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Grouting of canaliculae in residual soils and behaviour of the foundations of Balbina Dam

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ABSTRACT: The residual soils of the Brazilian Amazonic region show the presence of canaliculi in many sites. Treatment of these foundation conditions should take in consideration the local logistic and climatic conditions. The utilization of soil-cement grouting through manchette valves at pressures above the hydraulic fracturing pressures of the soil was conceived and used. Special in-situ and laboratory tests were planned in order to better evaluate the sensitivity of the variables involved. With the beginning of the raising of the water in the reservoir piezometric data is already available showing the improvements.

1 INTRODUCTION

The Balbina Hydroelectric Scheme will generate 250 megawatts in the Uatumã River, Amazon Basin.

The embankment dam is a homogeneous earthfill with average height of 30 meters. Its foundations consist of silty-clayey residual soils generated by the weathering of vulcanites. Among the geotechnical-geological features conditioning the design of the embankment dam it is emphasized the existence of localized points with permeability higher than 10^{-3} cm/sec.

Different phases of subsoil investigation associated the high permeabilities to the presence of tubular cavities, with diameters varying from millimetric to centimetric, intercommunicating and with an erratic geometric pattern. These cavities are generically called canaliculae and are thought to be generated mainly by termite activity. This activity is fossil and linked with the last glacial period (de Mello, L.G. et al, 1987).

2 FOUNDATION TREATMENT

Many different alternatives were studied prior to the definition of the foundation treatment to be used in the dam (Sathler, G. et al, 1985; Remy, J.P.P. et al, 1985).

Grouting of the residual soils using the tube a manchette technique was proved to be the best alternative costwise, when the analysis included the logistic and climatic peculiarities of the Amazon region.

The concept behind the treatment of the foundation through grouting aims at creating a zone under the embankment in which all localized permeability singularities are eliminated and the foundation can be treated as homogeneous, in terms of statistics of averages (de Mello, V.F.B., 1977).

Using the tube a manchette technique, grouting can be done localizedly, applying pressures high enough to generate hydraulic fracturing of the soil, with penetration and filling of the canaliculae and voids intercepted by the lenses of grout.

The advantages of this concept of treatment are: a) grouting can be intensified in regions where the intake is higher; b) treatment can be done all year round, despite of climatic changes; c) use of conventional equipment; d) the same boreholes can be used to treat the decomposed rock underneath the residual soil. The only disadvantage of this treatment is its pioneer characteristics, requiring a rigorous supervision of the work.

3 TREATMENT METHODOLOGY

The methodology used in the treatment resulted from the experience of the professional team involved, and was optimized many times as a function of the results and data collected.

The systematic used during the major part of work can be summarized as:

a) Water loss tests were done in the residual soils with pressure stages of 0.2; 0.4; 0.7 ... kg/cm^2 untill hydraulic fracture occurred. Through this testing the determination of the coefficient of permeability prior to treatment and relevant indications of the pressures in which treatment should be pursued were gathered.

   Special techniques to assure perfect contact of the expansible packers with the walls of the borehole were developed in order to avoid preferential vertical seepage which would invalidate all the testing.

b) Three lines of grouting holes were planned, with grouting starting from the external ones in order to confine and improve treatment in the central holes.

c) Grouting was done using double packers specially developed in the site, which would seal against a PVC tube left in the borehole and grouted in its external side to develop contact with the residual soil (as shown in Fig. 1).

