Some Case Histories with Lessons to Learn in Dam Engineering

Luiz Guilherme de Mello

2nd Victor de Mello Goa Lecture

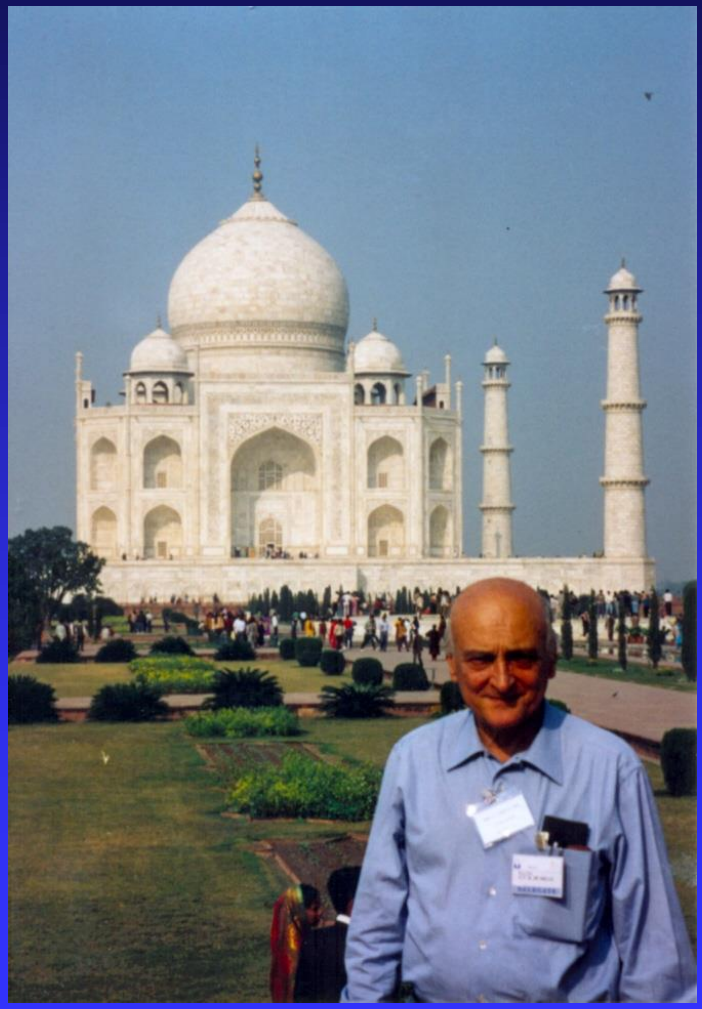
Goa Chapter

Indian Geotechnical Society

Victor Froilano Bachmann de Mello was born in Pangim, Goa on 14th May, 1926, one of six children.

