CONCRETE RECYCLING

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One of the more interesting new concepts that is gaining interest throughout the country is that of recycling old concrete pavements for aggregate in new construction. Recycling is consistent with the American Concrete Paving Association (ACPA) econocrete concept, which encourages the use of recycled concrete for subbases, composite pavements, and full-depth pavements. The Federal Highway Administration has endorsed this program and at the present time has a national evaluation program on the recycling of old concrete pavements.

Research by the U.S. Army Corps of Engineers indicates that the recycling of an old concrete pavement can actually enhance or improve the original aggregate, thus providing longer life than was possibly attained in the initial pavement. The depletion of supplies of high-grade concrete aggregates in certain regions, the need for better methods of solid-waste disposal, and energy conservation efforts have led to this accelerating interest in recycled concrete. Recycling of old concrete is feasible and should be considered whenever good aggregates are not available locally or when aggregate costs are excessive or where the costs of removing and wasting the old pavement are in excess of what the cost would be for recycling that material for new aggregate.

In 1970, aggregates produced in the United States totaled 1.8 billion tons. The highway industry used 47 percent of this, or approximately 800 million tons. It is estimated that, by 1985, production of aggregates will reach 4 billion tons/year and that highways will use 50 percent or 2 billion tons/year.

Of the various materials used in highway construction, aggregates constitute one of the major elements of cost—between 21 and 30 percent of the cost of all materials and supplies and between 10 and 14 percent of the total construction cost (excluding the cost of right-of-way and engineering).

Recycled concrete can be used as an aggregate base or subbase for pavement, or these bases can be cement treated with soil-cement techniques. It can be used in econocrete subbases (lean concrete) by using concrete mixing plants and slipform pavers. Recycled concrete can also be used as aggregates in new concrete pavement if tests of new concrete made with crushed-concrete aggregate indicate acceptable strength and durability.

Recycled Concrete Research

Laboratory research on recycled concrete was carried on in Europe and the USSR shortly after World War II and more recently by the U.S. Army Corps of Engineers Waterways Experiment Station in Vicksburg, Mississippi, and the Iowa Department of Transportation.

In European countries during the late 1940s and early 1950s, considerable amounts of debris produced by bombing and shelling were used in rebuilding urban areas after World War II. The majority of this work used bricks and material identified as rubble for aggregates during the rebuilding process.

A. D. Buck of the Waterways Experiment Station (WES) has reported on comparisons between some 1946 test results on waste concrete from the USSR and results of tests made at WES. Where comparisons are possible, the agreement between the Russian results and the present work is excellent.

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USSR	WES
New concrete was no better than the waste concrete that was used as aggregate.	No comparison possible. Waste concrete used was of good quality.
The use of concrete fines as sand required an undue increase in the cement content of a mixture.	Mixture 3 was the only one that used concrete fines as sand. It required 47 lb/yd^3 more cement than mixtures 1 or 2 (natural sand). This is not regarded as excessive.
Compressible strengths were lower when concrete was used as aggregate.	Concrete containing waste concrete as coarse aggregate ranged from 300 to 1100 lbf/in^2 lower in compressive strength than corresponding control mixtures.
The specific gravity of crushed concrete aggregate tended to be lower than that of natural aggregates.	Work confirms this; in addition, the absorption tends to be high.
The cement factor could be lowered if the crushed concrete aggregate was moistened, not saturated, before use.	The coarse aggregates were inundated; the fine aggregates had moisture added 24 h before mixing the concrete to satisfy their absorption.
For equal compressive strengths, the flexural strength of mixtures with crushed concrete aggregate was higher than that of control mixtures.	No flexural tests were made.
Mixtures with crushed concrete aggregate stiffened rapidly but consolidated well with vibration.	No such difference was noted with crushed concrete as coarse aggregate only, but mixture 3 (all aggregate crushed concrete) was stiffer than the control, even though it appeared to be wet.

The research by Buck showed that the mixtures containing crushed concrete as fine aggregate required more cement and were slightly stiffer. However, the increased cost for additional cement should be partly or wholly compensated by the advantage to be gained by using the crushed concrete fine aggregate instead of having to dispose of it. Blending with natural sand, modification of mixture proportions, or use of water-reducing admixtures might permit lowering the cement content and improve the workability when one is using crushed concrete as sand.

