Roller-Compacted Concrete for Heavy-Duty Pavements: Past Performance, Recent Projects, and Recommended Construction Methods

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ABSTRACT

Roller-compacted concrete (RCC) for pavements combines the technologies of cement-treated aggregate base (soil-cement) and portland cement concrete to produce a rigid slab of moderately high strength capable of carrying heavy wheel loads. Aggregate should be well-graded gravel or crushed rock, 100 percent passing the 7/8-in. (22-mm) sieve. Fine aggregate up to 14 percent passing the No. 200 (75-μm) sieve is acceptable. RCC for heavy-duty pavement has been used in British Columbia since 1976. The first installation was a 4-acre (1.6-hectare) log-sorting yard on Vancouver Island. Since that time 10 other RCC heavy-duty pavements have been built. In 1983 a coal storage area using RCC was the first project in a severe winter climate. In 1985 RCC was used for container storage areas in Houston, Texas, and Tacoma, Washington. The U.S. Army Corps of Engineers built heavy-duty RCC pavements to carry military vehicles at Fort Hood, Texas, and Fort Lewis, Washington. An aircraft parking area was built at Portland, Oregon--the first use at an airport. Some of the most significant projects that have been built since 1976 are reviewed and the construction process is described.

Roller-compacted concrete (RCC) has been used over the last 10 to 12 years in several parts of the world, primarily in water control structures. During that same period, a soil-cement type mixture with 12 to 14 percent portland cement content was being used for heavy-duty pavements in the forest industry of British Columbia, Canada. Because the materials and mixing process for both the dams and pavements are similar, the term "roller-compacted concrete" has been chosen to describe the heavy-duty pavement construction process.

It is important for the reader to have a clear understanding of what is meant by roller-compacted concrete in reference to heavy-duty pavements. RCC for paving differs from its application in water control structures in the following respects:

- The surface of RCC pavement is subjected to abrasion from traffic, log stackers, container carriers, and military vehicles;
- In winter climates, RCC must withstand the action of freezing and thawing cycles and the possible application of deicing salt; and
- RCC heavy-duty pavement has a much higher portland cement content than that used in dams. Fly ash is sometimes used in the range of 15 to 20 percent by weight of total cementitious materials.

The following definition of RCC heavy-duty pavement is suggested(1): the mixture of

1. Aggregate (natural gravel or crushed rock), which is graded from 100 percent passing the 7/8-in. (22-mm) sieve to a maximum of 14 percent passing the No. 200 (75-μm) sieve (note: in two-layer construction, the maximum size of coarse aggregate may be increased to 1 1/2 in. (40 mm) in the base layer);
2. Type I (Type 10 in Canada) portland cement (may include other cementitious additives such as fly ash);
3. Water in the quantity required for maximum density; and
4. Other additives, such as accelerators, retarders, and water reducers.

The mixture is blended into a heterogeneous mass of zero slump. Placement is by asphalt paving machine and compaction is achieved with steel-wheel and rubber-tired rollers.

RCC heavy-duty pavements may be single or multiple layers depending on slab thickness and the capacity of the placing equipment. The pavements contain a high portland cement content (12 to 14 percent by weight of aggregate) in the top layer for freeze-thaw durability and wear resistance. To assure a smooth, dense surface, the maximum coarse aggregate size in the surface layer should not exceed 7/8 in.

In multiple-layer construction, the portland cement content of the bottom layer may be reduced to 6 to 8 percent by weight, similar to ordinary cement-treated aggregate, because wear resistance is not a factor.

EARLY RCC PAVEMENT PROJECTS

The first roller-compacted concrete heavy-duty pavements in Canada were built in British Columbia in the mid-1970s by the forest industry. In response to pressure from the provincial government to reduce the amount of wood debris entering the water from coastal log-sorting operations, the forest industry expanded its program of construction of dry-land log sorts. The goal was total elimination of log sorting in the water. A number of dry-land log sorts were already in operation that had asphalt or gravel surfacing.