Vila do Monte Altinho

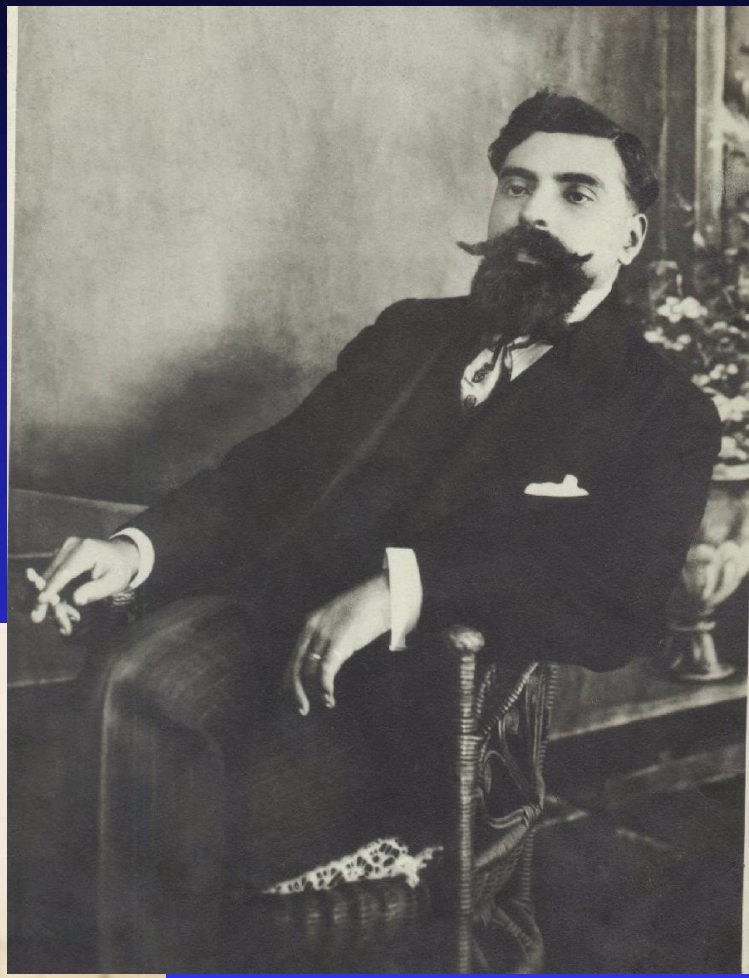
Dehli ICSMGE 1994



In 1937 Victor went to Bishop Cotton Boys School in Bangalore.

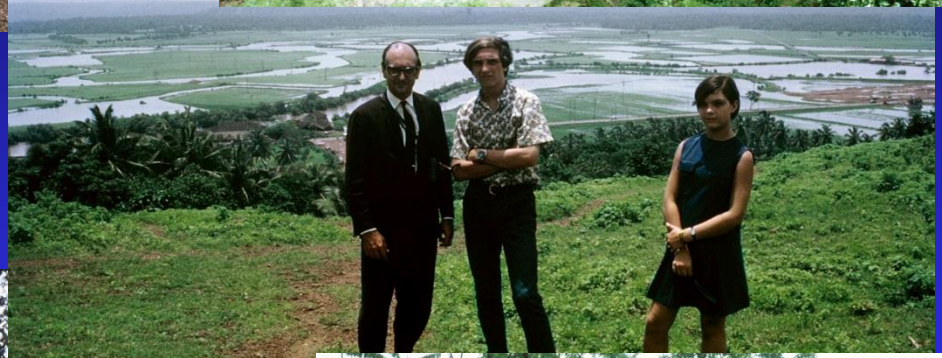
Kothavala Cup in recognition of Best All-rounder

