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5. Earthfill and Rockfill Dams

5.1 Embankment Dams on the Flanks

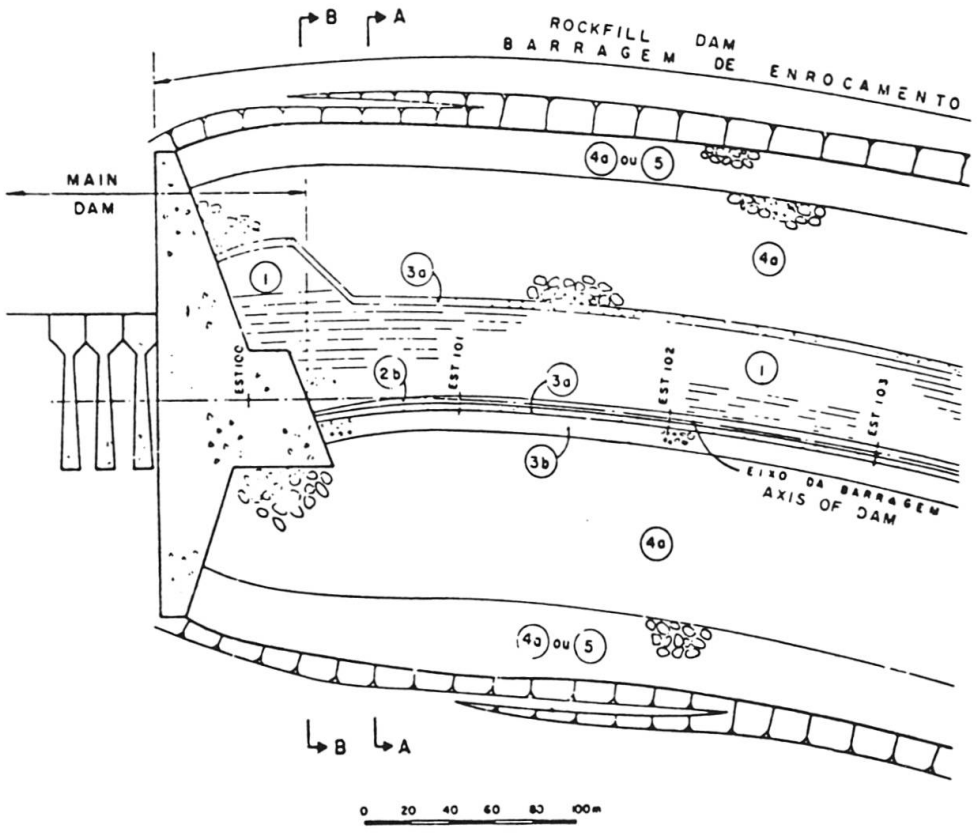
On both banks, above El. 160 approximately, there is an extensive mantle of residual soils formed by the decomposition of basalt. These soils are generally homogeneous clays, of medium to high plasticity, porous, compressible and with low strength. The depth of the overburden increases with distance from the river.

These factors, together with the low heights required for the extreme flanks of the dams, favored the selection of earthfill dams for the long extremity on the left bank and for a shorter portion west of the Spillway on the right bank. At the location of the left Earthfill Dam there is no interference with any concrete structure or construction plant, nor are there any constraints on space. Also the quarry areas are located at a convenient hauling distance.

Two principal factors favored the selection of a rockfill dam for the left bank stretch between the river and the Left Earthfill Dam: (1) the feasibility of using, without rehandling, a large amount of rock obtained from the excavation of the Diversion Channel, and (2) the reasonable depth at which sound rock was available for founding the impervious core.

Excavation of considerable amounts of overburden was required for the foundation of the Rockfill Dam. However, this material was utilized for construction of berms on the Left Earthfill Dam and for the two dikes which were built to intercept the Bela Vista and Pomba Quê creeks and divert them into the Paraná River upstream of the work area.

Fig. 9 Plan of Overlap Between Rockfill Dam and Main Dam



1 – Clay core

2b – Filter

3a – Fine transition

3b – Coarse transition

4a – Rockfill

5 – Rockfill > 60 cm

5.2 Rockfill Dam

5.2.1 Geological Conditions and Foundations

The natural ground surface in the area of the Rockfill Dam sloped gently upwards from El. 165 to El. 182. The residual soil, over the underlying rock, varied from 5 to 15 m in thickness. All the overburden was removed and most of the Rockfill Dam was based directly on sound, dense basalt. The thickness of this basalt strata is about 30 m. It is moderately jointed, but generally has low permeability.

