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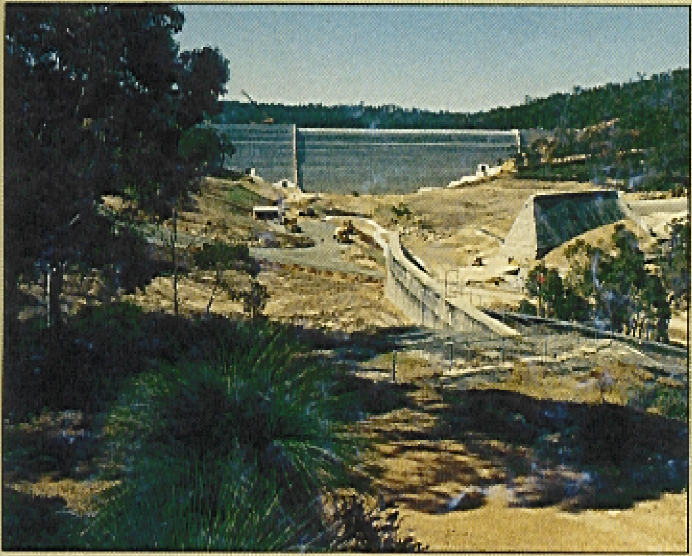

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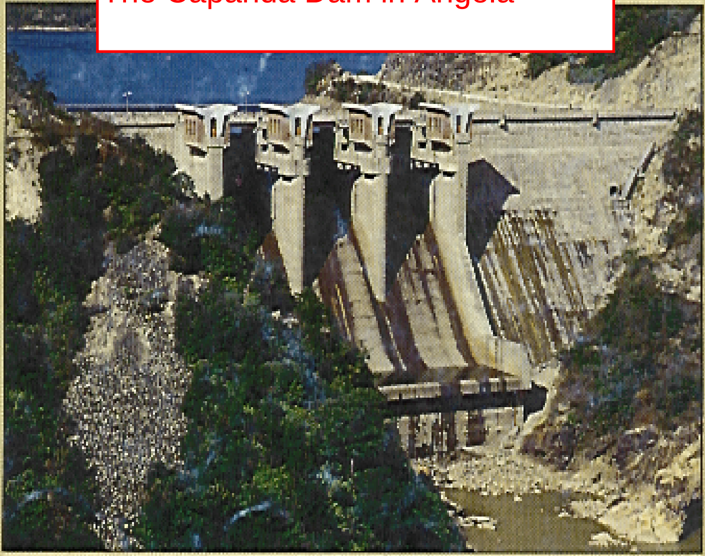


Roller compacted concrete

The Capanda RCC dam in Angola

By **F.R. Andriolo and M.T. Schmidt,** Consultant* and Manager**

Construction of the Capanda hydro plant, on the Kwanza river, in the middle of the northern region of Angola is described. The scheme is about 450 km from the capital, Luanda, and incorporates the country's first RCC dam.

The plant is being constructed for the Angolan Government, represented by Gabinete de Aproveitamento do Médio Kwanza (GAMEK). The work is being carried out by a Brazilian-Soviet consortium comprising Construtora Norberto Odebrecht S/A (the Brazilian contractor for the civil works) and V/O Technopromexport (the Russian designers and supplier of the electrical and mechanical equipment).

The main structures are as follows:

- an RCC gravity dam, with a spillway and flip bucket incorporated in the central part of the dam, and a bottom outlet;
- a water intake structure;
- four water intake tunnels;
- a powerhouse to accommodate four Francis turbines of 130 MW capacity each, and an annexed erection bay building;
- a switchyard with 220 kV transmission lines connecting Capanda to the national grid; and,
- cofferdams and a diversion tunnel with a cross section of 180 m^2 and the capacity to allow for a maximum discharge of 3600 m^3/s, which corresponds to a flood with a 25 year return period.

The Capanda dam and all appurtenant works are on the Malange plateau at an elevation ranging from 950 to 1000 m. The Kwanza river flows through a canyon at an elevation of 850 m.

The Kwanza is one of the largest and most important rivers in Angola, flowing 1160 km across the country (from east to west) to the Atlantic Ocean. Its basin covers an area of 147 940 km^2.

