

MICHIGAN DEPARTMENT OF TRANSPORTATION RECYCLES CONCRETE FREEWAYS

Gerald J. McCarthy, Michigan Concrete Paving Association
William J. MacCreery, Michigan Department of Transportation

The Michigan Department of Transportation in 1983 and 1984 has completed four (4) major interstate projects providing for recycling existing concrete pavement into a new concrete roadway and shoulders. These projects were located on I-94 in Kalamazoo, Michigan, and on I-75 south of Detroit. The projects totalled approximately 27 miles in length and the average costs were \$850,000 per dual 24' roadway mile. The major state-of-the-art construction innovations are in breaking the existing concrete, removing the reinforcing steel and crushing the existing concrete into specification coarse and fine aggregates for use in the final concrete pavement. Special attention must be given to the type of materials used in, and the condition of, the existing concrete pavement. These facts will determine the final mix design and such items as the amount of fine aggregate that will be permitted to be used, the amount of water reducer, whether or not fly ash should be used, etc. Michigan is going to recycle several more sections of approximately 30 year old interstate highways in 1985. Life cycle cost analyses were completed on one specific project upon which bids will be taken in 1985. These analyses indicate that at a 5% discount rate for money and determining the major contract maintenance that would be needed for a 35 year life for each alternate, an approximate 15% cost advantage is attained in using concrete over the comparable bituminous design alternates which were used in this specific case.

The evidence is compelling that future highway construction work will involve rebuilding old roads, rather than building new. The volume of rebuilding to be done makes it urgent that new economical ways be found.

The benefits of recycling pavements have been publicly discussed during the past few years and have been as accepted as "mom and apple pie." Asphalt recycling has evolved into a widely accepted technique but concrete pavements, especially those with reinforcement, seem to have been more intimidating and have lagged behind in recycling potential. However, thousands of miles of concrete roadway lie begging

for treatment and the traditional overlay isn't always the best response. This is especially true for urban freeways where bridge clearances present problems for thick overlays or where a long term (35 years or longer) rehabilitation is desired. In these cases, some type of reconstruction is the best solution.

Background

Some of the enthusiasm on the part of MDOT arises as a result of success in recycling asphalt pavements. The first asphalt recycling research projects were done in-place in 1974 and hot-mix recycling was first done in 1977. In 1982, 43% of all our hot-mix contained some recycled materials and recycled hot-mix now averages about \$4.00 per ton less than virgin mix. With the success of asphalt recycling so striking, it is easy to see why our research engineers began planning a concrete recycling project.

We had planned to recycle a concrete pavement more than five years ago, but the recession forced a reordering of priorities. Thus, until 1983, MDOT's only field experience with concrete recycling was our Testing and Research Laboratories providing guidance on two projects done by city and county agencies, wherein distressed concrete pavements were crushed and used as aggregates in fresh concrete.

Selection of Projects

Our research engineers believed that sufficient laboratory and field work had been done to indicate that quality concrete could be obtained using recycled aggregates. The major problem was to develop specifications and production methods for economically and reliably getting the desired product. Therefore, one of the criteria in selecting candidate projects was size; a project large enough to warrant a contractor using the best equipment and methods available.

By selecting Interstate projects, the State could recycle the projects with its available matching funds, and the Federal Government will provide an additional 5% in Federal aid for recycled

concrete paving projects. Thus, for the Department's first project in 1983, a 5.7 mile section of I-94 near Battle Creek was selected. This dual 24 foot roadway section of I-94 was constructed in 1958. The original design provided for transverse joints with dowel-bar load transfer constructed at 99 foot intervals. The pavement was 9 inches thick and reinforced with welded mesh and expanded metal. Transverse joint problems, including blow-ups, were numerous and classic manifestations of D-cracking were also widespread. Many slabs had cracks that were open and faulted. Ride quality, as measured by our Research Laboratory using the MDOT Rapid Travel Profilometer, was poor. There were some bituminous patches existing along the center line and at transverse cracks and joints.

