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# VI 7

## The Application of Pre-Stressing in Dams.

## Anwendung der Vorspannungen auf Staumauern.

## Utilisation des précontraintes dans les barrages.

M. Coyne,
Ingénieur en Chef des Ponts et Chaussées, Paris.

In Volume I of the Publications of the I.A.B.S.E., 1932, reference was made to certain possibilities of design in the strengthening of old dams, and an account was given of work planned in Algeria based on our ideas in application to the Cheurfas dam. At that time only preliminary studies had been carried out, but since then the work has been completed with entire success and is worthy of mention at the Congress.

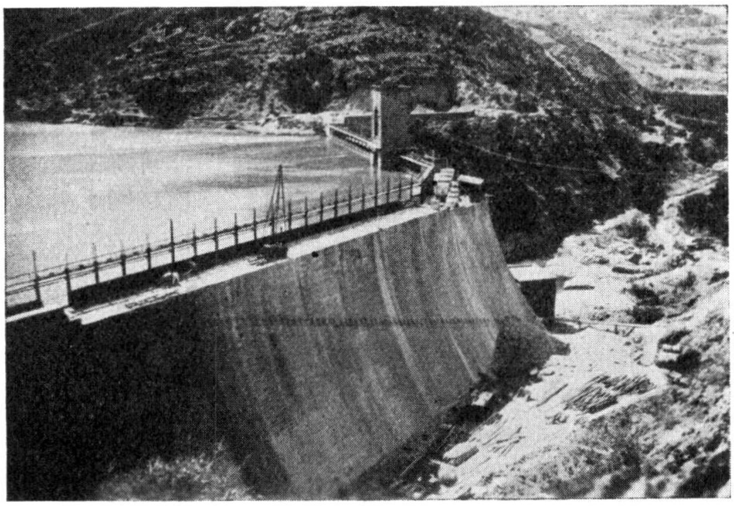


Fig. 1.
Cheurfas dam.

The Grands Cheurfas dam which is situated at Oued Mékerra 20 km above Saint-Denis du Sig in the Department of Oran, Algeria, was constructed between 1880 and 1882 with a view to the irrigation of the fertile plain of Sig, this being the name given to the Mekerra in the lower portion of its course. The structure is a gravity dam made of random masonry and has a maximum height of 30 m (Fig. 1).

It belongs to a series of French gravity dams constructed during the past century wherein the margin of safety is sometimes very low. A number of these dams have failed, notably that at Bouzey, and (to mention cases nearer to the present example) the Oued Fergoua and the Hebra dams.

It was in consequence of this last mentioned accident that the Government-General of Algeria decided to that the Cheurfas dam should be strengthened.

The procedure adopted for this purpose consists in attaching the structure to the ground below by means of tie bars, which in a sense play the part of very

