BOND AND DURABILITY OF CONCRETE AND RESINOUS OVERLAYS

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DISCLAIMER

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I. ABSTRACT

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 mainteinad on one beam, by cyclic loading, during placement and cure of a 1-1/2 in. overlay to simulate vibration due to traffic on a lane adjacent to one being overlaid.

Shear bond strengths ranged from 214 psi 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.

KEY WORDS: bond, bridge decks, concrete, durability, freeze-thaw, grout, maintenance, overlay, repetitious load, resinous concrete, vibration

II. SUMMARY

Overlays suitable for repairing concrete bridge decks heavily damaged by scaling and spalling are the subject of this report. Four series of tests were made to generate information from which repairs might be designed. These tests are:

1. Direct shear tests to determine the shear bond strength of bonding agents used to bond overlays to the base concrete.
2. Freeze-thaw tests to determine the durability of bonding agents and overlay materials.
3. Beam tests to determine the effect of overlays and repeated loadings on a reinforced beam, and to determine the effect of those loads on the bonding agents.
4. Repeated load tests under cold temperature to determine the fatigue characteristics of overlaid beams in freezing environments.

All of the tests were made in the laboratory using commercially available materials.

The findings, given in the same order as the tests enumerated above, are:

1. Grout made from portland cement, sand, and water developed an average direct shear of 541 psi from 12 specimens; epoxy bond developed 448 psi average for 12 specimens; latex modified concrete with no bonding agent developed an average of 382 psi from three specimens.

Air-entrained concrete developed the same bond shear strength as non air-entrained concrete. An epoxy overlay developed an average of 214 psi shear bond from six specimens, and a polyester concrete developed 344 psi average with six specimens.

2. All bonding materials with the exception of two of three specimens of latex modified concretes withstood ASTM C-290 freeze-thaw tests.

   The overlay materials, plain concrete, concrete reinforced with welded wire, chopped wire concrete, shrinkage compensated cement concrete, and latex modified concrete were tested in freeze-thaw. The latex modified material showed essentially no scaling whereas all others were moderately scaled at 50 cycles. All materials were air entrained.

3. Beams were measurably stiffened by the addition of overlays over 1 in. thick. There was a loss of approximately 10% in stiffness due to 2 million load cycles on the overlaid beams. It was found, too, that the overlay can be applied to the beam during low frequency, low amplitude vibration without harm.

4. Four overlaid beams were subjected to repeated loads during the time that ambient laboratory temperature was gradually reduced from 70°F to 20°F. The stiffnesses of the beams were reduced about the same as those in item 3 above but no harmful effects were found in the overlay, the bonding grout, or the beam.

The information gained in the study has been used to supplement information taken from published literature in producing a guide for designing and applying bridge deck overlays.

III. IMPLEMENTATION STATEMENT

The results of this study, supplemented by information contained in published literature, show that damaged concrete bridge decks may be effectively repaired by concrete overlays. Decks that have received heavy scale damage, spalling, and cracking may be brought back to an efficient serviceable condition by the application of a concrete overlay of about 1-1/2 to 2 in. in thickness. These findings have made it possible to outline steps that may be followed in applying such an overlay with assurance of years of added service life to the deck.

It is essential that the damaged deck be conditioned to receive the overlay. That overlay must be of high quality material and workmanship, and it must be adequately bonded to the base slab. Every phase of the repair operation must be carefully executed if the work is to be successful.

Preparation of the deck to receive patches and overlay requires removal of all loose and deteriorated concrete, and the steel must be cleared of rust and loose scale. Material containing oil and grease must be removed to permit good bond between new and old concrete. Care should be taken to prevent surface contamination from oil and grease from blasting sand and from tools and machines.

Holes and spalled areas extending below the top steel, a depth of about 3 in., should be patched before the overlay is applied. This allows for early shrinkage of the deeper material before the overlay is applied, and permits a greater compaction effort sometimes required in such areas. These areas are prepared for the patch by first removing all loose material. The chipping hammer is used in small areas, but if deep spalling covers a wide area, a concrete scarifier works well in removing deterioration. The chipping hammer, or the scarifier, should be followed by a high pressure water jet or sand-blasting, or both. This removes small loose particles and cleans exposed steel. All dust should then be removed. The base concrete should be surface dry to receive the patch but it should not be so dry throughout that mixing water needed for hydration of the patch material is absorbed by the concrete.

The sound concrete should be coated with a cement grout thoroughly worked into all surfaces, including vertical edges. The grout, a mixture of portland cement, water, and concrete sand, see Table A-3, should be worked in with a stiff brush or broom to leave a thickness of about 1/8 in. over the area to be filled. When the grout becomes damp dry, a low slump, 1 in. maximum, air-entrained concrete mix should be thoroughly compacted in the area to bring it up to the level of the top surface of the deck. Care must be taken to see that this concrete is worked under and around exposed steel and in other areas which might present difficulty. It should be rammed into place, if necessary, to force it into all areas. The surface should be given a rough finish, and no curing compounds should be used on it. It should be cured under matting for about 12 hours to prevent loss of moisture. The overlay may then be applied.

Epoxy may be used to bond the concrete patch instead of using cement grout. The preparation is the same for both but the surface must be thoroughly dry to receive the epoxy, and manufacturers' instructions must be closely followed for good results.

Removal of loose and damaged concrete on the deck proper may come before or it might follow the patching outlined above. Scarifiers, such as the Tennant machine, have been used in some operations. In others, hand tools such as light air hammers have worked well. Some operations have followed the scarifier with a high pressure water jet to remove loosened material. Air hammering should be used only over areas where damaged material is to be routed out. The entire surface should then be thoroughly sandblasted and all dust and loose material should be removed to provide a clean deck.

After cleaning, side forms are set and a vibrating screed mounted for compacting and finishing. The surface of dry concrete should be dampened to prevent it from removing moisture from the grout. No free water, however, should be on the surface when grout is applied. Grout should be thoroughly worked into the roughened, clean surface to about 1/8 in. thickness, ahead of the overlay placement operation. Here, too, epoxy may take the place of cement grout for bonding of the overlay. In so doing, instructions of the manufacturers should be carefully followed in both preparation and application.

Low slump, air-entrained overlay concrete, a seven sack mix with 1/2 in. maximum size aggregate, is placed over the damp dry grout and compacted with the vibrating screed. Additional compaction should be applied by tamping if the screed does not provide the effort necessary for thorough compaction. The surface should be finished by burlap drag, broom, or float to the texture desired.

Plastic shrinakge should be prevented by using water spray or monomolecular film or both prior to applying mats for curing. The overlay should be cured under wet or impervious matting for seven days. After removal of the mats and after drying, it should receive two coats of a mixture of boiled linseed oil and kerosene (or mineral spirits), 50% each by volume, at the rate of about one gallon per 40 square yards of surface. It can be opened to traffic after the linseed oil dries.

IV. REPORT OF RESEARCH

A. INTRODUCTION

Deep scaling and spalling in many concrete bridge decks have advanced to the point where 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 (1,2,3,4,5).

A study which was made to determine suitable overlays for repairing existing deteriorated concrete bridge decks is the subject of this report. It gives details of a laboratory study which led to the design of a field installation. The report of the field installation will be given in a separate report. The present report concerns materials, bonding methods, and flexural stiffness of relatively thin repair overlays to be applied on existing concrete bridge decks.

Much of the information developed in the research has been reported in Research Report 130-1 (6). This report extends the information contained in that report and gives information on other tests.

The research seeks to find ways of repairing concrete bridge decks which have deteriorated to the point where resurfacing is required. The deterioration normally comes from surface scaling and spalling.

