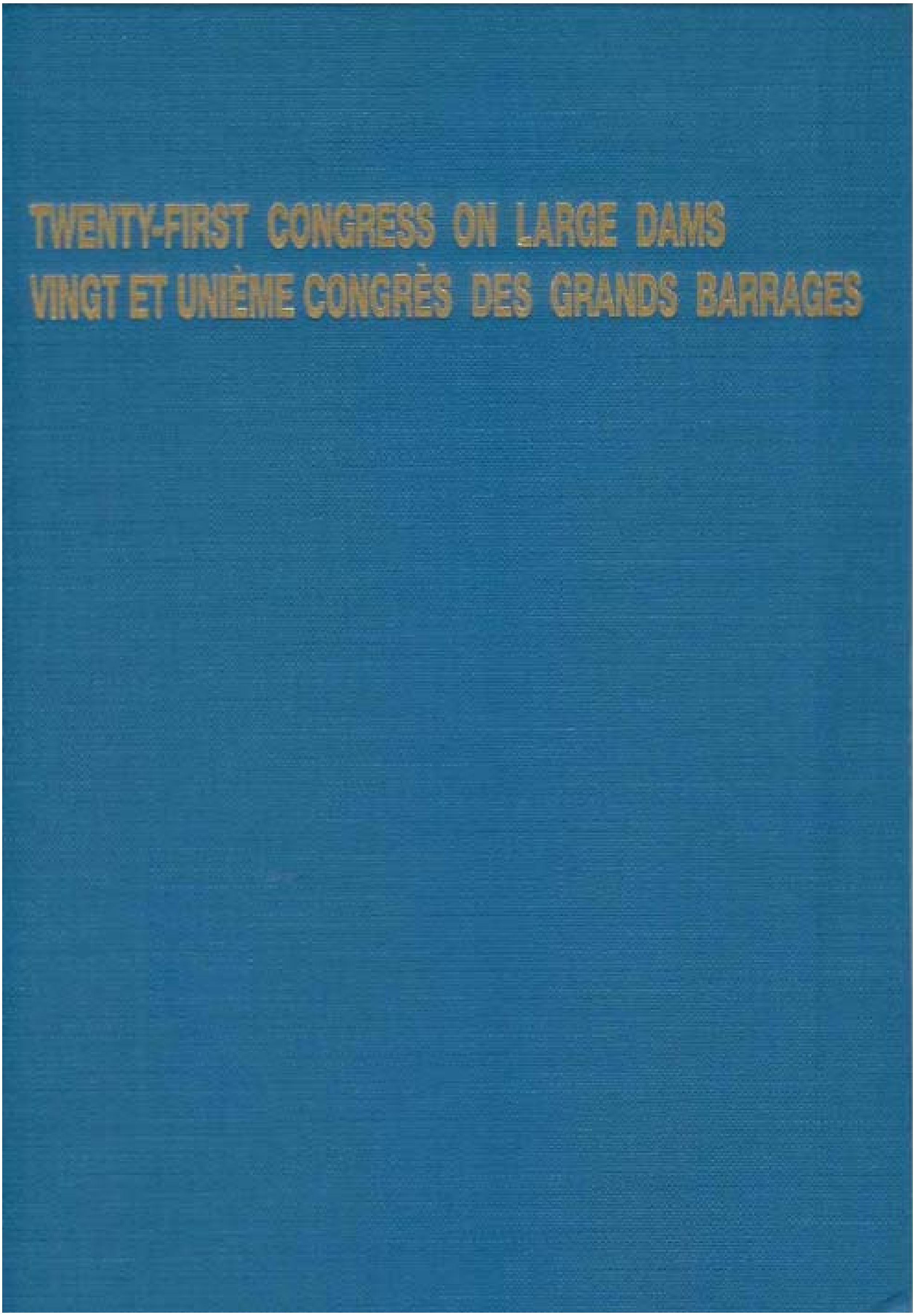

RIO DESCOBERTO DAM:
WATER SUPLLY SYSTEM FOR BRASÍLIA CITY-
BRAZILREHABILITATION AND PERFORMANCE

COMMISSION INTERNATIONALE
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RIO DESCOBERTO DAM: WATER SUPLLY SYSTEM FOR BRASÍLIA CITY- BRAZIL- REHABILITATION AND PERFORMANCE ( )

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BRAZIL

1- INTRODUCTION

1.1- GENERAL DAM CONSTRUCTION DATA

The Rio Descoberto Dam is located at 15^0 14’ south latitude and 48^0 16’ west longitude, geographic coordinates, and can be accessed by the BR-070 state paved road. The Dam is used as a reservoir for the Brazil’s Capital (Brasília City) water supply. At the spillway level the reservoir capacity is 1,000,000 m^3 and approximately 60% of the local population water consumption is supplied by the Descoberto reservoir, serving up to 1,200,000 people. The dam is concrete gravity mass type with 54,500m^3 total concrete volume. The typical section is trapezoidal with a top elongation, 3 m crest wide, 33 m maximum height and 265 m crest length.

