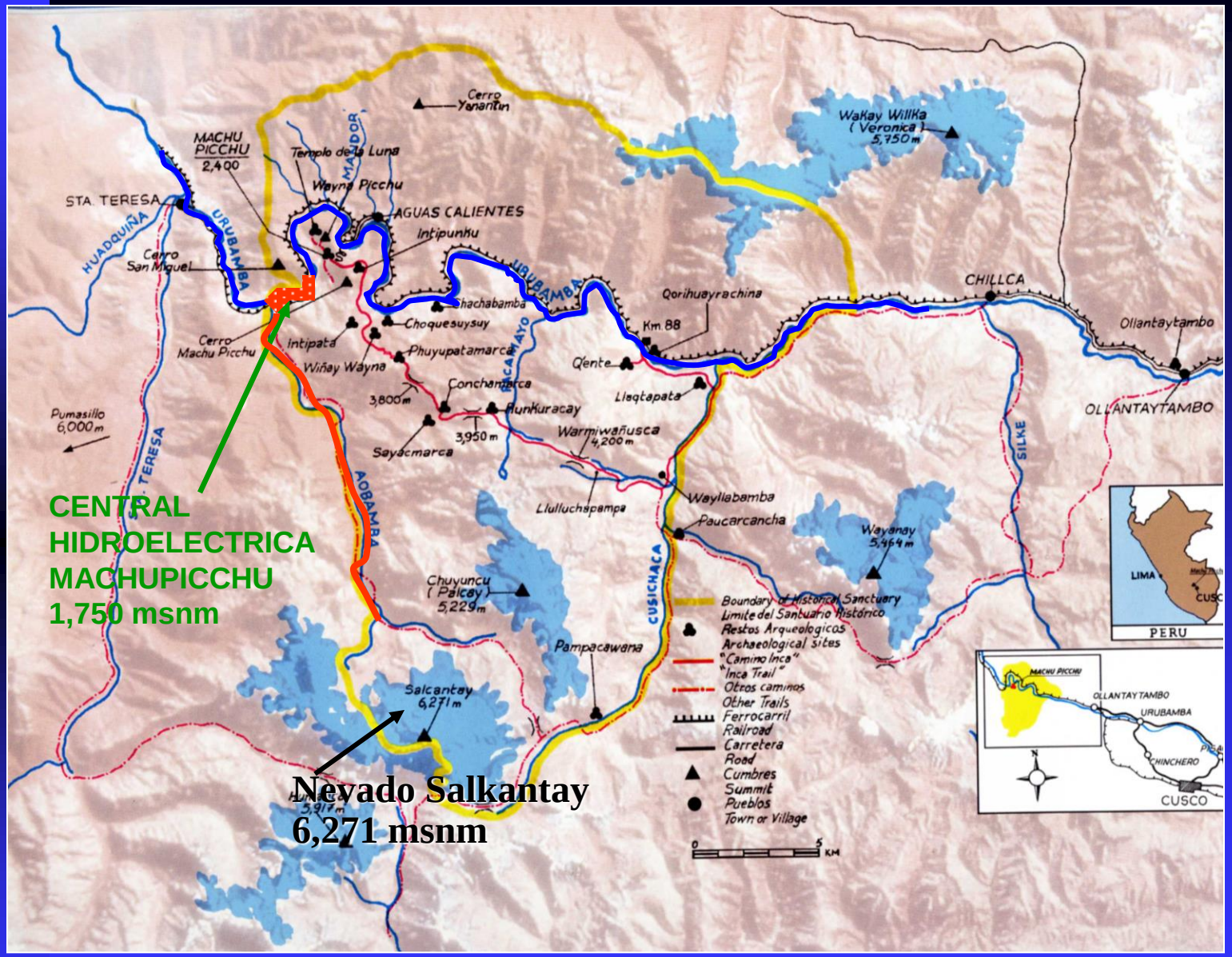
REHABILITATION OF THE CENTRAL MACHU PICCHU HYDROELECTRIC PLANT

CONSTRUCTION OF GALLERIES CONNECTING THE POWERHOUSE TO THE TAILRACE TUNNEL

OCTOBER 1, 2013



PROJECT LOCATION MAP

The flood that destroyed the works of the Central Hydroelectric Machu Picchu

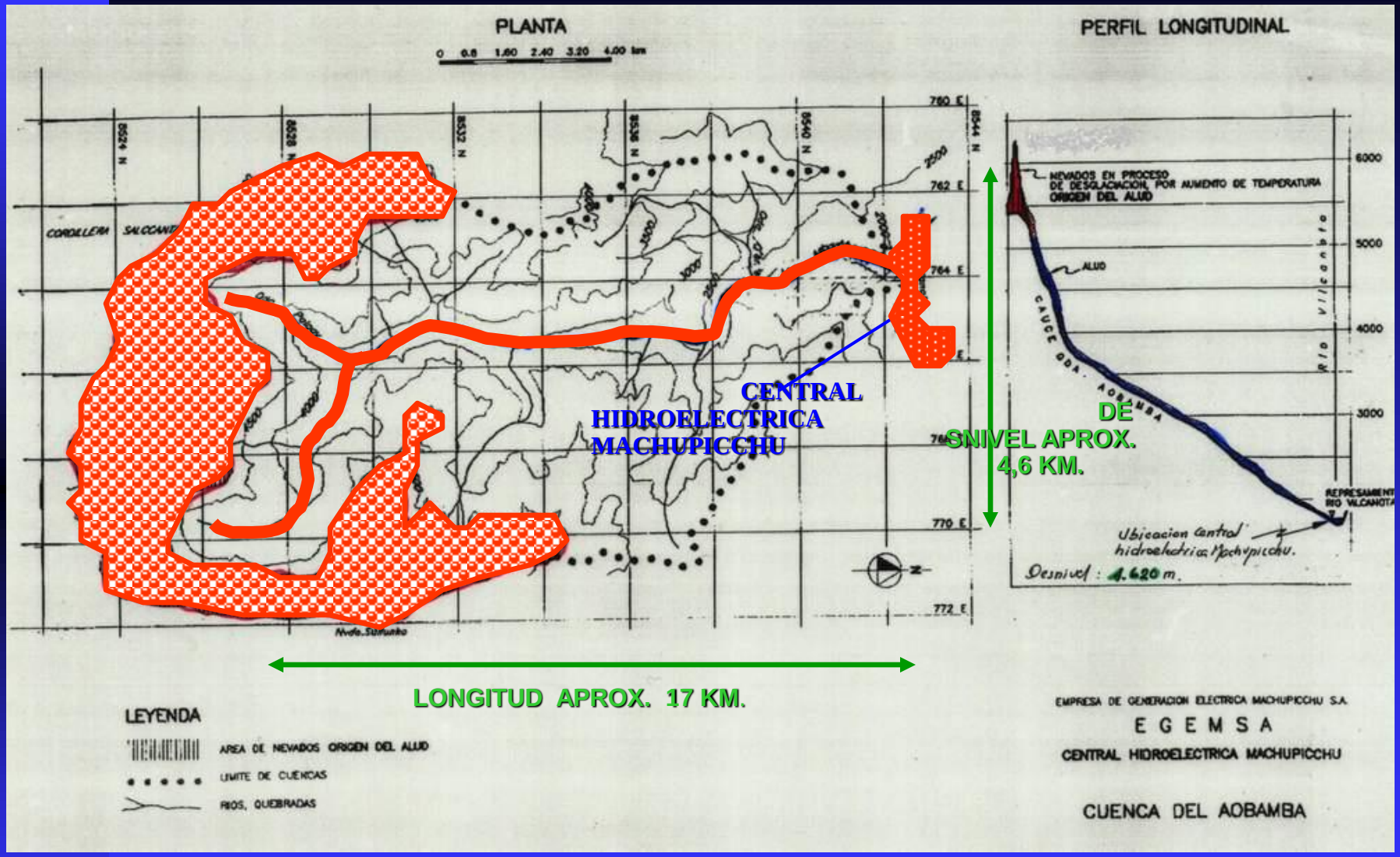
SALKANTAY GLACIER IN THE SLIDING ZONE

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

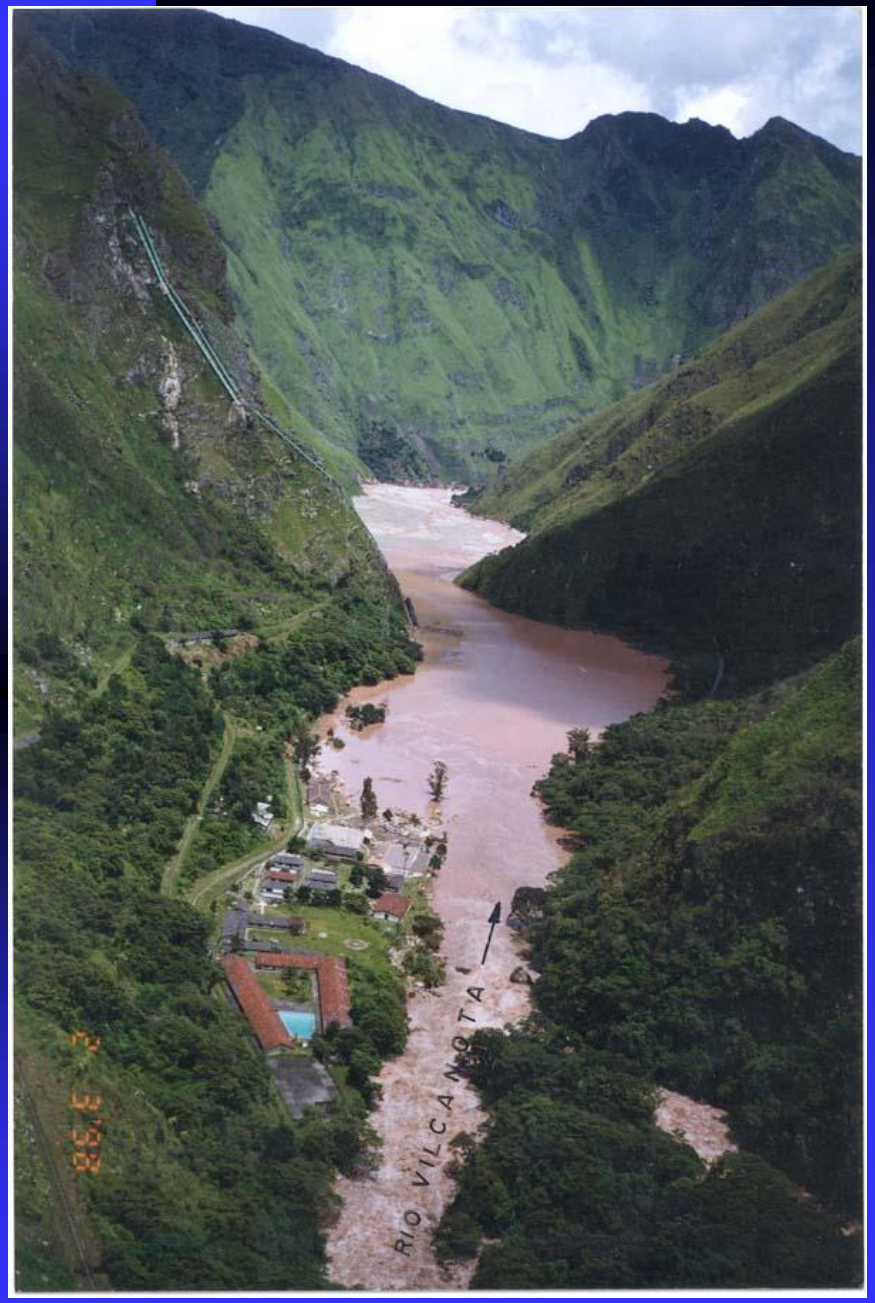


AOBAMBA WATERSHED AFTER THE FLOOD

SLIDE ARRIVING AT THE CONFLUENCE WITH THE VILCANOTA RIVER

PROCESS OF DAMMINGTHE VILCANOTA RIVER

DAMMED AREA AND NATURAL RESERVOIR



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

VISTA PANORAMICA DE LA CENTRAL
(14 DE JULIO DE 1999)

