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Quest and Probe Related to Erosion in the Wrap-Around of an Embankment

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SYNOPSIS: CESP's divers team found several basalt blocks scattered on the stilling basin of a power plant. Water flowing through bottom outlets was initially supposed to cause erosion in the upstream rip-rap of the wrap-around. Events chronologically reported are: Underwater inspection; removal of materials; monitoring devices behavior; hydraulic tests. Hinder analyses led to recognition of misunderstanding on anomalous mechanism and misconception on the actual sources for the hauled rubbish.

INTRODUCTION

Companhia Energética de São Paulo - CESP, is the owner of 17 hydroelectric power generation stations in southern Brazil and is responsible for an installed capacity of over 8 300 MW and an annual power generation capacity around 26% of Brazil's energy supply.

To monitor the structural behavior of the dams, CESP created a branch of "Monitoring and Safety of Dams" appended to the Civil Engineering Central Laboratory , which is located in the town of Ilha Solteira, SP.

Bearing in mind the suggestions of H. Bolton Seed in his lecture at the ASCE's International Convention - N.Y. 1981, this paper describes some aspects of the performed investigations, that where related to a problem supposedly affecting the safety of a dam embankment.

Erosion in some of CESP's dams downstream toe (Jupiá Dam, Água Vermelha Dam, Ibitinga Dam) associated to the action of water flowing down the spillway had previously ocurred, requiring immediate restorative measures. Then the team dealing with safety monitoring of dams was faced with what one would call an "Wrap-Around Syndrome". Several rock blocks were found in the stilling basin of a power plant and were suspected to have their origin in the upstream rip-rap protection of the right embankment. High velocity water flowing through bottom outlets could eventually have dislodged those blocks from the submerged wrap-around section.

PROJECT LAY-OUT AND DETAILS

Mário Lopes Leão Hydroelectric Power Plant (formerly Promissão Hydroelectric Power Plant) is located on the Tietê River, approximately 500 km northwest of São Paulo city. It has an installed capacity of 264 MW and its first unity was commissioned in JULY75.

This project was constructed in a open valley with straight axis resulting in a crest lenght of 3 710 m and comprises homogeneous compacted earthfill on both right and left embankments, and concrete gravity structures: right transition wall, bottom outlets, intake/power- house system, erection hall and navigation lock. Maximum height of concrete structures is 59 m. The power plant is equiped with 3 x 88 MW Kaplan units, Ø 7,4 m each, with rated head of 27,4 m. Flood structures incorporate 5 bottom outlets with tainter gates and 1 controlled surface spillway with volet gate, for a total discharge capacity of 8 300 m^3/s.

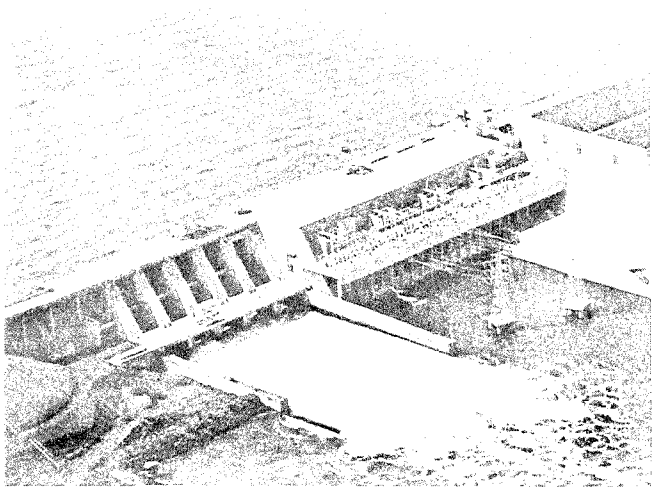


Fig. 1 - Aerial view of Mario Lopes Leão Hydroelectric Power Plant

Embankment fill material is compacted clay; horizontal drainage blanket and chimney drain were built up with natural sand; downstream slope protection is grass, and there is a rock-toe; along the upstream slope there is a rip-rap of large blocks, up to 1.20 m in diameter (average 0.50 m < Ø < 0.70 m).

