Roller-Compacted Concrete Pavement Construction at Fort Drum, New York

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During the 1988 and 1989 construction seasons, 335,000 m² (83 acres) of roller-compacted concrete (RCC) pavement 0.254 m (10 in.) thick was built for the U.S. Army, 10th Mountain Division (Light Infantry) at Fort Drum, New York. The design, construction, quality control practice, and durability of the RCC under the seasonal frost environmental conditions at this location were studied.

During the design phase of the new U.S. Army Fort Drum post, roller-compacted concrete (RCC) was selected as the best suited and most economical alternative for the construction of hardstand pavements used as parking area for heavy vehicles. The pavements must be capable of withstanding the action of heavy, low-speed, rubber-tired, or tracked vehicles such as troop-carrying trucks and tanks. In addition, the material used for these pavements must endure the low temperatures and multiple freeze-thaw (F-T) cycles that occur in northern New York State.

RCC is a construction technology that combines the features of cement-treated aggregate base, portland cement concrete (PCC), and asphalt pavements to produce a low-cost pavement material. RCC is constructed by placing a zero-slump PCC mixture by means of a heavy asphalt paver and compacting it with several passes of a vibrating roller. Large quantities of concrete can be placed quickly with a minimal amount of labor and equipment. No forms are needed and finishing is not required. These attributes save approximately 30 percent compared to pavements built with conventional methods.

Work crews from Black River Constructors (BRC, a subsidiary of Morrison-Knudsen), under the technical direction of Peltz Constructors, constructed the Fort Drum pavements. Peltz supplied the pavers, the portable mixing plant, and the technical expertise for the placement of the RCC.

RCC has not been successfully air entrained to date. Preliminary tests run on samples from early projects (*1*) revealed susceptibility to F-T cycles, so the U.S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory (CRREL) conducted an extensive research program on the F-T durability of RCC. CRREL is now testing samples from the Fort Drum RCC pavement and is monitoring the field performance through a system of sensors installed within and around the pavement.

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PAVEMENT DESIGN

The design procedure for RCC pavements is similar to, and follows the methodology for, designing conventional concrete pavements. The criteria affecting thickness design are flexural strength, fatigue, the supporting strength of the base and subgrade combination, and the type and volume of traffic. The U.S. Army Corps of Engineers has developed thickness design charts for RCC (*2*). RCC pavements typically are allowed to develop shrinkage cracks naturally. They occur at irregular intervals ranging from approximately 12 to 21 m (39 to 69 ft). Often, shrinkage cracks originate where the pavement has been discontinued or cut off to fit utilities. Test data from other RCC projects on load transfer resulting from aggregate interlock revealed an average of 18 percent load transfer with a large standard deviation (*3*). Therefore, thickness design of RCC pavements is based on no load transfer at the joints or cracks. The result is a thicker pavement.

The contractor determined the proportioning of the Fort Drum RCC mixture. Several trial mixtures were prepared to provide a range of flexural strengths (Figure 1). The mix design that was selected produced a 28-day flexural strength of 5.5 mega-Pascals (MPa) (approximately 800 psi), which exceeded the contractual specification of 4.83 MPa (approximately 700 psi). Table 1 presents the selected mixture, and Table 2 displays the aggregate gradation. Coarse and fine aggregate were both manufactured by and obtained from a local limestone quarry. PCC Type II and fly ash Type F from the Canadian manufacturer LaFarge were used. Approximately 25 percent of the cementitious material was fly ash. The water/cement ratio was 0.41.

CONSTRUCTION

Mixing, Transportation, Placement, and Compaction

The RCC paving operation commenced in June 1988 and was concluded in August 1989. A continuous twin-shaft pugmill mixing plant was installed at approximately 5- to 10-min haul time from the paving sites. The plant was capable of producing 535 m³ (700 yd³) of concrete a day. Dump trucks of 10-m³ (13-yd³) capacity hauled the fresh concrete to the paving site. Two heavy-duty pavers placed the concrete while working in tandem to minimize cold joints. These pavers have a heavy, vibrating screed and dual tamping bars, which were able to obtain 93 percent of the final density at the back of the paver. The design called for a pavement 25.4 $\pm$0.6 cm (10 $\pm$0.25 in.) thick.

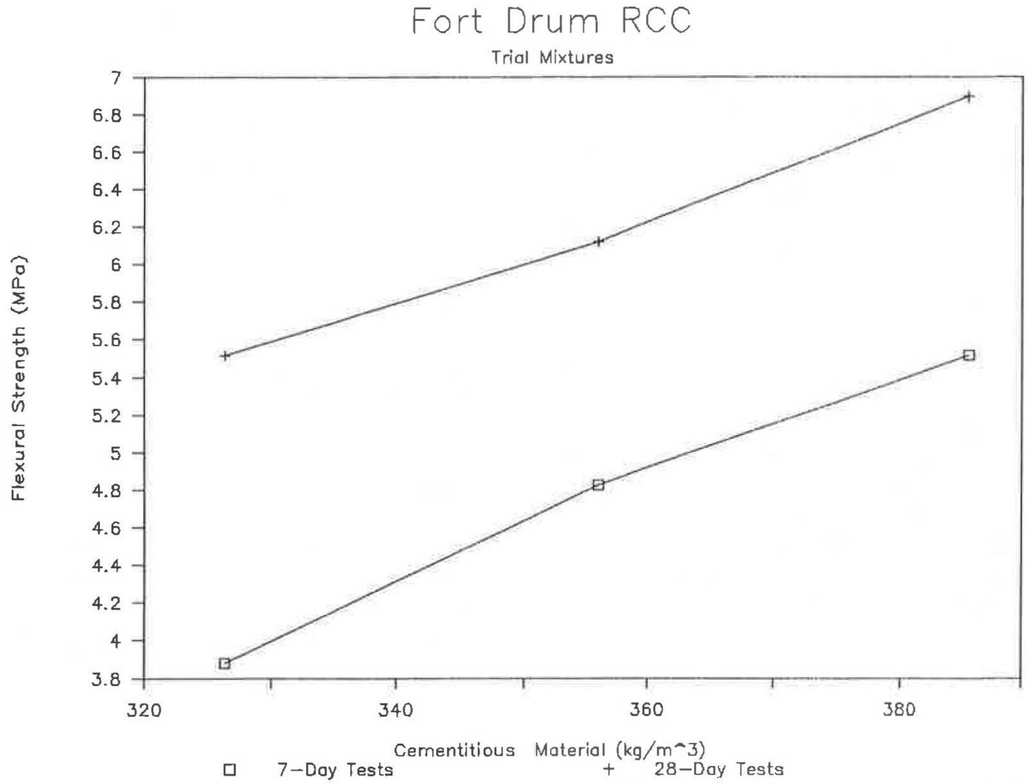


FIGURE 1 Flexural strength of trial mixtures.

