Earth Dams in Argentina

Barrages en terre en Argentine

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Summary

The construction of the La Cienaga earth dam of 28 m height was completed in 1925. For the last 25 years no new earth dams have been contemplated in Argentina, their use having been restricted to low saddle dams. At present two important earth dams are under construction and several others will be built in the near future. The authors give details of dams under construction and of some that will be started in the near future.

Las Pirquitas dam belongs to the earth and rock fill type. Its maximum height is 86 m which makes it one of the highest dams in South America. It requires 3·5 millions cub. m of different materials-most of which come from talus. The impervious core is made up of a mixture of talus materials and a small amount of clay available locally.

The second earth dam under construction is the Rio Hondo dam. It is 4 km long, with a maximum height of 29 m. It has a frontal spillway founded on preconsolidated clays. The earth dam itself — made of fine to medium sands and of silts and clays of low plasticity — is founded on loess in the abutments, and on sand on the river bed. Construction has just started, and it will be finished in about five years. The total earth movement will be of the order of 10 000 000 cub. m.

Badly fractured clayed sandstones stopped the construction of an Ambursen type dam designed for the El Cadillal canyon.

A new solution has been worked out instead by means of an earth dam.

In the case of the dam in the El Horcajo canyon, the existence of exceptionnally deep deposits of pervious sands and gravels made an earth dam the obvious choice, but the authors point out that very difficult foundation problems were thereby created.

Sommaire

La construction du barrage en terre La Cienaga, d'une hauteur de 28 m, fut terminée en 1925. Pendant 25 ans on n'a pas envisagé sérieusement en Argentine la construction de barrages en terre. Son emploi a été limité à l'exécution de digues destinées à fermer des seuils en relation avec des barrages en béton. A présent, il y a deux importants barrages en terre en construction. Plusieurs autres seront construits dans les prochaines années. Le présent rapport donne des détails sur les digues en construction et sur quelques-unes de celles qui seront commencées bientôt.

Le barrage Las Pirquitas appartient au type de terre et enrochements. Sa hauteur maxima est 86 m, ce qui en fait un des plus hauts barrages en Amérique du Sud. Sa construction utilisera 3,5 millions de mètres cubes de matériaux, la plupart de ceux-ci sont obtenus sur place. Le noyau imperméable est fait d'un mélange d'éboulis, et de la petite quantité d'argile disponible dans la région.

La deuxième digue de terre en construction est le barrage Rio Hondo. Elle a 4 km de longueur, avec une hauteur maximum de 29 m. Elle a un évacuateur de crues fondé sur de l'argile préconsolidée. La digue en terre elle-même — faite de sable fin à moyen et de silts et argiles de basse plasticité — est fondée sur du loess en ce qui concerne les culées et sur le sable dans le lit de la rivière. La construction de la digue a justement commencé, et sera achevée d'ici à peu près cinq ans. Le mouvement total de terre sera d'environ 10 000 000 m³.

La construction d'une digue type Ambursen projetée pour le défilé El Cadillal ayant été empêchée par la présence de grès argileux très fracturés, on a modifié le projet et construit à la place un barrage en terre.

Enfin, la présence de couches de sable perméable et de gravier jusqu'à une grande profondeur obligea à adopter le principe d'une digue en terre dans la gorge d'El Horcajo dont la construction posera de très difficiles problèmes de fondation.

Las Pirquitas dam

Las Pirquitas dam is located on the Del Valle River, in the Province of Catamarca, 27 km north of the city of Catamarca. The valley where the dam is located was created by a tectonic movement. Both abutments and the river bed are of gneiss. The river bed is covered by alluvial deposits, mainly blocks and boulders at the bottom, with overlaying sands and gravel. The abutments are covered with talus. The right abutment has an overthrust fold. In the thrust plane about 2 m of mylonite had to be removed. Fig. 1 shows the foundation conditions.