Foundations are divided in stretches determined by differing contact conditions. Approximately 17% of the right bank earthfill, all concrete structures and approximately 48% of the left bank dam are founded on sound basalt. Remaining portion of the right embankment and almost 15% of the left embankment are founded on colluvial soils. The rest of the left bank dam was built up over residual soils from sandstone. Right bank earthfill is 737 m long, with homogeneous section and slopes 1:2,5 (upstream) and 1:2 with berms 4 m wide at 10 m vertical intervals (downstream). Connection of this right embankment to the right transition wall is granted by means of a wrap-around; its upstream toe is protected by a small retaining wall, in the proximities of the bay for the far right bottom outlet gate.

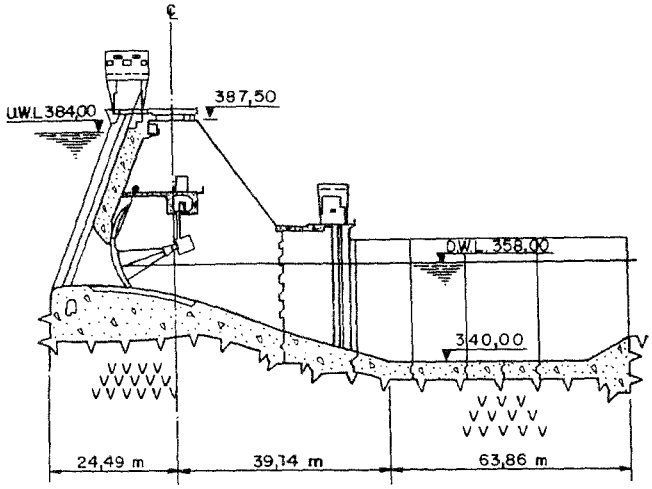


Fig.2 - Section through bottom outlet and stilling basin.

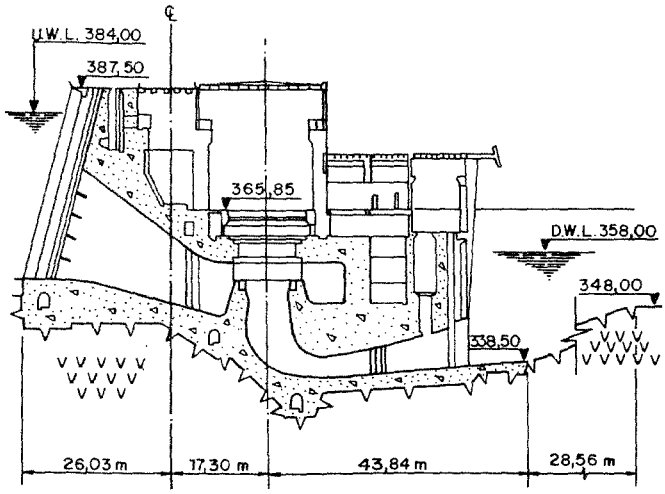


Fig. 3 - Section through water-intake and power house.

THE EVENT

Underwater Inspections Crew

CESP has developed its own team of divers cialized in underwater inspections of hydrau structures for its generating plants.

Periodically, after rain season ended, thorc examinations of submerged parts of spillwa stilling basins, and downstream riverbed programed. Such works are performed by div equipped with a portable TV camera so that engineer in charge of the job, at the surfa follows the inspection's progress and provi data storage, for hinder analyses.

Wondering an Erosion. The Inspections

During one of the afore mentioned routine un water inspections (1977), large amount of salt blocks, iron rebars and scaffolding pi and bracing components were found, scatte over the stilling basin, near the end sill. tially, those materials were suspected to h been detached and drawn backward from the vated rock-bottom downstream, by recirculat water.