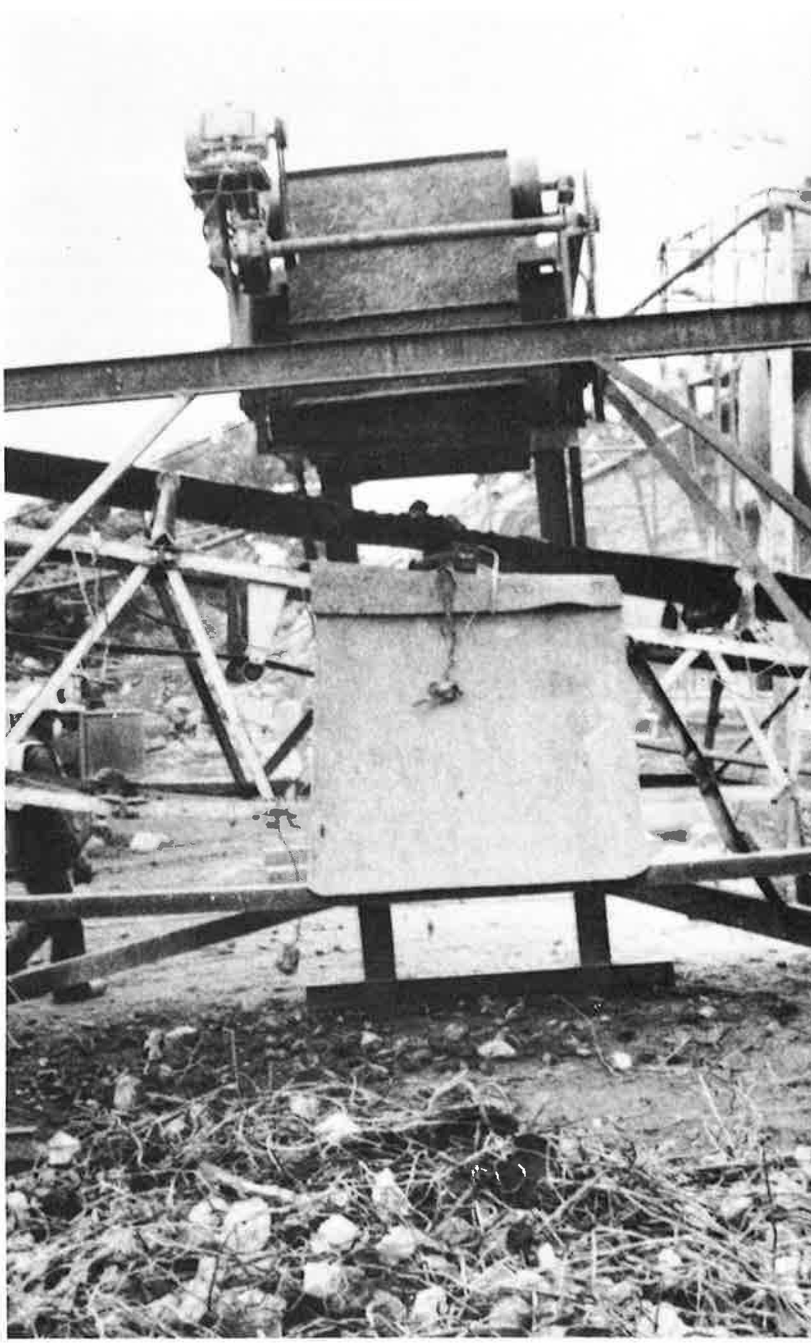
The reasons for the lower compressive strengths of mixtures containing crushed concrete as coarse aggregate (compared with mixtures containing only natural aggregates) were not known at that time. Several explanations were considered and rejected or could not be proved.

The improved frost resistance of mixtures 2 and 3, which contained concrete as aggregate, compared with the control mixture was substantial. It is thought that this improvement may have occurred because the old mortar, which coats many of the crushed concrete particles, effectively seals off the voids in the frost-susceptible porous chert particles and prevents them from taking up enough moisture to be damaged by freezing.