The asphalt did not perform well when subjected to hot summer temperatures, hydraulic fluid and fuel spillage, and damage from equipment forks. On the

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unpaved surfaces gravel was always being lost when wood debris was cleaned off the surface. The wood debris could not be burned when contaminated with gravel. The forest industry was ready for an alternative paving system that could solve these problems.

RCC appeared to offer the solution to most of them. RCC is not affected by summer temperature; petroleum products do not attack it; equipment forks cannot gouge it; and debris cleaned off the surface is not contaminated and thus is completely burnable.

RCC has another built-in benefit: it gains strength with age. New and higher-capacity equipment is constantly being introduced into the logging industry, which means higher axle loads. The RCC property of strength gain with age offers a factor of safety to the user at no additional cost.

British Columbia Forest Products, one of Canada's largest integrated forest products companies, took all these factors into account in 1976 when planning the 4-acre (1.6-hectare) dry-land log sort at Caycuse, Cowichan Lake, Vancouver Island. It was decided to build the entire pavement structure in cement-stabilized aggregate. The slab thickness of 14 in. (355 mm) required placement in two lifts. The top lift had a cement content of 8 percent by weight. At that time 13 percent was an arbitrary figure based on engineering judgment and some laboratory testing of beams and cylinders.

The pavement was placed into service in the fall of 1976. The paved area was doubled in 1979, again using RCC. The Caycuse dry-land log sort stands out as an excellent example of RCC performance. Surface maintenance over 9 years of constant use has been limited to replacement of a few areas of delamination between layers and patching of some raveled joint areas where compaction of the surface during placement was inadequate. British Columbia Forest Products reports that the Caycuse dry-land log sort is one of their most cost-efficient log-sorting operations.

MacMillan Bloedel Ltd., another of Canada's large integrated forest products companies, investigated RCC for some of their logging operations in the Queen Charlotte Islands off the north coast of British Columbia. The ability to use substandard aggregate, available locally at low cost, along with fewer handling problems associated with portland cement compared with liquid asphalt were perceived as advantages. By the end of the 1970s MacMillan Bloedel had four dry-land log sorts in service in the Queen Charlotte Islands and another at Port McNeil on northern Vancouver Island.

All of these projects used a slab thickness similar to the Caycuse pavement--14 in. constructed in two layers with a portland cement content of 13 percent by weight of aggregate.

The last of what could be considered the first RCC projects was built by Crown Forest Industries (formerly Crown Zellerbach Ltd.) at their sawmill and plywood plant at Coquitlam, British Columbia (near Vancouver), in 1979. Here raw logs are lifted from the Fraser River and stored until used by the mill. The loaded log stackers place the timber in storage fingers off a main traveled runway. Satisfaction has been such that two expansions of the storage area using RCC have been built since 1979. Although the RCC was slightly higher in first cost than an asphalt alternative, less expensive two-wheel drive log stackers operating on a smooth, hard surface could be used in place of four-wheel drive machines. The saving in equipment cost justified the higher first cost of the RCC pavement.

THICKNESS DESIGN

Slab thickness design for the early RCC pavements in British Columbia relied on engineering judgment, which was based on experience from heavy-duty cement stabilized base and portland cement concrete paving projects. This "super soil-cement," with cement content of 13 percent, was undoubtedly stronger than the normal cement-stabilized base mixture but little other engineering information about the material was available. Typical slab thickness was in the range of 12 to 14 in. (300 to 350 mm).

The thickness design method currently being used for heavy-duty RCC pavements in Canada is the Portland Cement Association (PCA) airport thickness design procedure (2).

It is assumed that the RCC exhibits flexural strength properties similar to those of normal slump concrete. However, this may attribute a higher degree of consistency to the RCC mix than should be expected. The whole process of aggregate selection, cement and water addition, and mixing of the materials in a pugmill is less precise than that for regular concrete. Therefore, to account for potential mix deficiencies, the flexural stress value selected in the design procedure should be lower than that for a typical slump concrete. This could be applied as a reduction coefficient to the stress value. A reduction of the order of 10 to 15 percent is suggested.