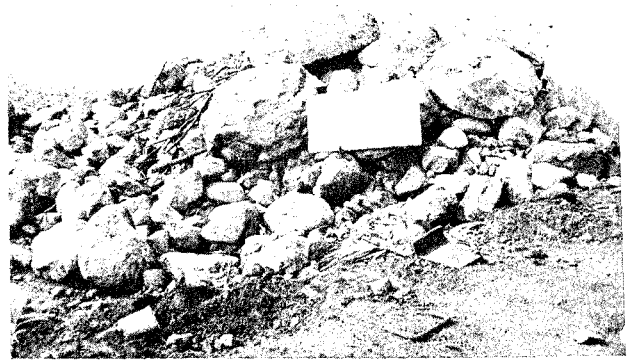


Fig. 4 - Material hauled off the stilling bas by divers.

All debris were then hand removed (NOV77) fr the stilling basin by divers, to avoid progre of erosion on the concrete slab surface abrasion.

A survey with a MS-36 Kelvin-Hughes hyd graphic echo-sounder realized in AUG79 reg tered a situation analogous to that one SEPT77, with another profusion of rubbi spread in the central region of the basin. Pr able erosion of the riverbed was under susp cion although some differences in the record bottom profile could have eventually occurre as a result of distortions due to a stron recirculating streamflow originated in th power-house's return channel. Notwithstandin when compared to a reference survey acc plished in JUNE78, that guessed erosion pr

gress was considered slow and restricted mainly to a small area near the right extremity of the end sill.

In OCT79 after an operation of the gates was made, flushing the basin and so providing ideal visual conditions for underwater inspections, it became evident that the blocks had been moved. They were now concentrated on an area 9 m x 8 m, near the concrete slab's downstream end. Due to operational convenience the materials were programed to be removed only in JULY80, when a new underwater inspection should be done. In this occasion, divers evidenced a larger quantity of materials (circa of 90 m^3) laying on the slab. And upon scanning the sloped riverbed till a certain distance far downstream of the end sill, they didn't find any evidence that could settle the initial hypothesized erosion. The suspicion arouse on a probable erosion of the right wrap-around upstream protection. Materials eventually would have swallowed by discharging flood through bottom outlets.

Divers were sent to inspect the upstream slope (22JUL80) and detected slight or no signs of movements in the rip-rapped basalt blocks. In the vicinities (up to 10 m) of the bottom outlets the blocks were clean, without the common ooze cover, found far away to the right. They also searched out, abandonned since construction phases, debris and iron bars similar to those ones discovered at the stilling basin on both prior inspections, and again (JULY80 to DEC80) all materials found in the basin were hauled.

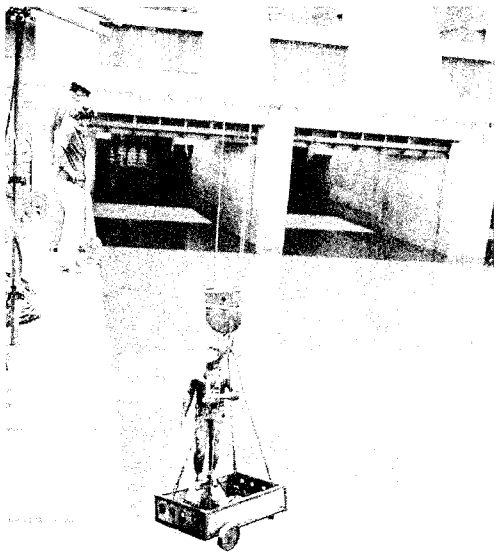


Fig. 5 - Hauling system used by divers.

Results of an echo-sounder survey showed that actual position of the right wrap-around's toe could eventually interfere with flow in the opening for the gate nearby.