TABLE 1 RCC SELECTED MIXTURE

Ingredient	Weight (kg)	Weight (lb)	Blend (%)	Absorption (%)	Volume (m³)
Cement	245.0	540.2	–	–	0.078
Fly ash	81.3	179.2	–	–	0.035
Crusher run	1,379.0	3,041.0	70	0.7	0.513
NY DOT #1B	586.8	1,293.6	30	1.1	0.220
Water	134.0	295.6	–	–	0.134
Entrapped air	0.0	0.0	–	–	0.020
Total	2,426.1	5,349.6	–	–	1.000

TABLE 2 COMBINED AGGREGATE GRADATION

Sieve Size (mm)	Sieve Size (U.S. Customary System)	Broad Specification Requirements (percentage of material passing)
19.000	¾-in.	100
12.700	½-in.	90–100
9.500	⅜-in.	75–90
6.350	¼-in.	55–75
2.000	#10	32–48
0.430	#40	11–24
0.180	#80	6–15
0.072	#200	3–7

Initially, the RCC was placed in two identical lifts to result in the 25.4-cm design thickness after compaction. Direct shear tests conducted on cores indicated poor bonding between layers. The contractual specifications required 98 percent of the maximum dry density of 2,315 kg/m^3 (144.5 lb/ft^3), as obtained from the five-point modified Proctor test. The optimum density was obtained at 5.8 percent moisture content. The contractor suggested that, by placing the concrete in one lift instead of two lifts, the interlayer bonding problem could be avoided, while still obtaining the required density. The production rate would also be expedited with economic advantage. In order to obtain the 25.4-cm thickness when compacted, the RCC was placed in one lift at a height of 28 cm (11 in.). The extra thickness was added to offset the approximate 10 percent reduction in thickness caused by rolling.

A 10-ton dual-steel drum vibrating roller followed the paver, compacting the concrete within 30 min after the addition of water to the aggregate cement mixture at the plant. Four vibrating passes (one back-and-forth motion is considered two passes) were necessary to achieve the specified density. Initially, rubber tire rollers were used to tighten the surface texture. The rubber tire rolling was soon discontinued because little advantage was gained from it.

Joints

Both horizontal and vertical joints are used in working with RCC. Horizontal joints are those between two layers of RCC. Vertical joints are perpendicular to the top surface of the pavement. At Fort Drum, only vertical joints were used, because the concrete was placed in a single lift.

Any RCC joint may be either a fresh joint or a cold joint. A joint finished within the initial setting period of the concrete is considered a fresh joint, otherwise it is a cold joint. The initial setting period varies with the placing temperature, cement type, and other factors. For most cases, this period is between 45 to 60 min from the time the water and cement are mixed.

To create a fresh joint and to minimize cold joints, the specifications required that adjacent lanes be placed and compacted together within 60 min. This condition was met by working the pavers in tandem and by limiting the distance between pavers. Cold joints were constructed by removing approximately 15 cm (6 in.) of the outer edge of the hardened paving lane by sawing. This distance was determined by noting the distance from the edge where the density reached the required 98 percent.

Shrinkage cracks were allowed to develop naturally in most of this project. The contractor was required to rout and seal all cracks with a bitumen sealer. Generally, these cracks were irregular in shape and spacing, so the routing might not intercept the entire crack. In an effort to minimize this problem, at a late stage of the project, the contractor decided to saw cut control joints at 18-m (59-ft) spacing to a depth of one-third of the pavement thickness. This practice was shown to be effective in controlling the shrinkage cracks at most of the locations where it was done.

Finishing and Curing

The RCC construction process does not include a finishing operation. The surface left behind the roller is the final one. The surface texture is similar to that of an intermediate asphalt course. The curing consisted of gentle water spray applied directly to the exposed concrete surface. The flow of water is controlled to keep the surface of the pavement with a wet appearance for 7 days. Failure to do so may result in shallow microcracks and spalling. Curing compounds are not used with RCC because of the low water/cement (*w/c*) ratio and the openness of the pavement surface.

QUALITY CONTROL

Several tests and techniques were used to monitor the quality of the Fort Drum RCC construction.

Strength

Beams and cores were taken during construction to verify the density and evaluate the compressive strength of the concrete. Once the required density was achieved, no difficulty arose in attaining the specified compressive and flexural strength for any location.

Density

Density is the most important control parameter in RCC construction. The density is measured in the freshly compacted concrete by means of a nuclear density and moisture meter in the direct transmission mode. The density is reported as a percentage of the maximum dry density as obtained from the five-point modified Proctor test. In this test, zero-slump concrete is treated as a soil. The mix proportions are determined by conventional methods using a *w/c* ratio of 0.38. The *w/c* ratio is then allowed to vary up and down from 0.38. A set of five samples with *w/c* ratios of 0.32, 0.35, 0.38, 0.41, and 0.44 are compacted as prescribed by the standard modified Proctor test commonly used for soils. The unit weight of each sample after compaction is determined, and a portion of it is then oven-dried to determine its moisture content as a percentage of the dry weight. Moisture content on the horizontal axis and calculated dry unit weight on the vertical axis are plotted. The peak of the curve so formed is identified to obtain the optimum moisture content and the 100 percent maximum dry density. The corresponding *w/c* ratio is also recorded, but the ratio is increased slightly at the mix plant to compensate for evaporation during transportation and placement.