One of the variables considered in rigid pavement design is the magnitude and frequency of wheel loadings. Unlike a highway where this information can be obtained from traffic and loadometer surveys, the traffic pattern on a dry-land log sort, for instance, is difficult to predict. Initially the owners will have a layout for the various operations that will be performed; however, this layout may be changed in later years. Therefore, with the possible exception of some of the remote parts of the yard, it must be assumed that the maximum wheel load and unlimited applications of load will be needed over most of the surface.

A typical log-stacker load is 220,000 lb (100 000 kg). Container sidelift equipment has a loaded-axle value of 250,000 lb. Table 1 shows a summary of core samples from several British Columbia projects. The values obtained support the view that RCC has strength properties similar to those of regular concrete and that therefore concrete pavement thickness design methods may be valid for RCC as well.

MIX DESIGN

The design of an RCC pavement has its origin in cement-treated aggregate base technology. The first RCC pavement at the Caycuse dry-land log sort was modification of a cement-treated base specification.

Through experience it is now recommended that the maximum size of coarse aggregate should not exceed 7/8 in. to provide a dense and smooth operating sur-

TABLE 1 Typical RCC Core Strengths from Some British Columbia Projects

Project	Year Built	Date of Sample	Avg Compressive Strength (psi)
Caycuse log sort, Vancouver Island	1976	1980	4,210
Caycuse log sort, Vancouver Island	1976	1984	5,880
Fraser Mills log yard, Vancouver	1982	1983	4,700
Bullmoose Coal Mine	1983	1983	2,220[a]
Fraser Surrey Dock, Vancouver	1984	1984	4,570[b]

Note: 1 psi = 6.89 MPa.

[a] Values are average 56-day core tests. The cementitious portion of the mix contained 50 percent natural pozzolan.

[b] Values are for 28-day field-cured samples (Nov. 1984).

