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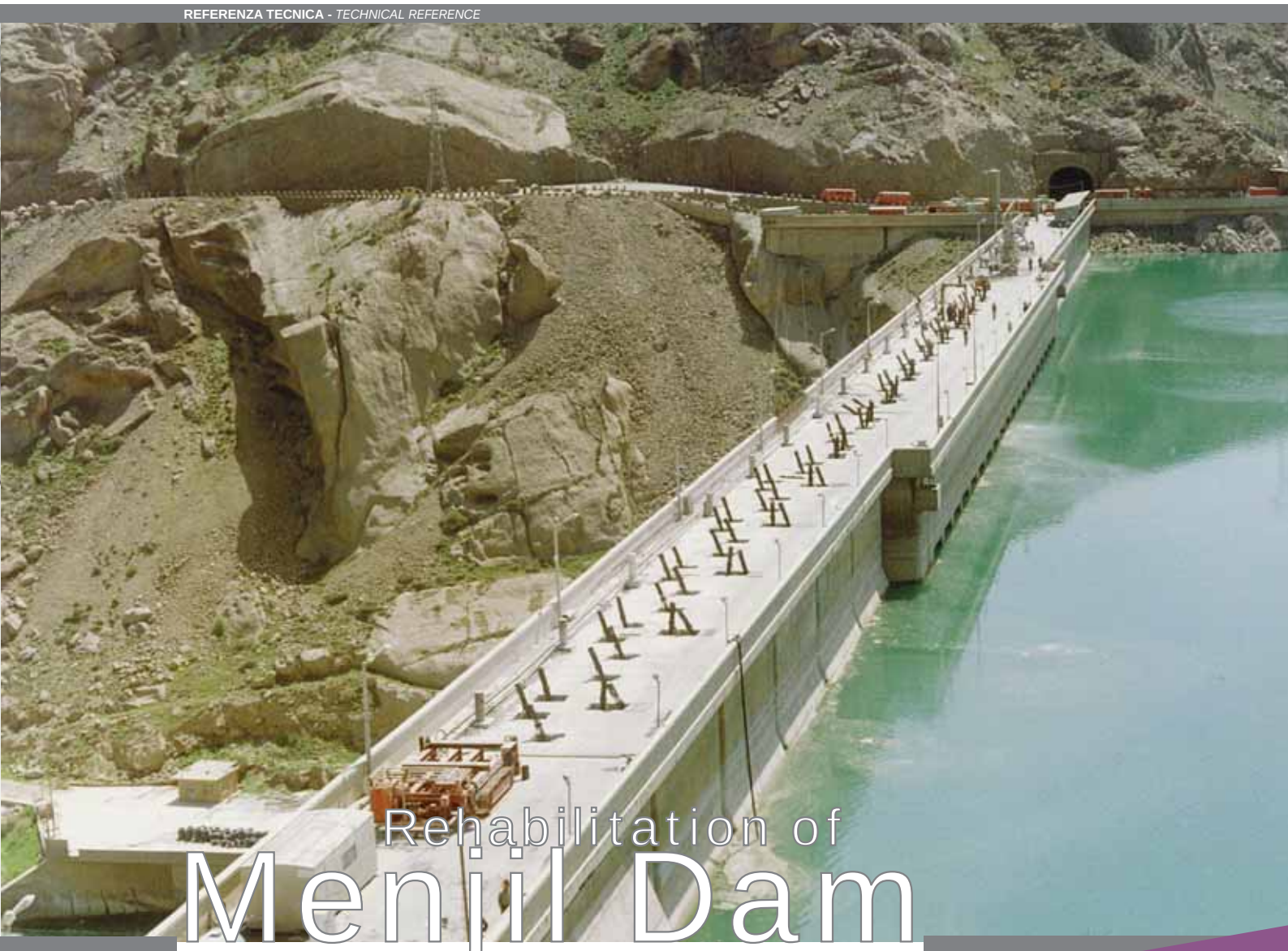
TREVI

REFERENZA TECNICA - *TECHNICAL REFERENCE*



Rehabilitation of Menjil Dam

Sefid-Rud river, Iran

Grouting

Anchors

Cliente : *Owner*	IRAN WATER & POWER RESOURCES
Contrattista principale : *Main Contractor* :	**RSR Rodio Sefid Rud JV Consortium**
Durata dei lavori : *Duration of work :*	**1990 - 1991**