Four series of tests, series 1 through 4, were made to provide information from which repair methods might be developed. Those series are described briefly here, and they are discussed fully later in the report.

Series 1: Direct shear tests to determine the shear bond strength of bonding agents used to bond overlays to base concrete.

Series 2: Freeze-thaw tests to determine the durability of bonding agents and overlay materials.

Series 3: Beam tests 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.

Series 4: Repeated load tests under cold temperature to determine the fatigue characteristics of overlaid beams in freezing environments.

B. TESTS

1. Series 1 - Shear Bond Tests

a. Purpose: This series of tests was made to determine the shear bond strength of bonding agents used to bond overlays to base concrete.

b. Specimens: The specimens consist of a concrete base, representing the bridge deck, and an overlay bonded to the cured base.

The base specimens were 7 in. cubes made of non air-entrained concrete. They were moist cured seven days then stored in the laboratory until needed for overlay, generally three or four weeks later. After storage, the finished surface of each cube was sandblasted in preparation for the overlay.

A bonding agent was used to bond the portland cement overlay materials on some of the base specimens, and on others it was omitted. Portland cement grout, epoxy, and polyester were used. The epoxy was allowed to become tacky after it was brushed on the dry prepared surface and the overlay was then applied directly to it. The cement grout was thoroughly brushed in on the dry prepared concrete surface to a thickness of about 1/8 in. It was allowed to become damp dry, and the overlay was then applied.

The concrete that used a latex additive made its own bonding agent by being thoroughly brushed into the surface similar to the grout discussed above. This process brushed out all of the coarse material leaving only the grout from the concrete. The latex modified concrete was applied over this grout. A polyester material, designated CDC-100 by the supplier, was a proprietary product supplied with the overlay material. The bonding material was applied with a brush and was allowed to harden before the overlay was applied. No bonding agent was used for the resin type concrete overlays.

All of the overlays in this series were 2 in. thick and were formed in wood forms on the base cubes as is shown in Figure 1. They were compacted in place by tamping and were finished off with a wood screed. The portland cement concrete overlays were moist cured seven days then stored in the laboratory until tested. The resin type overlays were cured in the laboratory under ambient conditions and were held with others in the laboratory until ready for shear tests. The latex modified concrete overlays were cured

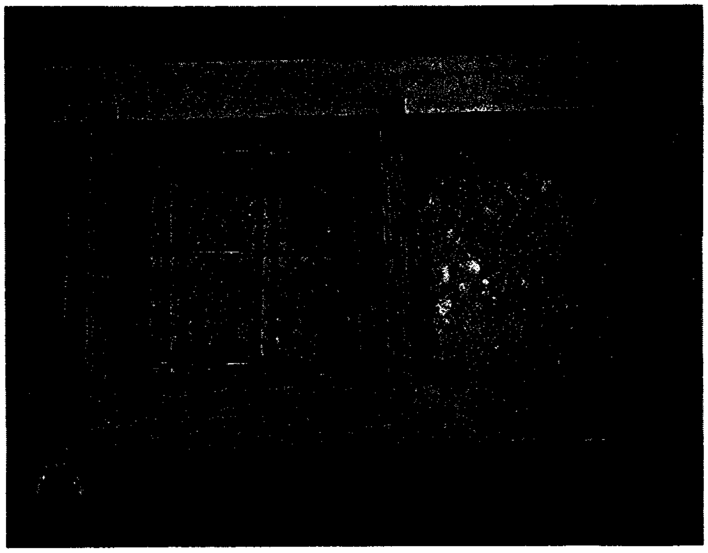


Figure 1. 7" Cubes Prior to Application of Bonding Agent and Overlay. The welded wire reinforcing in the left photograph is shown here only to illustrate how it is used in overlay Type B; it is removed prior to grouting.

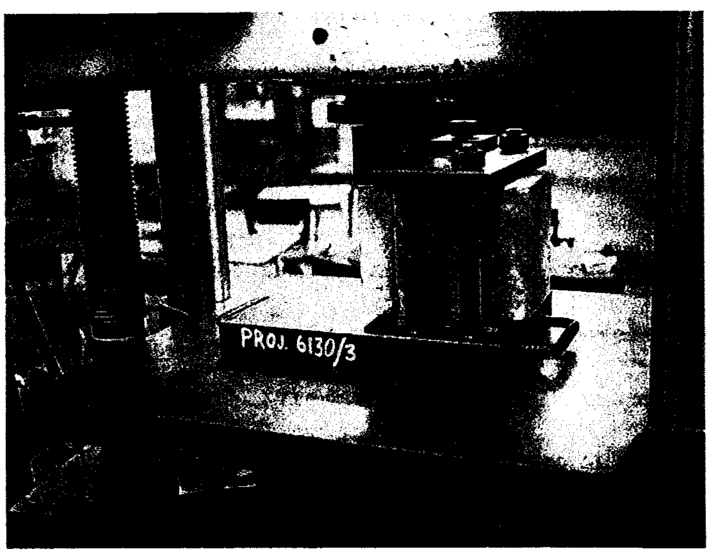


Figure 2. Testing the Bond Between Overlay and 7" Concrete Cube.

under wet mats 24 hours then cured in air until tested. Welded wire fabric, #4 gage wire on a 3 in. grid, was laid directly on top of the cement grout in overlay Type B, see Table A-2 and Figure 1.

c. Materials: Information on the portland cement concrete mixes for the cubes and overlays, as well as for other specimens, is given in Appendix A, Tables A-1 and A-2. All overlays, with the exception of F, were made of air-entrained concrete as shown in Table A-2. No air entrainment was used in the grout.

The epoxy mortar overlay was a mixture of Guardkote 250 epoxy and concrete sand on a 15% - 85% basis by weight. A proprietary product designated CDC-100, a mixture of concrete sand and a polyester resin formulation, was used for overlay J.

d. Tests and test results: When the overlay was seven days old, direct shear tests were made on the jig-mounted specimens as shown in Figure 2. This test is similar to that performed by Felt in pavement overlays (5). The failure surface generally followed the interface of overlay and cube with minor migrations, in some cases, into the base material and into the overlay. The bond strength, average rupture stress over the interface area, is shown in Table 1 as averages of either three or six tests, as indicated in the table.

A concrete bridge deck carrying service loads is stressed in horizontal shear which varies in intensity with distance from the surface to about mid-depth of the slab. When the slab carries an overlay, that shear stress at the interface of the overlay and the base slab is dependent on the shear at the section and the relative thicknesses of overlay and slab. A slab supported by beams is considered by AASHO (7) 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 say 3 ft, would cause a shear of 3.9 kips on a 7 in. wide section. Applying the horizontal shear formula, $v = \frac{VQ}{Ib}$, to the interface of a 7 in. uncracked slab with a 2 in. overlay for a 3.9 kip load, an interface shear is found to be

$$v = \frac{3900 \times (14 \times 3.5)}{425 \times 7} = 64.2 \text{ psi}$$

This stress, being only 30% of the minimum, 214 psi, strength shown in Table 1, would be safe for any of the bonds developed in the tests. Earlier overlays with no special bonding agent (6) developed 129 psi, two times the 64.2 psi computed above.

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.

TABLE 1. SHEAR STRENGTH OF OVERLAY BONDS

Overlay* Designation	Average Bond Shearing Stress (psi): Base Surface Preparation	No Bonding Agent	Grout Bonding Agent	Epoxy Bonding Agent	Other	Remarks
A	Sandblast		420	462*		Air entrained overlay
B	"		555	362		Air entrained overlay
C	"		668	565		Air entrained overlay
D	"		521	402		Air entrained overlay
E	"				382	Latex modified grout and overlay
	(Average		541	448	382)	
F	Sandblast		393			Not air entrained overlay
G	"		388			Air entrained overlay
H-1	"				458	Cement "A", latex modified grout and overlay
H-2	"				382	Cement "B", latex modified grout and overlay
I	"	214				Guardkote 250 overlay
J	"	344				CDC-100 (polyester) overlay

*See Table A-2 for description of overlay materials.

