Design and Construction of Bonded Fiber Concrete Overlay of Continuously Reinforced Concrete Pavement

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The purpose of this research was to study the design and construction of a bonded, steel-fiber-reinforced concrete overlay on an existing 8-in. continuously reinforced concrete pavement (CRCP) on Interstate 10 south of Baton Rouge, Louisiana. The existing 16-year-old CRCP, which is estimated to have carried twice its design load, contained several edge punch-out failures per mile. The research objectives were to provide an overlay with a high probability for long-term success by using a high-strength concrete mix with internal reinforcement and good bonding characteristics. A 4-in. concrete overlay containing steel fibers was designed. An inverted U-shaped reinforcing bar was added at the edge of the pavement to provide positive edge bonding. Shot blast surface cleaning of the existing tine surface easily met a specification requiring an average texture depth of 0.045 in. Water-cement grout was applied to the cleaned surface, producing bond strengths in excess of 900 psi. The concrete overlay in combination with 9-in. tied concrete shoulders reduced edge deflections by 60 percent under a 22,000-lb moving single axle load applied 2 ft from the edge. In general, the serviceability index of the pavement increased from 3.4 to 4.4, with measured profile index levels typically below the 5-in./mi specification. The bonded overlay has been in service since August 1990 and carries average daily traffic of 41,000 vehicles. Cores taken over transverse cracks in the overlay indicated reflection cracking from transverse cracks in the original pavement. Anticipation of reflective cracking was one consideration in using the steel fibers, which provide three-dimensional reinforcement.

Continuously reinforced concrete pavement (CRCP) became a standard rigid pavement design for Louisiana's Interstate construction during the 1970s. A total of 127 centerline mi was constructed on three Interstate routes 8 in. thick with identical section design details. The cross-sectional area of the steel was 0.6 percent; river gravel was used as coarse aggregate.

Performance of CRCP under heavy Interstate traffic varied, with several projects experiencing longitudinal cracking and multiple edge punch-out failures within only 5 years of service. Those pavements were typically reconstructed before they reached 10 years of age. Many of the remaining CRCP projects, including the subject overlay project, began to develop failures within 10 years of service. Previous performance has shown that this mode of failure continues at an increasing rate if not arrested.

In 1989 the Louisiana Department of Transportation and Development (LADOTD) selected a CRCP for overlay that contained several edge punch-out failures per mile and attempted to arrest the failures by thickening the 8-in. slab to a thickness sufficient to carry continued Interstate loads. The project selected for bonded concrete overlay was a 16-year-old, 4-lane section of Interstate 10, located south of Baton Rouge. The design objectives were to provide an overlay with a high chance of long-term success by providing strong concrete with internal reinforcement and excellent bond.

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EXISTING CRCP PROJECT

The existing pavement consisted of 8 in. of CRCP constructed over a 4-in. asphaltic concrete base and lime-treated soil. The roadway contained 14-in.-thick asphaltic concrete shoulders with no provision for pavement drainage. The 1990 average daily traffic was 41,000 vehicles (22 percent being trucks), and the pavement has carried approximately twice the design load for an 8-in. CRCP since it was opened to traffic in 1974. Longitudinal cracking and edge failures were first observed in 1984, indicating that structural failures probably occurred near the time the pavement had carried its design load. Average transverse crack spacing was estimated to be 4.5 ft. Before overlay the pavement contained two to three failures per mile and had an AASHTO serviceability index of 3.4.

The location of this section of Interstate 10 is between Siegen Lane and LA 42 (Highland Road) in East Baton Rouge Parish. The total project length is 5.2 mi, with 2.2 mi of actual concrete overlay constructed. The remainder of the project consists of bridges, overpasses, and roadway transition sections that were reconstructed of jointed plain concrete pavement up to 800 ft on each end of existing structures.

OVERLAY AND SHOULDER THICKNESS DESIGN

The total projected 18-kip load for a 20-year design resulted in an estimate of 39 million applications. Calculations using Louisiana's AASHTO design procedure indicated that a thickness of 12 in. was required to satisfy anticipated loads. On the basis of these calculations a decision was made to thicken the existing 8-in slab using 4-in. of bonded concrete.

