Roller-Compacted Concrete Pavement at Portland International Airport

JORY M. ABRAMS, JERRY L. JACKSHA, ROBERT L. NORTON, and DAVID J. IRVINE

ABSTRACT

Presented are the owner's and the consultant's perspectives on the development, design, and evaluation of key issues involved with construction of a roller-compacted concrete (RCC) pavement at Portland International Airport, Portland, Oregon. RCC has been used in the past for pavements that support heavy wheel loads, but this parking apron is the first use of it as a surface pavement for commercial jet aircraft in the United States. The loading conditions and other factors that led to the selection of RCC as an alternative to conventional asphalt-concrete (AC) pavement are discussed. Federal Aviation Administration methodology was used to develop pavement sections for both RCC and AC pavements. Specifications were developed to improve surface tolerances, smoothness, and joint control, and a method was devised to test field density. Bids were accepted for both alternatives and the six low bidders offered the RCC option at a lower cost than the AC option. The lowest RCC bid was 32 percent under the lowest AC bid.

The Port of Portland, Oregon, retained CH2M HILL to design an 8-acre aircraft parking apron at Portland International airport (PDX) for passenger jets. Portland cement concrete (PCC), roller-compacted concrete (RCC), and asphalt concrete (AC) were studied as pavement alternatives. Plans and specifications were prepared and alternative bids received for RCC and AC pavements. Port of Portland officials selected the RCC alternative and awarded the contract in May 1985; paving began in August 1985. In this paper the evaluation process, the design of the RCC and AC pavements, bid results, mix design, and key construction issues considered during the design are outlined.

RCC is a material with a low water/cement ratio. It has been used as pavement for log-sorting yards and shipping facilities and in dam construction. When RCC is used as a pavement, the design and the curing process are similar to those of conventional PCC, but the mixing and placing procedures are similar to those of a cement-treated base (CTB). Conventional asphalt paving equipment with steel drum vibratory rollers for compaction has been most often used for pavement applications. The trend, however, is toward pavers with tamping bars for precompaction of the RCC. These pavers may eliminate the need for compaction rolling and also solve much of the shoving problem that occurs when rollers make their initial pass on a thick lift of uncompacted RCC. The maximum size aggregate for RCC pavements should be 3/4 in., with typical cement content values of 12 percent and a water/cement ratio in the range of 0.3 to 0.4.

PORT OF PORTLAND'S REQUIREMENTS

To support a noise abatement program at Portland International Airport, a navigational aid system was recently installed by the Port of Portland. This new installation created a need to relocate the itinerant-aircraft parking area away from the new antenna system. Personnel at the Port were aware of several high-load pavements (log-sorting yards and port shipping facilities) that had been built in British Columbia using RCC and they became interested in the possible use of this material for the new parking area. It was decided that further investigation of RCC during the preliminary design phase was warranted. After that investigation, it was decided to proceed with RCC as an alternative to AC pavement.

RCC EVALUATION PROCESS

The initial RCC evaluation consisted of determining the feasibility of using RCC as a surface pavement material and developing the most up-to-date criteria for its use. This initial evaluation was based on research of previous projects, review of existing literature, discussions of RCC applications with experienced engineers and contractors, viewing of a test section placed by the U.S. Army Corps of Engineers at Fort Lewis, Washington, and the engineering experience and judgment of the design team.

CH2M HILL's evaluation indicated that the state of technology had progressed sufficiently to merit an RCC alternative design. The advantages of RCC for this particular application were its better resistivity to chemical attack from hydraulic oils and fuels, better long-term durability and therefore lower maintenance costs, negligible rutting or creep problems under long-term heavy loading, and a recent history of competitive costs.

On previous projects, a variety of natural and processed aggregates have been used for RCC. The two primary sources of processed aggregate have been concrete aggregate, consisting of gravel and sand mixtures, and AC aggregate, consisting of crushed material. The ability to use local sources of aggregate by modifying the mix design has been one of the main advantages of using RCC.

The Portland metropolitan area has an abundant

J.M. Abrams and J.L. Jacksha, Civil Division, CH2M HILL, 2020 S.W. Fourth Avenue, Portland, Oreg. 97201. R.L. Norton, Civil Division, CH2M HILL, P.O. Box 428, Corvallis, Oreg. 97339. D.J. Irvine, Port of Portland, P.O. Box 3529, Portland, Oreg. 97208.

supply of processed aggregate and some sources of naturally occurring gravels. Availability of aggregates was confirmed by contacting local suppliers to discuss gradation limits, availability, production, and costs. The preliminary gradation chosen was an Oregon Department of Transportation (ODOT) 3/4-in. minus crushed aggregate.