NOTE: The values shown represent the averages of three specimens for each overlay, A through D, and six specimens for each of E through I; and four specimens for J.

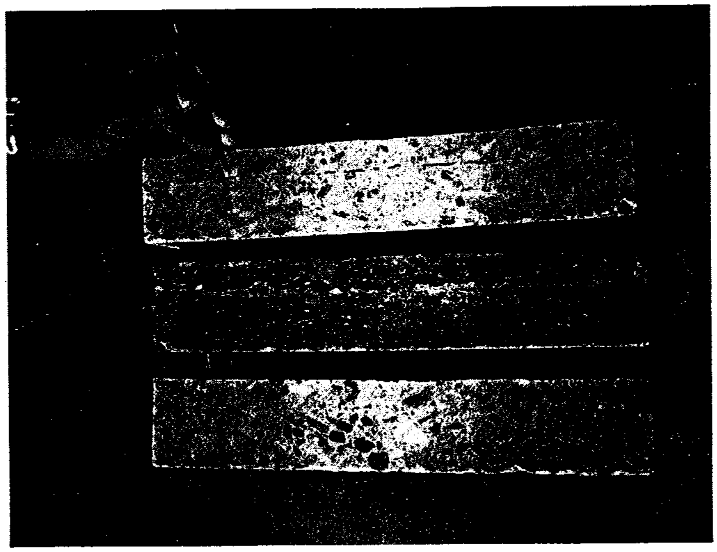
2. Series 2 - Freeze-thaw Durability

a. Purpose: This series of tests was made to determine the effect of freeze-thaw action on the durability of overlay material and the overlay bond.

b. Specimens: The specimens consisted of a 2 in. thick concrete base and a 1 in. thick overlay bonded to the cured base. Base slabs were 10 in. x 16 in. x 2 in. and 10 in. x 10 in. x 2 in. A #10 gage 3 in. mesh steel wire fabric was placed on some of the 10 in. x 16 in. slabs prior to overlaying in the same way as those described in Section B.1.b. The finished surfaces were sandblasted after seven days moist cure, and the bonding agent was then applied as described in Section B.1.b. One inch thick overlays were compacted on the prepared base slab, and the system was moist cured 14 days.

Each 10 in. x 16 in. x 3 in. composite slab was sawed into three 3 in. x 3 in. x 16 in. specimens as shown in Figure 3. The specimens formed in this way provided at least one face on which the bond line and the wire mesh, when used, could be observed during the freeze-thaw cycling. Each 10 in. x 10 in. x 3 in. specimen was equipped with a galvanized metal ring, Figure 4, to form a well to be filled with water for freeze-thaw tests. This type of specimen was used extensively in surface durability tests reported in Research Reports 130-2 and 130-3 (8,9).

Three 3 in. x 3 in. x 16 in. specimens were tested for each bonding agent, grout and epoxy, for overlays A, B, C, and D. Six



3" x 3" x 16" Specimens After Sawing. The line was drawn on the top specimen to delineate the interface of the 2" thick base and the 1" thick overlay.

Figure 3. Freeze-Thaw Specimens.

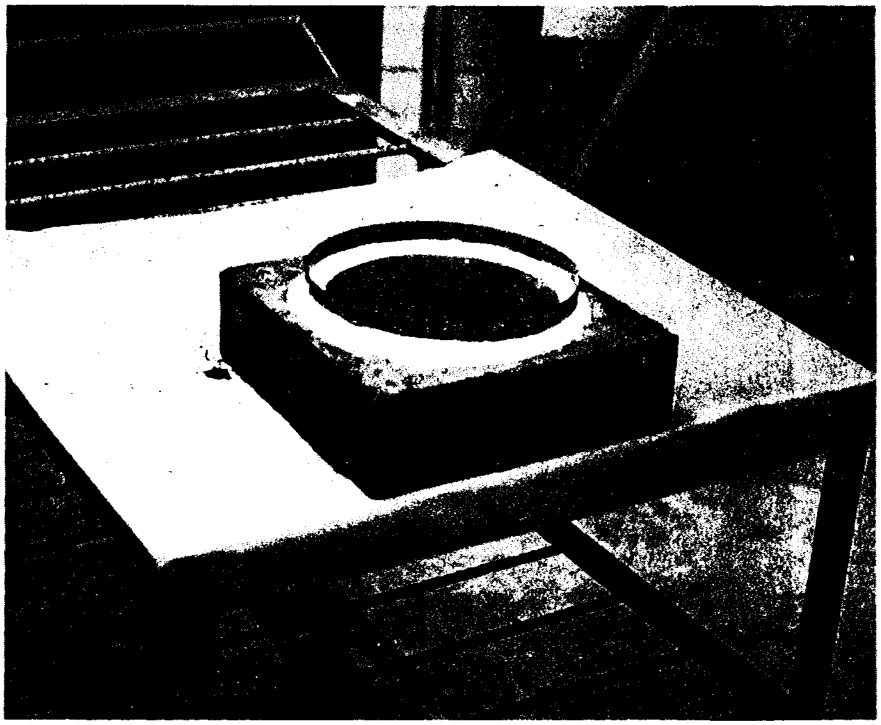


Figure 4. 10" x 10" Overlaid Specimen with Circular Ring Attached.

were tested for the self-bonding overlay type E. This makes a total of 30 specimens of this size.

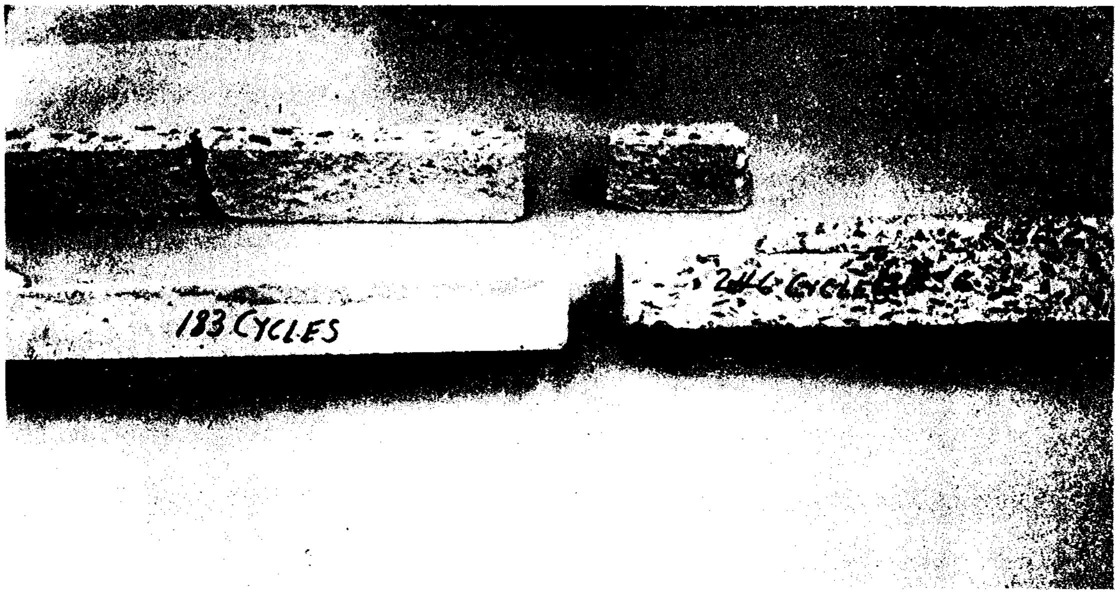
c. Materials: The base slabs, 10 in. x 16 in. x 2 in. and 10 in. x 10 in. x 2 in., were made of air-entrained concrete as shown in Table A-1. One inch thick overlays A through E, Table A-2, also were of air-entrained concrete.