The dam was originally designed as a rock fill type with a reinforced concrete upstream facing. When it was decided to transform it into a rock fill dam with an earth core, some of the structures were already under construction, including the diversion tunnel and the intake, and the dam had to fit in between. Fig. 2 shows the cross section of the dam as finally approved. Its height from the deepest part of the foundation to the crest is 86 m. The main materials for the construction of the dam comes from the talus. There is a grave local scarcity of suitable materials for an impervious core and therefore an unusual method was adopted to provide a core of adequate thickness. The small amount of clay available was mixed in a central plant with material screened from the talus. In such a way a good impervious core was artificially created. The dam requires 3 ½ million cubic metres of different materials, 75 per cent of which have already been placed.

Below the impervious part of the dam, the foundation rock 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. 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 rock fill dam. A foundation for the semi pervious (2a) pervious (2b) and filter zones was prepared by removing all weathered material

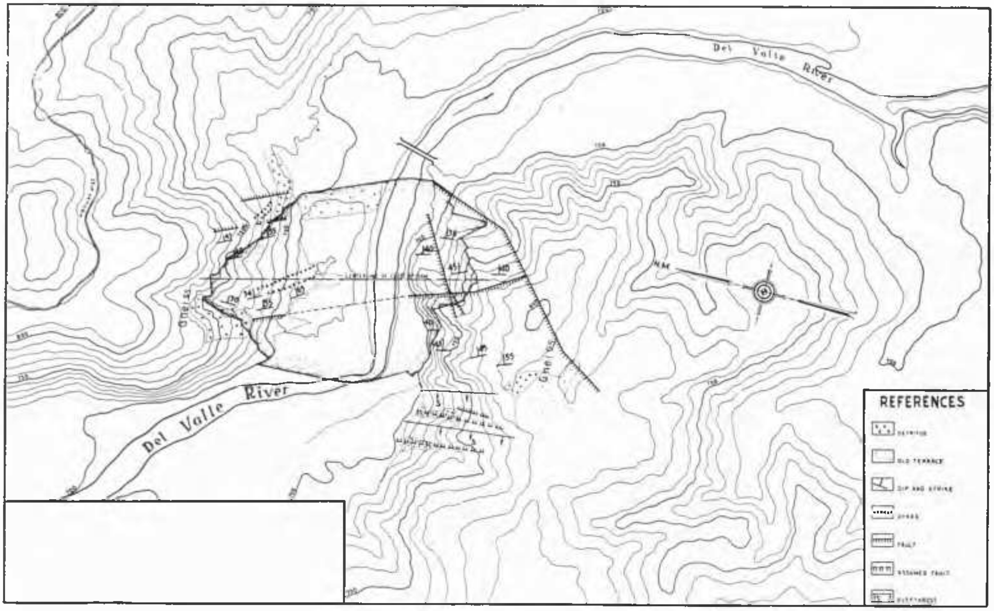

Fig. 1 Foundation conditions at Las Pirquitas Dam.
Conditions de fondation du barrage Las Pirquitas.

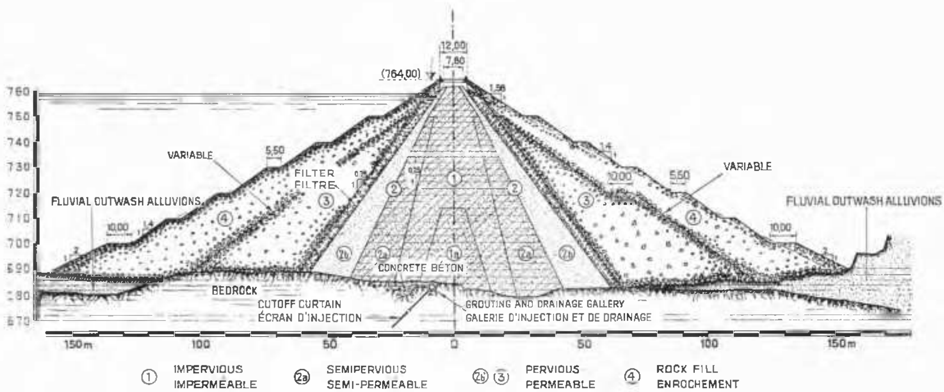

Fig. 2 Cross section of Las Pirquitas dam.
Section transversale du barrage Las Pirquitas.

