Present Soil Properties and Performance of the Arvo Dam During Twenty-five Years of Operation

Propriétés du Sol et Comportement du Barrage de l'Arvo au cours de Vingt Cinq Années d'Opération

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Summary

The Arvo Dam, 34·7 m in height, was built in southern Italy during the period 1927–31. As soon as construction was completed settlement observations were begun on seven reference points along the crest of the dam. At the same time measurements of the discharge rates from the drainage system were started.

In 1955 a vertical boring was made through the core from the crest to the foundation, undisturbed samples obtained and laboratory tests performed. Two samples of the downstream slope material were obtained from pits at two locations.

A study has been made for the purpose of interpreting the data obtained from observations on the structure in service and relating them to the soil characteristics determined in the laboratory as well as to the construction methods and the geological features of the site.

Sommaire

Le barrage de l'Arvo, d'une hauteur de 34·7 m, a été construit dans l'Italie du Sud pendant les années 1927–31. Aussitôt que la construction fut achevée, on commença la mesure du tassement de sept points de repère long du couronnement du barrage. Parallèlement on mesura les débits du système de drainage.

En 1955 on a exécuté un sondage dans le noyau, du couronnement jusqu'à la fondation; on a pris des nombreux échantillons intacts et on les a essayés au laboratoire. On a pris aussi deux échantillons dans la zone aval du barrage.

Les auteurs ont tâché d'interpréter les observations faites sur le barrage et de les mettre en rapport avec les propriétés des matériaux, les méthodes de construction et les caractéristiques géologiques de l'emplacement.

Introduction

The Arvo dam, 34·7 m in height, was constructed in the high plain of the Sila in Calabria (Southern Italy) during the years 1927 to 1931. The dam was designed and constructed using the criteria of the most up-to-date practice at that time. During the construction the characteristics of the materials used, principally the grain size distribution and the permeability, were checked and controlled.

The filling of the reservoir was begun on 13 June 1931; the dam was completed on 15 August of the same year. During the 25 years of service, from 1931 to 1956, the dam has given fully satisfactory performance in every respect. In this not too brief period of time the settlement of seven reference points established on the crest of the dam has been observed and recorded. Also the discharge rates from the drainage system have been measured.

Because of the considerable collection of data available on this dam, in December 1955 it was felt desirable to make a boring through the core from the crest to the foundation materials. Undisturbed samples were obtained. In addition samples were taken from pits on the downstream slope of the dam. These samples have been subjected to extensive laboratory tests.

Geological Conditions at the Site

The central and highest part of the Sila is characterized by palaeozoic rocks: granites and crystalline schists, greatly