A 9-in.-thick tied concrete shoulder was designed for both the 10-ft outside and the 4-ft inside shoulders. The shoulders were designed to be tied to the original 8-in. pavement and to be jointed every 15 ft with 1 1/4-in. dowel bars spaced on 24-in. centers.

CONCRETE MIX DESIGN

Concrete mix design for the overlay included 85 lb/yd^3 of deformed steel fibers conforming to ASTM A-820, Type I or Type II. The nominal length of the fiber was specified to be not less than 1 in. and not greater than 2 in. with an aspect ratio not less than 40 and not greater than 60. The fibers selected were 1-in. long with an aspect ratio of 42. A minimum of 7.5 sacks of cement per yd^3 was required with a maximum water/cement ratio of 0.40. A slump of 1 to 2 1/2 in. was specified to be measured after adding the fibers. Both a water reducing set retarder and an air entraining agent were required. The total air content was lowered to 3.5 percent ± 0.5 percent (percent by volume) from Louisiana's typical slip-form mix specification of 5 percent ± 2 percent to minimize the chance of upward swings in air content, which may affect bond strength (*1*).

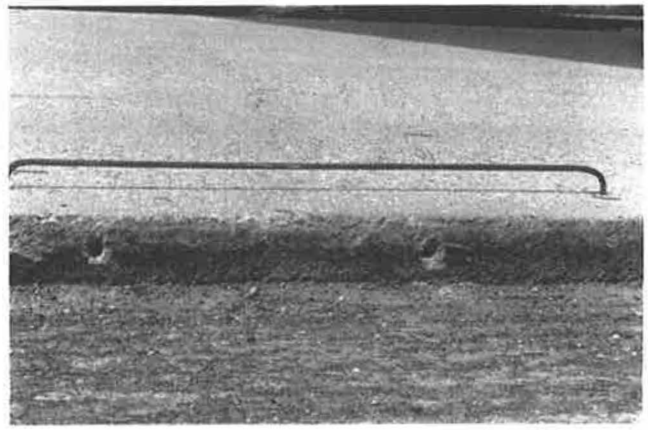

FIGURE 2 Edge bonding reinforcement bar (number 5 bar, 4-ft long, raised 2 in. above concrete).

EDGE BONDING REINFORCEMENT

An edge reinforcement technique similar to curb bars was included to discourage debonding along the slab edges, which may result from curling stresses in the concrete overlay. The technique used curb-type reinforcement bars epoxied into the existing slab surface 8 in. from each outside edge (Figures 1 and 2). The inverted U-shaped bars were 4 ft long with a 2-ft spacing along the slab edge. The plans called for the bars to coincide with the center of the 4-in. overlay and therefore to be raised 2 in. above the existing surface. This was considered adequate clearance for concrete flow under the bar because the top size aggregate in the mix was limited to 1/2 in. Internal vibrators were required on each side of the edge bonding reinforcement to maximize consolidation in this area. Transverse construction joints in the overlay were required to coincide with a reinforcement bar on each slab edge to pin the overlay to the original slab at these locations.

OVERLAY CONSTRUCTION

All patching of CRCP was accomplished in accordance with standard LADOTD patching procedures where reinforcement is replaced in-kind with appropriate lapping of steel. The patches were cured a minimum of 7 days before surface preparation.

FIGURE 1 Cleaned surface with edge bonding reinforcement bars.

An average texture depth of 0.045 in. was required following surface cleaning by roto-mill or shot blast. The contractor elected to use shot blast equipment with steel shot between 0.0046 and 0.0055 in. in diameter. The overall mean average texture depth achieved using the sand patch test (LADOTD TR 617) was 0.060 in. with a standard deviation of 0.009 in.

The specified minimum average texture depth was easily achievable on this project because the existing surface contained a transversely tined finish.

