REHABILITATION OF THE CENTRAL MACHU PICCHU HYDROELECTRIC PLANT

CONSTRUCTION OF GALLERIES CONNECTING THE POWERHOUSE TO THE TAILRACE TUNNEL

OCTOBER 1, 2013
CENTRAL HIDROELECTRICA MACHUPICCHU
1,750 msnm

Nevado Salkantay
6,271 msnm
The flood that destroyed the works of the Central Hydroelectric Machu Picchu

SALKANTAY GLACIER IN THE SLIDING ZONE
MELTING PROCESS AND SATURATION OF MORAINES
VIEW OF THE STARTING POINT OF THE SLIDE
MUDDY GROUND AT THE BOTTOM OF THE LAGOON OF THE GLACIER AFTER THE FLOOD
VALLEY OF THE AOBAMBA RIVER AFTER THE FLOOD
AOBAMBA WATERSHED AFTER THE FLOOD

CENTRAL HIDROELECTRICA MACHUPICCHU

LONGITUD APROX. 17 KM.

 nivel aprox. 4.6 km.
SLIDE ARRIVING AT THE CONFLUENCE WITH THE VILCANOTA RIVER
PROCESS OF DAMMING THE VILCANOTA RIVER
DAMMED AREA AND NATURAL RESERVOIR
FLOODING OF THE CAMP AREA

VISTA PANORAMICA TUBERIAS DE PRESION  
(15 DE ENERO DE 1998)

VISTA PANORAMICA DE LA CENTRAL  
(14 DE JULIO DE 1999)
REFERENCES OF RESERVOIR ELEVATION

TAILRACE CANALS

CONTROL STRUCTURE

RIO AOBAMBA

VISTA PANORAMICA DE LA CENTRAL
(ANTES DEL SINIESTRO – ENERO 1998)

VISTA PANORAMICA DE LA CENTRAL
(DESPUES DEL SINIESTRO – AGOSTO DE 1999)
CONTROL BUILDING BEFORE AND AFTER THE FLOOD
DISCHARGE CHANNEL FOR DRAINAGE
OPENING OF A DISCHARGE CHANNEL TO FACILITATE DRAINAGE
EWI projected the new discharge system of Power House 1 and 2 in anticipation of similar flooding.

This new system discharge would be underground, crossing under the Vilcanota River valley and discharging 2.0 km down stream through a tunnel excavated in the granite of the right bank.
PLAN VIEW OF THE REHABILITATION OF THE CENTRAL MACHUPICCHU HYDROELECTRIC PROJECT
PLAN VIEW OF THE BASIC DESIGN OF THE CONNECTION GALLERY

- **DISCHARGE TUNNEL**: 2.0 km. excavation in rock
- **CONNECTION**: 60 m. excavation in rock of tunnel
- **CONNECTION TUNNEL**: 140 m. excavation in alluvial Material
- **DISCHARGE TUNNEL**: 40 m. cleaning existing channel, 60 m. excavation in rock
- **POWERHOUSE 1**: 2 turbines Francis (50 MW)
- **ROUNDHOUSE 2**: 3 turbines Pelton (75 MW)
GEOLOGICAL PROFILE ACROSS THE RIVER VALLEY
POWERHOUSE #2 DISCHARGE
The contract documents enabled the contractor to provide an additional alternative.

- Hydro geological and geotechnical information were too poor for a safe freezing of soil approach and ground materials were too pervious and heterogeneous.

- Finally the Consortium proposed a pressurized shield alternative.
This technique has the following advantages:

- Excavation and lining simultaneous (safer for personnel and good structural quality).
- Recommended for excavation under high water pressure
- Safe operation in a wide range of soil conditions.
RANGE OF GRANULAR SOILS APT FOR A PRESSURIZED MIXED SHIELD

- Arcillas (Clays)
- Limos (Clays)
- Arenas (Sands)
- Gravas (Gravels)
- Bolos (Boulders)

SOIL EXCAVATED UNDER THE VILCANOTA RIVER

Possible si N (SPT) <15

REQUIERE MEDIDAS ADICIONALES
LIMITATIONS OF THE MACHU PICCHU PROJECT

- In addition to soil conditions, the project has an important limitation in access. The only access to the job site is a narrow gauge railway.
- The dimensions of the tunnels limited the TBM maximum diameter 3.2 m.
- This conditioned the maximum size of the machinery to be transported to the job site.
- As a result, the maximum size of the shield and tubes was limited by the internal diameter of the access tunnels.
Excavation of two parallel tunnels, with Launching and Reception pre-Tunnels excavated in the granite formation on both sides.