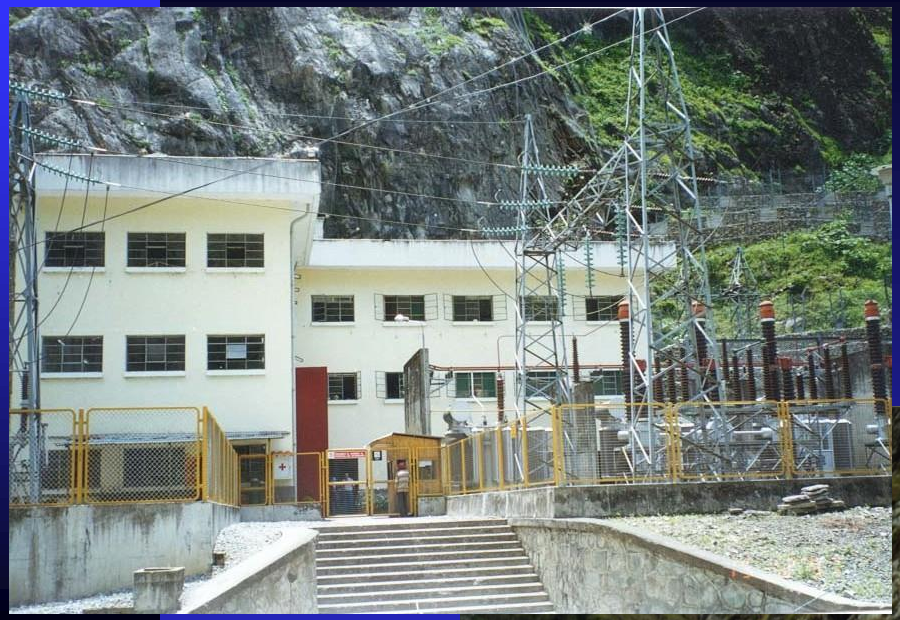
FLOODING OF THE OF THE CAMP AREA

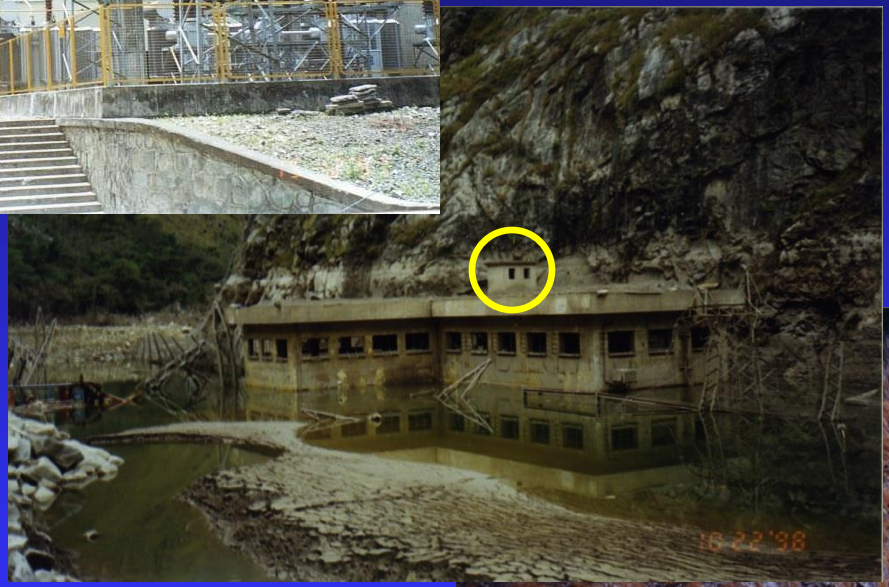
REFERENCES OF RESERVOIR ELEVATION

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





Recovery of the Central Machupicchu hydroelectric plant

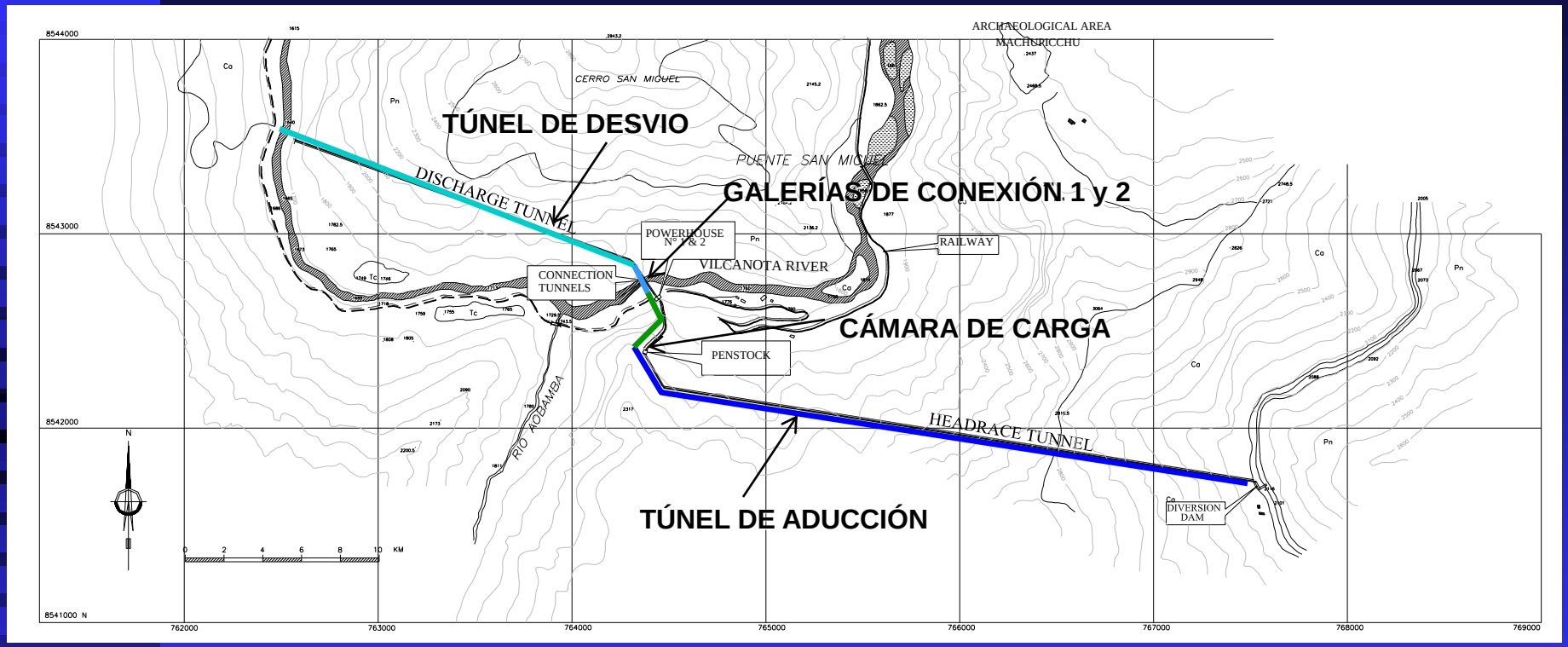
COFFERDAM AROUND THE CONTROL BUILDING

DISCHARGE CHANNEL FOR DRAINAGE

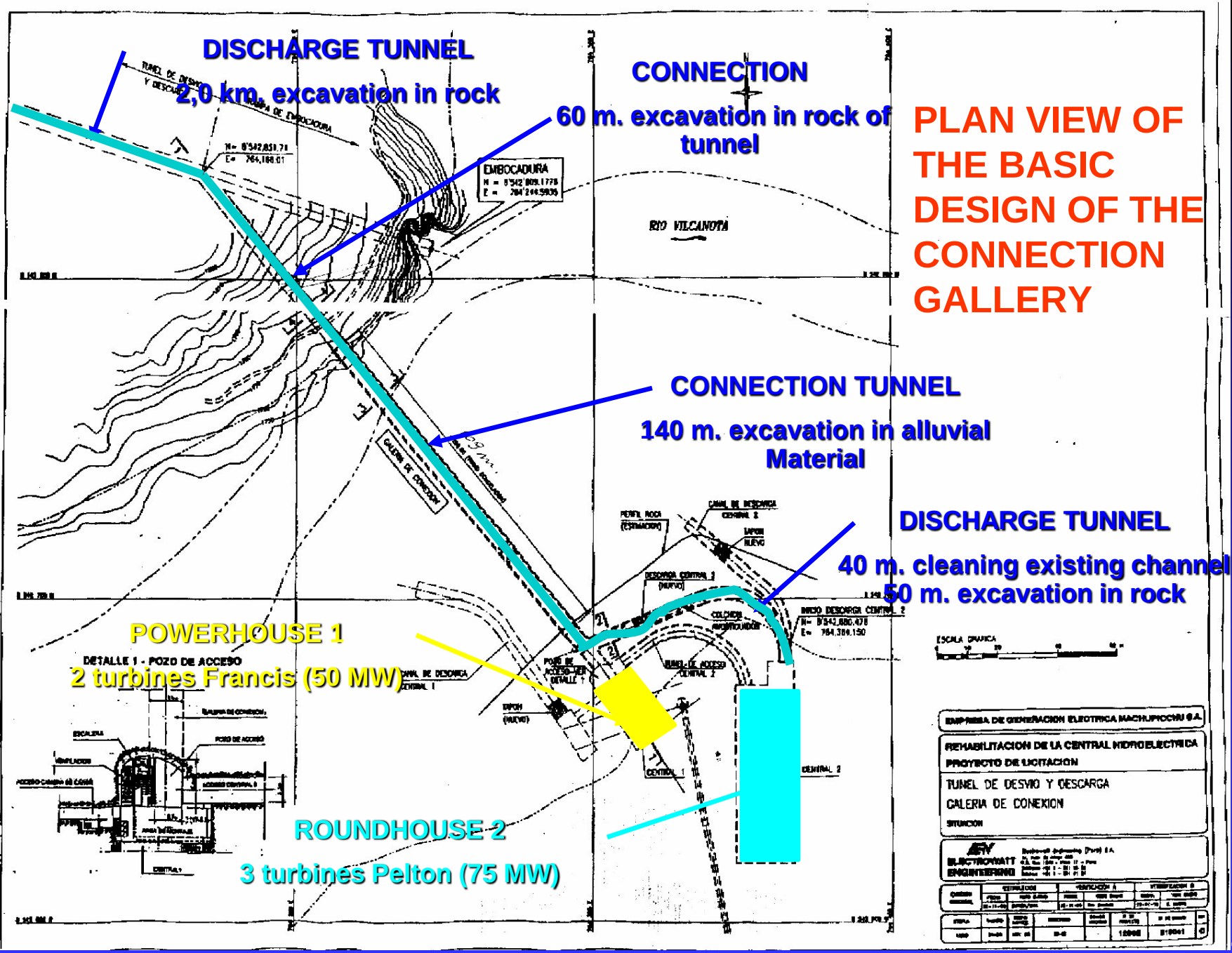
OPENING OF A DISCHARGE CHANNEL TO FACILITATE DRAINAGE

REHABILITATION PROJECT FEATURES

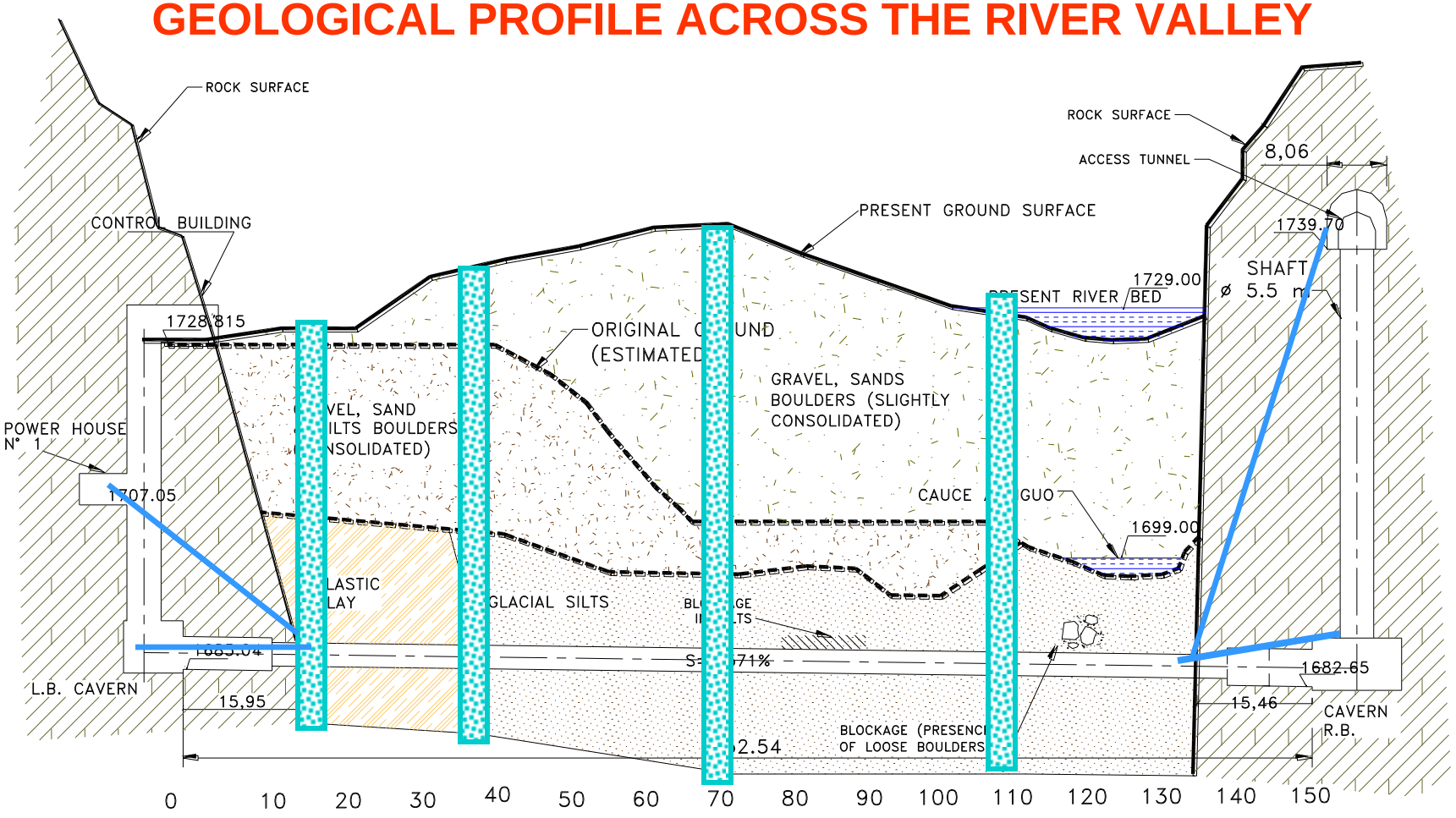
- EWI projected the new discharge system of Power House 1 and 2 in anticipation of similar flooding.
- This new system discharge would be underground, crossing under the Vilcanota River valley and discharging 2.0 km down stream through a tunnel excavated in the granite of the right bank.



