Long-term observations will be necessary to document maintenance costs and possible design modifications to improve on the construction and performance of a prestressed overlay system.

It is strongly recommended that qualified, experienced personnel be employed in the design, construction, and quality assurance of prestressed concrete pavements.

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Bonded Portland Cement Concrete Resurfacing

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The experiences of the state of Iowa in developing and refining the process of resurfacing concrete pavements by using portland cement concrete (PCC) are described. The methods of evaluating the condition of the underlying pavement and determining the thickness of the resurfacing layer are discussed. Several projects that used PCC resurfacing to satisfy different roadway needs are described. Several methods of surface preparation, the methods of bonding, and the bond test results are included and discussed. It is concluded that bonding a layer of PCC 50-75 mm (2-3 in) thick to an existing concrete pavement is a viable alternative to bituminous resurfacing for the rehabilitation and restoration of concrete pavements.

Iowa has more than 12 000 miles of portland cement concrete (PCC) primary and Interstate highways, secondary or county roads, and city streets. Approximately 15 percent of these streets and highways have been in service more than 40 years and have had little or no surface maintenance and no additional wearing surface. Many, however (especially those that carry high volumes of traffic), need surface attention at this time. The serviceability (rideability) is approaching, and in some cases has arrived at, the point at which surface restoration or reconstruction is imminently needed.

Nationally and locally, the trend has shifted from building miles of new pavement to restoring and rehabilitating the existing pavement. This has been for the most part due to financial, environmental, and ecological restrictions.

Historically, the restoration process on PCC roads and streets has usually involved resurfacing by using bituminous materials to provide an acceptable riding surface. The bituminous-resurfacing process has provided city, county, and state government agencies with a viable method of extending the service life of PCC pavement at a considerably lower cost than that of reconstructing or replacing the facility.

Since 1976, this nation has been made aware that petroleum and products derived from petroleum are becoming more and more expensive. Further, and more important, is the forecast that this nation's supply of crude oil is quite limited and may be exhausted before the turn of the century. Thus, there is a stong emphasis on the search for substitute fuels, products, and methods that are not dependent on petroleum.

Various types of PCC overlays, which include plain, nominally reinforced, and continuously reinforced overlays, have been demonstrated on concrete pavements as well as a few cases on bituminous pavements. For example, since 1959, 13 different states, including Iowa (Greene County), have had projects that used continuously reinforced concrete overlays (1).

In 1973, a research project was conducted in Greene County that used 50- and 75-mm (2- and 3-in) thicknesses of fibrous reinforced concrete in various conditions of bonding: unbonded (two layers of polyethylene), partially bonded (wet interface), and bonded (dry cement broomed over wetted surface). Also, in the fall of 1954, PCC resurfacing was placed on US-34 in West Burlington, Iowa. This was reinforced by using steel mesh, and most of the project was bonded by using a nominal 6 mm (0.25 in) of cement-sand grout (2).

Although there is a variety of designs and construction procedures available, the projects mentioned above demonstrated the practicability of concrete for resurfacing in rehabilitating old concrete pavements. In previous attempts at full bonding of overlays, the information available indicates that complete bonding was not obtained.

A definite need existed for a high-strength, durable, skid-resistant, long-lasting, and economical resurfacing course for PCC pavements. Such a resurfacing course, completely bonded to the existing pavement, would provide additional support for the ever-increasing traffic loads and volumes on our roads and streets.

Iowa has had considerable success in the use of thin, bonded, dense concrete overlays used in the repair of deteriorated bridge decks (3). This process involves the removal of unsound concrete down to and around the top layer of steel reinforcement. The entire remaining area of the bridge-deck surface is removed to a nominal depth of 6 mm. This removal is most generally accomplished by using scarifying equipment.

