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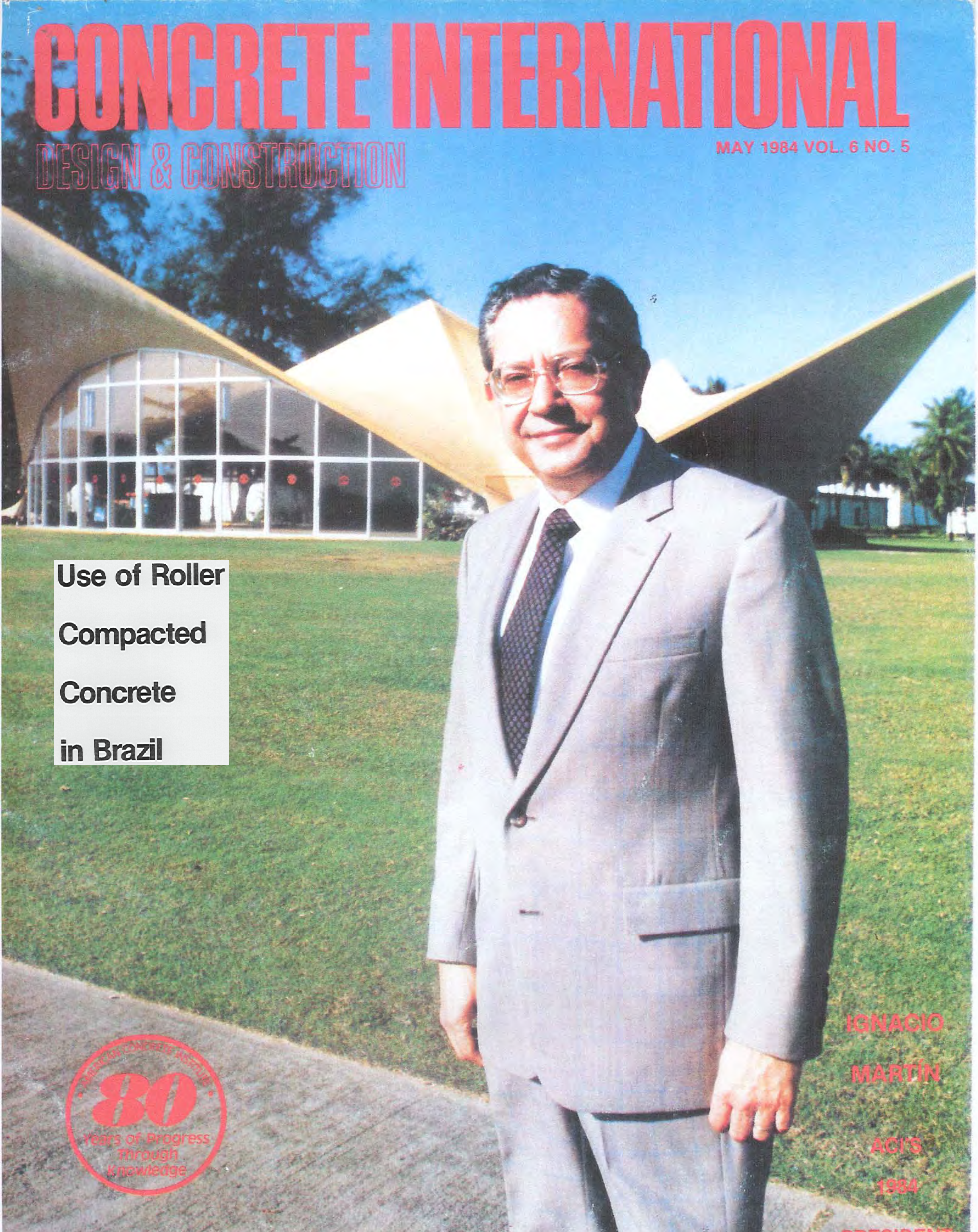

Use of Roller Compacted Concrete in Brazil

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General view of rollcrete placement at the Itaipu project.

Use of Roller Compacted Concrete in Brazil

by Francisco Rodrigues Andriolo, Gustavo Reis Lobo de Vasconcelos, and Humberto Rodrigues Gama

Roller compacted concrete (RCC) has been used in Brazil since 1976 and has been subjected to a number of studies. RCC allows continuous placement with the possibilities of time and cost economies in the construction of concrete gravity dams in that South American nation. This article also deals with laboratory studies, mix proportioning, placement procedures, and test methods.

