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Recycled D-Cracked Portland Cement Concrete Pavements in North Dakota

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ABSTRACT

This paper presents the North Dakota approach to recycling portland cement concrete pavements (PCCP) on the Interstate system. The first PCCP placed on the system was in 1958 and it was recycled in 1984. A committee was appointed to develop a rehabilitation philosophy and a program that would get a fast start on project lettings. The philosophy recognizes the need for recycling and the need for an interim repair strategy to keep the system in reasonably good driving condition. The program that came out of the committee started the recycling process and also developed concrete pavement restoration (CPR) projects consisting of joint repair, grinding to improve ride, asphaltic concrete shoulder recycling, and interchange overlays. The committee started its work by inspecting the entire Interstate system in February 1983 followed by a second inspection in April 1984. The 1984 inspection revealed a rate of deterioration greater than had originally been anticipated and this caused some rethinking concerning the cost effectiveness of scheduled CPR projects. The amount of joint repair, especially on the pavements with 20-ft joint spacing, will drive the cost up substantially. Originally, the CPR treatment was expected to extend pavement life from 10 to 15 years, but if joint deterioration keeps accelerating, 7 to 10 years may be a more realistic estimate.

With the passage of the 1982 Surface Transportation Assistance Act and the good possibility that the North Dakota legislature would provide additional funding for the state highway department, the development of an Interstate rehabilitation program became a priority item. The assignment was turned over to a committee consisting of: the five Interstate district engineers, a design engineer, a maintenance engineer, and an FHWA representative. The committee started its work by making an inspection of the entire Interstate system in February 1983 and submitted a program to the chief engineer on March 30, 1983. The system consisted of plain concrete pavements with 20-ft joint spacing, reinforced pavements with 39.5 and 61.5 joints and continuously reinforced. The initial program that was submitted contained a sufficient number of projects to cover Fiscal Year (FY) 1983 4-R (reconstruction/rehabilitation/rebuilding/resurfacing) funding. The first recycled PCCP project was let to contract in July 1983. During May 1983, the committee completed a program that would carry through FY 1988.

The 1983 field inspection identified D-cracking as the major problem with most jointed pavements and some continuously reinforced sections. A lack of joint maintenance has accelerated the deterioration to the point where some pavements may be recycled before they are 20 years old. Corroded steel in some sections of continuously reinforced pavement is reducing the life of these pavements. The first joint pavement to be recycled has been in service for 25 years. During the 1984 inspection, it was evident that the D-cracking phenomenon was accelerating pavement deterioration at an alarming rate in some cases. There was a noticeable change in one particular section that was originally scheduled for repair that now will have to be recycled.

The committee adopted a rehabilitation philosophy that PCCP should be recycled in kind, and an interim repair strategy should be used to keep pavements in service until recycled. Asphaltic concrete overlays have been ruled out for the present because of a rutting problem. The department has been unable to develop an asphalt pavement using local aggregates that will not rut under traffic volumes carried by the Interstate. Eventually, some overlay system will be needed to keep in service those continuously reinforced pavements that are structurally sound but that have a poor ride.

Concrete pavement repairs would include joint repair, broken slab repair, grinding to improve ride (when necessary), and selected recycling of asphaltic concrete shoulders and interchange overlays. The original thought was that pavements could be kept in service from 10 to 15 years with one repair-type project. The controlling factor in deciding whether a pavement should be repaired or recycled is generally the amount of joint repair that is necessary. Initial planning was based on the assumption that repaired pavements could serve for 10 years and recycled pavements could serve for 30 years. When the cost of repairs (joint repair, broken slab repair, grinding, and asphaltic shoulder recycling) approaches one-third the cost of recycled pavements then recycling is considered. Availability of funding and scheduling then become the controlling factors.

Recycling is the better of the two options, if cost effective, because by this process, a new system would exist rather than a patched-up model. The only further construction activity that should be necessary, which would occur in 15-20 years, would be grinding for ride improvement, along with an asphaltic concrete overlay of interchanges.