At the base of the basalt, at about 30 m depth, there is a zone of breccia about 1 m thick. The permeability of this breccia was found in field tests, to range from 0.2 to 0.6 l/min/m/kg/cm^2.

At a depth of about 40 m below the rock surface, there is the joint A discontinuity, which has a considerably higher permeability.

5.2.2 Cross-Section of the Rockfill Dam

The Rockfill Dam has a central core of compacted clay with a vertical downstream face and an upstream face slope of 1V : 0.6H. The thickness of the core is always more than 0.65 H, where H is the reservoir head.

The clay core is protected on the upstream side by a 2.5 m thick zone of fine transition, consisting of minus 3'' crushed rock. The downstream face of the core is vertical. Protection against piping of clay fines is provided by a 2-m thick sand filter, then a 2.3-m wide fine transition zone of minus 3'' crushed rock and finally a coarse transition composed of crushed rock 3'' to 12'' in size. The coarse transition zone is 3.2 m thick at the crest and its downstream face has a slope of 1.0 V : 0,1 H. The external slopes of the outer shells of rockfill are 1.0 V : 1.8 H on the upstream side and 1.0 V : 1.6 H on the downstream side.

The foundation for the impervious core, the filter and the transition zones was sound rock, while the rockfill shells were based on slightly weathered rock after removal of the rippable weathered material.

Two rows of 8-m deep low pressure grout holes were provided at 10-m centers under the clay core to cut off seepage through the superficial portion of the basalt. Sub-horizontal joints exposed under the core area and extending 10 m upstream of the core were slush grouted and sealed with cement mortar. Generally, the grout take in the shallow cutoff holes was nominal.

The length of the Rockfill Dam is 1984 m. Its total volume is 12.8 x 10^6 m^3 of which 10.7 x 10^6 m^3 is rockfill, transition and filter, and 2.1 x 10^6 m^3 is clay in the impervious core.

5.2.3 Rockfill – Concrete Dam Interface

The determination of the location of the western end of the Rockfill Dam, where it meets the concrete buttress dam, was dictated by the construction schedule and the temporary installations for concreting of the Main Dam and the Powerhouse, in particular the cableways. If the Rockfill Dam was extended into this area, its construction could only have been undertaken after the dismantling of the cableways early in 1982. Considering that all the embankment dams were scheduled for completion by the end of 1981, construction of a rockfill portion in this area would have critically interfered with the schedule. For this and other reasons, it was decided that the interface between the Rockfill Dam and the concrete dam should consist of a transverse concrete gravity end wall located just east and clear of the cableways.

The embankment is wrapped around the longitudinal portion of the concrete gravity wall. It is 70 m long with face slopes of 1.0 V : 0.34 H upstream and 1.0 V : 0.46 H downstream. The impermeability of the contact was assured by extending the clay core along the upstream face of the longitudinal concrete wall. The impervious clay zone was also widened to 8 m at the crest and with a slope of 1.0 V : 1.0 H. The length of the longitudinal contact between the clay core and concrete is equal to the hydrostatic pressure.

In the interface portion, the external slopes of the Rockfill Dam were maintained. The end of the longitudinal concrete wall was inclined to the vertical as well as to the axis of the dam, so that with settlement of the embankment the clay would exert a positive pressure against the concrete. Pressure cells have been installed at three different locations to measure pressures at the clay-concrete contact.

5.3 Transition between Rockfill Dam and the Left Earthfill Dam

A 300 m long transition from the Rockfill Dam to the Left Earthfill Dam was necessary to accommodate the differences in foundation conditions and requirements and the cross-section of the two embankment dams.

On the upstream side, the clay core of the Rockfill Dam was gradually widened by increasing its upstream slope from 1.0 V : 0.6 H to 1.0 V : 3.0 H at the eastern end of the transition while the rockfill zone was gradually reduced.

Similarly, the downstream vertical filter was progressively replaced by compacted soil which was widened until it matched the 1.0 V : 3.5 H slope of the Earthfill Dam. The external slopes were also gradually flattened to match those of the Earthfill Dam at the end of the transition.

The internal system of drainage in the transition portion consisted of a 2.0-m wide vertical filter, which is continuous with the filter zones of both embankment dams, and of a 1.5-m thick carpet filter draining horizontally to the downstream side and located directly on the foundation.

For most of the transition portion, the overburden of residual soil was excavated to the bed rock. About 100 m from the end of the Left Earthfill Dam, the excavation was sloped up to firm soil.

