1978 CONTINUOUSLY REINFORCED CONCRETE PAVEMENT WORKSHOP

A SUMMARY REPORT

By

Richard W. Kinchen
Pavement Research Engineer

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NOTE ON WORKSHOP PROCEEDINGS

The Louisiana Department of Transportation and Development is presently compiling a complete set of proceedings from the 1978 CRCP Workshop. The Federal Highway Administration is to publish and distribute the proceedings as soon as that document is prepared.

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BACKGROUND DISCUSSIONS ON CRCP

Session I on the morning of Wednesday, February 15, 1978, was devoted to background discussions on the subject of continuously reinforced concrete pavement (C.R.C.P.). Formal presentations explained the history, design, construction, and distress signs of CRCP, as well as the relation of the Federal Highway Administration (FHWA) 3-R program to CRCP.

The first concrete road in the United States was officially built in 1908 at Detroit, Michigan. By 1924 the U.S. had over 31,000 miles of these concrete roads.

These early pavements were full-width, non-reinforced and jointed. They were built without dowel bars or longitudinal center joints. These first concrete pavements presented problems. The joints experienced faulting and produced rough rides. Uncontrolled center cracking required maintenance.

Longer joint spacings and steel fabric were employed to minimize the rough ride and to keep the anticipated mid-slab cracks tight, respectively. However, eventually these steel mesh/dowel bar pavement systems also developed distress at the joints and cracks.

Bureau of Public Roads engineers attempted to eliminate such problems at joints when they used CRCP experimentally in 1921 on the Columbia Pike near Washington, D.C. These engineers probably reasoned that higher percents of longitudinal reinforcement "used continuously" would hold tight the shrinkage cracks that occur in concrete pavements. CRCP could also control warping, provide improved load transfer, and yet not impair the structural integrity of the pavement.

Additional experimental CRC pavements were built in Stilesville, Indiana (1938), Vandalia, Illinois (1947), Hightstown, New Jersey (1947), Fairfield, California (1949), York and also Hamburg, Pennsylvania (1956), and Baltimore, Maryland (1959). Four CRC pavements were built in the 50's in Texas on a non-experimental basis. Michigan constructed its first CRCP in 1958 as a part of Interstate Route 96 between Grand Rapids and Lansing.

Hence, by 1959 there were 192 two-lane miles of CRCP in the United States. This mileage increased to 1450 by 1963, to 10,000 by 1971, and to over 13,000 miles today. Twenty-eight states now include CRCP in their state standards. Design standards have varied from state to state through the years.

In years past, design engineers specified thickness of continuously reinforced concrete pavement based on the Westergard interior stress equation. The percentage of steel was specified through analysis of the strengths of the concrete and the steel. The concrete thickness and steel percentage were determined independently.

Today, designers consider fatigue and the need for continuity in determining the appropriate thickness of a CRC pavement. Concrete strength, steel strength, and subgrade friction are considered in specifying percentage of steel for such a pavement. An AASHTO equation, $P_s = (1.3 - 0.2F) \frac{f_c}{f_s} \times 100$, is available as a guide in the design of the percentage of steel. Current design of CRC pavements is based upon certain assumptions. Distress mechanisms are assumed to be the same as those in jointed concrete pavement. Design is predicated upon loads being applied at the interior of the pavement panels. Uniform pavement support is assumed, as is 100% load transfer at cracks within the pavement. Presently, thickness and steel percentage are determined independently.

Experience has shown that design must also be based on predicted field conditions. For example, the assumed uniform support may not materialize if voids occur due to swelling soils, densification, pumping, etc. If such a case is anticipated, it may be necessary to increase the thickness of the pavement.

Future design should include all of the variables presently considered. Additional factors which should be included are subgrade strength modulus, coefficients of thermal expansion for both concrete and steel, voids, loss of load transfer, changes in temperature, reinforcing bar diameter, friction movement, and time-dependency variables (concrete strength, subgrade strength, etc.).

Design decision criteria should address allowable stresses and allowable crack widths. Equations have been developed to predict stresses in the reinforcing steel and crack widths and crack spacing in the pavement. Determination of pavement thickness and of percentage of reinforcing steel are dependent steps in the overall design of CRC pavements.

Design trends for CRCP have called for pavements that are thin relative to conventional concrete pavements. The State of Illinois initially specified that CRCP would have 0.7 the thickness of its conventional counterpart. That factor was derived from very early performance data from the Vandalia pavements of the '40's as Illinois was developing its design procedures. However, both the CRCP and the conventional concrete control section at Vandalia were exceptionally good pavements with perhaps atypical performance. Illinois quickly realized that the factor of 0.7 was not conservative enough and changed to a factor of 0.8, raising its minimum design thickness for CRCP to eight inches. The Illinois Research Engineer considers the factor of 0.8 to be not conservative and suggests there should be no difference in thickness for equivalent continuously reinforced and conventional concrete pavement designs.

The dimension most common to design and construction of CRCP is the need for continuity and uniformity. Attention to the following points will help translate continuity from design to construction:

1. The design splice length should be adhered to in construction.
2. Care should be given to the vertical position of reinforcing steel. General recommendations are that steel should be placed at mid-depth with a tolerance of ± one inch and that two and one-half inches of concrete cover should be considered a minimum.
3. Gaps should not be incorporated into CRCP. Should gaps be required for one reason or another, recommendations to establish continuity include setting minimum construction lengths and maintaining a uniform temperature with respect to a previously-poured end.
4. At least one state uses mortar-enriched concrete when beginning a day's run at a construction joint. This is to help bonding and consolidation and to introduce a high-early strength factor so as to minimize the effect of the break in continuity.
5. Design thickness should of course be strictly adhered to. Increasing this thickness increases the cross-sectional area of the pavement and thus decreases the percentage of steel therein. This action can have a major effect on crack spacing and crack width.
6. Uniform slump and uniform consistency should be achieved. Placement of very low slump concrete by slip form equipment does create a need for concentrated vibration efforts.

