Behaviour of a Single-Line Grout Curtain

Comportement d'un écran d'injection en une seule ligne

A. J. L. BOLOGNESI, *Consulting Engineer, Buenos Aires, Argentina*
O. MORETTO, *Consulting Engineer, Buenos Aires, Argentina*
D. A. PRONSATO, *Engineer, Agua y Energía Eléctrica, Buenos Aires, Argentina*
C. H. ZARAZAGA, *Engineer, Agua y Energía Eléctrica, Buenos Aires, Argentina*

SUMMARY

Evidence on the behaviour of grouted cut-offs has been required frequently. This paper presents the results of accurate piezometer observations from a tunnel below an earth dam. From these data the inefficiency of indiscriminate grouting, still widely used, is clearly demonstrated.

SOMMAIRE

Fréquemment on demande des preuves permettant de juger de l'efficacité des écrans d'injection. Cet article donne les résultats des observations piézométriques précises exécutées dans un tunnel au-dessous d'un barrage, desquels on peut déduire clairement l'inefficacité de l'usage irrationnel des voiles d'injections.

LAS PIRQUITAS is the first major earth dam built in Argentina. Its characteristics have been described elsewhere (Grandi, *et al.*, 1961). It has a grout curtain built by a well-known firm, with the unusual feature, for an earth dam, of a concrete grouting gallery partially buried in the foundation rock below the impervious core. Piezometer holes placed in this gallery afforded the opportunity of checking the behaviour of the grout curtain. Theoretical analysis shows very clearly that rock grouting can generally be limited to the existing definite pervious zones of a dam site. Yet, indiscriminate grouting is still widely used and Las Pirquitas was no exception to this rule. Fig. 1g shows the cut-off grouting design adopted for this dam.

Piezometer and seepage observations have been made for a period of nearly a year with the reservoir practically full. The results obtained for the river-bed section of the dam, shown in Fig. 1g, made it possible to compare the theoretical with the actual behaviour of the grout curtain. This comparison points out that small seepages do not necessarily indicate effective grouting. At Las Pirquitas, piezometer observations clearly show that the grout curtain had practically no effect in changing the natural conditions existing at the site.

FOUNDATION ROCK

Both abutments and the river bed are composed of gneiss with the strata dipping approximately 45° downstream. On the thrust plane of an overthrust fold on the right abutment, about 2 m of mylonite had to be removed.

FOUNDATION TREATMENT

As indicated above, this paper deals only with the part of the foundation located in the river bed, because it is there where the effectiveness of the grout cut-off can be best determined. For that reason only the part of the foundation where piezometer holes D_2 to D_{16} are located (Fig. 1g) is described. As indicated elsewhere (Grandi, *et al.*, 1961), the foundation rock below the impervious core of the dam, was thoroughly cleaned after the weathered material had been removed. Cracks and holes were filled with concrete and consolidation grouting applied to a depth of 6 m with a maximum pressure of 7 kg/sq.cm. A concrete grouting gallery was partially buried in the foundation rock below the impervious core to avoid interference between foundation grouting and construction of the fill. From this gallery, a 35-m-deep single line grout curtain was installed, making an upstream angle of 42° with the vertical. For the section under study, 183 tons of Portland cement were grouted through 46 holes. The average grout take, under a maximum pressure of 25 kg/sq.cm., was 110 kg of cement per meter of grout hole.

PIEZOMETER OBSERVATIONS

Inside the gallery and behind the grout curtain, boreholes 100 mm in diameter and 22 m deep were drilled every 20 m. The upper part of each borehole was fitted with a nipple and a valve that allows either drainage of the hole into the gallery, or reading of the pressures by means of pressure gauges located at elevation 682. These pressure readings, for reservoir elevations ranging from 746.55 to 755.58, are given in Table I. The spillway crest elevation is 755.50.

