Recycling of Concrete Freeways by Michigan Department of Transportation

GERALD J. McCARTHY

ABSTRACT

Presented in this paper are the design and construction history of four major concrete recycling projects completed in Michigan in 1983 and 1984. These projects totaled approximately $27 million in construction costs and were completed on I-94 in western Michigan and I-75 south of Detroit. The criteria for design, the construction methods, the equipment used, and the utilization of materials are discussed. Two areas are discussed in detail: (a) The type of equipment used to break up the concrete and process the broken concrete, and (b) the mix design (for utilization of the broken-up concrete aggregate) used for the finished portland cement concrete pavement.

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 methods be found.

The benefits of recycling pavements have been publicly discussed during the past few years and have been readily accepted. 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 is not 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 the Michigan Department of Transportation (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 percent 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 being so striking, it is easy to see why the MDOT research engineers began planning a concrete recycling project.

The researchers had planned to recycle a concrete pavement more than 5 years ago, but the national economic recession forced a reordering of priorities; consequently, MDOT's only field experience with concrete recycling, until 1983, was the MDOT 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

MDOT's research engineers believed that sufficient laboratory and fieldwork had been conducted to indicate that quality concrete could be obtained by 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's size had to be large enough to warrant use of a contractor and 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 would provide an additional 5 percent in federal aid for recycled concrete paving projects. Thus, for the Department's first project in 1983, a 5.7-mi section of I-94 near Battle Creek was selected. This dual 24-ft roadway section of I-94 was constructed in 1958. The original design provided for transverse joints with dowel-bar load transfer constructed at 99-ft intervals. The pavement was 9-in. 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 the MDOT 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. The total average daily traffic (ADT) for both directions of the roadway in 1980 was 28,000, with 23 percent of the vehicles classified as commercial.

Three additional projects were selected and reconstructed in 1984. One of the projects was on I-94 near Paw Paw, Michigan, and had characteristics that were similar to the project completed in 1983. Two additional projects on I-75 south of Detroit were also completed in 1984. These projects had ADT counts near 40,000 with 30 percent of the vehicles classified as 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.

The MDOT specifications for controlling the crushed concrete aggregates was used for the 1983 project (1). 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 95-100 percent passing the .75-in. sieve, rather than the 95-100 percent passing the 1-in. sieve specified for virgin aggregate. The 1984 projects permitted 95 to 100 percent passing the 1-in. sieve.

In addition to the usual job control testing, additional information was needed to thoroughly evaluate strength and durability of the recycled mix. Table 1 gives the sampling 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 Sampling Plan

Number of Sampling Sites	Type of Sample	Number of Samples per Site	Purpose
1/mi of 24-ft pavement	6 x 6 x 20 in. beams	6	Flexural strength testing at 7, 28, and 90 days. Two beams per test.
1/mi of 24-ft pavement	6 x 12 in. cylinders	6	Compressive strength testing at 7, 28, and 90 days. Two cylinders per test.
1/mi of 24-ft pavement	3 x 4 x 16 in. 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 performed 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, 4-6 weeks were saved through this added flexibility.

Precast concrete median barriers were used to help guide traffic at the crossovers. Throughout the remainder of the job, plastic reflectorized delineators, spaced 100 ft apart, were used to separate the two-way traffic. Such delineators were mounted on plastic posts fit into bases that had been cemented into place. For night delineations, reflectorized buttons were cemented to the pavement to supplement the posts. At job-end crossovers, street lights were installed to add to the safety of vehicles making the transition 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 in each direction which, because of shear 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-mi job for $4.47 million. For this $784,000 per mile, Michigan motorists received a new dual 24-ft roadway with concrete shoulders replacing the old bituminous ones and with 10-in. slabs replacing the old 9-in. ones.

A subcontractor, Molesworth Contracting Company, headquartered in 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 12-15 in. wide. Next, a backhoe pulled a 30-in., curved, pointed, hard-steel picker tooth ("rhinohorn") 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. The rubble was then stockpiled and crushed to size using a jaw crusher followed by two-roller crushers.

Crushing did not go smoothly, however, 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-percent, recycled coarse aggregate with 20 percent of the total fine aggregate being recycled. The proportion of fine aggregate that consisted of crushed concrete was increased to 50 percent, then to 75 percent, and even to 100 percent for a small quantity.

Five oz. of water reducer was used in all the pavement, and fly ash was used in about 22 percent of the concrete. Where fly ash was used, it was 5.1 sacks of cement and 72 lb of fly ash per yd³.

For the 1984 project on I-94, Eisenhour Construction Company was again the low bidder, contracting to do the 8.96-mi job for $7.99 million or $888,765 per mile. The Michigan Department of Transportation added $100,000 per mile in costs to this project by adding a new 4-in. 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

The project was 8.96 mi in length, consisting of two 24-ft pavements.

The subcontractor for crushing (spartan aggregate) was responsible for actually processing the broken concrete into commercial aggregate, having started approximately 3 weeks before the paver started and finishing approximately 2 weeks before the paver finished. By dividing the job into quarters, it was possible to complete the main 24-ft pavement, which takes a considerable amount of coarse aggregate. Then, the contractor was able to complete the shoulders (tapered 10-ft, 6-in. 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 for the remaining work on the main roadway.