( )-***“Barrage du Rio Descoberto: Approvisionnement d’Eau pour la Ville de Brasilia-Brésil- Réhabilitation et Fonctionnement”***

Figure 01- Rio Descoberto Dam localization
Image 01- Barrage du Rio Descoberto – Localisation

The Rio Descoberto Dam body can be divided in three main parts, the 125 m length left abutment, 85 m length right abutment and the 55 m length central spillway (*see Figure 02*). The spillway is "Creager" type with a type II USBR dissipation basin.

The dam construction was performed by blocks, separated by contraction joints, during the years 1971 and 1974. The concrete blocks placement sequence was intercalated. In each vertical contraction joint, between the concrete blocks, a water-stop "O" type (300*10mm) was used.

The dam is composed of 18 blocks, named "A" to "R". All the blocks are 15 m wide, with the exception of "A" (10 m wide). The crest level is at El. 1,034m and the spillway level is at El. 1,030m.

1.2- Opening Remarks

The dam, mass concrete gravity type, was finished in 1974. Some leaching water started to be observed at the downstream face few years after the end of the construction, and filling the reservoir.

Some remedial works were adopted in different periods, as grouting and drainage systems, with no remarkable success. After these remedial works CAESB have adopted a new approach looking for the origin of the problems, to adopt a definitive solution. After several analyses, the problem origin diagnosis was the presence of pyrite in the concrete aggregate combined with the acidic water action.

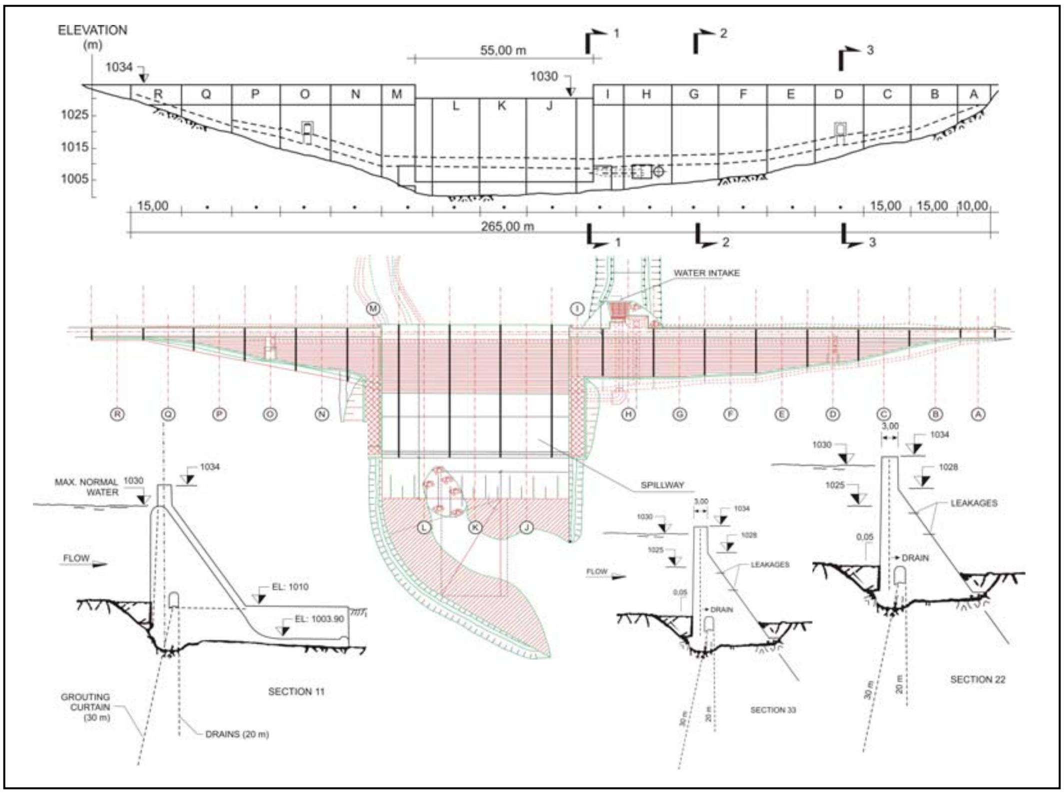


Figure 02- Dam plant, upstream view and sections
Image 02- Plan du barrage, vue de l'amont et sections

The consequences of pyrite composed concrete aggregate was known by the Descoberto Dam designers by the time of construction [01], but the pale local experience with that kind of problems allowed the use of a low level pyrite concrete aggregate in this construction work. Posterior happenings including the pathologies observed at this dam, and the Fonsagrada Dam [02] collapse report from Spain, demonstrated however, that even very low pyrite levels on hydraulic structures concrete aggregate might cause serious problems.