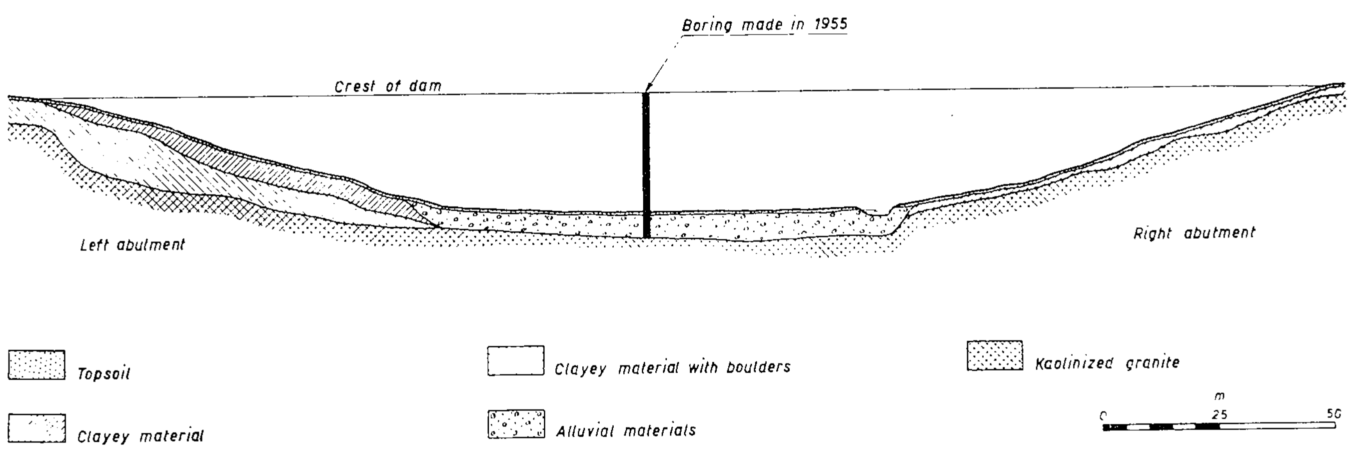

Fig. 1 Foundation materials. Profile on axis of dam
Terrains de fondation. Coupe longitudinale

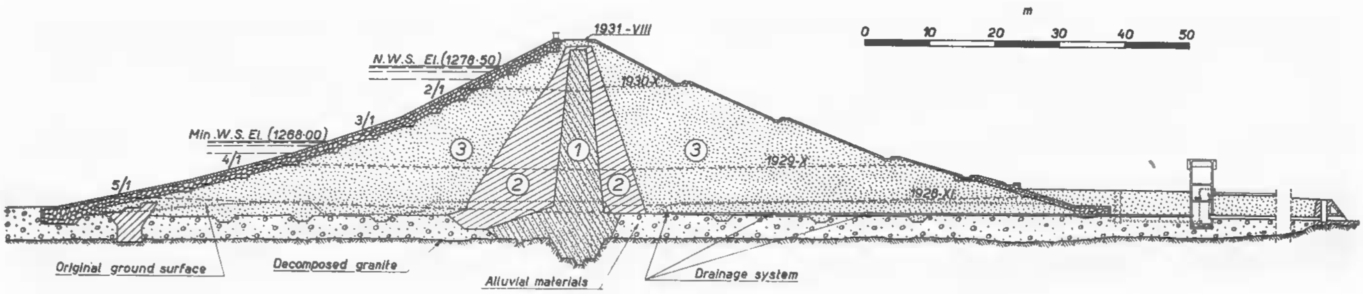

Fig. 2 Typical cross-section of dam
Section type du barrage

deformed by tectonic forces. Interbedding of different rocks and pegmatitic intrusions can be observed. Water is able to seep along the surfaces of contact of contiguous materials and through the numerous fractures in the structure.

The ridges of the high plain are not far distant from the Tyrrenian Sea on Italy's west coast; the drainage systems are towards the south east and east generally. In these stream basins the crystalline rocks on the surface have been profoundly altered and frequently kaolinized so that there is an impermeable cover of variable thickness on the slopes up to a certain elevation. Locally, in the lowest points of the valleys, soil deposits transported from the surrounding rocky masses are encountered.

This is the general character of the high plain and it is typical of the site at which the dam was constructed (Fig. 1). The formation of decomposed granite was found to be very uniform; however, during the excavation of the cut-off trench, water came from the sides of the excavation in many places, but the total quantity was not large.

Construction Details and Methods

The dam (Fig. 2) has a central core of clayey material of low permeability (Fig. 3, material 1). Coarse grained materials were used in the construction of the slopes (Fig. 3, material 3). Between the core and the external slopes two symmetrical zones were formed of materials having intermediate characteristics.

The material for the core was obtained from compact beds of decomposed granite, which had been transported in past times down the slopes by gravity and which were, as a result, well mixed. The soils for the intermediate zones were obtained

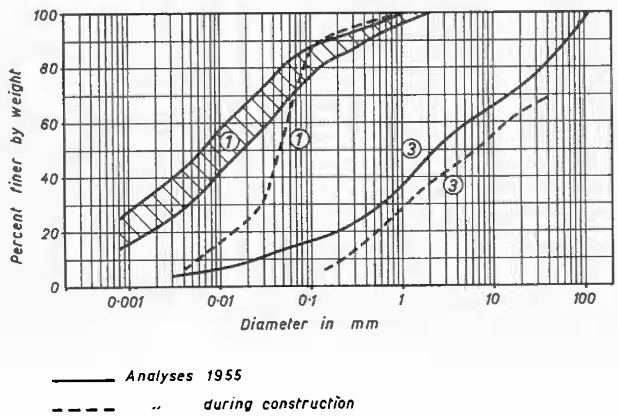

Fig. 3 Grain size distribution
Courbes granulométriques

from areas of residual altered granite and for the slopes the deposits of alluvial material in the floor of the valley were used.