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 t per hr, while the paver would use between

3,000 and 3,500 t 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-in. x 42-in. opening, and worked well in removing 95 percent of the reinforcing steel from the concrete pavement. The equipment used at the aggregate processing plant is given in the following table.

Crushing Equipment	Cost ($ thousand)
1 21-in. x 42-in. Hewett Robbins Primary	250
5 50-ft Conveyors	150
2 Stacking Conveyors	150
1 42-in. Vibrating Feeder	30
4,339 Secondary and Screen + Power Unit	350
350-kW Generator	60
1 6-yd³ Loader	220
2 Dings Magnets	40
1 Stockpiling Crawler Dozer	200
Total	1,450

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 persons as follows:

- Bulldozer operator,
- Loader operator,
- Person assisting in picking the steel,
- Person running the primary, and
- 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 yd. The material, as it was reprocessed through the plant, resulted in 85 percent of a Michigan 6A material, with 100 percent passing the 1.25-in. sieve and 90 percent passing the 1-in. sieve. This left 15 percent of the recycled material in fines passing the .375-in. sieve. (Actually, it is interesting to note that after grinding up and processing a 24-ft wide, 9-in. thick concrete pavement, there was enough coarse aggregate left to construct a new 24-ft wide, 10-in. thick concrete pavement with a 9-ft concrete shoulder and a 5-ft 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 efficiently loaded.

In the plant production itself, the primary jaw reduced the material to a 4-in. minimum diameter. As previously stated, this separated more than 95 percent 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 electromagnets. 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 on the exact haul distance, between $7.00 and $9.00 per ton at the job site. The contractor has estimated somewhere between a 50 percent and 65 percent savings by using the recycled material. It was also felt that there was a good chance that the recycled coarse aggregate would be more durable than the original aggregate. The reason for this would be all of the freeze-thaw 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. Core measurements on the new concrete indicate strengths of 3,600 to 5,800 psi at 28 days.

The secondary crusher was a set of three rollers, with the first reducing the size down to approximately 2 in. and the third down to approximately 1.125-in. 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 one-half of the job and two shifts for the second one-half of the job to coordinate with the production of the paver. Approximately 2 mi of 9-in., 24-ft pavement was crushed and screened per week on two shifts.

TWO RECYCLING PROJECTS ON I-75, SOUTH OF DETROIT

The first project, 6.7 mi of dual 36-ft 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 6 mi of 1 36-ft roadway, located further south in Monroe County. The contractor for this project is John Carlo, Incorporated, 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 have 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 7-mi long recycling project. The project was coordinated with the local government agencies and the elected local officials before taking bids on the project, which helped to alleviate--but not eliminate--the problem of detouring traffic.

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

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, the attempt was made to carry two lanes of traffic in each direction. Several accidents occurred that were attributed to the inability to slow down the traffic caused, in turn, by the large amount of commercial vehicles and the absence of refuge-shoulder areas. This particular section of I-75 carries in the vicinity of 50,000 vehicles per day, with 30 percent being commercial vehicles traveling 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-ft 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, 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 was a much higher capacity than the plant previously discussed. Approximately 250 t per hr is the capacity of this type of an impact crusher. However, the end result is 65 percent 6A coarse aggregate and 35 percent sand. The method for breaking up the material in the field was a diesel drop bar, which was somewhat similar to that used on the other jobs, had a brand name of "Thumper," and was pulled with a D9 engine. The capacity of the removal from the street was approximately 500 yd^2 per hr, 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 that picks up the steel, and eliminates almost 100 percent of it. No hand-picking was 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, also.

In this particular job, the economics appear to have been approximately even as compared to using virgin aggregates or using the recycled material, and this is also considering that 50 percent of the recycled sand can be used in the final mix. On the southern-most job, which was limestone aggregate, the highway department determined that rather than permitting a use of 50 percent of the recycled sand, only 25 percent would be permitted and the water reducer would be increased from 5 to 8 oz; however, 50 percent of crushed fines would be permitted in the shoulder.

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

RESULTS

Test results have shown the concrete to have high durability with respect to freeze-thaw cycling. Tests showed that some samples 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 for this, although it was not obvious at the time, was 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 MDOT for these high-volume, heavy commercial-vehicle-usage freeways indicate an advantage to the recycled concrete process versus other design-construction processes or materials.

The results of 2 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: (a) the type of aggregate used in original pavement; (b) the condition of the existing pavement (i.e., D-cracking); (c) the amount of recycled fines to be permitted in the new concrete; (d) the use of fly ash; and (e) 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.

SUMMARY

Based on construction costs, state-of-the-art improvements in equipment, and the excellent end product, it is safe to assume that expanded use will be seen on a national basis of the process of recycling old concrete for use in the new pavement structure. In fact, Michigan plans five more major interstate concrete recycling projects in 1985 as part of rebuilding their transportation infrastructure.

REFERENCES

1. Standard Specifications. Section 7, Special Provision for Pavement Concrete Using Crushed Concrete as Coarse Aggregate, Michigan Department of Transportation, Lansing, Jan. 1983.

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