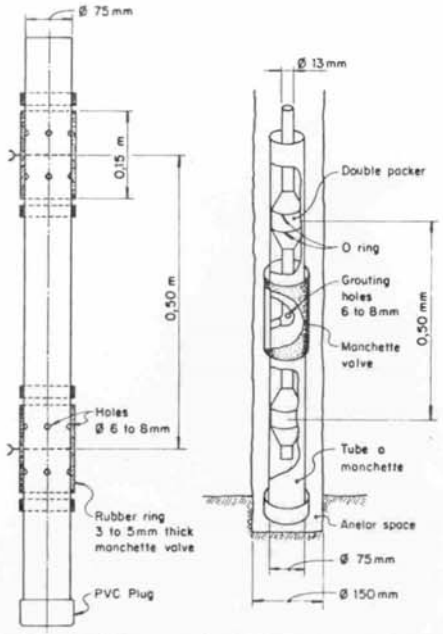

FIG. 1 - TUBE WITH MANCHETTE VALVE AND GROUTING PACKERS

d) The grouts studied to treat the soil were different than those used to fix the PVC grouting tube. Both used as much as possible the local clayey residual soils in order to reduce costs of treatment.

The specification of the soil-cement grout asked for:

1. uniexial compressive strength at 28 days of 1.5 kg/cm^2;
2. viscosity ≤ 50 cP;
3. sedimentation factor ≤ 5%;
4. fluidity in Marsh cone of 40 to 45 seconds;
5. yield limits ≤ 0.1 g/cm^2.

e) Grouting was undertaken from the lowest manchette valve towards the top, at pressures compatible with hydraulic fracturing pressure previously determined.

f) Treatment was stopped when 300 litres of grout was absorbed by the soil or after 10 minutes of no intake of grout.

g) Water loss tests were performed in specially located boreholes to document the benefit of the treatment, limiting the maximum pressure of the test at 1.0 kg/cm^2 not to fracture the soil.

At the beginning of the treatment special tests and experimental stretches of work were performed to supply the technical committee with data which, in turn, helped optimize its specifications. The special tests include:

- Carefully performed water loss tests in drained and in undrained conditions. Fig. 2 presents two of the referred tests, from which the pressure which causes hydraulic fracturing and the minor principal total stress $\sigma 3$ were interpreted. Following Bjerrum and Andersen (1972) discussions, the coefficient of earth pressure at rest Ko can be estimated, provided that $\sigma 3$ is assumed to be horizontal. This value was estimated to vary between $0.21 \leq Ko \leq 0.36$.

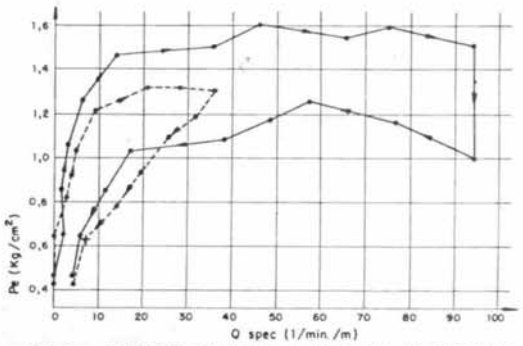

FIG. 2 - GROUTABILITY TEST - HYDRAULIC FRACTURING OF THE RESIDUAL SOIL

- Inspection trenches specially dug in treated areas showed valid the assumption of the orientation of $\sigma 3$.

  Once the value of Ko is known, many theories exist which enable the pressure of hydraulic fracturing of a medium to be estimated (Bjerrum et al, 1972 ; Kennard, 1970; Haisom-Fauhurst, 1967; Morgenstern and Vaughan, 1963; etc.). The data collected allow the following relation to be established between the formulation proposed by Bjerrum in:

$$\Delta_{\sigma} \text{obs} = 7.82 + 1.02\ \Delta_{\sigma} \text{Bjerrum}\ (t/m^2)$$

- Special tests were also performed to try to collect data of pressure head losses in the grouting system.

4 EVALUATION OF THE TREATMENT

The evaluation of the improval of the residual soil of the foundation of Balbina dam with respect to its permeability was done through water loss tests carefully done after the treatment.

In fig. 3 some test results are presented in relation to the information collected before grouting. The benefit of the treatment is obvious. In the mentioned figure, the interpretation of the water loss tests following Babouchkine's (1965) formulation is presented.

5 FILLING OF THE RESERVOIR

Filling of the reservoir started in mid 1987 and has been monitored continuously. Although the rainy season has not been able to fill the reservoir as expected, partial data is already available, and it indicates the benefit of the treatment.