Overlay E provided its own bond and no additional bonding agent was used for it. Both grout and epoxy were used for each of the other overlays, A, B, C, and D.

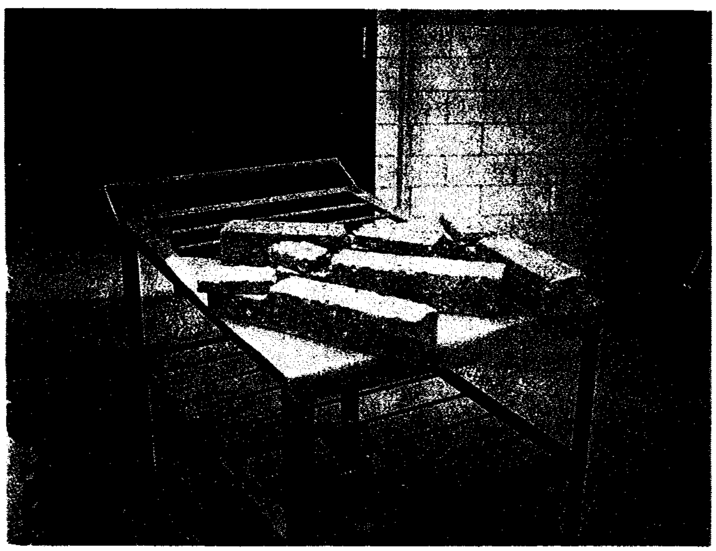
d. Tests and test results: The 3 in. x 3 in. x 16 in. specimens formed by sawing the larger slabs were tested for freeze-thaw durability in accordance with ASTM C-290 (10).

All specimens, except two of the overlay E, completed 300 freeze-thaw cycles. The overlay 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 overlay E had deteriorated to the point where the overlay could be pulled away from the slab by hand. Figure 5 shows the six specimens of overlay E after testing.

No distress was noted in any other overlay during this test. Table 2 gives information on overlay material as well as its durability. Overlays C, both grout and epoxy bonded, showed no loss in dynamic modulus after the 300 freeze-thaw cycles. The overlay material of these specimens contained 9.2% air, Table A-2, high air content being characteristic of that material. If the high percentage of air benefited the bond durability of this overlay, it



(a) Separation of Overlay E Specimens
After 183 and 246 Cycles.



(b) Overlay E Specimens After 300 Cycles.
The Overlay Was Pulled Away by Hand.

Figure 5. Overlay E in ASTM C-290 Test.

TABLE 2. PROPERTIES AND DURABILITY FACTORS OF OVERLAY CONCRETES

Overlay Designation	10" x 16" x 2" Slabs			1" Overlays			Durability Factor (ASTM C-290) of Overlayed System (Average of 3)
	% Air	Cement Factor sk/yd^3	W/C gal/sk	% Air	Cement Factor sk/yd^3	W/C gal/sk	
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
CE	5.3	5.55	5.84	9.3	7.95	5.95	100
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**

*In the designation, the first letter refers to the overlay type shown in Table A-2, and the second letter, G for grout, E for epoxy, and N for none.

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

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. Table 2 shows that all base slab material had almost the same percentage of air.

The wells formed by the metal ring fixed to the 10 in. square overlays were filled with salt brine solution, 5% by weight, and then they were subjected to two freeze-thaw cycles daily. The response of the overlay surfaces to this action is shown in Figure 6 at approximately 50 freeze-thaw cycles. The test showed that the bonding agent had no influence on surface deterioration.

The photographs in Figure 6 show overlay E with 9.2% air to have much less surface scaling than the 9.3% concrete with wire fibers of overlay C.

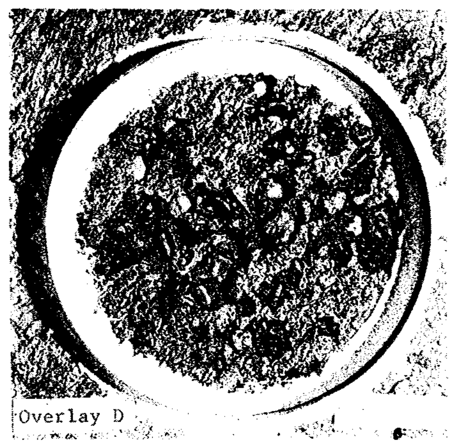
Although the plain concrete of overlay A shows a little greater durability factor than overlay B, which contained welded wire fabric, no difference could be observed visually. The evidence shown in Table 2 shows that neither the grout nor epoxy bonding agent will give trouble because of freeze-thaw action provided that it is properly placed. All other surfaces, A, B, and D, show moderate surface scaling. The concrete for those overlays contained 4-1/2% to 5% air.

The 10 in. square overlays were ponded continuously from 22 to 26-1/2 days under a 5% salt-water solution. About one half of that time was spent in a freezing chamber, and the other half in a thaw chamber. None of the 30 overlays of this series came loose from the

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).

Figure 6. Typical Overlays After Freeze-Thaw Action Under Ponded Salt Water.

base specimens, nor showed any indication of coming loose. If the overlay is properly bonded, no water can collect for ice lenses under the overlay even if the solution does migrate through the overlay.

3. Series 3 - Beam Tests

a. Purpose: These tests were designed to provide information on the added rigidity provided by overlays and to determine if fatigue failure would occur in the bonding material.

b. Specimens: Details of the 32 test beams, nominally 7 in. wide x 5 in. deep x 96 in. span, appear in Figure 7. The concrete mix and properties are shown in Table A-1.

The top and bottom #4 reinforcing bars were held in place during casting by supports fixed to the plywood forms. Compaction was by internal vibrator, and a wood screed was used for finishing the top surface.

Forms were removed at one day age and the beams were then cured under wet mat until they were seven days old. The beams dried in the laboratory after removal from moist cure. To simulate a cracked bridge deck, they were cracked by gradual loading at mid-span until cracks appeared on the tension side to about mid-depth of the beam. They were then turned over and cracked on the other side. The cracks thus formed, extended approximately to mid-depth from each side. Sandblasting of the finished surface to expose coarse aggregate in preparation for the overlay followed the cracking operation.

Load deflection data from midspan loading and midspan deflection were taken for each beam before further processing. Bonding agents as described in Section B.1.b were used on most beams before the overlays were applied. The latex modified concrete overlay provided its own bonding, as did the epoxy mortar overlay as described in Section B.1.b. The CDC-100 material overlay used a polyester binder which was applied by brush just prior to the CDC-100 overlay. The schedule of overlays and bonding agents appears in Table 3.

The 1/2 in. to 2 in. thick overlays were placed in one layer and were struck off with a wood screed. The concrete overlays were compacted with a pneumatic surface vibrator. Figure 8 shows various steps in the overlay operation.