We must be aware of the effects of what is done during construction. The performance of CRCP could be a little more dependent upon good construction workmanship than the conventional concrete pavements. The CRC pavement is a complicated one and warrants the most up-to-date methods of design, construction, and repair.

Construction specifications for CRC pavements should address the need for continuity. Design criteria and experience indicate that a lack of continuity will introduce some form of distress.

Distress, once identified and diagnosed, can be dealt with through maintenance procedures. Continuously reinforced concrete pavements are supposed to crack. So in identifying distress one must determine whether or not cracking is a necessary and acceptable means of stress relief or is a phenomenon that will lead to a structural and/or functional breakdown at a later date. The latter mentioned phenomenon represents a potential failure.

Proper diagnosis of potential failures includes determining the cause of the distress. There is a danger in attempting to determine this cause by simply looking at the surface of the pavement. It is difficult and dangerous to try to standardize distress signs with which to compare distress found on the roadway. CRCP distress can be better evaluated by means of indicators that can be related to future pavement performance. For example one source uses the following types of criteria in designating pavements as potential problems: Dynaflect Maximum Deflection $\geq$ 0.90 milli-inches*, Dynaflect Surface Curvature Index $\geq$ 0.07 milli-inches*, and number of crack intersections > 4 or 5 per 100 feet of pavement.

We must determine the probable cause of potential failures in order to conduct an effective maintenance management program. The Federal Highway Administration is encouraging the States to implement maintenance management practices on CRCP and all other types of pavements on the Interstate system in connection with a 3-R Program. The Congress created the 3-R Program through the 1976 Federal-aid Highway Act to effect resurfacing, restoration, and rehabilitation of Interstate pavements. Federal-aid funds are available to cover all such 3-R work except routine maintenance operations such as seals and pot-hole repair.

*Deflection measured at 1.0 foot from pavement edge.

The 1976 Act provided for an estimate of 3-R needs on the Interstate System. A study was conducted by the FHWA in cooperation and in consultation with the States to assess these needs. A report on the study was completed and sent to the Congress in September, 1977. The study showed that in terms of 1975 dollars, there is a 3-R needs backlog of about $2.6 billion on 8000 miles of older Interstate segments. Thereafter the continuing annual need for 3-R work is estimated to be $950 million, excluding inflation. The study indicated that distribution of 3-R funds would most objectively be based on a combination of vehicle miles of travel and lane-miles open to traffic. Most of the funds needed for the backlog and for future needs are attributable to pavements and shoulders.

The 3-R study revealed that few states had good pavement life data to predict pavement performance. It seems that good pavement performance data is a requisite to properly managing a system of pavements. And the level of expenditures involved in the 3-R needs certainly warrants proper management of our pavement systems. The 3-R era provides the element of opportunity for pavement management, and the most should be made of it.

MAINTENANCE AND REHABILITATION METHODS FOR CRCP

Session II in the afternoon of Wednesday, February 15, 1978, was a series of discussions of maintenance and rehabilitation practices in which the CRC pavement is rejuvenated yet retained as the primary riding surface. Discussions covered a value engineering analysis of repair procedures, actual current patching methods, polymer concrete patching materials, subdrainage, undersealing, and concrete shoulders.

In 1977 the Federal Highway Administration sponsored a four-state study concerning value engineering (V.E.) analysis of repair of CRCP. The states of Arkansas, Louisiana, Mississippi and Texas performed the cooperative study.

The V.E. study group was comprised mainly of maintenance engineers with a great deal of experience in repairing CRCP. The group broke the repair operation into components and analyzed each to see if a cheaper, faster or more expedient method or material would satisfy the requirements for that component. Listed below are the most suitable repair alternatives that could be developed. A concensus could not be obtained on all items; hence, alternate solutions are included in the discussions.

1. Locate the area to be patched. While that section of highway is closed to traffic, it may be cost effective to simultaneously repair adjacent areas which have the potential of soon becoming pot holes.
2. Detour the traffic. Signs, barricades, detour arrows, and cones can be applied to detour traffic; however, all must conform to the Manual of Uniform Traffic Control Devices to avoid liability in law suits.
3. Delineate the area of pavement to be removed. A knowledgeable person should use paint, chalk, keel, or other suitable material to delineate the area to be removed. The

transverse mark should be perpendicular to the centerline and not on a skew. Field experience indicates that cracks tend to cross skew cuts, resulting in weak triangular slivers of concrete which hasten deterioration of pavement adjacent to the patch.

Transverse cuts should be made at least two feet from a transverse crack. If this cannot be done because all of the transverse cracks are too close together, it is probably better to cut along a crack than leave a narrow piece of existing concrete between the patch and the adjacent crack. One of the most prevalent forms of additional failure after patching occurs adjacent to the patch. It is believed that many failures adjacent to a patch happen because not enough attention was given to selecting the spot where the patch should end.

4. Remove the failed or distressed area. One approach to begin this activity is to make a saw cut from one to two inches deep around the perimeter of the patch. This is to provide a smooth unspalled face for the patch to join with the existing concrete. However, sawing is slow and expensive, as most aggregates are very hard. Also the saw cut does not always provide for a smooth vertical face on the existing concrete. Hence, it appeared that sawing could be eliminated but the study group was not in agreement that it should be.

The concrete is most commonly broken out by means of a jack hammer. However, a tractor-mounted pneumatic- or hydraulic-powered pavement breaker works much faster. The entire area of distress can be broken into small pieces and removed by means of shovels, loaders, etc. Many times when this method is used, there is a practice of cutting the steel in the middle and bending it upward and out of the way so that the concrete beneath the steel can be removed. The steel is then bent downward and spliced where it has been cut. Such treatment of the steel is not recommended because it is very detrimental to the bond between the steel and the existing concrete.