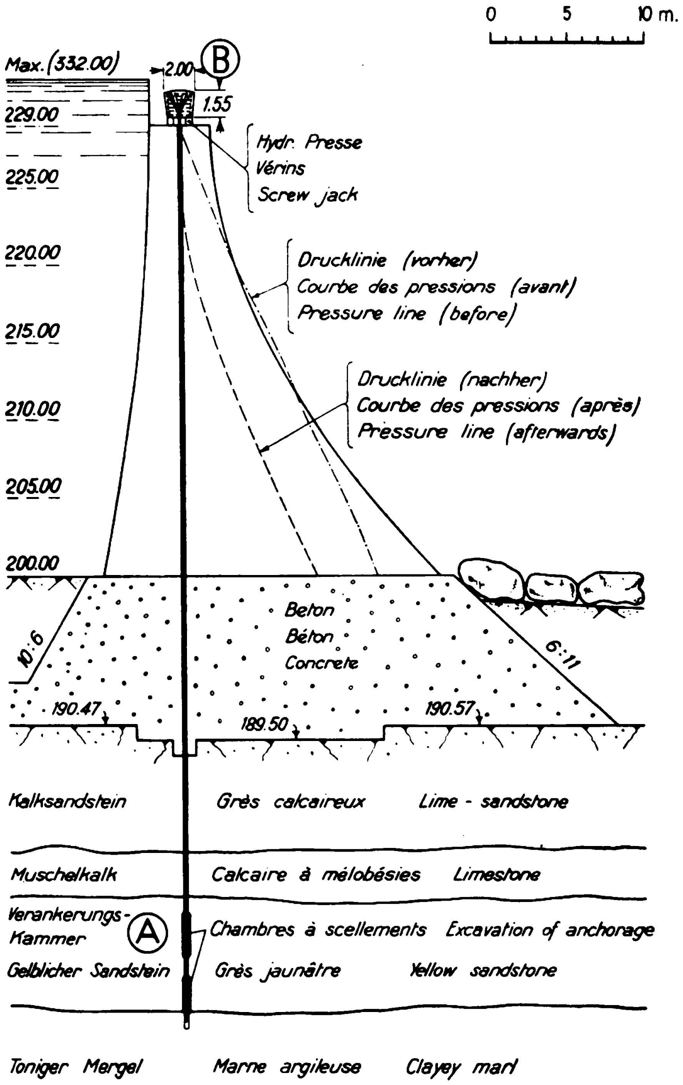



Fig. 2.

Effect of anchoring tie in changing the line of pressure.

large turnbuckles. If, for instance, such a tie be assumed to be stretched between the point A in the foundation and the point B on the crest of the dam (Fig. 2), it will be seen that by adjusting the load and the number of tie bars the line of pressure can be modified at will, and the structure may be given any desired factor of safety, or its height may be increased. (The increase provided for at Cheurfas was 3 m.) So far nothing more is involved than a new application of a very simple idea which is constantly being used in current practice; but the novelty lies in the scale of the forces involved, for in fact each of the ties exerts a force of 1000 tonnes at the crest of the dam and as there are altogether 37 of them in the work the result is to form an artificial load equivalent in the aggregate to one-third of the natural weight of the structure and half of the pressure due to the water. The line of pressure can thus be controlled at will, and is deflected powerfully in the direction of safety.

It need hardly be said that the introduction of forces of this order was a matter which called for long and careful preparation, particularly since the foundation

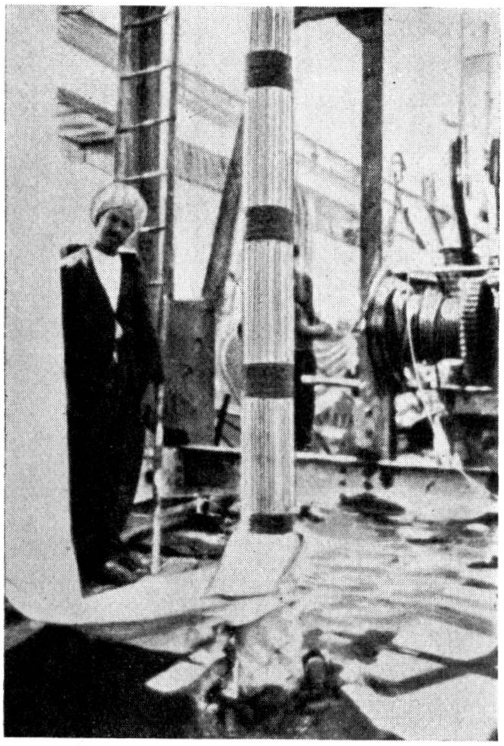


Fig. 3.

Insertion of the 1000-ton anchoring tie.

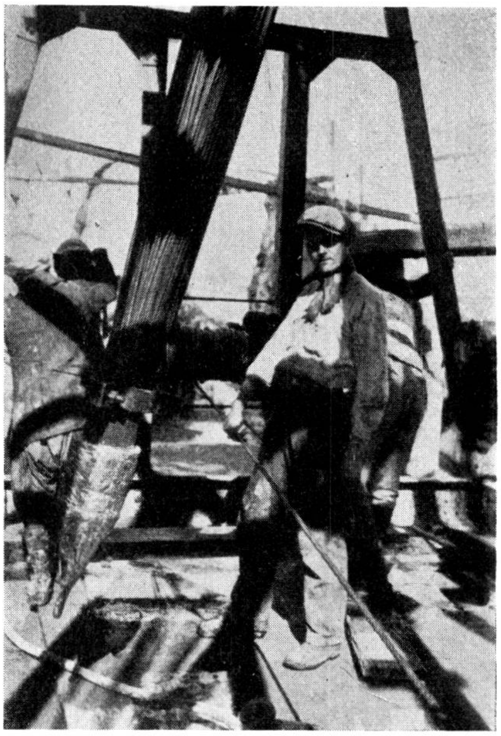


Fig. 4.

