A STUDY OF REINFORCED CONCRETE BRIDGE DECK DETERIORATION: REPAIR

by

Raouf Sinno
Assistant Research Engineer

and

Howard L. Furr
Research Engineer

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A STUDY OF REINFORCED CONCRETE BRIDGE DECK DETERIORATION: REPAIR

Introduction

The problem of deteriorating concrete bridge decks exists throughout the United States. A number of bridges in the Texas highway system have reinforced concrete decks that are deteriorated to the point that repairs are required. Deterioration has taken the form of scaling, potholing, and delamination of the concrete surface. Cracking observed in some bridge decks extends completely through the slab, top to bottom, reducing the stiffness of the deck.

Repairs have been made by using asphaltic overlays, epoxy concrete, polyester resins, and portland cement concrete. The portland cement concrete overlay or patch is possibly the most desirable if it can be placed efficiently, made to stay in place, and serve its purpose adequately.

It is the purpose of the research in progress to determine the mix or mixes and the method or methods of application of portland cement concrete, and other promising concretes, that will produce durable and economical bridge deck overlays that will strengthen badly deteriorated reinforced portland cement concrete bridge decks. Reinforcement is sometimes needed in such repairs and, because of that, the effective use of reinforcement in the added concrete will be studied.

This report covers the progress that has been made in the study of the repair phase of Research Study Number 2-18-68-130.

Research Objectives

The development of effective concrete overlays and patches for repair of badly deteriorated reinforced concrete bridge decks will seek to:

a. Determine an effective and practical treatment of a reinforced concrete deck in need of major repairs to enable it to receive, and to bond to, an overlay of concrete.

b. Determine the mix proportions of portland cement concrete and of other materials that appear to be promising that will serve most effectively as an overlay material of thickness as might be required for the repair.

c. Determine how the overlay can be effectively bonded to an old concrete.

d. Develop a technique for reinforcing the overlay if reinforcing is required.

Research Program

To meet the needs of the study, the research program was divided into three parts:

1. Survey and evaluate the available literature and experience of others in bridge deck repairs.

2. Make laboratory tests which will evaluate the parameters involved to secure practical specifications and information as to the effectiveness of a thin bonded overlay in serving its purpose adequately.

3. Make field tests using the most effective system of repair based on the laboratory tests and observe its performance.

Literature Survey

The technique of resurfacing concrete with concrete was traced by Gillette[1] to go as far back as 1910, with the observation that a bond was developed that was in existence over 30 years. The Ohio Turnpike Commission[2] has concluded from its field tests on deteriorated concrete surfaces that the notion that new concretes cannot be made to bond to old concrete is a misconception. Experiences reported by the British Columbia Department of Highways[3] on resurfacing of deteriorated concrete bridge decks with thin concrete overlays where severe weather conditions occur have indicated adequate bond between the two concretes and that an excellent riding surface can be obtained. The feasibility and adequate performance of bonded concrete overlays reported in the literature are not confined to any one locality and are convincingly encouraging.

Other methods of repair are also used by various researchers and governmental agencies. The surfacing most widely used as a general practice for repairing scaling, spalls, or other surface failures in concrete bridge decks is the use of bituminous materials—asphaltic overlays. Although such repairs are quick and easy, and possibly economical, experience has indicated that they are usually of a temporary nature and sometimes only hide the problem. Meeker et al.[2] believe that bituminous surfaces appear to absorb and hold ice control chemicals in contact with the concrete surface over a greater length of time, thus accelerating the destructive forces already at work. In addition, bituminous overlays offer little additional stiffness to the existing bridge deck while adding undesirable increase in dead load.

The use of adhesive additives to concrete overlays, epoxy concretes, and commercially advertised chemicals has been attempted in field and laboratory tests. All of these have one thing in common; they are expensive methods of repair. Complete knowledge of methods of handling, rigid field control, and ample experience in their application are required. Sometimes, these requirements are difficult to meet or guarantee. Nevertheless, the use of these methods of repair is desirable under certain conditions, and thus reliable research data on their use are needed.

Among the major advantages in using concrete in the repair of concrete surfaces is that the cost of the material is reasonable, it is comparatively easy to handle and control, it has a satisfactory skid resistance, and the familiarity of construction crews with its use gives it a definite advantage. In patching concrete surfaces, retention of color likeness can be of an additional advantage.

The parameters to be determined for bonded thin concrete resurfacing can be divided into three major categories: (a) preparation of existing surface, (b) specification for new concrete and the use of any bonding agent between new and old concrete, and (c) specification for placing procedures.

Comprehensive laboratory research to evaluate the above parameters was undertaken by Felt[3,4] in the early 1950's. His recommended procedures were applied in field tests on deteriorated reinforced concrete bridge decks. Field and laboratory tests reported by Felt confirmed the feasibility of repairing concrete surfaces with bonded concrete overlays provided that a clean sound old concrete surface is exposed, high quality grout and concrete is used, and first class workmanship is employed. Brushing and flushing old concrete surfaces with acid etching to insure a clean surface free of residue and loose particles before placing cement grout, as a bonding agent, was recommended. Gillette[1] reviewed approximately 15 small and large bonded concrete overlays of various sizes 10 years after they were placed and found that good bond between the freshly overlaid concrete and the existing concrete surface must be the primary goal. Some loss of bond was found on practically every project along longitudinal construction joints with most areas being small in size. He concluded that for concrete pavements adequate bond can be obtained with normal construction equipment and materials, and thus chemical adhesives are not necessary. A bond strength of 200 psi was considered to be adequate and that when such bond is obtained, it will endure.

Laboratory Tests

Purpose

The laboratory tests in the first year of the research in progress were designed to evaluate and collect information on the following parameters:

1. Design of overlay concrete.

2. Preparation of existing deteriorated bridge deck surface.

3. Requirement of a bonding agent.

4. Contribution of the concrete overlay to the stiffness of the bridge deck.

5. Effect of cyclic loading on the endurance of the bond, variation of the stiffness, and ultimate load capacity of the composite deck.

Test Specimens

A. Standard 6 in. by 12 in. cylinders were cast for the purpose of determining the mechanical properties of the concrete.

B. Concrete cubes 7 in. × 7 in. × 7 in. were made. The surfaces of these cubes were prepared to receive 2 in. thick concrete overlay. The purpose of these specimens was to collect data on the strength and properties of the bond between the two concretes.

The cubes were cured for 14 days in a 100 percent humidity room after which the overlay concrete was cast, and curing continued for an additional seven days.

C. Test beams 8 ft.-6 in. long by approximately 7 in. wide of various depths were used to establish a procedure for evaluating the parameters (4) and (5) above. Three of those beams had been used in an earlier program and were cracked and had been stored outside for some four years. They were made of lightweight concrete and were used because of their age and cracked condition.

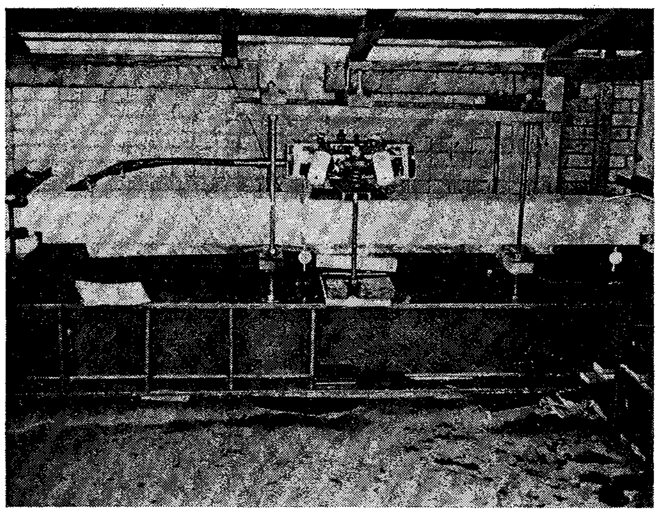
Normal weight concrete beams having the same length were cast at a later date. Type III cement was used, and the beams were cured under a wet mat for 7 days, after which they were stored in the open air. Details of the beams are shown in Table 1. All beams were precracked, using the cyclic loader shown in Figure 1, before placing the overlay.

All beams were prepared to receive 1½ in. to 2 in. thick concrete overlay by chipping or brushing the top surface of the beams. Chipping to approximately ¼ in. depth was done with a chisel to create a rough surface. Brushing the concrete surface was done with a steel brush to remove any laitance or film present and provide a roughened surface.