The **Menjil dam**, *on the Sefid-Rud river, is located in Iran 200 km North West from Teheran and 100 km from the Caspian Sea. It is a concrete gravity dam with 24 buttresses and has maximum* **height of 106 m and 417 m crest length**. *The dam was completed in 1962 and was built for irrigation and power generation purposes.*

The catchment area is **58 000 km²** *with a 1.8 billion m³ reservoir and a 4.2 billion m³ yearll average water supply. The irrigated area is 2200 km while the power generated per year is 420 million kWh. On the 21st of June 1990 an earthquake of 7.3 on the Richter scale occurred, which wiped out the two built-up areas situated close to the dam and caused severe damage to the dam itself. Thirty six hours after the earthquake took piace, a group of experts, in spite of tremendous difficulties, finally reached the site in order to inspect the consequences of the seismic event.*

The dam did not show evidence of irreparable structural damage such as to impair its stability, but the buttress upper part showed cracks, mostly horizontal, up to 2 cm wide, going from upstream to downstream, and reaching 20-25 m from the dam crest. In addition, so that displacements of 1.5 to 2 cm of the concrete were detected along the working joints. Immediate rehabilitation measures were required to assure regular impounding during the forthcoming 1991 season, the harvest would not be compromised.

The treatrnent consisted of repair to the cracks, in order to avoid water seepage and restore the monolithism of the structure. In addition, anchors were foreseen, to be installed below the cracks, from the dam crest to the embankment, to increase the safety coefficient against fissuring, should a new earthquake occur.

Cracks treatment with epoxyresm

The works began with the drilling of exploratory boreholes to ascertain in a more realistic way the status of the dam (Water Power & Darn Construction February 1994).

The first investigation works were aimed at assessing the state of the working joints, since these showed the most alarming signs of damage.

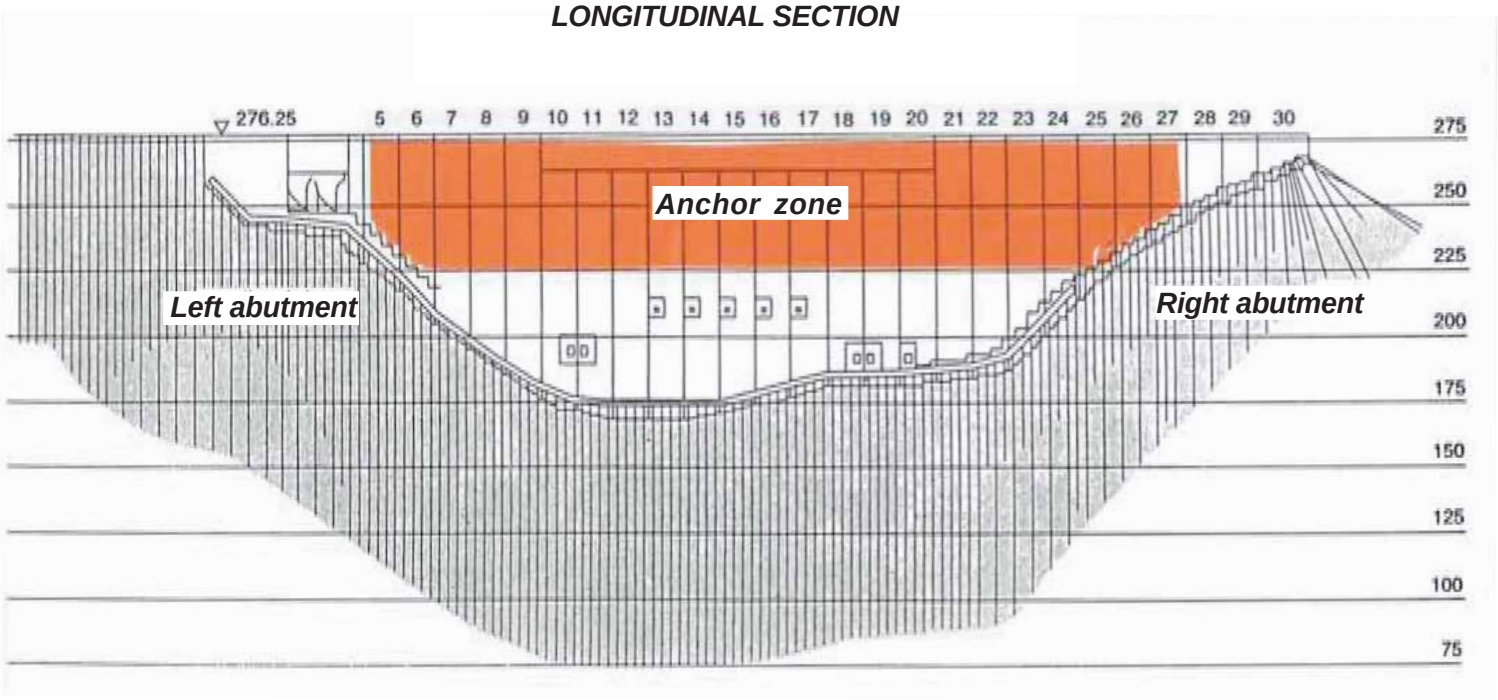
A borehole was drilled on each buttress, parallel to the upstream face of the dam and centred in the middle of the buttress. A water test was done on each working joint, every 2 m, and on intermediate levels when necessary. The water tests results indicated 57 elevations where water takes were measured between 51 l/min and 0.4 l/min. Lower values were disregarded by the engineer, who considered it unnecessary to treat these concrete workingjoints. Epoxy resin with inorganic filler was used in conjunction with specific studied procedures to bond the two faces of the concrete fissures.

