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# Dam Foundation Settlements due to Saturation

Tassement d'un barrage dû à la saturation des fondations

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## SUMMARY

A porous sandstone and a lateritic soil constitute the compressible and pervious foundation layers of considerable depth for the earth dam of Jurumirim. The post-saturation of the foundations due to the filling of the reservoir produced an additional settlement besides those due to consolidation. The behaviour and character of these settlements due to saturation and their comparison with the calculated values based on previous laboratory tests are the subject of this paper.

## SOMMAIRE

Un grès poreux et un sol latéritique constituent la fondation perméable et compressible du barrage en terre de Jurumirim. La saturation postérieure de ces couches d'une épaisseur considérable due au remplissage du réservoir produit un tassement additionnel à ceux dus à la consolidation. Le comportement et le caractère de ces tassements dus à la saturation, ainsi que la comparaison avec les valeurs calculées en partant des essais de laboratoire, sont présentés dans ce travail.

THE USINAS ELÉTRICAS DO PARANAPANEMA S.A. (USELPA), one of the Brazilian producers of electric energy in the state of São Paulo, has completed the construction of the Jurumirim power plant, the most upstream one of a complete hydraulic exploitation scheme of the Paranapanema river. The capacity of Jurumirim is 100,000 kw, the maximum water head 37.50 m, and the mean water discharge 173 cu.m./sec. The total maximum water volume of 7.2 billion cu.m. with a corresponding surface of over 400 sq.km. is stored by means of a concrete dam, 56 m high, incorporating

the powerhouse and the spillway, and by a lateral earth dam closing a depression on the left bank (Fig. 1).

Of all the measurements and observations made during construction and so far during the operation of the dams, the settlements of the earth dam due to saturation of the foundation layers are the most interesting ones and are the subject of this paper.

Servix Engenharia S.A., Rio de Janeiro, was in charge of the general project. The geological survey was made by Dr. H. Haberlehner. The site investigation, laboratory

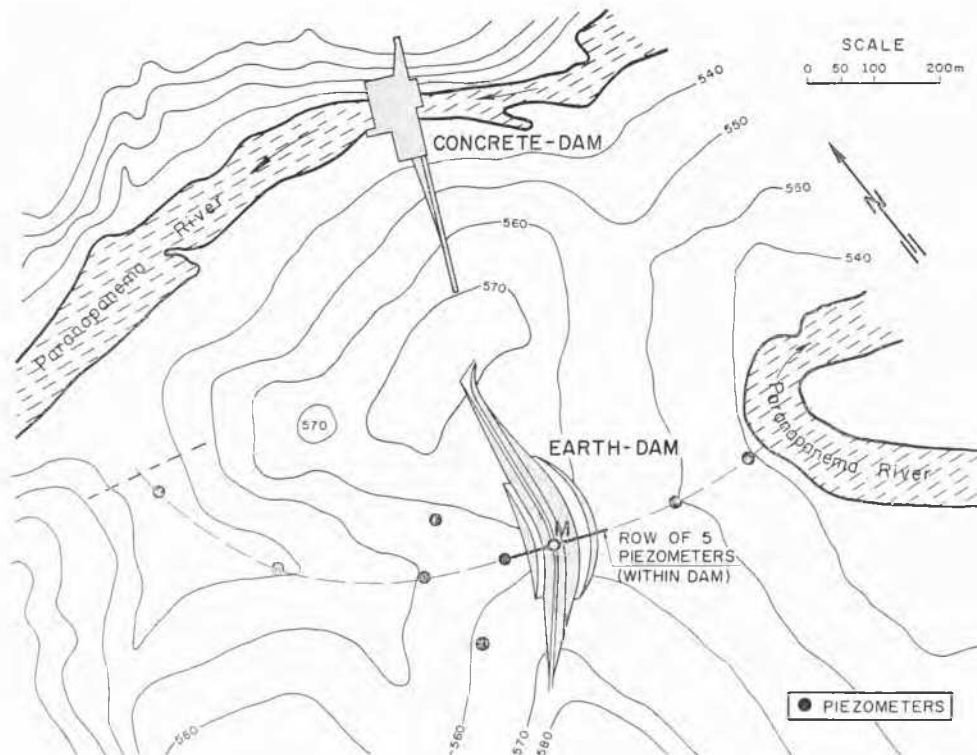


FIG. 1. General plan of Jurumirim dam site.

testing, and the project for the lateral earth dam were subcontracted with Rodio S.A., Rio de Janeiro.