Use of a Herrenknech joint shield AVN 2500, 3.15 m diameter, with pipe jacking technology.

The shield is launched from the cavern of the right bank.
View of the site from the ruins of Machu Picchu

Discharge Tunnels
Front Chamber (3) Pressurized Chamber (4), Main Wall (1), (12) air bubble. (5) opening between Chamber (3) and (4) Pressure Chamber.

The bentonite mud is pumped to the front chamber through the main (9), connected to the feed pump.

The suspension mixed with soil is sucked from the mains (6 and 7), after passing through the sieve of the crusher (13) bowl decanter where it is separated and returns by pumping to the main system to a pond.

Sediments that accumulate below the opening (5) are eliminated by alternating feeding and return flows through the pipes (8 and 7).
SPECIAL ADAPTATIONS FOR THE MACHUPICCHU PROJECT

- Cutting machine head had a "mixed" type arrangement. It was equipped to dig so much rock crystal as soft material mixed with gravel and boulders.
- The backing of the machine was designed to support up to 5 bars of pressure.
- The machine is equipped with special areas of pressure control, to work under pressure if necessary.
VIEW OF THE CUTTER HEAD
The design of the connecting tunnels

The new hydraulic design consisted of replacing a single tunnel discharge, by two smaller tunnels, twin and parallel. The owner asked a flow rate of discharge of the Central recovered 57 m³/sec. This meant that two new discharges had to work under pressure.
CAVERN OF RIGHT BANK
LOGISTICS

- The machine and the concrete pipes were manufactured in Germany, so the biggest logistical problem was transport both from the Rhein region to Machu Picchu.

- The idea was to use inland waterways directly to Antwerp, then you transport maritime (Matarani) Peruvian port and rail transport to work.
Secuencia de Lanzamiento 4

Descenso y montaje del Cilindro

Máquina N° 1

1. Bulonado de la brida de acero en pared caverna
   y relleno del hueco con espuma o inyección impermeable.
2. Por medio de la estación de empuje, desplazar el escudo
   para adelante.
3. Instalar el soporte provisional de sello y freno entre el carril
   empuje y la brida de acero, para guiar la máquina el
   pre-Fanel
4. Descender el Cilindro de la Máquina N° 1

LOWERING PARTS OF THE MACHINE
NORMAL OPERATION OF THE SHIELD
LOWERING PARTS OF THE MACHINE
MOUNTING OF THE SEAL OF LAUNCH - TUNNEL NO.1
ASSEMBLING THE CUTTING HEAD
ASSEMBLY OF THE MACHINE IN THE LAUNCHING CAVERN ON THE RIGHT BANK
ASSEMBLY OF THE MACHINE
ASSEMBLY SEAL AND BRAKE TUBES
ASSEMBLY OF THE INTERMEDIATE JACKING STATION
CONCRETE PIPES

- Concrete pipes were designed to withstand the maximum jacking loads, and internal pressures.
- Its dimensions are 3.1 m (outside diameter), and 0.30 m of wall thickness.
- Used reinforcement was coiled, F 10 mm @ 8 mm
- The quality of concrete used was B55 (Norma DIN)
CONCRETE PIPE SECTIONS

- Supplied pipe types were:
  - Type I (joint with TBM)
  - Type II (with 3-port injection)
  - Type III (without injection ports)
  - Type IV (short pipe for the intermediate station).
  - Type V (interjack long pipe) Gallery 2
- Typical length of the pipe was 2.5 m.
STOCK OF CONCRETE PIPES
PROBLEMS RELATED TO THE PIPELINE TRANSPORTATION.