until sound rock was reached. No cleaning of cracks, concrete filling of holes, nor consolidation grouting was performed. Below the pervious zone (3), towards the axis of the dam, the foundation was prepared to expose the rock in the foundation leaving the boulders, gravel and sand in between the outcrops. Below the outer part of the pervious zone (3) and below the rock fill zone (4), only silty material was removed; the dam rests on dense alluvial deposits. On the abutment the dam rests on rock.

Fig. 3 shows the grading of the materials for the different parts of the dam. Materials comming from the talus are classified in a central plant by passing them over a 3 inch screen. The material larger than 3 inches goes to zone 3 of the dam and the smaller to zone 2a. One portion of this minus 3 inch talus material is mixed in a pug mill mixer with about 30 per cent clay, adding water to obtain optimum moisture. The product of this mixture is material 1. It has a plasticity index of about 10 and belongs to the *GC* group.

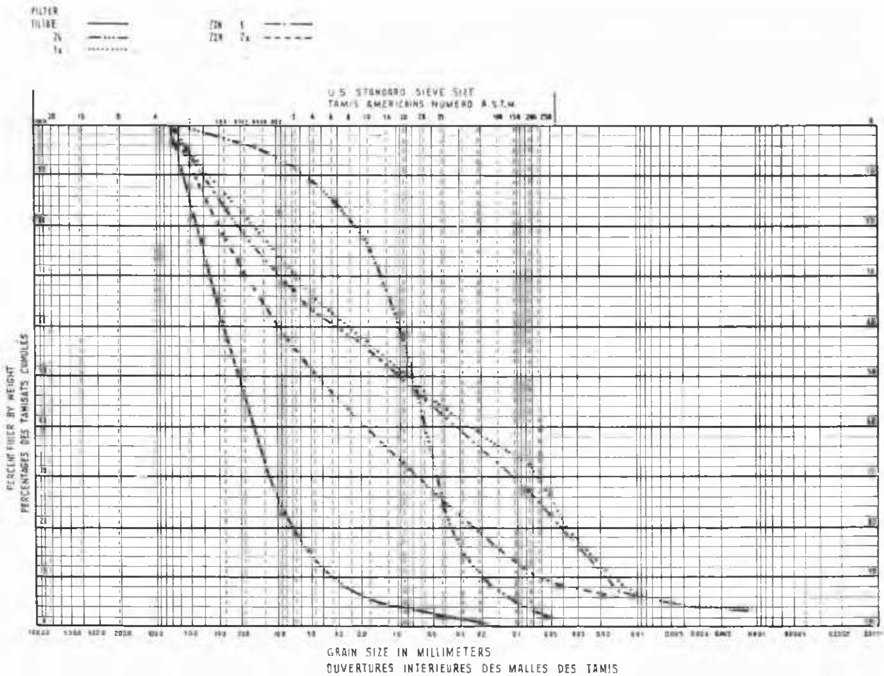

Fig. 3 Grading of the materials for the different parts of Las Pirquitas dam.
Granulométrie des matériaux pour les différentes parties du barrage Las Pirquitas.

The material used in zone 2b is clean sand. Its function is to prevent any internal erosion from developing as a result of movements of the dam. The filter material is produced by screening and washing the minus 3 inch fraction of the classified talus material.

The outer parts of the dam are made with the classified talus material larger than 3 inches (zone 3) and with rock comming from the spillway excavation and from quarries specially opened for that purpose.