A stiff slurry grout consisting of 7 gal of water to one bag of cement was sprayed on the cleaned dry concrete surface just ahead of the paver. The 4-in.-thick steel-fiber-reinforced concrete overlay was then placed and finished with a slip-form paver using string line control. The concrete mix with its high cement factor provided adequate extra paste to coat the steel fibers, and the mix proved to be as constructible as normal slip-form paving concrete. Artificial turf drag was selected as the drag finish but was discontinued because of fibers catching on the material. Burlap drag was then substituted with no apparent problems, followed by transverse tinning on 1/2-in. centers. White pigmented curing compound was applied at one and a half times the normal application rate. Finally, the entire overlay paving was covered with a clear plastic membrane for a minimum of 72 hr.

Project requirements limited the temperature of plastic concrete to 90°F. This proved to be an occasional problem while the westbound roadway was being paved; however, measured concrete typically only exceeded the specification by several degrees. The contractor elected to pave the eastbound roadway during the evening to avoid upward temperature swings. Temperature restrictions on plastic concrete have subsequently been revised to a maximum of 95°F for placement of concrete overlay mixes in Louisiana.

OVERLAY BOND STRENGTH

Two methods were used to determine overlay bond strength. One was the Iowa Department of Transportation shear collar

FIGURE 3 ACI pull test was one test used to measure overlay bond strength.

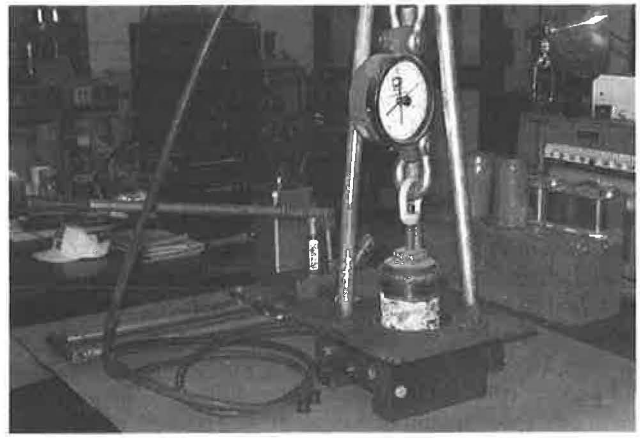

FIGURE 4 Cores of bonded overlay pull tested in laboratory.

method, in which the overlay is sheared at the bond interface using the collar device mounted in a laboratory compression tester (*2*). The other method was an American Concrete Institute (ACI) procedure that subjects the specimen to a direct pull in an attempt to disbond the overlay (Figures 3 and 4). The latter method is suitable for field evaluation because a core is drilled through the overlay and into the original pavement approximately 1 in. below the bond interface. Next, a threaded connection cap is epoxied to the top of the core and allowed to cure for several hours. Finally, the pull apparatus is screwed into the connection cap, and the force required to debond the specimen is recorded. Field tests using this procedure were unsuccessful because all failures occurred either at the epoxy bond interface or at delaminations in the original pavement layers. An additional set of cores was taken to the laboratory to repeat this test so that the epoxy could be allowed additional time to cure.

Bond strength data are presented in Table 1 for both the shear collar and pull test procedures. The average bond strength measured with the shear collar was 943 psi, which significantly exceeds the 200 psi minimum traditionally specified. The average pull strength was 128 psi, which exceeds the 100 psi minimum set forth by ACI for multicomponent epoxy adhesives used to bond fresh concrete to hardened concrete (ACI 503.2-79) (*3*).

SURFACE SMOOTHNESS AND RIDE QUALITY

Quality control measurements were conducted daily using a profilograph to check the 5-in./mi specification requirement.

TABLE 1 OVERLAY BOND STRENGTH FOR SHEAR COLLAR AND DIRECT PULL TESTS

CORE LOCATION	SHEAR COLLAR, PSI	DIRECT PULL, PSI	LOCATION OF FAILURE IN DIRECT PULL TEST
1	906	86	Field - Failed at epoxy/overlay interface.
2	832	91	Field - Failed at epoxy/overlay interface.
3	836	-	Field - Core removed by Contractor.
4	816	-	Field - Core damaged by vehicle.
5	1290	118	Field - Failed at epoxy/overlay interface.
6	736	6	Field - Failed in existing pavement.
7	1129	36	Field - Failed at epoxy/overlay interface.
8	1145	145	Field - Failed at epoxy/overlay interface.
9	1107	91	Field - Failed at epoxy/overlay interface.
10	916	95	Field - Failed at epoxy/overlay interface.
11	884	91	Field - Failed at epoxy/overlay interface.
12	868	91	Field - Failed at epoxy/overlay interface.
13	868	111	Lab - Failed at bond interface.
14	1063	159	Lab - Failed at bond interface.
15	1033	48	Lab - Failed in old concrete.
16	664	115	Lab - Failed at bond interface.
Average	943	128*	

*This average is based only on those test which failed at the bond interface.