The existing surface is scarified to remove road oils, linseed oil, etc., as well as the surface concrete that has the highest concentration of chloride ions from the interface. The entire surface is vigorously sandblasted and then air-blasted prior to the concrete-placement operation. The blasting is required to provide a clean dry surface to which a thin layer approximately 50 mm thick of dense, low-slump PCC is bonded. The bond is obtained by brushing on a grout of creamy consistency that consists of equal parts by weight of cement and sand immediately before the concrete placement.

By applying the same principles and methods learned from bridge-deck repair and resurfacing since 1965, it was felt that this system could provide a viable alternative to the bituminous resurfacing that has traditionally been used in the restoration and rehabilitation process on PCC pavements.

From the successful experience with bridge-deck repair and resurfacing in Iowa, it was expected that dense PCC could be placed and bonded to an existing concrete pavement. However, it was recognized that higher production, different equipment, and higher-slump concrete would have to be used to provide an economically viable process for large-volume projects.

A typical one-day bridge-deck resurfacing placement is 15-183 m (50-600 ft) long and 4-7 m (14-22 ft) wide and uses 19-mm (0.75-in) slump concrete on a prepared (ground or scarified) surface. This concrete is mixed in a small paddle mixer or a Concretmobile (a self-contained unit that produces concrete by using volumetric proportioning).

Obviously this rate of production would not be economical if a project 11-16 km (7-10 miles) long were to be resurfaced. Also, conventional paving equipment would require a higher-slump concrete for production and workability.

EVALUATION OF PAVEMENT FOR RESURFACING

In choosing a project location for the first attempt at thin bonded PCC resurfacing, the Iowa Department of Transportation (IDOT) looked for a project that would be considered typical and for which the traditional bituminous resurfacing would be the obvious corrective measure to take. In 1976, a section of concrete pavement of US-20 in Black Hawk County (northeast Iowa) was chosen for the first attempt at PCC resurfacing (4). This was a nonreinforced concrete pavement 200 mm (8 in) thick that was exhibiting deterioration in the form of D-cracking. There was considerable spalling of the transverse joints near the intersection with the centerline longitudinal joint. Some bituminous surface patch repair was already in existence.

The thickness for the first project was arrived at from previously mentioned experience gained from the bridge-deck repair system. It had been learned that machine placement of thicknesses less than 50 mm often resulted in tearing of the surface. A nominal 50-mm thickness is usually used in the bridge-deck repair and resurfacing system.

During the first project an attempt was made to duplicate, wherever possible, the already tried and tested system that was being used on bridge decks. The then-recent availability of the high-production scarifying machines in widths of approximately 2.4 m (8 ft) as well as the availability of superplasticizing admixtures provided the necessary items that enabled such a project to be attempted.

The self-propelled scarifying machine was able to break up the existing surface to a nominal depth of approximately 6 mm at a forward speed of approximately 6 m/min (20 ft/min). This provided a production rate that made the concept of applying the bridge-deck repair system to a highway project much more feasible.

The concrete mixture used on bridge-deck repair is a high-strength, low-slump (19-mm) mixture that cannot be placed by using existing conventional slipform paving equipment. The superplasticizing admixtures made possible the design of a concrete mixture that had a workability similar to concrete mixtures used in concrete paving but still maintained the very low water/cement ratios of traditional bridge-deck repair mixtures (the design water/cement ratio is 0.328 water to cement by weight).

This project clearly established that concrete that had a low water/cement ratio could be increased to conventional paving workabilities to allow its placement by using conventional slipform equipment in a thickness range of a nominal 50 mm. Also, it was demonstrated that mixtures of this type could be proportioned, mixed, and transported by means of transit mix trucks and that the inherent problems with the high slump loss that accompanies the use of superplasticizers could be and were overcome.

With the successful completion of the first demonstration project, an application that had a different requirement was investigated. This was a case of a relatively new concrete pavement 150 mm (6 in) thick that, because of changing traffic conditions after the road had been completed, was now considerably underdesigned.