Materials were transported from the borrow areas to the site

Fig. 4 The dam during construction, from the left abutment
Le barrage pendant la construction; vue du côté gauche

Fig. 5 Filling the cut-off trench
Remblayage de la tranchée de parafouille

in dump cars on an industrial railway (Fig. 4); they were spread by hand in layers 20 cm thick in the core and 30 cm in the remainder of the cross-section. Oversize stones were also removed by hand. Rolling and watering proceeded simultaneously; the water content used was that amount necessary to give the material a degree of consistency described as 'normal consistency'. This standard probably depended entirely on the judgment of the engineer.

In filling the cut-off trench a different procedure was used. Because of the seepage mentioned previously it was not possible to use the rollers. The materials were distributed by the workers, mixed with the water and finally left undisturbed for some time (Fig. 5).

Characteristics of the Core Material

In December 1955 a boring was made in the dam from the crest to the foundation and undisturbed samples obtained. The energy necessary to drive the sampler was measured and Fig. 6 shows these data.

The material '*A*' (Fig. 6) consisting of decomposed granite was encountered first. The fraction 0·02 to 2·0 mm predominated with the fraction < 0·02 mm always present. Plasticity was medium-to-low and the material was not at all homogeneous. Often particles with diameters of 2·0 to 10·0 mm were encountered.

Subsequently a brown material designated '*B*' was encountered. It was of the same origin as material '*A*', but the grain sizes were smaller, the plasticity medium and the material on the whole more homogeneous.

During the sampling operations it was found that in the strata *a*, *b* and *c* the soils were soft and had very high water contents. In fact they were so soft that it was not possible to obtain intact samples of these strata.

The strata *a* and *b* were in that part of the embankment constructed at the end of the construction season in 1929 and the stratum *c* was in the part of the embankment constructed at the end of the next season. Since the placement area was sloped downward towards the core (Fig. 2), during the two periods of inactivity water from rain and melting snows increased considerably the moisture contents of the surface stratum. When work was resumed in the spring, these wet soils were not removed; they were covered with drier materials and then rolled.

The grain size distribution of material '*B*' is shown in Fig. 3. The average values of the Atterberg limits are PL = 0·25; LL = 0·41; PI = 0·16; the values of LL range between 0·37 and 0·46. On the Plasticity Chart (A. Casagrande) the material '*B*' is represented by a short and narrow band between the inorganic clays of medium plasticity and the inorganic silts of medium compressibility.

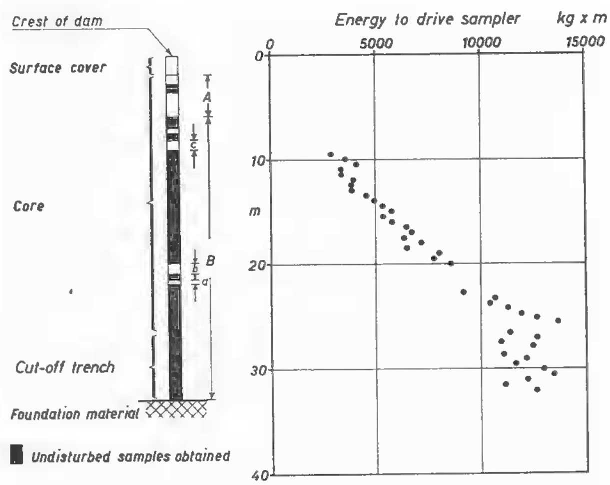

Fig. 6 Boring made in 1955
Sondage exécuté en 1955

In Fig. 7 the values of PL and LL are plotted at the depths where the samples were obtained. Straight lines are the result of a statistical examination of the test data. At a depth of 17 to 18 m there is a definite discontinuity, although the magnitude is small. This shows that the material '*B*' is not homogeneous as one would believe on the basis of its appearance. This experimental result is perfectly explainable, because just when the embankment had reached this elevation in July 1930 it was found necessary to change the borrow area.