Another means to remove distressed concrete is to cut a trench around the bad area and remove that portion of the slab as a unit. After the trench is made, the steel therein is cut with a torch. The new steel will be welded in place. If the new steel is spliced by tying only, the trench has to be wider so that sufficient lap can be obtained. A grade-all can be used to break the slab loose from the base. A chain can then be placed on the slab and the slab loaded on a truck for disposal. Clean-up of the debris follows.

If the area to be patched is small, it may be more expedient to remove the concrete under the steel by hand methods without removing any of the steel. This brings up the question of what the minimum size of the patch should be. The original manuals specified a minimum 12' or lane width by 10' long. Many crews have had satisfactory results by putting in smaller patches, provided all of the unsound concrete was removed and the cause of the distress, such as a void under the pavement, was eliminated by the repair. Arkansas reported very little difference between the cost of a full lane width patch and a partial lane width patch.

5. Replace the steel, if it has been removed. Based on experience, the study group concluded that it is satisfactory just to replace the steel with the same size and number of bars that had existed.

6. Prepare the hole. The hole, steel, and forms should be pre-wet. The study group doubted that it is cost-effective to apply epoxy or grout to try to obtain better bond between the patch and the existing concrete.

   The use of a side form is also debatable. A side form yields a professional-looking patch and the even edge will minimize problems if the shoulder material later needs to be removed by blading.

7. Spread, strike off, and vibrate the concrete. The use of a mechanical vibrator would appear to be the best way to assure adequate consolidation.
8. Finish the concrete so as to make it smooth. The study group decided that in some cases too much finishing is being done, using too much time and manpower and perhaps weakening the surface of the patch.
9. Provide for texture in the patch at least equal to that in the adjacent concrete.
10. Cure the patch. The most economical and practical means to accomplish this appears to be by means of a membrane curing compound.

Conventional patching methods should be periodically evaluated and updated as appropriate. This entails reviewing written instructions and field application thereof. A few tips in addition to or in reinforcement of those offered by the Value Engineering team follow:

1. Full-depth saw cuts are encouraged to enhance removal of the concrete and steel.
2. The air hammer can be an invaluable tool in chipping out concrete. North Carolina has successfully used an impact-type pavement remover which can be attached to a tractor-backhoe rig. One limitation of this pavement remover is inside small patch areas where the device destroys the reinforcing steel.

3. The sub-base should be in just as good if not better condition when it is patched as it was during the first placement of the pavement.
4. Attention should be paid to mix designs and cure times for CRCP patches. For patches less than 5 square yards, the State of North Carolina uses an $8\frac{1}{2}$-bag Type III cement mix with no accelerator and with a $1\frac{1}{2}$-inch slump. Such patches are allowed to cure for 24 hours prior to the lane being opened to traffic. For patches larger than 5 square yards, that state uses a 9-bag Type I cement mix with a $1\frac{1}{2}$-inch slump and provides 48 to 72 hours of cure time. North Carolina cures its patches by applying curing compound, covering it with polyethylene, and then adding about six inches of sand.
5. Concrete should be placed by the trough and by shovel. The vibrator should not be used to actually place the concrete, as this action pulls grout to the top of the mix and increases the chance of the mix scaling under traffic.
6. Serious consideration should be given to placing a form at the shoulder edge of a patch during the patching operation. The State of North Carolina has had to repair patches because the edges at the shoulder tend to break off.
7. Finishing by hand is acceptable for small patches. North Carolina applies a small Shugart screed adjustable in length from about 18 to 30 feet to finish larger patches. The screed weighs less than 800 pounds and can be folded and placed in the back of a pickup truck for transporting.

The V.E. team discussed the use of various patching materials that bear additional study. One such material is polymer concrete.

Polymer concrete is a system in which aggregates (coarse aggregates, sand, and in some cases filler material) are combined with a chemical compound designated generally as a monomer. The monomer reacts chemically (polymerizes) and binds the aggregate in a very stable matrix. The mix incorporates approximately 12% monomer and 88% aggregate by weight. Polymer concrete itself does not contain a hydrated cement paste, although portland cement can be used as a filler.

Basically there are four steps in the placement of a polymer concrete (PC) patch. These steps are described below.

1. Prepare the hole or the area to be repaired. Any unsound material around the patch area should be removed so that the new material is placed against a clean sound surface. This surface should also be relatively dry. It is usually sufficient to air dry the surface for one or two days. If it has rained the night before, then the surface must be dried by a heater.

   Asphalt, oil, and other contaminants must be removed from the area. For shallow patches, the area should be cleaned down to beneath the top layer of reinforcing steel. This is to help secure bond between the patch and the surrounding concrete. All loose scale or rust on the reinforcing steel should be removed by sandblasting.
2. Formulate the monomer and select the aggregate. For ease in handling and measuring materials in the field, one can use pre-calibrated volumetric containers. This eliminates the need to weigh out different batch quantities in the field.

   Several different types of aggregates have been used successfully in the production of polymer concrete patches. This includes silica, quartzite, granite, and limestone. The aggregate must be in the dry condition (less than 1% by weight), so it must be dried before it's taken to the field.

3. Mix the materials. A variety of conventional mixers have been used to mix polymer concrete in the field. The aggregate should be mixed for a while to get good distribution of fine and coarse material. Then the chemicals are fed directly into the mixer. The mixer is to run until the aggregate has become thoroughly saturated with the monomer.

4. Place and finish the P.C. patch. The mix can be discharged directly from the mixer or hauled by wheelbarrow to the location to be patched.

   Basically, if the repair is less than three inches in depth consolidation can be obtained by hand tamping or by using vibrating screeds. For patches greater than three inches in depth, finger vibrators can be used to quickly distribute material between the reinforcing steel.