#### GENERAL DESCRIPTION

The Paranapanema river flows from east to west through the Paraná sedimentary basin and constitutes a major effluent of the Paraná, the most important river in southern Brazil. Overlying the palaeozoic deposits of this sedimentary basin are mesozoic, mostly cross-bedded, Aeolian, Botucatu sandstone, and basaltic lava flows. The latter constitute the major mass of volcanic rocks known in the world.

The Jurumirim site is located where the river enters the lava fields carving a distinct valley out of the hard basaltic rock. Upstream of the site, the basalt was completely removed by erosion. While the concrete dam rests on basalt, the lateral earth dam rests on sandstone overlain by 8–11 m of lateritic residual soil. Migration of fine particles (originated from the formerly overlying basalt) as a result of water percolation makes the transition between the sandstone and the lateritic soil indistinct. In the foundation area of the earth dam, this transition was found at depths varying between 8 and 11 m.

The sandstone is characterized by a loose cementation, its grains being round and quite uniform, corresponding to a medium to fine sand with some compressibility. The void ratio is approximately 0.5 and the permeability coefficient, as determined *in situ* as well as in the laboratory, varies generally from  $1 \times 10^{-4}$  to  $2 \times 10^{-3}$  cm/sec. The Terzaghi standard penetration tests indicate values (blows per 30 cm) lower than 15 for the upper few meters of the sandstone and over 30 further down.

The overlying lateritic soil is a clayey sand, with characteristics similar to those of the sandstone, although it is more porous, considerably more compressible, and somewhat less pervious near the surface (see characteristics, Fig. 2). The

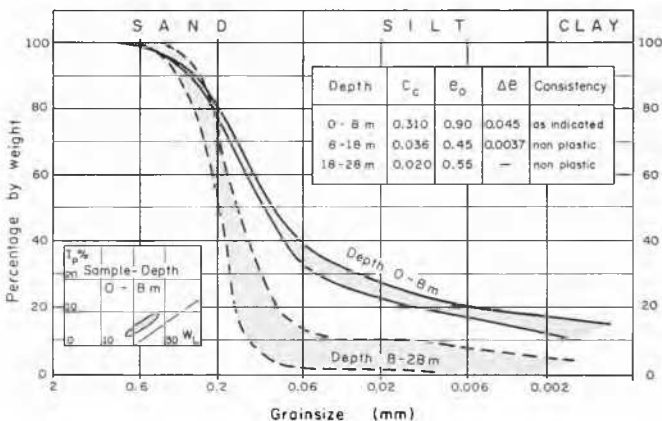


FIG. 2. Soil mechanics characteristics of the foundation material.

Terzaghi standard penetration tests indicate values lower than 15 blows per 30 cm.

The earth dam, as shown in plan (Fig. 1) and in section (Fig. 4), has a maximum height of 15.90 m and a crest length of 470 m, involving the compaction of 280,000 cu.m. of soil. The core and blanket consist of just slightly more clayey sand than the upstream and downstream zones, so that the dam can for practical purposes be considered homogeneous. The inclined filter was brought in just for additional safety and was compacted simultaneously with the downstream zone.

As the extremely thick, pervious foundation is relatively

homogeneous and to avoid artificial concentration of the hydraulic gradient, no cut-off was planned. In order to reduce water losses and hydraulic gradient, however, an upstream clay blanket was placed. To collect some of the percolation water and to relieve any pore water pressure (lower permeability near the surface), a line of 12-inch vertical sand drains, 15 m deep was put along the centre of the downstream berm. They were placed every 15 m to start with, intermediate ones being left dependent on future observations. They discharge into the horizontal sand filter.