TABLE I. PIEZOMETER READINGS

Reservoir elevations (m)	Foundation uplift pressures (kg. cm.$^{-2}$)							
	D_2	D_4	D_6	D_8	D_{10}	D_{12}	D_{14}	D_{16}
746.55	4.10	4.00	4.00	3.80	3.80	4.00	3.80	4.00
749.68	4.20	4.20	4.40	3.80	4.10	4.20	4.00	4.20
751.80	4.40	4.60	4.40	4.00	4.20	4.10	4.40	4.20
752.28	4.60	4.30	4.30	4.20	4.20	4.00	4.10	4.20
752.74	4.80	4.50	4.60	4.30	4.30	4.40	4.30	4.50
752.99	4.60	4.60	4.60	4.20	4.40	4.30	4.30	4.40
753.52	4.80	4.70	4.60	4.70	4.60	4.50	4.60	4.60
754.32	4.80	4.65	4.60	4.65	4.55	4.50	4.55	4.55
754.47	4.80	4.65	4.60	4.65	4.55	4.50	4.60	4.55
755.04	4.60	4.80	4.60	4.20	4.60	4.20	4.50	4.50
755.54	4.80	4.70	4.80	4.10	4.40	4.40	4.60	4.60
755.58	4.80	4.70	4.60	4.20	4.40	4.40	4.50	4.40
Averages								
752.87	4.608	4.533	4.508	4.233	4.341	4.291	4.354	4.391

Foundation uplift pressure averaged for all readings = 4.4073.