PLAN VIEW OF THE REHABILITATION OF THE CENTRAL MACHUPICCHU HYDROELECTRIC PROJECT

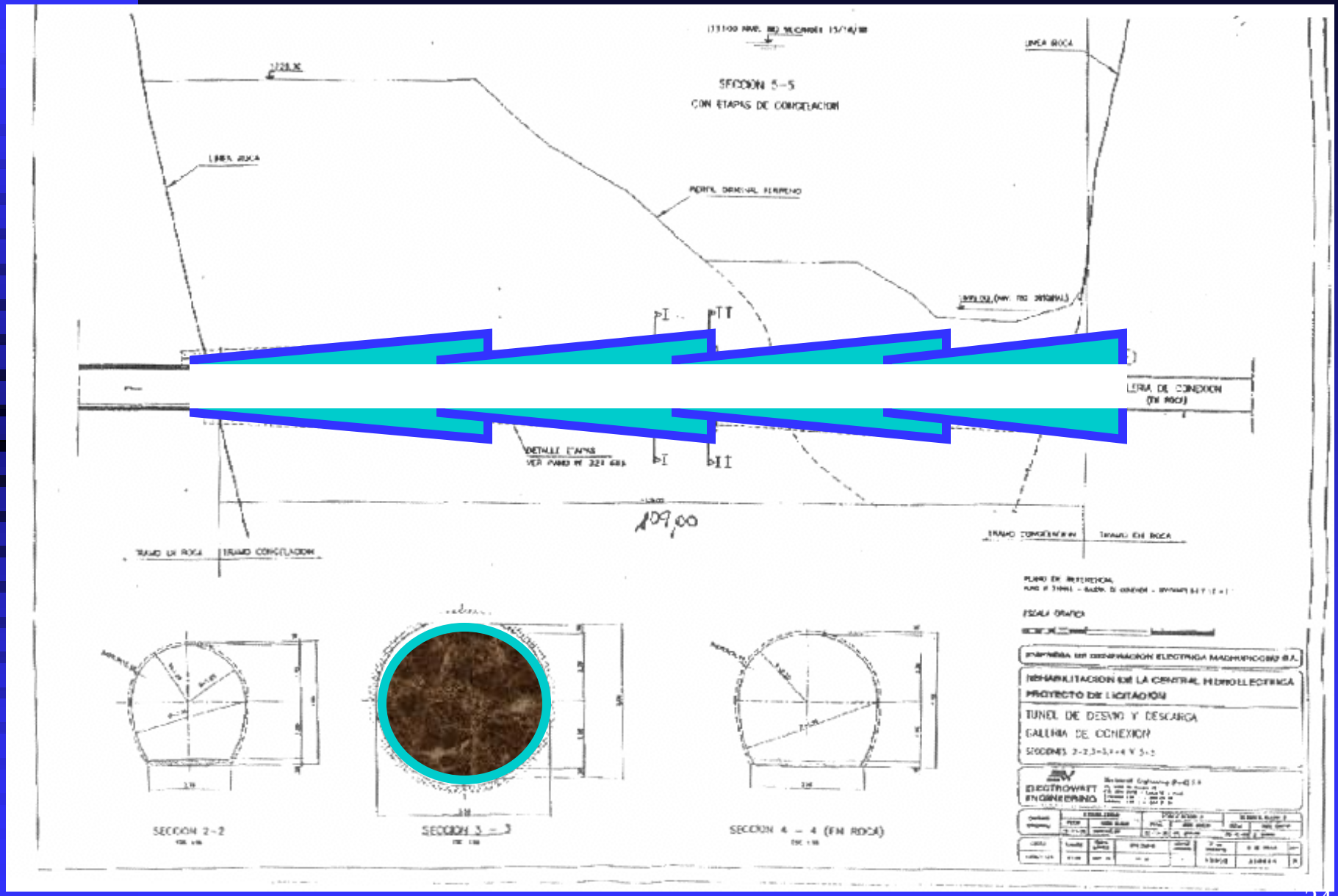

DISCHARGE TUNNEL
2,0 km. excavation in rock
CONNECTION
60 m. excavation in rock of tunnel
PLAN VIEW OF THE BASIC DESIGN OF THE CONNECTION GALLERY
CONNECTION TUNNEL
140 m. excavation in alluvial Material
DISCHARGE TUNNEL
40 m. cleaning existing channel
50 m. excavation in rock
POWERHOUSE 1
2 turbines Francis (50 MW)
ROUNDHOUSE 2
3 turbines Pelton (75 MW)
EMBOCADURA
RIO VILCANOTA
GALERIA DE CONEXION
DETALLE 1 - POZO DE ACCESO
EMPRESA DE GENERACION ELECTRICA MACHUPICCHU S.A.
REHABILITACION DE LA CENTRAL HIDROELECTRICA
PROYECTO DE LICITACION
TUNEL DE DESVIO Y DESCARGA
GALERIA DE CONEXION
SITUACION

GEOLOGICAL PROFILE ACROSS THE RIVER VALLEY



POWERHOUSE #2 DISCHARGE

DESIGN BASICS OF SOIL FREEZING



SECOND ALTERNATIVE OF CONNECTION GALLERY

- 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.

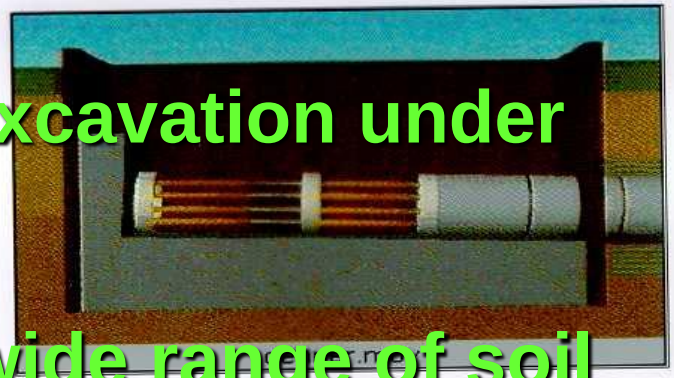
PRESSURIZED SHIELD

- **This technique has the following advantages:**

Simulación de Excavación de Galería con el sistema PIPE JACKING, se observa el avance de la TBM y los tubos empujados por la estación de Empuje

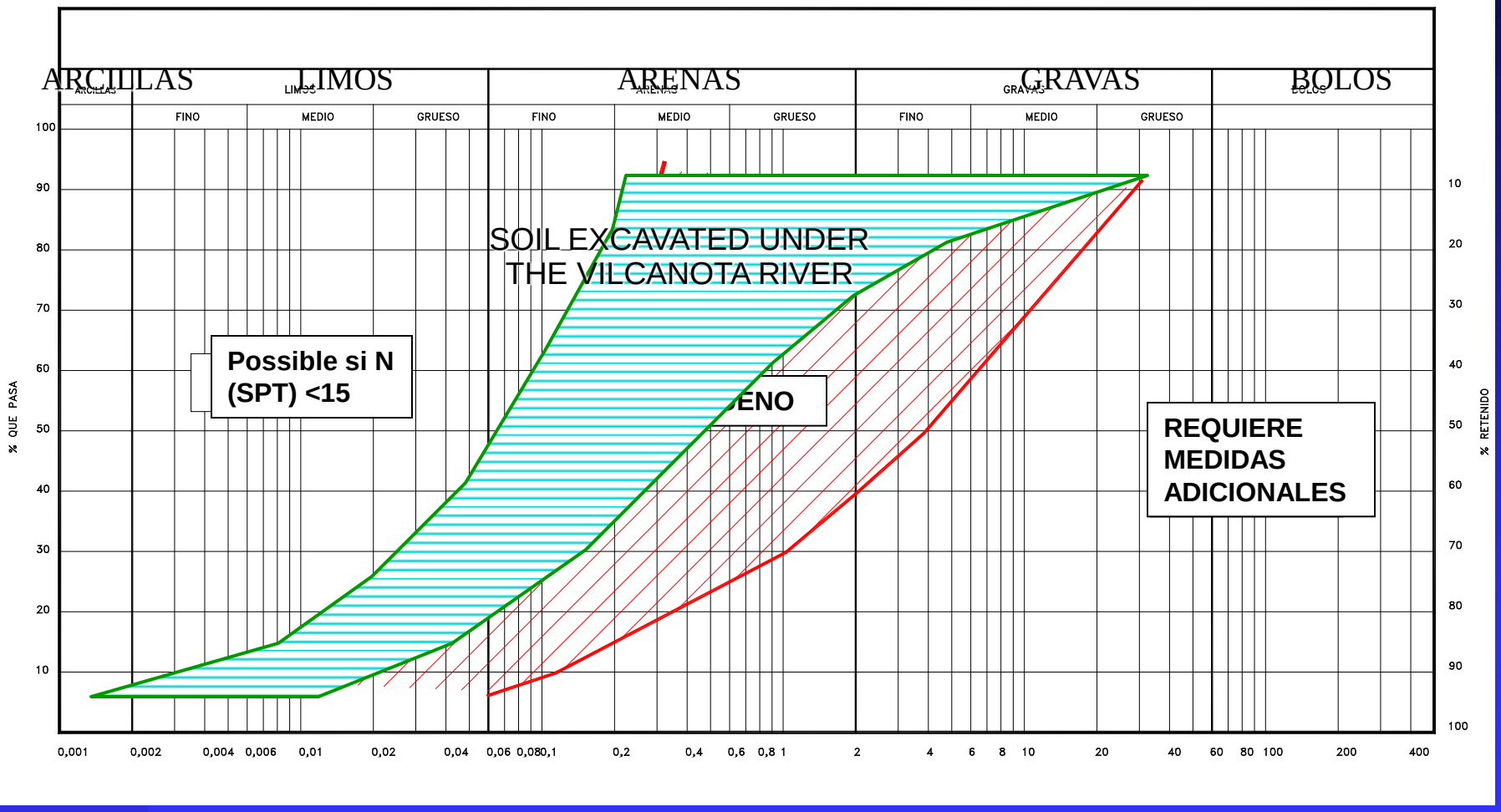
Cámara de Lanzamiento de los tubos, Ingreso de uno de los Tubos, el cual debe ser empujado hacia la Galeria en excavación

En este gráfico se representa todo el proceso, el tubo baja, es empuajdo conjuntamente con la TBM, y queda isto para el siguiente tubo, este proceso se repite hasta alcanzar el otro pozo



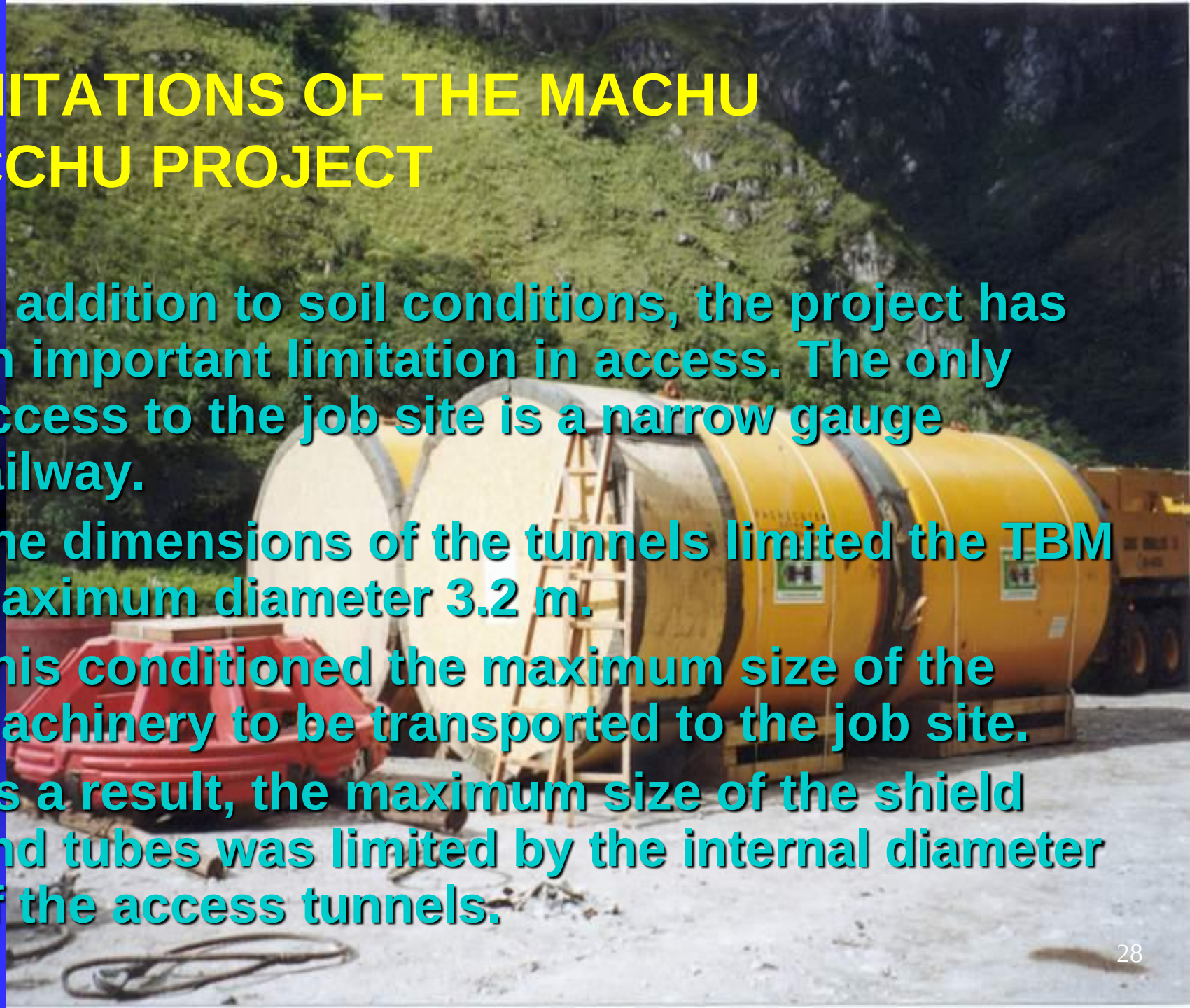
Estación de Empuje, se observa el sistema en operación, los tubos con la TBM a la cabeza, son empujados por los JACKs, hasta, generar espacio para ingresar otro tubo