Few years after filling the reservoir, leakages started to be observed at the downstream block "I" face. At the end of the 70´s decade some wide fissures started to be observed too. From that time, until the performance of this project in 2000, the water leakage increased strongly, becoming into long horizontal leaching planes across the dam section.

1.3- CHRONOLOGY

From the first problems appearing until the full rehabilitation diaphragm works, started in 2000, three remedial interventions were performed, without remarkable success. Those interventions were based in epoxy and grout injections. The summary of this chronology is displayed in the Figure 03, below.

1.3.1- First Intervention

Since the mid 70´s decade leakages were observed at the "I" block's downstream face. In 1981, as usual in leakage dam treatment method, the first intervention was performed. The solution was based in epoxy injections applied from the downstream face

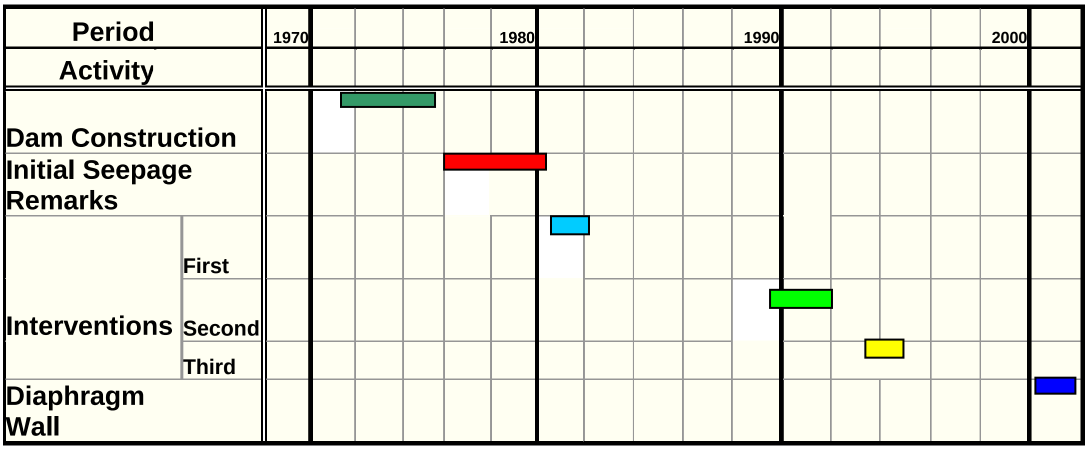


Figure 03- Chronology of the interventions
Image 03- Chronologie des actions

1.3.2- Second Intervention

Between 1989 October and 1990 July, the second intervention was performed. The works were guided by a preliminary diagnosis report made in 1988. This report indicated concreting joints failures as the origin of the problem. These works consisted in the combination of grout injection filling at the upstream face with internal drainage holes near the downstream face.

Right after the completion of these works dam appearance was satisfactory, without leakages at the downstream face and only some weak moisture spots could be observed at the upstream inspection gallery's walls. The inspection gallery was satisfactory and the foundation drains of the dam were operating well.

Unfortunately, just three years after the completion of these works, the dam structure was worse than it was before.

1.3.3- Third Intervention

In 1993 the Descoberto Dam was presenting serious problems. Moreover than the leaching horizontal planes at the downstream "**E**", "**I**", "**G**" and "**O**" block's face with significant flow, the fissure problem had also increased. At the leaching blocks, new percolating horizontal planes raised. The inspection tunnel was flooded and full of carted material from the rock bottom drains.

During the course of this intervention the Owner of the Dam, CAESB, decided to adopt a new approach in order to reach the cause of those chronic problems. At this time a Consultant Committee was constituted, formed by the Prof. Dr.Victor de Mello, Eng. Francisco Andriolo and Eng. Walton Pacelli de Andrade. The committee recommended **[03]** the collection of samples of inner inspection gallery drains sediment, dam's concrete, reservoir and drain water analyses.

The analyses indicated [04, 05] the presence of pyrite in the concrete aggregate and foundations. The combination of the presence of that mineral with the action of acidic (pure) water, was contributing to the degeneration of the concrete structure of the Descoberto Dam. The main pathologies observed were pyrite reactions [02, 04 to 10].

The best solution was to implant a waterproof barrier, avoiding the contact between the reservoir water and the body of the dam.

The injection works were suspended and a 4.2m long pilot drive of the diaphragm secant piles wall was built for testing and experience purposes.

2- OWNER CONDITIONS - SITUATION ANALYSIS

2.1- GENERAL

After the three interventions with no successful results, now with a deeper research of the problem developed by the committee, CAESB decided to fully rehabilitate the Descoberto Dam. Starting from the conclusions of the committee, observing the increase of the structural problems, CAESB started to search alternatives for the dam rehabilitation in order to bid the best options.