Zone 1a, zone 1 and zone 2a are compacted to maximum density with sheep foot rollers similar to those used by the U.S. Bureau of Reclamation. Zone 2b and the filter zone are compacted by vibration using tractors on fully saturated material. Zone 3 and 4 are truck dumped and accomodated by means of monitors.

The stability of the dam was checked against the possibility of a circular type of slide during construction and sudden drawdown, and against sliding along the base with a full reservoir.

Rio Hondo dam

Rio Hondo dam is located on the Dulce River in the province of Santiago del Estero near the city of Las Termas, at a place called Rio Hondo. The soil profile here is made up of a several of layers of preconsolidated silts and clays, separated by thin layers of water bearing sand with artesian water. The top soil stratum, to a depth varying between 5 and 10 m, consists of loose silt, with a structure that collapses when it is saturated under load.

The Dulce river cut its bed through this formation by erosion to depths varying from about 30 to 50 m. Consequently the soil profile at the dam site is made up as follows (Fig. 4).

In the river bed, there is a layer of fine to medium sand, with underlying strata of preconsolidated clays and silts constituting the original virgin ground. Erosion has been more intense on the right than on the left. On the right side, the original preconsolidated soil appears at a depth of 2 m below the river bed; on the left side, the clay and silt strata are overlaid by 25 m of sand. At the river banks, to depths varying from 5 to 10 m, the soil profile consists of loose silt, with a high natural void ratio and a loose structure.

The design of the earth embankment of this dam has been devided in two parts :

1. On the river banks, its cross section constitutes a uniform earth embankment with an L-shaped dowstream drainage blanket. Presaturation will be used to consolidate the foundation during construction.

2. At the river bed, the cross section is that of a two-zoned embankment (Fig. 5). The upstream zone is formed of silty clay or clay existing at the river banks; the downstream zone with sand from the river bed. These two zones are divided by an L-shaped drainage blanket of clean permeable river bed sand.

A frontal spillway, outlet works and power station have been located at the river bed and founded on the shallow preconsolidated clays existing near the right bank.

Seepage and piping is being controlled by an impervious blanket extending 500 m upstream from the axis of the dam.

Very extensive subsoil and material investigations were carried out to study in detail the foundation conditions and the quality of the materials used in the construction of the