- **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.**



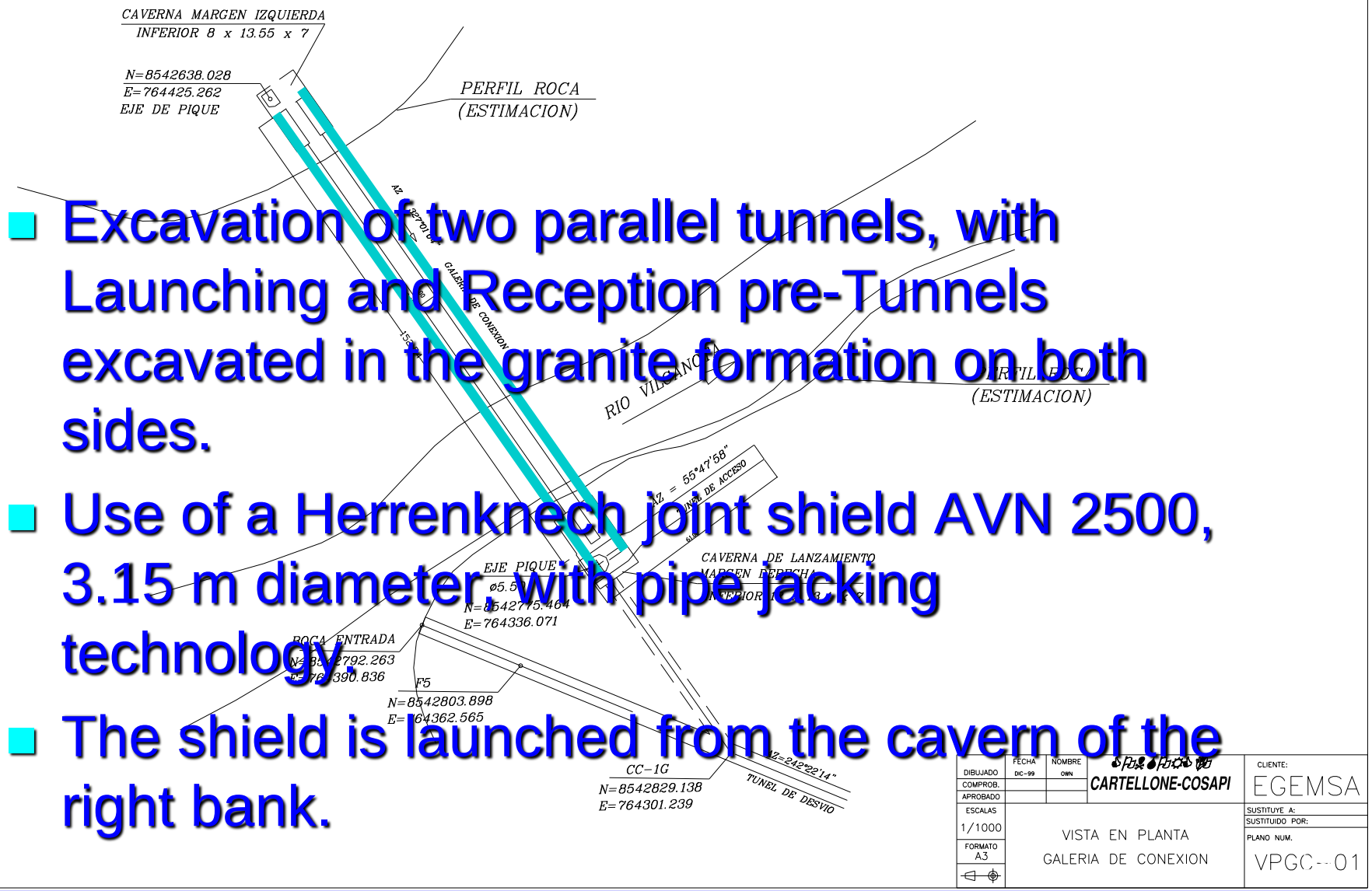
RANGE OF GRANULAR SOILS APT FOR A PRESSURIZED MIXED SHIELD

LIMITATIONS OF THE MACHU PICCHU PROJECT



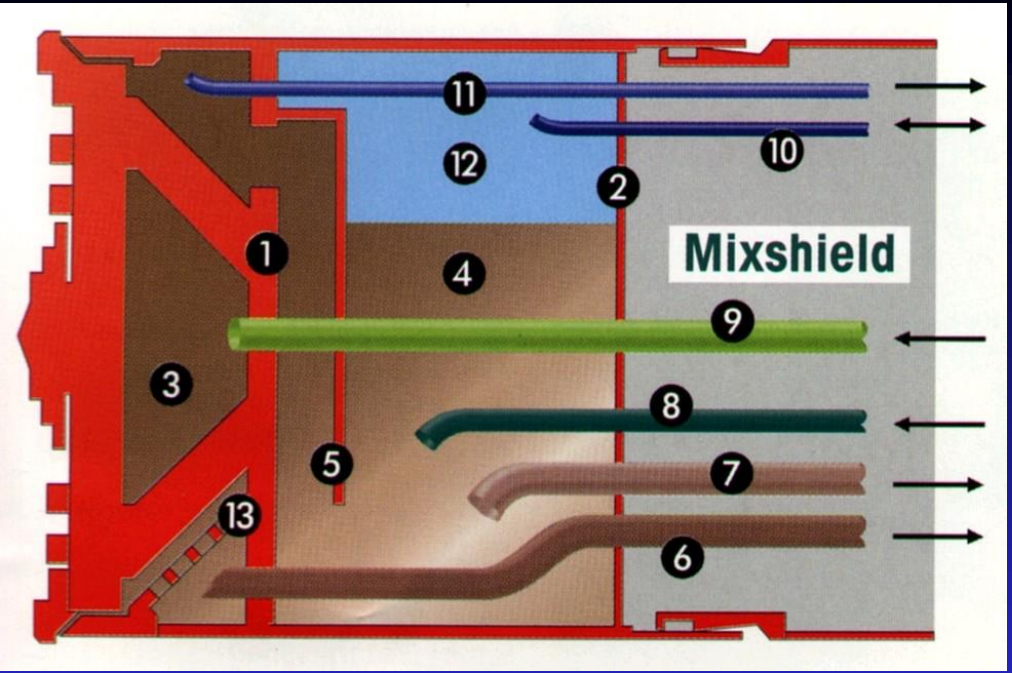
- In addition to soil conditions, the project has an important limitation in access. The only access to the job site is a narrow gauge railway.
- The dimensions of the tunnels limited the TBM maximum diameter 3.2 m.
- This conditioned the maximum size of the machinery to be transported to the job site.
- As a result, the maximum size of the shield and tubes was limited by the internal diameter of the access tunnels.

THE ALTERNATIVE PROPOSAL



- 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



MAIN WORKING DIAGRAM OF A PRESSURIZED AVN D TYPE SHIELD

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

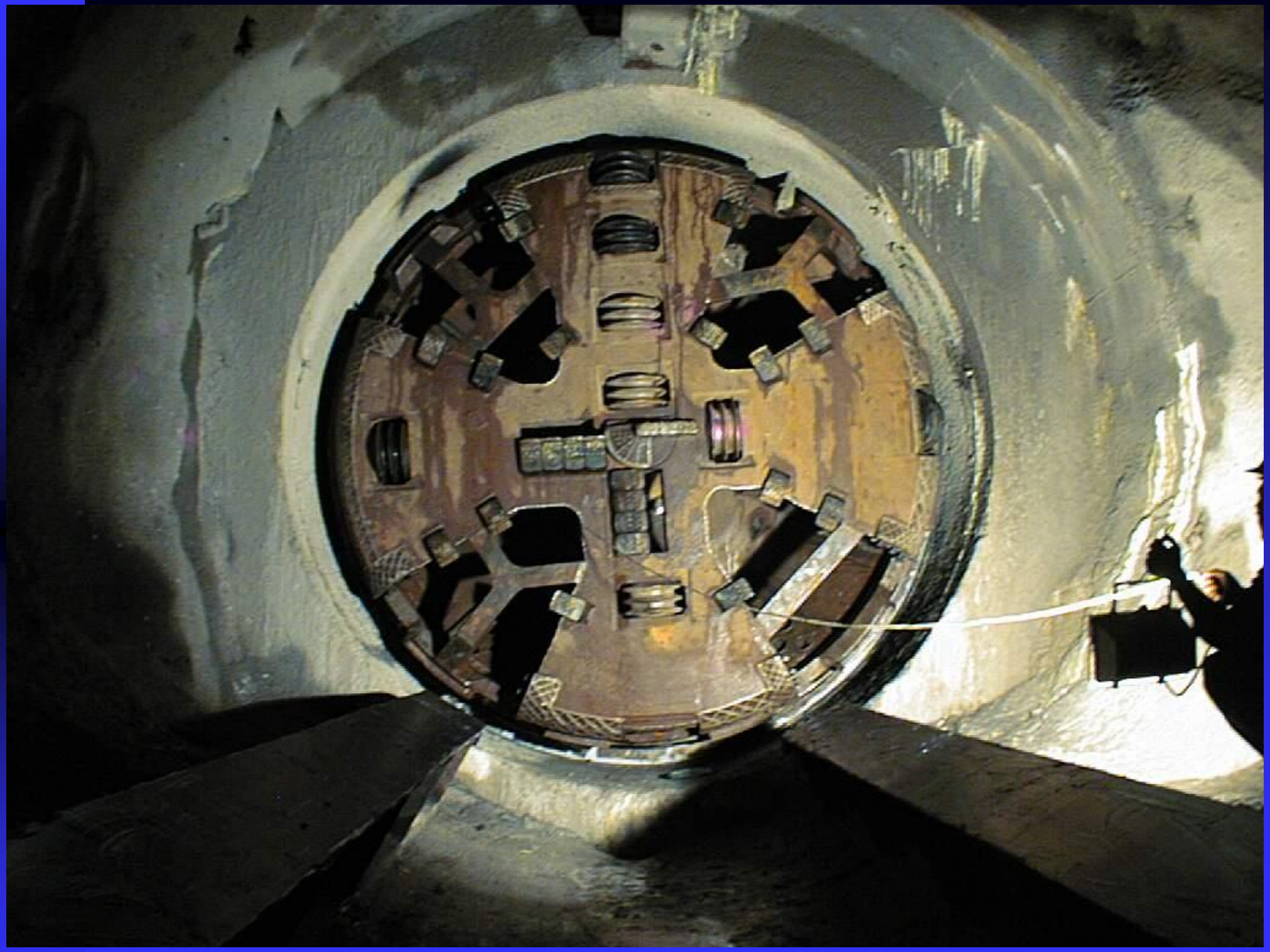
The bentonite mud is pumped to the front chamber through the main (9), connected to the feed pump.

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).