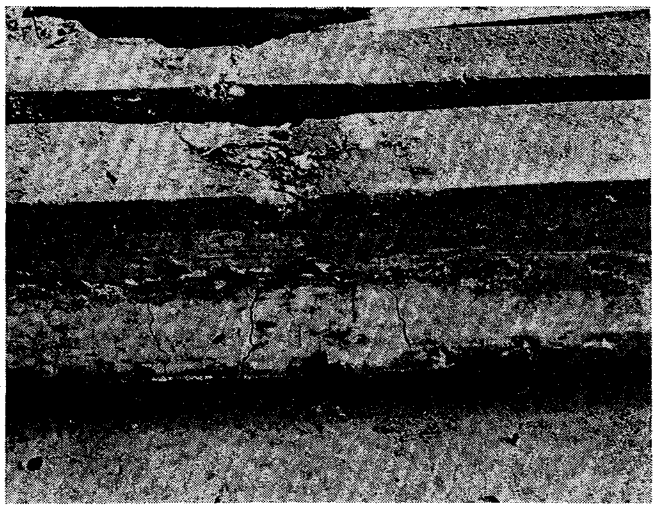
TABLE 1. BEAM AND OVERLAY DETAILS

Beam Designation	BEAM									OVERLAY		
	Concrete Type	Dimensions (in.)				Reinforcement			Beam Surface Preparation	Binder	Thickness (in.)	Reinforcement
		Wide	Thick	d	d'	Top As'	Bottom As	As/bd %				
1	LW	6⅞	6½	5	1½	1-#5	1-#5	0.902	Chipped	Grout	1½	none
3	LW	6⅞	6½	4¾	1½	1-#5	1-#5	0.949	Chipped	Epoxy	1½	none
4	LW	6⅞	6	4¼	1	1-#4	1-#4	0.684	Chipped	Grout	1½	none
1-A	NW	7	4⅝	3⅛	⅝	2-#4	2-#4	1.83	Chipped	Grout	1½	none
2-A	NW	7	5	3¾	1¼	2-#4	2-#4	1.52	Chipped	Grout	1½	none
3-A	NW	7	5	3¾	1¼	2-#4	2-#4	1.52	Chipped	Grout	2	3×3×10 ga. mesh
4-A	NW	7	5	3¾	1¼	2-#4	2-#4	1.52	Chipped	Grout	2	none

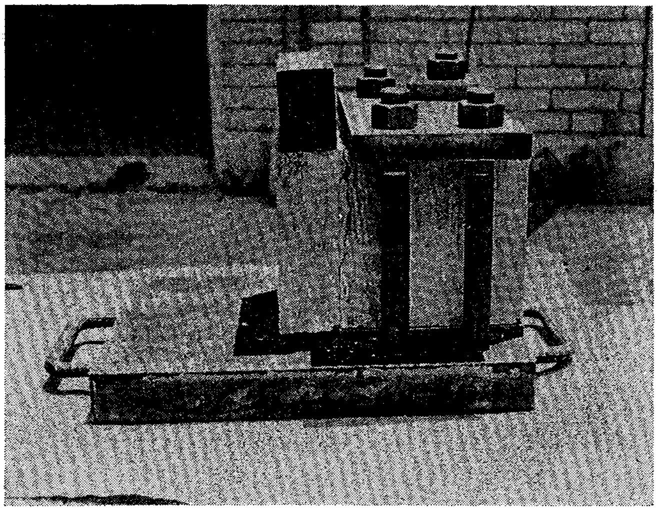
Property	Beam concrete	Overlay concrete		
Age	28 day	7 day	14 days	42 day
f'c (psi)	4258	2900		4380
E½ f'c (ksi)	6060	6100		5700
Split Cyl f'_T (psi)		421	468	



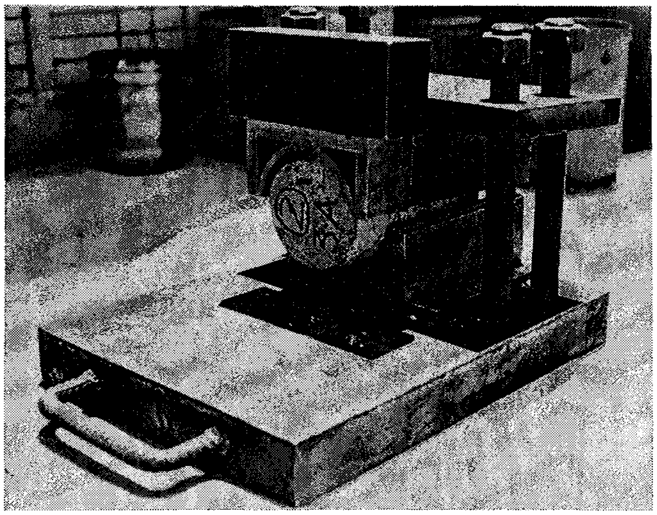
(a) Overlaid test beam in cycle loading machine.



(b) Overlaid test beam ruptured by bending in static load test.



(c) Overlaid cube in shear rig.



(d) Overlaid cylinder in shear rig.

Figure 1. Test specimens.

Mortar grout and Texas Highway Department Epoxy Adhesive A-103 were used separately as binders between the freshly overlaid concrete and the beam. The grout was brushed evenly to a thickness of approximately ⅛ in. using a steel brush. The epoxy was brushed with a paint brush creating a tacky film approximately 1/16 in. thick.

Table 1 shows the method of preparation of beam surface, thickness of overlay, type of bonding agent, and reinforcement in the overlays used for each beam. Beam 3A was reinforced with 10-gage, 3 in. × 3 in. wire mesh.

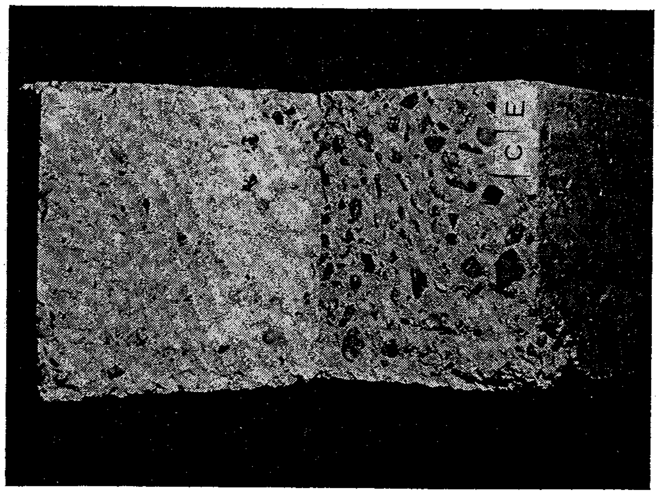
Materials

Concrete used in laboratory tests was made either to prepare beams, designated here as base specimens, or concrete overlays to be placed on these specimens.

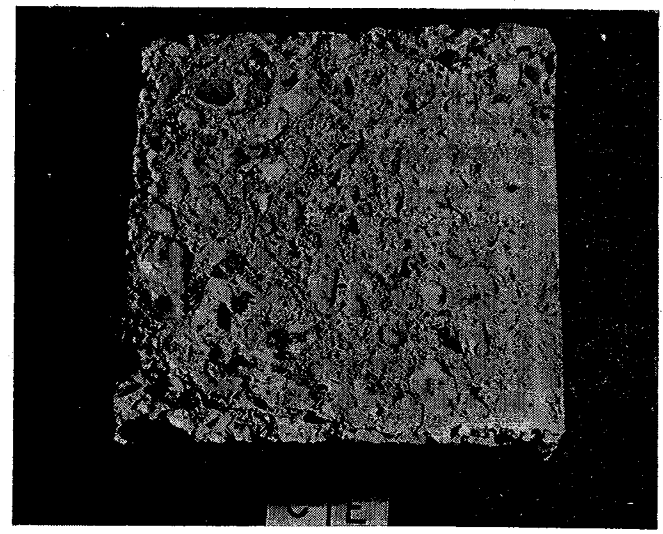
A. Beam concrete: Type III cement, gravel, and natural sand were used except for the old lightweight concrete beams. The gravel had ¾ in. maximum size aggregates; gradations of the coarse and fine aggregates are shown in Figure 3.

The mix design per cubic yard was as follows: Gravel, 1930 lbs.; sand, 1270 lbs.; cement, 517 lbs.; water, 275 lbs. No air entraining agent was used. Concrete was mixed in a 6 cu. ft. drum mixer using the following procedure: Gravel and sand with approximately half the mixing water were mixed together for about 3 minutes, then the cement and the remaining water was added and mixing continued for an additional three minutes.