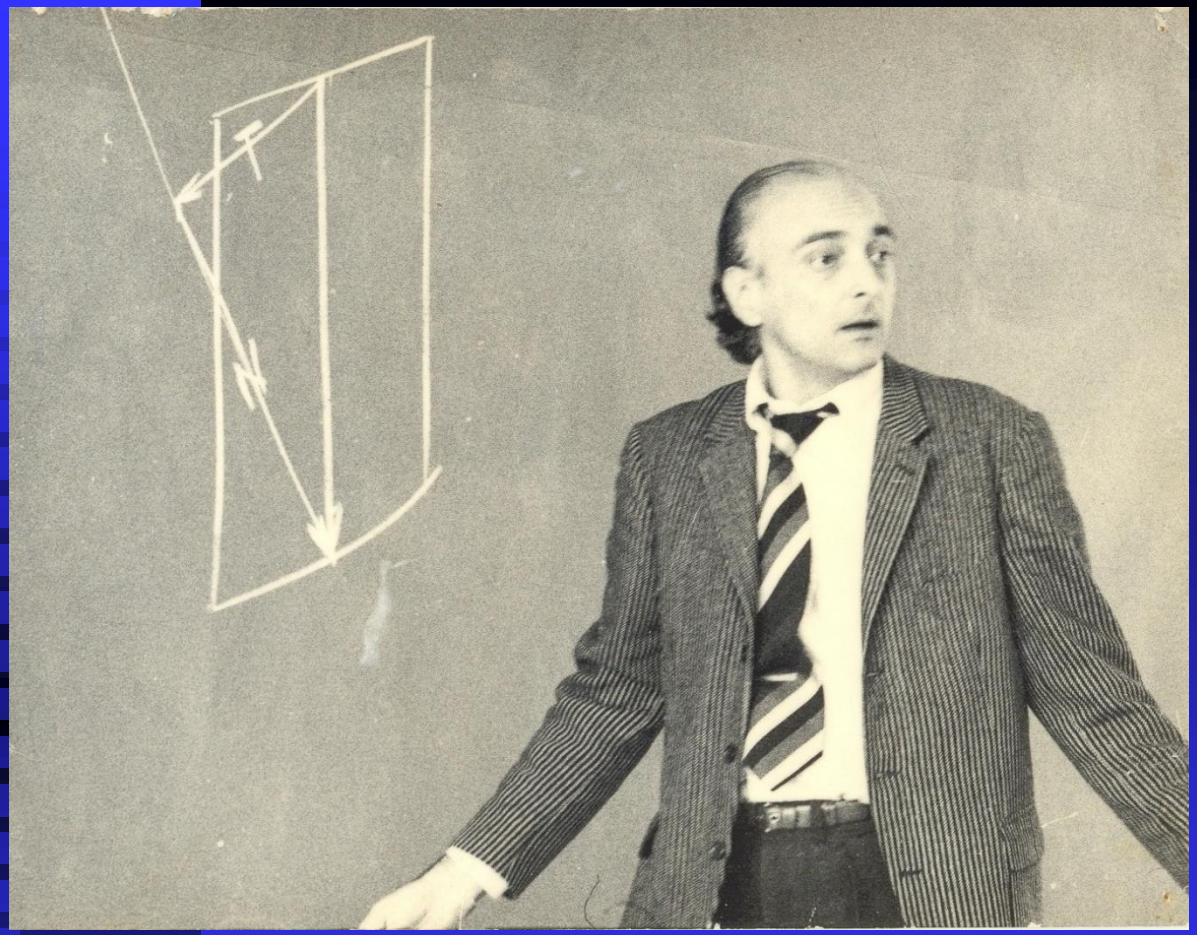
Victor and Dr. Froilano de Mello



MIT
BSc jun 46
MSc sept 46
DSc feb 49

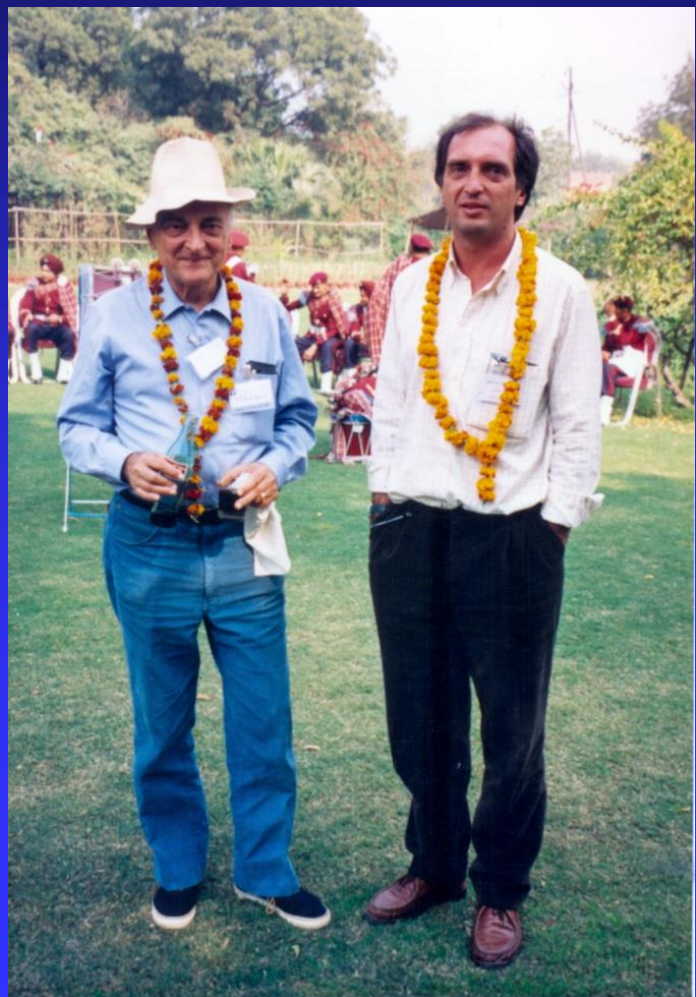