After the road had been constructed in 1968, a commercial development that consisted of a grain terminal resulted in very heavy truck traffic on a road designed for normal secondary-road traffic. Thus the desire to increase the load-carrying capacity by bonding on a layer of concrete was the motivation for the second project.

In 1977, a 2.6-km (1.6 mile) research project was constructed in Clayton County, Iowa (5). An objective of this project was to determine the feasibility of proportioning and mixing a dense concrete mixture by using superplasticizing admixtures in a conventional central-mix batch plant. A second objective was to determine whether a conventional (without superplasticizers) paving mixture of conventional water/cement ratios, still in the nominal 50-mm thickness, would achieve an adequate bond and would adequately strengthen the section for the existing and anticipated traffic.

The successful completion of the project provided the necessary technique and process development to give IDOT confidence in the process. The procedure was considered a viable design consideration for rehabilitation and/or restoration of a deteriorated or deficient concrete pavement.

In 1978, still another condition was considered as a possibility for remedy by using a bonded PCC overlay. An existing four-lane divided facility had been widened by using PCC and later resurfaced by using asphaltic concrete. One particular 0.8-km (0.5-mile) stretch of this pavement was on a down grade in a 72-km/h (45-mph) speed zone and was carrying a considerable number of heavy trucks. At two traffic signals on this portion of pavement, the existing surface was exhibiting a washboarding or rippling effect caused by the braking action of the trucks. This section of roadway has been heater-planed several times to restore a smooth riding surface, and each time the result was short-lived and the roughness reoccurred.

A project was developed to remove the existing approximately 75 mm of asphaltic concrete, scarify the exposed concrete surface, and replace the removed asphalt resurfacing by using a bonded PCC overlay. This project was successfully constructed and completed in the spring of 1978 and is performing excellently.

With the experience described above, it was felt that the mixing, placement, surface preparation, bonding, etc., techniques were sufficiently developed and refined so that the process or method was ready to be used on a project in which it would be subjected to our highest traffic count and most severe loading. This would be on a section of our Interstate system.

It was felt that there were several things to learn from performance under traffic. A project site was chosen that consisted of two sections of PCC pavement. One section consisted of a continuously reinforced concrete (CRC) pavement 200 mm thick that abutted a 250-mm (10-in) mesh-dowel concrete pavement. Both pavements, which had been constructed in 1966 and 1965, were exhibiting deterioration in the form of D-cracking.

The CRC pavement was exhibiting a considerable amount of typical D-cracking deterioration along the longitudinal joint. There were several locations at which the secondary cracking was present in large areas, some as wide as a 3.6-m (12-ft) lane width and, on occasion, completely across the 7.3-m (24-ft) roadway. On the mesh-dowel section, the deterioration was present at the transverse joints that were spaced at 23.3 m (76.5 ft) as well as almost continuously along the centerline longitudinal joint.

Since this was to be Iowa's first experience with overlaying a CRC pavement, additional testing and evaluation were done in order to facilitate the design of the overlay or resurfacing thickness. Cores from the existing section were visually evaluated as well as tested for compressive strength. Due to its visible condition, it was obvious that this pavement needed some sort of rehabilitation and in certain areas was no longer a sound section for its full thickness.

The 75-mm thickness of PCC overlay for this project was influenced more by experience than by theoretical design. The performance of the previous projects and their traffic were considered. Also, it was known that there would be substantially more truck traffic on the Interstate, and this was considered in the decision to increase the thickness to more than that of previous overlays.

After the thickness decision had been made, the 75-mm design was evaluated by the normal pavement design procedure. Iowa uses the Portland Cement Association method, or rigid-pavement design (6). This method is based on fatigue of the concrete due to flexural stresses. Since it was expected that sufficient and adequate bond would be obtained to make the resurfacing or overlay act as a monolithic section, the thickness design was approached as that of a new monolithic pavement. It was determined that a new pavement section of plain PCC for this traffic under these conditions would need to be 267 mm (10.5 in) thick. It was felt that by scarifying existing pavement to a nominal depth of 6 mm, the existing pavement would result (as will be described later) in being approximately 190 mm (7.5 in) thick. Therefore, on the assumption that the remaining pavement was sound, an overlay 75 mm thick would provide a section considered to be sufficient to carry the design loading. It was recognized that, due to the D-cracking present, the remaining slab was not in a completely sound condition. For this reason, no consideration was given for the existence of the continuous reinforcement.