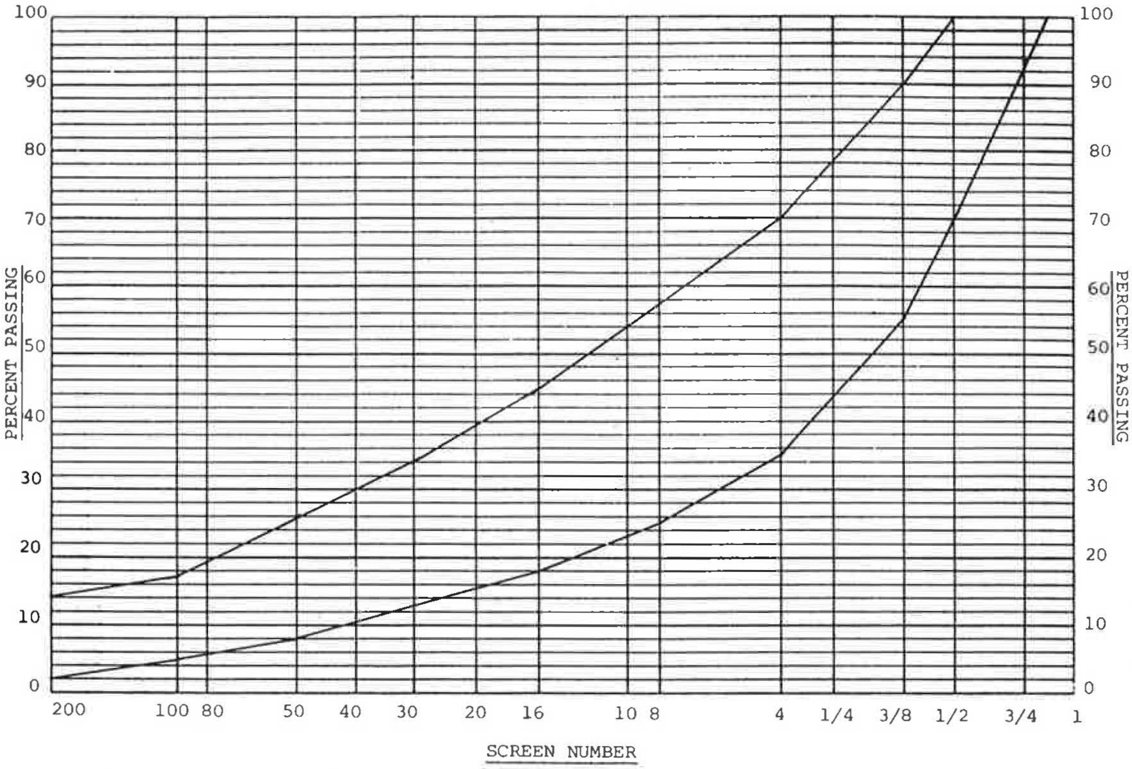

FIGURE 1 Typical aggregate gradation envelope for single-lift mix.

face. The fraction passing the No. 200 sieve can be as high as 14 percent. In two-lift construction the maximum coarse aggregate size in the base layer can be increased to 1 1/2 in. (40 mm) because a smooth operating surface is not required. Figure 1 shows a typical aggregate gradation envelope for a single-lift mix.

Water content for the mix is selected on the basis of optimum moisture content for maximum density and not on the water-cement ratio. Hydration of the portland cement is a secondary effect of the presence of the water. Compaction at the correct moisture content is vital during the placing operation to ensure a high-density surface finish and close surface-level tolerance.

Although the cement content on the early projects was selected rather arbitrarily at what was considered to be a safe level, materials engineers now approach selection of cement content on the basis of flexural strength of laboratory cast specimens. Typical 28-day flexural values of 600 to 700 psi (4.1 to 4.8 MPa) are attainable and frequently specified. Most samples are made on a vibrating table or using procedures for making and testing zero-slump concrete specimens (3). Whether this procedure truly represents field conditions for RCC in place is unknown; however, the error is probably on the side of safety.

The question of other additives to the RCC mix is often raised. Several of the projects in place have used fly ash (the Bullmoose Coal Mine loadout used a natural pozzolan at 50 percent of total cementitious content). Most have been in the range of 15 to 20 percent. It is suggested that pozzolanic additions be limited to 20 percent for pavements until further evaluation of field samples is made.

The need for an air-entraining agent in the RCC mix has often been discussed. It was included in some early projects; however, there is no conclusive evidence that freeze-thaw durability is improved. Other projects have used no air-entraining agent and are performing well in freeze-thaw environments.

CONSTRUCTION

The construction procedures involved in building an RCC pavement are not complicated. Common roadbuilding equipment is used, and although there are parts of the process that require particular attention, no specially skilled tradesmen are needed (4).

Because RCC heavy-duty pavement is a rigid slab, all of the load is carried in the slab itself. There is no need for a granular base, although a 6-in. (150-mm) lift of crushed gravel is often used as a working surface for fine grading and accurate thickness control of the RCC slab.

Subgrade preparation is no different than for other roadbuilding methods--uniformity of the subgrade should be ensured, soft subgrade areas should be removed, the water table should be kept out of the freezing zone where possible, and any fine-grained, frost-susceptible materials should be removed.

RCC is usually produced in a continuous-flow pugmill mixer. A premix-type concrete batching plant can be used, although the rate of production is slower. The mix-in-place method of blending portland cement with aggregate is not suitable for RCC construction and should not be used. It does not provide the necessary quality control or uniformity of blending of the portland cement and aggregate.

Care must be taken to minimize segregation while handling the RCC mix. Crushed aggregate is helpful in this respect. Discharging the mix into a holding hopper off the end of the pugmill belt and periodically emptying the mix into waiting trucks also reduces segregation.