A processed AC aggregate was selected because it is less susceptible to segregation during placement than rounded or subrounded gravel. In addition, discussions with the Corps of Engineers indicated that RCC has a higher flexural strength when angular rock is used. It was thought that AC aggregate would give a better surface finish, and there were enough local suppliers of this material to ensure that costs would not be prohibitive. Natural gravels were not considered because of the availability of the crushed processed AC aggregate and because there is the question of material uniformity in most natural sources.

An important task was to evaluate whether local contractors were available and receptive to use of RCC. Numerous northwestern contractors were contacted to determine their experience with RCC or CTB. CTB is similar to RCC in that the cement and aggregate are often mixed in a pugmill or batch plant, placed in thick lifts, and compacted with vibratory rollers. For this application, the main difference between CTB and RCC was that the RCC surface required much tighter elevation tolerances. In addition, to obtain the high flexural strengths on which the design was based, the RCC mix had to be more tightly controlled in terms of amounts of aggregate, water, cement, and pozzolan. Transverse and longitudinal joints as well as the curing process were also critical for placing RCC as a finished surface pavement.

There are several contractors in the area with CTB experience, and a few had RCC experience. It was found that many asphalt-paving contractors were interested in learning about RCC and in bidding on the project. Generally, they were receptive to use of RCC because the equipment required and the placement techniques used were similar to those of AC or CTB.

DESIGN CRITERIA

Field Investigation

A field investigation was conducted by CH2M HILL and Port of Portland personnel in December 1984. This investigation included surveying, soils sampling, and testing. Soils investigation included the excavation of test pits with a backhoe. Materials encountered were tested for density, moisture content, and California bearing ratio (CBR). In general, the test pits showed that there were about 2 1/2 in. of AC pavement above 4 to 6 in. of crushed aggregate base course. The existing subgrade consisted of clean sand known locally as Columbia River dredge sand, having a CBR value of 20 percent. This sand was located as near the surface as 0.75 ft and as deep as 7.0 ft (the maximum pit depth). Layers of silty sand with a CBR of 5 percent were also located in several of the backhoe pits. This silty sand was as near the surface as 1.0 ft and as deep as 6.0 ft. This weaker silty sand was used for the design subgrade.

Aircraft Operations

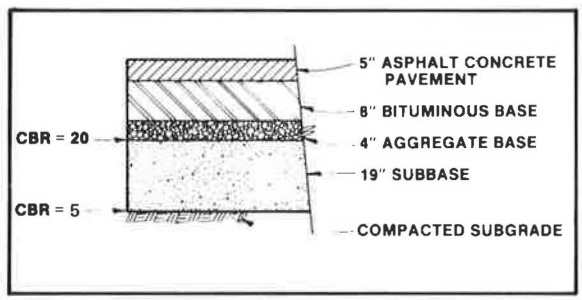
Forecasts of aircraft operations for the parking apron were prepared by the Port of Portland for a 20-year design life. The aircraft predicted to use the facility and their respective weights and operations are summarized in Table 1.

TABLE 1 Forecast of Aircraft Operations for Port of Portland North Side Remote Parking

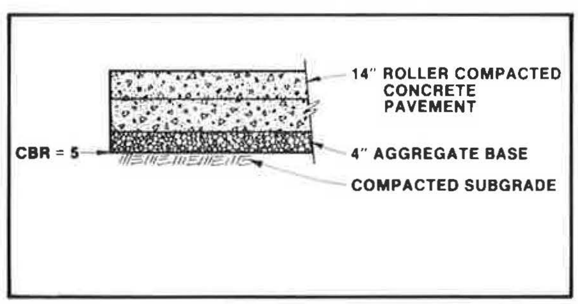
Aircraft	Aircraft Weight (lb)	Predicted Operations per Year
B747	564,000	8
DC10-10	363,500	22
A300	281,000	4
B767	270,000	22
DC8-50	240,000	8
B757	198,000	24
B727	154,500	184
DC9-50	110,000	26
DC9-80	128,000	6
B737	103,000	64

AC Pavement Design

The AC pavement design was based on the methodology provided in Federal Aviation Administration (FAA) Advisory Circular 150/5320-6C (1). On the basis of the aircraft weights and operations data in Table 1, the design aircraft chosen for the AC pavement was a DC-10. The recommended pavement section from this analysis was 5 in. of AC, 8 in. of bituminous base, 4 in. of aggregate base, and 19 in. of subbase, for a total pavement section thickness of 36 in. (see Figure 1). The AC pavement section was verified by using a computerized multilayered systems analysis.