Total average daily traffic for both directions in 1980 was 28,000, with 23% of the vehicles classed as commercial.

Three additional projects were selected and re-constructed in 1984. One of the projects was on I-94 near Paw Paw, Michigan, and had very similar characteristics to the project completed in 1983. Two additional projects on I-75 south of Detroit also were constructed in 1984. These projects had ADT's near 40,000 with 30% commercial and were existing 6 lane freeways.

Specifications and Testing

Excepting the requirement for using crushed concrete as aggregate for the new mix, Standard Specifications were used for controlling the work. This meant, among other things, that 28 day minimum compressive strengths for the pavement would be expected to be at least 3,500 psi and for the shoulders, 3,000 psi.

A copy of the specifications for the 1983 project used for controlling the crushed concrete aggregates is attached as Appendix A. Because the tests made on the original virgin coarse aggregate had shown it to have poor durability and the existing slabs showed extensive D-cracking, MDOT's Testing and Research Laboratories decided to reduce the allowable maximum coarse aggregate size; the propensity of aggregate to manifest D-cracking is diminished by reducing particle size. Recycled coarse aggregate was required to have 95 to 100% passing the 3/4 inch sieve, rather than the 95 to 100% passing the 1 inch sieve, specified for virgin aggregate. The 1984 projects permitted 95 to 100% passing the 1 inch sieve.

In addition to the usual job control testing, additional information was wanted to thoroughly evaluate strength and durability of the recycled mix. Table 1 shows the sample plan for obtaining information for evaluating the research study. Durability tests were made following the provisions of ASTM C-666(B); that is, where water-soaked beams were frozen in air and thawed in water through 3,000 cycles. Both elongation and sonic modulus were used to evaluate changes in the concrete.

Table 1.

Number of Sampling Sites	Type of Sample	Number Per Site	Purpose
One each mile of 24 foot pavement	6 x 6 x 20" beams	6	Flexural strength testing at 7, 28 and 90 days. Two beams per test.
One each mile of 24 foot pavement	6 x 12" cylinders	6	Compressive strength testing at 7, 28 and 90 days. Two cylinders per test.
One each mile of 24 foot pavement	3 x 4 x 16" beams	6	Durability testing.

Traffic Control

For the 1983 and 1984 projects, except the northerly I-75 project where southbound traffic was directed to another State trunkline, all construction work was done on closed-off roadway sections while the other roadway carried two-way traffic. At the request of the contractor, a mid-job crossover was added to the I-94 projects. Originally, crossovers were to be built only on each end of the project. With the mid-job crossover, the work could be sequenced in quarters rather than halves. According to the contractor, four to six weeks were saved through this added flexibility.

Pre-cast concrete median barriers were used to help guide traffic at the crossovers. Throughout the remainder of the job, plastic reflectorized delineators, spaced 100 feet apart, were used to separate the two-way traffic. Such delineators were mounted on plastic posts fit into bases that had been cemented in place. For night delineation, reflectorized buttons were cemented to the pavement and supplemented the posts. At job-end crossovers, street lights were installed to add to the safety of vehicles transitioning from a dual to a single roadway.

The southerly I-75 project attempted to carry 2 lanes each direction on a 3 lane pavement, plus the shoulder. After a few accidents, it was determined to run 1 lane of traffic each direction which, because of sheer volume, slowed the traffic down and in fact, backed the traffic up during peak hours. However, it resulted in a safer situation.

Construction Methods

For the 1983 project on I-94, Eisenhour Construction Company, headquartered in Aurora, Colorado, was the low bidder, contracting to do the 5.7 mile job for \$4.47 million. For this \$784,000 per mile, Michigan motorists received a new dual 24 foot roadway with concrete shoulders replacing the old bituminous ones and with 10 inch slabs replacing the old 9 inch.

A subcontractor, Molesworth Contracting Company, Port Huron, Michigan, did the pavement removal and crushing. Two 18,000 ft-lb diesel pile hammers, each mounted through the bed of a scraper, were used to break the existing pavement into chunks 12 to 15 inches wide. Next, a backhoe pulled a 30 inch curved pointed, hard-steel picker tooth ("rhino-horn")

through the chunks to remove as much reinforcing mat as practical. A front-end loader shook out more mesh and windrowed the rubble. More mesh was removed during loading of the rubble into trucks by more shaking and by dropping the material to the ground.