Figure 04- Downstream face of "O" concrete block showing a great leakage

Image 04- Parement aval, face du bloc en béton "0" montrant une grande fuite

Figure 05- Internal part of the gallery showing the water flow

Image 05- Côté interne de la galerie montrant le débit d'eau

2.2- BASIC REQUIREMENTS

Five basic requests were imposed by the owner for the rehabilitation techniques:

I. The rehabilitation method must prevent the water access to the dam concrete body and foundations;
II. The water supply must be fully maintained during the rehabilitation works;
III. The water quality must be fully maintained during the rehabilitation works;

IV. The method efficiency must be possible of being tested by sections during the performance of the rehabilitation works;

V. Grouting based impermeabilization solutions wouldn't be accepted.

Figure 06- Brown material in the gallery floor

Image 06- Matériel marron par terre dans la galerie

Figure 07- Internal crack in the downstream zone of the galleryflow

Image 07- Fissure interne sur le parement aval du débit de la galerie

Figure 08- Downstream face of "O" concrete block damaged by aggregate reaction

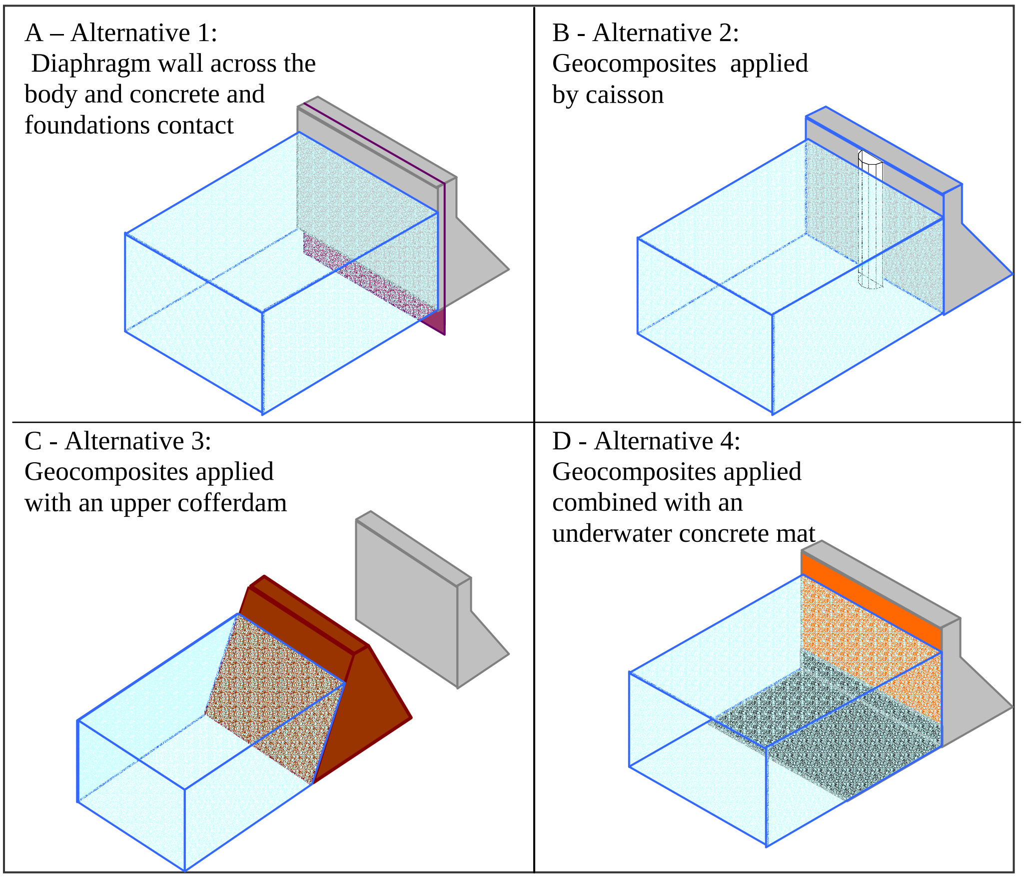
Image 08- Parement aval, face du bloc en béton "0" endommagé par réaction du granulat

Figure 09- Aggregate reaction at the upstream face of the gallery

Image 09- Réaction du granulat sur le parement amont de la galerie

3- AVAILABLE METHODS

After the definition of the owner conditions, four main rehabilitation methods were initially selected. One of these methods was based on the secant pile diaphragm wall experience from 1993 and the three remaining were solutions based in geocomposites barriers application, with some variations, as illustrated below.



A-Secant pile diaphragm wall, performed from the crest, drilling sequences near the upstream face reaching until 5m into the rock foundations

B-Geocomposite barrier applied at the upstream face of the dam dried by caissons; the barrier would be applied from the maximum water level down to the reservoir bottom

C-Geocomposite barrier applied at the dry upstream of the dam after the construction of a cofferdam

D-Geocomposite barrier underwater applied from the maximum water level down to the reservoir bottom, combined with inferior face and foundation protection by waterproof concrete mat.