The question that had to be answered before a program could be developed was whether the existing pavements should be kept in service with asphaltic concrete overlays or the recycling process should be started. There were two major factors that dictated recycling. The inability to design an asphaltic concrete overlay that would not require frequent milling and recycling because of rutting, and the fact that it looked like PCCP should last at least 25 years. The first recycled pavement has been in service for 25 years with no joint maintenance, so with adequate maintenance, recycled pavements should provide equal or better performance. In fact, 30 years looks reasonable barring any unforeseen problems with the recycled concrete. Life-cycle costs also support the recycled options. There are other advantages to recycling as follows:

- Clearance under structures may be increased.
- Substandard ramps and tapers can be upgraded at the same time.
- No rutting problem would exist.
- Few traffic interruptions would exist.
- Subgrade problems can be corrected.
- No widening is necessary.
- Less aggregate is required.
- Portland cement concrete shoulders are an option.

A typical life-cycle cost analysis of one project that has been let to contract is as follows for recycled PCCP:

First cost pavement overlay = $386,129 per mi,
Service life = 25 years,
Salvaged value = assumed equal for all alternatives,
Annual maintenance = $1,000 per mi,
Interest rate = 10 percent,
Inflation rate = 6 percent,
Value of salvaged bituminous shoulder material = $73,000 per mile.

The cash flow diagram (cost per mile) is as follows:

Maintenance = $1,000 per year per mi,
$386,129 - $73,000 (salvaged bituminous shoulder) = $313,129,
Present worth = present cost + future cost x $[(1 + \text{inflation})/(1 + \text{interest})]^n$ = $313,129 + USPWF x $[(1 + .06)/(1 + .1)]^1$ = $331,129 + [$1,000 x (8.883) x (0.963664)] = $313,129 + $8,560 = $321,689,
where USPWF is the uniform series present worth factor.
Annual cost per mi = present worth (capital recovery factor at 10% - 25 yr) = $321,689 x (.11017) = $35,440.

A typical life-cycle cost analysis of one project that has been let to contract is as follows for hot bituminous pavement overlay:

First cost pavement overlay = $202,975 per mi,
First cost recycled overlay = $73,626 per mi,
Service life = 7 years,
Salvaged value = assumed equal for all alternatives,
Annual maintenance = $1,000 per mi,
Interest rate = 10 percent,
Inflation rate = 6 percent.

The cash flow diagram for 21 years is as follows:

0 (year)	7	14	21
$1,000	$1,000	$1,000	
(Maintenance)	(Maintenance)	(Maintenance)	
$202,975	$73,626	$73,626	

Present worth = annual cost of the USPWF at 10 percent - 6 years = $1,000 (4.355) = $4.355.

The equivalent cash flow diagram for 21 years is as follows:

0 (year)	7	14	21
$202,975	$73,626	$73,626	
+	+	+	
$4,355	$ 4,355	$ 4,355	

Present worth = present cost + future cost x $[(1 + \text{inflation})^n/(1 + \text{interest})]^n$ = $207,330 + 77,981 x $[(1 + .06)/(1 + .1)]^7$ + $[(1 + .06)/(1 + .1)]^4$ = 212,330 + 60,170 = 46,427 = $313,927 per mi.
Annual cost per mile = present worth (capital recovery factor - 10 percent - 21 years) = $313,927 x (.11562) = $36,296.

Three projects were let to contract in 1983 and were completed in 1984. The first project on Interstate 94 (I-94) was let to contract in July 1983 with the stipulation that a part of the project had to be completed in 1983. The reason for this was to have time over the winter to deal with any problems that developed in the process. Table 1 gives data from the three projects.

DESIGN DETAILS

Design specifications for Projects 1-3 are given in Table 2. Further design details are as follows:

TABLE 1 Project Costs

Project No.	Location	Length (ft)	Year Constructed	Total Cost Cost ($)	Cost per Mile ($)	9-in PCC[a] Removal ($)	8-in. VRPC[b] Removal ($)	Placing Recycled 10-in. PCC ($)	Placing Recycled 9-in PCC ($)
1	I-94-Route N.D. 30 to Cleveland	12.2	1983-1984	4,732,565	387,915	2.10/yd^2	–	10.15/yd^2	–
2	I-29 Hillsboro north and south	10.7	1984	4,520,159	442,444	–	4.37/yd^2	–	7.90/yd^2
3	I-94 Eckelson to Route N.D. 1	13.2	1984	5,193,014	393,410	4.00/yd^2	–	10.56/yd^2	–

[a] Portland cement concrete.
[b] Virgin recycled cement pavement.