The **main characteristics** *of the treatment for filling the voids were:*

¥ grouting was done in non-confined spaces; the surface to be treated was dry or wet
¥ the cracks were treated individually
¥ high pressures were used during grouting.

Typically, a grid of boreholes distributed along the surface to be treated, and intersecting it, was drilled in order to grout the resin under pressure (6 to10 MPa at crack location).
Based on the resin characteristics (viscosity and pot-life) and grouting features (pressure and flow-rate), the distance between boreholes ranged from 1 to 2 m at crack elevation.

LONGITUDINAL SECTION



The pattern of grout holes was devised considering the spacing necessary to obtain interconnections while grouting, as well as the constraint of not crossing the location of the anchors, since most of the grout packer is normally left inside the hole at the end of the injection. To isolate the crack to be individually grouted, the boreholes were drilled up to 0.5 m below the identified crack and the grout packer was installed 0.5 m above the same crack. The result was a 1 m long grouting pocket with the crack in the middle. The pocket minimum length was mandatory, since the precise location of the crack was unknown.
The grout packer was connected to the grouting pump by steel pipes and by high pressure grout hoses.
The injection begins at one point of the crack, and it continues until the resin interconnects with a nearby borehole.
At that point the injection is shifted to the interconnected borehole. These steps are repeated until all the drilled boreholes are used.

Once the resin starts to flow inside the crack, it displaces the water, generally present due to the drilling operations or water tests, and dries the crack faces adhering to them effectively.

During the injection of the major cracks, it was noted that resin not only was flowing along the concrete working joint, but also along inclined cracks intersecting the major one, as an extensive network of secondary fissuring, that largely contributed to increasing the crack surface to be treated.
Upon completion of the treatment, a series of check holes was drilled: the cores recovered showed that concrete working joints as well as the secondary fissures were perfectly bonded by the resin grouting.

Anchor design

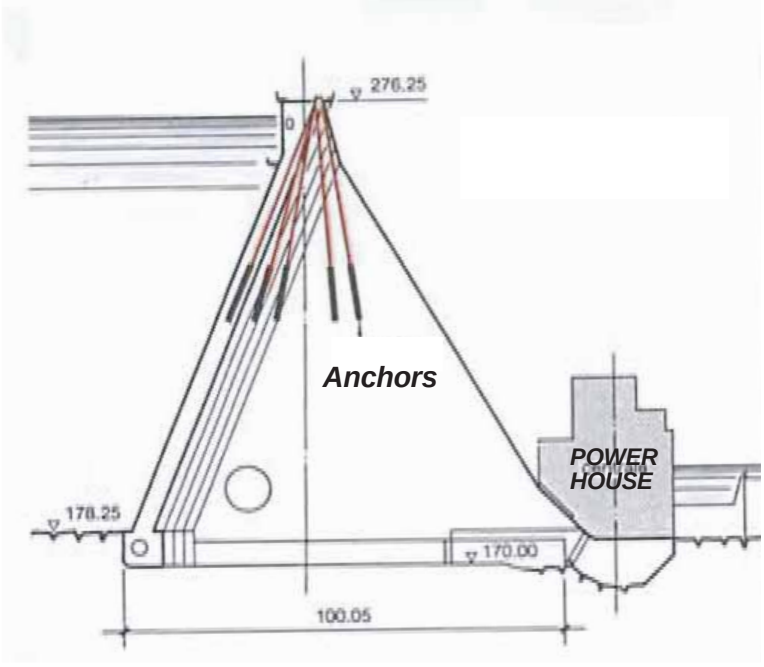
The design provided the **application of a load up to 100 MN on each of the 24 buttresses, by installing 12 anchors, for a total of 234 anchors**, *having the following characteristics:*