The nuclear gauge is initially calibrated with a block of concrete of measured unit weight to determine any necessary correction constant for the actual field measurements.

Experience from prior RCC projects has indicated that the density in the vicinity of vertical joints tends to be lower than the density at other points. This may lead to spalling along the joints. At Fort Drum, density measurements were obtained along the joints and the paving lanes at 61-m (200-ft) intervals by means of a single-probe nuclear density meter in the direct-transmission mode. The probe was inserted within the RCC pavement along one side of the joint, with the apparatus straddling the joint, thereby determining the density across the joint. The values obtained were checked against the density required for acceptance. Core samples were taken at the joints to verify the nuclear gauge readings. The core diameter, height, weight, and moisture content were determined in the laboratory to calculate the corresponding dry unit weight. The dry unit weight determined in the laboratory agreed with the density given by the nuclear gauge within 5 percent for most cases.

Smoothness and Texture

The smoothness of the surface was checked using a 3-m (10-ft) straightedge on lines 1.53 m (5 ft) apart, parallel with, and at right angles to, the centerline of the paved area. Undulations in the surface of less than 1 cm (⅜ in.) were initially noticed at regular intervals of 2.44 to 3 m (8 to 10 ft). Water would pond and freeze in these undulations, posing a potential safety problem. These undulations were caused by the paver screed settling when the paver hopper was allowed to be empty while waiting for a new supply of concrete. The contractor corrected this problem by maintaining a more continuous feed of concrete to the paver hopper and by adjusting the sensors that control the settlement of the paver screed.

F–T DURABILITY RESEARCH

A full-scale RCC laboratory F–T experiment conducted at CRREL (*3*) showed that, after 300 F–T cycles, the material properties did not reveal any important decay. The compressive strength measured after 300 F–T cycles was slightly higher than the compressive strength at the beginning of the cycling. The dynamic modulus of elasticity after 300 F–T cycles was between 66 and 91 percent of its value at the beginning of the test. The temperature limits and the induced moisture conditions during this experiment were rather severe.

Field Monitoring of the Fort Drum RCC Pavements

In 1988, CRREL installed one set of environmental sensors in each of two representative locations at the Fort Drum RCC project. Each set of sensors measures the following parameters:

- Air relative humidity,
- Precipitation,
- Barometric pressure,
- Wind speed,
- Wind direction,
- Direct solar radiation,
- Reflected solar radiation,
- Concrete moisture,
- Groundwater table,
- Air temperature,
- Pavement surface temperature,
- In-concrete temperature at several depths,
- In-base/subbase temperature at several depths, and
- Subgrade temperature at several depths.

Athough presentation of detailed data from that study is beyond the scope of this paper, a summary of the temperatures during the 1988-to-1989 winter is presented in Figures 2a–2i and in Figure 3.

Figure 2a shows the hourly air temperatures 1.37 m (4.5 ft) over the pavement surface. Sixty-five F–T cycles were recorded from November 15, 1988, to April 24, 1989. For the moisture in the atmosphere, one F–T cycle occurs when the temperature falls below 0°C and then returns to above 0°C.

Figure 2b shows the temperatures at the concrete upper surface. The sensor was embedded in the concrete at only 2 mm from the pavement surface. Twenty-four F–T cycles were recorded during the 1988-to-1989 winter. For the moisture inside the concrete, one F–T cycle occurs when the temperature falls below −5°C and then returns to above 0°C.

Figures 2c–2e show the temperatures and number of F–T cycles at several depths inside the concrete during the study period.

Figure 2f shows data from a temperature sensor embedded in the concrete at only 4 mm from the RCC-base interface. Only four F–T cycles were recorded during the 1988-to-1989 winter.

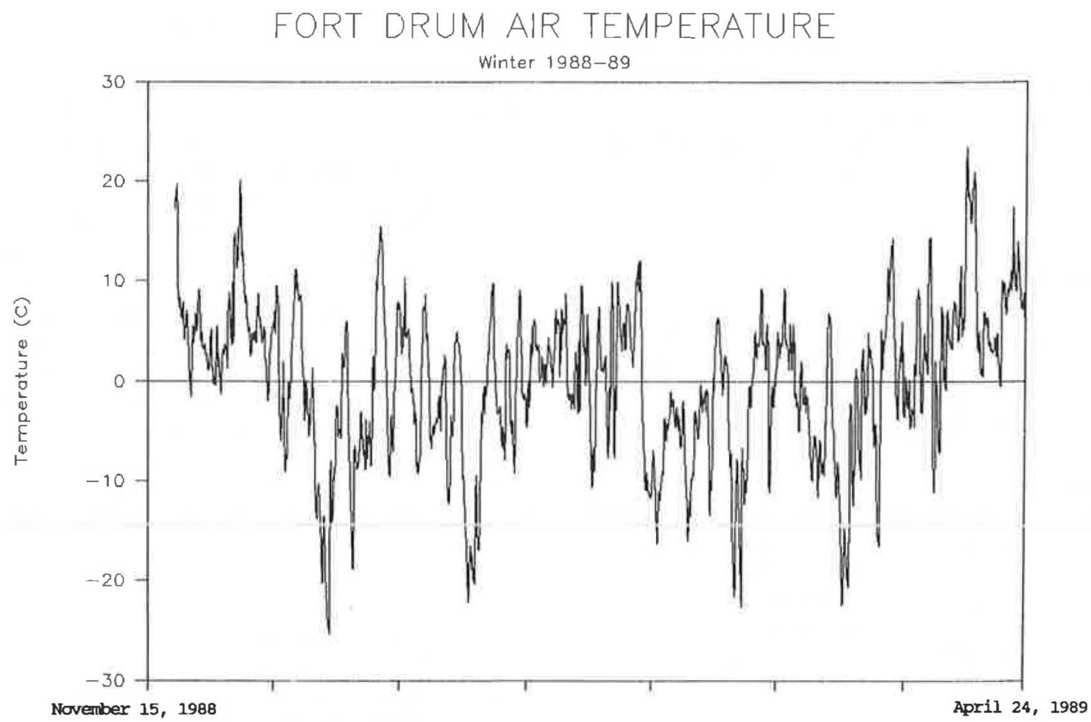
Figure 2g shows data from a sensor embedded in the granular base course. For the moisture inside a granular soil, an F–T cycle occurs when the temperature falls below −0.5°C and then returns to above 0°C. Nine F–T cycles were recorded at this point during the test period.