Gradual changes of the Atterberg limits occur in each one of the materials: these variations can be interpreted as slight variations that occurred as the working face of the borrow pits was advanced.

Fig. 7 shows also the moisture content *W* of the samples taken in 1955. Here also are noted the same slight trends observed in the Atterberg limits.

The following table shows representative values of PL, LL, *W*.

Variable	*Depth* m	*Mean value*	*Standard deviation*
PL	0 –17·20 17·20–34·80	0·226 0·271	0·012 0·014
LL	0 –17·20 17·20–34·80	0·394 0·424	0·021 0·021
W	0 –17·20 17·20–34·80	0·298 0·319	0·033 0·042

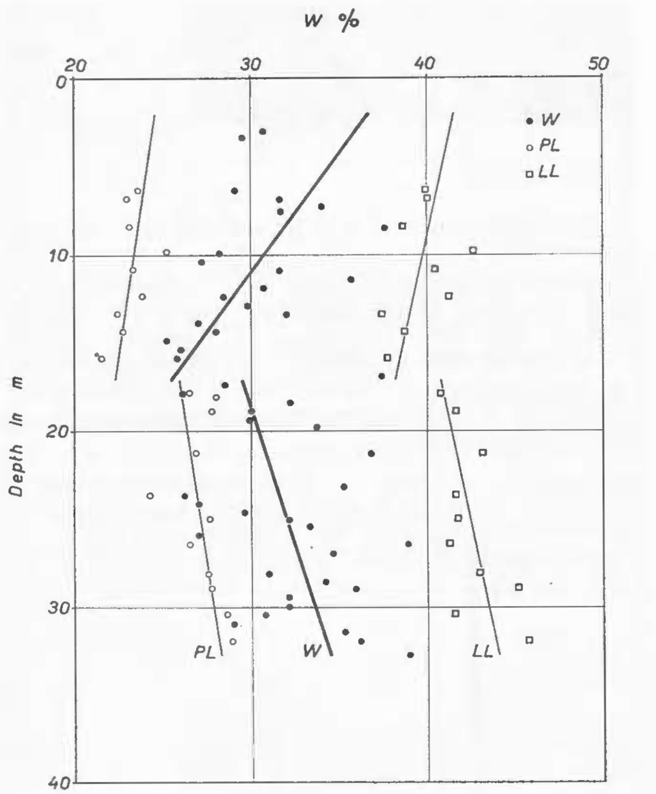

Fig. 7 Atterberg limits and water content in 1955 in the core of dam
Limites d'Atterberg et teneur en eau en 1955 dans le noyau du barrage

Unfortunately very little data are available on the water content and the dry unit weight of the materials immediately after rolling. These few values correspond to the continuous curve in Fig. 8. From an examination of this figure and with a knowledge of the construction methods we find a basis for believing that the original moisture content was in excess of the optimum.

Also in Fig. 8 are shown the values of *W* and dry unit weight of the same materials in 1955: there is definite indication that a condition of complete or almost complete saturation exists now.

Settlement Observations

Shortly after the dam was finished settlement observations began on seven reference points on the crest of the structure. It seems evident (Fig. 9) that there is no relation between the amount of settlement and the height of the embankment where the reference point is located.

The progress of the settlement has been gradual and with the exception of one reference point, which has not changed elevation appreciably since 1950, the structure continues to settle. There seems to be justification for believing that the settlements of the crest over the 25-year period since the dam was finished were independent of the height of the embankment.

The average settlements are shown in Fig. 10, the value reached in 1955 is about 14 cm. This amount of settlement would result in an average decrease of 0·025 in the voids ratio.