Dump trucks are normally used to haul the mix to the paving site. A maximum elapsed time of 60 min after mixing is the usual specification controlling haul and placing. At the pavement site the RCC mix is placed by an asphalt paving machine, preferably the type with the oscillating-tamping screed rather than the vibrating-pan screed. Although some pavers are capable of placing material up to 24 ft (7.3 m) wide, it has been found that limiting the placing width to 12 to 14 ft (3.6 to 4.3 m) helps to reduce segregation. The augurs tend to segregate the mix at the greater placing width.

It must be stressed that on the basis of experience to date, the only placing equipment that is suitable for obtaining a quality RCC pavement surface is an asphalt paving machine. Graders, bulldozers, or other types of spreaders tear the surface during final finishing. Graders have been used successfully, however, to spread base-layer material.

The depth of lift that can be placed with the conventional asphalt paving machine is limited to about 10-in. (250-mm) uncompacted thickness. It should be noted that the thickness of the lift and the amount of compaction needed to bring it to the specified density have a significant bearing on the surface tolerance of the completed pavement. A typical 10-in. uncompacted lift will compress by about 1 to 1 1/2 in. (25 to 40 mm) under vibratory compaction. Some sections of the surface may become more compressed than others during rolling, which leads to unevenness in the final surface. It is reported that new heavy-duty pavers are capable of compaction over 90 percent of Modified Proctor density, leaving much less compaction required from subsequent rolling. They are also reported to be capable of much thicker lift placement, which in some cases will eliminate the need for two-lift construction.

In a discussion of surface tolerance it is important for owners and designers to have a clear concept of the type of equipment that will use the pavement and at what speed it will travel. A pavement that is perfectly satisfactory for the slow-speed operation of a container carrier may not be smooth enough for short-wheelbase trucks hauling the containers to the transfer area.

At the present time, RCC pavements are not recommended for moderate or high-speed traffic. Until the construction industry can consistently build RCC pavements to meet a surface tolerance of 1/4 in. (6.35 mm) in 10 ft (3 m) or less, RCC should only be used for heavily loaded industrial pavements with traffic at low operating speeds.

Compaction of the freshly placed RCC mix should follow immediately behind the placing operation without delay. The rolling sequence starts with vibratory steel-wheel equipment followed by a rubber-tired compactor. A nonvibrating steel roller may be used for final finish. In-place density is measured by conventional field methods, usually the nuclear densitometer.

When the design thickness of the slab is such that two-lift construction is required, the top layer must be placed on the same day as the base layer so that maximum bond between layers is obtained. No special procedures are used to bond the two layers together, but where temperature, wind, and humidity may dry out the surface of the base layer, it should be kept moist.

It has been found that density of the free edge can be improved by delaying compaction of the outside 18 in. (450 mm) for about 20 to 30 min after placement.

JOINTS

RCC exhibits normal concrete shrinkage properties. Spacing of shrinkage cracks is somewhat greater, however, generally 40 to 60 ft (12 to 18 m).

No attempt is made to form or sawcut control joints in an RCC pavement. On the basis of 10 years of observation of forest industry pavements, the joints show no serious distress and require minimum maintenance. On a dry-land log sorting yard, wood debris soon fills the joint space, thus acting like a joint filler.

Cold joints in an RCC pavement require special attention. These occur when construction stops at the end of a working shift and a vertical face remains along the final pass of the paver. Once compacted, this face should be cut back with a grader blade into compacted material and left for the night.

When construction starts the following day, the cut-back, hardened face should be sprayed with water immediately ahead of the first pass of the paver. On some projects a cement-water grout has been brushed onto the hardened face. Special care should be taken to ensure adequate compaction along this cold joint. Observation of existing projects in service shows that this area of the pavement is the most prone to deterioration.

The vertical construction joint between passes of the paver as the surface is placed does not require any special bonding treatment. Water spray should be available, however, in the event of severe drying conditions. Delay of edge compaction until the next strip of pavement is placed ensures good density at the longitudinal joint.

Manholes and catchbasins are usually boxed out and later set to grade with regular concrete.