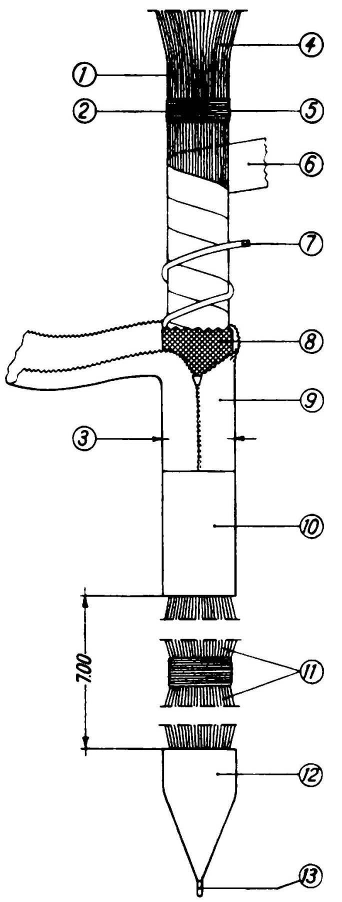
Bottom end of 1000-ton anchoring tie.

underneath the dam is of very inferior quality, consisting of soft sandstone containing pockets of chalk, marl and even quicksand.

Vertical shafts 25 cm in diameter and 50 m deep were cut through the dam into the foundation below, and at the bottom these shafts were widened out to form two anchoring chambers one above the other each 3 m long and 38 cm in diameter, by means of an enlarging tool. Within each shaft there was introduced a cable consisting of 630 parallel wires of hard steel, 5 mm in diameter (Fig. 3), and these wires were bound over the whole length except for some metres at the bottom (Fig. 4); where they enter the anchorage chambers they spread out under the weight of the cable itself. Cement was then injected at the bottom of the shaft by means of a pipe lowered together with the steel cable, but to prevent the whole length of the cable from being sealed and grouted to the shaft it was enclosed, above the level of the anchorage chambers, in a special sleeve of bituminous material between two fabric covers (Fig. 5). Except where actually sealed, the cable is, therefore, completely independent of the surrounding masonry shaft.

Above the crest of the dam the wires are spread on to a reinforced concrete crosshead, jacks being inserted between this and the crest to exert the necessary stretching force (Fig. 6 and 7). The unit stress in the steel is of the order of 80 kg/mm², or between six and seven times the permissible stress in reinforced concrete.

All the anchorages carried out in this way proved completely successful at the first attempt, despite the bad quality of the ground, and in the course of time




(1) 630 Nos of galvanised steel wires, each 5 mm in diam.

(2) 15 cm diam. of bound cable,

(3) 20 cm average diam. of completed cable.

(4) Flintcote coating.

(5) Bindings every 50 cm.

(6) Canvas soaked in Flintcote.

(7) Aloë-rope.

(8) Plastic layer (compound of fat and bitumen).

(9) Canvas cover with Zip-fastener.

(10) Mortar cover over wires and canvas.

(11) Wires laid bare for concreting-in.

(12) Conical white-metal shoe.

(13) Injection pipe.

**Fig. 5.**

Construction of anchoring cable.

they have lost at the most a few hundredths of their initial tension. The tension is easily controlled, and can at any time be restored by replacing the jacks under the crosshead of the cable.

The adoption of this system made it possible to realise an economy of ten million francs (Fig. 8). The credit for it is due to M. *Vergniaud,* Ingénieur en Chef des Ponts et Chaussées, and M. *Drouhin,* Ingénieur des Ponts et Chaussées, in conjunction with Messrs. *Rodio* as contractors.

The procedure can be applied in a number of ways. It has for instance been used for strengthening the lighthouse in the sea near Jument d'Ouessant (Fig. 9), rendering that structure invulnerable to even the heaviest storms, despite the great violence of their impact against its sides. This was accomplished by fixing the lighthouse to the ground by half a dozen tie bars, each stressed by 1500 tonnes.