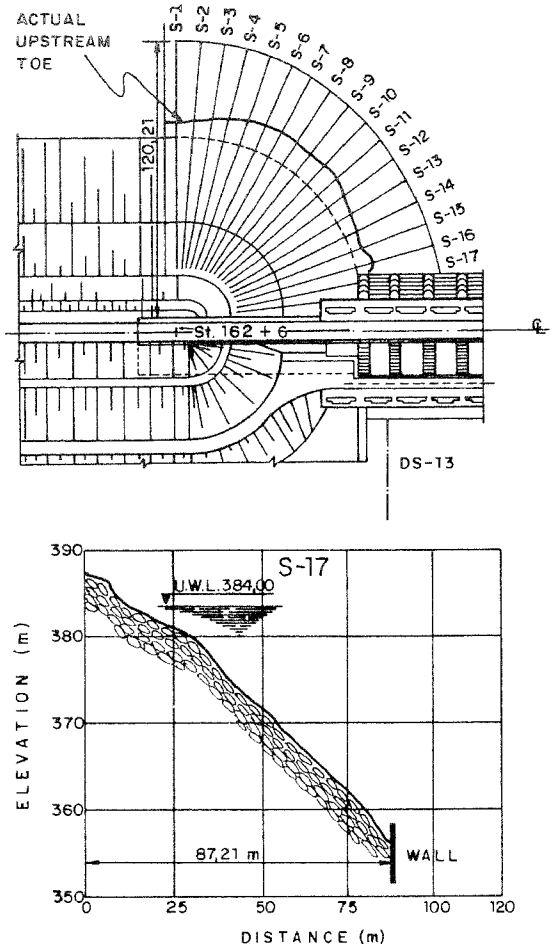


Fig. 6 - Echo-sounder survey. Plan and S-17 profile.

Monitoring of the Embankment

Aiming to control the behavior of the right embankment, the following monitoring instruments were installed, during construction phases:

Foundations:
- Standpipe piezometers and USBR twin tube hydraulic piezometers
- Settlement devices

Embankment body
- Standpipe piezometers, USBR twin tube hydraulic piezometers
- Maihak vibrating wire pressure transducers and Warlan pneumatic pressure transducers
- Settlement devices and surface monuments

The main instrumented cross-section is located in the station 165 whereas the wrap-around is spread out between stations 158 and 162. So there was no instrumentation available exactly in the probable affected area. Instruments in station 165 didn't present any alteration at all, when new data were compared with previously registered values. Visual inspection in the upstream rip-rap protection showed that some blocks had slided but perhaps this could had been caused by severe action of high waves over

the steep slope.