Two different cross sections of the embankment were used during construction in order to separate the treatment of the foundation from the earthmoving and compacting, which have to be done in a very defined time of the year due to the heavy rains. For this matter in some areas the grout buffer was positioned in the upstream of the dam and linked to the impervious core of the dam by a compacted berm, while in some other areas the grout buffer was positioned just underneath the core of the dam.

Figures 4 to 7 present a cross section of the dam in the described situations with plots of the elevation of the compacted fill, of the water level in the reservoir and measured pore pressures in hydraulic piezometers.

As can be seen in the figures, operational water levels are to reach elevation 50.0 m so more data need to be collected and will be published by the authors as soon as available.

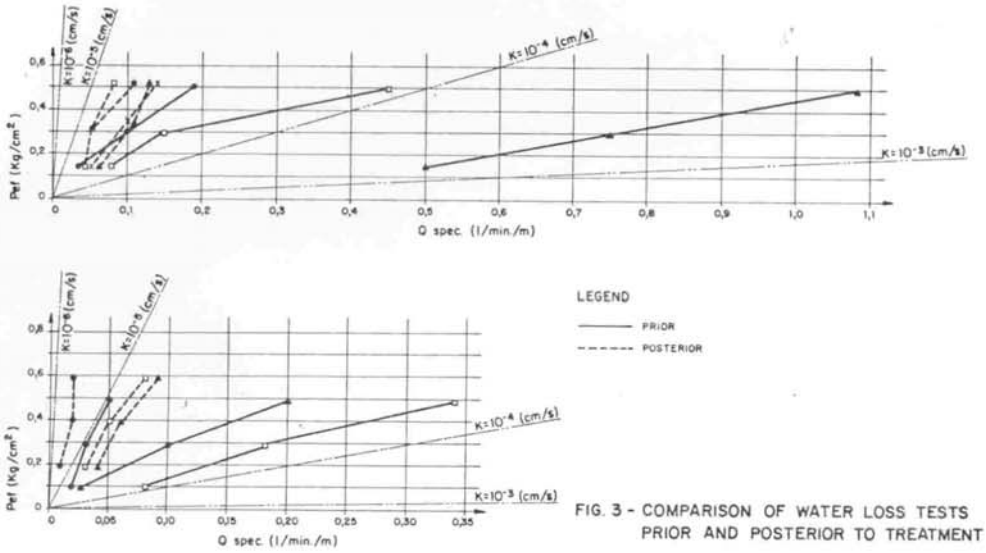

FIG. 3 - COMPARISON OF WATER LOSS TESTS PRIOR AND POSTERIOR TO TREATMENT

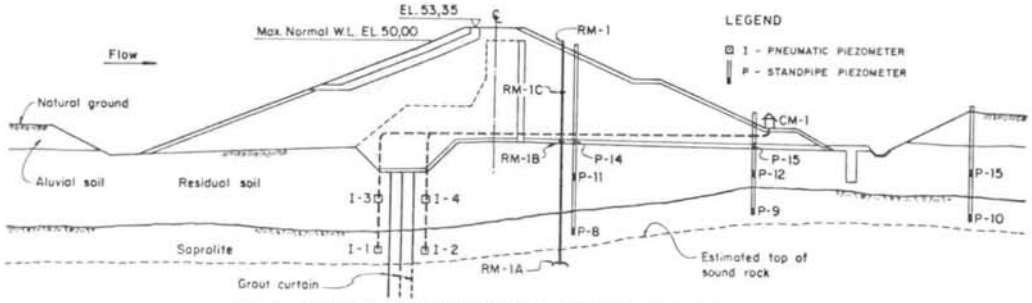

FIG. 4 - TYPICAL INSTRUMENTATION ON THE LEFT ABUTMENT

