Figure 1. Crushed concrete/asphalt from a recycled pavement was first used in California for a concrete base.

Figure 2. A steel punch on trench hoe was used on Lyon Co. Iowa's Route 75 to punch holes in asphalt and concrete.

Recycling Portland Cement Concrete

By Gordon K. Ray

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 an increasing interest in recycled concrete. Research in laboratories and experience at several projects have proved that recycling concrete for use in new concrete is feasible and should be considered whenever good aggregates are not available locally or where their costs are excessive.

Recycled concrete is simply old concrete that has been removed from pavements, foundations, or buildings and then crushed. Sizes of crushed concrete can be specified for its intended use. Reinforcing steel or other embedded items, if any, must be removed and care must be taken to prevent excessive contamination of the concrete by dirt or other undesirable materials such as plaster or gypsum from buildings.

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 lean-concrete (econocrete) bases using concrete mixers and slip-form pavers. It can also be used as aggregate in new concrete pavement if tests of new concrete made with crushed-concrete aggregate indicate acceptable strength and durability.

Early Examples

An early example of recycled pavement is on U.S. Route 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. To provide for future construction of a four-lane divided roadway and 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 in Dallas, Texas, in 1964, a new 8,800-foot runway, parallel taxiway, high-speed turnoffs, holding apron, and an extension of an existing 4,500-foot runway were built of new 13-inch concrete. All of this pavement was placed on a 6-inch cement-treated subbase (CTSB). The contractor used crushed concrete from old pavement on the site of the new runway as his aggregate in the CTSB. The mix was composed of 72 percent crushed concrete, 28 percent natural sand, and 4 percent cement by weight. A continuous-flow pug-mill mixer was used. The mixed material was hauled in dump trucks and spread $7^1/_2$ inches thick prior to rolling and compaction with steel-wheeled, vibrator, and pneumatic-tired rollers.

The first use of recycled concrete in a lean-concrete (econocrete) base (LCB) for a new concrete pavement was in California. The contractor used a mixture of recycled concrete and asphalt (Figure 1). A crusher was set up and contractors were invited to dump old concrete or asphalt there. They were charged a $5-per-ton dumping fee. The materials were crushed to a maximum size of $1^1/_2$ inches. The lean-mix concrete required 8 percent ce-

A diesel hammer pulled by a rubber-tired tractor is shown breaking up old pavement for removal and crushing.

Figure 3. Power shears were used on the Iowa project to cut reinforcing bars exposed during concrete removal.

Pavement

ment. A central mixing plant with 7½-yard mixing drums was used and the mixed concrete was hauled to the site in belly dumps. The only unusual occurrence was the entrainment of excessive air, perhaps due to the asphalt in the mix. A detraining agent was added to the mix to keep the amount of entrained air within specified limits.

The subbase was placed 0.4 foot thick and 50 feet wide by a specially modified slip-form paver, which was later used to slip-form the 48-foot-wide concrete pavement on the subbase. The lean-mix base looked like a concrete slab. Normal white membrane curing compound was used. The average 28-day compression strength on cores from the lean-concrete base was 734 psi. Since completion of this project, California has conducted additional research on lean-concrete base. Standard specifications have been developed and several concrete paving projects have been built with concrete pavement on LCB.

In 1976, the Iowa Department of Transportation (DOT) recycled an old concrete slab on U.S. Route 75 in Lyon County. The 41-year-old, 18-foot-wide concrete slab had been overlaid with 3 inches of asphalt in 1958. In March 1976, the contractor began breaking up and removing the old pavement. Holes were punched in it at about 2-foot centers in both directions to create slabs about 2 feet square (Figure 2). The asphalt was first removed using an end loader, then the concrete was removed with a backhoe. The two materials were recycled to a maximum size of 1½ inches. Reinforcing, consisting of smooth edge bars and center line tie bars, was cut at the site and removed after primary crushing (Figure 3). The crushed concrete was used as aggregate in a concrete mix with 564 pounds of cement and a natural sand for about 1 mile of the project. This concrete was placed 9 inches thick.

The last half mile of the project was a composite section. There, a 7-inch lower course consisting of a mixture of recycled concrete and asphalt was placed 23 feet wide with a slip-form paver. The mix also contained a natural sand, but only 470 pounds of cement. Immediately behind, the slip-form paver placed a 4-inch top course that used only recycled concrete as coarse aggregate and a 564-pound cement factor (Figure 4). This top layer wrapped around the base to form a final slab 24 feet wide and 11 inches thick.

This project demonstrated that recycling is an economic alternative to hauling good new aggregates up to 50 miles. The price of removing and crushing the old pavement was $4.30 per square yard. The contractor indicated that 75 to 80 percent recovery of an old pavement can be anticipated. The DOT also concluded that, on future projects, any bituminous overlays should be removed, crushed separately, and stockpiled for future use.