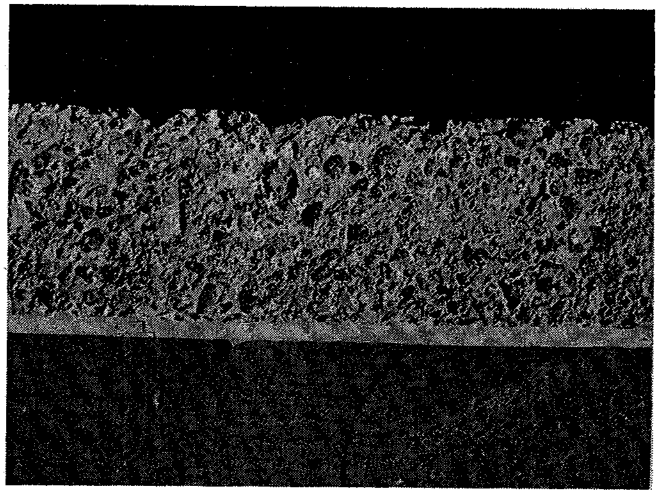
The 8 ft.-6 in. beams and the 7 in. cubes were cast in wood forms. An internal vibrator was used, and the surface was smoothed by wood screed.



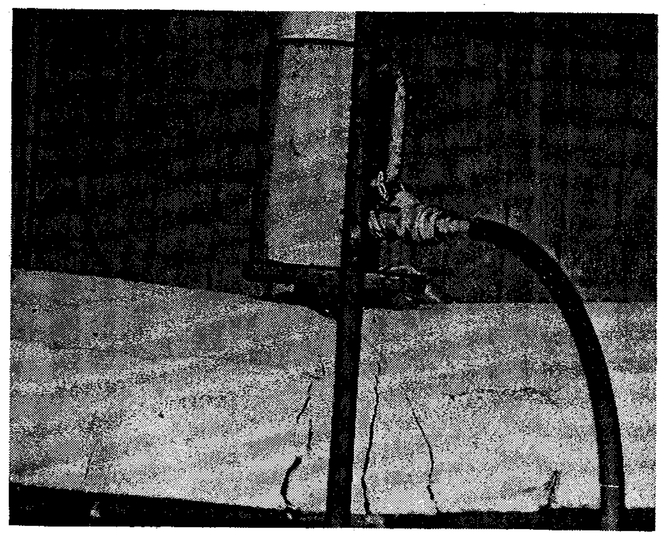
(2a) Sheared cube with overlay.



(2b) Overlay sheared from cube shown in (a).



(2c) Surface of beam prepared for overlay.



(2d) Static test failure of overlaid beam.

Figure 2. Cube and beam overlays.

B. Overlay concrete: Type III cement, ½ in. maximum size gravel, and natural sand were used. The gradations of the coarse and fine aggregates are shown in Figure 4.

The mix design per cubic yard was as follows: gravel, 2000 lbs.; sand, 1208 lbs.; cement, 658 lbs.; and water, 295 lbs. In the series reported here, no air entraining agent was used. Concrete was mixed in a 2 cu. ft. rotary mixer using the same procedure as for beam concrete. The overlay concrete for all specimens, see Table 2, was vibrated in wood forms with an internal vibrator. The need for a surface vibrator for the overlays was recognized, and a pneumatic vibrator was modified for that purpose. The surface was smoothed by a wood screed.

Overlay concrete containing steel fibers, specimen S4, was mixed using the same procedure outlined above. Sufficient additional water was added to produce a 4 in. slump, then steel fiber was introduced into the mix by sifting it through a ½ in. sieve while the mixer was turning. The fibers had the effect of greatly stiffening the mix. The final mix containing one percent by weight of 0.010 × 0.022 × ¾ in. bright finish, cold drawn steel fiber had a workable consistency. Placing the steel fiber reinforced concrete presented no problems, especially when vibrated with the surface vibrator.

Grout: Grout made of Type III cement, sand, and water was brushed on top of specimens to be overlaid to about ⅛ in. thick in order to develop sufficient bond. Sand was graded as follows:

Sieve Size	Percent Passing by Weight
#30	5
#40	60
#100	20
Pan	15

Grout mix design was the same for all specimens, except overlays for cubes of Series S3 and SS3 where

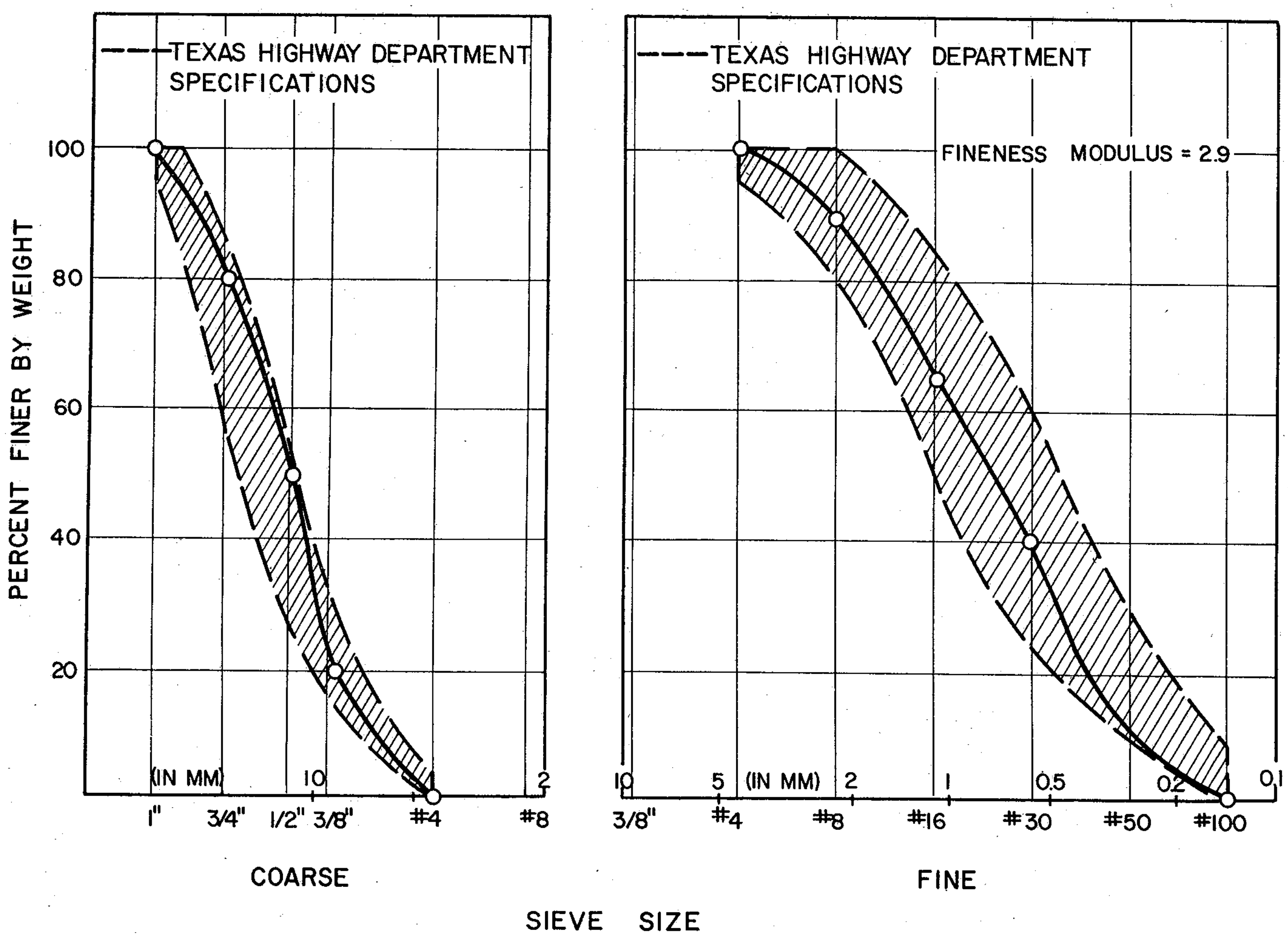


Figure 3. Gravel and sand gradation for beam concrete.

various grout mixes were studied, See Table 2. A cement:sand ratio of 1:¾ by weight was used with 0.5 lbs. of water per pound of cement. This resulted in a workable mix that could be spread and brushed easily on top of the concrete specimens. Epoxy: Texas Highway Department Epoxy Adhesive A-103 was used as another bonding agent. The procedure for mixing and applying the epoxy was as described in the THD usage instructions leaflet.