Figure 10- Illustration of rehabilitation methods previous choice alternatives

A- Mur diaphragme aux pieux sécants, performé à partir de la crête; séquences de perforation, près du parement amont, en atteignant jusqu'à 5m dans les rochers de fondations.

B- Barrière géocomposite appliquée au parement amont du barrage, sechée par caissons; la barrière serait appliquée à partir du niveau maximum d'eau jusqu'au fond du réservoir.

C- Barrière géocomposite appliquée au parement amont du barrage après la construction d'un batardeau.

D- Barrière géocomposite sousmarine appliquée à partir du niveau maximum d'eau jusqu'au fond du réservoir, combinée avec le parement inférieur, et protection de fondation par une natte de béton sousmarin.

Image 10- Illustration d'alternatives des choix préalables des méthodes de

rehabilitation

4- ADOPTED METHOD

4.1- GENERAL

The alternatives of application by caissons (**B**) and with the cofferdam (**C**) were excluded, due to the fact that with these two alternatives was impossible to guarantee that the water supply and quality would be fully preserved during the works and these alternatives didn't contemplate the foundation treatment and protection.

After this selection CAESB bid the diaphragm wall and the underwater application geocomposite barrier alternatives. The ECL Engineering Ltd. Contractor won the bid offering the method described by this paper. The cost of that option was much lower than the underwater application geocomposite barrier option.

4.2- CONCEPT

The process concept is based on the construction of a waterproof secant pile diaphragm wall inside the body of the dam, 70cm far from the upstream face. The diaphragm was performed from the dam crest without any interference with the reservoir water, need of water level drop or intake obstruction. The secant bores were performed in sequence by drilling equipment with the use of a special guiding template. A drilling sequence composes an up to 2.60m long panel. The minimum acceptable thickness of the diaphragm panels was 2".

The minimum thickness was mechanically tested and recorded by a VHS underwater system. After the completion of a drilled panel, it was filled by mortar using *"tremie"* system. After the mortar filling of a panel, the last bore of the filled panel is drilled again and this bore starts the next sequence (see Figure 11). During the drilling process the panels are always filled with water in order to provide equal pressures between the panel and the reservoir.

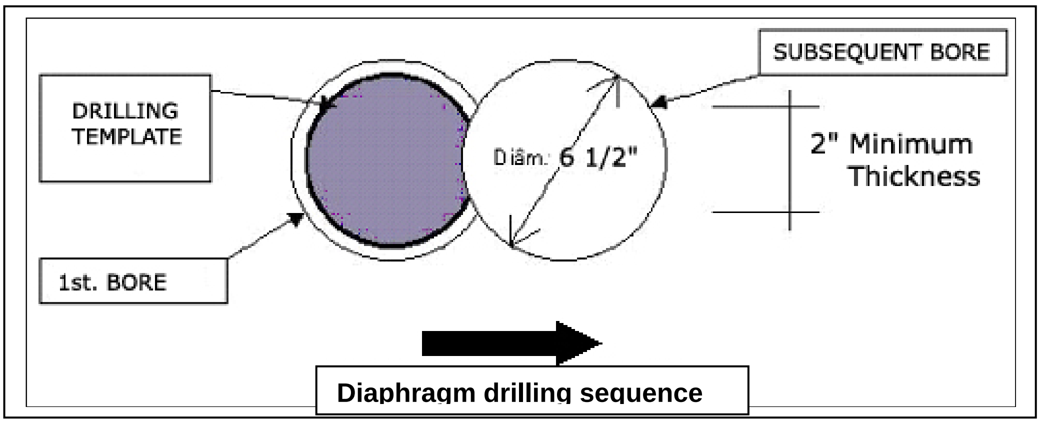


Figure 11- Drilling sequence
Image 11- Séquence de perforation

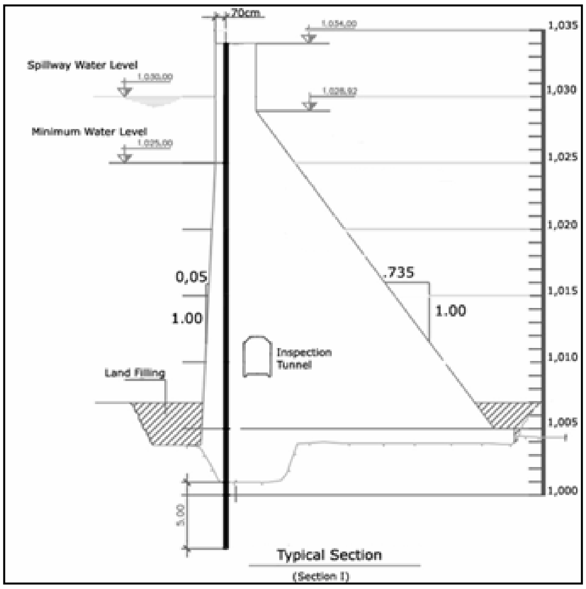


Figure 12- Transversal section with diaphragm insertion
Image 12- Section transversale avec insertion de mur diaphragme

4.3- FIRST EVALUATION

Before the beginning of the diaphragm wall rehabilitation works, several additional tests, analyses, and stability calculations were performed. The scope included permeability, capillarity, compression and shearing tests at samples of the pilot drive of the diaphragm drive built in 1993, collected with rotary drilling probe extractors**.** Shearing tests at samples extracted from the contact between the diaphragm mortar and the concrete of the dam were also performed, in order to check the adherence between these different materials.