The Capanda project area is underlain by a massive expanse of meta-sandstone and sandstone schist (quartzo-feldspathic schist) from the Cambrian period; it is slightly inclined.

The main permanent structures of the Capanda project are arranged in a compact layout, which takes maximum advantage of the geological and topographical characteristics of the area.

The main features of the dam are shown in Table I. The design concept can be summarized as follows:

- a downstream slope of 0.74:1.00 (h:v) and a vertical upstream face;
- the upstream face is impermeable and consists of a concrete facing and a PVC membrane fixed to the inside of concrete precast panels with a concrete bedding mix covering the concrete construction joint surfaces;
- the central and downstream zones were built to withstand mechanical (shear, friction and compressive) forces. There is a systematic form of drainage to reduce pore pressure action;
- the roller compacted concrete has a minimum required strength of 80 kgf/cm^2 at 180 days.

In an attempt to achieve the required strength for the RCC for the dam structure, it was originally planned to use an RCC mix with a cement content of 60-80 kg/m^3 with an additional use of 80-100 kg/m^3 of a filler material (known as Po de Pedra in Portuguese), from the meta-sandstone crushed rock. This has some pozzolanic properties, as has been indicated in recent studies developed by A. Ossipov at the Hydroprojekt Institute in Moscow.

The stability analysis relating to shear displacement between layers (taking into account the construction joints) led to the decision to use a bedding mix between the joints. This bedding mix was mainly used in an area of the upstream part of the dam, but it was also used in the downstream zone, if the time between successives layers exceeded 8 h.

The overturning stability analysis led to the adoption of a downstream slope of 0.74:1 (h:v), with a minimum RCC density of 2400 kg/m^3.

The preliminary studies on materials and concretes for the Capanda project were carried out at the Itaipu Binacional Concrete Laboratory in Brazil. The basic studies were planned and began in 1987, and aimed to meet the following basic objectives:

- to optimise and reduce the cement content in the concrete mixes to a minimum, within the required safety values;
- to conduct extensive research on the characteristics of the available meta-sandstone rock to be used as concrete aggregate, to test for the possibility of the alkali-silica reaction, and to assess the real need for pozzolanic materials;
- to maximise the use of crushed sand from the meta-sandstone rock;
- to research the benefits of the filler (Po de Pedra), as a reducing agent against the alkali-silica reaction, and to increase the strength and watertightness of the RCC-mix;
- to test the concrete mixes;
- to test the materials and manufactured products (rebars, water-stops, admixtures, and so on) before shipping them to Angola.

*Andriolo Engenharia, Av. dos Semaneiros, 505, CEP 05463 São Paulo, Brazil; and
**Construtora Norberto Odebrecht S/A, Salvador, Brazil.

Table I — Main features of Capanda dam

Maximum height (m)	110
Crest length (m)	1200
Total concrete volume (10^{3}m^3)	1154
RCC (10^{3}m^3)	757
Conventional concrete in the dam (10^{3}m^3)	104
Total dam volume (10^{3}m^3)	861
Conventional concrete in other structures, including intake and powerhouse (10^{3}m^3)	293

The studies and research[1,2] indicated the following:

- the cement (Cimangola) available in Luanda, is useful for mass concrete, and has the following characteristics:

C3S	45.1 per cent
C2S	24.9 per cent
C3A	9 per cent
C4AF	11.7 per cent
Compressive strength (28 days)	339 kgf/cm^2

- the crushed rock material, when checked with standard tests, was found to be sound and suitable for use as aggregate.
- the Po de Pedra (finer than 0.15 mm) proved to be a satisfactory agent to reduce the expansion effect of alkali-silica reaction, with a moderate pozzolanic-activity, and also to reduce the concrete permeability.

The upstream impermeable zone of the dam is composed of conventional concrete (a mix considered to be watertight) and, as an additional safety measure, a geomembrane, fixed to precast concrete panels, developed by Odebrecht.

Pouring the concrete facing, close to the geomembrane.

The main reasons for the selection of a PVC membrane were:

- previous experience with PVC in other civil engineering projects, and in particular as the impermeable element in other RCC dams;
- the fact that PVC is used as the water-stop for contraction joints in dams up to 200 m high, and has been found to perform well for a long time; and,
- PVC is a thermo-plastic material and can thus be easily welded and handled.