Another factor that contributed to the overall pavement structure and added conservatism to the design was that a drainage system was installed to remove water from directly under the pavement. Slotted polyethylene tubing 100 mm (4 in) in diameter was placed in a trench 250 mm wide located 610 mm (24 in) below the top of the existing pavement on each side. Outlets were provided at approximately 305-m (1000-ft) intervals. These drains were covered by using a designed porous backfill material. From previous experience with this type of drain installation, it was expected that stability of the subgrade would be substantially improved. This would directly affect the load-carrying capacity and longevity of a given pavement thickness.

The 75-mm bonded PCC overlay was placed on a 7.2-km (4.5-mile) section of I-80 in western Iowa in the summer of 1979. From all observations and evaluations to date, the resurfacing is performing as expected.

SURFACE PREPARATION

Since the beginning of the dense, low-slump-concrete bridge-deck repair system in Iowa in 1965, the importance of proper and complete surface preparation has been paramount. The success and long-term performance of any bonded overlay are directly related to a properly prepared surface.

In the bridge-deck repair system, the surface, as previously described, is scarified followed by a vigorous sandblasting. The scarifying is primarily to remove road oils and other surface contaminants from the interface and secondarily to provide a clean surface. The sandblasting operation is considered one that further cleans any oil drippings, spillages, etc., that might be left on the surface after scarification. The intent is to have a clean dry surface, free from any loose particles at the time of concrete placement. To remove any dust subsequent to sandblasting, the surface is cleaned by using an air blast just prior to the grouting and concrete-placement operation.

Through the various development stages of the thin-lift, bonded resurfacing technique, various other types of surface preparation were investigated and attempted. They were sandblasting alone, high-pressure water blasting alone, and a small amount of shot blasting. All these methods appear to be capable of providing a sufficiently clean surface with which to achieve sufficient and adequate bond by means of the grouting system that has been used to date. The only shortcoming of these techniques that we are aware of at this time is that in the single project in which high-pressure water blasting was used, the water blast was not capable of removing the painted traffic lines. It is important that paint, tire marks, etc., be removed in order to achieve a complete bond.

On the I-80 resurfacing project, the method of preparation chosen was that of scarification followed by sandblasting. The primary reason for this choice was the existence of a considerable amount of D-cracking on a large percentage of the roadway surface. It was felt that the scarifying effort would remove the partly fractured pieces, which would result in the sound surface needed for bonding the subsequent overlay. Specific locations of more-advanced D-cracking deterioration, such as along the centerline joint, were scarified to a nominal depth of 25 mm (1 in).

Due to the straight-line configuration of the mandrel, or cutting head, on the scarifying machine, to scarify a pavement that had a crown, generally depths in excess of 6 mm resulted. [The scarifying machine on this project used a mandrel that was approximately 3.6 m (12 ft) wide. Even by using a machine that was full-lane width, four passes were required in order to achieve complete coverage of the existing surface and not have to remove excessive amounts of pavement.]

It should be mentioned that any areas of deterioration such as blowups or punchouts that would normally be repaired by full-depth repairs for the traditional bituminous resurfacing were treated in a similar manner as part of the preparation for PCC resurfacing.

Pressure-relief joints have been constructed in Iowa's concrete-resurfacing projects to provide for the expansion and contraction forces caused by temperature changes. These have been approximately 100 mm (4 in) wide, spaced at approximately 305 m (1000 ft), and sawed full depth through the resurfacing roadway.