Keywords: compacting; concrete dams; costs; **gravity dams; mix proportioning; placing; roller compacted concrete; tests;** vibration.

With the construction of large projects in Brazil, mainly hydroelectric power structures, technologists have continually searched for materials and new construction methods for greater concrete placement in shorter periods of time.

This research has been directed at materials such as cements with low heat of hydration, use of coarser aggregates, use of pozzolanic material, and concrete cooling methods to minimize or even totally avoid the cracking of concrete.

In recent years, attention has also been directed at new mix techniques for the construction of rock fills and embankments often necessary for mass concrete projects. The result of this attention has led to roller compacted concrete, commonly referred to as RCC or rollcrete.

RCC, in which a no slump concrete is used with a sandy aspect, permits the use of equipment in the construction of rock fills at a continuous placement. This leads

Rollcrete was applied to a permanent structure for the first time in Brazil at the Tucurui Dam navigational lock.

to the possibility of time and cost economies in the construction of concrete gravity dams.

RCC evolution

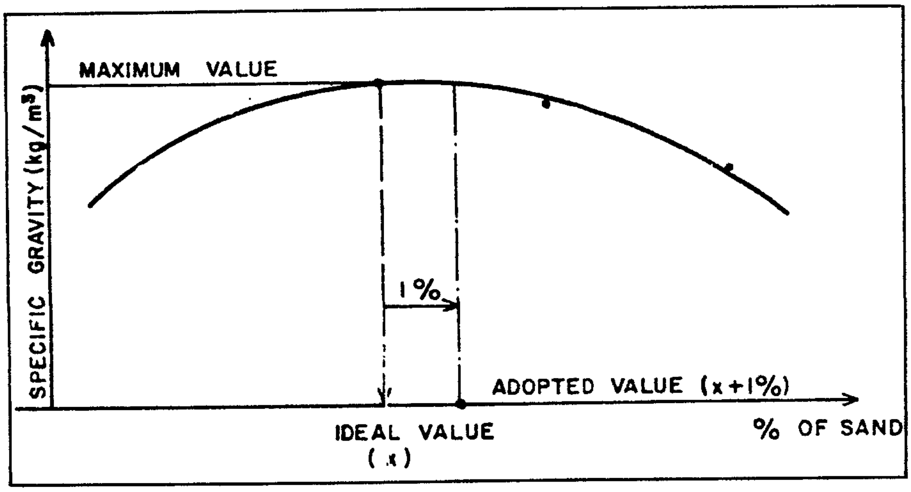
Rollcrete was used for the first time in Brazil in 1976 in the paving of warehouses constructed at the site of the Itaipu Dam. The following year, at a project in Sao Simao, a rollcrete application was used for the filling of low intake diversion galleries.

Both of these projects aroused the curiosity of designers, owners, and contractors and led to studies of other possible uses of rollcrete.

In early 1978, the material was again used at the Itaipu project, this time for back filling of an access slope to the foundations of the diversion structures. The volume applied was about 26,000 m^3.

At the same time, an access slope to the assembly area at Itaipu was paved with rollcrete.

Beginning in 1979, testing and studies were performed at the Tucurui Dam project to determine possible applications of rollcrete to the structures there. These studies resulted in the April 1982 placement of rollcrete at the upstream head of the blocks of a navigation lock at Tucurui.



A consolidation test was adapted to determine the specific weight versus sand percentage of the total aggregate.

Technical features

The rollcrete used in these projects was a dry concrete consolidated by external vibration of a roller. The major difference from conventional concrete is in consistency.

Rollcrete to be consolidated must be sufficiently dry in order to support the weight of vibration equipment but also sufficiently wet to permit adequate distribution of the paste in the concrete mass during mixing and consolidating.

Fresh rollcrete presents some differences from conventional concrete. Any granular mix probably can be consolidated until it reaches maximum density under appropriate vibration; however, this vibration must be stronger than that for conventional concrete.

Aggregates

The choice and control of aggregates influence the quality and properties of rollcrete as they do in conventional concrete. However, aggregate gradation for rollcrete is not as important for the desired consolidation due to the difference in consolidation equipment that is used.

At Itaipu, the coarse aggregate was obtained by crushing black basalt from the excavations for the foundations of the structures. Before processing the basalt, the materials were preselected by routine soundness tests in function of several lava flows.