TABLE 2 Design Specifications

	Project No. 1	Project No. 2	Project No. 3
Typical sections			
Inside shoulder width (ft	4	4	4
Total lane width (ft)	24	24	24
Outside shoulder width (ft)	10	10	10
Inside shoulder width (in.)	10	9	10
Slab thickness (in.)	10	9	10
Outside shoulder thickness (in.)	10	9	7
Surface finish	Tined	Tined	Tined
Transverse joint dowels	No	No	No
Rumble strips outside shoulder 100 ft c-c	Yes	Yes	Yes
Granular Subbase (in.)	4	–	4
Recycled hot bituminous base (in.)	–	2	–
Longitudinal joints			
Saw depth (in.)	2.75	2.5	2.75
Joint width (in.)	.125-.375	.125-.375	.125-.375
Tie bars (Number 5 x 2 ft x 6 in at 4 ft 0 in. c-c)	Yes	Yes	Yes
Hot pour joint sealer	Yes	Yes	Yes
Transverse joints			
Performed or sawed	Yes	Yes	Yes
Spacing staggered (ft)	14-18	12-16	14-16
Skew 1 to 6	Yes	Yes	Yes
Material requirements			
Concrete crushed to 1-in. maximum size	Yes	Yes	Yes
60 percent crushed PCC retained No. 4 sieve	Yes	Yes	Yes
Coarse and fine aggregate must meet standard material specifications	Yes	Yes	Yes
Recycled concrete mix proportions			
45 percent recycled coarse aggregate	Yes	Yes	Yes
15 percent recycled fine aggregate	Yes	–	–
15 percent virgin fine aggregate	Yes	–	–
30 percent virgin fine aggregate	–	Yes	Yes
517 lb cement per yd^3	Yes	Yes	Yes
31.6 gal maximum water content per yd^3	Yes	Yes	Yes

Special Provisions for Material

1. All salvaged material is the property of the state.
2. Recycled concrete aggregate must meet the regular concrete aggregate specifications of the North Dakota State Highway Department.

Construction Requirements

1. Bituminous shoulder material should be salvaged before PCC removal.
2. Contractor shall be required to conduct operations so as not to contaminate materials.
3. All bituminous patching and bituminous joint filler shall be removed prior to PCC pavement removal.
4. PCC concrete shall be crushed and split on Number 4 screen.
5. Crushing operation shall produce material that has 65 percent retained on Number 4 sieve. All foreign material and steel shall be removed.
6. All concrete shall be placed in accordance with normal department specifications.
7. Pavement surface riding quality: A California profilograph was used to check riding quality of the mainline pavements where the posted speed limit is 40 mph or greater. The specification requires a pavement surface with a profile having 0.7 in. or less of roughness per 0.1 mi to quality for full contract unit bid price per yd^2. For pavement having less than 0.5 in. per 0.1 mi, the contractor earns a bonus and for pavement having over 0.7 in. per mi, a penalty is applied. For pavement having over 0.9 in. per 0.1 mi, corrective action such as grinding or replacement is required. Unit bid price adjustments are as follows:

Less than 0.5 in. per 0.1 mi = $0.50 per yd^2 bonus
0.5 to 0.9 in. per 0.1 mi = bid price
0.9 to 1.0 per 0.1 mi = $2.00 per yd^2 deduction
1.0 to 1.1 per 0.1 mi = $3.00 per yd^2 deduction
Over 1.1 per 0.1 mi = corrective work

Construction Procedures

Project 1 was started in August 1983 and completed in 1984. All construction procedures used were those that are considered normal in North Dakota except for the breaking and removing of old concrete, and the crushing of old concrete to produce concrete aggregate.

Pavement Breaking

The first operation after the contract signing was pavement breaking. Three types of pavement breakers were tried and the unit that did the best job of breaking and crushing was a Resonant Pavement Breaker, which became the production unit. The rate of breakage is dependent on the stability of the subgrade, and since the subgrade in this case was very wet, production was considerably slower than originally anticipated. Considerable downtime was experienced because of machine failure, but considering this was a new machine, the mechanical problems had to be solved. The results were very good.