- working load	**8400 kN**
- breaking load	**14000 kN**
- working/breaking load ratio	**0.6**
- average total length	**40 m**
- bond length	**12 m**
- inclination to the vertical	**3¡ to 22¡**

The calculation of the bond length was made assuming an equivalent uniform distribution of bond stress along the bond length. Based on the British Standard Code of Practice for Ground Anchorages, BS 8081:1989, it was assumed the ultimate concrete/grout bond value equal to 1.4 N/mm^2 with a load factor of safety equal to 1.75.

Each anchor was fully grouted type, composed of 54 strands, individually greased and sheathed, in the unbounded free length. The strand was of 15.2 mm (0.6 in) diameter type, seven wire steel, in accordance, with ASTM A416-85 Grade 270 K, 140 mm^2 nominai steel area, with a guaranteed ultimate tensile strength of 1,862 N/mm^2, a guaranteed breaking load of 260.7 kN and a minimum load at 1 per cent extension (yield point) of 221.5 kN.
The design of the block to support the anchor head was

CROSS SECTION



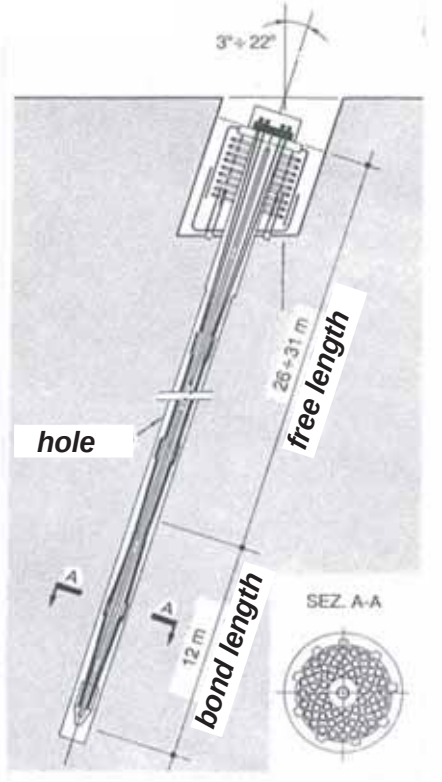
based on the evaluation of the stress state within the block, in accordance with the ultimate limit state theory.