   Finishing can be accomplished by using a wooden float or by using a steel trowel. Texture for skid resistance can be effected by working a monomer-saturated coarse aggregate into the surface or by broadcasting coarse-grained sand over the patch.

   An alternate method of placing a mix involves discharging dry aggregate into the hole, tamping, and then saturating with monomer in place. This method is recommended for shallow patches that are 10 square feet or less in area. The Research Engineer from Texas advises that his state has used this type of polymer concrete patch with success. Moreover, he does not consider this technique to be too complex to use.

Polymer concrete has its advantages and disadvantages. PC basically combines the pre-mix characteristics of portland cement with high strength, long-term durability, and rapid curing times. Polymer concrete has been placed at temperatures varying between 35^{o} and 95^{o} F (although there are restrictions on the temperatures at which some systems can be placed). Compressive strengths in excess of 5000 p.s.i. have been obtained in approximately two hours. Hence polymer concrete could be considered as a suitable material for repairing structures in areas where traffic conditions allow closing an area for only a very short period of time.

In regard to disadvantages of PC, the estimated cost is $250 to $300 per cubic yard. Work time (defined as the period in which mixing, placing, and finishing must be completed) can vary from 15 minutes to a little over an hour. High vapor pressure in some PC systems require the use of polyethylene film or a curing blanket to avoid evaporation from the surface. Aggregate must be pre-dried. And the monomer systems are considered flammable and toxic, requiring a certain degree of care in handling. Hence, the States must evaluate the advantages and disadvantages of polymer concrete and decide if PC patching is a viable alternative to conventional patching methods.

One maintenance activity that can be used independently or in conjunction with patching or overlaying CRCP is undersealing. In this activity asphalt cement or a soil cement slurry is injected beneath the pavement to fill voids that exist. Care must be taken to avoid raising the pavement in the void-filling process.

Indiana undersealed a CRCP project near Indianapolis on a research basis. Most of the distress occurred in a segment of pavement approximately 1½ miles in length. Hence, the distribution of drill holes varied from 302 holes in 3000 feet of more severely distressed pavement to six holes in a 1400 foot segment with less severe distress. Initially, the holes were placed in two rows per lane, with the holes staggered at four-foot intervals. As workers injected slurry into one hole, they would note the presence of slurry in an adjacent hole indicating distribution of the material. Later in the undersealing project, the crew changed its technique and began placing a row of holes at eight-foot intervals in the middle of the lane. Bid prices for this job were $3 each for the drill holes and $175 per ton for the asphalt underseal material. In the areas where underseal was placed there were no failures after two years.

The Dynaflect was an essential tool on the Indianapolis project. Indiana used the Dynaflect first to locate weak areas in the pavement system, using a first sensor reading of 0.9 milli-inches or greater as an indication of the need to underseal. Indiana then evaluated the project immediately after undersealing and periodically thereafter. A reduction in deflection was noted, and the undersealing was considered a success.

Another approach which has been used successfully to extend the life of CRCP is the use of portland cement concrete shoulders. To add such shoulders to old pavements, holes must be drilled in the edge of the existing pavement to install tie bars. These holes can be easily placed by new tractor-mounted equipment capable of drilling 2, 3, or more holes simultaneously. The tie bars can be secured by grouting with epoxy or by using self-anchoring tie bolts. In new construction, tie bars can be placed in the plastic concrete near the rear of the slip form paver. Bent tie bars can be installed mechanically or manually and later straightened to tie the shoulder to the mainline. Some contractors prefer to use a 3-piece tie bolt by inserting one half and the coupler into the lane by machine and screwing the other half into the coupler before the shoulder is added. Small slip form pavers are available for adding 4-foot or 10-foot wide shoulders. One state has extended the paved width of its traveled lanes and designated a portion thereof as a shoulder.

The primary advantage of concrete shoulders is in reducing edge deflections. This is very beneficial, as truck traffic encroaching on paved shoulders can produce excessive deflections and cause distress in both the pavement and the shoulder. Additionally, there is no dropoff at the shoulder edge (and hence no safety hazard) where properly designed concrete shoulders are used along concrete pavements. And tied concrete shoulders enhance drainage by preventing the development of an open longitudinal shoulder joint which invites water into the pavement system.

Performance of mainline and shoulder pavements of any type depends very much on the designers ability to predict and control moisture content therein. Moisture can seriously undermine pavements through the mechanism of moisture accelerated distress, commonly referred to as pumping.

The most common source of moisture in pavements is rainfall. Any climate that has approximately 15 inches or more of rainfall per year might be considered as a basis for specifying drainage procedures for pavements. Moisture can enter pavement systems directly as rainfall through cracks and edges, or it can seep from high ground, or it can move up from the water table as capillary or vapor water. Hence, gravity and the water table position are important factors in drainage. If the water table is close to the structural system, vertical drainage is limited.

Darcy's law in Hydraulics applies to movement of moisture in pavement systems. Darcy's law relates quantity of moisture flowing to a coefficient of permeability and to a hydraulic head factor. Hence, moisture flow is a function of the properties of the materials comprising the system and of the hydraulic head which develops therein. Very coarse-grained, well-graded materials drain quite freely, whereas fine-grained soils hold water. Maximum flow of water through a material occurs at saturation, whereas moisture flow through an unsaturated material decreases with time.

Hence, the designer should understand the characteristics of both the materials and the climate in order to properly provide drainage for pavement systems. He can then normally specify one or a combination of three approaches to control water in the pavement system-protection, desensitization, or evacuation.

