of that normally required in service. The base material must be properly prepared to receive the bonding material.
2. Properly bonded concrete overlays of 1-to 2-in. thickness will undergo at least 2 million load cycles without bond failure.
3. Thin concrete overlays can be placed and cured on a vibrating base similar to a bridge deck under controlled traffic loads. Such an overlay will bond firmly to the base material when bonded with portland cement grout.
4. Portland cement grout and epoxy bonded concrete overlays will undergo ASTM C 290 durability test without failure.
5. Air entrainment provides excellent resistance to freeze-thaw scaling.

RECOMMENDATIONS

It is recommended that strong consideration be given to portland cement concrete overlays for bridge decks requiring surface repair. An overlay cannot solve the problem of a deck that is deteriorated from top to bottom, but it can be used to repair decks with deep scaling and delamination. Such an overlay repair installation must be carefully designed and properly placed. It should be sealed with a waterproof membrane if it is to be subjected to de-icing salts.

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DISCUSSION

Jerry Shackelford and Harvey Shafer, Dow Chemical Company

The authors have presented a convincing case for bonded, cement-rich, air-entrained concrete deck overlays. And yet, the results of the freeze-thaw scale durability tests suggest that the material used for repair causes the problem.

We at Dow have been working on latex modification of portland cement compositions, both in the laboratory and in the field, for many years. The depth of these investigations was manifested in 1969 when J. E. Isenburg reported on his research of both modified and unmodified materials by way of the scanning electron microscope.

Among the things we have learned is this: When you include a film-forming latex in a portland cement composition mix, you have an entirely different material with different handling characteristics and, more importantly, different curing requirements.

Curing needs for these materials are not unique and likely are more easily met under actual construction conditions. These needs are simply a short moist-cure followed by air-cure, which is necessary to allow the polymer to harden.

Synthetic latices, suitable for cement modification, contain air-entraining materials and so must not be used with additional air-entraining agents in the mix. Excessive air in the bonding matrix prevents proper bonding and allows infiltration of liquids to the bond interface.

When we relate these two variables to the Furr and Ingram paper, particularly to series 1 tests (shear bond) and series 2 tests (freeze-thaw durability), we may understand the relatively poor performance of the latex-modified specimens.

Both wet curing and use of air entrainment considerably reduce the effectiveness of the system. Because it appears that one or both were present in these tests and that therefore the properties of the system were not optimized, the validity of the evaluation may be questioned.

LaRue Delp, State Highway Commission of Kansas

Kansas is in the middle of a rather extensive program of repairing 5 to 10 percent of all bridges in the state, many with extensive deck deterioration. The scaled and spalled areas vary in magnitude and frequency. They range from the initial stage to full-depth deterioration. Temporary repairs are generally made on a day-to-day basis until about 30 to 40 percent of the deck reaches some degree of damage. Another criterion is the rate of deterioration. A contract is then let for the covering of the entire deck with a combination of full deck repair and/or a 2-in. bonded overlay.

We are currently programmed to advertise bridge repair contracts throughout the state for about $1 million annually, much of which is this type of work. We believe, at least for the present, that the program will be one of a continuing nature; however, there is no indication of any type of failure to date in the completed work on deck overlays. Some bridges are now more than 6 years old.

The report by Furr and Ingram, showing factual data of the various tests on this type of work, is of tremendous value for programming. It could furnish some sound guidelines.

For many years my role has been exclusively that of programming the repairs on all facets of the highway system. It is a constant process of weighing the economics of repair versus replacement. I mention this to point out the necessity for knowing the types of concrete (lightweight or conventional) and aggregate (limestone versus sand gravel, etc.). In many locations, the concrete in situ continued to deteriorate after the initial repairs were made, even though it appeared to be sound. This may eventually prove to be true on some of the bonded overlays covering the entire deck.

This is mentioned to point out the necessity of further comprehensive research that will develop guidelines oriented toward the aggregate of the in situ concrete as well as the bonding agent.

Although Kansas follows, for the most part, a rather rigid plan of repair and has been very successful with its use of bonding agents, difficulty is experienced in determining the strength of the in situ concrete. More work should be done to provide adequate data for determining the feasibility or practicality of a concrete deck overlay and the methods of measurement used for both the area and depth of deteriorated concrete.

The Furr and Ingram report covers the bonding agents very effectively and is a useful tool for programming bridge repair.

AUTHORS' CLOSURE

The State Highway Commission of Kansas has the most extensive experience in concrete bridge deck overlays known to the authors. The comments of Delp are particularly valuable because of that experience.

The maintenance engineer is always faced with the problem of deciding when a temporary repair program should be replaced with a major repair job. The practice of Kansas in overlaying when 30 to 40 percent of the deck shows damage might be helpful to others in deciding when a major repair job is warranted. Case histories are needed in developing information that is necessary for maintenance programming. Pieces of information on costs, installation, and performance are available here and there in literature, but a coordinated program is needed. An agency that would collect such information from highway departments throughout the country, classify it, and send it to interested parties would be very helpful in maintenance planning.

A number of state highway departments have used latex-modified portland cement concrete in bridge deck overlays and in other concrete repairs on bridges. Shackelford and Shafer of the Dow Chemical Company have been very helpful in providing assistance in the use of such material. Our test program showed laboratory freeze-thaw scaling to be almost negligible in the latex-modified material and in air-entrained portland cement concrete. The consensus now seems to be that spalling can be combatted best by keeping water out of the concrete. If this is correct, an impervious cover over the new concrete deck would solve the spalling problem provided that such a cover is feasible.

The latex-modified concrete specimens used in series 2 freeze-thaw durability tests were moist-cured according to ASTM C 290. At the time of those tests, it was not known that the moist cure normally given ordinary portland cement concrete would be detrimental to bonding of this material. The latex-modified concrete specimens used in series 1 shear bond tests were moist-cured 1 day and then air-cured for 6 days. No air-entraining agent was used in either of these test series.