On the 1979 Interstate resurfacing project, the pressure-relief joints were sawed in the CRC pavement by using a large-diameter wheel saw prior to resurfacing. As soon as possible after resurfacing, the joint was sawed by using a diamond saw over the previously formed relief joint. It was then filled to full depth by using a polyurethane material.

At several relief-joint locations on the project, debonding of the adjacent resurfacing was detected prior to opening of the roadway. When the unbonded resurfacing had been removed, the old pavement appeared to be uniformly covered with bonding grout. It is presumed that there was some movement in the underlying pavement before the grout developed sufficient bond strength. This may have been caused by the increase in ambient temperature during placement in addition to that from the hydration of the resurfacing.

The unbonded overlay was removed and the areas were sandblasted, regrouted, and patched by using PCC. The repairs were successful. A change in pressure-relief joint design and construction will be considered for future projects.

BONDING PROCEDURE

In the first attempt at concrete resurfacing in Iowa, in 1954, a cement-sand grout of approximately 6 mm was placed (2). However, as indicated in the documentation of that project, the bonding layer not only was apparently excessively thick but was allowed to dry prior to the placement of the concrete. Thus, in all probability, it became a bond breaker rather than a bonding layer.

In the planning stages prior to Iowa's 1976 project of a bonded PCC resurfacing, a review of the research previously done on bonding was undertaken (7). This report of 10 years of performance of bonded resurfacings seemed to indicate no minimum bond strength, as measured in shear. It was determined that 1379 kPa (200 lbf/in²) is apparently adequate and that when such a bond is obtained, it will endure. The extensive amount of bond testing that has been done on the projects constructed to date in Iowa seems to confirm this.

Although small areas of delamination have been detected on various concrete-resurfacing and bridge-deck repair projects, cores have indicated the delamination to be below the interface in the vast majority of cases.

From core testing and observation to date (with the possible exception of the previously described experience at certain pressure-relief joints on CRC pavement), there has been no indication that bond has ever been lost once it had been attained.

The most critical factor that affects bond, in our opinion, is that the surface must be extremely clean and dry prior to the placement of the grout and subsequent placement of the concrete resurfacing. The virtues of a clean surface are readily apparent. The virtue of a dry interface results in some penetration of the grout into the existing or underlying surface. This creates an adequate and satisfactory bond.

Bond Testing

Much has been mentioned about the bond and bond testing. The testing jig used has been a shop-made shear collar, and the technique and test method were designed by and for IDOT. Basically, the jig consists of a two-part collar (Figure 1) that fits over a core 100 mm (4 in) in diameter; the junction of the two sliding parts is lined up over the bond line or interface between the underlying pavement and the resurfacing layer. The collar is then placed into a testing machine (Figure 2) and put in tension; the load required to shear off the resurfacing is then measured in kilopascals. This is recorded as the bond strength. The bond strengths that have been obtained to date from the various types of surface preparation are given in Table 1.

Grout Mixture and Application

The grout mixture that has been used on all bridge-deck repair projects as well as on all but the last resurfacing project has consisted of equal parts by weight of type 1 portland cement and sand that has enough water to make a creamy consistency. Care is

Figure 1. Testing jig.

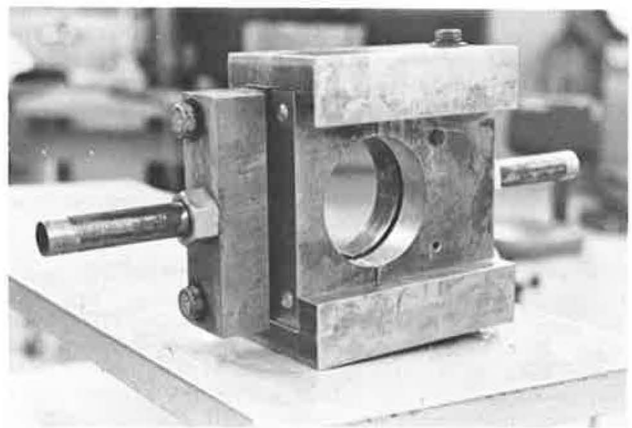

Figure 2. Hydraulic testing machine, jig, and specimen.