Additional stability analysis were made considering the extreme hypothesis of break of the small dam´s body part between the diaphragm and the upstream face. These calculations were made attending to a CAESB concern about the aggressive soluble effects of the soft water of the reservoir, with very low solid suspensions, on the upper part of the dam that would be in contact with the water.

That concern was also dissipated by the evidence that even being in contact with the water, that part has the reactive effects severely decreased after diaphragm insert as a consequence of the end of the reaction renovation and leaching. Laboratory tests have also been made with the mortar mixture indicated by the project designers and performance tests simulating the underwater mortar application conditions, in order to verify the possibility of segregation.

5- PERFORMANCE AND LOGISTICS

The works were performed by two main groups of activities, drilling teams and mortar underwater application team:

5.1- DRILLING

The drilling activities were performed with drilling equipments using DTH (down the hole) hammers, guided by a special alignment template developed for this project. The drilling machinery had to be adapted specifically for the project in order to have the drilling equipment tower aligned at the diaphragm axis.

Figure 13- Drilling machine during operation

Image 13- Perforatrice en opération

Figure 14- Alignment template used for drilling control

Image 14- Gabarit d'alignement utilisé pour contrôler la perforation

Figure 15- Alternated drilling panels for the diaphragm

Image 15- Panneaux alternés de perforation pour le diaphragme

Figure 16- Inspecting the diaphragm panel with TV camera

Image 16- Inspection du panneau du diaphragme avec une caméra de télévision

Figure 17- Discharging the mortar from the truck mixer to the placement pump

Image 17- Décharge du mortier de la bétonnière dans la pompe de placement

Figure 18- Filling the drilled diaphragm panel with mortar by a *"tremie"* pipe

Image 18- Remplissage du panneau perforé du diaphragme avec le mortier par un tuyau trémie

The project included 70,000 meters of 6" and 6 ½" drilled bores in 18 months of work in two shifts. Midsize drilling equipments were used in the project (with weight between 6 and 11ton). At the peak of production the job site had five drilling machines working at the same time, four at the dam crest and one at the spillway top. The deepest hole reached 38 m depth, at block "I", and 22 meters was the average drilling depth of the project.

Boring deviations caused by flexion were minimized by the use of 4" masts. Several types of bits were tested at this project, the concave and drop center types had to be remarked for their best performance and alignment. The guiding template was built machining heavy hot rolling steel pipe. The drilling sequence illustrated above at Figure 11 consists in drilling a panel first bore that works as a guide for the next using the template. Moreover than guidance, the template is necessary to avoid bores overlay.

5.2- MORTAR PLACEMENT

The mortar filling was made underwater with "*tremie"* type tube. The work was done from the dam crest. The "*tremie"* pipe was connected directly to the mortar pumping line. The mortar pumping was made from pumps positioned beside the drum mixer parking area at the abutments outside border. In occasions when the pumping distance was longer than 100 meters, two serial disposed pumps were used.

Two operational problems had to be solved:

- The total mortar volume applied at the project was not enough to assure the viability of the installation of a mixing plant at the job site;
- The distance from the job site to the nearest local concrete mixing plant (approximately 60 Km) was too long, consuming more than 50% of the mortar lifetime in the journey.

These problems were solved by the construction of a cement storage place and a dosage ramp. With these very simple devices, the dosage of cement and admixtures could be made at the job site into drum mixers loaded with the specified amount of sand and water. This procedure of dosage at the job site ended the mortar lifetime problems and enhanced the quality control.

6- QUALITY CONTROL

6.1- WATER QUALITY CONTROL

The water supply for Brasília City, by the Rio Descoberto Reservoir system is made from an inlet at the "**H**" block upstream face. The water is pumped through a 48" welded steel sewer straight for a Water Treatment Plant approximately 5 Km farther. At the Water Treatment Plant inlet the turbidity, coloration and colliform rates at the water are continuously controlled. Those indexes were kept stable during the works. Samples of the reservoir water had also been collected during the project performance and analyzed, including the determination of solid particles in suspension rate. This rate was, in fact, very low, as it is normal in high altitudes. These analyses showed that the quality of the water was not affected by the construction works.

6.2- PROCESS CONTROL

6.2.1- Water Losses Flow Control

Since the beginning of the works, the downstream face and inspection gallery water loss flows were controlled. At the downstream face small wooden channels where installed, discharging in a collect point.