Anchors construction

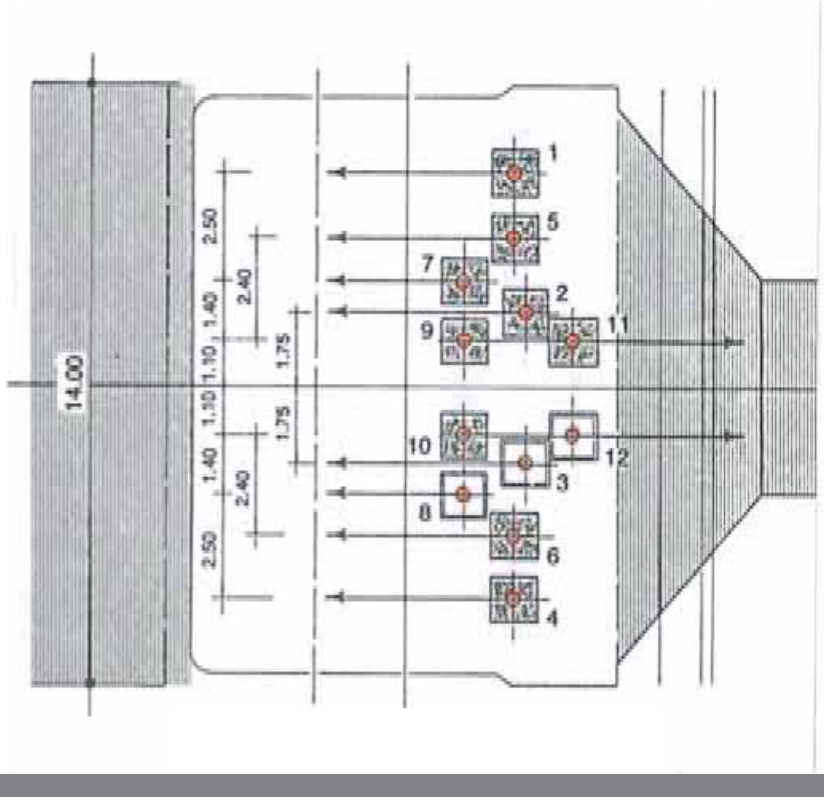
The operations concerning the anchors' construction were carried out on each buttress, upon completion of all the resin grouting works.
The first operational phase consisted of carefully positioning the rig toward the drilling direction; the most delicate situation was that of the two anchors installed in the buttresses where the distance between hole and wall was 1.27 m.
Upon completion of a guide hole 278 mm diameter, 2 m deep, by rotary percussion method, the anchor hole 254 mm diameter, was drilled up to the full length using a down-the-hole hammer with a foaming agent diluted in water as drilling fluid and as cleanser. A string of drilling rods 194 mm diameter was used.

Complete filling of the borehole was carried out with water. Water loss was measured after l0 minutes to verify the borehole watertightness. In general, all the water losses were lower than 1 litre/minute, regardless of the water head applied.
After accurate washing up of the borehole wall by flushing with compressed air and water through the drilling string, a temporary plug was placed at 1.6 m depth.

TYPICAL ANCHOR



BUTTRESS 13 PLAN



Then the anchor block recess, 1.30 m wide, was constructed; this being mandatory to house the anchor head below the road ' pavement on the crest of the dam. The operation was carried out by drilling a series of intersecting boreholes, 1.5 m deep, with down the hole hammer.

Subsequently, the installation of the pre-assembled reinforcement was carried out together with the steel pipe and the bearing plate, followed by pouring the concrete, having 35 MPa minimum characteristic strength.

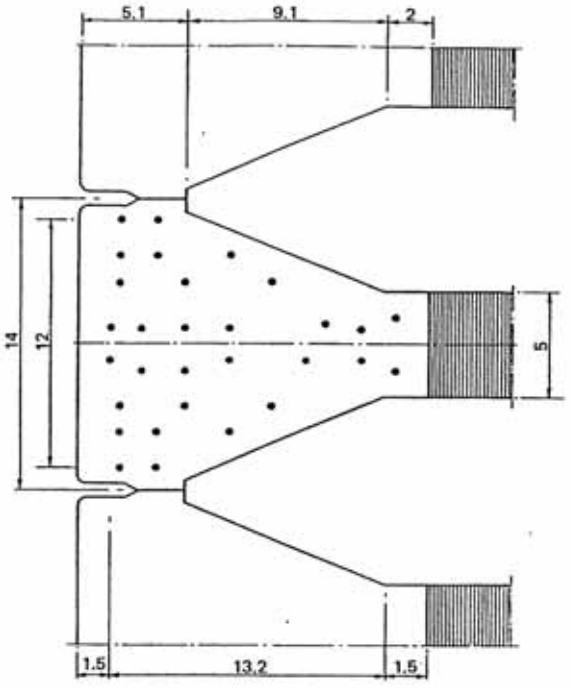
The anchors were installed to the desired inclination by means of a crawler-mounted homing equipment, nicknamed "mammoth" for its remarkable size.