ASPHALT CONCRETE PAVEMENT SECTION



ROLLER COMPACTED CONCRETE PAVEMENT SECTION

FIGURE 1 Pavement sections.

RCC Pavement Design

The design procedures used to determine thickness requirements of RCC pavement for this project were also based on FAA's Advisory Circular 150/5320-6C (1) and are similar to those normally used for PCC pavements. The design aircraft for RCC was determined to be a Boeing 727 with a total gross weight of 154,500 lb instead of the DC-10 used for AC.

The critical aircraft for a flexible pavement design is not necessarily the same as that for a rigid pavement design because of inherent differences in the performance of rigid versus flexible pavements subjected to aircraft load. The pavements designed for this project were based on the loading conditions presented in the section entitled Aircraft Operations and thus can be considered equivalent.

In accordance with the referenced advisory circular, a subgrade modulus value K was estimated for the subgrade by converting field CBR values and analyzing known K-values for soils of this type. A K-value of 100 pci was used for the silty sand subgrade. The flexural strength for RCC pavement was assumed to be 800 psi. With these criteria, it was determined that an RCC pavement section thickness of 13 in. was required to support the aircraft loading. For pavements supporting aircraft weighing over 100,000 lb, the FAA recommends the use of a stabilized subbase. For this design, 4 in. of stabilized subbase would have reduced the RCC pavement thickness to 12 in. As a cost-saving measure, it was decided to recycle the existing asphalt concrete and base rock on the site to provide a working platform and subbase for the RCC. Because this recycled material does not qualify as a stabilized subbase, the total RCC pavement section thickness was left at 13 in.

The design strength was later modified during the mix design to 700 psi, on the basis of the 28-day beam tests, causing the thickness to be increased by 1 in., to 14 in. (see Figure 1). The RCC pavement thickness was verified by using the Portland Cement Association's computerized concrete pavement design program (2).

KEY CONSTRUCTION ISSUES

To achieve FAA's recommended surface tolerances and texture (3), attention was focused on five areas:

1. Materials,
2. Mix design,
3. Construction equipment,
4. Paving techniques and paving details, and
5. Field density control.

Materials

Aggregate

For this particular pavement, the locally available State of Oregon AC aggregate was chosen. This aggregate gradation was modified slightly by adding intermediate screens and by increasing the percent passing the No. 200. Some of the advantages of using AC aggregate are as follows:

- It is less susceptible to segregation during placement as compared with rounded or subrounded gravel and coarse concrete aggregate;
- The angularity of the particles has generally resulted in higher flexural strengths than those obtained with rounded or subrounded gravel;
- It produces a surface similar to that of conventional asphalt concrete, which was desirable for this pavement application; and
- There are currently 10 to 15 local suppliers.

Portland Cement

In accordance with ASTM C150, the portland cement used for this particular mix is a Type I cement. The specifications, however, also allowed Type II and Type I-II cements.

Pozzolan

The pozzolan for the mix was an ASTM C618, Class C or Class F. Pozzolan Class F was the preferred material because of its uniform chemical composition. It is supplied from Centralia, Washington.

Mix Design

The RCC mix design is very sensitive to aggregate gradation, and it was not feasible to specify a particular aggregate source in the bid documents. Therefore, to assist contractors in preparing a bid, a preliminary mix design was included in the bid documents, as follows:

Material	Weight per Cubic Yard (lb)
Cement	360
Pozzolan	150
Water	165
Aggregate	3,510

After the low bidder designated an aggregate source, a final mix design was completed that used actual aggregate material being stockpiled for the RCC. The mix design method used was that outlined in the Corps of Engineers Manual EM 1110-2-2006 (4). The materials breakdown by weight per cubic yard is as follows:

Material	Weight per Cubic Yard (lb)
Cement (Type I)	488
Pozzolan (Centralia Class F)	119
Water	260
Aggregate	3,250

Although properties of the aggregate selected by the contractor were still within the range specified in contract documents, they differed from those used to develop the preliminary mix design. The average gradation of the aggregate is shown in Figure 2.