Comparison of data for test mixtures containing recycled waste concrete as coarse aggregate with data for control mixtures shows the following:

1. There were no unusual problems in mixing or working with the test mixtures.
2. The test mixtures have compressive strengths that are about 300-1200 lbf/in^2 lower than the corresponding control mixtures at all ages tested through 180 days.
3. The resistance to accelerated freezing and thawing is greatly improved when the waste concrete originally contained chert-gravel coarse aggregate.
4. The resistance to freezing and thawing is a little lower but essentially comparable when the waste concrete originally contained limestone coarse aggregate.

Electromagnet removes steel mesh from conveyor belt before concrete enters crusher.



5. Volume changes in response to temperature changes or to continued exposure to moisture at a constant temperature were similar and normal.

The findings of mixture 3, which contained waste chert-gravel concrete as coarse and fine aggregate, were generally like the control mixtures except that cement demand was somewhat higher and workability was slightly lower than for the control mixture.

The results of Buck's work indicate many reasons in favor of the use of crushed discarded concrete pavements as concrete aggregates. If additional work indicates that the lower concrete strengths obtained with waste concrete as coarse aggregate are not a serious problem, then all existing specifications should be revised to permit and encourage the use of crushed pavement of similar concrete as concrete coarse aggregate.

If, in addition, the mild undesirable effects of waste concrete fine aggregate on workability and cement content of concrete mixtures can be eliminated or reduced or tolerated, then the use of this material should also be encouraged by specification revisions.

Research by Stamatia Frondistou-Yannas and Taichi Itoh of the Massachusetts Institute of Technology indicates that recycled concrete can be used not only as pavement base material but also as a substitute for natural aggregate in concrete.

Recycled concrete has been reported to have higher flexural strength than conventional concrete of equal crushing strength while possessing freeze-thaw resistance and volume stability under thermal and moisture changes that compare favorably with typical values of these properties for conventional concrete, while also being equally workable with the latter.

These favorable results have been obtained when "clean" pieces of concrete debris have been used to replace natural aggregate. Such clean concrete, usually the product of highway demolition, is not contaminated with gypsum, wood, plastics, glass, metals, or brick. However, most concrete debris is generated during demolition of buildings and is mixed with these contaminants, the most undesirable of which are wood and gypsum. Wood is harmful because it is soft and subject to large volume changes in drying and wetting; gypsum enters into undesirable chemical reactions with cement. Since gypsum (in forms found in construction) and wood have lower densities than recycled concrete, they can be easily removed by means of equipment now used by the sand and gravel industry to aggregate beneficiation. Whether one starts with contaminated or clean concrete debris, one can therefore always end up with clean recycled aggregate and use it to produce recycled concrete that performs satisfactorily.

Pioneer Recycling Projects

In the summer of 1976, and again in the summer of 1977, the two roadways of a freeway north of Paris, France, received extensive rehabilitation. The work involved complex traffic-handling problems, removal of the existing outer-two concrete lanes of the three-lane roadbeds, removal of the cement-treated base, and stabilization of the underlying foundation soils. Reconstruction involved recycling of the old concrete pavement for use in the new lean concrete base layer and in the new concrete pavement. This entire 5.3 miles of reconstruction of the southbound lane was completed in seven weeks. This pavement carries the heaviest traffic in France—150 000 vehicles/day, more than 20 percent of which is trucks.

The pavement was broken up by two machines that drop 7-ton weights from a height of 7 ft, hitting the slab every 16 in. Average production was 12 000 yards^2/day. The recycled concrete aggregate was mixed with 269 lb of cement and 118 lb of fly ash per cubic yard to make the lean concrete subbase. The subbase and pavement were placed with a slipform paver.

The northbound lane was similarly reconstructed in the summer of 1977. The experience from the 1976 project permitted modifications that accelerated the operations in 1977. In 1977 the shoulders were constructed of porous concrete composed of recycled concrete aggregate with nothing below a 5-mm size and 253 lb/yard^3 of cement. The French state that this project opened the door to a new era of technology for concrete roads.

One of the early examples of recycled pavement is on US-66 in Illinois. During World War II, construction of four-lane highways was not permitted. However, inadequate roads could be modernized. Illinois built a new two-lane roadway adjacent to an existing narrow worn-out pavement. Then, to provide for future construction of a four-lane divided roadway and to comply with the wartime restrictions, the old pavement was torn up. The concrete was crushed and stockpiled for use as the aggregate base course for postwar construction of the two additional lanes.