Vila do Monte August 1967



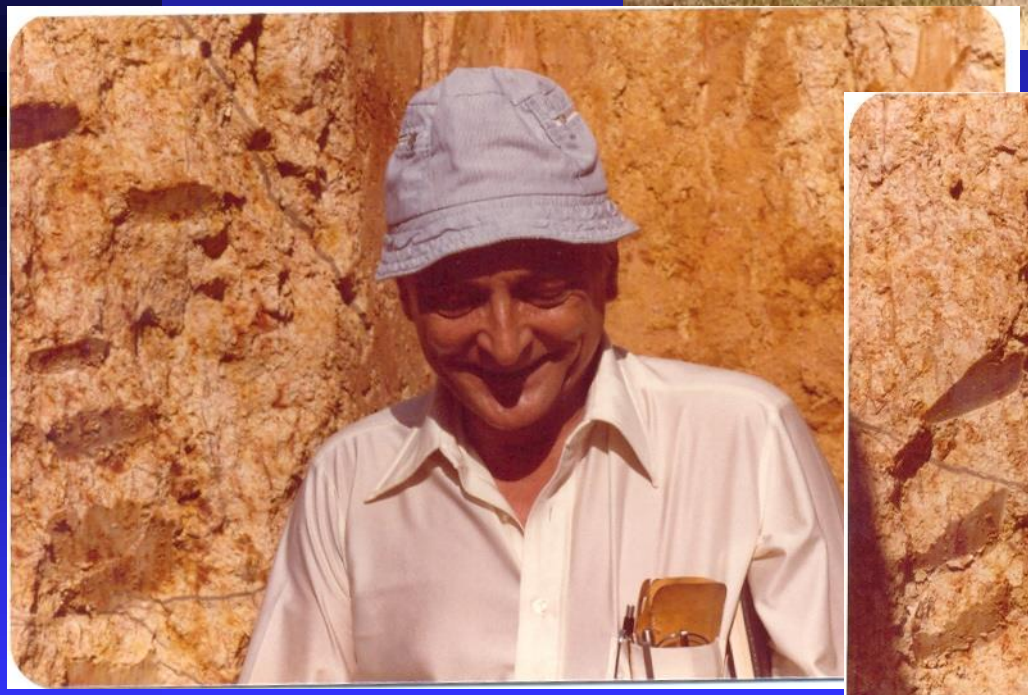


Lecturing Bishop's stability method at the Poli-USP courses in1973

13th International Conference, New Delhi 1994