Test Results

A. Cylinders: Cylinder tests on beam concrete were intended to verify that the concrete meets the THD Specifications for bridge deck concrete, Class A concrete. Results are given in Table 1.

The mechanical properties of the overlay concrete were determined at 7- and 42-day ages, and test results are shown in Table 1. The indirect tensile strength, f'_T, was determined from the split cylinder test using the following relation;

$$f'_T = \frac{2P}{\pi DL}$$

where P is the ultimate load, D and L are the diameter and length of the cylinder, respectively.

B. Cubes: The 2 in. thick freshly overlaid concrete was sheared off as shown in Figure 1. The first series of tests, S3 and SS3, were made to study the bond stress of various grout mixes as bonding agents, see Table 2. Bond stress was determined by dividing the direct shear load by the cross sectional area of the cube.

The cement:sand ratio of 1:0.75 gave the highest bonding stress when the cube surfaces were brushed clean or sand blasted. Consistent results were obtained for both series, S3 and SS3, except in the case where the grout had no sand in it. Based on these results the cement:sand ratio of 1:0.75 seems to be the desired mix, and this mix was used on all grouted overlays on cubes and beams.

The second series of tests, Table 3, studied the effect of various surface preparations and bonding agents. Overlays made on dry surfaces showed higher bonding strength with epoxy binder than with grout binder. However, when the surface was damp or wet, epoxied overlays had very little bond, and grouted overlays showed approximately 10 percent lower bond stress. These results are in agreement with the findings of Felt[4] in his comparative study of wet versus dry surfaces on bonding of grouted overlays.

TABLE 2. SHEAR TEST RESULTS FOR OVERLAY BONDED TO 7-INCH CUBES

Series (Description)	Cubes Desig-nation	Surface Prepa-ration	Grout Mix Cement: Sand	Overlay Concrete	Bonding* Stress (psi shear)
S3	A	Brushed	1:1½	7(sk)	427
(Dry surface	B	Brushed	1:1	7(sk)	424
before placing	C	Brushed	1:¾	7(sk)	537
overlay)	D	Brushed	1:0	7(sk)	506
SS3	A	Sand Blast	1:1½	7(sk)	408
(Dry surface	B	Sand Blast	1:1	7(sk)	428
before placing	C	Sand Blast	1:¾	7(sk)	535
overlay)	D	Sand Blast	1:0	7(sk)	367

*Average of two cubes.

The surfaces of Series SS1 were soaked with motor oil for 3 days before surface preparations were made. Again, epoxied overlays showed higher bond stress than grouted overlays for chipped surfaces. Grout on a brushed surface showed little bond, while sand blasted surfaces gave similar results to those chipped. These results indicate that brushing existing bridge decks might not be sufficient to remove oil traces that might have deposited on that surface.

C. Beams: The overlaid beams were tested under repeated loads using a cyclic loader as shown in Figure 1. The mid-span load-deflection diagrams were measured from the precracked beams before placing the overlays. From these diagrams the stiffnesses, EI, of the beams were determined. Before applying the cyclic loads and after the overlay was cast, these tests were repeated, and new values for the stiffnesses were determined, see Table 4.

The cyclic load was determined as follows:

Step 1: The load that produced 20,000 psi in the tension steel before placing the overlay was determined using the Working Stress Design Method, ACI 318-63.

Step 2: The mid-span deflection that corresponded to that load from Step 1 was read from the mid-span load-deflection diagram.

Step 3: Forty percent of the deflection determined in Step 1 was applied statically. This was done by forcing down the cyclic loader on top of the beam by tightening the nuts that hold the loader in place.

TABLE 3. BOND STRESS FROM DIRECT SHEAR TEST ON 7-INCH CUBES

Series (Description)	Cubes Desig-nation	Surface Prepa-ration	Bonding Agent	Overlay Concrete	Bond* Stress (psi shear)
S1	A	Chipped	Epoxy	7sk	531
(Dry surface	B	Brushed	Epoxy	7sk	612
before placing	C	Chipped	Grout	7sk	458
overlay)	D	Brushed	Grout	7sk	458
S2	A	Chipped	Epoxy	7sk	94
(Surface soaked	B	Brushed	Epoxy	7sk	77
with water for	C	Chipped	Grout	7sk	405
24 hrs. Overlay	D	Brushed	Grout	7sk	410
was placed on					
wet surface)					
S3 (See Table 2)					
S4	A	Chipped	Grout	7 sk, 1% Stl. Fiber	325
(Dry surface	B	Brushed	Grout	7 sk, 1% Stl. Fiber	455
before placing	C	Brushed	Grout	7 sk, 3″ □ Wire Mesh,	544
overlay)				10 gage wire	
SS1	A	Chipped	Epoxy	7sk	452
(Surface soaked	B	Chipped	Grout	7sk	343
with motor oil	C	Brushed	Grout	7sk	55
for 3 days)	D	Sand Blast	Grout	7sk	327
SS2	A	Chipped	None	7sk	129
(Dry surface	B	Brushed	None	7sk	187
before placing					
overlay)					
SS3 (See Table 2)					

*Average of two cubes.

Step 4: The rotational velocity of the rotating eccentric weights on the cyclic loader was adjusted to induce a total downward deflection equal to that determined in Step 2.

Step 5: The deflection determined in Step 2 was modified after every half million cycles by running another load-deflection test. Then Steps 3 and 4 were repeated.

Three loading types were used. Loading Type I corresponds to the load that produces 20,000 psi in the tension steel before the overlay is placed. Loading Type II corresponds to 150 percent of that load. Loading Type III is equal to loading Type I, with the exception that the beam is turned over so that the overlay is primarily in tension while the beam is primarily in compression. After one million cycles of Type III loading the beam was turned over to its original position, and a static load was applied to determine the ultimate load capacity.

The stiffness of the beam, EI, before placing the overlay and at various stages of loading is shown in Table 4. The ratio of the stiffness with overlay to the stiffness before placing the overlay is shown in the last column. The mid-span load-deflection diagrams of the beams are shown in Figures 5 to 11. These figures give a comparative picture on the improved stiffness of the beam after the overlay is placed and its decrease at the end of loading Type I.

It is believed that if bond failure takes place during cyclic loading, then a drastic decrease in the stiffness occurs. No beam tested to date showed a noticeable bond distress under loading Types I and II. Tension cracks already in the precracked beam extended vertically under loading Type II; some extended all the way through the overlay. Under loading Type III, the overlay cracked vertically during the first few cycles of loading. However, these cracks in the overlay did not extend horizontally at the interface of the beam and the overlay. Beams 3-A and 4-A, which had a 2 in. overlay, were an exception. A small 3 in. long horizontal crack appeared at the interface under loading Type III. These two beams had a sudden failure when loaded statically to failure, and a complete separation of the overlay from the beam occurred.

The bond between the overlay and beam 1-A was broken intentionally at two points, 2 ft. from the center line of the beam for a distance of 5 in. This was done by placing a strip of plastic 5 in. wide on the top of the beam before placing the overlay. No distress was noticeable at these points at any time during loading.