In 1977 the Iowa DOT awarded two more contracts for recycling old pavements. One contract called for breaking up, removing, and crushing old concrete north of Council Bluffs and stockpiling it. Later in the year a contract was awarded on I-680 in which the recycled concrete was used as

Figure 4. Lower course by preceding paver is mix of the recycled asphalt/concrete covered by 4-inch top course.

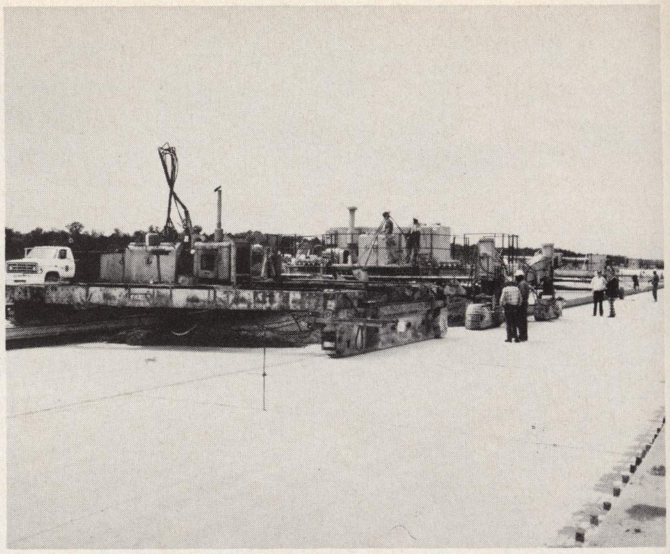

Figure 5. Slip-form paver placing 14-inch concrete over lean concrete base in runway keel strip, Jacksonville.

aggregate in an LCB for a new concrete pavement and as aggregate in new concrete shoulders.

Again, the recycled concrete was split into two sizes, 1½ to ⅜ inch and −⅜ inch. In the lean-concrete base, the mix contained 50 percent of the recycled coarse aggregate, 25 percent recycled fine aggregate, 25 percent natural sand, and 300 pounds of cement per cubic yard. The 6-inch concrete shoulders also contained 50 percent of the coarse and 25 percent of the fine recycled concrete aggregate and 25 percent natural sand but, in this exposed concrete, the mix design called for 564 pounds of cement per cubic yard.

The bid prices on this project were $1.40 per square yard for pavement removal and crushing (for 55,000 cubic yards), $2.33 per square yard for the lean-concrete base (43,000 square yards), and $7.10 per square yard for the concrete shoulders (37,000 sq. yds.).

As a result of their 1976 project in Lyon County, Iowa DOT decided to use salvaged asphalt in fills rather than in concrete, that the crushed-concrete aggregate for the recycled concrete should be broken into two sizes rather than one, and that natural sand should be used to ensure good concrete workability.

A contract was awarded in 1977 to recycle almost 17 miles of old concrete on Iowa Route 2 in two counties. This contract called for removing the 16-year-old asphalt overlay and using it in fills. Then the 45-year-old concrete pavement was broken up with a traveling diesel hammer, removed, and crushed. Secondary crushers divided the concrete into two sizes, 1½ to ⅜ inch and −⅜ inch. This project is of special interest since the original concrete contained a sand gravel aggregate in a maximum size of about ⅜ inch.

As in the Lyon County project, this old pavement contained reinforcing bars around the edges of the slabs and 11-foot-long transverse bars that were placed at 3-foot centers. These smooth bars were easily removed from the old crushed concrete and sold for scrap.

In January 1978, a contract was awarded for repaving the 17 miles of Route 2 in the two counties with 8 inches of new concrete using the stockpiled recycled concrete. The 1977 contract had called for removing almost 160,000 square yards at a price of $1.30 and crushing approximately 128,000 square yards at a price of $2.00. The contract for repaving almost 243,000 square yards was bid at $6.60 per square yard. The mix design called for 1,083 pounds of recycled coarse aggregate, 637 pounds of recycled fine, 934 pounds of natural fine, and 626 pounds of cement per cubic yard. The Iowa DOT estimates that it saved $100,000 by recycling the old pavement.

Runway Keel Strip

In 1977 concrete recycling was used in the construction of a new keel strip in a runway at the Jacksonville, Florida, International Airport. The center 50 feet of a 150-foot-wide, 11-inch-deep runway was in considerable disrepair due to a combination of overloads, inadequate drainage, and poor-quality subbase. Rather than overlay the entire runway, it was decided to recycle the concrete in the two center 25-foot-wide lanes. The 11-inch concrete was broken up by a drop hammer, removed, and hauled to a plant on the airport site where the old concrete was crushed and separated into two sizes, 2 inches to ⅜ inch and −⅜ inch.