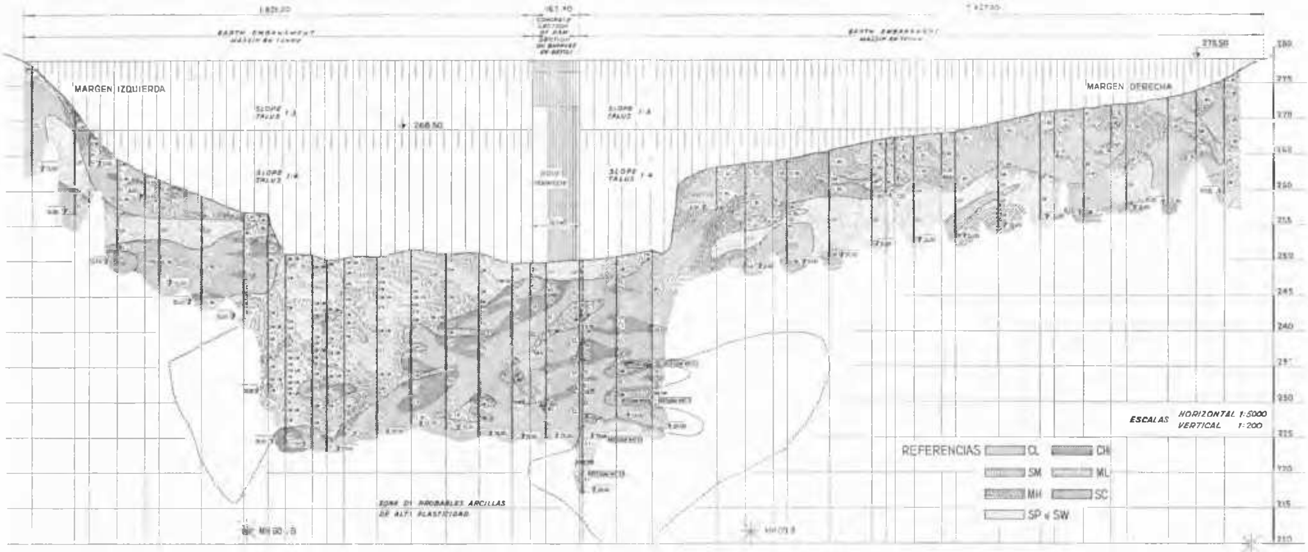

Fig. 4 Longitudinal soil profile at Rio Hondo dam.
Profil longitudinal du sol du barrage Rio Hondo.

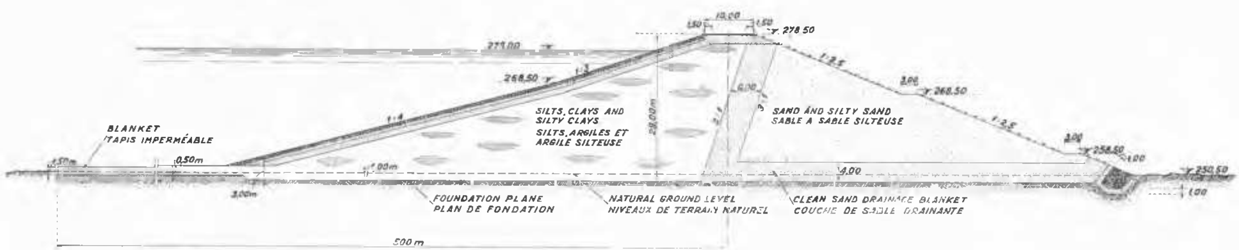

Fig. 5 Cross section of Rio Hondo dam.
Section transversale du barrage Rio Hondo.

dam. The soil is of a highly lenticular nature, and a very detailed study was necessary so that the concrete section of the dam would be placed at the best location from the point of view of the foundation.

At the right abutment there is artesian water at shallow depth, following sand instrusions coming from the right banks. Construction of the concrete section was arranged so that none of these intrusions was encountered during excavation.

Soil investigations to determine the quality of materials for the construction of the earth dam showed that two types of materials are available : (1) clean and slightly silty fine sand, and (2) silt, silty clay or clay of low plasticity. An extensive investigation was undertaken to determine the mechanical properties of these materials. The sand showed an angle of internal friction of 35° 30′ for a relative density of about 0·7. The silty soil was tested under two conditions of drainage : (a) undrained, after the soil had been compacted with optimum moisture at maximum normal Proctor density ; (b) drained, after the soil had been compacted with optimum moisture at normal maximum Proctor density and fully saturated. The results showed the same angle of internal friction for the undrained and for the drained triaxial tests, the only difference being in the amount of cohesion that the soil exhibited under both conditions of drainage. The angle of internal friction was equal to 33° in both cases ; cohesion to about 0·50 kg per sq.cm for the undrained tests, and to about 0·9 kg per sq.cm for the drained test.

Stability analysis of the silty soil slopes of the dam embankment showed that the factor of savety was controlled by the value of the cohesion exhibited by the soil. It was therefore decided that control of the soil to be placed at the embankment should aim to obtain a value of this cohesion. Therefore, this control specifies a minimum value for the unconfined compressive strength of the silty soil to be placed in the dam, compacted at optimum moisture and normal maximum Proctor density. No other measure of quality control will be made. To control the behaviour of the dam during and after constuction, an extensive set of piezometers will be established. On the river bank sections of the dam, the piezometers aim to measure pore presure in the loose silt foundation during construction, since saturation of this loose silty foundations will make this period the most critical for these sections of the embankment. Failure can occur only through the foundation and the piezometers will control neutral stresses in this material.