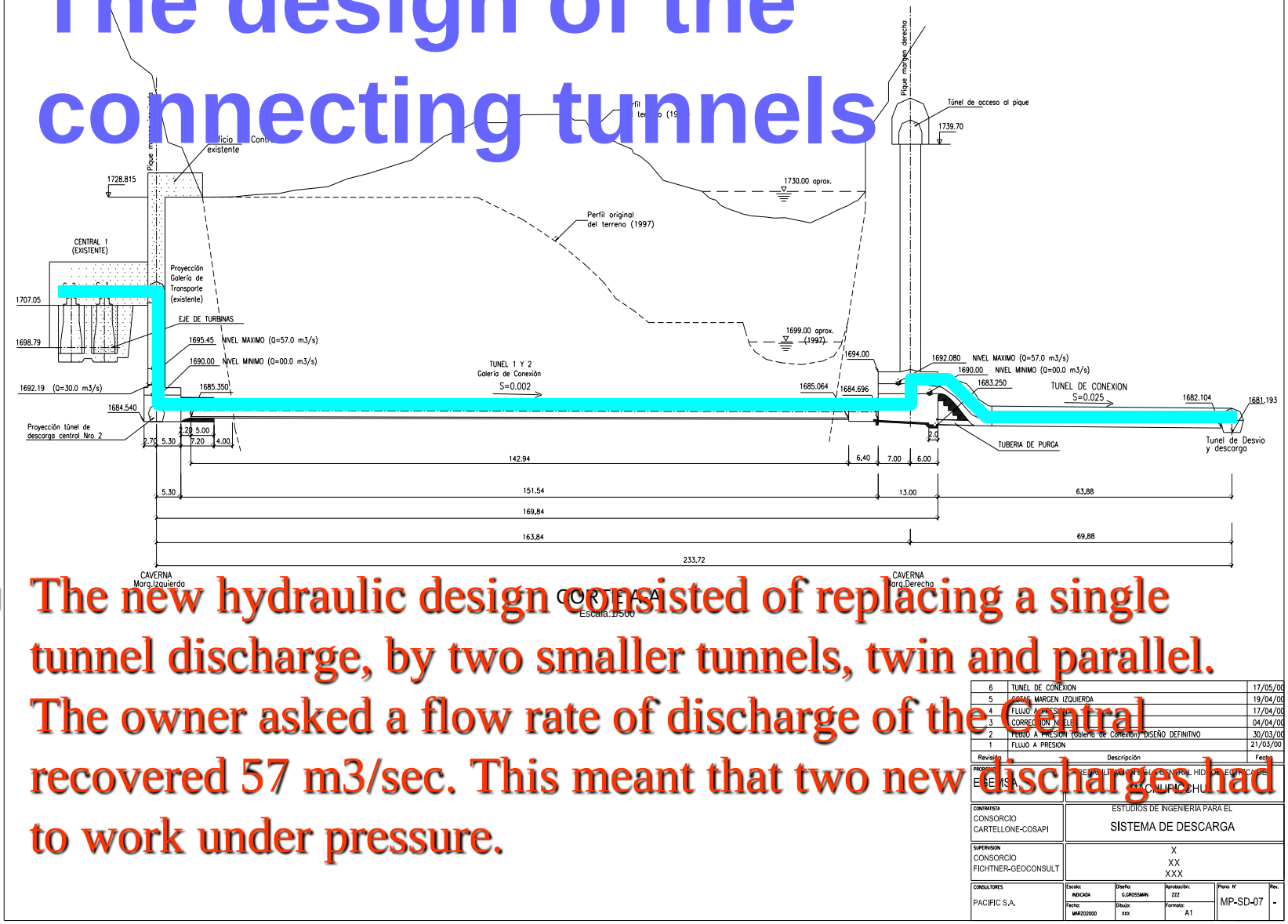
SPECIAL ADAPTATIONS FOR THE MACHUPICCHU PROJECT

- 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

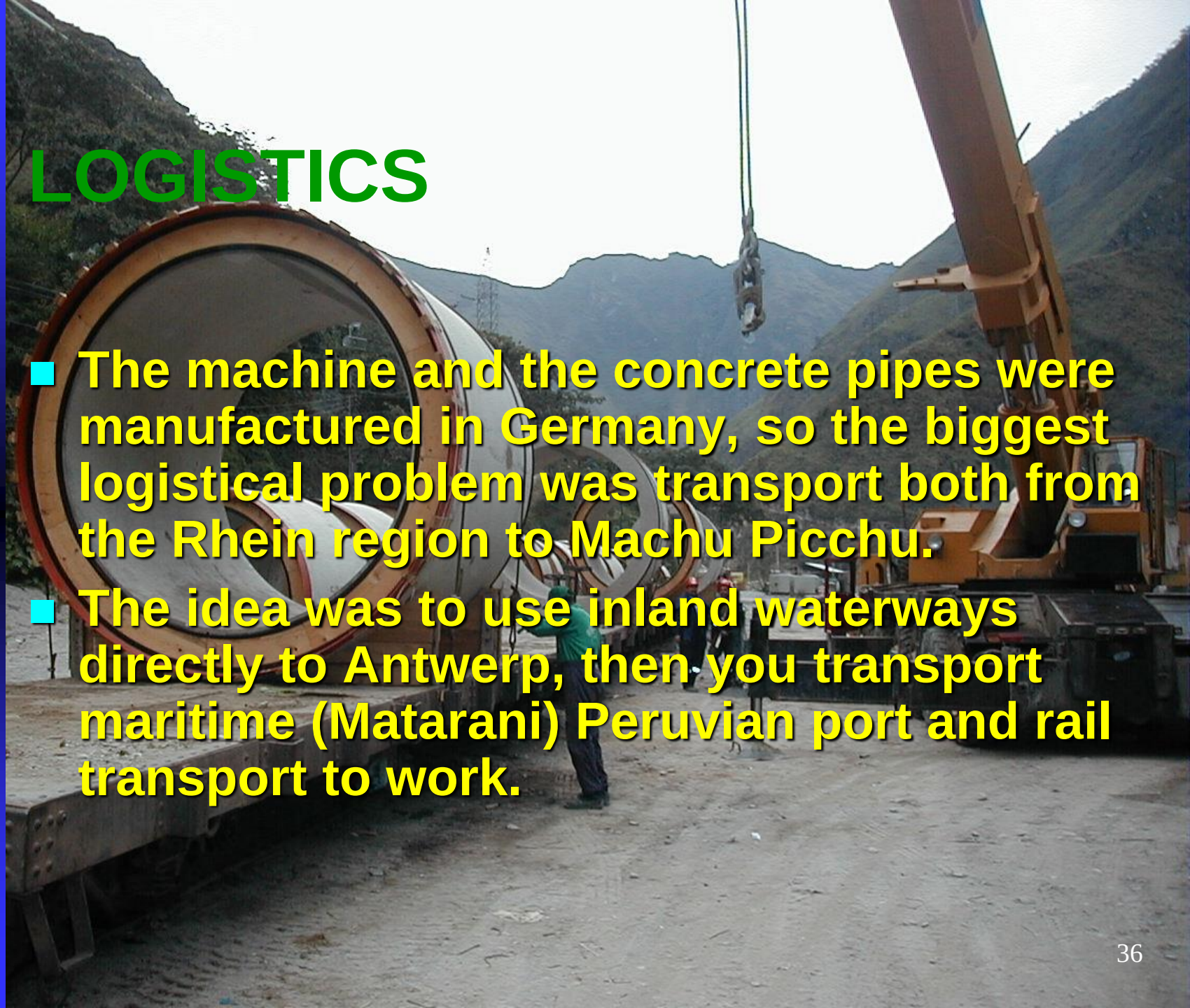
The design of the connecting tunnels



- 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



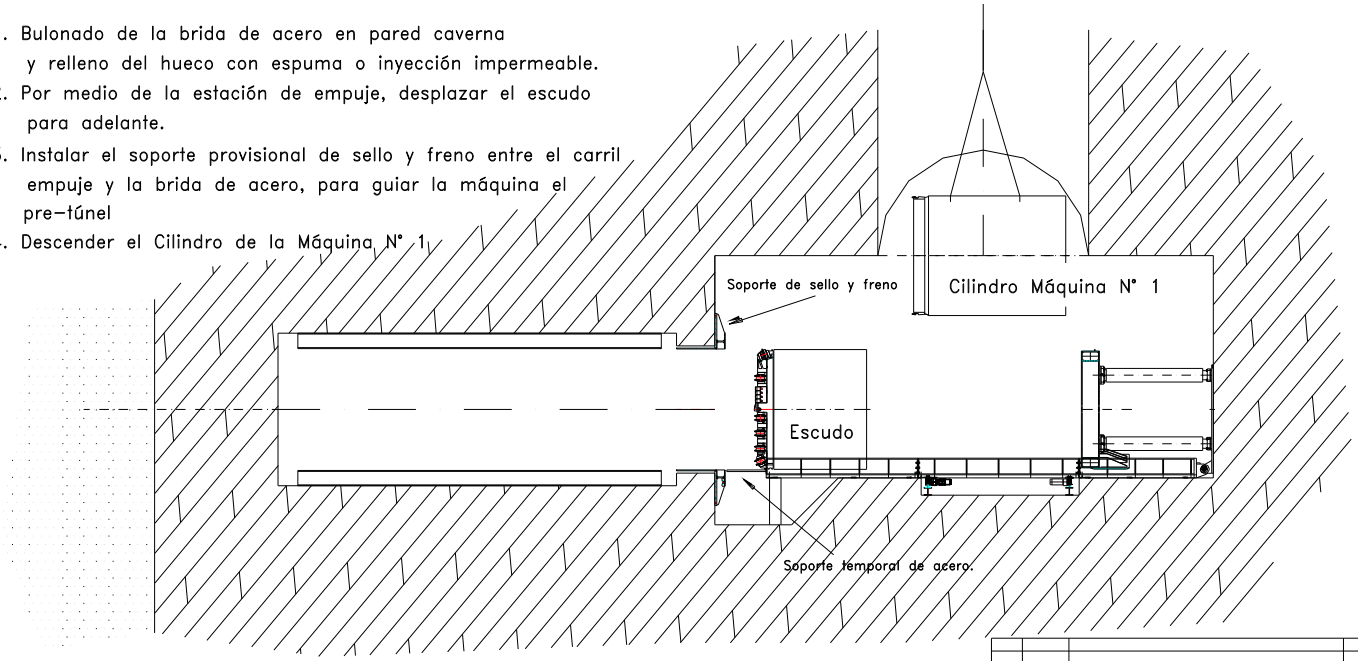
- The machine and the concrete pipes were manufactured in Germany, so the biggest logistical problem was transport both from the Rhein region to Machu Picchu.
- The idea was to use inland waterways directly to Antwerp, then you transport maritime (Matarani) Peruvian port and rail transport to work.

Secuencia de Lanzamiento 4

Descenso y montaje del Cilindro

Máquina N° 1

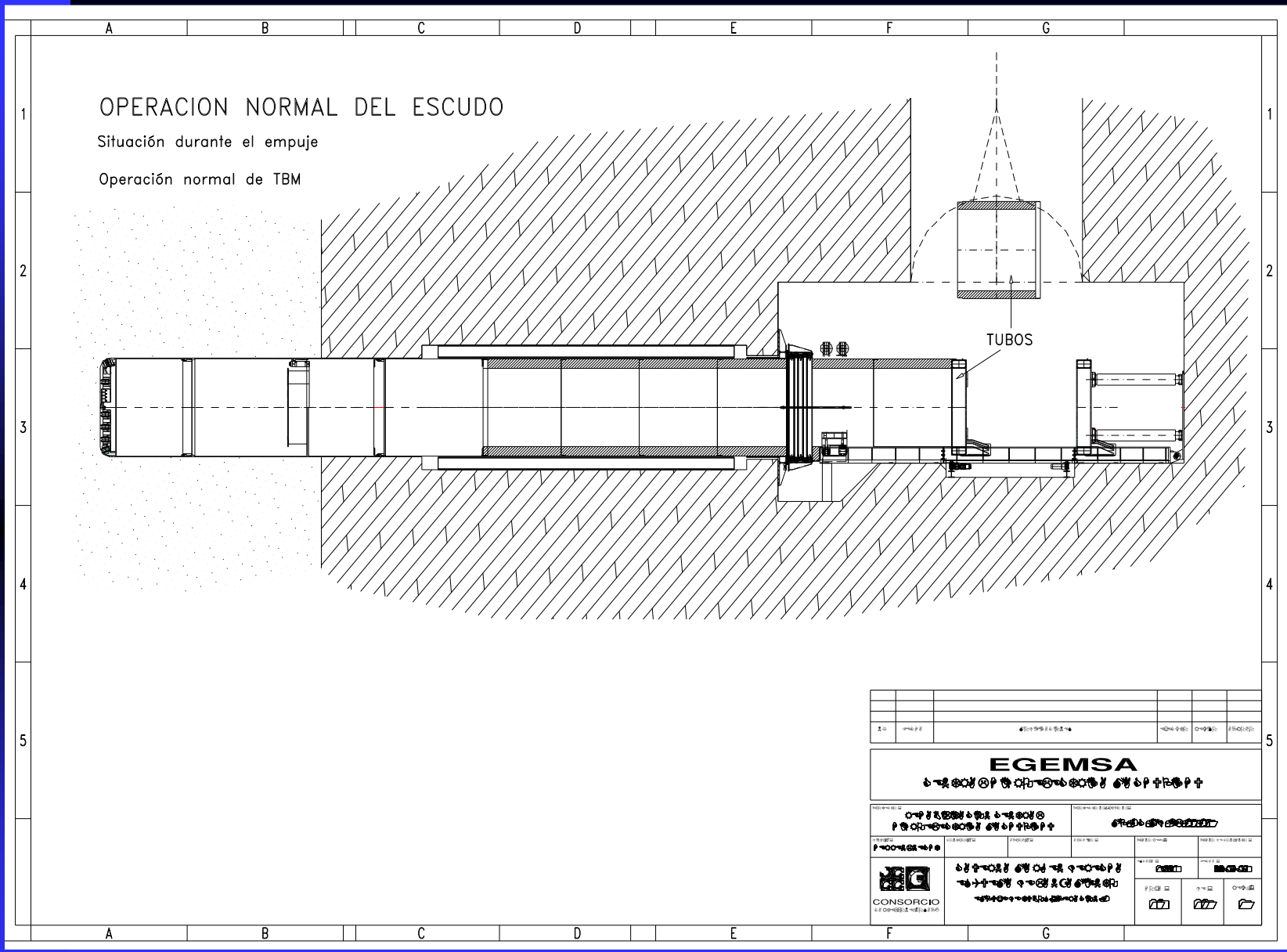
1. Bulonado de la brida de acero en pared caverna y relleno del hueco con espuma o inyección impermeable.
2. Por medio de la estación de empuje, desplazar el escudo para adelante.
3. Instalar el soporte provisional de sello y freno entre el carril empuje y la brida de acero, para guiar la máquina el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



EGEMSA

CONSORCIO

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

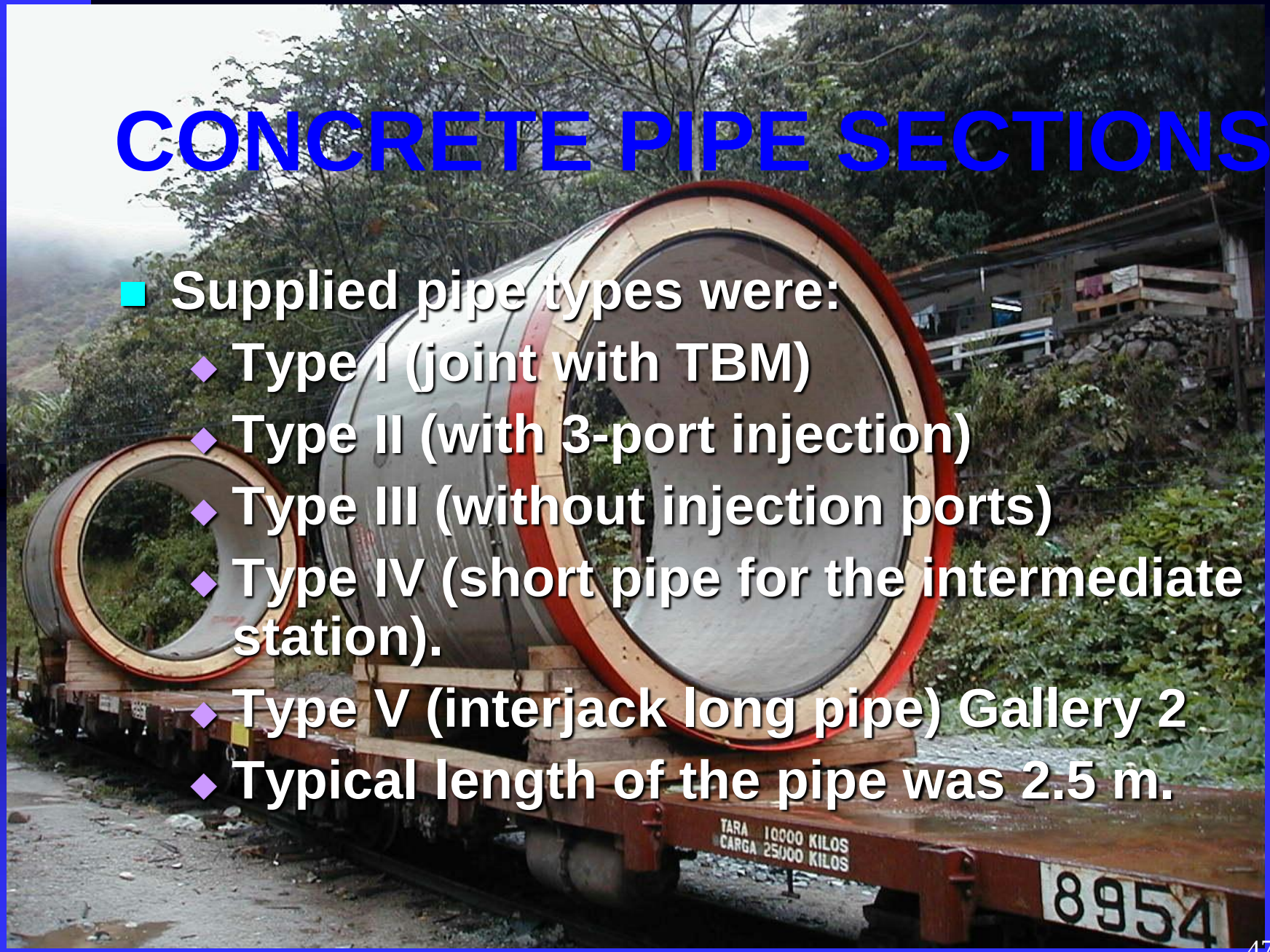
ASSEMBLY SEAL AND BRAKE TUBES

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)