At Love Field, Dallas, Texas, in 1964, a new 8800-ft runway, parallel taxiway, high-speed turnoffs, holding apron, and an extension of an existing 4500-ft runway were built of new 13-in concrete. All of this pavement was placed on a 6-in cement-treated subbase. Seventy-two percent of the crushed concrete from the old pavement was used on the site of the new runway as aggregate in the subbase, along with 28 percent natural sand, and 4 percent cement by weight.

The first use of recycled concrete in an econocrete subbase (lean concrete) for a new concrete pavement was in California. The subbase was placed 0.4 ft thick and 50 ft wide in one pass with a slipform paver. The same paver was later used to slipform the 48-ft wide concrete pavement on the subbase. The subbase, using the recycled concrete and asphalt, looked like a concrete slab. The average 28-day compression strength on cores from the lean concrete base was 734 lbf/in^2. The contractor used the econocrete subbase as a haul road for the pavement construction.

In 1976 the Iowa Department of Transportation (DOT) recycled an old concrete slab on US-95 in Lyon

County. The 41-year-old, 18-ft-wide concrete slab had been overlaid with 3 in of asphalt in 1958. The asphalt was first removed, then the concrete, and the two materials were recycled at a site adjacent to the project to a maximum size of 1.5 in. The crushed concrete was used as aggregate in a concrete mix with 564 lb of cement and a natural sand for approximately 1 mile of the project. This concrete was placed 9 in thick.

The last half-mile of the project was an econocrete composite section. A 7-in lower course consisting of a mixture of recycled concrete and asphalt was placed 23 ft wide by means of a slipform paver. The mix also contained a natural sand, but only 470 lb of cement. Immediately behind, the slipform paver placed a 4-in top course that used only recycled concrete as coarse aggregate and the 564 lb of cement factor. This top layer wrapped around the base to form a final slab 24 ft wide and 11 in thick.

As a result of this project, constructed by the Irving F. Jensen Company, the Iowa DOT concluded that recycling old portland cement concrete pavements into new pavements is a viable reconstruction alternative.

This project demonstrated the feasibility of using a locally available aggregate of less-than-normal paving quality in a lower course and covering it with concrete by using high-quality, more expensive aggregates.

From the experience gained on this project, the Iowa DOT in 1977 awarded two more contracts for recycling old pavements. In Pottawattamie County the contract called for breaking up, removing, and crushing old concrete and stockpiling it for use in 1978.

In Page and Taylor Counties in southwest Iowa, a contract was awarded to recycle almost 15 miles of old concrete on IO-2. This contract called for removing the 16-year-old asphalt. Then the 45-year-old concrete pavement was broken up, removed, and crushed.

This old pavement contained reinforcing bars around the edges of the slabs and 11-ft-long transverse bars that were placed with 3-ft centers. These smooth bars proved to be quite easy to remove from the old crushed concrete. The contractor sold the salvaged steel (almost 500 tons) for scrap at $40/ton. The recycled concrete aggregate, with the addition of natural sand, acted like any other normal concrete mix. The contractor and agency reported no unusual problems and were pleased with the results. The Iowa DOT now considers recycled concrete a usable design alternative on all projects.

Early in 1977, concrete recycling was used in construction of a new keel strip in a runway at the Jacksonville (Florida) International Airport. Rather than overlay the entire runway, it was decided to recycle the existing concrete in the two 25-ft-wide center lanes. The 11-in concrete was broken up by a drop hammer, removed, and hauled to a crushing plant on the airport site.

After removal of the concrete, the old subbase and the subgrade were removed to a depth of 14 in below the old

Broken concrete pavement is loaded into a primary crusher for recycling into concrete aggregate for new pavement.

grade. Then a 6-in filter course of the recycled coarse aggregate was placed and compacted. On the filter course, a 6-in layer of econocrete base was placed by a slipform paver. Since the coarse aggregate for the new concrete had to be hauled from Miami, the economic gain from recycling the old pavement is obvious.