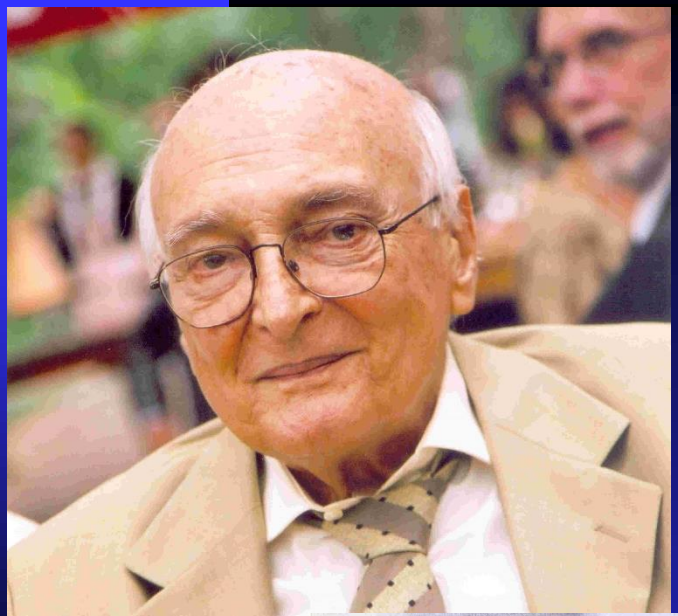


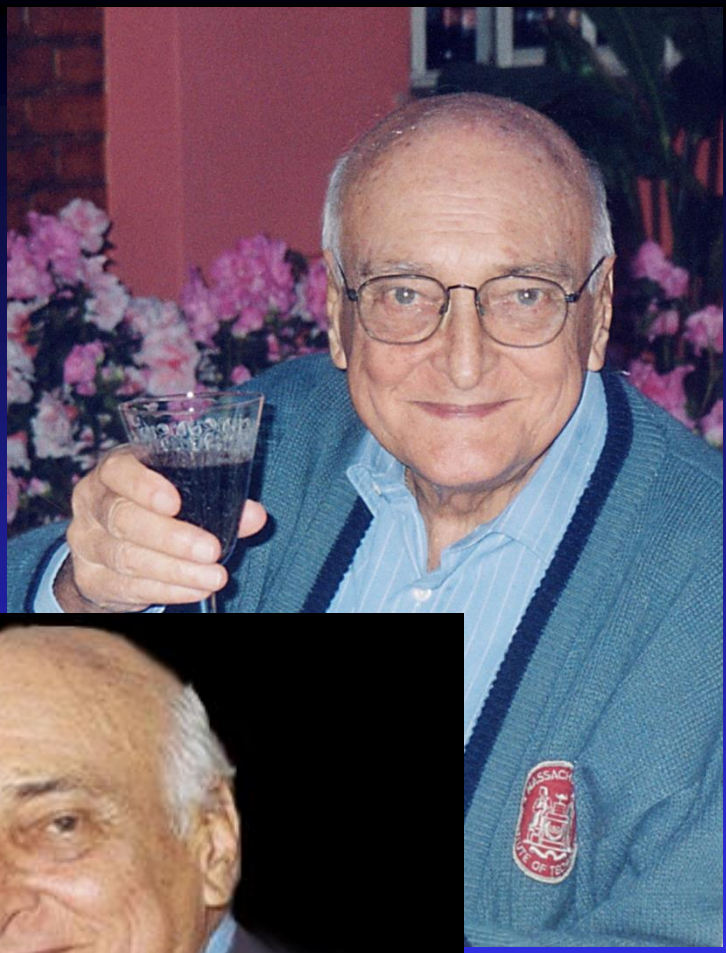
Victor “in action” in the job site of Balbina HPP 1982