Rubble was stockpiled and then crushed to size using a jaw crusher followed by two-roller crushers.

Crushing did not go smoothly and production was slow. Therefore, the contractor began slip-form paving, using a mix consisting entirely of virgin aggregates. When enough crushed concrete was stockpiled, the contractor began using 100% recycled coarse aggregate with 20% of the total fine aggregate being recycled. The proportion of fine aggregate that consisted of crushed concrete was increased to 50%, then to 75%, and even to 100% for a small quantity.

5 ounces of water reducer were used in all the pavement and fly ash was used in about 22% of the concrete. Where fly ash was used, it was 5.1 sacks of cement and 72 lbs of fly ash per cubic yard.

For the 1984 project on I-94, Eisenhower Construction Company was the low bidder, contracting to do the 8.96 mile job for \$7.99 million or \$888,765 per mile. The Michigan Department of Transportation added a \$100,000 per mile in costs to this project by adding a new 4 inch open graded draining aggregate and continuous edge drains, so the costs of the basic recycling were almost the same on the 1983 project.

Recycling Concrete Pavement On I-94, West of Kalamazoo, Michigan

1984 Project on I-94

The project was 8.96 miles in length, consisting of two (2) 24 foot pavements.

The subcontractor for crushing (Spartan Aggregate) was responsible for actually processing the broken concrete into commercial aggregate and started approximately three (3) weeks before the paver started. He finished approximately two (2) weeks before the paver finished. This was made possible because by dividing the job into quarters, the main 24 foot pavement which takes a considerable amount of coarse aggregate was completed, and then the contractor completed the shoulders (which were tapered 10"-6" thick), which required considerably less coarse aggregate and allowed the subcontractor responsible for processing the aggregate to catch up and provide a stockpile of coarse aggregate for the paving contractor to use when he started the main roadway again.

On recycling projects, it is absolutely necessary to have complete coordination between the processing of the coarse aggregate and the production of the concrete paver. For example, on this particular job, the capacity of the gravel plant was approximately 150 tons per hour, while the paver would use between 3,000 and 3,500 tons of coarse aggregate per day. The aggregate processing plant is the key item in a recycling project.

This particular project used a primary and secondary system for breaking up the concrete. The primary crusher jaw had a 21" by 42" opening, and worked very well in removing 95% of the reinforcing steel from the concrete pavement. The equipment used at the aggregate processing plant is listed in Appendix B; however, it is interesting to note that the estimated cost for this crushing plant would be approximately \$1.5 million. The total labor required at the plant consisted of five (5) persons: a dozer operator, a loader operator, one person assisting in picking the steel, one person running the primary and a foreman-mechanic type person on each shift.

The material used in the existing concrete pavement was a 4A limestone and a 10A natural aggregate, with a 2NS sand and 5.5 sacks of cement per yard. The material, as it was re-processed through the plant, resulted in 85% of a Michigan 6A material, with 100% passing the 1½" and 90% passing the 1". This left 15% of the recycled material in fines passing the 3/8".

Actually, it is interesting to note that after grinding up and processing a 24' wide, 9" thick concrete pavement, there was enough coarse aggregate to construct a new 24' wide, 10" thick concrete pavement, with a 9' concrete shoulder and a 5' concrete shoulder.

To date, none of the recycling jobs in Michigan have resulted in having any value to the left-over temperature reinforcing steel that had been in the concrete and in fact, the material is a detriment and must be hauled to a dump site. It also bulks considerably, so the truckloads are not very efficiently loaded.

In the plant production itself, the primary jaw reduced the material to a 4" minimum diameter. As previously stated, this separated more than 95% of the steel from the concrete. The large pieces of steel were thrown off the belt by hand. Those that got by were taken off by two electro magnets. The material, after it left the primary jaws and passed under an electro magnet, went through a feeder and into a surge pit, which resulted in a metered uniform flow to the secondary.