As this pervious and compressible foundation of considerable depth is far more important than the dam proper, measures to observe the settlements, saturation, and infiltration with respect to the foundation were provided. Of all these observations, special attention was given to the settlements, particularly to those due to saturation of the foundation layers.

#### SETTLEMENT OBSERVATIONS

Besides topographic measurements along the crest, settlements at various elevations were registered at the location of maximum dam load, as shown schematically in Fig. 3.

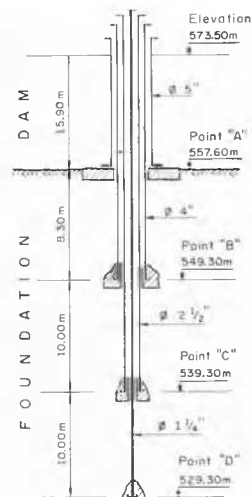


FIG. 3. Device for settlement observation at different elevations of the foundation (without scale).

Before the compaction of the dam, a hole was drilled to depth of point B and there enlarged. Then, an adequate volume of mortar was poured in and the 4-inch tube fixed. After setting of the mortar, drilling proceeded inside the 4-inch tube and the same procedure was repeated at points C and D, respectively. For control purposes, an identical device was installed 5 m away. Since they gave practically the same values, the readings of only one device are shown in this paper.

The soil characteristics given in Fig. 2 are representative of those found in the foundation at the location of highest dam load (M, Fig. 1). These mean values of a great number of tests were used for the settlement analyses summarized in Tables I and II. The consolidation settlements were computed by the Terzaghi formula and gave, as expected, higher values than observed. Fig. 4 shows the settlement and the load curve as a function of time. It also shows the typical dam section indicating the sequence of compaction work.