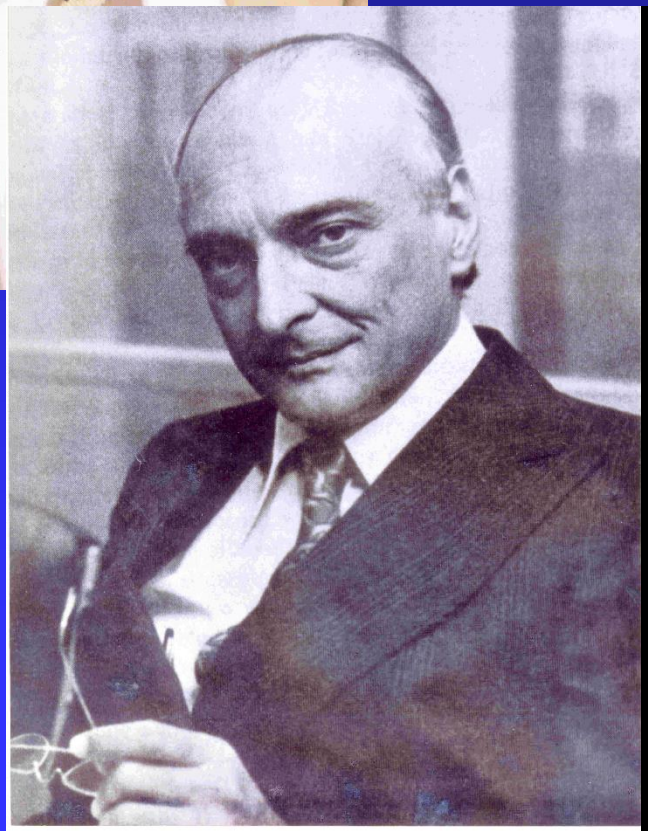


With the ISSMGE President's gavel

Different fotos
of later stage







Finally, the Lecture .....

Victor used many, many sayings throughout his life, many in latin or english, one of each being:

"*Choose your love, and love your choice*".

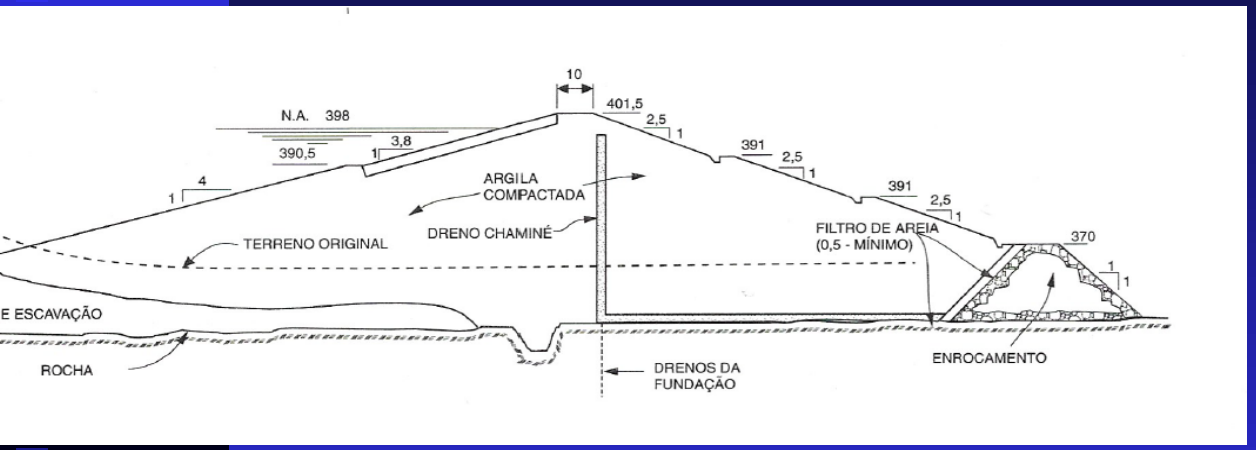
I chose to be a geotechnical engineer.