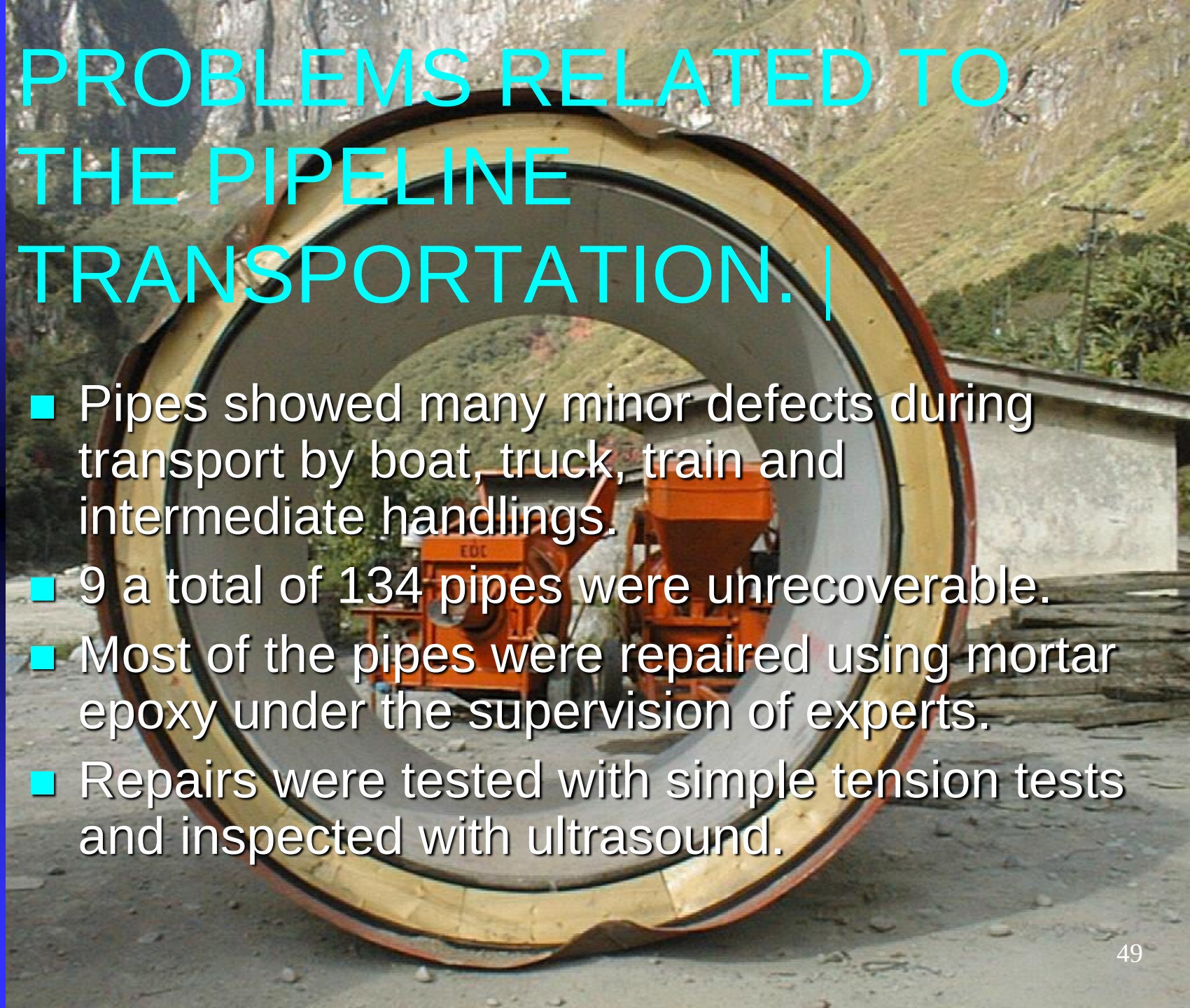
CONCRETE PIPE SECTIONS



- 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

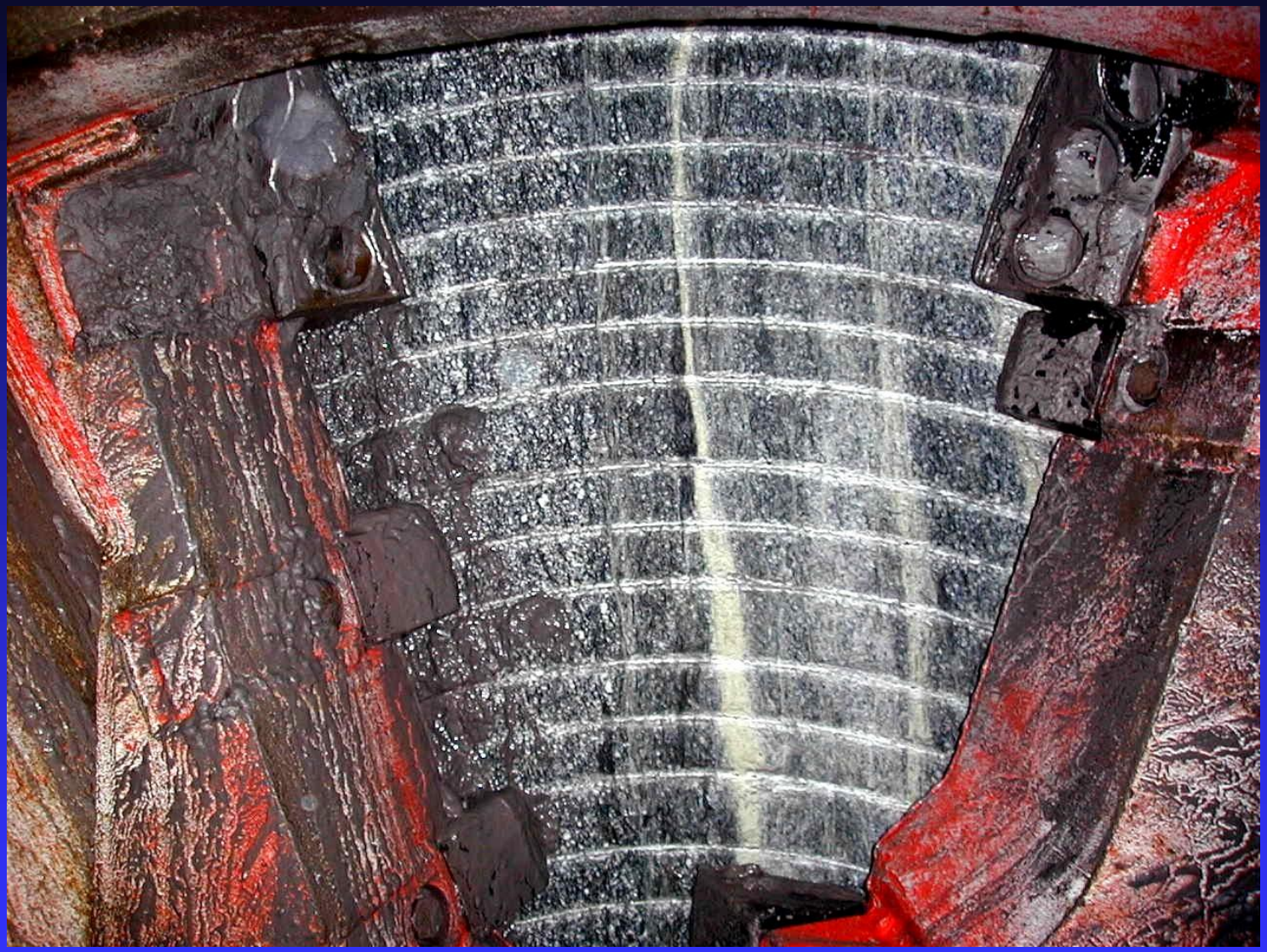
PROBLEMS RELATED TO THE PIPELINE TRANSPORTATION.



- Pipes showed many minor defects during transport by boat, truck, train and intermediate handlings.
- 9 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