Some engineers have considered the value of offsetting the vertical joint of the top lift by 3 to 4 ft (1 to 1.3 m) when two-layer construction is used. The value of good bond between lifts, so that the total slab acts as a single layer, cannot be overstressed. To leave a strip of base exposed for a day or more to gain the advantage of offset vertical joints in the base and top layers is unwise. It is recommended that (a) all base and surface layers be completed in the same working day and (b) the vertical joint be continuous through both layers.

When RCC is placed over large areas, the direction of paving should be parallel to the shortest dimension. Although this may appear contrary to the natural inclination of the contractor, it does ensure that cold joints left overnight are in the shortest direction.

CURING

RCC requires curing in the same way as regular concrete. Because the water content in the mix is established on the basis of optimum moisture content for maximum density and not the water/cement ratio, there is practically no free water available as a reserve for curing. Therefore water from an external source is vital to strength gain in the first days after placement.

Most projects built to date have used aluminum pipe irrigation systems with sprinkler heads to distribute the water. Although the initial cost may be high, once in place the system can be set up to operate automatically at minimum cost. On a dry-land log sort, water is usually available from a nearby stream or lake and can be obtained by using a small pump. A public water source could supply curing water for a container terminal or bulk storage pavement.

Time of year, daily maximum temperature, wind, and humidity all have a bearing on curing conditions. Cool fall weather with frequent rainfall could reduce the amount of curing needed, whereas hot, dry summer conditions may dictate constant sprinkler operation.

A water truck with spray bar is also an acceptable curing method, provided that the operator is well aware of the need to keep the pavement surface continuously wet.

Membrane-forming concrete curing compound can be used if the cost can be justified. Because of the more open nature of an RCC surface, the curing compound should be applied at the rate of 100 to 150 ft^2/gal (2.0 to 3.0 m^2/L).

The length of cure time is important. Once again the same factors affecting regular concrete apply. A minimum of 5 days' moist curing is recommended under normal summer temperatures. This could be reduced to 4 days in hot weather with full-time wet cure and should be extended to 6 days or longer in cool spring and fall weather conditions. In some cases, when the owner requires access as soon as possible, the cement content of the RCC mix can be increased by 3 to 4 percent to provide early strength gain in the slab. In other cases, maximum loads should be restricted for the first week or two while the slab gains strength.

COST

The aggregate for RCC can have a very wide gradation curve (Figure 1). Many sources can be considered for RCC raw material that would otherwise be unsuitable for regular gravel base course. It has been found that aggregates with as much as 14 percent passing the No. 200 (75-µm) mesh sieve produce compressive strengths of 4,000 psi (27.6 MPa) or more at 28 days.

The acceptability of previously rejected gravel pits also means shorter haul distances, a further cost saving. The reduced need to open new aggregate pits might eliminate the need for environmental impact studies, surely a significant cost benefit.

The total thickness of an RCC pavement is much less than that for a flexible pavement of the same load-carrying capacity. In cut situations this means a saving in excavation cost. In fill locations it means that lower-cost fill material can be placed to within a few inches of the final RCC base grade, thus saving the cost of expensive gravel.

Figure 2 shows a typical cost estimate format that an engineer might follow. The figures are relevant to coastal British Columbia in 1985.

COST ESTIMATE FORMAT

Cost Information:

	$/Ton
Portland cement, Type I	86.00
Aggregate, purchase, haul, crush, stockpile at plant	4.00
Process through central mix plant	2.30
Set up and dismantle cental mix plant (Lump Sum)	20,000.00
Place RCC mix through paver, including compaction	1.50
Haul mix on site	1.00
Cure	0.50

Engineering Information:

Area of the project 8,000 sq. yd.
Traffic and loading data (Supplied by the designer)
Subgrade information (Specific to the project)
RCC slab thickness (assumed values) T = 12 in.
T_1 = 4 in.
T_2 = 8 in.
Portland cement content (by weight of aggregate)
T_1 = 12%
T_2 = 8%
Aggregate unit weight 2 Tons/cu. yd.