The low absorption values (about 1 percent) and Los Angeles abrasion loss (less than 15 percent) as well as high specific weight of more than 2.9 ton/m^3 indicate the good quality of material.

The particle shape with values of particles "not sharp/elongated" higher than 90 percent show the good performance of the set materials and crusher plant. The compressive strength of the basalt used was 1500 to 2000 kgf/cm^2.

Values up to 800,000 kgf/cm^2 were obtained for the modulus of elasticity and 0.25 for the basalt poisson's ratio. The specific heat obtained for basalt aggregates was 0.205 cal/g C which was within the known values for basalt (0.180 to 0.240 cal/g C).

The values of the coefficient of linear thermal expansion of basalts were about 5×10^{-6}/C. The behavior of soundness sulfate exposure and alkali-aggregate reaction tests showed values estimated to be innocuous.

The fine aggregate used at Itaipu was composed of a natural sand dredged from the nearby Paranaiba River and a manufactured sand obtained from the rock crushing. Studies indicated that adequate composition for fine aggregate for rollcrete should be 50 percent manufactured sand in weight and 50 percent natural sand with a fineness modulus of about 2.65.

At Tucurui, the coarse aggregate from excavating at the dam's foundation was a dense metagraywacke crushed and classified in maximum sizes of 19, 38, 76, and 152 mm.

The absorption test showed values lower than 0.5 percent. The Los Angeles abrasion loss was lower than 10 percent and particle shape not sharp or elongated was higher than 90 percent.

The specific heat value obtained was 0.2 cal/g C and the alkali-aggregate test (chemical method) also classified the aggregate as innocuous. Only natural sand from the Tocantins River was used and the fine aggregate was submitted to a water scalping sand classifying tank, furnishing sand with an average fineness modulus of 2.35.

Values lower than 0.40 percent of absorption and specific heat of 0.175 cal/g C were obtained.

At Sao Simao, the coarse aggregate was obtained by crushing the dense basalt from the excavations of the dam foundations. These also were classified in the four maximum sizes of 19, 38, 76, and 152 mm.

Average values of absorption were at the rate of 1 percent and the specific weight higher than 2.9 ton/m^3.

The fine aggregate was formed by natural sand from the Paranaiba River and manufactured sand from basalt crushing. The ideal mix was 65 percent manufactured and 35 percent natural by weight. After mixing, the product was submitted to a coarse sand classifying system (predominantly manufactured sand) and fine sand (predominantly natural).

Cement, pozzolanic material

Rollcrete mixes can be produced with any kind of cement or pozzolanic material as can conventional concrete.

However, fines content is very important and this makes the choice of the pozzolanic material significant in order to fill the voids that otherwise would be filled by cement and water. Thus, some care must be taken in the choice and use of the pozzolanic material.

At Itaipu, the values of the cements tested were of a blaine fineness of about 3.500 cm^2/g, C_3S about 50 percent, C_3A lower than 8 percent favorable for a heat of hydration of about 80 cal/g at 28 days. Fly ash from the south of Brazil was used and was of good chemical composition.

At Tucurui, the cement used was from a manufacturer from the northeast region of the country. The average blaine fineness was about 2.900 cm^2/g with a heat of hydration of about 95 cal/g at 28 days and C_3S plus C_3A of 63 percent.

The specific weight of the rollcrete was determined by weighing of a known volume.

The molding of a cylindrical specimen and compacting with hammer tamper.

The pozzolanic material was obtained from calcination of clay from a site near the city of Joao Pessoa and had a blaine fineness of about 7.500 cm^2/g.

The cementitious materials were brought to the construction site by sea and river by barge.

At Sao Simao, the cement used was a type with blaine fineness of about 3.000 cm^2/g and an average heat of hydration of 80 cal/g at 28 days. The pozzolanic material was a fly ash from the south of Brazil.

Water

The mixing water for rollcrete is not different than that for conventional concrete. At Itaipu, the mixing water was previously checked to determine if required standards had been met.

These tests showed values of pH of about 7.0, bicarbonate content of about 45 mg/l ($CaCO_3$), chloride content of about 3 mg/l (Cl^-) and sulfate content of about 15 mg/l (SO_4).