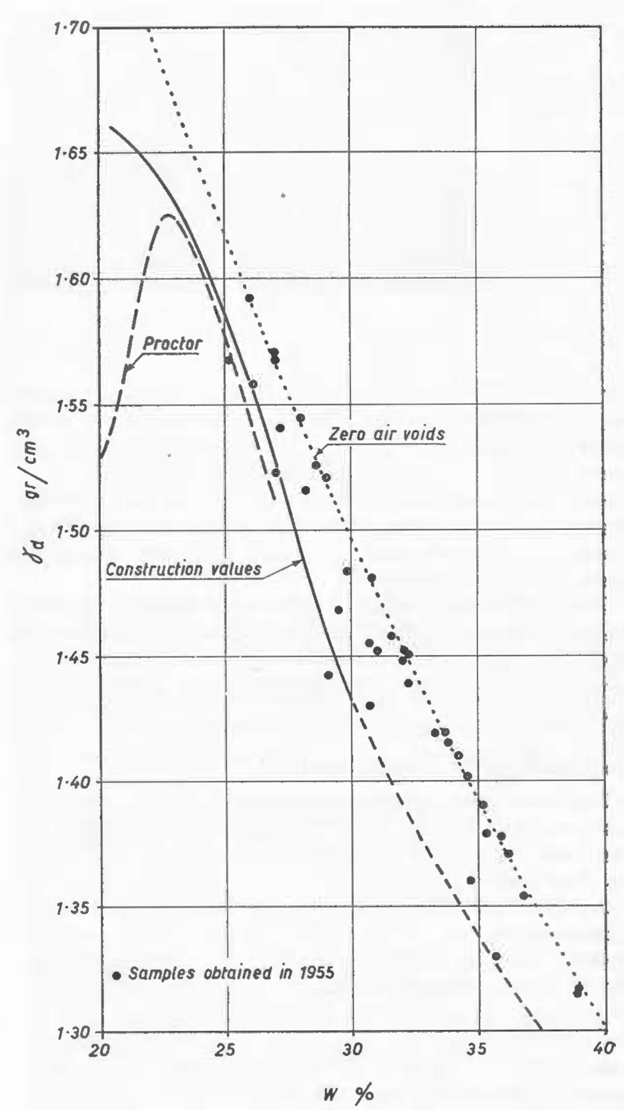

Fig. 8 Dry unit weight—water content
Poids unitaire à sec. Teneur en eau

The interpretation of these data in the absence of parallel data on the pore water pressures in the core is not easy. Nevertheless, it may be interesting to consider some of the possibilities.

In our opinion the rocky formation, into which the cut-off trench has been cut, is so strong that its deformation would be negligible. Since the various points on the crest have settled almost equally over this lengthy period of observation it seems to indicate that the core materials placed in the structure below a plane about 13 m under the crest have not contributed to the total settlement appreciably.

On the basis of this assumption two hypotheses can be made:

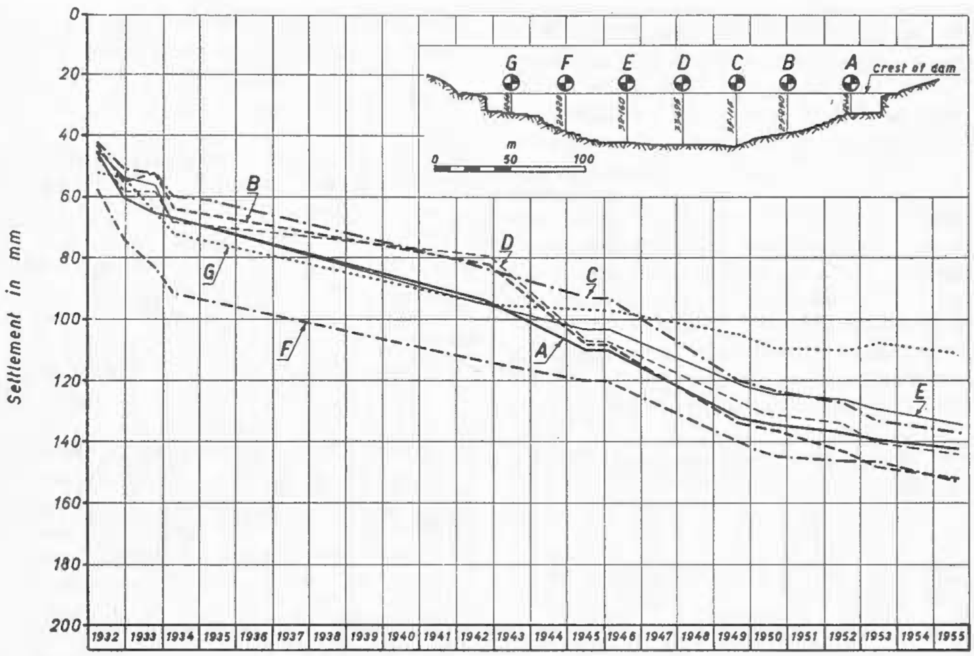

Fig. 9 Settlement data
Tassements mesurés

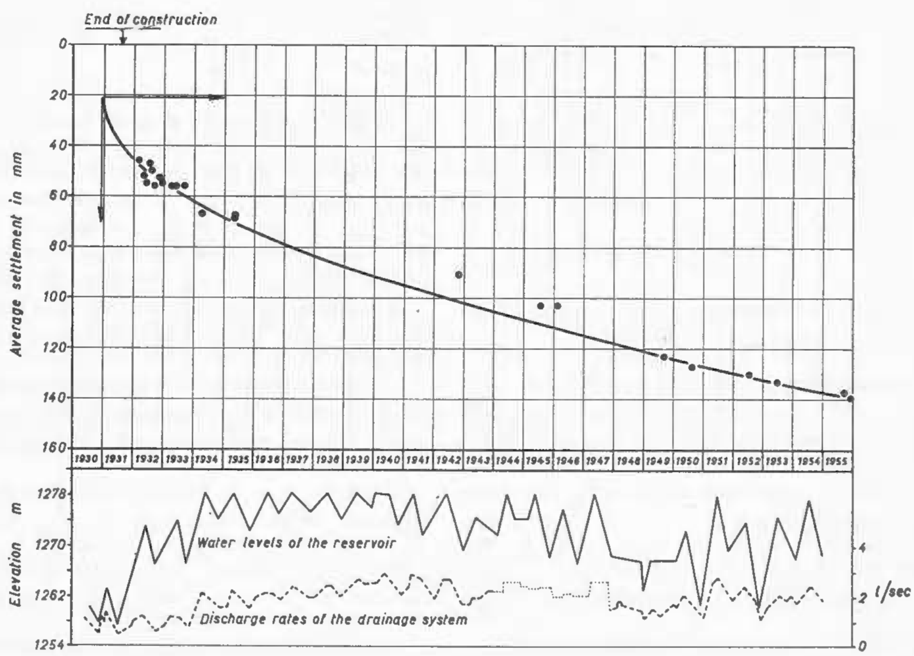

Fig. 10 Settlement–time curve for dam
Courbe de tassement du barrage en fonction du temps

(a) at the beginning of the measurements the materials below this plane were already fully consolidated under the action of the superimposed soils; (b) on the contrary, the consolidation of these lower materials even now is negligible and neutral pressures still exist in them.

Justifications for considering the second hypothesis are: the very low permeability of the core material; also the relatively low permeability of the intermediate zone materials; the conditions and the construction practices used in construction of the cut-off trench; and finally the form of the core and the intermediate zones on either side with the width greater at the bottom than at the top of the section. Further support of hypothesis (b) is gained when it is recalled that the strata *a*, *b*, *c* discussed previously had absorbed large amounts of water during the construction period and after 25 years were found to be still soft and with a very high moisture content.

Consolidation tests were made on 12 of the undisturbed samples obtained in 1955. Examination of the results shows that they can be grouped in two categories. The first category includes the samples obtained from 0 to 15 m depth from the crest and the second group the remaining ones. Fig. 11 presents a curve that is typical of each of the groups.

The study of these curves supports the idea that in the lower zone of the core effective pressures are still negligible. They make it possible, also, to evaluate the effective pressures in the upper zone; from these values and on the basis of the voids–ratio–pressure curves it is possible to calculate a settlement of the crest of the dam very close to the value of 14 cm which has occurred.

The trend of the time–settlement curve (Fig. 10) is also significant. The settlements measured until 1935 and those subsequent to 1948 fall along a parabola with axis horizontal and its vertex on the abscissa at a point which corresponds to the beginning of the year 1931, a few months before the dam was completed. Therefore the experimental time–settlement curve is very similar to that indicated by the theory of consolidation for one-dimensional compression.

There is also a convincing explanation of the settlement rates during the period 1935 to 1948.