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Cost Estimate		$/Ton of Mix
1. Supply aggregate into stockpile at mixing plant site		4.00
2. Portland cement content:		
Top layer: .12(4/12 x 2000) x ($.043) = 3.44		
Base layer: .08(8/12 x 2000) x ($.043) = 4.59		
Total:		8.03
3. Process through mixing plant	2.30	
4. Place, compact, and finish	1.50	
5. Cure pavement (water)	0.50	
Total: (process, place & compact, cure)		4.30
6. Haul mix on site		1.00
7. Set up and dismantle central mix plant: $20,000/(8000 x 12/36) x 2) =		3.75
Subtotal:		21.08
Add: Engineering (5%), Profit (15%)		4.37
Total Cost per Ton		$25.45
Cost per sq. yd.		$16.97

FIGURE 2 Typical cost-estimate format.

RECENT DEVELOPMENTS

RCC Overlay: Honeymoon Bay, British Columbia

In the summer of 1985, 4 acres (1.6 ha) of an existing asphalt dry-land log-sorting yard were overlaid with 11.5 in. (292 mm) of RCC. This was the first use of RCC as an overlay to an existing pavement in Canada.

The original yard was built in 1974 and is located within a few miles of the first RCC log sort at Caycuse, as noted elsewhere. The flexible pavement structure was 4 in. (100 mm) of asphalt on 18 in. (450 mm) of granular base. Plate-bearing tests in the spring of 1985 indicated k-values from 200 pci to less than 100 pci. Numerous failures in the original pavement had been patched with both asphalt and concrete.

The equipment using the yard was the Wagner L90 log stacker.

The gravel aggregate was 3/4 in. (20 mm) crushed material with 8 percent passing the No. 200 mesh sieve. Cementitious content was 12 percent by weight, composed of 10 percent portland cement and 2 percent fly ash. Laboratory testing before the job yielded flexural strengths in the range of 650 psi (4.5 MPa) at 28 days.

The mixing-plant capacity was 500 tons/hr. Because the RCC slab was designed for a thickness of 11.5 in. (292 mm), the contractor planned for two-lift construction. The existing failed asphalt surface was first sprayed with water. The first lift of RCC mix, approximately 6 in. (150 mm) thick, was end dumped onto the old surface and spread with a motor grader. A vibratory steel roller then compacted this base layer. Within a few minutes, the asphalt paver placed the surface layer to final grade and a steel vibratory roller completed the work.

Freeze-Thaw Testing

During 1984 and 1985 the Cold Regions Research and Engineering Laboratory of the U.S. Army Corps of Engineers carried out a program studying the freeze-thaw durability of RCC at their facility in Hanover, New Hampshire. A full report will soon be published by the Corps of Engineers. Until now, severe cold weather experience has been limited to one project in northern British Columbia--the Bullmoose Coal Mine at Tumbler Ridge. The design depth for frost in this area is 8 ft (2.4 m). Most other RCC log yards are in coastal areas where numerous freeze-thaw cycles occur but where winter temperatures are not severe.

Portland International Airport

Early in 1985 the Port of Portland, operators of the Portland, Oregon, International Airport, awarded a contract for construction of 9 acres (3.6 hectares) of parking area for commercial jet aircraft at the Portland Airport. The general contractor was Intertec Contracting Company of Portland, Oregon, and the subcontract for placing the RCC was awarded to Jack Cewe Limited of Vancouver. The Cewe Company has built most of the RCC projects in Canada.

The Portland Airport project was the first use of RCC heavy-duty paving at an airport facility in North America. Thickness of the slab was 14 in. (355 mm). The aggregate was 3/4 in. crushed gravel and the cementitious content was 14 percent, consisting of 10 percent portland cement, Type I, and 4 percent fly ash.