The final design flexural strength was 700 psi at 90 days, which would require at least 600 psi at 28 days. Given the project schedule, the flexural strength of the mix design was confirmed by using 28-day beam tests. Beams were made according to ASTM C192-81, with some modifications in the method of consolidating the RCC in the molds. An average of five beam tests at 28 days produced a flexural strength of 710 psi. Some additional strength is anticipated between 28 and 90 days. It is planned to cut beams in the pavement to confirm the flexural strength at 90 days.

Construction Equipment

Mixing Plant

The mixing plant specified is a central type having a stationary, twin-shaft, pugmill-type mixer. The plant is to be either a weigh-batch type or a continuous-mix type. The specified minimum plant output is a manufacturer-rated capacity of 600 tons/hr, which is on the high side of conventional plant output for the area. This output was specified to allow rapid placement of the RCC and thereby reduce the

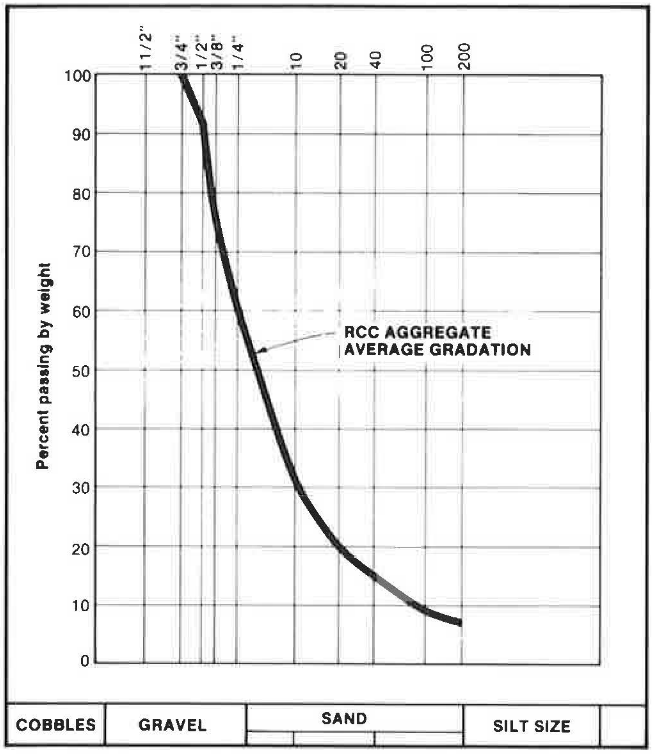


FIGURE 2 RCC aggregate gradation.

number of cold joints. Drum mixers were not allowed because of past problems with mixing uniformity and consistent output.

Paving Machine

Two RCC pavers were specified in order to eliminate the cold joint between the top and bottom lifts of RCC. Each paver was specified as a heavy-duty, track-mounted, self-propelled type, commonly used in asphalt concrete paving but modified to place RCC. Modifications to the augers are typically required to place the thicker RCC lifts without voids or segregation. Because of the surface tolerances, the pavers are to be electronically controlled for both line and grade.

As previously discussed, the current trend is toward a paver with tamping bars for precompaction. The contractor proposed a single paver of this type along with paving pattern modifications. This proposal was accepted and one of these pavers was used throughout the job.

Rollers

Vibratory rollers specified for compaction were to be self-propelled, double-drum, steel-wheel rollers having a shipping weight of at least 10 tons. Finish rolling with a rubber-tired roller was not required; however, many of the contractors believed that the surface would be improved with such treatment.

Curing Equipment

A water truck with a spreader pipe containing fog spray nozzles was used for the initial cure of the RCC. It is important to initially apply a fog spray rather than use a sprinkler system to prevent erosion or washing away of the surface cement. Subsequent curing was done with a sprinkler system. The contractor proposed this method of curing and equipment as an alternative to the specified water-and-burlap cure.

Paving Techniques and Paving Details

Paving

The RCC section of 14 in. is to be placed in two equal thicknesses, or 7 in. per lift. No more than 60 min was allowed to elapse between compaction of the first lift and placement of the second. On the basis of experience, this requirement was needed to allow a bond between the first and second lift. Misting or watering on the first lift was not allowed.

Construction Joints

Two types of construction joints occur: fresh joints where the adjacent RCC material is placed within 60 min and cold joints where adjacent material is placed after more than 60 min. For fresh vertical joints, the only requirement was to have a near-vertical face before the adjacent RCC panel was placed. Fresh horizontal joints (between lifts) required no preparation before placement of the second lift. Cold horizontal joints were not allowed.