It is, however, chiefly in new work that the process has been found effective and economical. The thrust of arch bridges or the tension in the cables of suspension

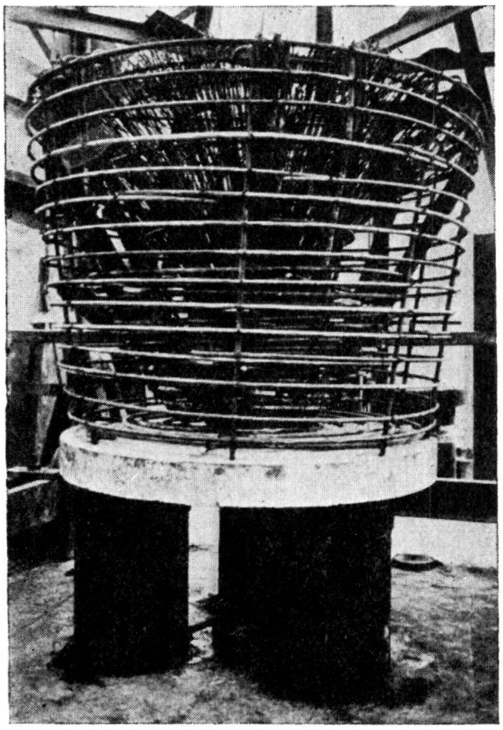


Fig. 6.
Reinforcement of head of anchoring tie.

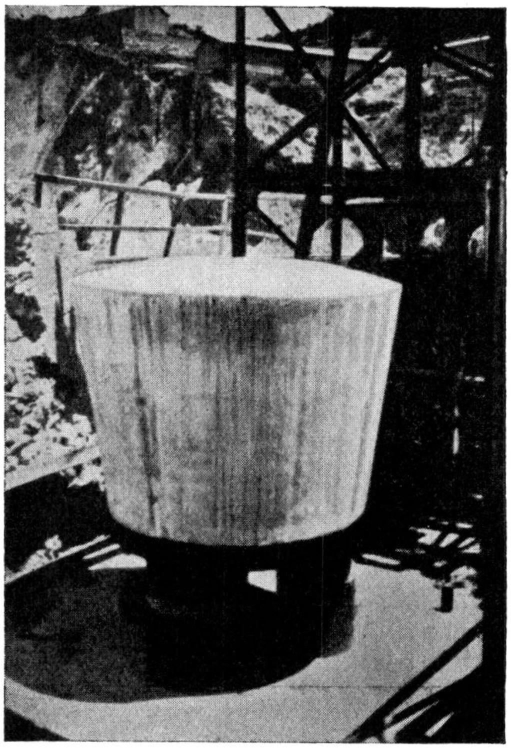


Fig. 7.
Concrete head of anchoring tie on three hydraulic jacks.

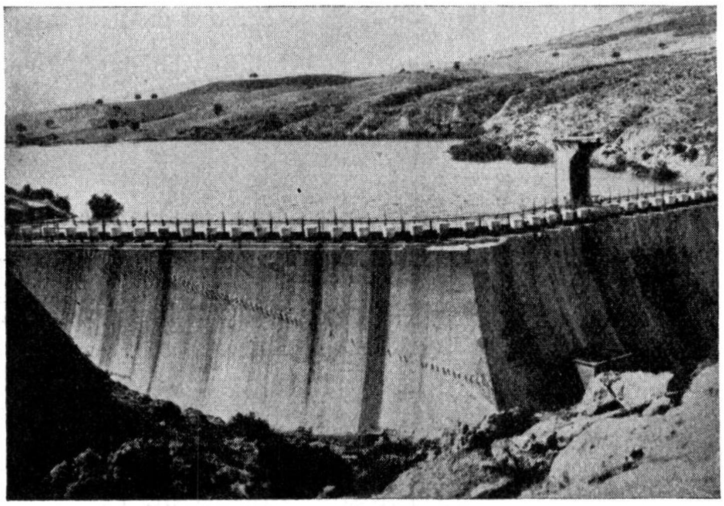


Fig. 8.
General view of Cheurfas dam after its reinforcement by 37 1000-ton anchoring ties, the heads of which may be seen.

bridges can be taken up in the same way, without the need to use huge masses of masonry which are costly and bulky.