Stressing

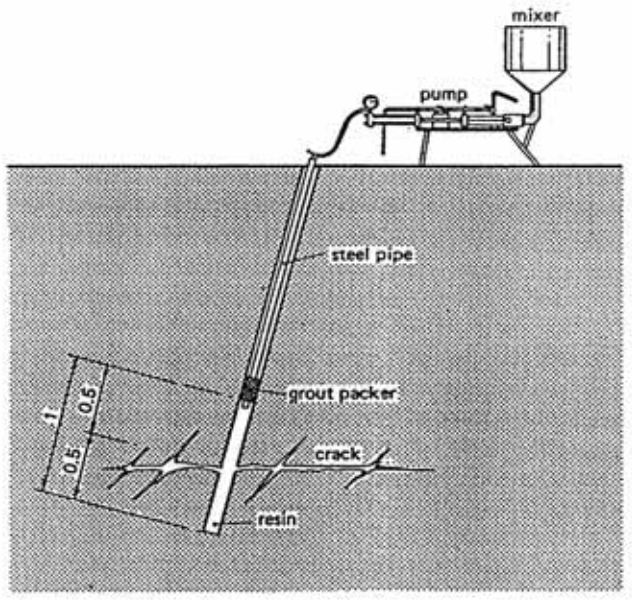
Since the type of anchor had known characteristics and the location of the anchors was within the dam concrete body, it was decided to perform the on-site suitability test of two selected working anchors during the construction period, also considering the very tight schedule of operations.

This in spite of knowing that the performance of proving tests is generally completed prior to the installation of the working anchors. It is worthwhile to note that all the other anchors have been tested by simple stressing test method.

LAYOUT OF RESIN BOREHOLES



TREATMENT OF CRACKS



During the controlled lowering into the borehole, the anchor was held by a hydraulic braking device and finally hold-up by means of a steel support.

Afterwards the anchor grouting was carried out by filling the borehole with cementitious mix, having a water/cement ratio equal to 0.38 and characteristic unconfined compressiv strength greater than 35 MPa.

Anchor stressing was performed by means of a 12500 kN multi-strand jack with homing equipment and electric power pack.

Cracks filled by resin

On-site suitability tests

The stressing sequence of the on-site suitability tests, previously agreed with the resident engineer, was selected in accordance with the Swiss Standards for Ground Anchorages, SIA 191, by applying the stressing procedures specified for the proving test, without reaching failure.

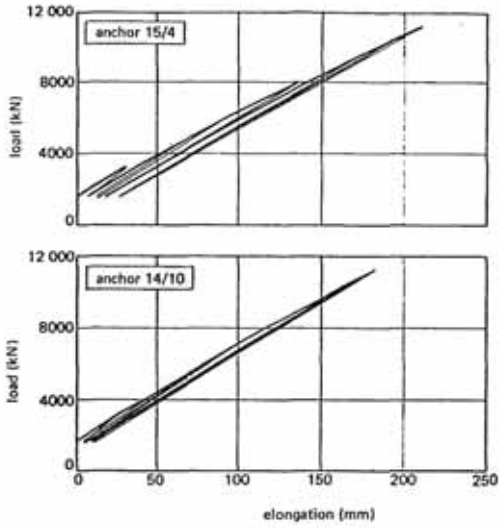
The maximum load of 11200 kN (80% breaking load) was reached with 5 steps of 1600 kN and two of 800 kN, starting from an alignment load of 1600 kN. The load at the intermediate steps was kept constant during either 5 or 15 minutes and at the maximum load for 50 minutes. At the end of the test the locking load was aplied. Anchor N.4 of buttress 15 (40.84 m) and anchor N. 10 of buttress 14 (38.25 m) were tested obtaining results complying with the assumed conditions:

by means of lift-off test. All the recorded lift-off values are represented in figures and they show the decrease in scattering achieved after the final stressing sequence was adopted.