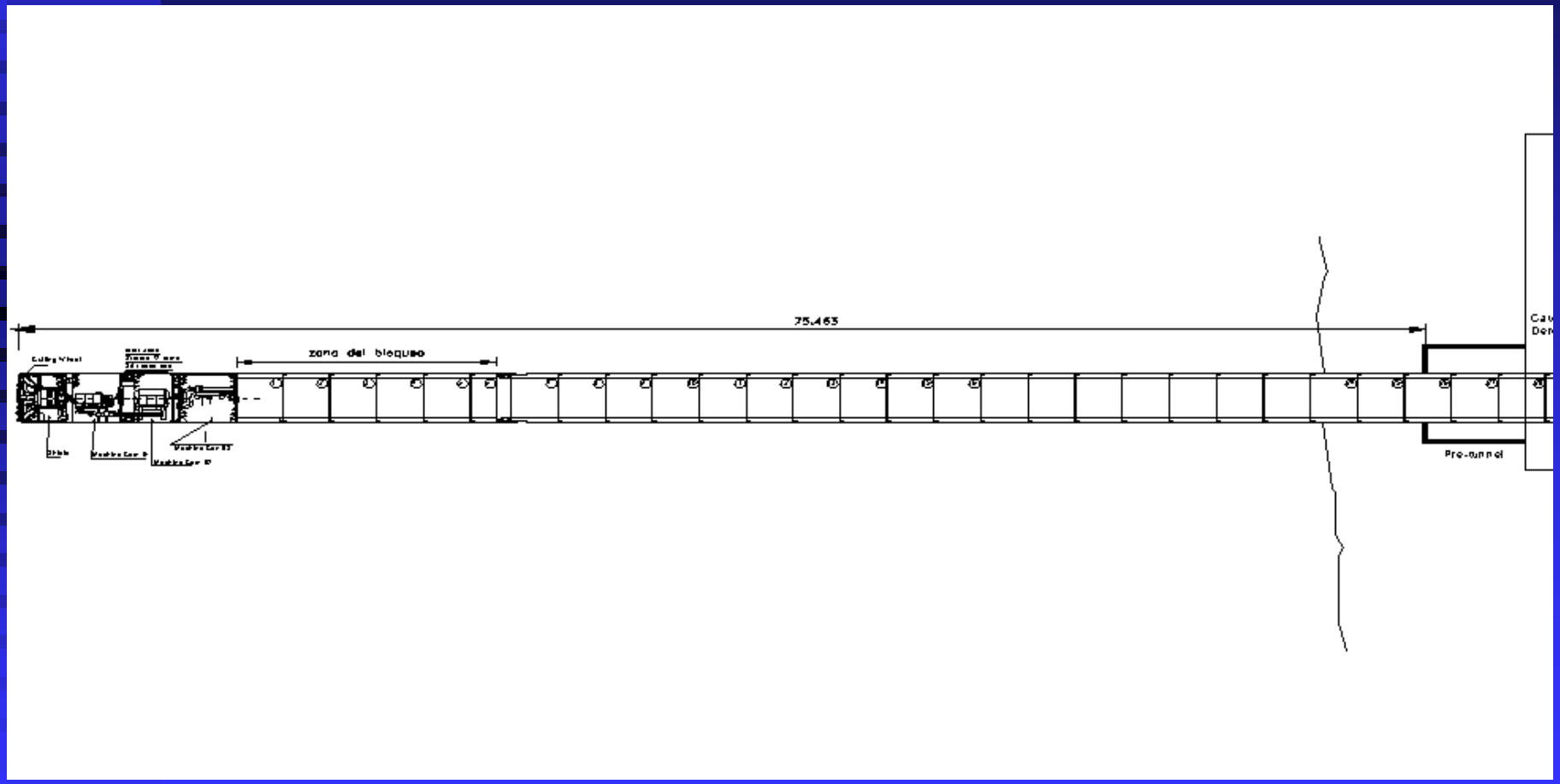
GEOLOGICAL CONTINGENCY GALLERY 1

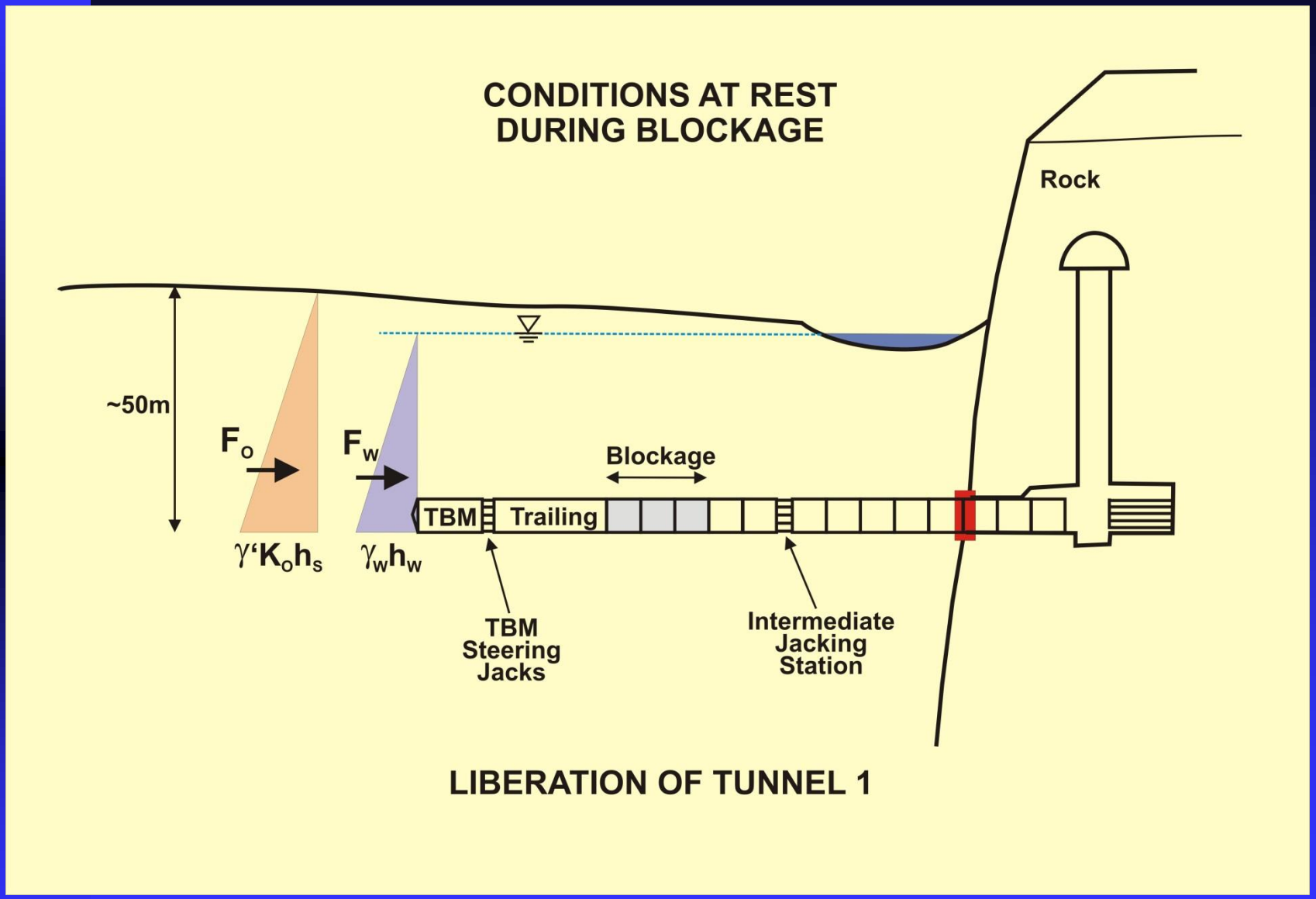
- The advance in Tunnel #1 suddenly stopped after approx. 60 meters from the cavern on the right bank.
- The blockage was limited to 5 pipes behind the machine, between the inter-jack and the machine.
- Blocking lasted over 60 days, all efforts by using the normal means available on the site could not move the section of the pipe and the trapped machine.

GEOLOGICAL CONTINGENCY Tunnel #1

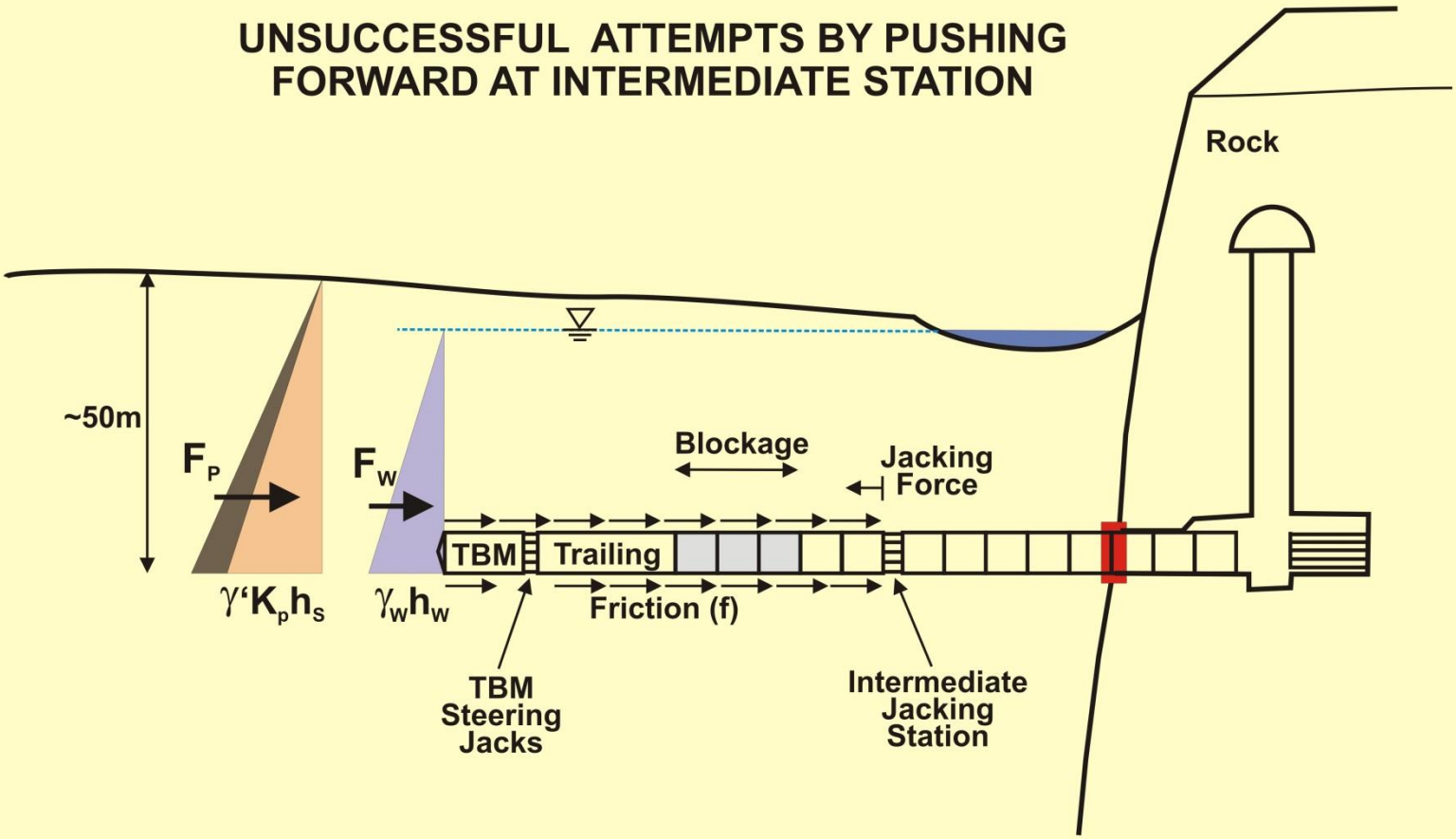
- In order to achieve the necessary geological information, the consortium made three exploratory surveys, two of them around the blocked pipes. Samples were tested in the laboratory in Lima.
- At the same time, consulting engineers went to the site to analyze the problem, and Herrenknecht made some 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
Rock
~50m
F_o
F_w
Blockage
TBM
Trailing
$\gamma' K_o h_s$
$\gamma_w h_w$
TBM
Steering
Jacks
Intermediate
Jacking
Station
LIBERATION OF TUNNEL 1