Figures 2h and 2i show data from temperature sensors located within the subgrade material. For moisture inside a silty soil, one F–T cycle occurs when the temperature falls below −2°C (or lower in many cases) and then returns to 0°C. Because no recorded temperature reached −2°C, no F–T cycle occurred.

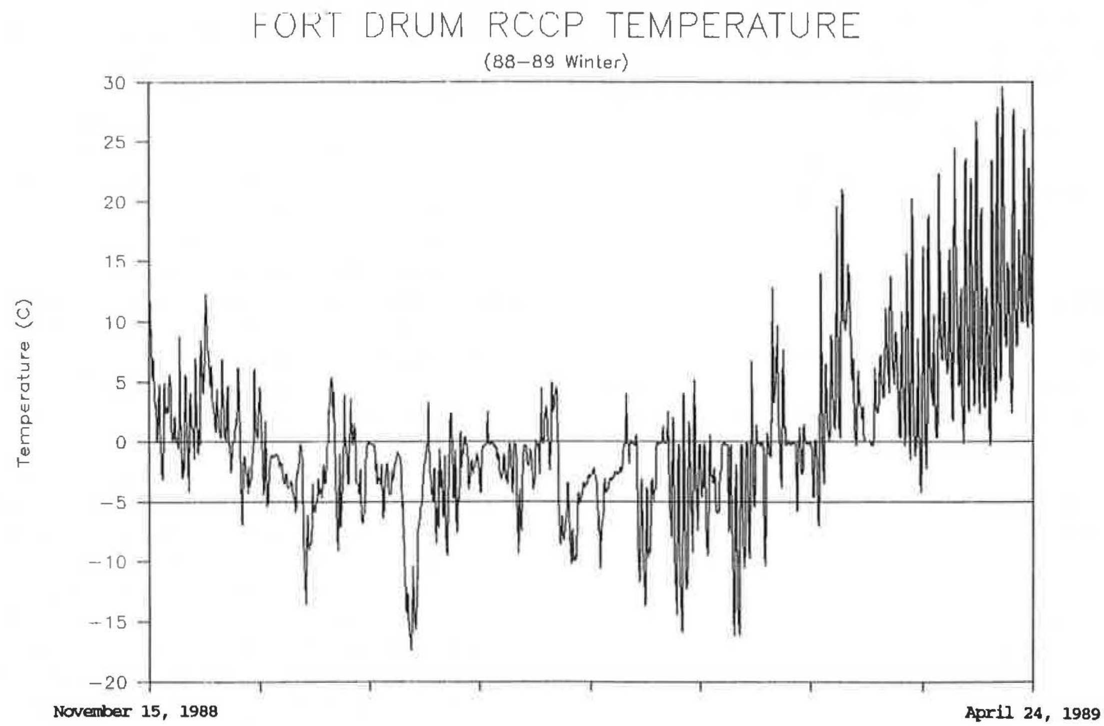
Figure 3 shows a profile of the number of F–T cycles that occurred at several depths through the RCC slab, the base course, and the subgrade. Notice that 65 F–T cycles were recorded in the air but only 24 cycles at 2 mm below the pavement upper surface.

An air F–T cycle and an in-pavement F–T cycle differ conceptually. Measurement of an air F–T cycle uses temperature data from sensors located at 1.37 m above ground level (standard weather thermometer level). It is based on the freezing point of pure water at atmospheric pressure. One F–T cycle occurs when the temperature falls below 0°C and then returns to above 0°C.

The in-pavement F–T cycle concept uses data from temperature sensors embedded in the pavement material at several depths. It is based on the temperature at which freezing of capillary water starts. This temperature was found to be approximately −5°C (*4*). Moisture in concrete is an alkaline solution rather than pure water. If a sealed container having a small air release valve is filled with water to 91.7 percent of its volume and then subjected to a sustained subfreezing temperature, the water will occupy 100 percent of its volume; the air will be expelled. If the same container is filled with more than 91.7 percent of its volume and then subjected to a sustained subfreezing temperature, the excess water will be expelled. If the container is a concrete capillary void critically saturated (more than 91.7 percent of its volume is filled with moisture) and the release valve is a gel pore, the excess moisture will be expelled through the pores when the water freezes, causing high hydraulic pressure. If this pressure exceeds the tensile strength of the cement paste, breakdown occurs. Therefore, in the in-pavement F–T cycle concept, a cycle



(a)