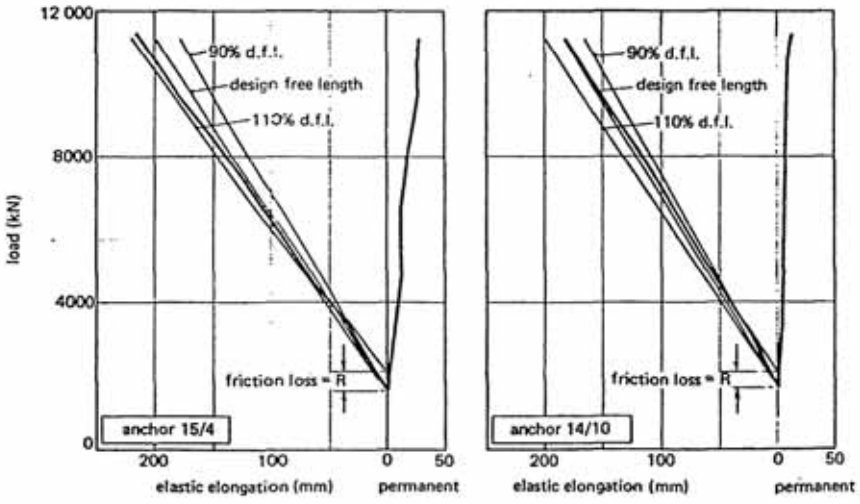
Long term monitoring

To ensure a surveillance method of the anchors' behaviour over a fairly long period, 40 of them were equipped with a threaded head and two hydraulic load cells (12500 kN capacity, 1% f.s. accuracy) with hand pump indicator have been permanently allocated to the project. Corrosion protection grease was injected below the anchor head and inside the galvanized protection cap.
The recess was then covered with a removable and watertight steel plate. On all the monitored anchors, a first load cell reading was performed a few hours after stressing. This measurement was then compared with a reading taken five days later. The loss of load between the first two readings being lower than 1 per cent, the cutting of the protruding strands and all the finishing operations could start for all the anchors of the same buttress. A monitoring programme including monthly readings was implemented and results obtained until the completion of the anchors contract are shown in the figures. It can be seen that the load losses are within acceptable limits as required by FIP Recommendations.

Test anchors:
LOAD/ELONGATION
DIAGRAMS



Test anchors:
ELASTIC AND PERMANENT ELONGATION
Versus
LOAD DIAGRAMS



¥ deformation increased less than 2% *of calculated elastic elongation at 5' observation time or less than 1% at 15'*

¥ angles tangent ratio between reloading and unloading curves not smaller than 0.9

¥ apparent free tendon length, *calculated by the straight line of diagram of the elastic deformations should be done to the theoretical one; the actual values, expressed as percentage of the theoretical ones, were respectlvely 99% and 100%.*

Simple stressing tests

A simple stressing sequence was adopted for anchors testing, reaching the proof load of 11200 kN and locking off at 10400 kN, equal to 1.24 service load. This locking load has been determined after a few series of stressing operations, in order to obtain the compensation of loss of load caused by the wedges drawn-in. For all the anchors, at the completion of the stressing operation and before removing the jack, the value of the load applied was verified

Site organization

Mobilization started in October 1990 and resin grouting works began mid-November and were completed at the end of April 1991.
The total quantity of drilling was 19000 m, corresponding to 1200 holes.
The resin consumption was 92000 kg.
The anchors' installation lasted from January to July 1991.

Two hundred and thirty four anchors, for a total of 9210 m were installed using 544300 m of strand with a total service load equal to 1966 MN.