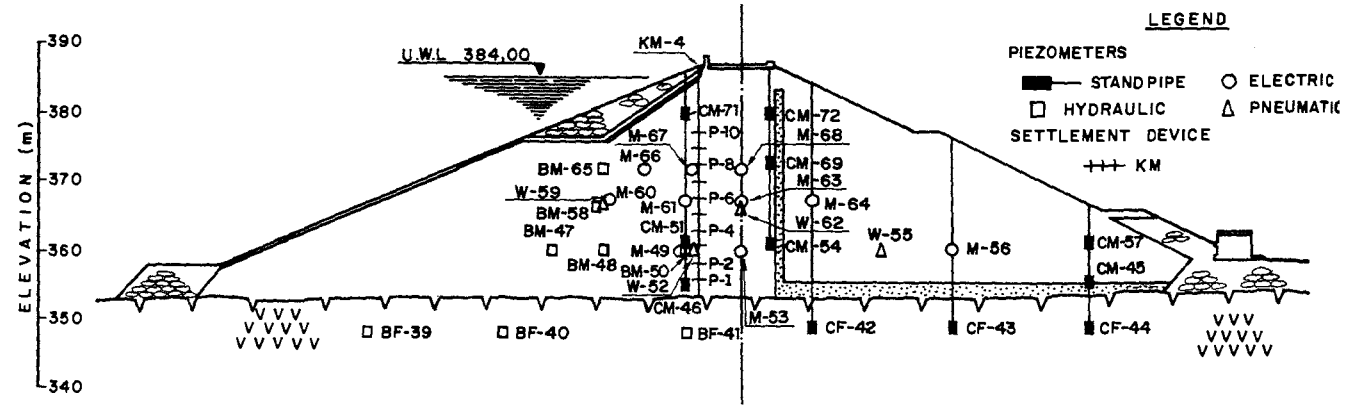


Fig. 7 - Instruments installed in station 165

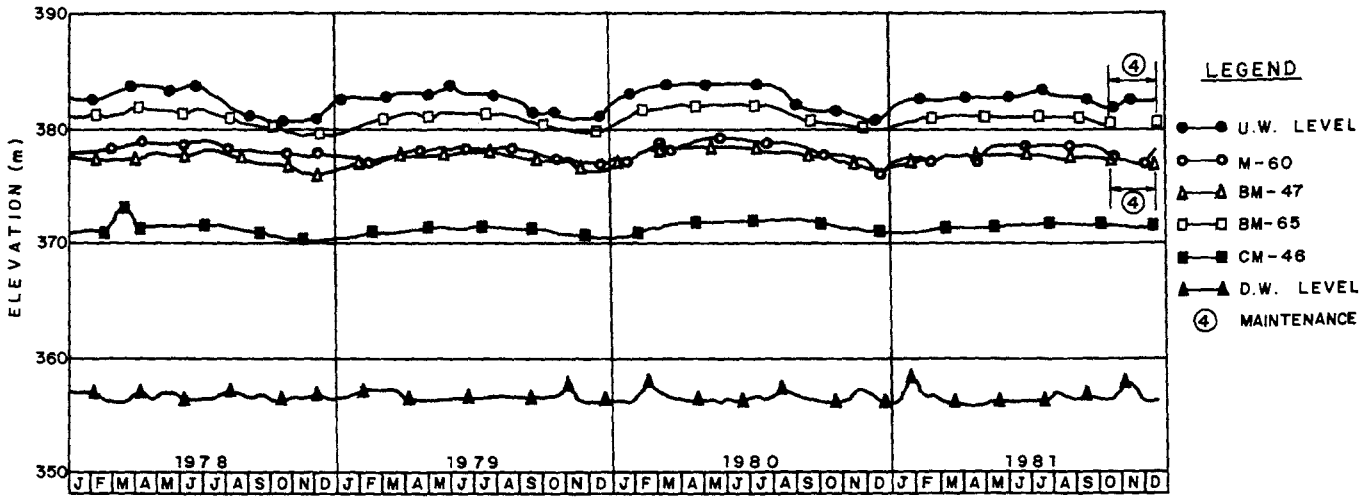


Fig. 8 - Some of the piezometric read-outs in station 165.

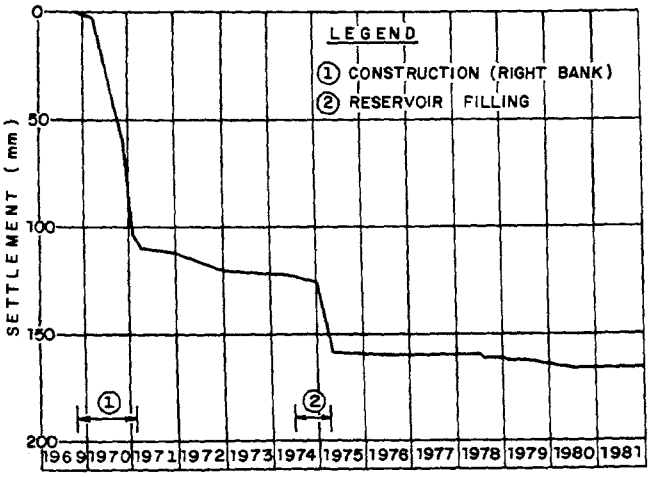


Fig. 9 - Settlement records. KM-4 meter.

Hydraulic Tests

In order to define real influence of discharge operations in that suspected removal of slope protection, some gate operational tests were programmed and then performed.

According to SOGREAH specifications there had been adopted symmetrical maneuvers for gates operations, starting with the Central one, gate n$^{\underline{o}}$ 3. Such rule was stated as a means to avoid wearing out of the concrete slab's surface by solids due to recirculating water in the stilling basin.

From DEC14th to DEC16th80 several gate tests with operation of the flood structures in symmetrical hydraulic conditions were programmed and accomplished. Prior to those operations, divers inspected both the upstream toe and the stilling basin. In the submerged upstream slope some large blocks in possible critical points were selected and then were marked by means of

a special white painting and even some ones were tied by a wire.