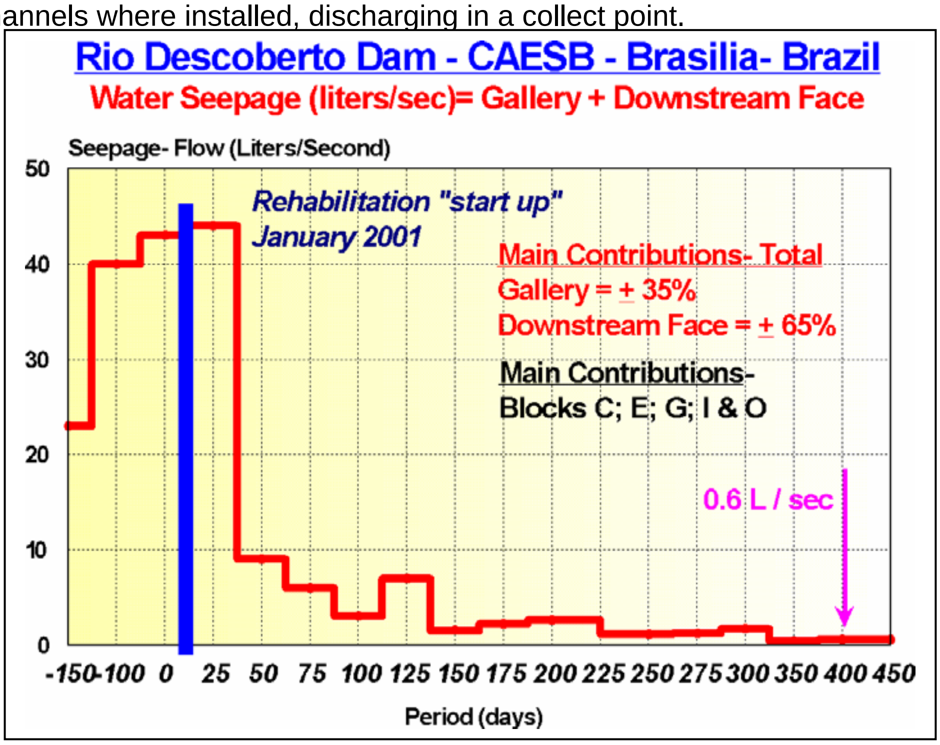


Figure 19- Water seepage control during the remedial works
Image 19- Contrôle de l'infiltration de l'eau pendant les travaux de réparation

At the inspection tunnel the flow measurement was made straight into the upstream pressure relief drains. The measurement was made by graduated containers and chronometers. During the job, the flow was strongly decreased (99%).

6.2.2- Diaphragm Continuity

The continuity of the diaphragm panels was controlled by mechanical testing and underwater VHS video system. The mechanical test was made by letting down a steel plate with the minimum diaphragm thickness allowed (see Figure 14). This steel plate was suspended by two ropes, and this procedure was hand made in order to assure the necessary sensitivity. In case of any kind of obstruction or discontinuity, the plate wouldn't reach the bottom of the diaphragm panel. In case of persistence of doubt after the mechanical test, the VHS underwater camera was used to inspect the suspect drive (see Figure16). This video system was also used to check and register the contact between different drives.

6.2.3- Mortar Control

Besides the initial analyses made before starting the works, during the project all the mortar applied was controlled and tested. The controls were made by casting 10 cylindrical specimens at each truck mixer (6m3 capacity). From those ten specimens, four of them were experimented at compressive tests at 4-days age, four were tested at 28-days age and the two remaining were kept tagged with all the data concerning the mortar recorded. The average compressive strength was 27 MPa; 3-days, 7-days, 28-days and 63-days age testing series have also been made.

Figures 20- Control of the mortar used
Images 20- Contrôle du mortier utilisé

6.2.4- Mortar Drilled Cores Tests

Cores were drilled from the mortar placed in the diaphragm and tested. The following statistical data were obtained:

Property	***Mortar (diaphragm)***	***Interface Concrete (dam)-Mortar (diaphragm)***	***Concrete (dam)***
Absorption (%)	1.22		
Specific Weight (t/m3)	1.97 – 2.08		2.52
Permeability (m/s)	10^{-11} – 10^{-10}		
Compressive Strength (MPa)	12.7 – 31.1		25.7
Splitting Tensile Strength (MPa)	1.87	1.14	4.51
Direct Tensile Strength (MPa)	1.07 – 1.80		2.32
Shear Strength (MPa) under Normal Pressure: 2.0 MPa	2.77 – 5.57	2.05 – 3.77	5.03 – 5.14
Shear Strength (MPa) under Normal Pressure: 4.0 MPa	3.92 – 6.63	3.10 – 3.66	6.43 – 6.76
Shear Strength (MPa) under Normal Pressure: 6.0 MPa	5.57 – 8.38	4.50 – 6.10	12.42

Figure 21- Statistical data from drilled cores
Image 21- Données statistiques des noyaux perforés

Figure 21- Drilled cores from diaphragm mortar

Image 21- Noyaux perforés du mortier du diaphragme

Figure 22- Drilled cores from diaphragm mortar, interface, and from the old concrete from the dam

Image 22- Noyaux perforés du mortier du diaphragme, contact entre couches et du vieux béton du barrage

7- CONSTRUCTION CHRONOLOGY

The drilling works started in September of 2000 at the block “Q”, this was the first block finished in January 2001. The average drilling rate was 5000 meter per month, and the peak drilling month rate was reached in June 2001 with 8000 meters drilled in 30 days, working with five drilling equipments.