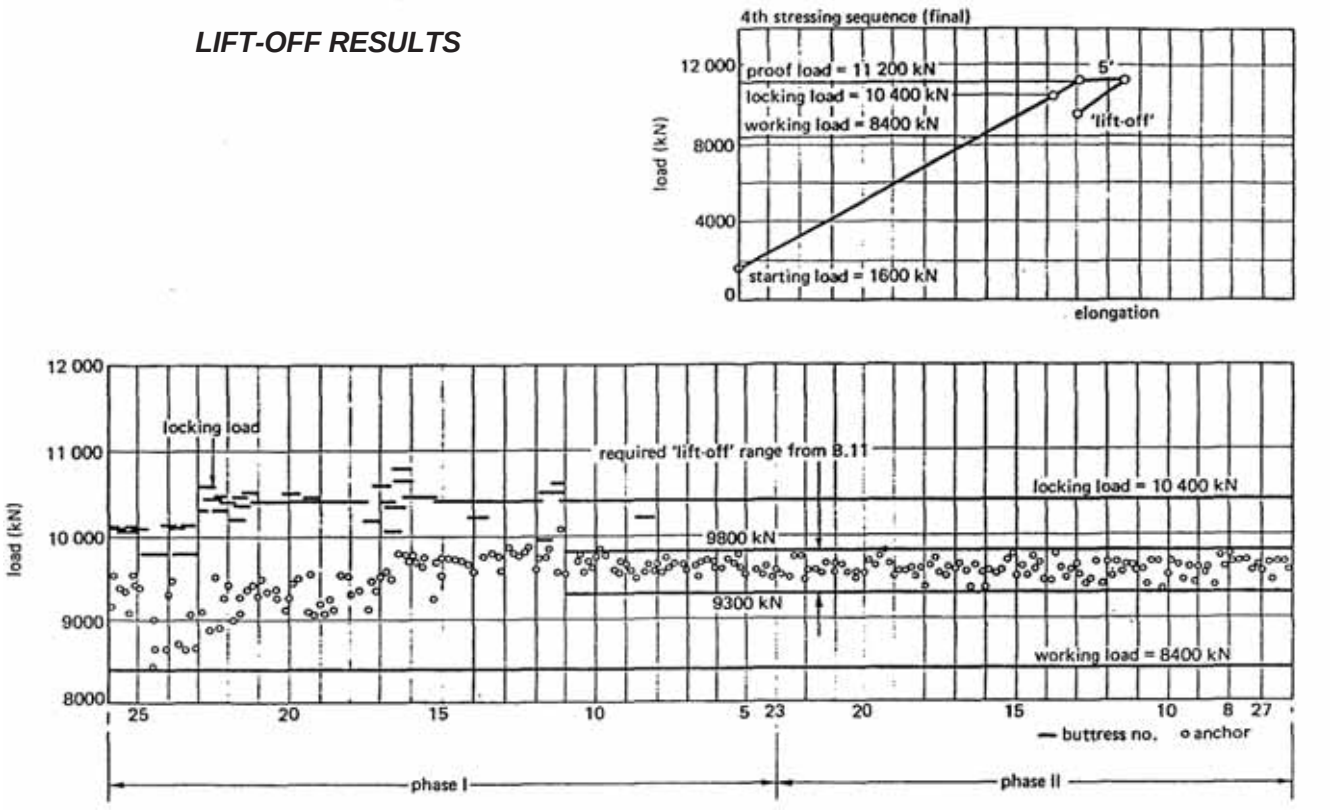
Two drilling rigs were used, 24 hours a day, for 6 days per week.

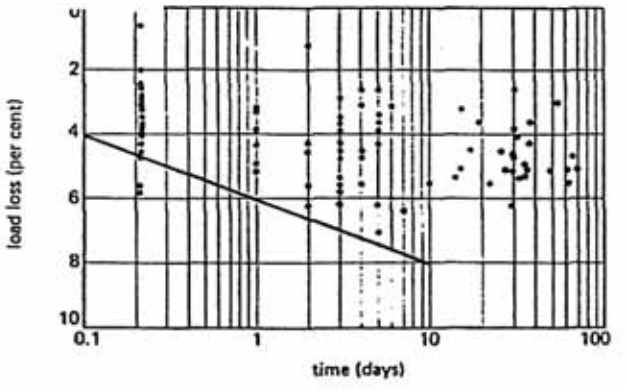
With the scope of having part of the anchors already installed by the time of the maximum impounding level, in order to provide a preliminary and partial safety measure in case of a major seismic event occurring with full reservoir, the installation of anchors was carried out in two different phases; each phase comprised the construction of 6 anchors for buttress.
The supply of the resin as well as of the materials for the anchors' construction was organized with subsequent deliveries from Europe, made first by air, in order to comply with the tight schedule.

A special shed was constructed for anchor assembling operations and for housing the automatic greasing machine for the strand wires of the anchor free length. An area of the site was devoted to the preparation of the reinforcements of the anchor head blocks.

In addition to the main camp (offices, accommodation and canteen) power generating units were installed for electricity and compressed air production.

LIFT-OFF RESULTS





LONG-TERM MONITORING RESULTS

Conclusion

The project was successfully carried out within the time schedule fixed by the client, thanks to an exceptional organizational effort for the quick mobilization of means and personnel.
The accurate optimization of the site activities from the organizational, technical and technological viewpoints made it possible to carry out the resin grouting treatment and the installation of a large number of high capacity anchors without any reciprocal interference, in as narrow a space as the crest of the dam and with significant logistical and environmental constraints.
This made it possible to carry out the impounding in the expected time, thus avoiding the possibility that a severe earthquake might deprive the nation of a substantial part of the expected harvests.

a TREVIGroup company

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