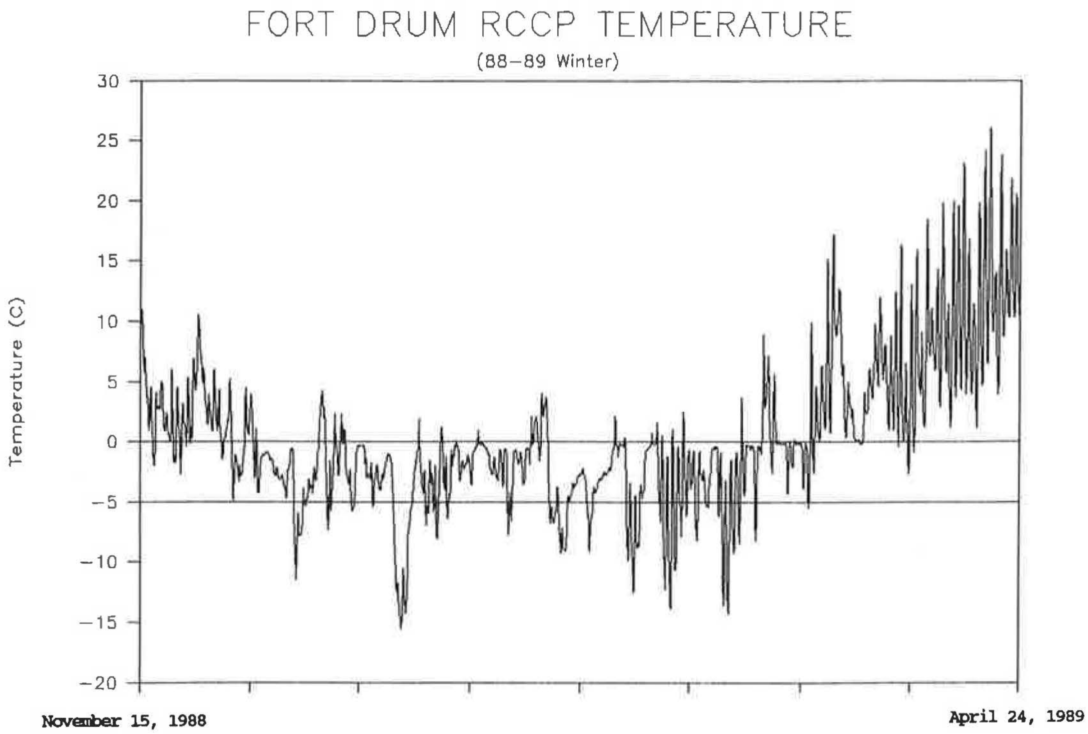


(b)

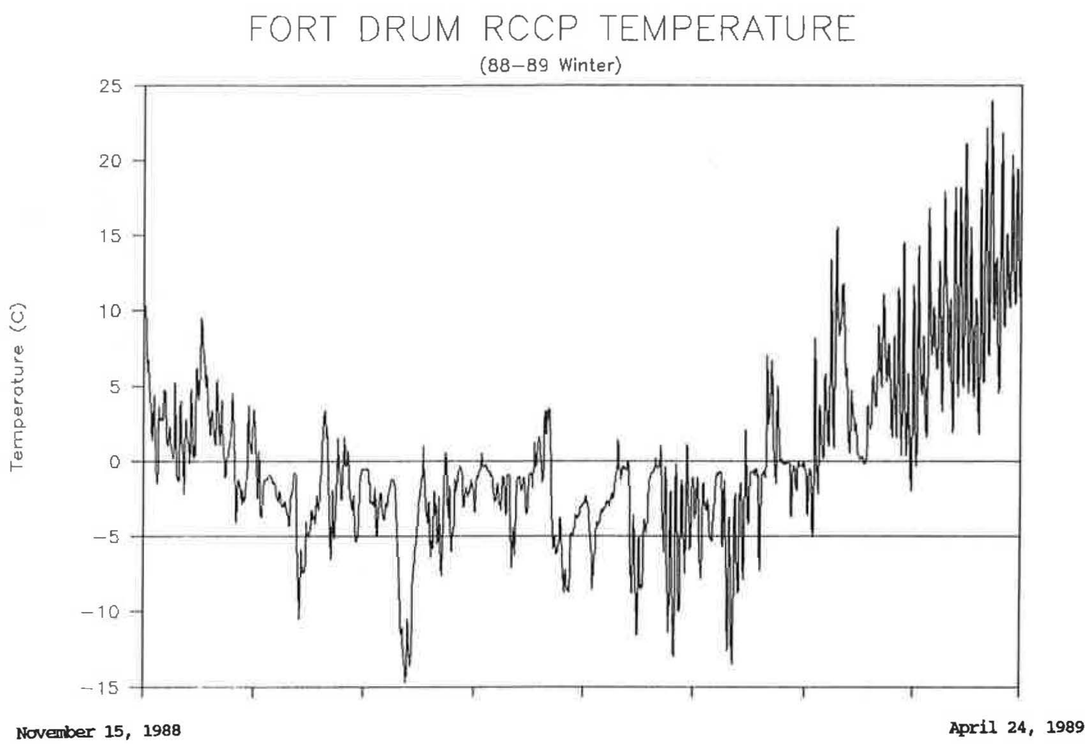
FIGURE 2 Temperatures (a) at 1.37 meters (4.5 ft) over the pavement surface; (b) at the pavement surface (2 mm into RCC); (c) at 0.05 m (2 in.) below the pavement surface; (d) at 0.076 m (3 in.) below the pavement surface; (e) at 0.15 m (6 in.) below the pavement surface; (f) at 0.25 m (10 in.) below the pavement surface; (g) in the granular base 0.05 m (2 in.) below the RCC-base interface; (h) at 0.86 m (34 in.) below the pavement surface, within the glacial till subgrade; and (i) at 1.47 m (58 in.) below the pavement surface, within the glacial till subgrade.

FIGURE 2 ***(continued on next page)***

FIGURE 2 *(continued)*



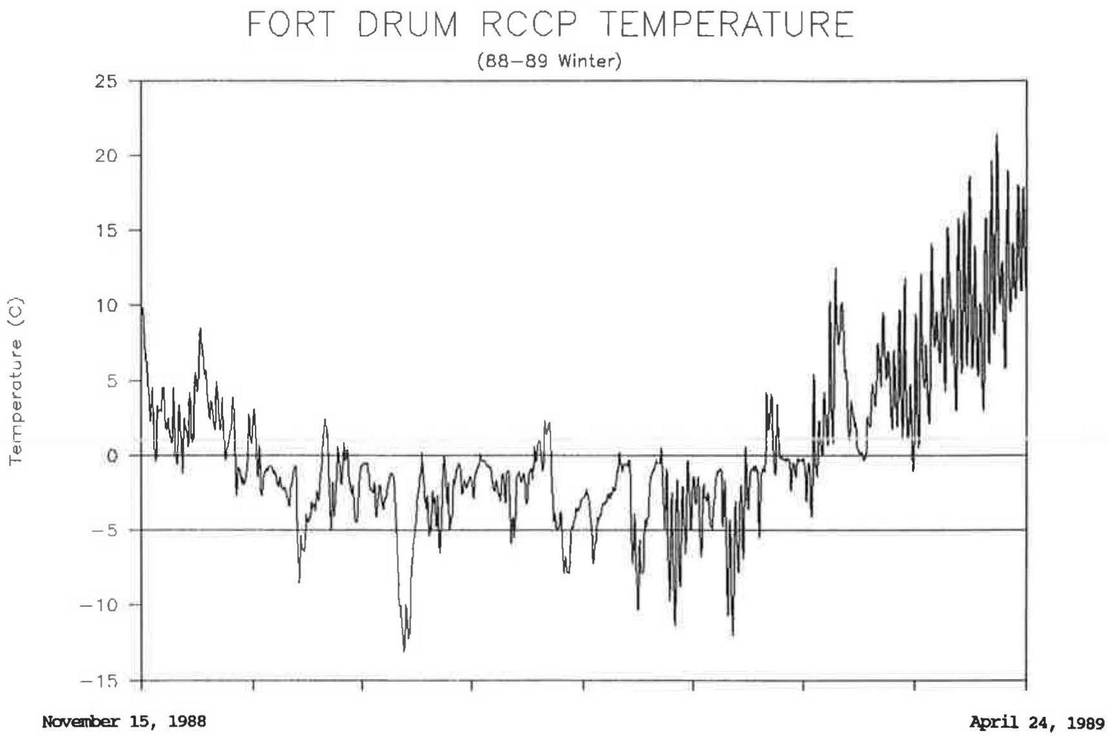
(c)