At Tucurui, the filtered mix water presented these main characteristics: amount of solids 0.10 mg/l; chlorides 17.85 mg/l (Cl^-); sulfates 0.007 mg/l; and pH of 7.05.

Admixtures

The use of agents as a way of increasing concrete consistency and retarding set time to keep rollcrete sublayers without cold joints, especially in warm weather, is a recommended practice.

No agents were used for the concrete mix at the Itaipu project in placements at temperatures not higher than 7 C. At Tucurui, a retarding agent (Sika plastiment R. D.) was used at 0.3 percent per weight of the equivalent cement, increasing setting time to about 6 hours.

Mix proportioning

There is no standard yet established in Brazil for the proportioning of mixes for rollcrete. The recommendations of ACI Committee 207[1] was used by the laboratories. These include:

—Determine the composition of several aggregate gradations for a minor incidence of voids as described in ACI SP-46.[2]

—Determine the amount of mortar to obtain the maximum specific weight by using the determined consolidation method.

—Determine the amount of paste for a maximum specific weight regarding the ideal percentage of mortar.

—Establish the required ratios of cement/pozzolanic material and water/cement equivalents for the required properties.

The mix proportions, as stated, were based on SP-46 recommendations as well as on other technical data. Since rollcrete is no slump concrete, the determination of the ideal amount of sand as related to the total amount of aggregate can not be obtained from these methods.

In spite of this problem, a consolidation test was adapted by varying the percent of sand and measuring the specific weight of fresh mixture for each case by plotting a graph.

The ideal amount of sand is that which produces a maximum specific weight in the consolidation test. An amount of 1 percent is added to this ideal percentage of sand to absorb possible variations of the constituent materials of the rollcrete mix.

A hammer tamper was used for the consolidation test; it had a weight of about 20 kg and an average frequency rate of 100 hits per minute. Rollcrete was placed into a metallic cylindrical mold with a diameter of 45 cm and height of 25 cm, then consolidated in 3 layers with 1 minute each layer. After these operations, the cylinder was weighed.

The amount of mixing water for each sand percentage was obtained by a vibration test with the use of a vibratory screening machine. This test consisted of filling the upper level of a cylinder, 25 cm in diameter, and turning the machine for 45 seconds.

It should be emphasized that the measurements of molds, time of consolidation, vibration, and other matters were experimental and of relative value since prior standardization was not in effect.

Test results

At Itaipu, laboratory trial mix tests were conducted in two phases. The first was carried out on the rollcrete used in the back filling of the access ramp and many mixes were proportioned to obtain an average compressive strength of 140 kgf/cm^2 at one year.

Permeability tests were also conducted in accordance with U. S. Bureau of Reclamation methods with standard specimens.

The second phase was undertaken prior to construction to obtain a better approach to RCC techniques. In this phase, the mixes were tested to obtain the optimum ratio between the sands, natural and manufactured.

In May 1979, Itaipu Binacional programmed a full-scale test fill of 200 m^3 to evaluate the RCC for eventual application at the job site. The use of the mix with maximum size aggregate of 76 mm in this test showed a reduction in the water content, probably due to the performance of the large mixer of the batching plant.

At Tucurui, the laboratory trial mix tests were also divided into two phases. In the first, 22 mixtures were studied by varying the amount of cement and pozzolan to attend all classes of strengths specified for the main structures.

In this phase, the amount of sand regarding total aggregate weight was kept at a constant 25 percent which represented average values of conventional mass concrete used in the dam. In this manner, verification was carried out to determine the correct percentage of pozzolanic material replacing the cement.

In the second phase, the studied mixes were those to be used at the navigation lock structure to obtain a strength averaging 100 kgf/cm^2 at 90 days. A total of 46 mixtures were tested with maximum size aggregates of 19, 38, and 78 mm and the pozzolanic material used in place of the cement was 40 percent by solid volume.

The use of this 40 percent material decreased the permeability of the mix and increased its efficiency. The compressive strength was obtained by using cylindrical samples compacted by a hammer tamper with the samples consolidated in 3 layers for 1 minute each.

In April of 1982, a full-scale test fill was constructed at Tucurui with about 90 m^3 to evaluate the equipment and to gain a better un-

The gravity transition walls at the Tucurui Dam navigation lock.

At the Tucurui Dam project, the rollcrete was placed upon a thin layer of mortar.

derstanding of rollcrete. A smooth vibratory roller was used and its passes were coordinated to obtain a maximum density.