Protection can involve waterproofing the roadway and providing lateral protection for the shoulders using materials that do not allow water to enter. Portland cement concrete shoulders provide protection and are particularly appropriate when the mainline pavement is concrete because of similar thermal conductivity characteristics. Another protective technique is to place a dense-graded asphalt plug at the interface of the mainline pavement and the shoulder. This plug is to hinder water from entering the system and then minimize hydraulic ejection of materials by that water which does so intrude. An asphalt plug works well when there is good surface runoff and vertical drainage to the water table. Good joint sealant (per se) between the shoulder and the mainline pavement can also be beneficial in preventing water from entering the pavement system.

Desensitization to moisture involves means such as compaction control, chemical treatment, and stabilization of embankments. Undersealing can serve a similar purpose after the road is built. Additionally, the State of Georgia has placed a 1-inch layer of dense concrete over a granular base and then added the concrete riding surface. This is to minimize pumping if the granular material becomes saturated.

Evacuation of moisture involves removing water from the pavement system. Such removal can be considered in the structural design of the pavement section by specifying materials that will transmit water. If the materials are sufficiently permeable, then drains can be called upon to remove water passing through the system. The States are using various types of drains to remove water in pavements.

In Illinois, a standard procedure is to place a four-inch diameter pipe underdrain 30 inches down from the pavement edge. The pipe periodically leads through the shoulder to a headwall with outlet.

Illinois backfills underdrains with sand. This material should be used with the knowledge that with time it may adversely affect the rate of flow in the drain. In the long term it may be more beneficial to backfill with an envelope of more-coarse material, sacrifice the loss of some fines through the drain, and retain the best possible flow through the drainage system.

California has a design that places a slotted two-inch diameter "mini-drain" at the base course. The "mini-drain" is a fairly-hard plastic pipe that reportedly can be placed cheaply.

Georgia is placing drains at some distance from the edge of the pavement. That state is using an open-graded asphaltic concrete to allow water to move down through the pavement, across the pavement edge, through a granular material and into a drain.

There are drawbacks to the use of drains. Initial placement of drains is expensive. Once placed, drains must be maintained so that they serve as sinks and not as sources of water to the pavement system.

Most people clean drainage pipes with a high-pressure jet stream. It is important to have access to the lateral in order to maintain the pipe. Hence, curved laterals may prove more practical than right angled laterals for the purpose of cleaning.

It is important that the pavement designer be able to predict the moisture that his pavements will be subjected to. He needs to know what he is trying to drain and where the water is coming from. Equally important, the designer must know methods of controlling moisture. Then the designer can tailor his drain systems to meet his particular needs.

REHABILITATION CRITERIA AND THE ASPHALT CONCRETE OVERLAY FOR CRCP

Session III in the morning of Thursday, February 16, 1978, began with a discussion of the criteria of rehabilitation versus continual patching of CRCP. Discussions then concentrated on the asphalt concrete overlay as a means of rehabilitating CRCP.

A recent survey was made of a number of CRCP projects in Illinois. All structural failures were counted. Indications are that one can plot a graph of the amount of patching (in square yards or in percent area of the truck lane) for an individual project versus the associated accumulated 18-Kip loadings. And, where trends exist, he can use the plot to predict future patching needs.

One can repair distresses in CRCP through patching operations. The cost of such patches in Illinois and in Indiana is approximately $100 per square yard when done by state personnel. To this must be added the costs and problems to the public of lane closures. Hence, over a period of time the cost of patches can become extensive. In such cases rehabilitation can become more economically feasible than continual patching.

Rehabilitation of various sorts can be resorted to. Sub-drains, concrete shoulders, undersealing, epoxy for cracks and punchouts, overlays, and combinations of these features represent alternatives to continual patching and <u>should</u> seriously <u>be considered</u> in lieu thereof.

There are at least three decision criteria regarding the selection of a rehabilitation method and when it should be applied. The first criteria is the total cost of the project for the analysis period. This would include the cost of the rehabilitation and future patching and the salvage value at the end of the period.

The second criteria is the extent of patching required subsequent to the rehabilitation. In Illinois, state transportation authorities become very concerned if a pavement has over 2% of its area patched. Indications are that the timing of rehabilitation (i.e., at 2 years, 10 years or whatever pavement age) has a direct bearing on total present cost and future patching requirements.

A third decision criteria is the length of time that lanes must be closed to traffic in order to effect the rehabilitation. Such down time (in conjunction with excessive future patching requirements) is a primary consideration in opting for overlays even if other cost analyses are favorable.

If rehabilitation criteria indicate that an overlay would be an acceptable alternative to rejuvenate CRCP, a next logical step would be to effect a structural analysis to determine the thickness of overlay required to accommodate a future traffic loading. The Federal Highway Administration is sponsoring research to develop a "Universal" overlay design method for such structural analysis.

The method is termed "Universal" because it is based on an analytical model applicable to pavements and overlays of various types. For CRCP this methodology will handle overlays of not only asphalt concrete but also of unbonded jointed concrete, unbonded CRCP, and bonded CRCP.

The "Universal" method can generally be divided into five steps. The first step is project site investigation comprised of field deflection testing, some in-place materials sampling, and performing a pavement condition survey. Second step, deflections are studied to determine if the project is uniformly strong or if the project must be sub-divided and provided varying overlay designs. Thirdly, the existing roadway materials and the proposed overlay material must be evaluated for elastic modulii. These properties are of the existing slab which serves as the new base. The procedure is based on the assumption that the existing slab will be repaired so as to restore the continuity of the reinforcement and provide a continuously reinforced concrete base course for the new overlay. Credit is then given to the continuous reinforcement by dividing the CRCP slab thickness by 0.8 and thus converting it to an equivalent thickness of conventional pavement. This credit reduces the required thickness of bituminous overlay by about 1-1/4 to 1-1/2 inches. The design engineer may conversely elect to give no credit for the continous reinforcement if the concrete is deteriorated severely enough.