TABLE 2 NONDESTRUCTIVE TESTING EDGE DEFLECTIONS UNDER A MOVING 22,000 lb LOAD

	AVERAGE EXPERIMENTAL RESULTS	
Stages	Pavement Deflection	Shoulder Deflection
Pre-Construction	0.0062 in.	0.0048 in.
Pre-Overlay Shoulder milled 5 in., etc.	0.0069 in.	0.0060 in.
After Concrete Overlay	0.0033 in.	0.0038 in.
Post-Construction With Tied Shoulders	0.0025 in.	0.0019 in.

On one occasion the profilograph trace indicated that the paving of an entire day was significantly out of tolerance, resulting in a profile index of 12-in./mi. A thorough examination of the paving equipment resulted in the discovery of an equipment sensor that was malfunctioning. After replacement of the sensor the profile index returned to the 5-in./mi level on subsequent paving lots. It is important to note that without daily quality control testing with the profilograph the paving equipment problem would have gone undetected during construction. The overall ride quality of the pavement increased from an AASHTO serviceability index of 3.4 to 4.4 after placement of the concrete overlay.

DEFLECTION TESTING

An indication of the reduction in edge deflection attributable to the fiber concrete overlay and to the tied concrete shoulder was provided by measuring deflections induced by a slowly moving 22,000-lb single axle load. The load was applied 2 ft from the outside pavement edge while the time-deflection profile was measured with transducers and an oscilloscope recording system. Placement of concrete overlay resulted in a reduction in edge deflection of approximately 50 percent. The 9-in. tied concrete shoulder reduced the deflection another 10 percent for a total reduction of 60 percent, as calculated from the data presented in Table 2.

OVERLAY CRACKING

A survey of transverse cracks before overlay indicated that the CRCP contained an average crack spacing of approximately 4.5 ft. Expectation of reflective cracking through the overlay was a major consideration in using steel fibers because they have the potential of providing three-dimensional reinforcement throughout the overlay. The first indications of reflective cracking became apparent 3 months after the overlay was completed. After 1 year of service, some areas of the overlay were found in which only 30 percent of the cracks reflected through and others in which essentially 100 percent of the cracks reflected through. In all locations surveyed the reflection cracks are tight and are not expected to present a problem in overlay performance.

PROJECT COSTS

The total cost for the 5.2-mi project was $5,618,356, of which $1,033,768, or $16.85/yd², was for the 2.2-mi-long bonded concrete overlay and $61,242, or $1.00/yd², was for surface preparation. Major item costs in addition to the overlay costs required to complete the project included removal and replacement of pavement for transitions at bridges, portland cement concrete shoulder construction, signs and barricades, temporary pavement markings, temporary detour roads, mobilization, and precast barriers.

CONCLUSIONS

1. A 4-in. fiber concrete overlay was successfully bonded to a 16-year-old CRCP that had carried twice its design load. The overlay was constructed in an attempt to arrest progressive development of edge failures and to provide slab thickness designed for 20 years of Interstate highway loading.
2. Design variables included to increase the probability of long-term performance include the following: (a) concrete reinforced with steel fibers and a high cement factor, (b) a clean, textured bonding surface, (c) edge bond reinforcement that pinned the overlay along slab edges, and (d) full-width tied concrete shoulders.
3. After 1 year of service varying degrees of transverse cracks have reflected through the bonded overlay; however, the cracks were anticipated and are held tight by the steel fiber reinforcement.
4. A combination of water-cement grout and a clean, textured surface provided excellent bond between fresh and hardened concrete as indicated in the results of the Iowa shear collar test.

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