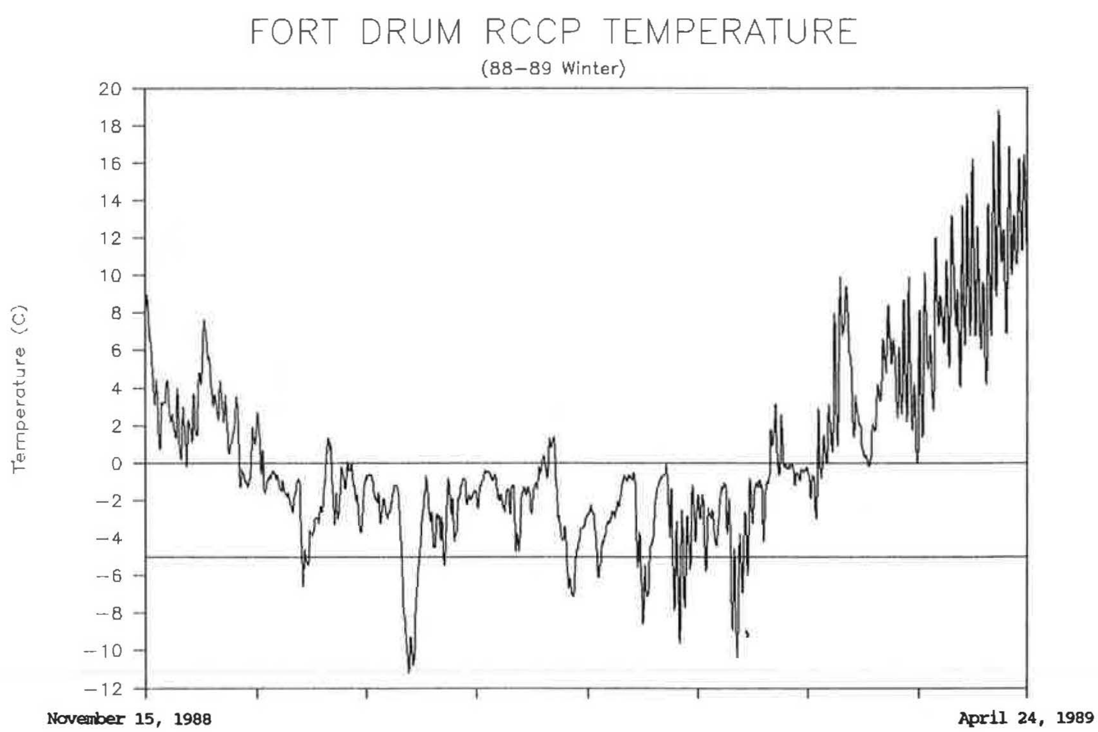
(d)

FIGURE 2 *(continued on next page)*

FIGURE 2 ***(continued)***



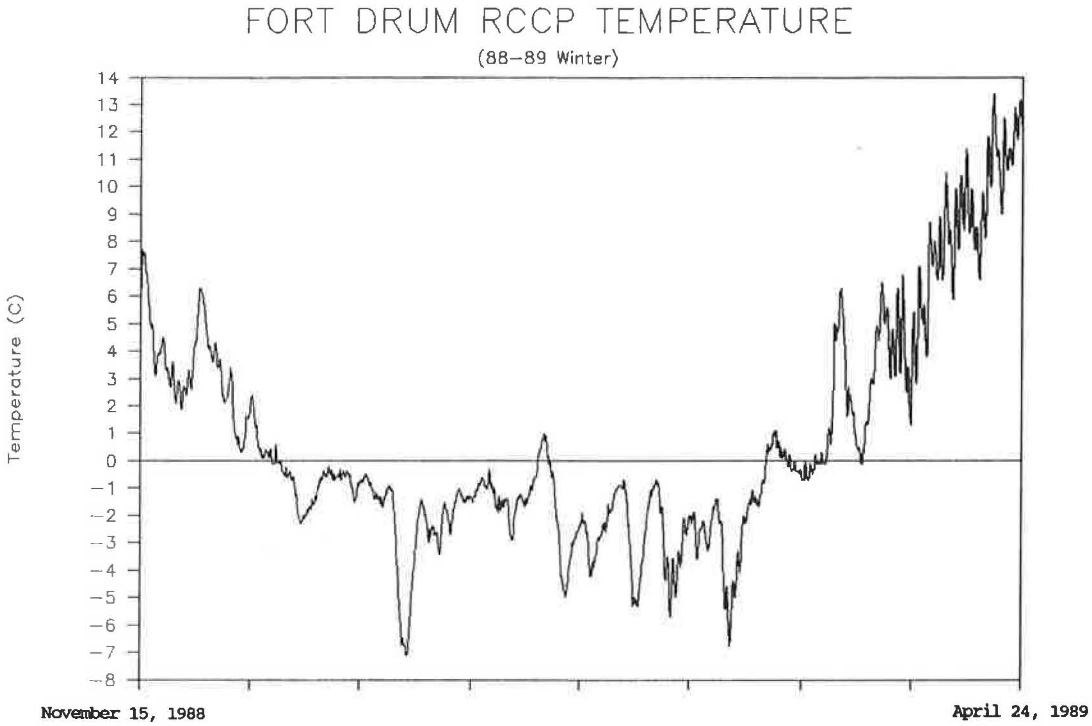
(e)