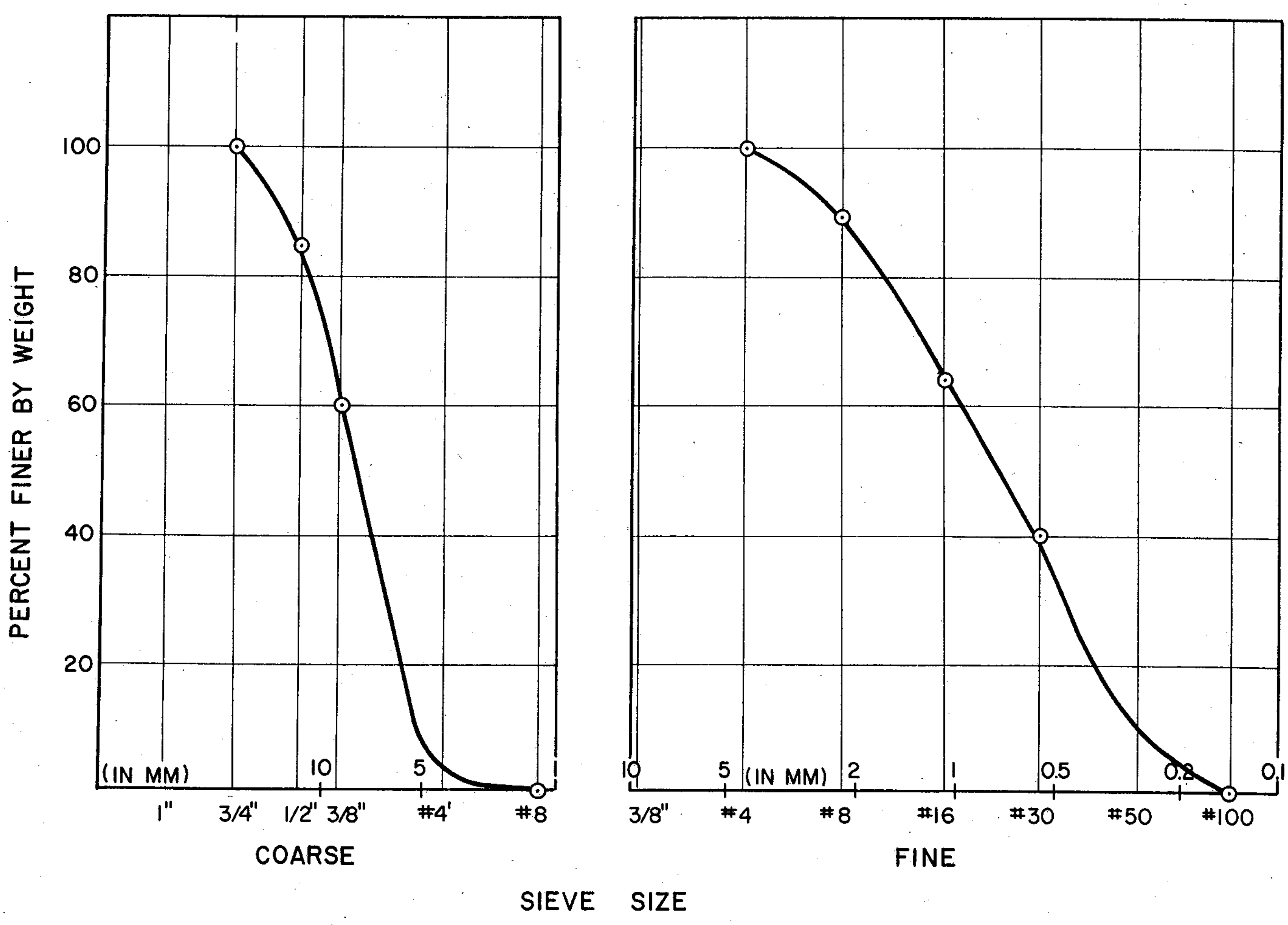


Figure 4. Gravel and sand gradation for overlay concrete.

TABLE 4. EFFECT OF CYCLIC LOADING ON THE STIFFNESS OF THE BEAM

Beam No. and Conc. Type	No. of Cycles (in millions)	Measured Stiffness (Kip-in^2)	Type of* Loading	(EI) With Overlay / (EI) No Overlay
1 Lightweight	No Overlay	14,000		
	0	414,000	I	2.96
	1.0	372,000	I	2.66
	4.0	315,000	I	2.25
	7.0	354,000	I	2.53
	0	153,000	III	1.09
	1.0	14,000	III	1.00
	Load to Failure		Static	
3 Lightweight	No Overlay	119,000		
	0	498,000	I	4.18
	1.0	433,000	I	3.64
	2.0	388,000	I	3.26
	0	226,000	III	1.90
	2.0	122,000	III	1.03
	Load to Failure	128,000	Static	1.07
4 Lightweight	No Overlay	112,000		
	0	344,000	I	3.07
	1.0	288,000	I	2.57
	2.0	271,000	I	2.42
	0	192,000	III	1.71
	0.5	187,000	III	1.67
	Load to Failure		Static	
1-A Normal Weight	No Overlay	97,000		
	0	329,000	I	3.39
	1.0	335,000	I	3.45
	2.0	312,000	I	3.22
	0	312,000	II	3.22
	1.0	312,000	II	3.22
	0	164,000	III	1.69
	0.67	153,000	III	1.58
	Load to Failure	249,000	Static	2.57
2-A Normal Weight	No Overlay	252,000		
	0	697,000	I	2.77
	1.0	719,000	I	2.85
	2.0	575,000	I	2.28
	0	575,000	II	2.28
	1.0	404,000	II	1.60
	0	273,000	III	1.08
	1.0	170,000	III	0.67
	Load to Failure	294,000	Static	1.17
3-A Normal Weight	No Overlay	198,000		
	0	498,000	I	2.52
	1.0	400,000	I	2.02
	2.0	400,000	I	2.02
	0	400,000	II	2.02
	1.0	329,000	II	1.66
	0		III	
	1.0		III	
	Load to Failure	34,000	Static	1.71
4-A Normal Weight	No Overlay	119,000		1.00
	0	736,000	I	6.14
	1.0	594,000	I	5.0
	2.0	575,000	I	4.83
	0	575,000	II	4.83
	1.0	557,000	II	4.68
	0	391,000	III	3.29
	1.0	222,000	III	1.86
	Load to Failure	409,000	Static	3.44

*Load Type I: Midspan loading producing calculated stress in bottom steel of 20 ksi tension.
II: 150% of load type I.
III: Midspan loading on beam turned top side down to produce tension in the surface normally exposed to traffic.

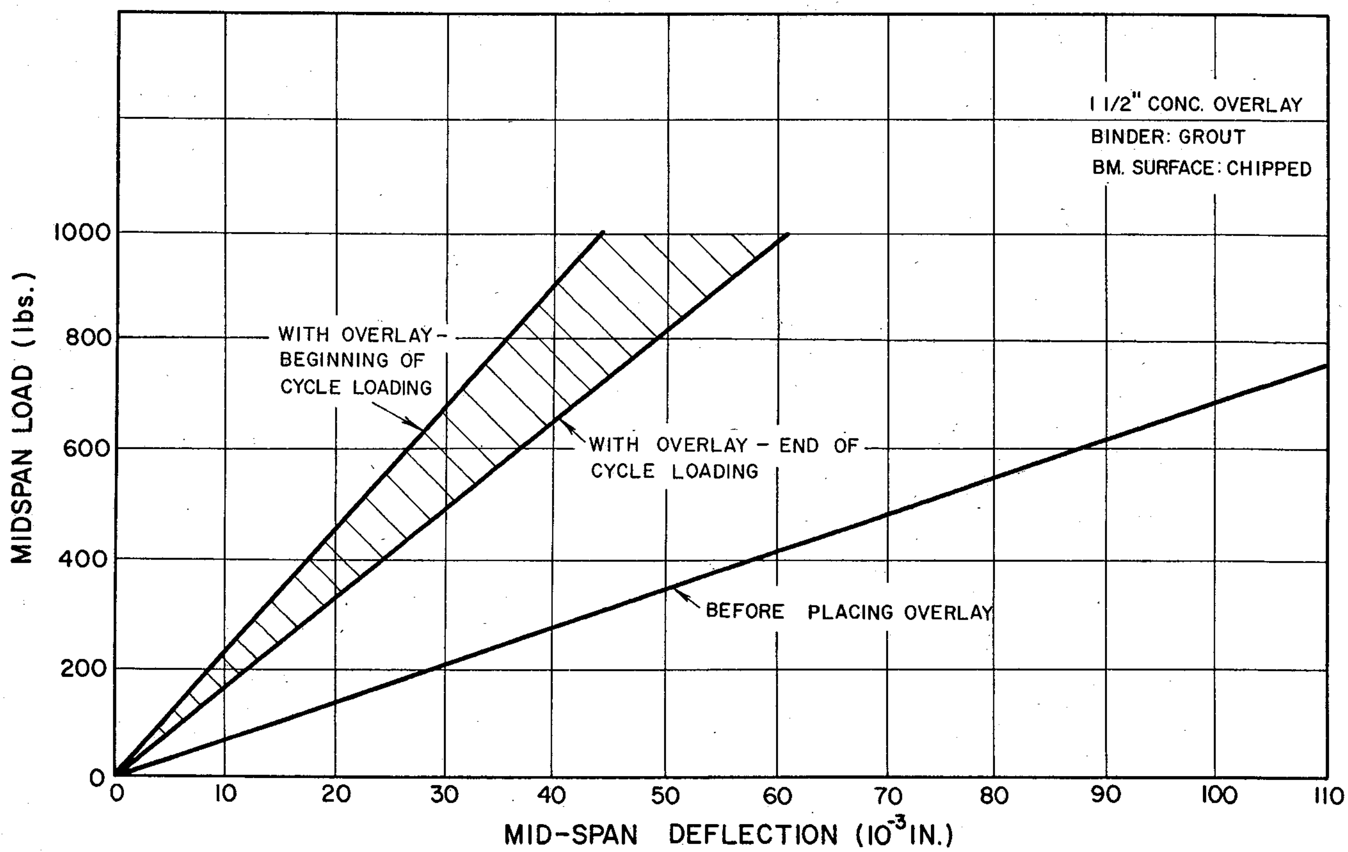


Figure 5. Load-deflection relationship for Beam 1.