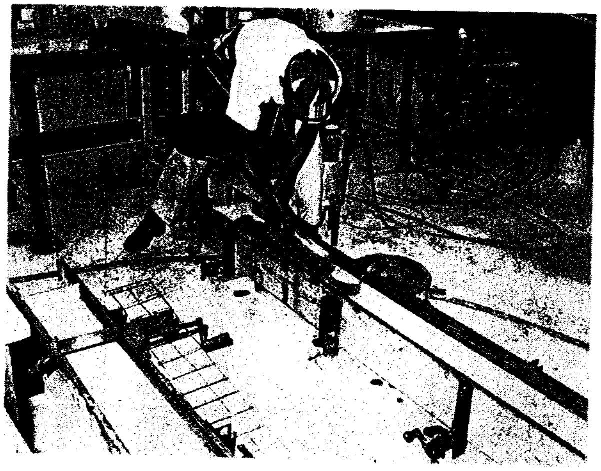
All concrete overlays, except the latex modified material, were cured under wet matting until they reached seven day age. The latex modified material was moist cured under mat for one day, and the resin type overlays were cured in air. All beams remained in the laboratory until the tests were scheduled. This period varied from two days to some six weeks. The four beams tested under freezing temperatures dried at least one month in the laboratory before they were frozen.

c. Materials: The materials used for the beams and overlays of this series are the same as were used for specimens of series 1 and 2. Descriptions are given in Section B.1.c, and properties of the overlay materials are given in Table 4.

TABLE 3. BEAM SCHEDULE AND STIFFNESS RATIOS
(See Fig. 7 for beam dimensions)

Beam Designation	Overlay: Type ***	Overlay: Bonding Agent	Overlay: Thickness (ins.)	Overlay: Age of Test (days)	P ÷ Δ**: No Overlay (1)	P ÷ Δ**: With Overlay, No Cycling (2)	P ÷ Δ**: With Overlay, 2 Million Cycles (3)	(2) ÷ (1)	(3) ÷ (1)
AG-12	A	Grout	2	38	3810	41,100	37,800	10.7	9.9
AE-12	A	Epoxy	2	38	3740	25,000	23,500	6.7	6.3
BG-12	B	Grout	2	39	4450	34,200	29,200	7.7	6.6
BE-12	B	Epoxy	2	32	4210	18,600	-------	4.4	---
CG-12-1	C	Grout	2	10	5200	36,900	29,200	7.1	5.6
CG-12-2	C	Grout	2	11	4600	15,800	15,300	3.4	3.3
CE-12	C	Epoxy	2	9	3150	12,400	11,600	3.9	3.7
DG-12	D	Grout	2	34	5000	18,800	18,400	3.8	3.7
DE-12	D	Epoxy	2	9	4700	19,500	16,400	4.1	3.5
EG-12-1	E	L.M.*	2	--	4550	17,800	16,300	3.9	3.6
EG-12-2	E	L.M.*	2	--	3980	12,400	11,800	3.1	3.0
AG-11	C	Grout	1 1/2	39	3880	22,200	20,000	5.7	5.2
AE-11	C	Epoxy	1 1/2	20	5000	13,300	18,200	2.7	3.6
CG-11	C	Grout	1 1/2	11	3850	14,400	16,700	3.7	4.3
BG-11-1	B	Grout	1 1/2	9	3960	7,870	8,450	2.0	2.1
BG-11-2	B	Grout	1 1/2	9	4080	12,700	10,800	3.1	2.6
CG-11-1	C	Grout	1 1/2	10	3920	8,640	8,330	2.2	2.1
CG-11-2	C	Grout	1 1/2	10	4000	9,520	10,100	2.4	2.5
DG-11-1	D	Grout	1 1/2	13	4830	12,100	12,600	2.5	2.6
DG-11-2	D	Grout	1 1/2	13	3450	8,930	9,500	2.6	2.7
EG-11-1	E	L.M.	1 1/2	10	3670	8,350	8,430	2.3	2.3
DG-11-3	D	Grout	1	10	3640	9,490	8,090	2.6	2.2
DG-11-4	D	Grout	1	10	3840	11,100	9,100	2.9	2.4
GK250-1	I	None	1/2	7	4040	4,430	4,250	1.1	1.1
GK250-2	I	None	1/2	7	5080	5,650	4,800	1.1	1.0
GK250-3	I	None	1/2	6	4130	4,590	4,720	1.1	1.1
GK250-4	I	None	1/2	6	3960	4,380	4,410	1.1	1.1
CDC100-1	J	Polyester	1/2	7	3840	5,150	5,370	1.3	1.4
CDC100-2	J	Polyester	1/2	7	3740	4,090	4,090	1.1	1.1
CDC100-3	J	Polyester	1/2	2	2860	4,680	5,000	1.6	1.8
CDC100-4	J	Polyester	1/2	2	2960	4,190	4,360	1.4	1.5
					Avg. of 31 = 4067				

*Latex modified cement concrete.
**Midspan load ÷ midspan deflection.
***See Table A-2 for description of overlay type.



(a) Applying Grout Bonding Agent to Sandblasted Surface of Beam.

(b) Beam Prior to Overlay After Application of Bonding Agent (grout).

(c) Vibrating Overlay Concrete.

Figure 8. Stages of Beam Overlay Operation.

TABLE 4. PROPERTIES OF OVERLAY CONCRETE

Overlay Type	Compressive Strength f'_c (psi)		Modulus of Elasticity* (10^3 psi)		Split Cylinder Tensile Stress T (psi)	
	7 Day	28 Day	7 Day	28 Day	7 Day	28 Day
A-1**	3180	---	6360	---	442	---
A-2	3179	---	6420	---	432	---
B	---	---	---	---	---	---
C	4195	4457	3850	4.28	591	739
D	3371	---	5550	---	369	---
E-1***	3562	3880	3960	4.76	380	443
E-2	3333	---	3870	---	457	---
E-3	3564	---	4560	---	437	---
G	565	---	23	---	194	---
F	3600	---	1775	---	367	---

*Secant modulus at 1/2 breaking strength.
**A-1 is non air entrained; A-2 is air entrained.
***E-1 and 2 used one brand of cement; E-3 used another brand of cement.

d. <u>Beam tests and test results</u>: The beams were tested under static and cyclic loads 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 were used to determine the stiffness added by the overlay, and to determine if there was any loss in stiffness brought about by the 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 which was cast and cured on the vibrating beams. Details of all of the beam tests are given below.

(1) Static load-deflection tests: The simply-supported beam was loaded at midspan to 400 lbs in increments of 100 lbs after cracking and before the overlay was applied. Midspan deflections were read for each load increment. The beam stiffness, EI, was computed from the simple beam deflection formula:

$$EI = \frac{L^3}{48} \frac{P}{\Delta}$$

The ratio $\frac{P}{\Delta}$ was taken from the plot of load versus deflection.

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 lbs and readings were taken at smaller load increments. A typical plot of the pre-overlay and post-overlay data is shown in Figure 9. Stiffness values for the overlay in compression are given in Table 3.

The same type of static load deflection tests were made at intervals of 500,000 load cycles during the repeated load tests described below. Typical load deflection plots are shown in Figure 9 at zero and 1.5 million cycles for overlay in compression.

(2) Cyclic load tests: Cyclic loads were applied by a machine with rotating eccentric weights pictured in Figure 10. The loader 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.

An elastic analysis was made to determine the magnitude of midspan load necessary to produce 20 ksi tensile stress in the bottom steel of the cracked overlaid beam. The deflection corresponding to that load was then read from the static load deflection curve of the beam under study, and the loader was operated at the cyclic rate necessary to produce that load. 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.