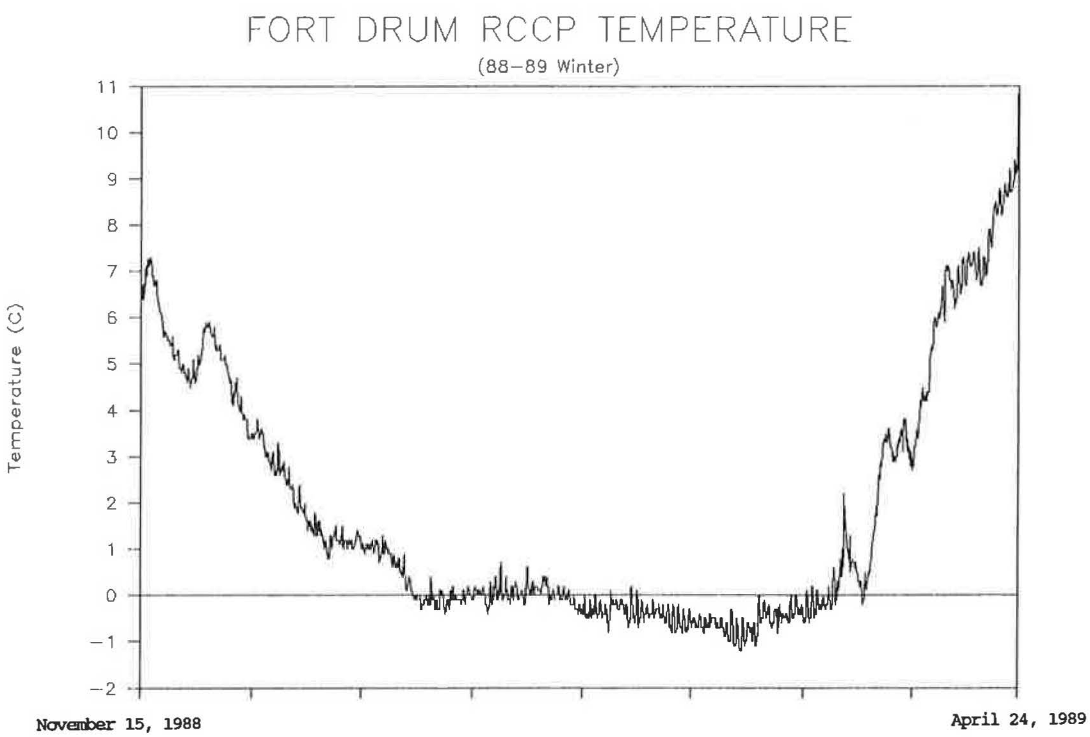
(f)

FIGURE 2 ***(continued on next page)***

FIGURE 2 ***(continued)***



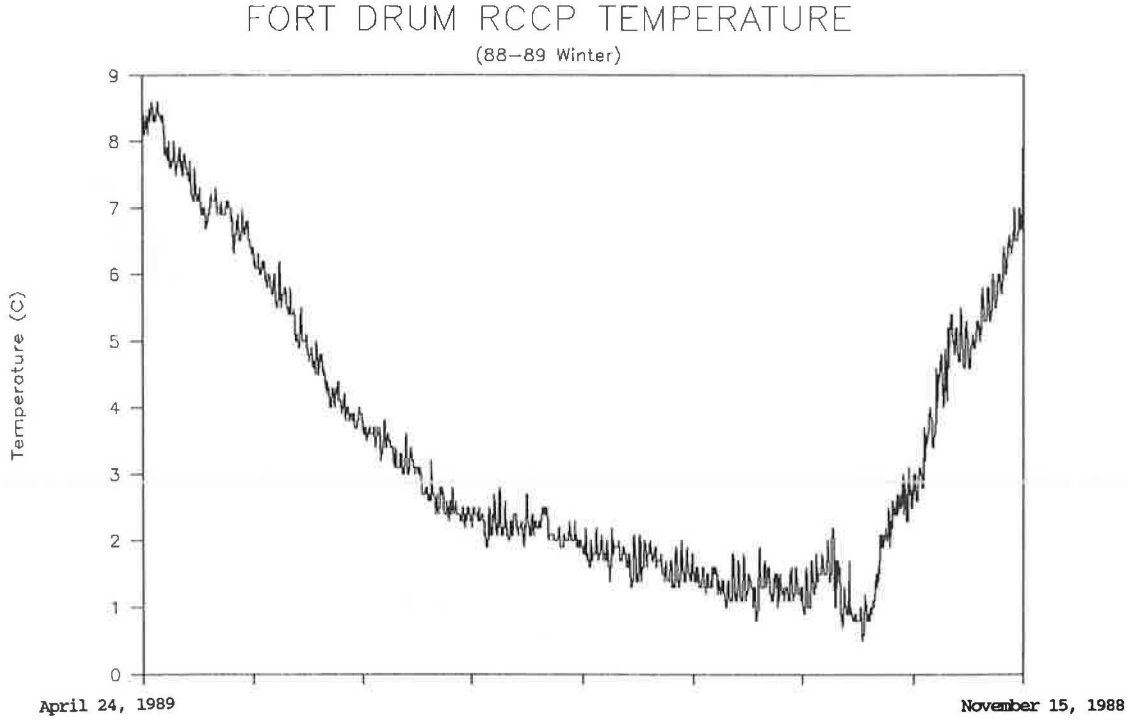
(g)



(h)