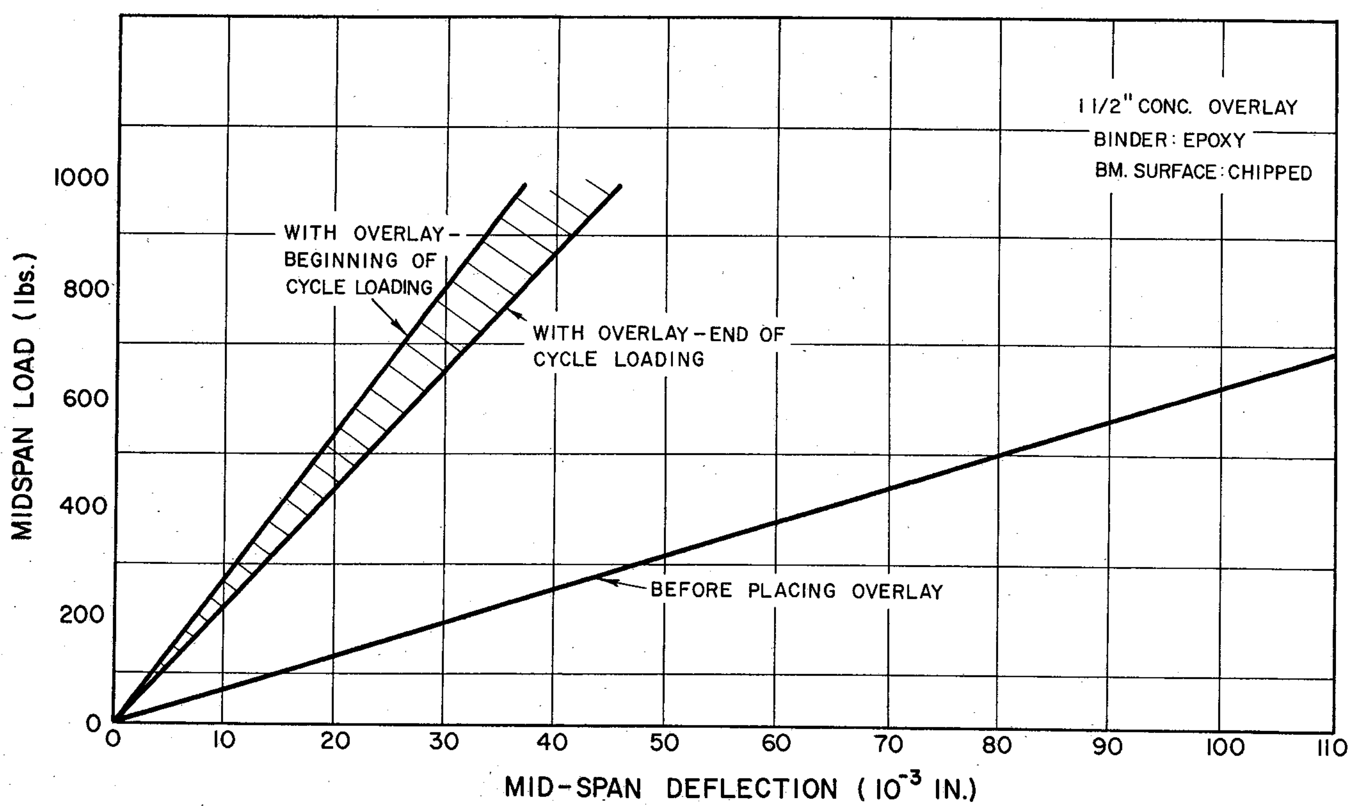


Figure 6. Load-deflection relationship for Beam 3.

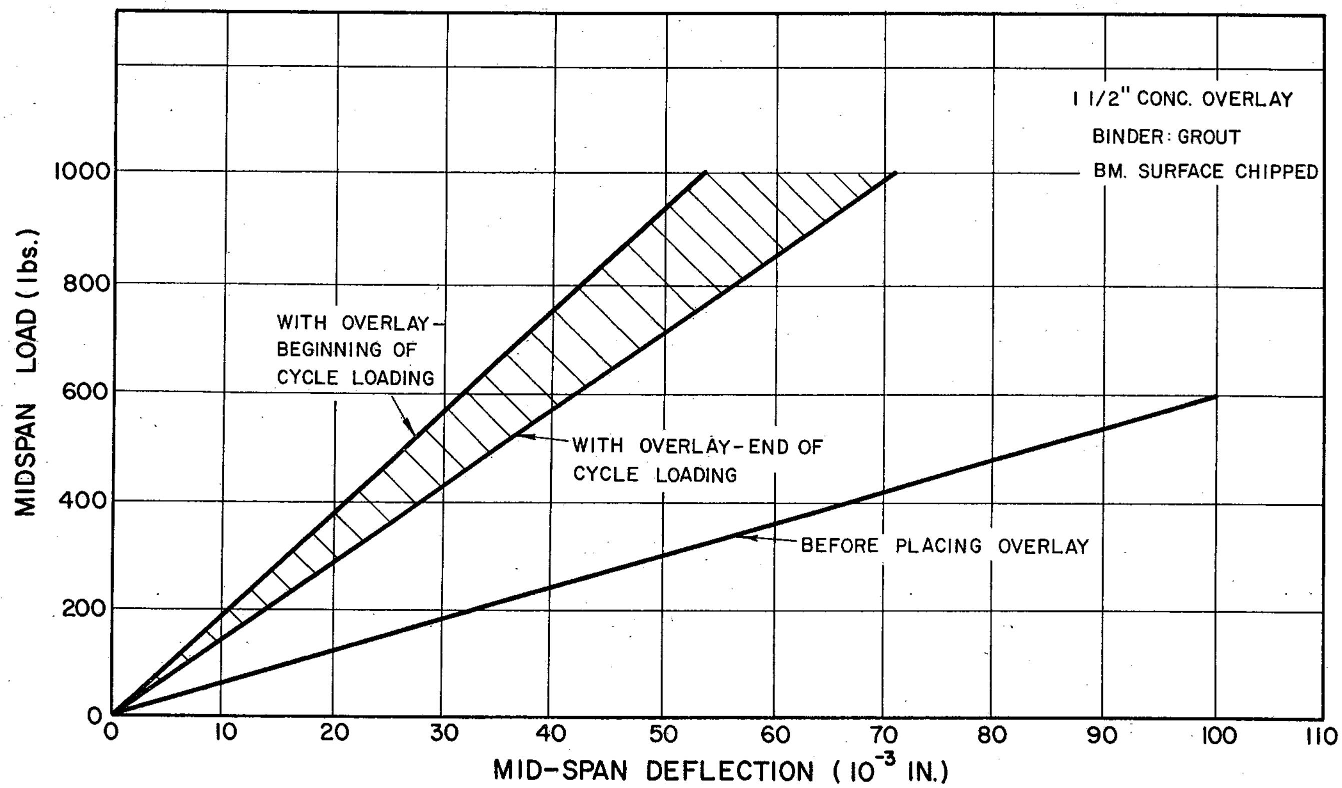


Figure 7. Load-deflection relationship for Beam 4.