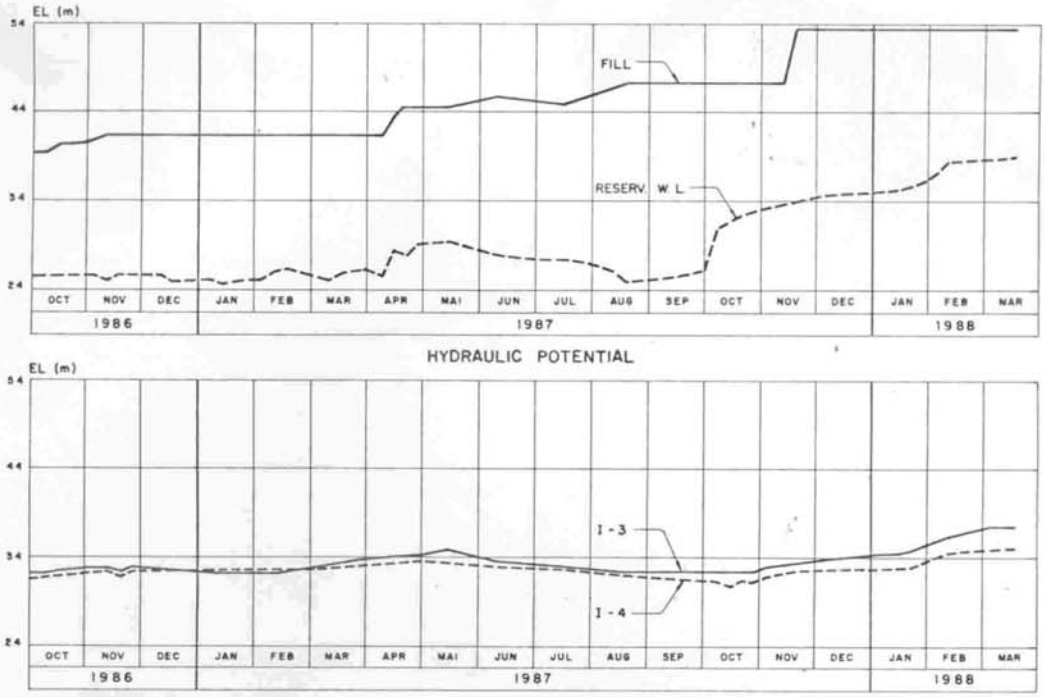

FIG. 5 - PORE PRESSURES MEASURED ON THE LEFT ABUTMENT

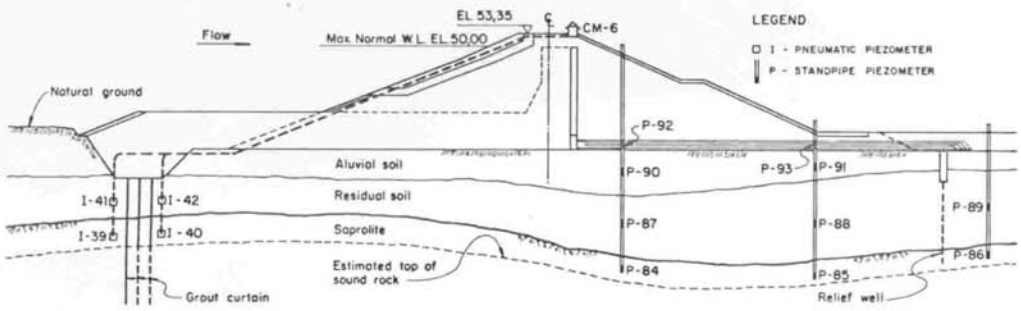

FIG. 6 - TYPICAL INSTRUMENTATION ON THE RIGHT ABUTMENT

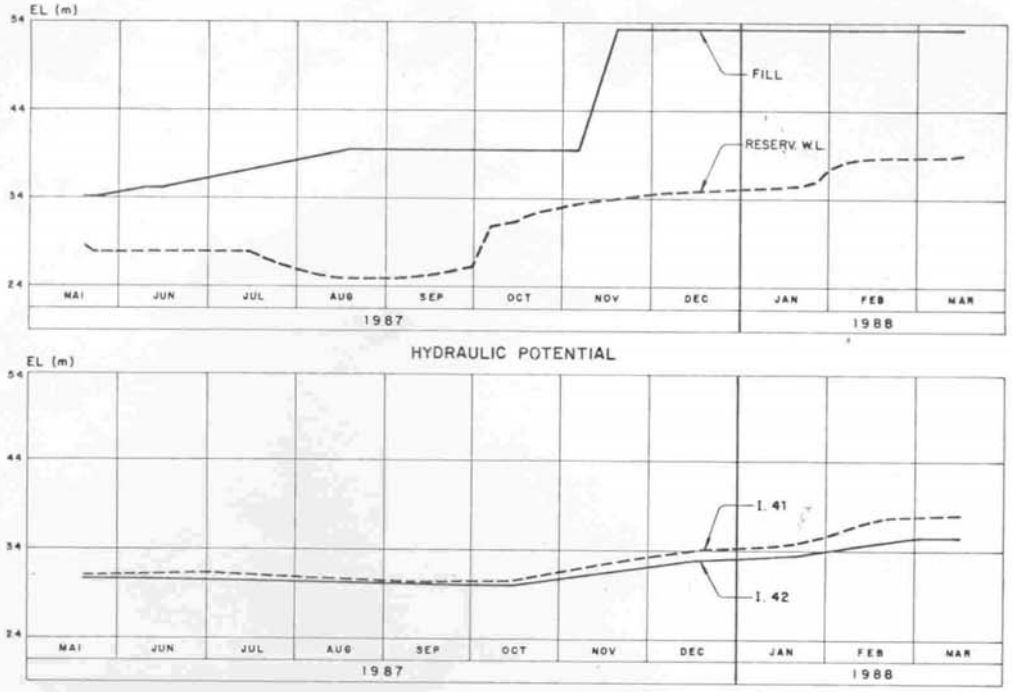

FIG. 7 - PORE PRESSURES MEASURED ON THE RIGHT ABUTMENT

6 CONCLUSIONS

The data collected so far as well as situ inspections demonstrate the validity of the use of the discussed treatment to homogenize and diminish the permeability of a residual soil with a net of open canaliculae. It is our belief that this type of solution should be pursued in equivalent situations, as well as developed for other geological environments in which this concept of treatment may be thought.

7 ACKNOWLEDGEMENTS

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REFERENCES

Babouchkine in Bogomolov, G.V., 1965. Hydrogeologie. Ed. de la Paix, Moscow-URSS.

Bjerrum, L. and Andersen, K.H., 1972. In-situ measurements of lateral pressures in clay. Proc. Fifth European Conference SMFE, Madrid-Spain.

Bjerrum, L. et al, 1972. Hydraulic fracturing in field permeability testing. Geotechnique vol. 22.

de Mello, L.G.F.S., Franco Filho, J.M.M., and Alvise, C.R., 1987. O tratamento de solos residuais condicionados por canalículos: um caso de obra. In portuguese. Conferência Iberg-Americana sobre Aproveitamentos Hidraulicos, Lisbon-Portugal.

de Mello, V.F.B., 1977. Reflections on design decisions of practical significance to embankment dams. Geotechnique vol. 23.

Haimson, B. and Fairhurst, C., 1967. Initiation and extension of hydraulic fractures in rocks. Society of Petroleum Engineers Journal.

Kennerd, R.M., 1970. The measurement of soil permeability in-situ by the constant head test. PhD thesis, University of London.

Morgenstern, N.R. and Vaughan, P.R., 1963. Some observations on allowable grouting pressures. Geotechnique.

Remy, J.P.P. et al, 1985. Choice of the foundation treatment of the Balbina Earth Dam. 15th International Conference on Large Dams, Lausanne-Switzerland.

Sathler, G. and Camargo, F.P., 1985. Tubular cavities in the residual soil of the foundation of Balbina Earth Dam - Amazon - Brazil. 15th International Conference on Large Dams.