Cleaning Joints and Loading

Immediately following the breaking operation, labor crews hand-picked approximately 90 percent of the old joint filler material with the remaining 10 percent removed at the crushing plant. (The front-end loaders worked very well loading out the broken concrete, leaving little that needed to be hand-picked.)

Subgrade Preparation

The subgrade preparation was a normal operation except that the depth had to be increased because of the high moisture content. The plan called for 12 in. of scarification and recompaction, but it became necessary to work 24 in. in a number of areas and, in a few areas, lime was added to provide the necessary stability. The subgrade was disked to dry, laid with motor grader, compacted with a vibratory sheepsfoot roller, and trimmed to final section with a subgrade finisher.

Crushing Broken Portland Cement Concrete

The crushing plant consisted of one primary crusher, one cone crusher, and one screening plant to split the material on the Number 4 sieve. Both fractions met the department standard specifications for concrete aggregate except for the minus 200 material. The coarse aggregate for the last project let to contract in 1984 called for washing the recycled aggregate to remove the 200 material.

Absorption was much higher than expected for the recycled aggregate, running 4.5 percent for the coarse fraction and 10.3 percent for the fine fraction. Moisture contents were running 3.2 percent in the coarse fraction and 7.2 percent in the fine fraction. Apparently, the rate at which the aggregate absorbed water varied considerably from batch to batch making it difficult to control the water-cement ratio. Prewetting the aggregate on the conveyor while loading the mixer was tried, but was not helpful.

Mix Design

The plans specified that the concrete aggregate shall consist of 60-percent recycled coarse aggregate, 20-percent recycled fine aggregate, and 20-percent virgin fine aggregate. Originally, 5.5 bags per yd^3 of laboratory mixes produced strengths of 4,200 psi, but subsequent laboratory mix designs using all job materials produced strengths of only 3,500 psi, which is the pavement concrete design strength. Specifications allowed the contractor to replace 15 percent of the portland cement with fly-ash, and fly-ash was used in the laboratory mixes. Field data reveals considerable variation in 28-day-plus strengths between cylinders and cores taken from the pavement. Core samples taken in fall 1983 averaged approximately 2,900 psi, while samples taken from the same locations in July 1984 showed a strength gain of approximately 700 psi. Apparently, strength gain is slowed by the particular fly-ash used when temperatures drop in fall.

Subsequent projects allow the use of fly-ash, but at the state highway department's option. Fly-ash will not be used if design strengths cannot be obtained. In addition, all virgin fine aggregates will be used in the future, which will make it easier to obtain the design strengths in the field.

Mixing and Placing

Mixing was done in a conventional stationary plant and placed by slipform paver. The recycled mix is harsh and along with the problem of controlling the watercement ratio because of the high absorption rate of the recycled material, finishing was difficult. To improve the strength and finishing characteristics for the 1984 work, the mix design was changed to use 55 percent coarse and 45 percent fine aggregate with the fine fraction consisting of 20-percent recycled and 25-percent virgin. Results in 1984 were much improved over 1983.

Concrete Shoulders

The 4-ft inside shoulder was placed with the 24-ft of driving lanes and the 10-ft outside shoulder was placed in a separate operation. Conventional finishing methods were used and rumble strips were installed at 100-ft intervals. Most recent designs provide for 6-ft rumble strips spaced at 60-ft intervals.

Longitudinal and Transverse Joints

All joints were sawed with the transverse skewed at a ratio of 6 to 1 and randomly spaced between 14 and 18 ft. Longitudinal joints were filled with a rubberized hot pour sealing and preformed compression seals for the transverse joints. More recent projects are using skewed joints randomly spaced at 12, 13, 14, and 15 ft.

SUMMARY

In general, the recycling of PCC would appear to be a viable option to present-day overlay systems because of the following advantages:

1. It is a cost-effective procedure.
2. The procedure encourages material conservation.
3. The procedure provides an opportunity to correct design and structural deficiencies economically.
4. The number of construction cycles over the life of the pavement can be reduced.

At the present time, the most critical factor is the durability of the recycled concrete. There is no data at this time that would lead one to expect less durability than was developed by the original concrete with proper maintenance.

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