In this particular area of Michigan, the coarse aggregate would have cost, depending upon the exact haul distance, between \$7.00 and \$9.00 per ton at the job site. The contractor has estimated somewhere between a 50% and 65% savings by using the recycled material. We also feel that there is a good chance that the recycled coarse aggregate will be more durable than the original aggregate. The reasons for this would be all of the freeze/thaws cycles that the existing pavement has gone through, in addition to the fact that the concrete has an ultimate set and many of the pieces of new aggregate sheered in the existing aggregate as compared to sheer in the mortar. Therefore, the mortar is stronger than some of the existing aggregate. Fine aggregate would have cost between \$4.00 and \$5.00 per ton in this area of Michigan. Cores on the new concrete indicate strengths of 3,600 to 5,800 psi at 28 days.

The secondary crusher was a set of three (3) rollers, with the first reducing the size down to approximately 2" and the third down to approximately 1-1/8". There was little or no recirculation and practically no evidence of any pieces of steel left in the finished product. The aggregate plant was run one shift for the first half of the job and two shifts for the second half of the job to coordinate with the production of the paver. About two miles of 9", 24' pavement was crushed and screened per week on two shifts.

Two Recycling Projects on I-75, South of Detroit

The first project, 6.7 miles of dual 36' roadway, is located approximately in Woodhaven, Michigan. The contractor is Midwest Bridge Company from Williamston, Michigan, with a low bid of \$9.8 million. The second project is located 6 miles of one 36' roadway, further south in Monroe County. The contractor for this project is John Carlo, Inc., from Mt. Clemens, Michigan, and the low bid was \$4.8 million. The Levy Company was the subcontractor for crushing the aggregate on both jobs.

On the northerly job, southbound traffic of I-75 was re-routed for the duration of the job to an adjacent State trunkline with a minimum type adverse distance. There has been no traffic handling problems on this particular project, but the public relations problem has resulted in complaints from adjacent businesses that have been deprived from the southbound traffic at the interchanges in this approximately seven mile long recycling project. The project was coordinated with the local governmental agencies and the elected local officials prior to taking bids on the project, which helped to alleviate but not eliminate the problem of detouring traffic.

In addition to this, the contractor set up his plant at a site that was not zoned for concrete plant or concrete crushing operations and this resulted in a court action which finally was solved by the contractor agreeing to do certain things for the adjacent property owners and residential homes, such as wash their homes when the project is completed, provide air conditioning, provide dust control, only work certain hours with operations that provided a lot of noise, etc.

The recycling job to the south provided only for recycling the northbound roadway, and two-way traffic was maintained on the southbound roadway. At the beginning, through the use of a shoulder, they tried to carry two lanes of traffic in each direction. Several accidents happened because of the inability to slow down the traffic because of the large amount of commercial traffic and no refuge-shoulder areas. This particular section of I-75 carries in the vicinity of 50,000 per day, with 30% of the vehicles being commercial. This is the commercial vehicle traffic between Toledo and Detroit.

The primary difference on these projects as compared to the I-94 project was the use of an impact crusher-hammer mill, which is an entirely different method of breaking up the existing concrete. The existing aggregate in the northerly 36' concrete pavement was a slag aggregate, and in the southern project was limestone. The impact crusher-hammer mill was specially built for a project such as this, and is extremely portable and could be operated running down a grade. It is even designed to operate and go underneath bridges. This is a one-sequence type of operation and does not require a secondary. Thus, the area for the actual plant operation is considerably less than the primary/secondary process.

The end result of this material being ground up is a much higher capacity than the plant previously discussed. Approximately 250 tons per hour is the capacity of this type of an impact crusher. However, the end result is 65% 6A coarse aggregate and 35% sand. The method for breaking up the material in the field was a diesel drop bar, somewhat similar to that used on the other jobs, had a brand name of "Thumper", and was pulled with a D9. The capacity of the removal from the street was approximately 500 square yards per hour, and the materials picked up using a backhoe probably resulted in more fines being carried back to the plant than would a front end loader type operation.