Soon after each test stage had been finished divers returned to inspect the previously visited areas and became aware that only a few blocks in the rip-rap had changed their original position (one side-turned and other rolled downward or was drawn out and couldn't be found). And in the stilling basin most of the debris had been washed, now resting on the downstream slopped river-bed. The remains had been moved on the slab, each time lying on a different situations that had been set.

Although it was not possible to found a cofferdam or other cause for the removal of materials backward from the downstream area of the stilling basin, some contribution from an unseen source was not completely excluded. And the fact that some blocks in the upstream rip-rap had been moved, when the first gate had been operated, just gave strength to the hypothesis of erosion in the wrap-around upstream section.

By that occasion a first survey was made with the echo-sounder sailing along the power-house's return channel and downstream river-bed.

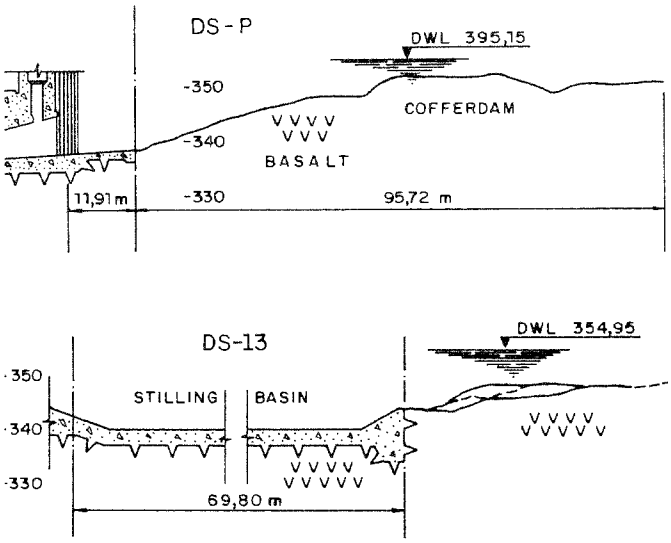


Fig. 10 - Echo-sounder survey in the return channel and in the stilling basin

A particular rule of hydraulic operation for the gates was then set out, as a matter of safety control, while further studies were developed, in order to reveal the real extent and causes of the event.

InSEPTEMBER 18th and 19th, 1981 an additional program for hydraulic tests was schedulled:

As a first step, three groups of basalt blocks were identified by color painting (orange/ yellow/gray with yellow strips) and then placed by divers, in particular selected upstream and downstream positions.

The divers verified the inexistence of materials of any sort in the stilling basin, and also discovered the remnants of a cofferdam in the river-bed, downstream of the power-house's return channel. That structure should have been completely removed when construction ended, but unfortunately it had not been.

Second step: the first gate was kept open for 30 minutes (position XIV; h = 7 m) and all three generating unities were shut-down. In the stilling basing an exceptional recirculating flow pattern could be seen and near the downstream end of the dividing wall (between tailrace and power-house's return channel) the high speed flowing water displayed a sudden lowering of about 2 m. This allowed calculation of water speed as approximately 6 m/s, which indicated possibility of rubbish being drawn by the flooding water.

Fig. 11 - Flow in the basin while first gate only was opened.

All upstream marked blocks were still standing in the same place without signs of movement, even those identified "in situ" with paint, in the DEC80 tests. It became clearly evident that all debris now found by divers in the central area of the stilling basin, including some blocks identified by gray and yellow strips, had its source in a cofferdam, abandonned at the power-house's return channel (and well upstream of the dividing wall's downstream end).