A representative of the Asphalt Institute advises that if a CRC pavement can be provided an overlay before excessive deflections develop, then four inches of dense-graded asphalt concrete should be adequate. If the CRC pavement has major spalling and deflection-induced pumping, then about six inches of dense-graded asphalt concrete or a crack relief overlay combining open-graded and dense-graded layers of asphalt concrete could suffice.

The crack relief overlay is comprised of three different layers. The first layer to be placed on the existing slab is a three and one-half inch open-graded crack relief layer. Three aggregate gradations used successfully in this layer are indicated very generally as follows: 1.) 100% passing the 3-inch and 0 to 2% passing the 3/8-inch sieve (most successful gradation), 2.) 100% passing the 2 1/2-inch and 0 to 5% passing the No. 8 sieve, and 3.) 100% passing the 2-inch and 0 to 5% passing the No. 100 sieve (least successful gradation). An AC-40 grade of asphalt cement and cement contents ranging from 1.5 to 3.0% are suggested for the crack relief layer. The crack relief layer is then covered with a binder course and a dense-graded surface course. The State of Arkansas is presently rehabilitating a CRC pavement with a crack relief overlay comprised of three and one-half inches of crack relief layer, two inches of binder course, and one and one-half inches of dense-graded surface course.

The State of Arkansas is sponsoring research in which strain sensors (inductance coils) are placed in existing slabs and in the overlays for conventional and continuously-reinforced concrete pavements. Vertical and horizontal movements are being determined to identify the primary causes of reflective cracking in bituminous overlays. The data could indicate the effective retardation of reflective cracks attributable to the various asphalt concrete mixes.

The Asphalt Institute representative proposes that frequency of propagation of cracks from concrete pavements through bituminous overlays is inversely proportional to the number of cracks in the concrete pavement. The thought is that the amount of energy or stress that will be relieved at each crack in the concrete pavement depends on the number of cracks available for such relief. He thus proposes that with as many as 500 to 1000 linear feet of cracks per 100 feet of pavement, the special crack relief overlay can be disregarded in favor of a more conventional overlay. This opinion is based on observations and calculations involving about three and one-half to four inches of asphalt concrete mix.

The State of Minnesota has a limited amount of CRCP, built primarily between 1965 and 1970. The State has applied asphalt concrete to CRCP and concluded that such an overlay is not the ultimate solution for rehabilitation. That state encountered a problem in bonding the overlay to the existing CRC pavement.

Minnesota offers the following advice for coping with the bond problem: 1.) the surface of the CRC pavement should be roughened by a scabbler or machine, 2.) a tack coat must be applied uniformly and 3.) a minimum of three inches of bituminous concrete overlay should be applied (total of leveling, binder, and wearing courses). Prior to applying the overlay, it is also recommended that broken sections of pavement be repaired so that the failures will not reflect through the overlay.

The State of Texas has many miles of CRCP. Some of these pavements are 15 to 18 years old. One such project was built in 1960, incorporating certain design and construction deficiencies. Hence, the project began deteriorating early. In 1969 Texas placed an experimental asphalt concrete overlay on this project with two-, four-, and six-inch thicknesses. Dynaflect deflection tests indicated about a five percent reduction in deflection for each inch of overlay. By 1974 overlays of all three thicknesses exhibited reflective cracking, although very little was noted on the six-inch overlay.

Texas does employ the Dynaflect to locate problems that should be corrected before a CRC pavement is overlaid. Texas has used the device to locate potential punchouts in the pavement and voids beneath the pavement.

RIGID PAVEMENT OVERLAYS FOR CRCP

Session IV in the afternoon of Thursday, February 16, 1978, included discussions of rigid pavement overlays. The presentations were conceptual as regards rehabilitating CRCP, as the speakers related experiences in applying portland cement concrete overlays to conventional asphalt and portland cement concrete pavements. Early successes with the rigid pavement overlay indicate that it could represent a viable approach to rehabilitating CRCP as well.

There are several approaches that can be taken to rehabilitate pavement by rigid pavement overlays. These general approaches are 1.) by means of partially bonded (direct) overlays in which no attempt is made to bond or prevent bond of the overlay and the existing slab, 2.) by means of unbonded (separated) overlays in which a bond breaker is placed between the existing pavement and the overlay to prevent reflection cracking or in which a leveling course is placed on top of the existing slab to provide a smooth surface for the resurfacing and 3.) by means of bonded (monolithic) overlays in which positive attempts are made to secure bond between the overlay and the base pavement.

There are also several types of concrete overlay designs that can be used in conjunction with the above approaches. These designs include 1.) plain concrete with or without dowels in the transverse contraction joints, 2.) nominally reinforced concrete with mesh or welded wire fabric in the slabs and dowels in some or all of the joints, 3.) fiber-reinforced concrete in which steel or other type fibers are mixed in the concrete to give better spall resistance and to provide a tougher surface which could minimize reflection cracking, and 4.) continuously reinforced concrete overlays which rely on the longitudinal steel to prevent reflection cracking.

The appropriate approach and concrete overlay design will depend to a large extent upon the condition of the base pavement. Is that base pavement structurally adequate? Is the existing pavement suffering from poor drainage, saturated subbase or subgrades, and pumping? Is a bond breaker needed, and should joints in the base slab/overlay system be matched? A large amount of good engineering judgment is required to evaluate the existing pavement and select the proper concrete overlay design.

Several surveys of concrete overlays have been made in recent years. In 1975 an ad hoc committee began compiling a list of CRC overlays existing in the United States. A subsequent report summarized the designs and performance of 23 such projects located in 11 states. The majority of the projects surveyed were in good or excellent condition.

Similarly, in 1977 the Portland Cement Association and the American Concrete Paving Association surveyed rigid pavement overlays other than those of continuously reinforced concrete. Information was compiled on 39 projects in service in the U.S. Overlay thicknesses varied from four to eight inches, and ages ranged from 7 to 36 years. Many are over 20 years in age. Serviceability ratings on most of these concrete overlays were "good" or "very good".