FIGURE 2 ***(continued on next page)***

FIGURE 2 *(continued from previous page)*



(i)

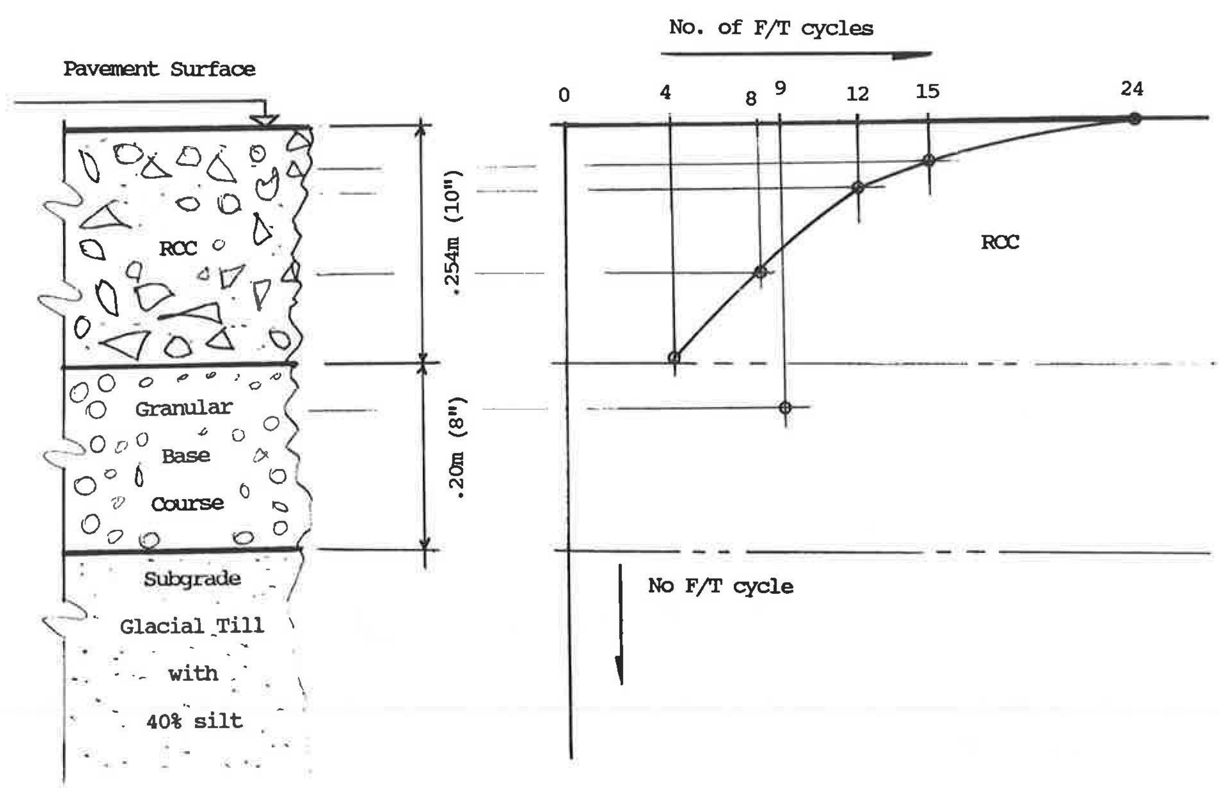


FIGURE 3 **Fort Drum RCC pavement freeze-thaw cycle profile, 1988-to-1989 winter.**

occurs when the temperature falls below $-5°C$ and then goes above 0°C.

Typically, as occurred here, the density of an RCC pavement decreases gradually from top to bottom. In Figure 3, the number of F–T cycles decreases in the same manner. Thus, although the lower density at the lower levels reduces the F–T durability of the material, the number of F–T cycles is also smaller at those depths.

Future Research

Using the RCC technology in large projects commonly permits savings of about 30 percent compared to alternative paving methods. This advantage explains the growth in acceptance of RCC construction. The F–T durability concern has diminished in view of the results from the Fort Drum field study. In 1990, the U.S. Army Corps of Engineers, Pennsylvania State University, the Pennsylvania Department of Transportation, and several private firms initiated a joint research project intended to introduce the RCC technology to high-speed, heavy-load highways.

CONCLUSION

RCC is an economical construction method appropriate for low-traffic, heavy-load pavements. Its overall engineering properties are similar to those of a conventional PCC (*5*). A quality control and quality assurance program must be implemented to ensure that strength, density, smoothness, and texture requirements are met. The spacing and location of saw-cut shrinkage and dilation joints must be carefully designed considering the location of utilities and any other discontinuity. In most cases, density is the key RCC quality control parameter. Density in the vicinity of construction joints tends to be lower than elsewhere, which frequently calls for additional compaction. If proper density is not achieved, spalling may soon occur. The number of cold joints may be minimized by keeping the hauling, paving, and compaction operations within the initial setting time. Proper curing practice is essential to avoid excessive shrinkage cracks and shallow micro-cracks, which lead to premature surface deterioration.

The conceptual distinction between the number of F–T cycles of the air moisture and the number of F–T cycles of the moisture inside the concrete is essential to evaluate the F–T durability of pavement materials properly. Figure 3 shows that the number of F–T cycles that moisture in the concrete pavement experiences is substantially smaller than that of the moisture in the air.

Research at CRREL has proven that the F–T durability of properly constructed RCC is good (*3*). CRREL is laboratory testing core and beam samples from the Fort Drum RCC pavement to verify their F–T durability. The test results were not available as of this writing, but the performance of the Fort Drum RCC pavement at the end of two winters and 1 year of service is satisfactory. No major distress has been observed.

The acceptance of RCC as a paving technology is growing rapidly, motivated by savings on the order of 30 percent and faster construction. In 1989, General Motors built 544,000 m^2 (approximately 135 acres) of RCC pavement at its new Saturn automobile plant in Tennessee. In 1990, the Massachusetts Port Authority (MASSPORT) plans to expand one of its large RCC pavements in Boston. Government and industry are working together to bring the advantages of RCC to our national highway system, making possible enormous savings in construction and maintenance costs.

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