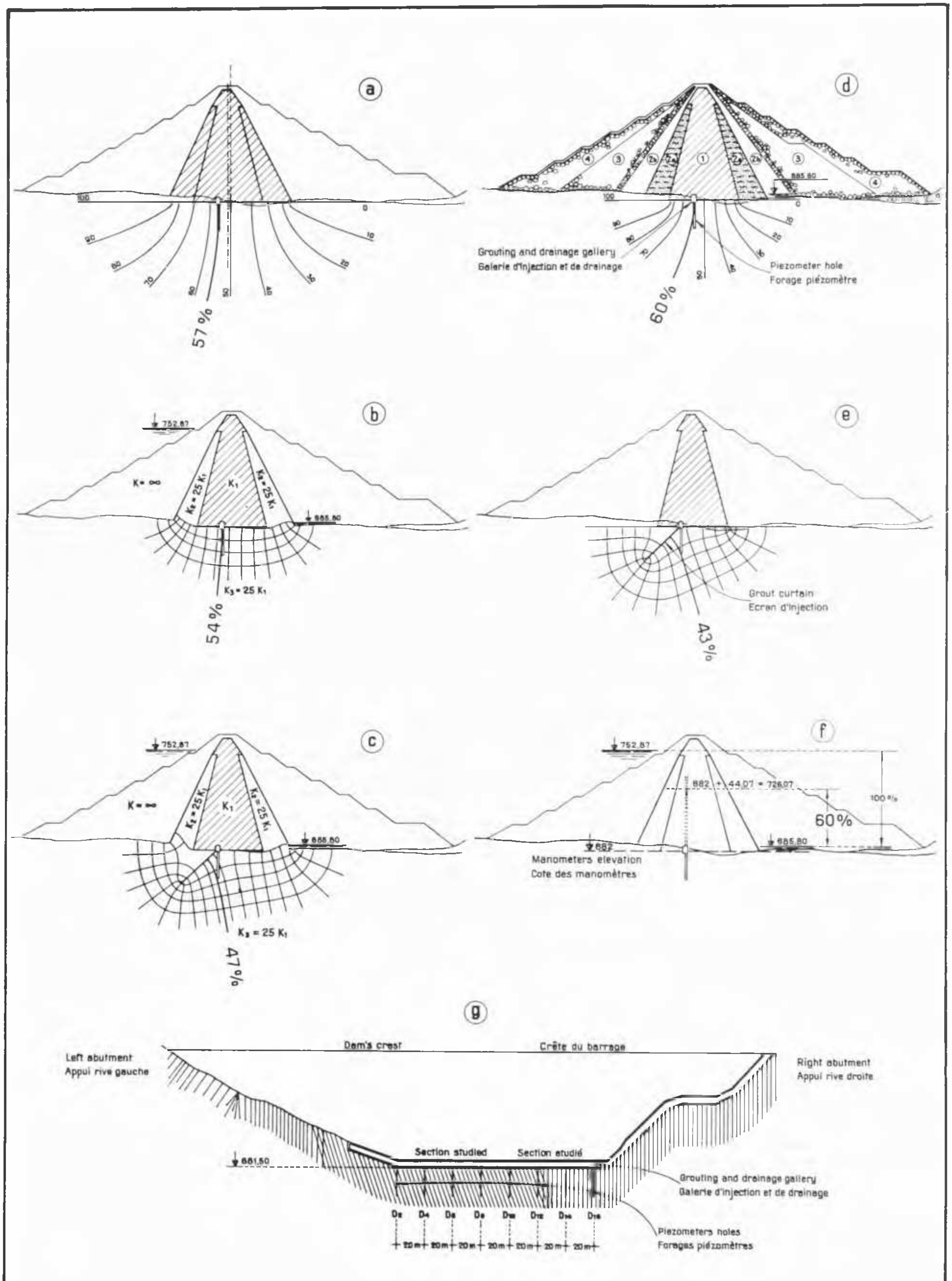

FIG. 1. Las Pirquitas Dam grout curtain; estimated and actual performance.

Fig. 1f shows graphically a summary of results. With an average reservoir elevation of 752.87 and a tailwater elevation of 685.80, an average uplift pressure of 4.407 kg/sq.cm. (44.07 m) is obtained, giving a water elevation of 726.07 at piezometer level. This indicates that at the piezometer location, 40 per cent of the hydraulic head had been dissipated. The piezometer holes must then be cut by the equipotential line representing 60 per cent of the hydraulic head.

SEEPAGE

Total seepage through the foundations, abutments, and embankment was only 35 litres per second for the average reservoir elevation indicated above.

INTERPRETATION OF RESULTS

In addition to the information given in Table I, permeability tests, according to the U.S.B.R. method, were performed on samples from zones (1) and (2a) during the construction of the embankments, and water tests of the Lugeon type were made on the foundation rock during the construction of the grout cut-off. Because of the very nature of these tests, their accuracy is much less than that given by the piezometer readings. Consequently, their values have not been introduced in the analysis, and have only been used as a guide to select tentative interpretations.

To determine how the grout curtain performed, 5 different hypotheses are shown in Fig. 1. In all of them the rock is assumed semi-infinite in extent and isotropic in permeability, with Darcy's law valid. The equipotential lines in Figs. 1a and 1d were determined from the equations of seepage through a permeable foundation below an impervious dam. They are hyperboles with focuses at the edges of the base of the dam. For the cases shown in Figs. 1b, 1c, and 1e, flow nets were used to find the corresponding equipotentials. In Figs. 1a, 1d, and 1e, the equipotentials are a fraction of whatever head is introduced between the upstream and downstream side of the dam. Within drawing precision, the statement is also valid for Figs. 1b and 1c.

The five different hypotheses correspond to the following possible alternatives:

1. Zone 1 can be taken as impervious; the foundation is pervious in relation to zone 1, and zone 2a is pervious in relation to the foundation. Two cases are considered: ineffective cut-off (Fig. 1d) and perfect cut-off (Fig. 1e).
2. Zones 1 and 2a are considered impervious in relation to the foundation, and the cut-off ineffective (Fig. 1a).
3. Zone 2a and the foundation have the same permeability, which is 25 times greater than the permeability of zone 1. Two cases are considered: ineffective cut-off (Fig. 1b) and perfect cut-off (Fig. 1c).

By comparing the highest equipotential line cutting the piezometer holes with the actual drop in hydraulic head (Fig. 1f), it is clear that the grout cut-off has been ineffective, and that the dam has performed as if it had an impervious core (zone 1) with a zone 2b considerably more pervious than the foundation, as assumed in the hypothesis of Fig. 1d. It is to be remembered that the rock is neither semi-infinite in extent nor isotropic in permeability but, for the conditions shown in Fig. 1d, both the introduction of anisotropy and the limitation of the depth of the permeable foundation changes the distribution of the equipotentials below the foundation very little.

The pressure measurements presented here prove that the grout cut-off has been ineffective, and they add to the growing evidence pointing out the dubious efficiency of single-line grout cut-offs. From this study, one reaches the inevitable conclusion that even a perfect grout cut-off of the same design would have added practically nothing to the safety of the dam.

Grout cut-offs should only be used where a thoroughly competent and detailed analysis shows that they will be efficient for the purpose for which they are envisaged.

REFERENCE

Grandi, A. L., J. J. C. Riva, D. A. Pronsato, A. J. L. Bolognesi, and O. Moretto (1961). Earth dams in Argentina. *Proc. Fifth International Conference on Soil Mechanics and Foundation Engineering*, Vol. 2, pp. 613–18.