The State of Iowa completed construction of two notable and very successful thin, bonded concrete overlays on existing concrete pavements in 1976 and 1977. The projects utilized the "Iowa Method" of low-slump dense concrete overlay construction which had been developed for bridge deck resurfacing.

With the development of new high-production equipment for scarifying concrete surfaces it is quite feasible to bond a thin layer of new concrete on an existing pavement. The scarification is followed by sand blasting. Then, after vacuuming and final cleaning with compressed air, a bonding grout consisting of equal parts cement and sand and enough water to form a thick paste consistency is brushed into a dry surface. Before the grout can dry the new 2 inch surface course of low-slump dense concrete is placed with a slip form paver. Whether or not this would be successful on a CRC pavement would depend to a great extent on the amount of distress at cracks in the CRC pavement, and whether the pavement was suffering from excessive deflection.

The State of Wisconsin placed a continuously reinforced concrete overlay in 1973. The existing pavement was a nine-inch thick unreinforced concrete pavement built in 1953 with 20-foot joint spacing. The base pavement traversed a low-lying swampy area. Due to variations in the longitudinal profile of the existing pavement, the intended grade line for the overlay required thicknesses of CRC varying from five and three-quarters inches to nine inches.

The contractor on the Wisconsin overlay broomed the concrete slab to get it clean. He then placed a six-mil polyethylene sheeting on the existing slab to break the bond with the overlay. The polyethylene came in 24-foot wide rolls of varying length. A mastic was used to secure adjacent sheets of the polyethylene. And longitudinal steel placed ahead of the paver also served to protect the polyethylene from the forces of the wind. The contractor used a 24-foot wide standard Rex paver operating on forms to place the overlay. The average thickness of the CRC overlay and average percent of steel placed was about seven and one-quarter inches and 0.67 percent, respectively.

On that U.S. Route 16 project in Wisconsin, a crack survey was made on the existing pavement prior to overlay. Subsequently, cracks in the overlay have been plotted over cracks in the original slab for determination of reflective cracking. However, there are so many closely spaced cracks in the overlay that it is difficult to determine which are reflection cracks. Variations in thickness of overlay and in percentage of steel have caused variations in crack patterns (clusters) in the CRC overlay.

The U.S. Route 16 overlay, approximately one mile in length and four years in age, has given pretty good service to the State of Wisconsin, except in the quality of ride provided. There have been grade settlements in this swampy area that required patching to provide a smooth ride.

The Oregon State Highway Division has successfully utilized continuously reinforced concrete overlays in the reconstruction of approximately 29 miles of Interstate highways. Interestingly, the CRC overlays were placed on existing and widened asphalt concrete pavements.

Most of the CRC overlay mileage in Oregon was on Interstate Route 5 between Salem and Portland and involved reconstruction from a four-lane to a six-lane facility. Since freeway traffic had to be maintained during construction, most of the mileage utilized the construction of two lanes monolithically with the third lane being added after traffic was shifted to the two new lanes.

The original mainline pavement on I-5 included five and one-half inches of asphalt concrete over nineteen and one-half inches of stone base course. The design thickness of the CRC overlays was eight inches, but actual thickness varied between seven and nine inches because of irregularities in the old surface. Longitudinal reinforcing was comprised of Number 5 bars placed at six and one-half inch spacings to provide 0.6 percent steel for an eight-inch thick slab. For approximately 23 miles on the I-5 overlay, chairs and Number 4 transverse bars spaced at five foot intervals were used. For about four miles on the I-5 overlay (as well as for about two miles on a CRC overlay on I-205 north of Oregon City), transverse steel was not used and the longitudinal steel was tube-fed. Some difficulty was encountered in the tube-feeding, as the sheaths that guide the reinforcement were easily knocked out of alignment and caused the spacing and depth of the steel to fluctuate. To prevent migration of the ends of the CRC overlays, terminal anchors were used at the ends and at structures. Normal practice was to install four anchors at 40 foot spacings for each terminal point. The anchors are reinforced concrete four feet deep and two feet thick. The use of four terminal anchors is probably ultra-conservative for the aggregates and climate in Oregon. In fact, several anchors were omitted during construction on one project. Thus far, there is no indication of any problem where only two anchors were used.

The oldest of the CRC overlays in Oregon is under five years of age. Repairs have been required at several construction joints where spalling has occurred probably due to poorly consolidated concrete. However, performance of the overlays has been good and very low surface maintenance costs are anticipated for many years.

The State of Georgia constructed its first rigid overlay in 1973. The project involved placing a continuously reinforced concrete overlay on an existing jointed concrete pavement on I-75. The base pavement was 10-inch deep plain concrete pavement without dowels. This existing pavement exhibited a large amount of faulting. The CRC overlay was eight inches deep and was placed directly on the existing concrete slab. Minor problems (i.e., multiple cracking) have occurred in the area of an old bypass. However, overall the CRC overlay is in very good condition.

Georgia is also conducting very interesting research involving rigid overlays on I-85 about 30 miles north of Atlanta. The base pavement is nine inches of concrete without dowels. The pavement was approximately 12 years old and was experiencing faulting at the time of the rigid overlay. Present average daily traffic count is 20,000 with 34% trucks. In 1975, one mile of the pavement was rehabilitated with four separate quarter-mile long overlays for evaluation purposes. The overlays were three-inch CRC, four and one-half-inch CRC, six-inch CRC, and six-inch plain pavement with dowels. Certain slabs which were experiencing deflections were repaired, and the pavement was undersealed prior to overlay.