In the main section of the dam, at the river bed, piezometers will be installed at three transverse sections to control the behaviour of the dam during construction and in service. This dam is under construction and its comprehensive and final design has been made by Societa Edison, Milano, Direzione Construzioni Impianti Idroelettrici.

El Cadillal dam

This dam has a remarkable history of previous failures, because of difficult foundation conditions. The last attempt was to build an Ambursen type dam. Construction started and some of the counterforts were built ; it was finally decided to revise the whole project. Several consulting engineers and geologists gave their opinion as to the best way to treat the foundation. All reached the conclusion that the solution would be extremely expensive and, what is more important, that its cost was unknown. It was decided to leave what had already been done and, using the existing knowledge of earth dams, to prepare a new design which would meet existing conditions both technically and economically.

The foundation rock is sandstone with some layers of clay. To find a zone where a satisfactory watertight curtain could be made at a reasonable cost, it was necessary to make a most careful geological investigation because most of the canyon wall are badly faulted and fissured. Fig. 6 shows the designed foundation treatment below the impervious core, which includes a cutoff wall and grouting. Grouting will be done from a tunnel to treat the right abutment. In the best cross section found in the canyon there are four faults and one area in which the rock is heavily fractured.

At the base of the valley floor the dam rests on gravel ; on the rest of the valley floor and at both abutments, the foundation rests on the detritus covering the slopes.

Fig. 7 shows the cross section of the dam. The main materials for its construction are gravels and sands from the valley floor and inorganic silty clays of loess origin with a Liquid limit between 20 and 30, and a plasticity index between 4 and 9. Dr. A. Casagrande was consultant for this job and he recommended many of the features adopted in the design. Among them, the use of an arched axis, a thick core of silty material, and a thick transition zone to insure the self healing of cracks through the core from whatever cause they might avise.

The stability of the dam was checked against a possible circular failure during construction and sudden drawdown and against the possibility of sliding along its foundation, both during construction and with full reservoir. Since abutments are covered by dense vegetation and thick layers of badly weathered detritus, readjustments in design may be

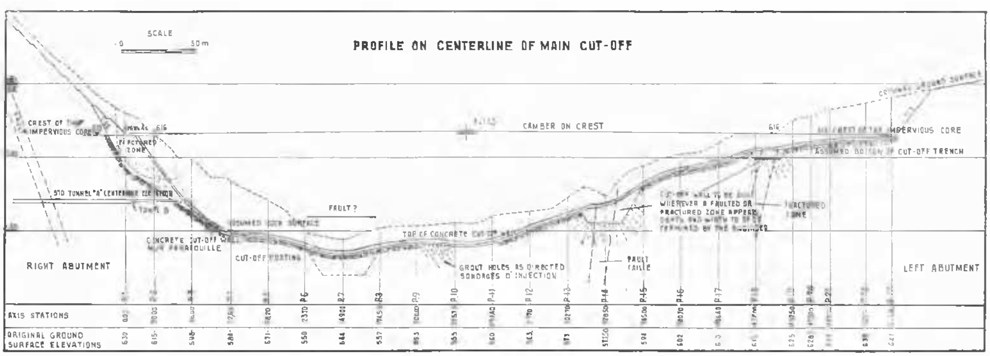

Fig. 6 Designed foundation treatment below the impervious core of El Cadillal dam.
Traitement projeté pour la fondation au-dessous du noyau imperméable du barrage El Cadillal.