After removal of the concrete, the old subbase and subgrade were removed to a depth of 14 inches below the old grade. The coarse recycled concrete was then placed in drainage trenches at each side of the keel strip surrounding a perforated plastic pipe. A filter fabric had been placed over the new subgrade and around the filter course in the trench. Then a 6-inch filter course of the coarse aggregate was placed and compacted. The adjacent slabs on both sides of the keel strip were undercut about 1 foot and the new filter course, subbase, and concrete extended below the adjacent lanes.

On the filter course, a 6-inch

layer of lean-concrete base was placed by slipform paver (Figure 5). The lean concrete used the two sizes of recycled concrete as aggregate and 250 pounds of cement per cubic yard, water, and water-reducing admixture for greater workability. The lean concrete, which had a 28-day compressive strength of 1,000 psi, was mixed in a 9-cubic-yard central mixer and hauled by dump truck. Two new 14-inch concrete lanes, each 25 feet wide, were later slip-formed on this base to complete the keel strip. Since the coarse aggregate for the new concrete had to be hauled over 250 miles, the economy gain from recycling the old pavement is obvious.

Recycling Plants

Perhaps of even greater significance than these few concrete pavement recycling projects are the numerous commercial concrete recycling plants in major metropolitan areas around the United States.

In Washington, D.C., two recycling plants have been established. One of these is primarily processing excavation material from the Metro subway construction, including a large quantity of gravel. The other uses a portable crushing plant to recycle torn-up asphalt and concrete roadways, parking lots, concrete buildings, as well as some tunnel muck from Metro. Excavating and demolition contractors find it more economical to pay to dump at this plant rather than to haul to landfills 10 to 20 miles outside the city.

In Chicago, one company runs a regular concrete recycling operation at two sites where wrecking contractors dump old concrete at a fee of $16 for a large trailer load. A portable crusher is then moved from site to site when a large enough stockpile is accumulated. The crushed material meeting Illinois coarse aggregate gradation criteria is sold for base course aggregate and railroad ballast. The Illinois DOT has not yet approved this recycled concrete for concrete pavement aggregate on Illinois highways, but as natural aggregate supplies are exhausted or become excessively expensive, they will no doubt reconsider this alternative aggregate source.

In Pontiac, Michigan, the City Public Works Department and a local contractor have combined forces. The contractor set up a plant in 1977 to crush about 840 tons a day at the Pontiac landfill and to crush all the broken concrete the city and local contractors haul to the dump. This operation solved a major problem in waste disposal for the city and provided a supply service for many contractors in the area.

Economic Feasibility

The economic feasibility of concrete recycling will depend on many factors. Researchers from the Massachusetts Institute of Technology have concluded that recycled aggregates are advantageous in many metropolitan areas where natural aggregates are locally unavailable and a 15-mile haul is a relatively short distance. They estimate a plant price for recycled concrete aggregates, even under conservative assumptions, at $2 per ton compared to $3.30 per ton for natural aggregates. Based on research conducted at the Army Engineer Waterways Experiment Station, they assumed slightly lower strengths for somewhat larger volumes of concrete (thicker pavements) when recycled concrete aggregates are used.

In a paper presented during a session on concrete recycling at the 1978 Transportation Research Board Meeting, it was concluded that a commercial plant producing 225,000 tons a year should be able to make a profit selling aggregate at $1.67 per ton compared to $3.30 per ton for natural aggregate. This would establish a savings from the use of recycled concrete aggregate even if 10 percent more cement is required to obtain the same strength which could be gotten from natural aggregate.

Table 1 lists some possible savings in energy by using recycled concrete aggregate. Calculations were made of the energy required to produce the materials (aggregates and cement), haul and mix them, and place a mile of 24-foot-wide, 10-inch concrete pavement. The Table compares total Btu's per mile between pavement using natural coarse aggregate (gravel or crushed stone) for various haul distances and pavement using recycled pavement at the same location or aggregate from a commercial recycling plant in a metropolitan area with a 10-mile haul to the job. Recycling existing pavement appears to be energy efficient whenever natural coarse aggregate must be hauled over 50 miles. Using aggregate from a commercial plant where the concrete rubble can be obtained as waste would make recycled concrete energy efficient regardless of haul distance because the energy required to crush old concrete appears to be less than that needed to produce new natural aggregate.

Summary

Recycled concrete appears to be a definite factor in future construction. 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 must develop optimum mix designs to make use of recycled concrete in an economical mix with proper workability and durability for job conditions and environment. Engineers will have to accept aggregates from recycled concrete for many applications and prepare suitable specifications.

TABLE 1. ENERGY REQUIREMENTS: MILLIONS OF BTU'S PER MILE OF PAVEMENT

Natural Aggregates	*Energy Requirements*
10-mile haul	7931
20-mile haul	7977
50-mile haul	8115
100-mile haul	8346
Recycled Pavement (on-the-job plant)	8148
Recycled Concrete (10-mile haul)	7829