It is, indeed, often a question of space which makes this expedient necessary. This is true in regard to certain abutments of arch bridges, or river training banks built on bad ground, which in this way can be fixed down with complete safety. Such a case arises on the right bank of the Marèges gravity dam which is founded on a thin ledge of granite. As a rule the quality of the ground will be sufficiently good to allow of dispensing with the precautions which were neces-

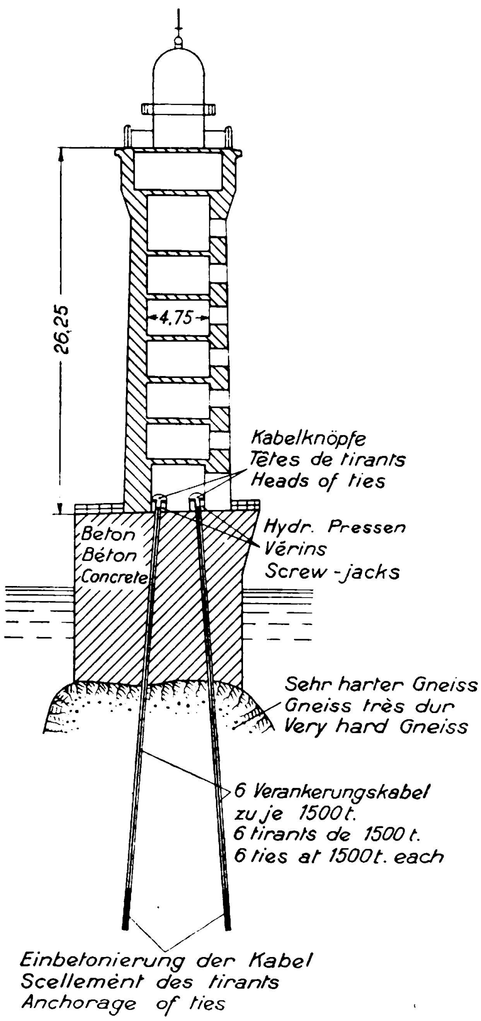



Fig. 9.

Section through lighthouse at Jument d'Ouessant with anchoring ties.

sary at Cheurfas, where the application was made the first time in difficult ground — for instance it should be unnecessary to enlarge the bottoms of the shafts and to provide the thies with a plastic protective cover; the tie could simply be introduced without any special preparation into a hole *not enlarged*, at the bottom of which an accurately pre-determined amount of cement grout would be introduced as in ordinary sealing work. Finally, after the tension had been imposed, the hole would be filled with concrete from top to bottom. Moreover the use of cables prefabricated in the workshop would greatly simplify maintenance on the job and would considerably reduce the cost (Figs. 10 to 15).

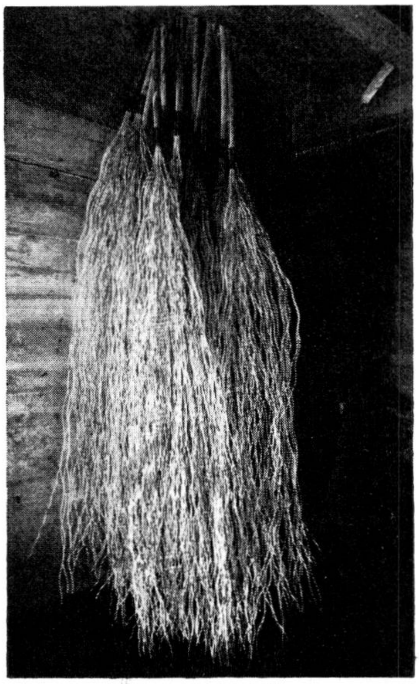


Fig. 10.
Marèges dam: anchorage of gravity abutment, showing the bottom end of the anchoring tie unravelled.

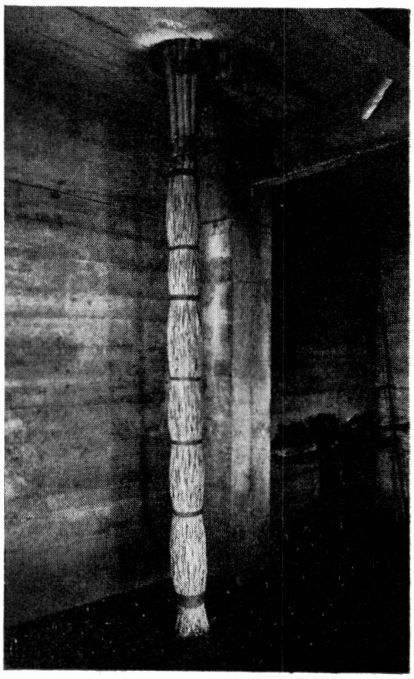


Fig. 11.
Marèges dam: anchorage of gravity abutment. The bottom end is shown bound to allow of insertion in the bore hole, but only the lowest of the bonds is to be retained.