(3) Overlays cast and cured on vibrating beams: A 2 in. thick overlay was cast on a beam while the beam was subjected to 400 load cycles per minute 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 approxiamtely simulate

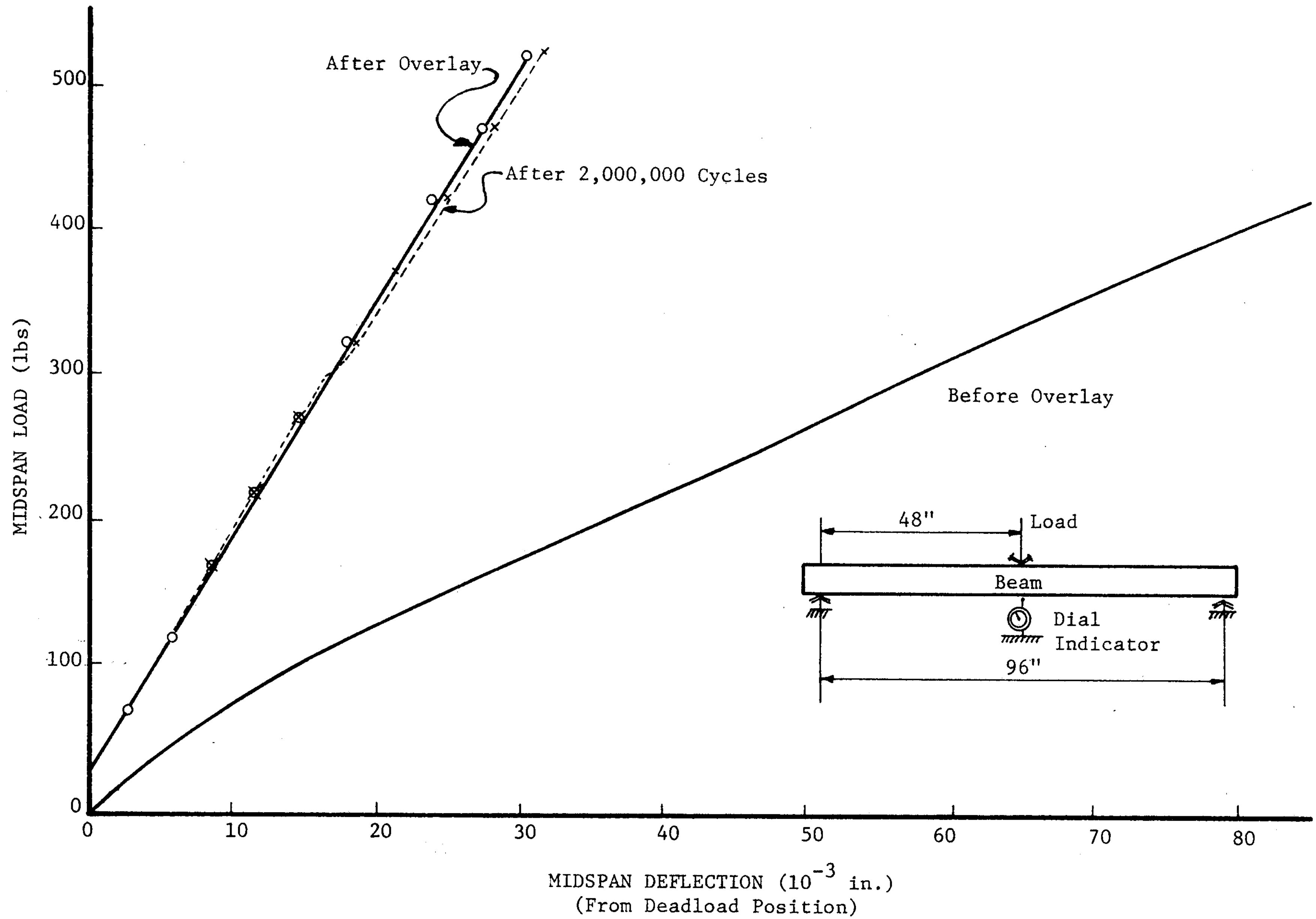


Figure 9. Static Load-Deflection Curves for Beam CG 12-2.

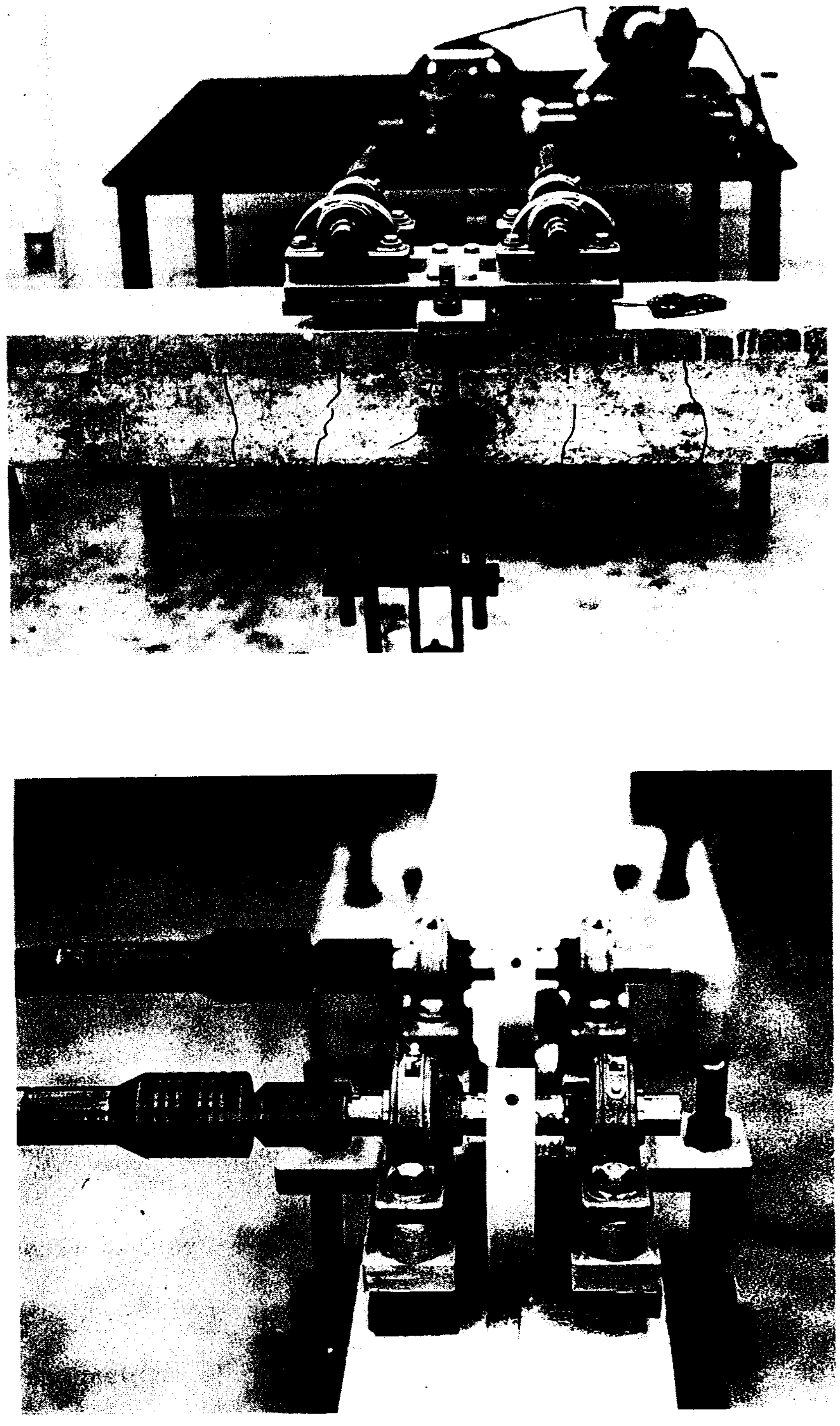


Figure 10. Cyclic Loader Used for Repeated Load Tests of Beams.

vibration of fresh overlay applied in one traffic lane with continuous traffic maintained in an adjacent lane. An overlay maintenance operation of this type would probably be made in some cases under such a condition (11).