From the record of the levels of the reservoir (Fig. 10) it is seen that until 1935 the level was in general rising with an

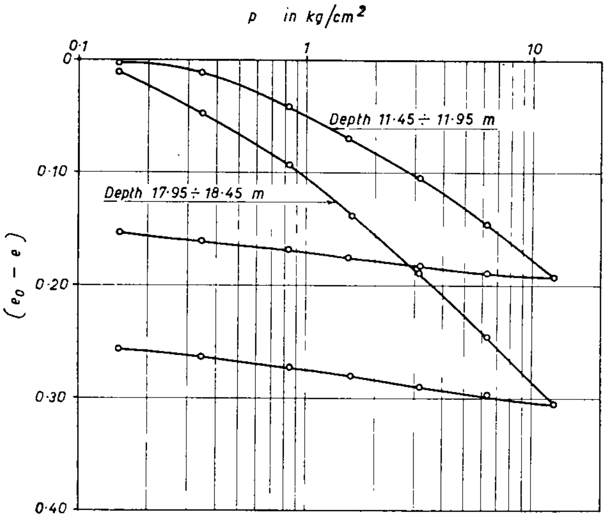

Fig. 11 e-log p curves for samples
Courbes, e-log p pour les échantillons

average value of 1270 m above sea level. From 1935 to 1942 there was a period in which the reservoir was almost always full; as a consequence the neutral pressures in the core due to the water levels of the reservoir were greater than before and the rate of settlement was less. After 1942 the levels of the water in the reservoir averaged somewhat less than in the previous period and finally from 1947 the average level was about the same as in the initial period of filling of the reservoir. Correspondingly, the settlement rates were increased and then returned to normal values.

Finally we are led to believe that the core of the dam is still under consolidation and the porosity of the material is decreasing slowly and gradually. However, one should not lose sight of the fact that, on the basis of the measurements made, the moisture contents at the present are higher than they were initially. This seems to indicate that during the period of service of the dam the air content has decreased and the water content has increased.

Discharge of the Drainage System

During the time the dam has been in service the amount of water collected and discharged by the foundation drainage system has been observed and measured (Fig. 10).

Before the dam was finished and the reservoir began to fill the drainage system was discharging about 1 l./sec. Later the amount increased to about 2 l./sec and has remained between 1 and 2 l./sec since that time. From the permeability tests made on the undisturbed samples of core materials values of k_w of the order of 10^{-8} cm/sec under effective pressures of 1 kg/cm^2 were obtained. When one takes into consideration the dimensions of the dam and the very low permeability coefficient, the amount of water which would seep through the dam is absolutely negligible and one can conclude that the water which was discharged from the drainage system has not come through the dam but through the foundation and the natural abutments. It is interesting also to know that during the construction of the dam very numerous permeability tests were made on the core materials. The maximum value believed acceptable was 8×10^{-8} cm/sec, but actually materials somewhat more permeable were frequently used.

Conclusions

The material used in the formation of the core of the dam is among the finest grained and the most plastic used to date. It was placed in the embankment at a moisture content in excess of the w_{opt} and sometimes greatly in excess of that value. During the construction of the dam and its service period the degree of saturation has increased; on the average it is now very close to 100 per cent.

It is believed that the material in the core is in the primary compression phase and that the neutral pressures have reached, and even today continue to have, very high values. In spite of this the behaviour of the dam has been fully satisfactory in service. This is probably due to the central position of the core; to the use of proper materials in the intermediate and outer sections and to the particularly favourable foundation conditions at this site. The quantity of seepage through the core is small but the drainage system has served a very useful function with respect to the filtration through the foundation and the abutments.

The level of the water in the reservoir has an influence on the phenomenon of consolidation in the core, but this seems to be an average effect which depends on the average water level over a period of years.

During the construction of the dam the material for the core was most carefully checked. Its grain size distribution and its permeability were studied. However the data from the grain size analyses indicate that a not entirely satisfactory experimental technique was used; the permeability test data are entirely valid.

During the placing operations the variable kept under control was the moisture content.

The method of obtaining samples from a dam some time after its construction has proved to be practical. Subsequent laboratory tests and correlation of all related data on the materials used, the construction methods, the behaviour of the structure in service, etc., provide material for useful study and basis for future design improvements.