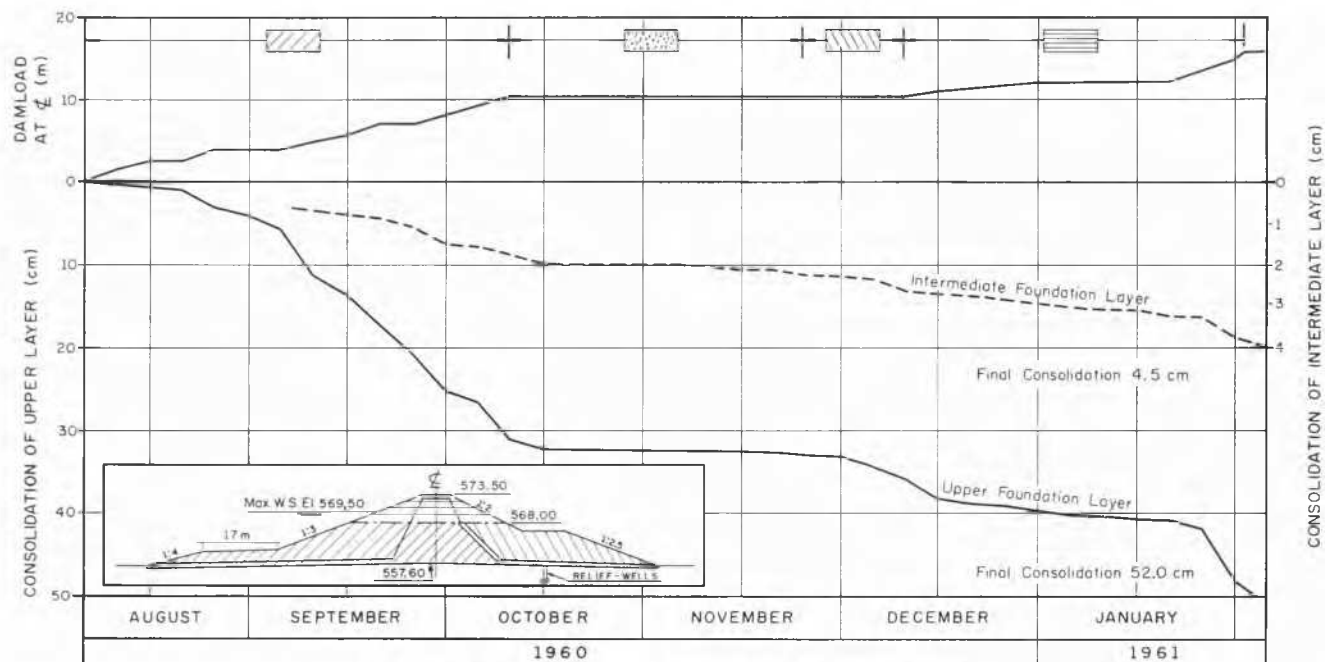


FIG. 4. Dam load and settlement curves due to consolidation.

TABLE I. SUMMARIZED SETTLEMENT ANALYSES FOR CONSOLIDATION\*

Layer elevation (m)	Thickness (m)	Initial pressure (tons/sq. m.)	Pressure increment (tons/sq. m.)	$C_e$ $1 + e_0$	Calculated settlement (cm)	Measured settlement (cm)
Upper 557.60-549.30	8.30	7.0	29.0	0.163	90.5	52.0
Intermediate 549.30-539.30	10.00	25.2	25.5	0.025	7.7	4.5
Lower 539.30-529.30	10.00	44.2	22.2	0.013	2.3	—

\*For calculation purposes, the unit weight of compacted dam material used was 2.0 tons/cu. m. and for the foundation, 1.9 tons/cu. m.

TABLE II. SUMMARIZED SETTLEMENT ANALYSES FOR SATURATION

Layer elevation (m)	Thickness (m)	Initial void ratio $e$ (after consolidation)	Void ratio decrease due to saturation $\Delta e$	Calculated settlement (cm)	Measured settlement (cm)
Upper 557.60-549.30	8.30	0.69	0.045	22.2	
Intermediate 549.30-540.00	9.30	0.34	0.0037	2.5	2.7
Both 557.60-540.00				24.7	19.8

All consolidation tests on unsaturated samples from the layers above the groundwater table showed a noticeable void ratio decrease as saturation proceeded. The average void ratio decrease of all tests, according to the layer, and the corresponding overburden pressure as given in Fig. 2 were used for the calculation represented in Table II. The additional settlement due to saturation is thus:

$$S = H (\Delta e / 1 + e),$$

where  $S$  = settlement due to saturation;  $H$  = thickness of the

involved layer;  $\Delta e$  = void ratio decrease due to saturation, determined by laboratory consolidation tests;  $e$  = void ratio after consolidation but before saturation. Unfortunately, a relatively large scattering of the void ratio decreases was observed, so that only a great number of tests can provide a satisfactory basis for the calculation.

Fig. 5 shows the water level of the reservoir, the groundwater table, the settlement curves of points A and B, all as a function of time. It can be clearly seen that settlement proceeded according to the degree of groundwater rise.

The groundwater table is being observed by a row of piezometers across the main dam section and other piezometers as indicated in Fig. 1 (the two upstream piezometers were abandoned as the reservoir level reached their elevation). The groundwater level indicated in Fig. 5 corresponds to the readings at location M (Fig. 1).

As long as the groundwater did not rise into the upper layer, the two points A and B descended at the same rate, thus showing that the upper layer, though moving down as a whole, remained at the same thickness as long as it was not affected by the saturation. On about June 25, 1962, the groundwater table passed point B and about 20 days later, this point stopped moving for the rest of the observation period. On about October 5, an increase of rate of groundwater rise occurred and about 20 days later, the corresponding increase of settlement rate can be noted. About February 15, 1963, the saturation line passed point A; again, about 20 days later, the settlement of this point stopped completely. No further settlement has been observed since.

Considering the limited precision of the laboratory determination of the void ratio decrease due to saturation, a satisfactory conformity between calculated and observed total settlement due to saturation can be noted.