Two 6 in. diameter cylinder molds were mounted on the vibrating beam. They were filled with the overlay concrete which was vibrated and cured with the beam. Two similar cylinders were made by standard procedures and cured on the floor near the vibrating materials.

One overlay, overlay type D, was cured six hours during the entire period of cyclic loading at the rate of 400 cycles per minute. That beam had a double amplitude (peak to peak) of 0.044 in. after it was first cast. At 24 hour age the amplitude had reduced to 0.008 in. The test was discontinued at 48 hour age and an inspection showed three tensile cracks near midspan in the overlay. 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. The cylinders were tested at 48 hours age, and those which were mounted on the vibrating beam showed considerably higher strength than those cast and cured in the normal way.

Vibrational amplitudes before and after the overlay material cured are shown in Table 5. The ratio of final amplitude to initial (plastic overlay) amplitude is 5.5. The amplitude to span ratio of 0.00046 before the overlay stiffened corresponds to a deflection of 0.33 in. for a beam spanning 60 ft.

TABLE 5. VIBRATION OF OVERLAID BEAM DG12

Beam	Overlay Type	Amplitude		Amplitude Span	
		Initial	Final	Initial	Final
DG12	A	0.044	0.008	0.00046	.0000835

It is not established that an overlay would or would not crack if placed while traffic is maintained. But, if traffic is controlled, it is not likely that beams not in the loaded lane of a bridge would deflect to a deflection-span ratio as great as that in the laboratory beam. It was established that the bond is not harmed by the deflection. The cylinder strengths were improved, no doubt because of the additional compaction of the plastic concrete during vibration.

4. Series 4 - Cold Temperature Flexure Tests

a. Purpose: This test was made to determine if the cycling of both load and temperature would adversely affect the overlay and its bonding agent.

b. Specimens: The beams used in this series are dimensioned in Figure 7. A 1-1/2 in. thick concrete overlay was bonded to each of the beams with grout. Beam forms were stripped at one day age and the beams were then moist cured seven days. They were dried 30 days in the laboratory and were sandblasted before the overlay was applied.

Overlays were moist cured seven days then dried in the laboratory until at least 30 day age before testing. The vertical faces of the beam were covered with a 1 in. thick layer of fiberglas insulation to simulate the effect of the slab concrete in a bridge deck. The top and bottom and ends of the beam were exposed.

c. Materials: The concrete used in the beams is described in Table A-1, coarse aggregate gradation 4. Overlay concrete was type A shown in Table A-2 and bonding material was grout described in Table A-3.

d. Tests and test results: The temperature was gradually lowered in the test chamber from 70°F to 20°F during which period the beam underwent cyclic loading. Figure 11 shows the time-temperature schedule, and details of the test are given below.

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°F to 20°F while load cycling was maintained at approximately 11 cycles per second. After 500,000 cycles, loading was stopped until the temperature rose to 70°F. Then, 16 hours after stopping, a static load deflection test was made.

No continuous record of room temperature was kept of either the descending nor the ascending curves. The freezing cycle required essentially a 12 hour day to draw the temperature from 70°F to 20°F. No record of temperature inside the beam concrete was taken.

The pattern established on the run from 70°F to 20°F for the first 500,000 cycles was maintained throughout the 2 million load

TABLE 6. COLD BEAM TEST

Definitions: S = stiffness and deflection of midspan ÷ load at midspan
S_D = S prior to overlay
S_w = S subsequent to overlay prior to cycling
S_f = S subsequent to overlay and cycling

Beam Designation	Overlay Thickness (in.)	Overlay Type	$S_w \div S_D$	$S_f \div S_w$
FT-1	1 1/2	Grout	3.4	1.0
2	1 1/2	Grout	3.1	.9
3	1 1/2	Grout	2.4	.9
4	1 1/2	Grout	3.5	.9

Note: Beam dimensions are given in Figure 3. Each beam was subjected to 2 million load repetitions.

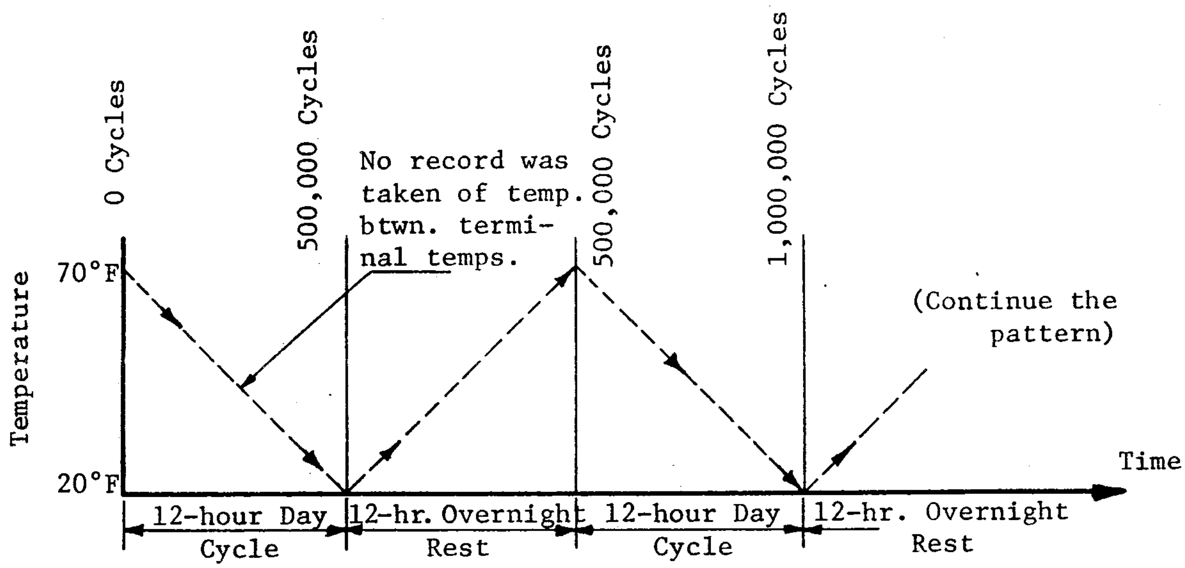


Figure 11. Temperature-Time -- Loading Cycle for Cold Beam Test.

cycle test. A total of five days was required for testing each beam subsequent to application of the overlay. Four of those days were spent in loading with the repetitive load.

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 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%.

V. RESULTS

Four series of tests were made and those tests have been described and discussed previously. The tests are named again here to bring back into focus the major objectives:

Series 1: Direct shear tests to determine shear bond strength of agents used to bond overlays to concrete.

Series 2: Freeze-thaw tests to determine durability of bonding agents and overlay materials.

Series 3: Repeated load tests at room temperature to determine the effect of repeated loads on the stiffness of overlaid beams.

Series 4: Repeated load tests during temperature drop from 70°F to 20°F.

Bond strengths of concrete overlays applied to sandblasted surfaces of 7 in. cubes using grout, epoxy, latex modified cement, Guardkote 250 epoxy, and CDC-100 polyester product were tested. The base concrete mix and cure were constant although several batches were made and they were not all cured at the same time. Bond strengths shown in Table 1 show that the weakest was 214 psi, in an average of six specimens, and the strongest was 668 psi in an average of three specimens. These tests, and previous ones (6), 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 of Table 1, considerably higher than the average bond from other materials in the same test series. Grouted specimens F and G in that table show that bond strength is not affected by the air entrainment used.