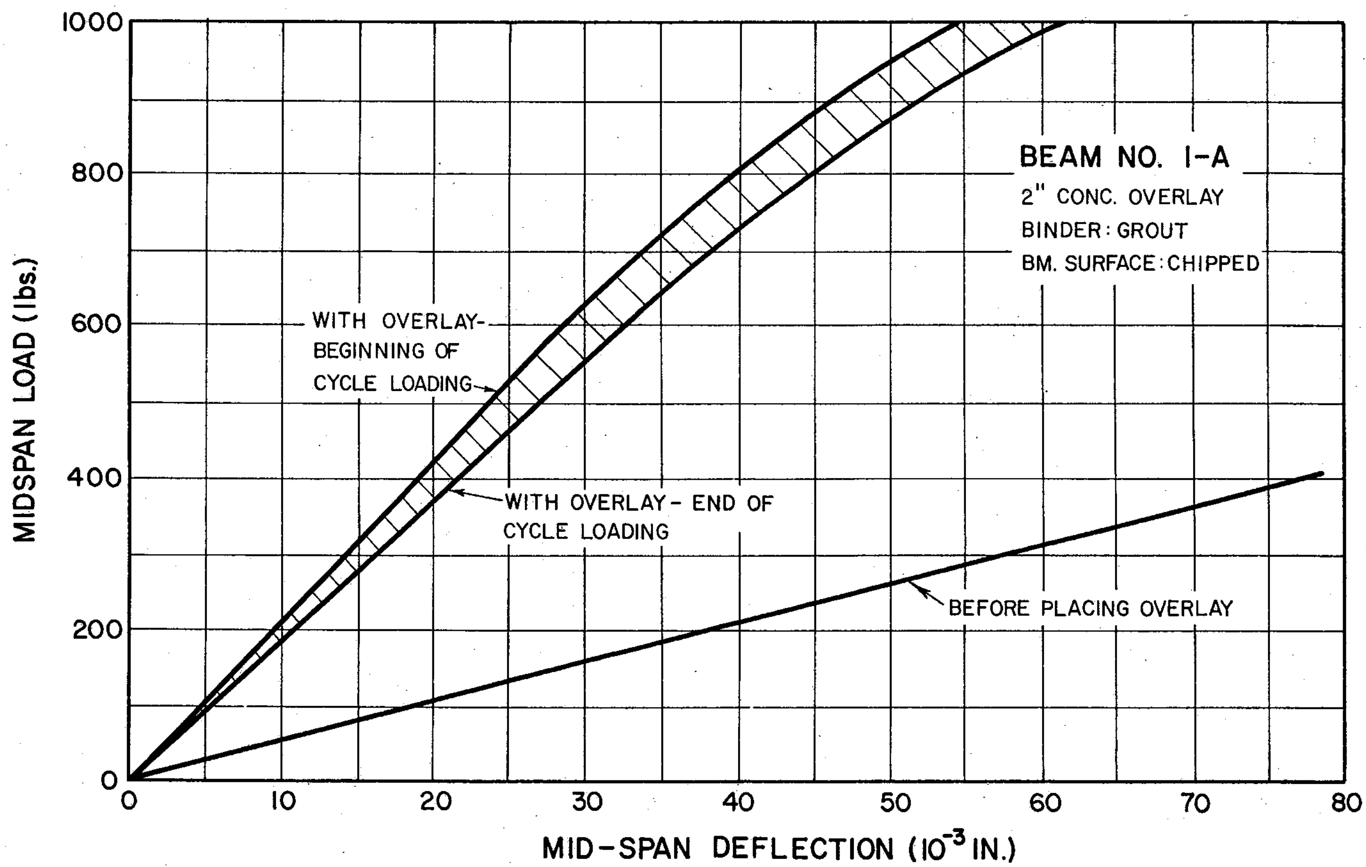


Figure 8. Load-deflection relationship for Beam 1A.

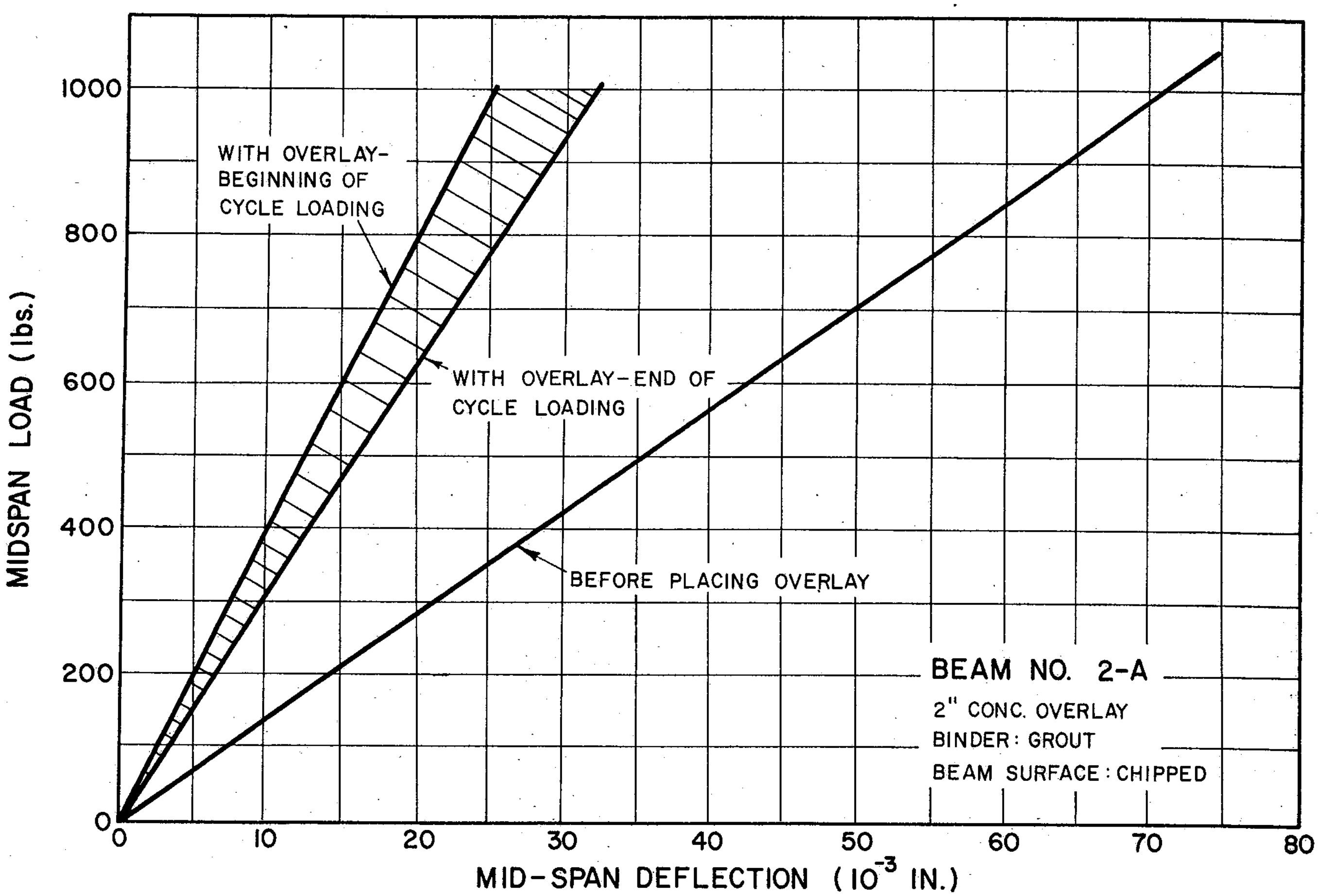


Figure 9. Load-deflection relationship for Beam 2A.