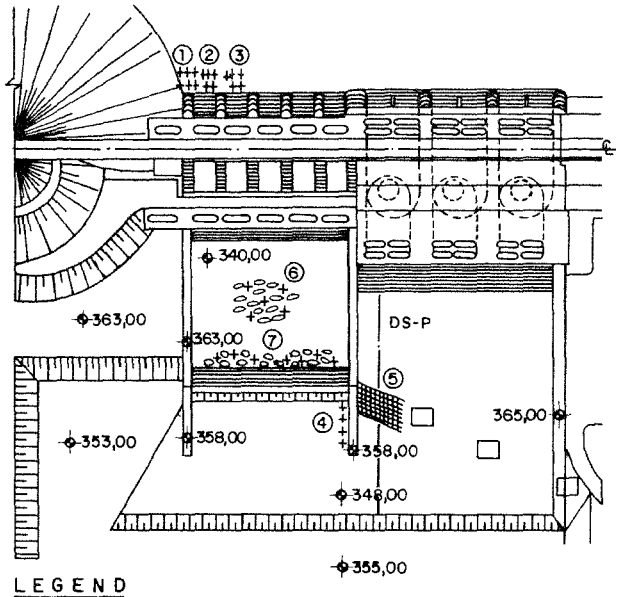
Third step: all five gates were kept open for 30 minutes (position III; h = 1,5 m) and with that hydraulic symmetrical operation, the water didn't show recirculation. As soon as the gates had been shut, divers were sent to inspect the upstream region and found no alteration at the control blocks. And all the material that was in the stilling basin downstream had been moved, now lying near the end sill. All small sized blocks had been carried away.

As a result of this test all maneuvers of the

gates should be following a hydraulic symmetrical operation, at least until the programmed removal of the downstream cofferdam remnants had been completed.

CONCLUDING REMARKS

As it was seen, fear of a not so uncommon anomaly (that had been dealt with in other dams) focused all thoughts on an erroneous direction. The cofferdam's physical existence had been registered in the echo-sounder reference survey (at the return channel), but it wasn't recognized at once because every one had been persuaded that the problem was really a probable erosion in the upstream slope, at the right wrap-around.
And the new supposition was taken for granted only after a review of old photographs, underwater inspection and proper hydraulic, tests could be undertaken.



LEGEND

* CONTROL BLOCKS (0,30 m < Ø < 0,40 m) PLACED BY DIVERS IN THE BEGINNING :
  - ① - 10 UN. (ORANGE)
  - ②&③ - 5 UN. EACH (YELLOW)
  - ④ - 10 UN. (GRAY AND YELLOW STRIPS)
- ⑤ - REMNANTS OF COFFERDAM
- ⑥ - MATERIALS FROM ITENS ④ & ⑤ AFTER OPERATION OF GATE # 1 ONLY
- ⑦ - MATERIALS FROM ITEN ⑤ AFTER OPERATION OF ALL GATES

Fig. 12 - Result of Hydraulic Tests. Plan

The cofferdam, composed of basalt blocks, a clayey seal and even having some construction debris, was then the actual source of all rubbish found in those underwater inspections of the stilling basin. The materials had been drawn back and sideways by recirculating flow, whenever a non-symmetrical operation of the gates ocurred. Topographic situation of the elevated river-bed downstream in the tail race acted a propitious barrier in establishing the recirculating flow.

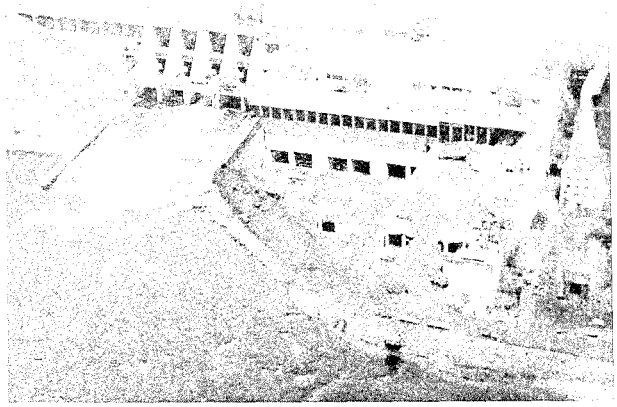


Fig. 13 - Cofferdam at return channel during construction.

As a conclusion, this case revealed that at an occasion one is faced with a problem under high velocity and turbulent water, he must proceed with caution: The actual problem may not be as evident as it appears.

ACKNOWLEDGEMENT

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