Tolerances

The surface tolerance of the RCC pavement was specified for both elevation and localized variance. The surface-elevation tolerance allowed was ±.03 ft from the specified finished grade. The localized variance was ±1/4 in. at any point measured along a 10-ft straightedge. (The tolerance on the first lift was only that its thickness be within ±1/2 in. of the specified thickness.)

There were also tolerances on the RCC material during mixing. The variation in cement and pozzolan was ±2.0 percent by weight and for water, ±3.0 percent by weight. The particle gradation tolerance for the aggregate was between 2 and 6 percent by weight, depending of the sieve designation.

Curing

A water-cure method rather than a membrane method was used to cure the RCC. Water was to be applied in a continual fog spray 24 hr a day for 7 days. Because of anticipated warm weather during paving, it was important to apply the fog spray immediately after final rolling of the finished RCC surface.

Field Density Control

The minimum acceptable field density was 98 percent of a specified density, which was determined during the final mix design period by constructing a 24-in.-square by 15-in.-high block of RCC from the mix and measuring its unit weight. The project team, in conjunction with the Corps of Engineers North Pacific Division Materials Laboratory, decided to use a large block of RCC as representative of the maximum density. There are no ASTM standards or other guidelines for the preparation of such a block.

The RCC was placed in a steel mold in three layers and consolidated with a hand-held pneumatic tamper, and vibrations were made to the mold until no further consolidation was observed. Densities obtained in the field were compared against the unit weight of this RCC block. A nuclear densimeter was used to calculate the field density according to ASTM D2922.

The large block of RCC was considered representative of the actual field-placed RCC. Past studies show that field densities determined with the nuclear densimeter were consistent but underestimated the density when compared with actual cores taken from the pavement. Therefore, use of the RCC block allows a means to calibrate the nuclear densimeter field readings. Daily calibration of the nuclear densimeter on this block will allow reliable and consistent field density measurements during placement of the pavement.

BID TABULATION

A cost savings of approximately $220,000 was realized for the RCC alternative over the AC alternative. The six lowest bidders all offered the RCC option at a lower cost than AC, as shown in Table 2. The lowest RCC bid was about 32 percent under the lowest AC bid. If the life-cycle costs of RCC and AC were compared, an even greater savings would result. In time, it is expected that this differential will narrow as RCC contractors increase prices for greater profit margins and AC contractors become more competitive.

Of the six contractors that bid for RCC, only one had had previous RCC experience, but each of the other five had had experience with CTB construction. In awarding the contract to the low RCC bidder, Port of Portland officials considered both the construction cost savings involved and the long-term heavy load conditions. The FAA was consulted and gave its approval to proceed.

TABLE 2 Paving Bids for Port of Portland North Side Remote Parking

	Bid ($)	
Contractor	RCC Alternative	AC Alternative
A	687,370.65	914,400.15
B	739,327.00	–
C	780,517.75	917,041.00
D	796,205.00	–
E	791,893.00	1,011,142.05
F	800,585.00	956,404.00
G	–[a]	908,773.25
H	–	1,040,811.80
I	–	1,036,323.40

[a]No bid.

CONCLUSIONS

RCC used for a pavement as a final wearing surface is relatively new. Typically, RCC is designed and cured as a PCC pavement and is mixed and placed similarly to CTB. The final surface texture falls between that of AC and that of PCC.

Where RCC has been used for heavy-duty pavements, it has provided significant savings on a construction cost basis as an alternative to AC and PCC pavements and is less expensive to maintain than AC pavements. Another benefit of RCC is its resistance to chemical attack from hydraulic fluid, fuel, and other hydrocarbons.

To achieve the desired RCC surface, tolerance, texture, and field density, particular attention should be given to the following:

- Gradation, degree of angularity, and tolerances of aggregate;
- Representative sampling of aggregate for mix design;
- Determination of maximum density for field density control;
- Allowable tolerances in RCC during pugmill mixing;
- Type of paver (conventional vibratory screed versus precompaction tamping bar screed);
- Paving patterns for compatibility of paving equipment and site configuration;
- Type of rollers to achieve density and surface texture desired;
- Treatment of horizontal and vertical joints;
- Allowable tolerances in the final surface elevations, localized deviations, and overall thickness; and
- Curing of RCC (water versus impermeable membrane).

As more knowledge is gained about the details of RCC design and construction and as manufacturers continue to improve paving equipment, RCC will become an even more acceptable pavement option.

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