The characteristics of the 2 mm-thick geomembrane installed at Capanda are shown in Table II.

RCC placement

The handling and batching system is a conventional concrete batching plant, which also produced the RCC in the initial period of the construction (from September 1989 to May 1990); it has been in operation from that time until the present, along with a pug-mill continuous mixing plant.

The conventional batching plant with tilting mixers and individual batch systems for each mix, are normally used for concretes with a cement content of more than 100 kg/m^3.

The pug-mill mixer type is normally used for soil-cement mixtures with specified volumetric proportions. The dimensions, volume and quality control for the Capanda project required some improvements to be made to the plant such as installing a continuous weighing system.

This enabled the contractor to start construction with a cement content of 80 kg/m^3 for the RCC mix, although preliminary studies had shown that it was possible to use a 60 kg/m^3 mix.

Table II — Characteristics of the Capanda geomembrane

Specific weight (g/cm^3)		1.25 ± 0.05
Tensile strength (kg/mm width)	minimum	2.14
Tensile strength (kgf/cm^2)	minimum	120
Ultimate elongation (per cent)	minimum	300
Tear strength (kgf)	minimum	6.4
Dimensional changes (per cent)	maximum	± 5
Volatile loss (kgf/cm^2)	maximum	0.5
Hydrostatic strength		15 to 20
Hardness		90 ± 10
Effect of alkalis		
change in weight	maximum	+ 0.25 − 0.10
change in hardness		± 5
Accelerated extraction		
minimum tensile strength	minimum	120
ultimate minimum elongation (per cent)		200

The continuous mixer plant is assembled with two continuous weighing conveyors and load cells, which lead to three pug-mill mixers. This layout permits a constant flow, with the minimum capacity of two mixers, even if one of the mixers is undergoing maintenance.

The RCC transporting system was based on the use of the 20 t capacity dump trucks which had been used during the excavation phase.

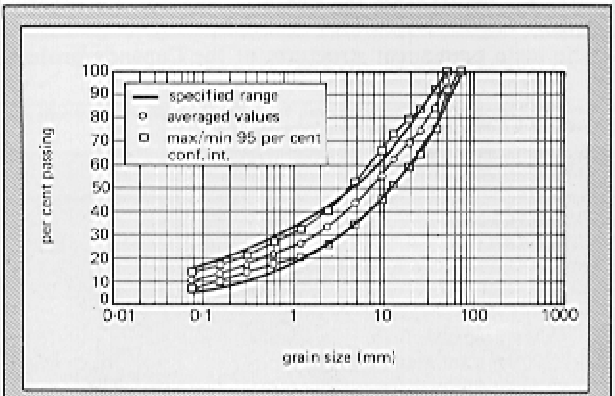
These trucks are used in two different ways:

- to transport the RCC from the mixing plants to the site; and,
- to transport the RCC from the vertical supply chute, located at the same level as the dumping site, to the dumping point.

The chute (or vertical transportation system) was anchored to the rock slope on the right side of the Kwanza river, and the RCC was discharged directly into the dump trucks. For safety reasons, flow control, and to minimize concrete segregation, it was necessary to install energy dissipators at regular points down the chute.

The trucks were loaded by another dissipator at the same level as the layer that was being worked on, to avoid them having to leave the work area.

The RCC is spread in layers of 0.45 m (uncompacted) and reduced to 0.4 m when compacted. A bulldozer (type CAT D6) is used to spread the material.



Grain size analysis for the RCC (pug mill mixers).

During the spreading and compaction of the RCC , the whole area is kept saturated with water (with a fog-spray system), to reduce the effects of evaporation and to avoid any section of the RCC drying.

The compaction is done by eight passes of a vibratory roller. Two types of roller are used; a VAP-70 (12 t), or a CC-43 (10 t).

Some difficulties occurred in obtaining an average density higher than 2400 kg/m^3, with RCC that had a theoretical density of 2447 kg/m^3; this required a greater effort on the part of the contractor and the quality control teams. Density has been checked using a nuclear densiometer.

A fog-spray (air-water jet), is used to control the hydration and thermal effects on the RCC during the curing cycle.