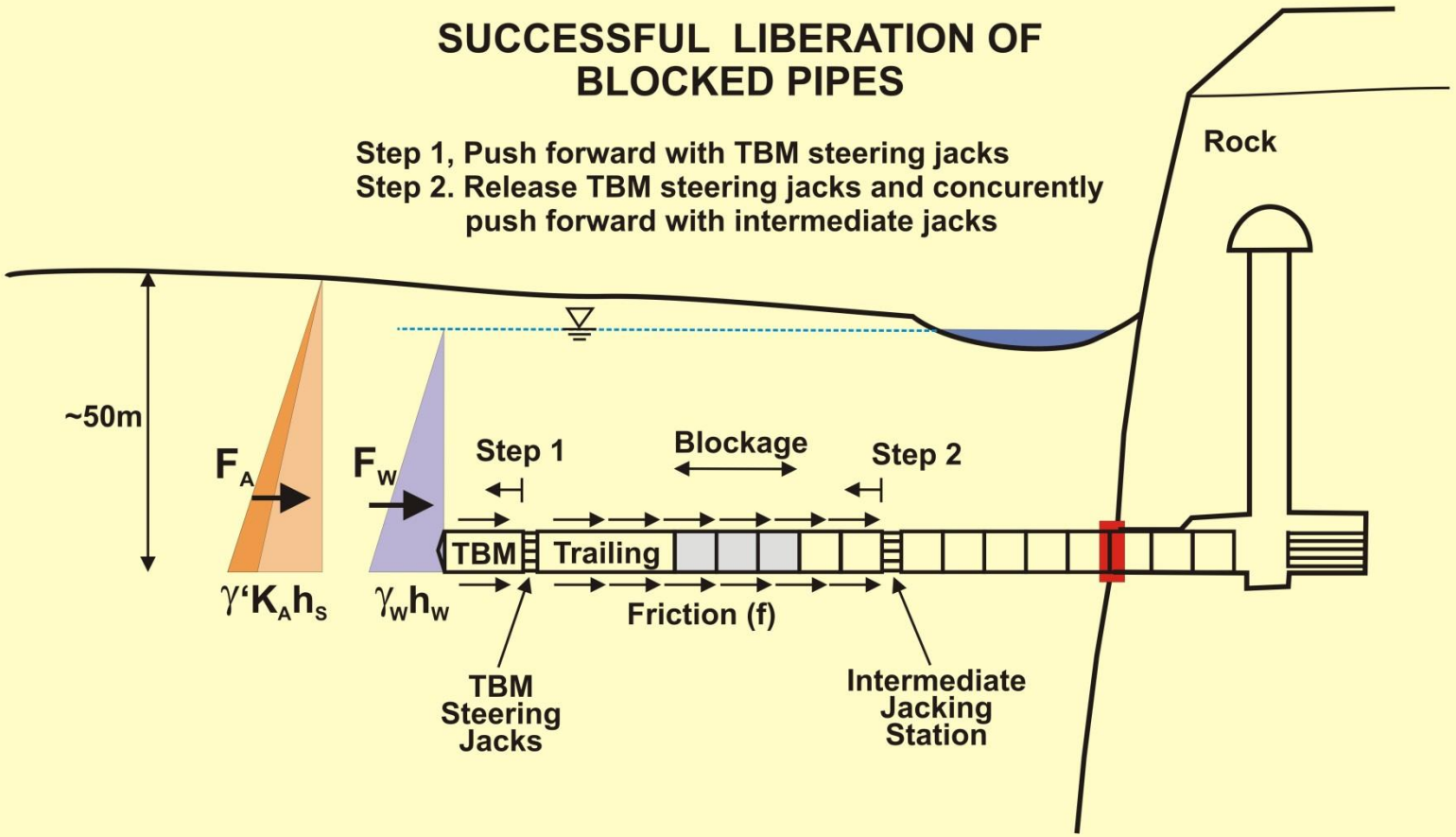
UNSUCCESSFUL ATTEMPTS BY PUSHING FORWARD AT INTERMEDIATE STATION



LIBERATION OF TUNNEL 1

SUCCESSFUL LIBERATION OF BLOCKED PIPES

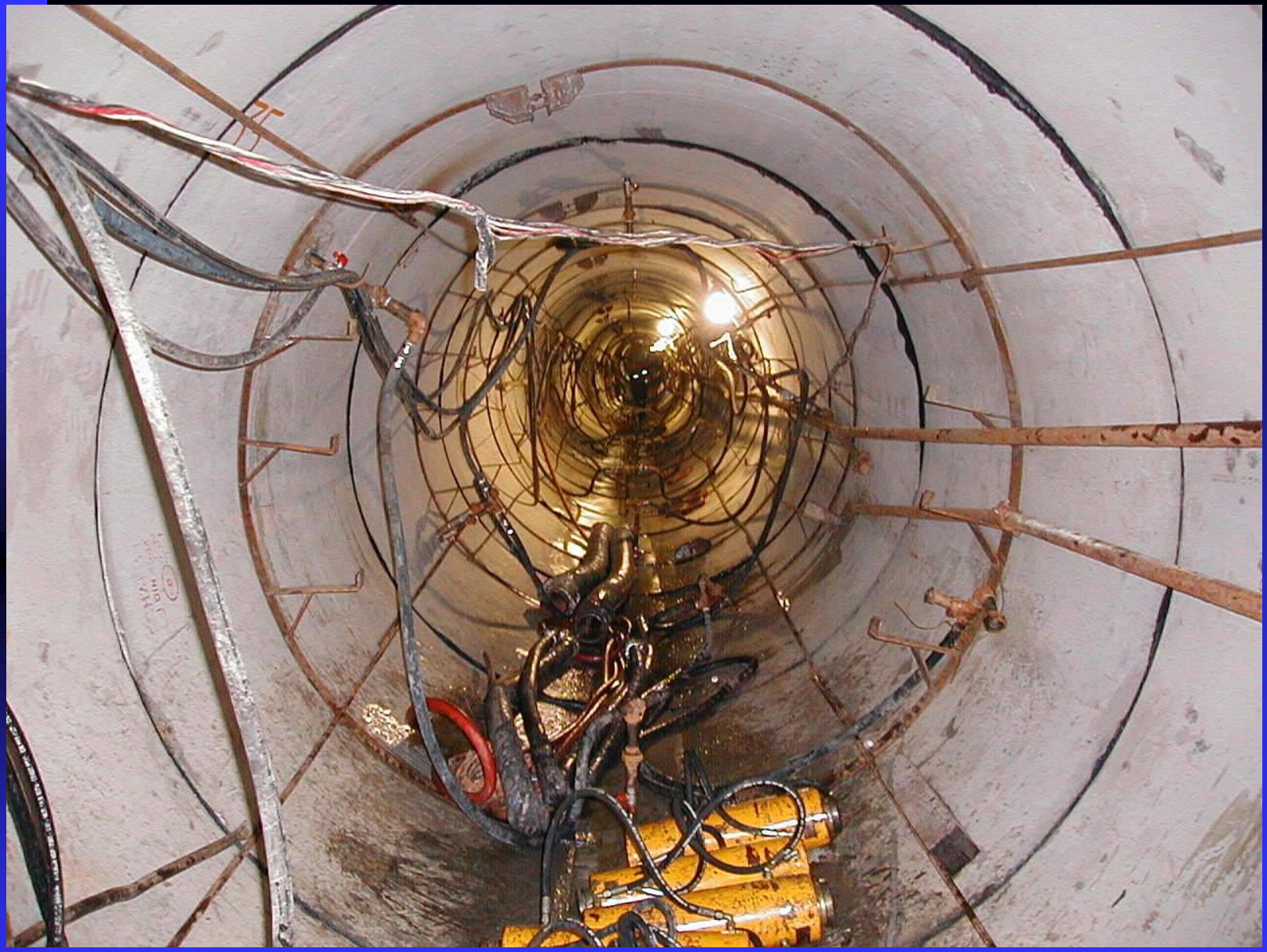
Step 1, Push forward with TBM steering jacks
Step 2. Release TBM steering jacks and concurently push forward with intermediate jacks



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

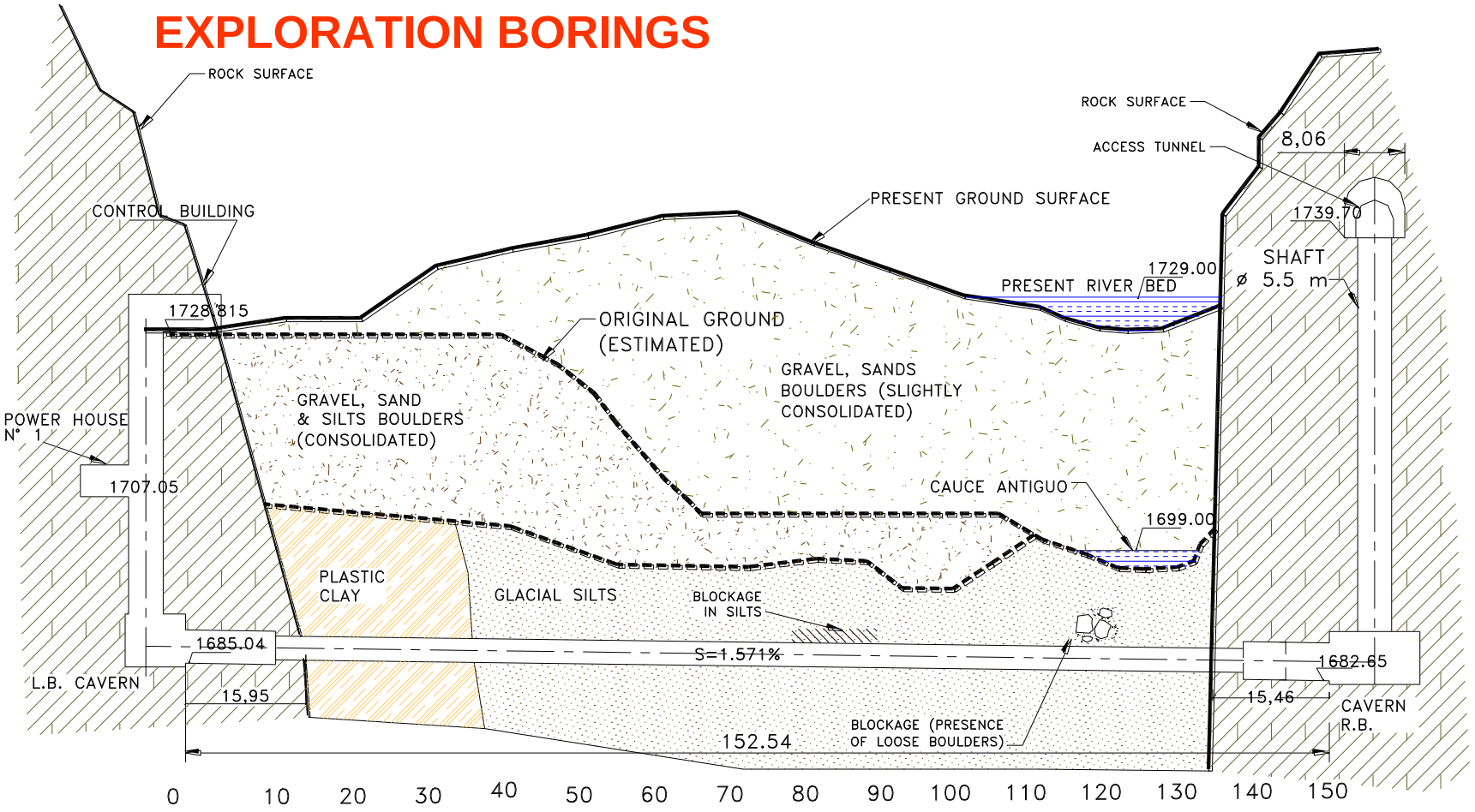


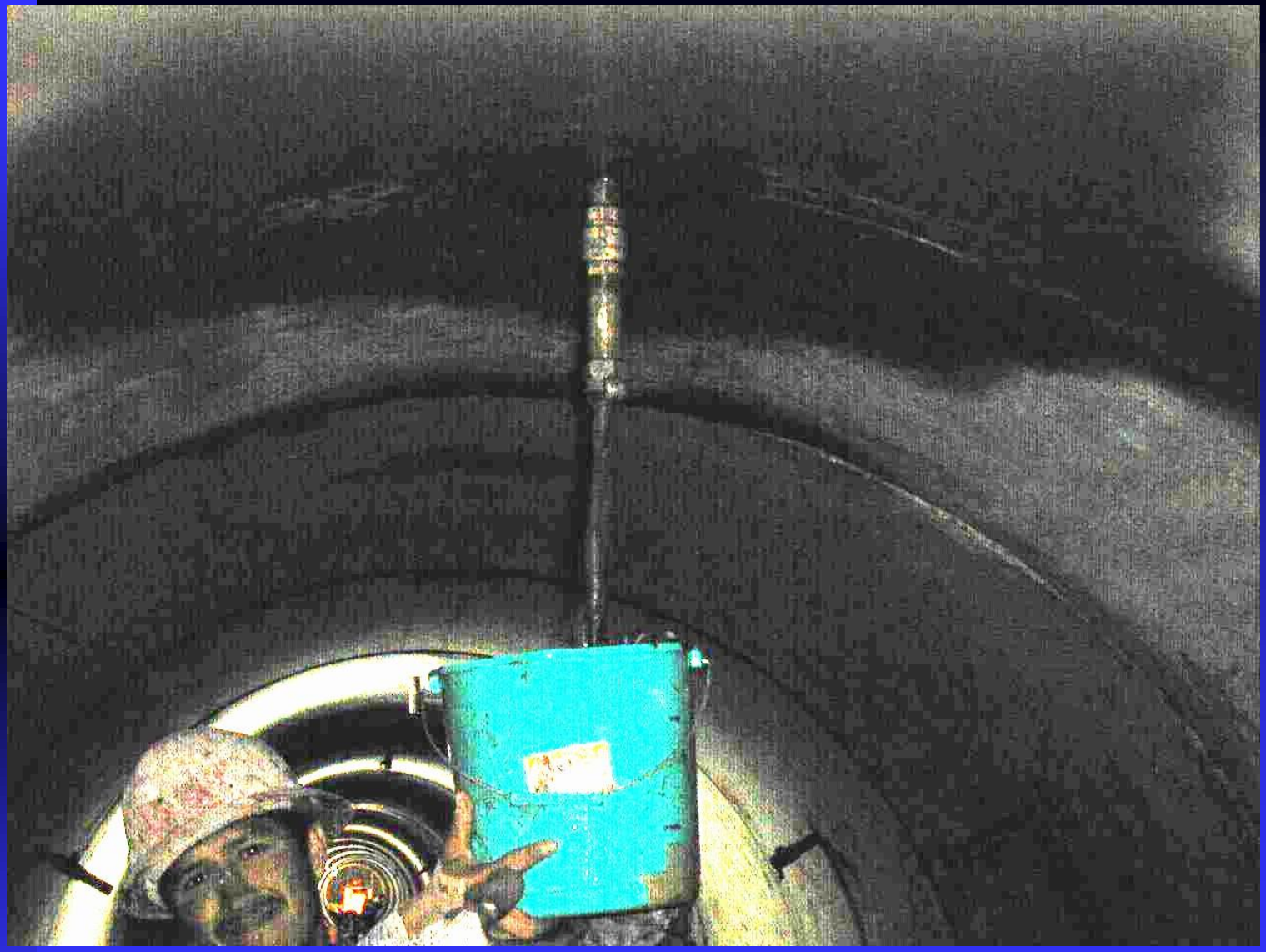
THE FIRST COMPLETED TUNNEL

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, viscos 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

SECOND TUNNEL

- 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.

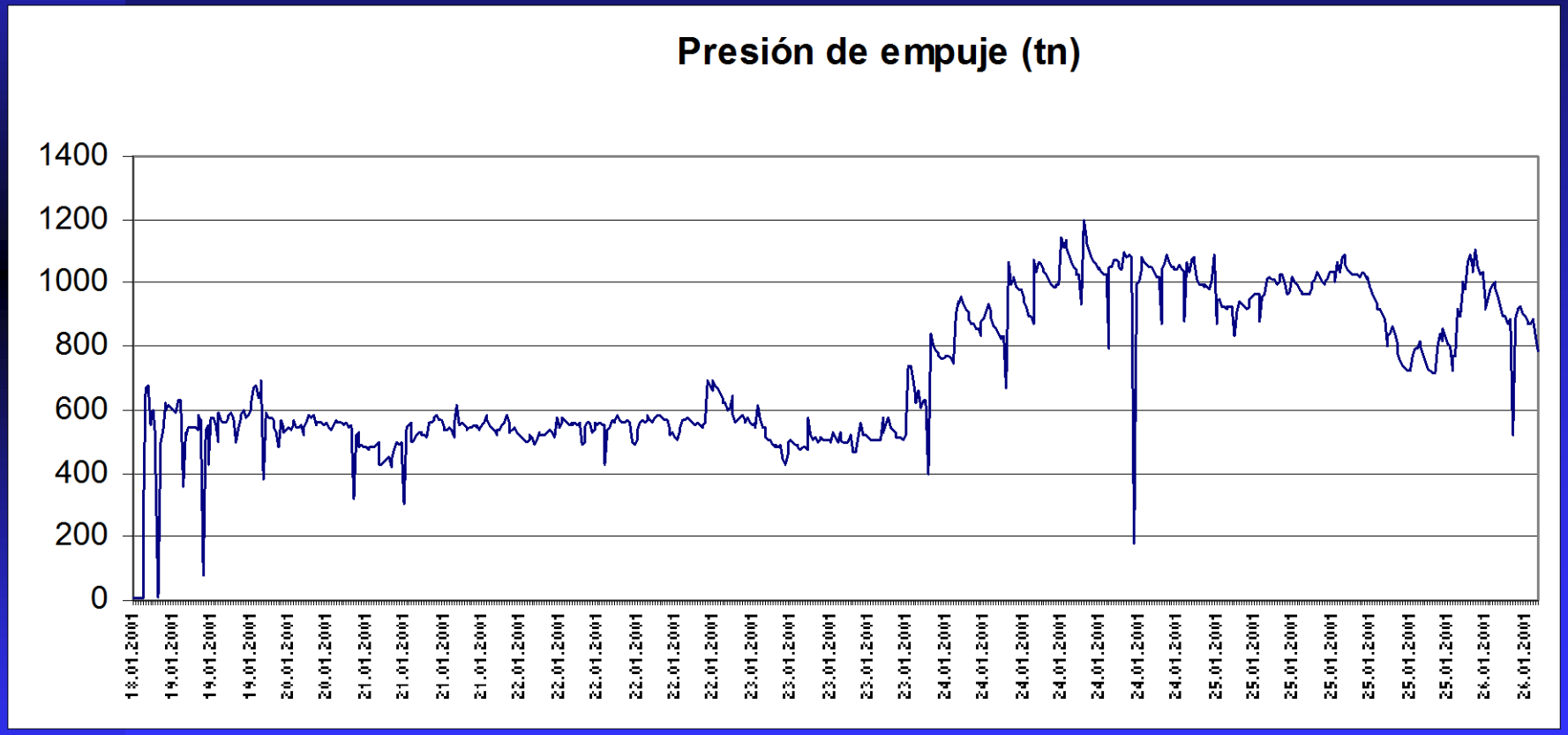
AFTER THE INCREASE IN DIAMETER CUTTING HEAD

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