#### CONCLUSION

The settlement observations presented in this paper show how neatly the settlement corresponded to the progress of

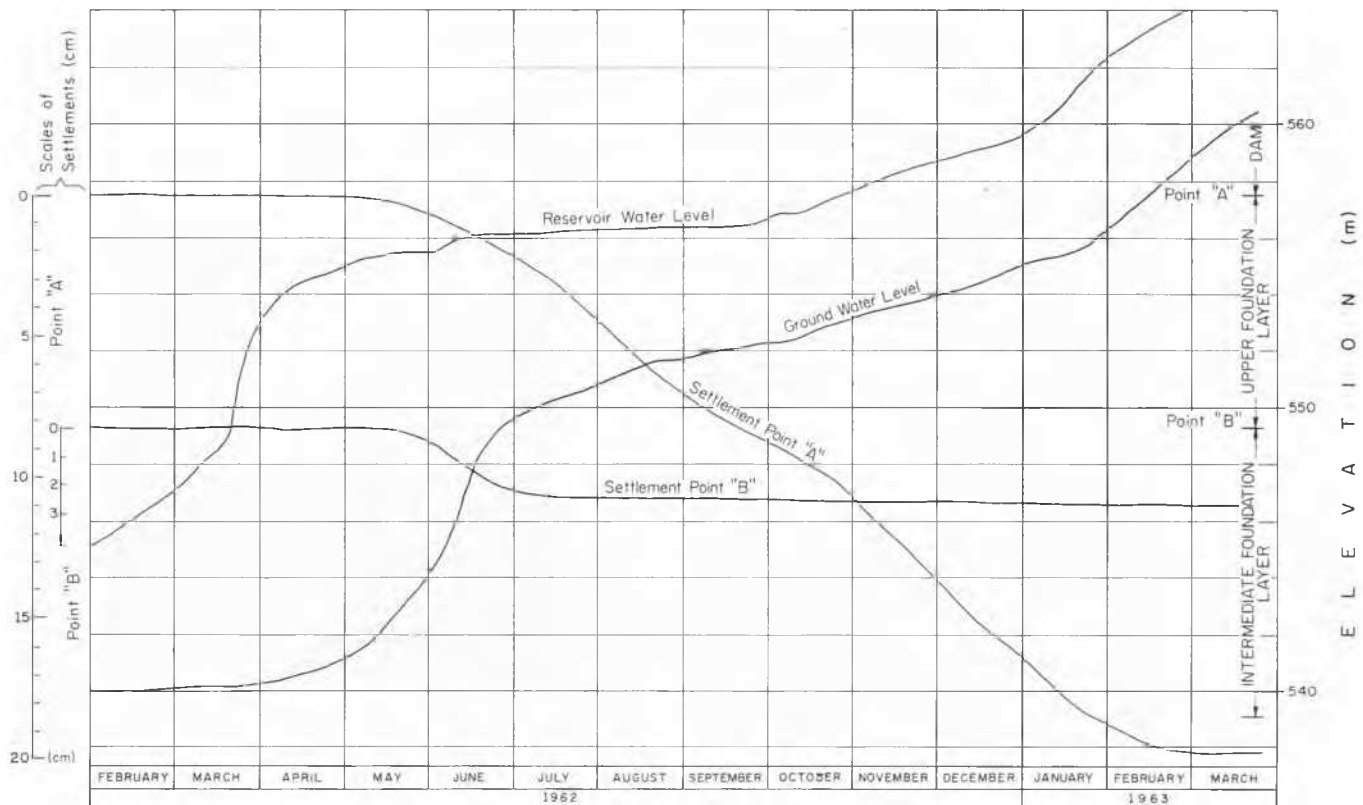


FIG. 5. Settlement curves due to saturation.

the saturation of the foundation. In spite of the relatively large scattering of the measurements of the void ratio decrease due to saturation in the laboratory, the mean value of a great number of tests permitted a satisfactory prediction of the total settlement due to saturation.

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