The first test overlay placed on I-85 was six inches of plain concrete with dowel bars. An open-cell neoprene was applied to seal the joints. The other three overlays were six inches, four and one-half inches, and three inches of continuously reinforced concrete, respectively. The six-inch and four and one-half-inch sections were reinforced with steel bars. The three-inch deep CRC overlay was reinforced with woven wire mat. All four sections have concrete shoulders tied to the main line by bars spaced at 30 inches.

In evaluation of the I-85 overlays, generally the six-inch plain and the six-inch and four and one-half-inch CRC overlays have been performing satisfactorily. Some spalling has occurred in the cracks of the four and one-half-inch CRC overlay. The three-inch CRC overlay has not performed satisfactorily. This thin overlay has extensive cracking and spalling and punch-outs and several distressed areas have been patched.

Strong opinions were expressed at the Workshop regarding the need to prevent bond between the base pavement and the concrete overlay. On the Georgia test overlays, curing compound was applied to the base slab to prevent such bond. That approach was not successful, as transverse cracks reflected into the new overlay even before traffic was allowed thereon. Hence the Georgia Research and Development Engineer favors the use of a leveling course or bond breaker per se to prevent keying the overlay to the old pavement. Conversely, a representative of the Portland Cement Association had surveyed 23 CRC overlays and had found no trend of improved pavement performance due to the use of leveling courses. No doubt this is one of many points that merits additional research and could be discussed at a future workshop on continuously reinforced concrete pavements.

OVERVIEW

Two principal themes at the workshop were expressed by means of figures of speech. First, it was related that "...this (CRCP) is a complicated piece of equipment, and we can't use Model T methods of repairing or even designing and building CRCP pavements." Certainly design should not be simplified, as field experience continues to indicate the importance of factors not initially considered. In the future, pavement thickness and percentage of reinforcing steel should be considered and determined concurrently within the design process. Additionally, equality of thickness for equivalent CRC and conventional concrete pavement designs has been proposed.

Construction of CRCP should command as much attention to detail as its design. The performance of CRCP could be a little more dependent upon good construction workmanship than the conventional concrete pavement. Hence, construction specifications addressing the need for continuity should be strictly adhered to.

Identification of distress in CRCP is no simple matter. Continuously reinforced concrete pavements are supposed to crack. So, in identifying distress, one must determine whether or not the cracking is a necessary and acceptable means of stress relief or is a phenomenon that will lead to a structural and/or functional breakdown at a later date. Proper diagnosis of potential failures in CRCP includes determining the cause of the distress. There is a danger in attempting to determine this cause by simply looking at the surface of the pavement. CRCP distress can be better evaluated by means of indicators that can be related to future pavement performance. Devices such as the Road Rater and the Dynaflect can provide valuable information indicative of the structural adequacy of CRCP.

A second principal theme at the workshop was expressed figuratively in the form of a question: "...are you going to maintain the building when the roof caves in, or are you going to maintain it so it won't cave in?" This refers to providing localized preventive maintenance on a continual basis versus deferring repairs until some unpredictable point in time when major "breakdown" maintenance is required to keep the road trafficable. The question is important. The answer is not as obvious as it may seem, particulary in those instances when continual maintenance becomes quite burdensome. The issue illustrates that, similar to the design, construction, and evaluation processes, the upkeep of the 13,000 two-lane miles of CRCP now in existence is not going to be a simple matter.

Localized patching is a necessary and logical means of maintaining a continuously reinforced concrete pavement during its early years. A four-state team of highway engineers has conducted a value engineering analysis of the repair of CRCP. The group broke the repair operation into components and analyzed each to determine the cheapest, fastest, and most expedient method or material that would satisfy the requirements for that component. The value engineering team developed a general set of guidelines for placing a quality patch in CRCP in an efficient manner.

A recent survey was made of a number of CRCP projects in Illinois. All structural failures were counted. Indications are that one can plot a graph of the amount of patching (in square yards or in percent area of the truck lane) for an individual project versus the associated accumulated 18-Kip loadings. And, where trends exist, he can use the plot to predict future patching needs and the point in time at which patching should be discontinued in favor of rehabilitation.

There are at least three decision criteria regarding the selection of a rehabilitation method and when it should be applied. The first criterion is the total cost of the project for the analysis period. This would include the cost of the rehabilitation and future patching and the salvage value at the end of the period. A second criterion is the extent of patching anticipated subsequent to the rehabilitation. Transportation authorities in one state become very concerned if a pavement has over 2% of its area patched. Indications are that the timing of rehabilitation (i.e., at 2 years, 10 years or whatever pavement age) has a direct bearing on future patching requirements and total present cost of the project. A third decision criterion is the length of time that lanes must be closed to traffic in order to accomplish the rehabilitation. Overlay construction, for example, can be quite expensive in terms of down time.

The Maintenance Engineer can resort to one or a combination of several rehabilitation methods for CRCP. Research in Illinois has demonstrated that sub-drains can have a positive effect on pavement performance. Concrete shoulders can provide support at the edges of our pavements. Such support is very important in light of findings from Georgia that truckers are driving much closer to the pavement edge than previous data has indicated. Undersealing is a viable rehabilitation technique. Indiana noted a reduction in deflection (and thus decreased the potential for hydraulic erosion) due to an undersealing project on a continuously reinforced concrete pavement. And, of course, the overlay is a popular method of protecting and improving our investments in CRCP. The Federal Highway Administration has sponsored development of a "Universal" overlay design procedure applicable to pavements and overlays of various types. For CRCP, this methodology will handle overlays of asphalt concrete, unbonded jointed concrete, unbonded CRCP, and bonded CRCP. The "Universal" method analyzes the existing roadway system and proposed overlay materials in conjunction with traffic projections to develop overlay designs. Without the benefit of such a mechanistic design procedure, a large amount of engineering judgment is required to evaluate the existing pavement and select the proper overlay design.