- Pipes showed many minor defects during transport by boat, truck, train and intermediate handlings.
- A total of 134 pipes were unrecoverable.
- Most of the pipes were repaired using mortar epoxy under the supervision of experts.
- Repairs were tested with simple tension tests and inspected with ultrasound.
DAMAGE TO THE PIPES
REPAIR WITH EPOXY MORTAR
VIEW OF THE GRANITE FACE, AT THE BEGINNING OF THE TUNNEL #1
GEOLOGICAL CONTINGENCY

GALLERY 1

- The advance in Tunnel #1 suddenly stopped after approx. 60 meters from the cavern on the right bank.

- The blockage was limited to 5 pipes behind the machine, between the inter-jack and the machine.

- Blocking lasted over 60 days, all efforts by using the normal means available on the site could not move the section of the pipe and the trapped machine.
In order to achieve the necessary geological information, the consortium made three exploratory surveys, two of them around the blocked pipes. Samples were tested in the laboratory in Lima.

At the same time, consulting engineers went to the site to analyze the problem, and Herrenknecht made some improvement by increasing force available at the main station of thrust. Two hydraulic pistons were added.
THE LOCATION OF THE BLOCKED SHIELD GRAPHIC SCHEME
CONDITIONS AT REST DURING BLOCKAGE

LIBERATION OF TUNNEL 1
UNSUCCESSFUL ATTEMPTS BY PUSHING FORWARD AT INTERMEDIATE STATION

LIBERATION OF TUNNEL 1
SUCCESSFUL LIBERATION OF
BLOCKED PIPES

Step 1, Push forward with TBM steering jacks
Step 2. Release TBM steering jacks and concurrently
push forward with intermediate jacks

LIBERATION OF TUNNEL 1
The combined efforts of improvement of the bentonite slurry (Mr. Lyon), and the assistance of Mr. Abbott's Jason Co., helped release the machine.

The tunnel was finally completed on 17 November, having been started in late August.
THE MACHINE-GALLERY # 1
THE FIRST COMPLETED TUNNEL
GEOLOGICAL ANALYSIS OF THE LOCK

- Findings from the exploratory program include:
  - The soil mass consists of fine, flowing and unstable glacial sediments.
  - The material behaves as a liquified sand as the shield advanced, flowing like a dense, viscous fluid.
  - The mass adheres very strongly on the porous surface of the concrete.
  - The friction force of this material exceeded the total available thrust force.
THE GEOLOGIC SITUATION AFTER THE DEVELOPMENT OF EXPLORATION BORINGS
LIQUIFIED SILT FLOWING THROUGH THE INJECTION PORTS
The following mitigating measures were adopted:

- Install three injection ports in all pipes.
- Coating of the pipes with waterproof and durable coating.
- Increase the diameter of the cutting head by 1 inch.
- Improve the force available in the station's main thrust.
MEASURES ADOPTED FOR THE SECOND TUNNEL

- The second thrust was undertaken on the basis of the experience gained in the Tunnel #1 and on the basis of the Geotechnical analysis by specialists.

- The following factors helped in the successful drive of the second tunnel:
  - Soil never stuck on the steel surface of the shield of the machine
  - The improvement in lubrication products kept the bentonite from mixing with the saturated soil.
  - The use of a adequate lubricant (bentonite) that does not mix with the surrounding soil is an important factor to maintain a sustained advance.
AFTER THE INCREASE IN DIAMETER CUTTING HEAD
IMPROVEMENT OF THE MAIN STATION OF THRUST
CONCLUSIONS

- The second tunnel was completed in 9 days, working 2 shifts of 12 hours a day.
- The intermediate jacking stations were never used.
- Maximum thrust force registered did not exceed 1000 tons, for the 150 meters of pipe.
- Thrust forces varied slightly throughout the push.
GRAPH OF THE THRUST FORCE IN THE TUNNEL # 2
HOLE-THROUGH OF THE TUNNEL # 2
TUNNEL # 2 COMPLETED
MONITORING OF THE ALIGNMENT OF THE PIPES - TUNNEL 2

GALERIA N°2
medición asientos a partir del 1/02/01
con líneas de tendencia polinómicas

días cm

tubo 49 tubo 54 tubo 53 tubo 26