The frequency control of the roller was obtained by using seismographs and tachometers. The coarse aggregate relationship for the concrete with maximum size aggregate of 38 mm was kept constant without causing segregation.

Project application

The designer, contractor, and owner agreed to use rollcrete in the navigation locks of Tucurui Dam. A typical conventional mass concrete of 2 m thickness to provide impermeability to the structure was decided upon. It was also agreed that the hydraulic surface would be protected by a line of drains located on the transition between the conventional concrete and the rollcrete.

There was also an agreement that a test fill with rollcrete precede actual placement on the lock.

The construction sequence at the Tucurui lock resulted from those experiences learned at Itaipu and the Tucurui test fill. The RCC was produced in batch plants with a nominal capacity of 4 x 200 m^3/hr and each batch plant had 4 tilt mixers of 3 m^3 each.

Water content was measured by filling a cylinder of 25 cm diameter and then vibrated for 45 seconds. Later, however, the vibration method was eliminated in favor of screening in a 4.8 mm sieve size.

The humidity of fine aggregate was controlled in time intervals of 15 to 30 minutes because the material was subject to variations. The coarse aggregates had their humidity determined every 12 hours without varying in a noticeable rate.

Mixing time was initially set at 4 minutes because of the good homogeneity of the mixture. During batching, this period was reduced to 2.5 minutes, the average mix time for typical mass concrete.

To check the physical properties of the rollcrete, cylindrical specimens were cast. For compaction in three layers (1 minute compaction each), a pneumatic tamper was used.

Transporting of the material to the site was accomplished by off-road trucks. As dumping was carried out, a compressed air-water jet was applied to the tire-axle assemblies as the vehicles moved along the access slope.

These same jets were used to treat the hardened surface to allow better bonding. Then, a thin mortar layer of 2 to 3 cm thick was placed before a new rollcrete layer was put down.

Placing was carried out by dividing blocks (900 m^2) in two longitudinal parts to avoid truck traffic on the fresh layers. Conventional concrete was used to seal each of the blocks and jointing was accomplished with a vibratory roller.

To make this jointing easier, the conventional concrete was placed first to act as a bed for the rollcrete. After vibration, two passes of the roller were carried out on the jointing of both concretes to eliminate any cracking during compaction.

Areas inaccessible to the large roller were compacted with hammer tampers. As concrete was dumped from the trucks, some small segregation took place but this was undone with shovels or the blade of a bulldozer.

This segregation may be partially avoided by placing the rollcrete over that already spread but without compaction. However, a better way to avoid segregation is to decrease the content of the coarse aggregate from the 38 to 76 mm size to a smaller size, starting with the initial mixture of 700 kg/m^3 to the ideal with only 300 kg/m^3.

To avoid the drying of the already compacted sublayer surface, an air-water fog spray was used to dampen the surface. If rain occurred, work was interrupted and

The rollcrete was spread in longitudinal blocks at Tucurui.

At Tucurui, spreading of the rollcrete was carried out in one block while compaction was accomplished in another. Rolls of plastic were kept on site in case of rain.

The jointing of the conventional concrete and the rollcrete was done by vibration.

the surface immediately protected with a plastic covering.

Curing during the initial 24 hours was accomplished by using only a plastic covering. After this 24 hours, the fog spray method was used.

Testing at the Tucurui lock was carried out by casting specimens at the laboratory and the sampling of cores from the blocks. The principal tests were those for compressive strength, splitting, shear strength, and permeability.

It was difficult to obtain core specimens due to the sandy condition of the rollcrete. As a result, many of the specimens were faulty.

References

1. ACI Committee 207, "Roller Compacted Concrete," (ACI 207.5R-80), American Concrete Institute, Detroit, 1980, 22 pp.

2. *Proportioning Concrete Mixes*, SP-46, American Concrete Institute, Detroit, 1974, 240 pp.

Inch-Pound Conversion Factors

1 cm	=	0.394 in.
1 m	=	3.281 ft
1 m^3	=	35.315 ft^3
1 kgf/cm^2	=	14.223 psi
1 cal/g/C	=	60.84 Btu/lb/F
1 cm^2/g	=	70.307 m^2/lb
1 mg/l	=	8.345×10^{-6} lb/gal.
1 kg	=	0.454 lb
1 kg/m^3	=	1.69 lb/yd^3

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