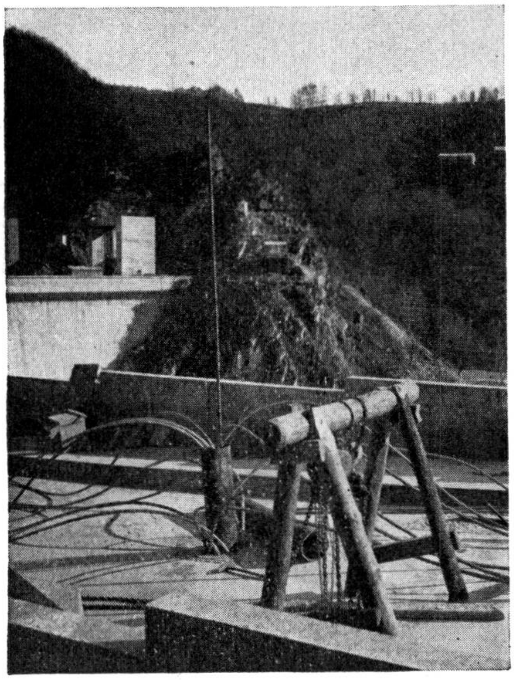


Fig. 12.
Marèges dam: anchorage of gravity abutment. Formation of the anchoring tie in progress on the crest of the dam, showing the pipe to be used for injecting cement grout around the bottom end.

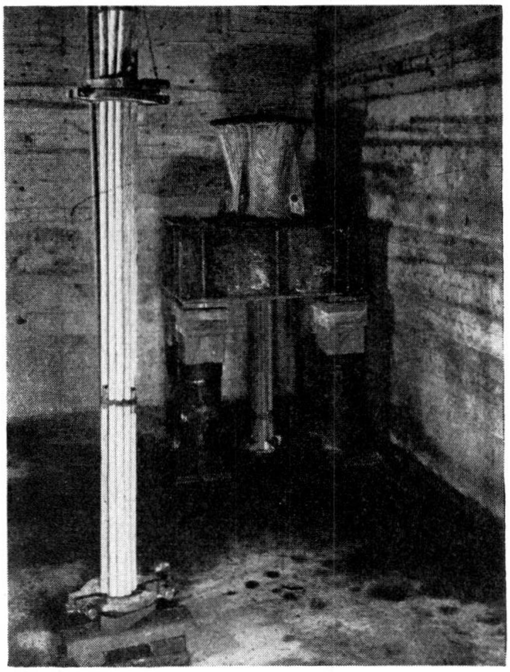


Fig. 13.
Marèges dam: anchorage of gravity abutment. In the foreground is part of an anchoring tie composed of 15 cables, and in the background the head of such a tie already tensioned and still supported on six hydraulic jacks.

The process thus made available is an accurate, powerful and economical means of creating certain artificial elastic conditions in mass structures, or even of greatly modifying their statical equilibrium. One may visualise in this way a fundamental change in most of the accepted forms of design for structures intended to resist lateral pressures.

Fig. 14.

Marèges dam; anchorage of gravity abutment. Anchoring head ready for casting the sleeve.

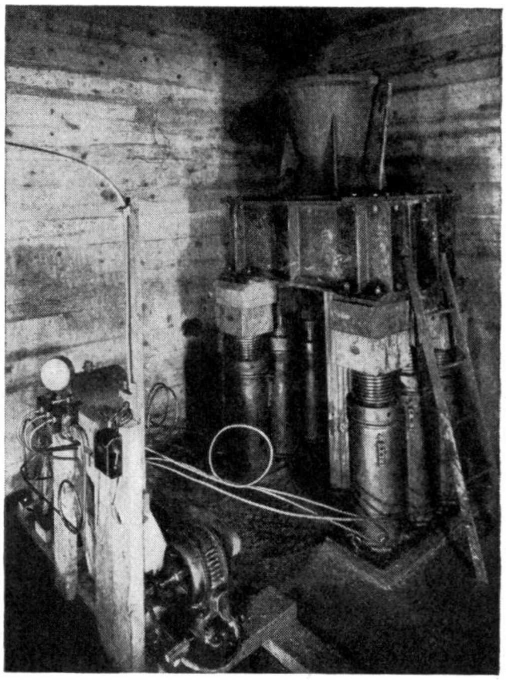


Fig. 15.

Marèges dam: anchorage of gravity abutment. Tensioning of tie by means of six hydraulic jacks.