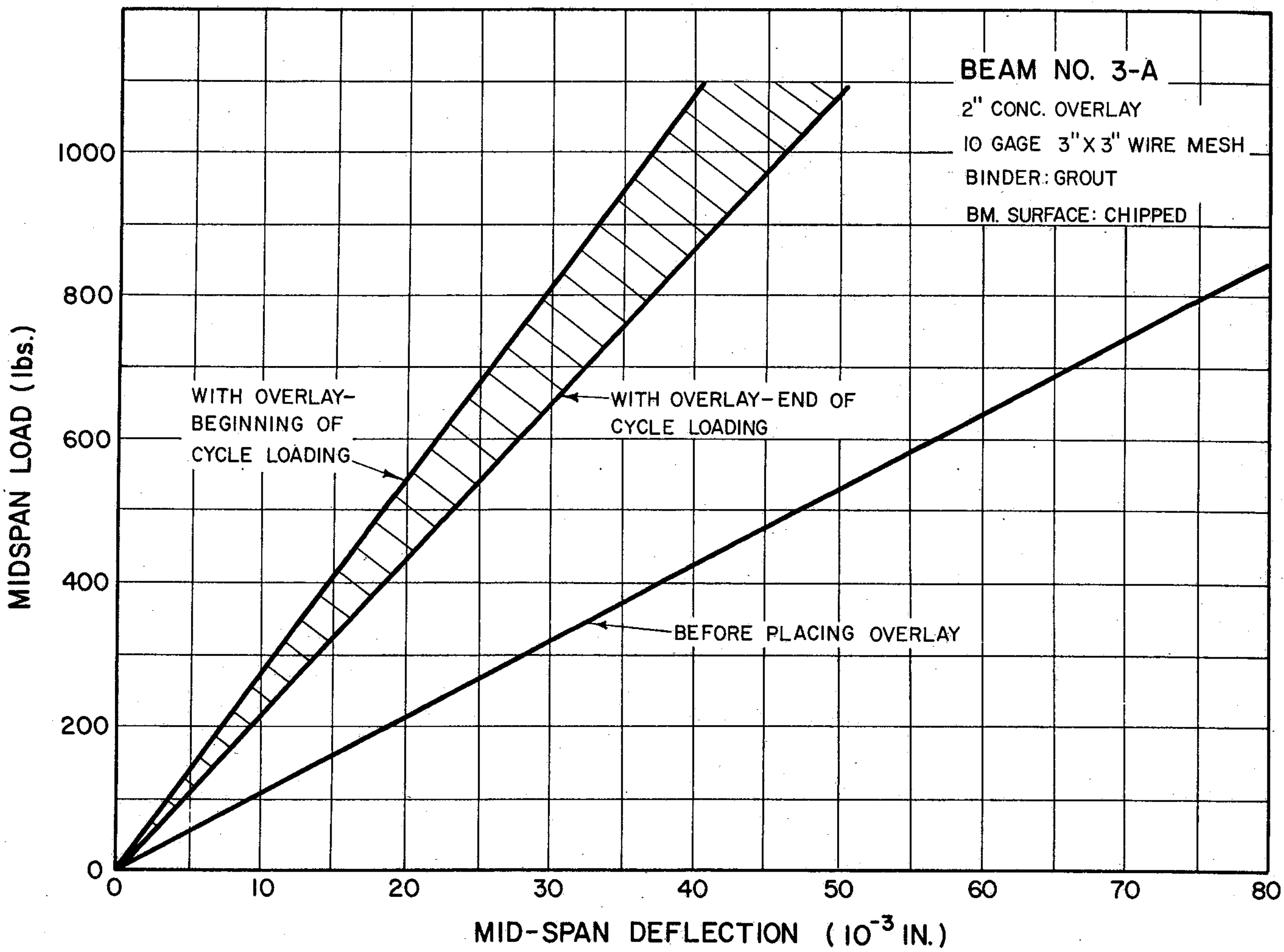


Figure 10. Load-deflection relationship for Beam 3-A.

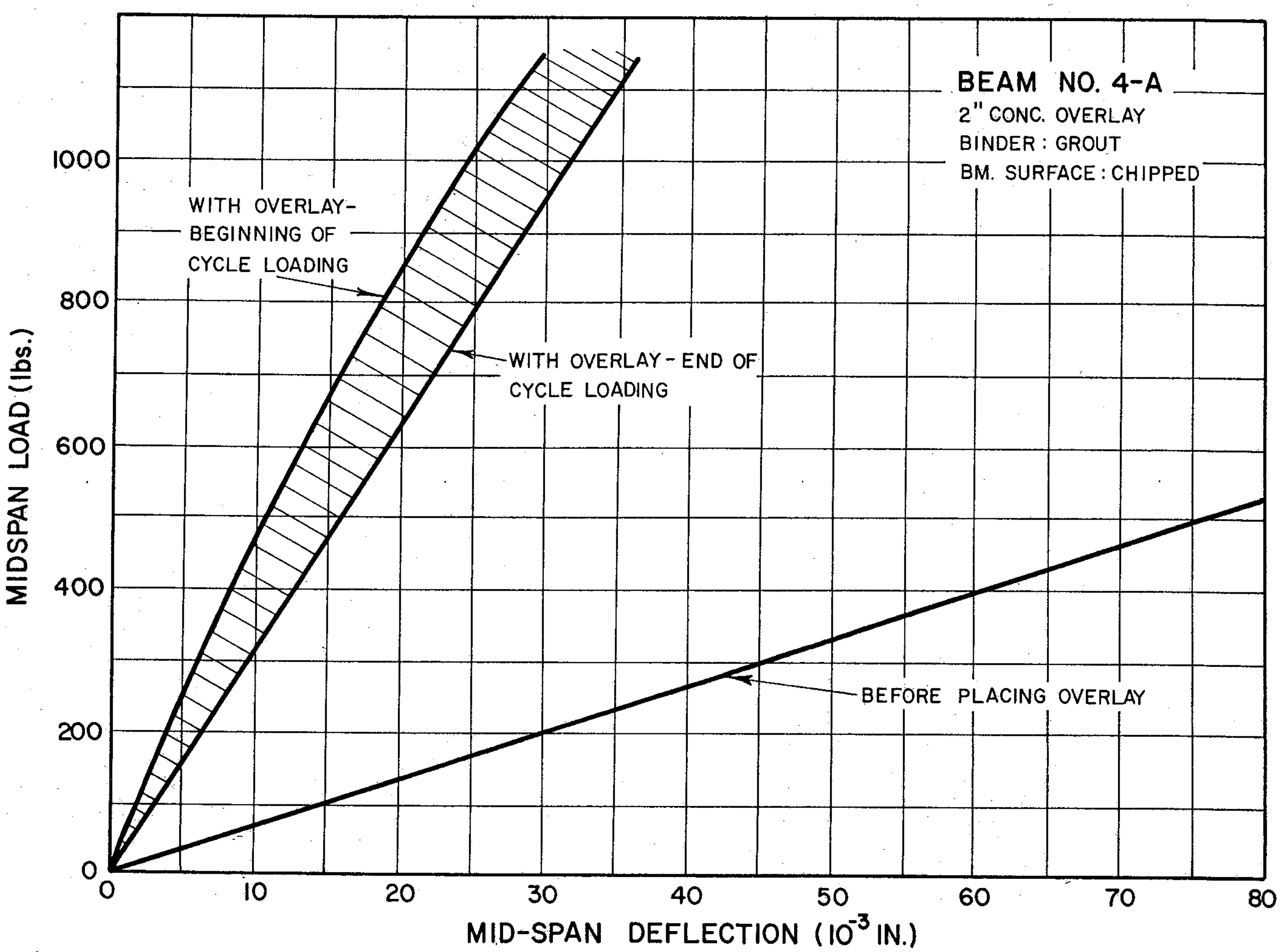


Figure 11. Load-deflection relationship for Beam 4A.

TABLE 5. THEORETICAL ULTIMATE MOMENT CAPACITY VERSUS MEASURED VALUES

Beam (Type)	Theoretical Ultimate Moment (Kip-ft) Without Overlay (M-1)	Theoretical Ultimate Moment (Kip-ft) With Overlay (M-2)	Measured Ultimate Moment (Kip-ft) With Overlay (M-3)	Measured (M-3) / Theoretical (M-2)
1 (LW)	7.05	11	11.37	1.03
3 (LW)	6.58	10.5	12.37	1.18
4 (LW)	3.65	6.26		
1A (NW)	4.54	9	8.94	0.993
2A (NW)	5.12	11.1	12.78	1.15
3A (NW)	5.12	12.8	15.41	1.20
4A (NW)	5.12	12.8	15.61	1.22

Conclusions

From the literature survey and tests performed so far, the following conclusions may be made:

1. Repair of deteriorated reinforced concrete bridge decks with thin concrete overlay is feasible.

2. Concrete overlays may be made to bond to existing deteriorated reinforced concrete by using cement grout or Texas Highway Department Epoxy A-103. Epoxy should not be used on damp or wet surfaces.

3. Preparation of existing bridge deck surfaces is necessary prior to receiving the concrete overlay. The extent of such preparation is still to be determined, but it is evident that a clean sound surface free from any foreign deposits is required.

4. Thin bonded concrete overlays increased the stiffness and the load carrying capacity of the laboratory beams.

5. Cyclic loading, within the working range, did not cause bond failure of grouted or epoxied concrete overlays placed on laboratory beams.

Future Work

Planned work for the future includes:

1. Overlays of other materials (epoxy resin and polyester concretes).

2. Shear tests of overlays of air entrained and non-entrained concretes to determine if bonding is influenced by air entrainment.

3. Placement of a P. C. overlay on a vibrating beam to determine if the concrete will set up and cure during vibrations.

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