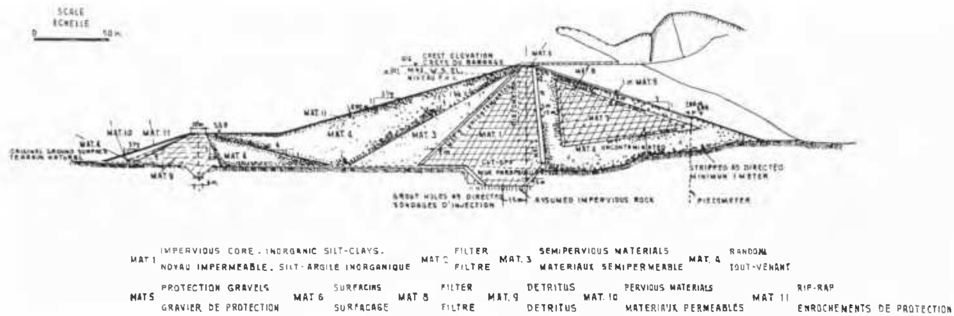

Fig. 7 Cross section of El Cadillal dam.
Section · transversale du barrage El Cadillal.

required after stripping the entire area to be occupied by the dam.

El Horcajo dam

This dam is located on the river Los Patos in the Province of San Juan, at a place where the river passes through a narrow valley, flanked by two abutments of unusually sound rock (red porphyry). Test boreholes revealed that the river bed alluvium fills a U-shaped valley floor to a depth of about 60 m with a narrow canyon that extends to about 150 m below the present valley floor.

This dam is founded mainly on well graded alluvial gravels ranging in size from boulders to fine sand with a trace of silt. Permeability tests in the alluvial material resulted in coefficient of permeability of the order 10^{-1} cm per sec. The proposed dam will consist of an earth embankment 117 m high, sa detailed in Fig. 8 of this paper with a total volume of 17.000.000 cub m Triaxial tests performed on the three types of material to be used in the construction of the embankment indicated the following values for the shear strength of the soil :

The gravel to be used in zones 1 and 4 to form the slopes of the dam shows an angle of internal friction of 39 degrees for a relative density of 0·6; the material for zones 2 and 3, when compacted to normal Proctor density and saturated, an angle of internal friction of 37 degrees, and a cohesion $c = 0{\cdot}4$ kg per sq. cm. Under similar conditions the soil that will make up the impermeable core dam, an angle of internal friction of 30° 30′ and a cohesion $c = 0{\cdot}2$ kg per sq. m.

Seepage control and safety against piping constitute the most difficult problems of this dam. The Preliminary design called for both an impervious blanket extending 1 000 m upstream from the axis of the dam and a cut-off wall made up by an injection curtain extending as shown in Fig. 8.

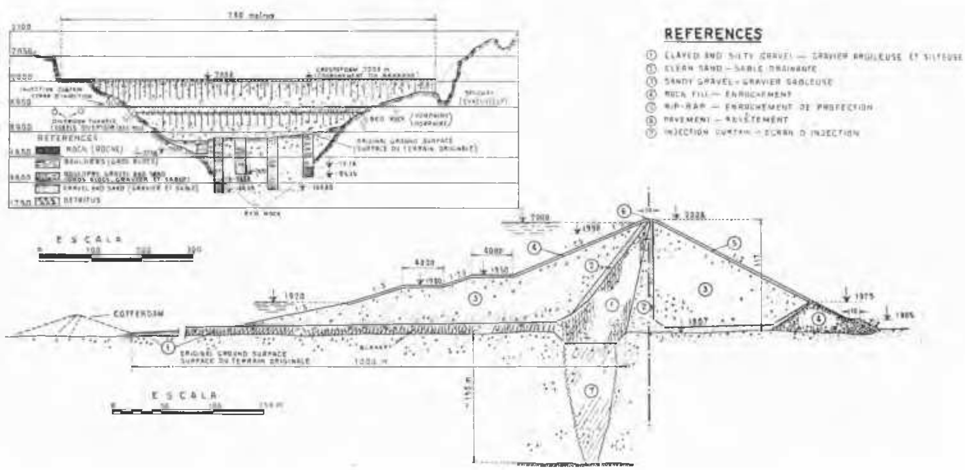

Fig. 8 Longitudinal foundation profile and cross section of the El Horcajo dam.
Profil longitudinal de fondation et section transversale du barrage El Horcajo.