The crushed material, when it leaves the crusher, comes out onto a magnetic belt which picks up the steel and eliminated almost 100% of the steel in this stage of the operation. There was no hand-picking required. This also would have the advantage of picking up any aggregates with an iron content, should it be desirable to remove them from the mix.

In this particular job, the economics appear to have been about even as compared to using virgin aggregates or using the recycled material, and this is also considering that 50% of the recycled sand can be used in the final mix. On the southern-most job, which was limestone aggregate, the Highway Department

has determined that rather than permitting a use of 50% of the recycled sand, they are going to only permit 25% and are increasing from 5 to 8 ounces of water reducer. However, 50% of crushed fines will be permitted in the shoulder.

On the northern project, to try to eliminate a strength problem in the cores taken on the first half of the job, the contractor was permitted to continue to use 50% recycled sand; however, he switched to 1A-P Cement and doubled the water reducer from 5 to 10 ounces.

Results

Test results have shown the concrete to have very high durability with respect to freeze-thaw cycling. Tests showed some samples to have lower strengths than desired; primarily where a high proportion of crushed concrete was used in the concrete fines. MDOT's Research Laboratory is completing tests to determine why that happened. Also, compressive strengths of concrete made at the site proved greater than cores taken from the pavement on 2 of the 4 jobs. One possible reason, although not obvious at the time, is that consolidation in the pavement may not have been as thorough as in the cylinders. Or, perhaps the cylinders' higher strengths reflected a different method of curing.

Life cycle cost studies completed by the Michigan Department of Transportation for these high volume heavy commercial vehicle usage free-ways indicate an advantage to the recycled concrete process versus other design-construction processes or materials.

One project on which life cycle costing was used in 1984 for a project to be bid in 1985 was reconstruction of approximately eight (8) miles of I-94, east of Kalamazoo, Michigan. Three options were compared:

1. Concrete Recycling

10 RJCP 41' Joints
4" OGDC
10" +/- Existing Sand
4" OGDC Underdrain

2. Concrete Removal - New Bituminous

130 PSY #1500 T
140 PSY #1500 L
1210 PSY #700 B
4" Agg Base
10" Existing Sand

3. Bituminous Overlay

130 PSY #1500 T
140 PSY #1500 L
770 PSY #700 B

These designs were based on 20 designs with 35 year life. Joint and crack filling were included in life costs for all three alternatives. Alternate #2 had major rehabilitation scheduled at 15 years and alternate #3 had two major rehabilitations at 12 and 25 years.

Present value costs for the three alternate designs were computed using three discount rates: 5, 7 and 10 percent. Results are tabulated as follows on a typical one mile segment of 24' wide pavement:

Table 2. Present Value of Lifetime Costs,
Single 24' Cost/Mile

Alternate/First Cost	5%	7%	10%
Recycled Concrete \$340,602	\$344,301	\$344,039	\$343,156
Bituminous Alternate \$408,962	454,766	446,065	435,297
Bituminous Overlay \$288,538	397,066	371,121	344,756

The difference between the bituminous overlay and concrete recycling design is sensitive to the discount rate. At 10 percent, the present value costs of those two options are about equal while lesser discount rates favor concrete recycling.

The results of two years of major concrete recycling projects in Michigan indicate the problems with breaking up the concrete, removing the temperature steel at the plant and processing the aggregate have not been a major consideration or problem. However, the mix design of new concrete is still a critical item and all of the variables must be taken into account. These are: the type of aggregate used in original pavement; condition of existing pavement (i.e., D cracking, etc.); amount of recycled fines to be permitted in the new concrete; use fly ash; and the amount of water reducer-super plasticizer in the mix.

The recycling process, as used on these projects, must be considered successful. Although problems were encountered in the operation, they were not insurmountable.

NOTE: Any appendix mentioned herein may be obtained by contacting Mr. Gerald J. McCarthy of the Michigan Concrete Paving Association