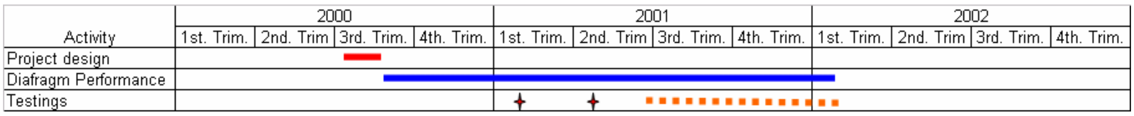


Figure 23- Construction chronology
Image 23- Chronologie de la construction

Figure 24- Rio Descoberto Dam and Reservoir during the rehabilitation works
Image 24- Barrage du Rio Descoberto et Réservoir pendant les travaux de réhabilitation

8- COMMENTS AND CONCLUSIONS

The methodology adopted for the Rio Descoberto concrete dam rehabilitation was successful to reach the following purposes:

- Less expensive offer;
- Guarantee the water supply in terms of quantity (no interruption) and quality;
- Reduce the water leakage to a normal level;
- Rehabilitate the dam structural safety

Since the Rio Descoberto Dam rehabilitation start-up, the water losses have been measured and at the blocks completed until January 2002 (all of them with exception of the "I" block), the loss flow has decreased from 34 l/s to 0,3 l/s. The last block under rehabilitation work in 2002 January, the "I" block, had the flow reduced from 15 l/s to 2,0 l/s with only 80% of this block diaphragm wall completed at that time. The first blocks completed in January and February

2000, the "**Q**" and "**C**" blocks, had no maintenance since then and remained with the same initial efficiency.

The method attended to all the technical requests presented by the Owner, CAESB, preserving the reservoir's water quality and keeping the CAESB capability of water supply along the course of the works, without any kind of problems or disturbance for the Brazil's Capital inhabitants.

ACKNOWLEDGEMENT

The contributions and recommendations from Prof. Dr. Victor F.B. de Mello are greatly acknowledged

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SUMMARY

The Rio Descoberto Dam, owned by CAESB - Companhia de Saneamento do Distrito Federal - Brazil, is used as a reservoir for water supply to Brasilia City - Capital of Brazil.

The dam, mass concrete gravity type, was finished in 1974. Some leaching water started to be observed at the downstream face since few years after the end of the construction, and filling of the reservoir.

Some remedial works were adopted in different periods, as grouting and drainage systems, with no remarkable success. After these remedial works, CAESB have adopted a new approach looking for the origin of the problems, to adopt a definitive solution. After several analyses, the problem origin diagnosis was the presence of pyrite in the concrete aggregate combined with the acidic water action.

A diaphragm wall was adopted as the rehabilitation methodology. This " In the wet" technique, permitted the water supply for Brasilia (1.2 million people) not to be interrupted or affected in the course of the rehabilitation works. The reservoir's water quality was continuously controlled during the process, and kept at the same level. The adopted methodology is described in this paper.

RÉSUMÉ

Le Barrage du Rio Descoberto, propriété de CAESB - Companhia de Saneamento do Distrito Federal - Brésil, est utilisé comme un réservoir de approvisionnement d'eau pour la ville de Brasilia – Capitale du Brésil.

Le barrage, type barrage-poids en béton de masse, a été terminé en 1974. De l'eau de lessivage a été observée sur le parement aval depuis quelques années après la fin de la construction et remplissage du réservoir.

Quelques travaux de réparation ont été adoptés dans différentes périodes, comme injection et systèmes de drainage, sans un succès expressif. Après ces travaux de réparation, CAESB a adopté un nouveau approche en cherchant l'origine des problèmes, pour adopter une solution en définitive. Après plusieurs analyses, le diagnostic du problème était la présence de pyrite dans le granulat de béton combiné avec l'action acide de l'eau.

Un mur diaphragme a été adopté comme la méthodologie de réhabilitation. Cette technique "à mouillé" a permis l'approvisionnement d'eau pour Brasilia (1.2 millions de personnes) de ne pas être interrompu ou affecté au cours des travaux de réhabilitation. La qualité de l'eau du réservoir a été continuellement contrôlée

durant le procès et a été maintenue au même niveau. La méthodologie adoptée est décrite dans ce travail.