5.4 Left Earthfill Dam

With the objective of optimizing the design, the Left Earthfill Dam was divided into two sections: (1) 10 to 30 m high, and (2) less than 10 m high.

The higher section of the dam, 10 to 30 m high, is 630 m long starting from the transition with the Rockfill Dam. It has essentially a homogeneous central section of compacted plastic clay with both upstream and downstream slopes 1.0 V : 3.5 H from crest down to mid-height and then 1.0 V : 2.0 H to the foundation. Stabilizing berms with very flat slopes were provided starting from the points of inflexion of the slope.

On the upstream side the berms become a 2-m thick blanket. Some portions of the berms were placed before the central section of the dam was started. Random soils, including plastic clay, saprolite and weathered basalt, as obtained from excavation for the foundation of the Rockfill Dam, were used for constructing the berms.

Compaction of the central clay section was done in accordance with the same specifications as for the core of the Rockfill Dam. In order to minimize differential settlements, the excavation for the foundation had a trapezoidal slope, removing a maximum of 3 m under the crest and 0,5 m at the upstream and downstream extremities of the central section. Under the berms, only the topsoil with organic matter was excavated.

Internal drainage is provided by a 2-m thick vertical chimney filter linked to a 1.0-m thick horizontal carpet filter. Crushed sand, which was a byproduct or reject from the primary crusher for making concrete aggregate, was used for the filters.

Seepage flow coming into the filters or coming through the foundation should drain through the natural layers of saprolite or weathered rock in the foundations. Several permeability tests made in bore holes, and experience from the Pomba Quê and Bela Vista Dikes, which were constructed nearby and on similar foundations, indicated that the strata of weathered basalt and saprolite would provide excellent natural drainage.

As an additional safety measure, after the filling of the reservoir a line of drainage wells would be bored near the toe of the dam. These wells would be 0.10-m in diameter, at 30-m spacing and would extend into the weathered basalt.

For the 1360 m long portion of the Left Earthfill Dam, where it is 10 m or less in height, the cross-section has constant slopes of 1.0 V : 3.0 H on both faces. It is constructed of compacted plastic clay and has no berms. The internal drainage system is similar to that provided in the higher sections.

The volume of the Left Earthfill Dam, including its transition with the Rockfill Dam, is 4.2×10^6 m^3, of which $0{,}6 \times 10^6$ m^3 is rockfill, transition and filter materials.

5.5 Right Earthfill Dam

Extending from the right abutment of the Spillway, the Right Earthfill Dam is 872 m long. Its maximum height is only 25 m.

A conventional homogeneous section of compacted plastic clay with a constant upstream and downstream slope of 1.0 V : 3.0 H was employed. The internal drainage system is similar to that provided in the Left Earthfill Dam.

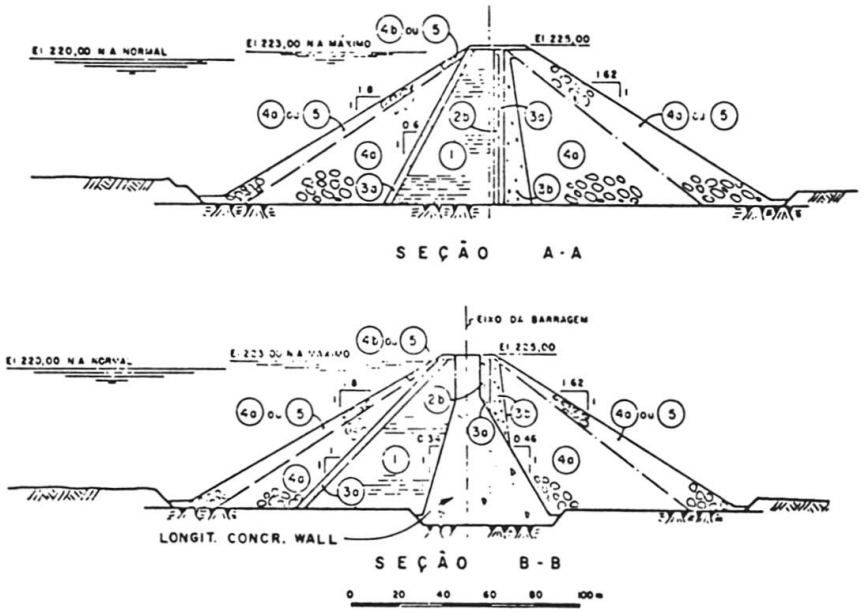


Fig. 10 Cross-sections of overlap between rockfill dam and main (concrete) dam