Commercial concrete recycling operations are successful in many areas of the country. I am aware of commercial operations in Chicago, Detroit, New York, Washington, D.C., Los Angeles, New Orleans, Savannah, and Pontiac, Michigan.

In Washington, D.C., two recycling plants have been established. One of these is primarily processing excavation material from the Metro subway, including a large quantity of gravel. The other plant uses a portable crushing plant to recycle torn-up asphalt and concrete roadways, parking lots, and concrete building structures, as well as some tunnel muck from Metro. Excavation and demolition contractors find it more economical to pay to dump at this plant rather than to haul 10-20 miles outside the city, where landfill operators charge $8-9/load. The finished material has been tested by the D.C. highway department as a subbase aggregate.

Energy Savings

In a paper presented by Ray and Halm at the TRB 1978 Annual Meeting, the energy savings derived from the use of recycled concrete aggregate was dramatically demonstrated.

This paper showed a comparison of total Btus per mile between pavement that used natural coarse aggregate for various haul distances and pavement that used recycled pavement at the same location or aggregate purchased from a commercial recycling plant that was a 10-mile haul from the job.

The paper concluded that recycling existing pavement appeared to be energy efficient whenever natural aggregate must be hauled more than 50 miles. Using aggregate from a commerical plant where concrete rubble can be obtained as waste would make recycled concrete energy efficient regardless of the haul distance, since the energy to crush old concrete appears to be less than that necessary to produce new natural aggregate.

Economic Feasibility

Two MIT researchers concluded that recycled aggregates had a distinct advantage in many metropolitan areas in which natural aggregates are unavailable and a 15-mile haul is considered to be a relatively short distance.

During TRB's 1978 Annual Meeting, Frondistou-Yannas told participants that a commercial plant that produces 225 000 tons/year "should be able to make a profit by selling aggregate at $1.67/ton, compared with the price of $3.30/ton for natural aggregate."

Several concrete recycling projects will be undertaken this year. Some of the states considering projects are Colorado, Minnesota, Illinois, and New York.

Unprecedented Reconstruction

Work is continuing on the reconstruction of more than 15 miles of the Edens Expressway, which connects the northern Chicago suburbs to the metropolitan inner city.

This $113.5 million project is the largest roadway-type highway contract ever awarded nationally. The agreement calls for around-the-clock work, 7 days/week, to comply with the two construction-season deadlines. Traffic in excess of 130 000 vehicles/day will be maintained during all operations.

Edens is anticipated to be only the first of other freeway reconstruction projects around the country as the Interstate system ages. Freeway widening and overlaying have become common, while the complete tear-out-and-rebuild concept is new. The six-lane reconstruction of Edens will be carried out on essentially the same centerline and within the present right-of-way, flanked by dense residential and business areas.

Traffic control will obviously be a big cost item; four of the six lanes of either old or new pavement must be available at all times. The first step was in May 1979, when 78 000 ft of temporary precast concrete barriers were placed in 10 days. The second step was closing all original northbound lanes to traffic and using the inner two southbound lanes and a fortified shoulder.

Noise control will also test the resourcefulness of the contractors under stringent requirements. Previous traffic noise levels will serve as a basis for the consultant responsible for establishing construction noise controls. Edens Expressway was constructed in 1951 and was overlaid 15 years later, at which time it had carried the equivalent of 27 years of traffic. Now, in 1980, it is being replaced after an equivalent of 45 years of service.

The northbound roadway was completed and opened to traffic before the penalty date of October 31, 1979. Both roadways will be kept open through the winter of 1979-80, and the southbound roadway will be completed in 1980. Many agencies will monitor the success of this unprecedented reconstruction job closely and will design future projects accordingly.

Conclusion

As hauling distances for natural aggregate exceed 50 miles, recycled pavement becomes a desirable alternative. As commercial recycling plants begin operation and recycling contractors develop more efficient methods, these relationships may make recycling an even more energy-effective alternative.

Indeed, recycling of concrete looks like a definite factor in construction in the future. Contractors, equipment manufacturers, and commercial aggregate producers will have to develop more sophisticated techniques for crushing, removing embedded items, and handling recycled concrete. Concrete technicians will have to develop optimum mix designs to make use of recycled concrete.in an economical mix with proper workability and durability for job conditions and environment.