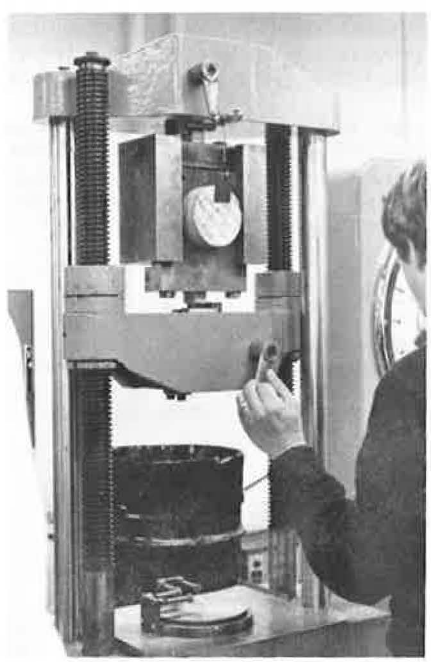

Table 1. Summary of bond strengths from various projects.

Project	Avg No. of Cores	Method of Surface Preparation	Bond Strength (kPa)
Black Hawk County (1976 project)			
Nov. 1976	10	Scarify and sandblast	7407
March 1977	10	Scarify and sandblast	5786
March 1979	7	Scarify and sandblast	4931
Clayton County (1977 project)			
1977	13	Scarify	2897
1977	14	Water blast	3855
1977	16	Sandblast	4083
1980	6	Sandblast	5186
1980	6	Water blast	4317
1980	6	Scarify	2828
1980	3	Scarify and sandblast	4600
Woodbury County (1978 project)			
1978	5	Scarify and sandblast	3979
Pottawattamie County (I-80, 1979 project)			
1979	17	Scarify and sandblast	3793

Note: 1 kPa = 0.145 lbf/in^2.

taken so that the grout is not so thin that it forms puddles in low spots. The grout is brushed on the surface by using a long-bristled broom. This brushing action aids in assuring a uniform coverage of the surface as well as in preventing any areas of puddling or excessive grout.

On the last concrete-resurfacing project on I-80, the contractor developed a system of spraying the grout on the surface rather than of brushing it on. In addition, he elected to use a mixture of only cement and water. This mixture had been previously evaluated in the laboratory and found to provide the same bonding characteristics as the cement-sand grout.

The cement-water grout was proportioned at the rate of 26.5 L (7 gal)/bag of cement, which converts to a water/cement ratio of 0.62 by weight. This grout was proportioned and mixed in one of the drums at the central mix-proportioning plant and was transported to the job site in an agitator-type truck. The truck was modified by placing pieces of rubber belting on the paddles so as to ensure continuous wiping of the bottom and sides of the truck box, thus preventing any settling of the cement from the mixture.

After various trials, a nozzle was selected that provided an even distribution of grout across a spray width of approximately 1-1.2 m (3-4 ft). This procedure appeared to work very satisfactorily and was considerably less labor-intensive than the method used on previous resurfacing projects in which laborers brushed the grout onto the existing surface.

The timing of grout placement is considered to be critical in achieving the maximum bond. It is most important that the grout be placed immediately ahead of the concrete and that the fresh grout be covered with concrete as soon as possible, before it has been allowed to dry.

SUMMARY AND CONCLUSIONS

After four projects, successfully completed over a four-year period, the techniques and methods needed to construct a bonded PCC resurfacing have been tested. The required procedures, although somewhat unique, are not particularly difficult. Any reasonably competent concrete paving contractor would be able to construct a bonded concrete-resurfacing project.

In review and evaluation of the projects constructed to date, bonded PCC resurfacing is considered a viable alternative to bituminous resurfacing for concrete pavement rehabilitation and restoration.

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