Table III — Compressive strength results of RCC mixes

Use		Batch plant		Pug-mill plant	
Required strength (kgf/cm^2)		80		80	
Control age (days)		90	180	90	180
RCC mix identification		F-76-BT	G-76-BT	F-64-PM	G-64-PM
Contents (kg/m^3)	Cement	80	70	80	70
	Water	102	102	102	102
	Aggregates	2265	2275	2262	2248
Cement content (kg/m^3)	Tests	115	25	28	237
	Average	77.6	68.4	82	70.2
	St. dev.*	4.9	3.8	8.4	10.1
	Covar.	6.3	5.6	10.3	14.4
Strength 28 days (kgf/cm^2)	Tests	53	16	9	57
	Average	86	78	93	78
	St. dev.	14.8	10.2	—	14.1
	Covar.	17.2	13.1	—	18.1
Strength 90 days (kgf/cm^2)	Tests	141	51	26	152
	Average	100	93	115	95
	St. dev.	15.9	8.7	17.1	13.3
	Covar.	15.9	9.3	14.9	14
Strength 180 days	Tests	—	18	—	13
	Average	—	95	—	101
	St. dev.	—	8	—	16
	Covariant	—	8.4	—	15.8

* Standard deviation

Table IV — Density values from the RCC layers

Number of tests	= 2252
Average (kg/m^3)	= 2.412
Coefficient of variation (per cent)	= 0.33

Table V — Compressive strength values from drilled core specimens

RCC cement content-mix (kg/m^3)	80	70
Number of tests	64	86
Average values-compressive strength (kgf/cm^2)	138	114
Coefficient of variation (per cent)	19.4	20.6
Age of tests	120 to 230 days	360 days

Treatment of the construction joints between RCC layers is used to improve the bond between the old and new layers.

To achieve this, the surface of RCC construction joints are treated to eliminate some carbonation or dirty material, and a thin layer of bedding-mix (conventional concrete — max. agg. size = 19 mm, 220 kg/m^3 of cement) is used. Cleaning is done with a wet-air jet (at 7 kg/m^2 pressure).

Progress and control

By October 1991, 450 × 10^3 m^3 of RCC and 54 × 10^3 m^3 of conventional concrete had been laid in the dam body.

Quality control is carried out at the aggregate crusher system, and during mixing, to check the water content, of the 19 mm wet-screened portion.

To check the homogeneity of the RCC mix, the cement content and the performance of the mixers, the RCC is tested daily (samples of the wet mix). The cement content is obtained by chemical analysis, to check the calcium content and (indirectly) the cement content.

The proportioning of the RCC mixes was done with aggregates with a specific weight of 2.65 t/m^3 (SSD

Aerial view of the aggregates and concrete facilities and the dam.

condition), and combined to reach a maximum density (or the minimum void index). A combined grain size curve of the type $p = (d/D_{max})^{1/3} \times 100$ per cent, for a D_{max} = 76 mm was used.

To minimize or eliminate some of the segregation, and to reduce maintenance of the pug-mill, it is normal to adjust the coarse fraction of the curve, thus reducing slightly the content of D_{max} = 76 mm aggregate. In an alternative procedure, it is normal to reduce the maximum size aggregate to a lower level. For the RCC for Capanda, it was decided to reduce the D_{max} to 63 mm.

Grain size analysis

The grain size analysis is done on the same sample that is tested for the cement content, in the wet screened fraction[3].

Each shift, or every 1000 m^3 of RCC, a set of cylinder specimens size 25 × 50 cm (d × h) are cast, with the full RCC mix. The compaction of these specimens is done using a pneumatic hammer in four layers, each layer being compacted for about 25 s.

The minimum required strength of the RCC mix is 80 kgf/cm^2 at half a year, the criterion being that 80 per cent of this strength should be above the design strength. As a safety precaution in the initial stages of compressive testing, the tests were carried out at 90 days.

Conclusion

The RCC technique shows the convenience of the use of some complementary control during the placing, spreading and compaction of the RCC, through density tests on the compacted layer, and through the compressive tests on specimens of drilled cores taken from the dam.

The main advantage of the RCC technique for Capanda has been its simplicity. □

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