All bonding agents except one, overlay E described in Table A-2, withstood the freeze-thaw cycling of test series 2. 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 64.2 psi which was 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. The cement grout provided the highest bond strength, and it is by far the easiest to apply.

Overlay materials were tested for freeze-thaw durability, in series 2, and for stiffness and fatigue in series 3 and 4. All materials performed well with the exception of overlay E, Table A-2, which came unbonded in one case at 183 freeze-thaw cycles and at 246 cycles in the other case. Table 2 shows that overlays made with chopped wire reinforcing had the highest durability factor, but it had over 9% entrained air. The mix was designed for 5% entrained air, and that was realized in most batches.

The chopped wire by nature entrains a high percentage of air, which possibly accounts for the higher durability rating of that material.

Specimens freeze-thaw cycled under brine, a very severe test, are shown in Figure 6. All overlays of this group with the exception of overlay E (Table A-2) were scaled. Overlay E is the one that came unbonded in the ASTM C-290 tests (Table 2). Based on results of freeze-thaw tests under brine reported in other tests (8,9), the performances of all specimens here were satisfactory.

The stiffness tests of series 3 and 4 show that a bonded overlay of 1 to 2 in. of concrete increase the stiffness of 5 in. thick beams from about two to five times the stiffness prior to overlay. Overlays of 1/2 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. These tests were not designed to provide extensive information on the stiffness of resin materials for that reason.

Concrete in 1 to 2 in. thicknesses can add considerably to the stiffness of existing bridge decks. All bonded well to the clean concrete of these tests, and none showed any distress under repeated loading.

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

CONCLUSIONS

Tests were made on certain materials to determine if those materials might perform well on highway bridges. Based on results of those tests the following conclusions are made:

1. Direct shear strength of grout used to bond concrete overlays to sandblasted concrete surfaces varied from 388 psi to 688 psi. Epoxy provided from 362 to 565 psi shear strength in similar tests. Both provide adequate shear for concrete overlays of 1 in. to 2 in. thick for concrete bridge deck concrete.
2. The grout and epoxy bonding agents did not break down under ASTM C-290 freeze-thaw tests.
3. Scaling of air-entrained concrete overlays with no surface treatment was moderate at approximately 35 freeze-thaw cycles under ponded brine.
4. Laboratory test beams were stiffened twofold to fourfold, respectively, with the addition of 1 in. thick and 2 in. thick concrete overlays.
5. Repeated loads up to 2 million cycles at room temperature failed to cause unbonding and fatigue failure of bonded concrete overlays using epoxy and cement grout.

   Repeated loads up to 2 million cycles at temperatures varying from 70°F to 20°F failed to cause unbonding and fatigue failures in concrete overlays 2 in. thick bonded with grout.

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A P P E N D I X

TABLE A-1. BASE SPECIMEN DESIGNS

Specimen Type	Coarse Aggregate Gradation	Mix Proportions lb/yd^3				Concrete Properties			
		Gravel	Sand	Cement	Water	%Air	Slump (in.)	C.F. sk/yd^3	W/C gal/sk
7" x 7" Cubes	4*	1942	1272	518	273	None	3	5.50	6.0
10" x 16" x 2" Slabs	3*	1761	1323	518	269	5.5	3	5.50	6.0
10" x 10" x 2" Slabs	3	1761	1323	518	269	5.5	3	5.50	6.0
7" x 8 1/2' x 5" Beams	4	1942	1272	518	273	None	3	5.50	6.0

*See Table A-2 for gradations.

TABLE A-2. OVERLAY DESIGNS

Overlay Type	Coarse Aggregate Grade (see table below)	Mix Properties (lb/cy.yd)				Concrete Properties				Comments
		Gravel	Sand	Cement	Water	% Air	Slump (in.)	C.F. (sk/cy.yd)	W/C (gal/sk)	
A	1	1821	1128	663	301	4.5	2 1/2	7.04	5.13	Plain concrete
B	1	1846	1142	664	285	5	2 1/2	7.06	5.00	4-gage welded wire, 3" x 3", placed on bonding agent
C	2	0	2390	748	394	9.3	None	7.95	5.95	Coarse aggregate replaced by 261 lbs of steel fiber, 3/4" long x 0.010" x 0.022"
D	1	1827	1132	665	309	5.0	4	7.06	5.25	Chem Comp cement used with 4-gage welded wire, 4" x 4", at mid-height of overlay
E	3	1531	1350	607	124	9.2	7	6.45	4.05	Concrete modified with latex additives, 3 1/2 gal/sk, latex was 48% water by weight
F	1	1846	1142	664	279	None	1 3/4	7.15	4.75	Not air entrained
G	1	1846	1142	664	270	5	2	7.04	4.60	Air entrained
H-1	3	1254	1568	627	131	5 1/2	4 1/2	6.67	4.04	Cement "A" latex modified grout
H-2	3	1254	1568	627	131	6	5	6.67	4.04	Cement "B" latex modified grout
I	7 1/2 lbs epoxy 50 lbs concrete sand									GuardKote 250, no primer, 15% epoxy, 85% sand by weight
J	8 1/4 lbs resin 33 ml catalyst 40 lbs sand									CDC-100 (polyester) primer - 4 lbs resin, 12 ml catalyst

Sieve Size	% Retained on Each Sieve			
	Grade 1	Grade 2	Grade 3	Grade 4
3/4	0	Steel fiber (steel wire cut into short lengths) 3/4" long x .010" x .022"	0	20
1/2	15		5	30
3/8	25		38	30
#4	58		57	20
#8	2		0	0

TABLE A-3. BONDING AND OVERLAY MIXES

---

1. CDC-100 (Polyester material)

Primer Coat: 8 lb. polyester cement with 24 ml. catalyst

Overlay Mix: 40 lb. concrete sand

10 lb. Pennglass mill white sand

10-1/4 lb. polyester cement

33 ml. catalyst

Mixing Procedure:

(a) Premix concrete and Pennglass sands

(b) Mix polyester cement with catalyst 30 sec.

(c) Add sand mixture and mix with drill and beater type paddle for 2 minutes or until balling is evident

(d) Place mix and compact it. (In the laboratory the butt end of a 2 x 4 was used for compaction.)

(e) Strike off with wood screed and follow with trowel strike off

2. Epoxy (Guardkote 250)

Overlay Mix: 7-1/2 lb. two-component epoxy mix

50 lb. concrete sand

Mixing Procedure:

(a) Mix the two components of epoxy 50%-50% by volume

(b) Combine epoxy and sand and mix 5 minutes with drill and beater type paddle

(c) Pour mix into waxed forms and strike off with a wood screed

(d) After the surface of epoxy mortar has lost its tackiness to touch, roll the surface with a roller to provide compaction, 10 to 20 lb. per lineal inch of contact under hand roller

3. Concretes A-D: Mixes are shown in Table A-2

Grout Mix: 1 part cement

3/4 part sand

1/2 part water

Mixing Procedure:

(a) Mix cement, sand, and water to a creamy consistency

(b) Apply grout to prepared surface with a stiff brush to a thickness of about 1/8 inch

(c) Place overlay concrete and compact it

(d) Strike off with wood screed or other suitable finish

Epoxy Mix: THD A-103 epoxy

(a) Thoroughly mix equal parts of components A and B

(b) Apply epoxy with a stiff brush to a thickness of about 1/8 inch

(c) Place overlay concrete and compact it

(d) Strike off with wood screed or other suitable finish

Concrete E: Mix shown in Table A-2

(a) Brush, with a stiff brush, a portion of the overlay mix onto the surface so as to separate the coarse materials

(b) Remove the coarse materials

(c) Place the overlay concrete onto the brushed surface and compact it

(d) Strike off with wood screed or other suitable finish