One of the outstanding features of this project was the substantial cost saving (approximately 30 percent) over the conventional flexible pavement that was tendered as an alternative at the time of bidding. The flexible alternative included 6 in. (150 mm) of asphalt pavement on 24 in. (600 mm) of granular base. (See paper by Abrams et al. in this Record.)

Fraser River Harbour Commission

The Fraser River empties into the Strait of Georgia near Vancouver. The course of the river through the interior of the province is such that it continuously picks up thousands of tons of sand and silt, which settle out as the river slows and discharges into the ocean. The river is navigable by ocean vessels for several miles upstream from the Strait of Georgia to the city of New Westminster, a few miles south of Vancouver.

In 1984 the Fraser River Harbour Commission decided to build an experimental entrance road into one of the dock areas. The aggregate was dredged sand, which is continuously removed from the river to keep shipping channels open. If the waste sand could be used successfully as RCC raw material, an extremely economical heavy-duty pavement could be produced.

The test project was on a very small scale, 2,500 tons, which resulted in some problems in consistency of mixing and placing. Furthermore, the work was carried out in November when nighttime temperatures dropped to freezing. Although part of the work incurred some frost damage and required a subsequent asphalt overlay, about half of the project was highly successful and remains in service as an exposed RCC pavement.

Compressive strength of the RCC at 28 days was 4,570 psi (31.5 MPa). Typical shrinkage crack spacing of approximately 50 ft (15 m) occurred. The 10-in. (250-mm) slab was placed with an asphalt paving machine in two layers. The aggregate was a blend of 50 percent natural gravel, 100 percent passing the 1-in. (25-mm) sieve, and 50 percent poorly graded river sand, predominantly in the No. 40 to No. 80 sieve sizes. There was very little minus No. 200 material.

In spite of the poor gradation of the mixture, good compaction was possible when 12 percent portland cement was added to the mix. In appearance the high sand percentage resulted in a very dense sandy surface. Although the pavement has only been exposed to traffic for 12 months, early observations indicate that it is resistant to abrasion and freezing and thawing.

CONCLUSION

Use of RCC for heavy-duty pavement grew from cement-treated aggregate base technology. Increasing the portland cement content of the mixture caused the surface of the pavement to gain abrasion and freeze-thaw resistance and eliminated the need for a protective surface. This "super soil-cement," which is now called roller-compacted concrete, is serving the needs of the forest industry in British Columbia by providing an economical, low-maintenance pavement that reduces equipment breakdowns, increases operating speeds, and generally improves the economics of harvesting trees.

In the last 3 years RCC use has expanded to military installations, container yards, airports, and heavy equipment storage. By the end of 1985 it was estimated that the equivalent of over 300 acres (120 hectares) was in place in the United States and Canada, with approximately 70 percent of that area having being built in the last 18 months of that period. Projects totaling over 100 acres are now in various stages of design and construction.

Enthusiasm must be tempered with caution. RCC is still an industrial pavement to be used for slow-speed traffic. The surface texture of RCC is more open than the dense, closed surface that most engineers associate with normal portland cement concrete. What some may consider to be a pavement with inferior appearance is frequently less expensive than other alternatives.

Three areas need further study and development:

1. A simple and reliable field method is needed for determining the quality of RCC in place. It may be that some of the present nondestructive methods of evaluating normal concrete can be applied to RCC. Work is in progress on a modified rebound hammer technique that may be applicable to RCC testing.
2. A method of sampling the fresh RCC mixture for laboratory testing is needed. At this time the method for sampling and testing zero-slump concrete is frequently used. Other engineers use field-molded beam specimens. A program to compare field-molded samples by various methods with beams or cores obtained from RCC pavements in place could provide valuable data on field control.
3. A placing method is needed that will ensure attainment of the specified density when RCC is placed in layers thicker than 10 in. There is lack of agreement among engineers about the ability to adequately compact RCC in single-layer construction of 14 to 16 in. (355 to 400 mm). New placing equipment now being introduced may provide the solution. Further studies to answer the question of density versus layer thickness are needed.

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