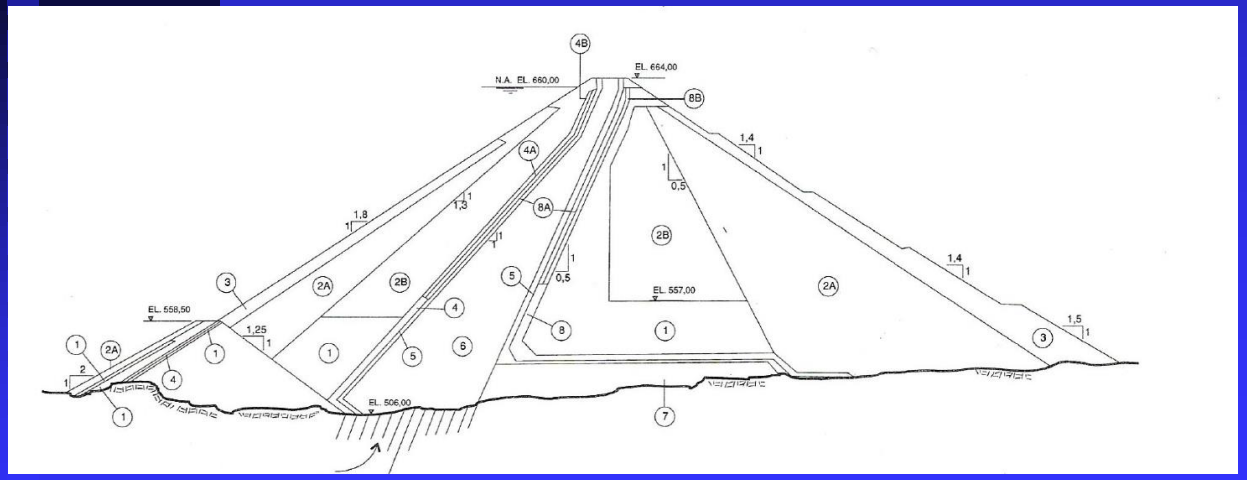
Victor loved the challenges that dam design require; he taught me, and

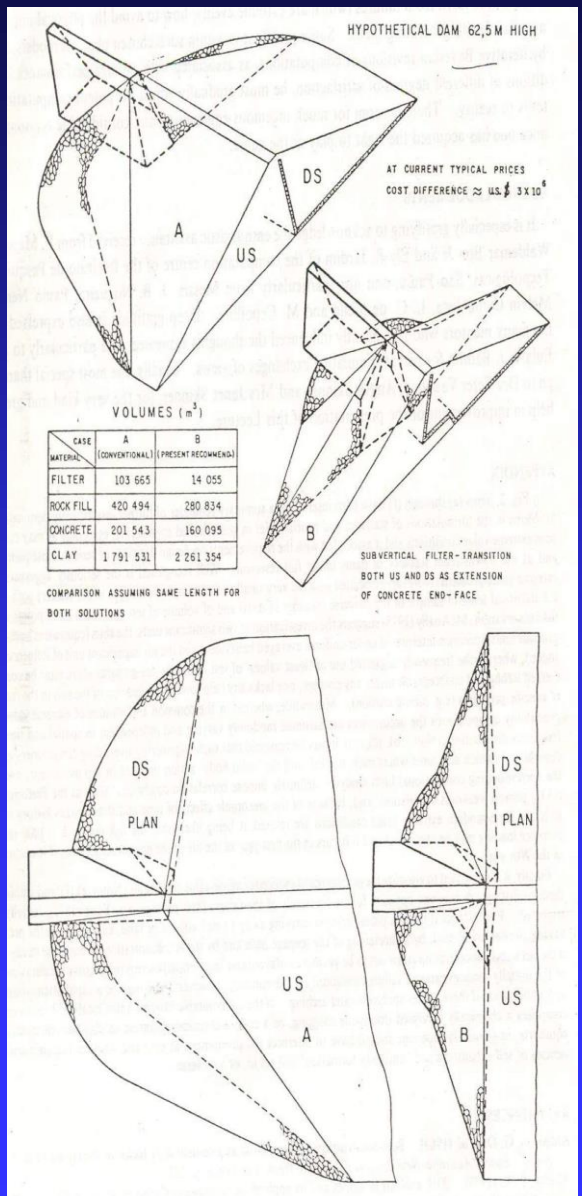
I was able to absorb part of his teachings.

Embankment dams are one of the structures that require intense attention and sound physical concepts: decision taking is based mostly on sound appraisal of concepts backed by sound analysis.

Important Contributions by Victor

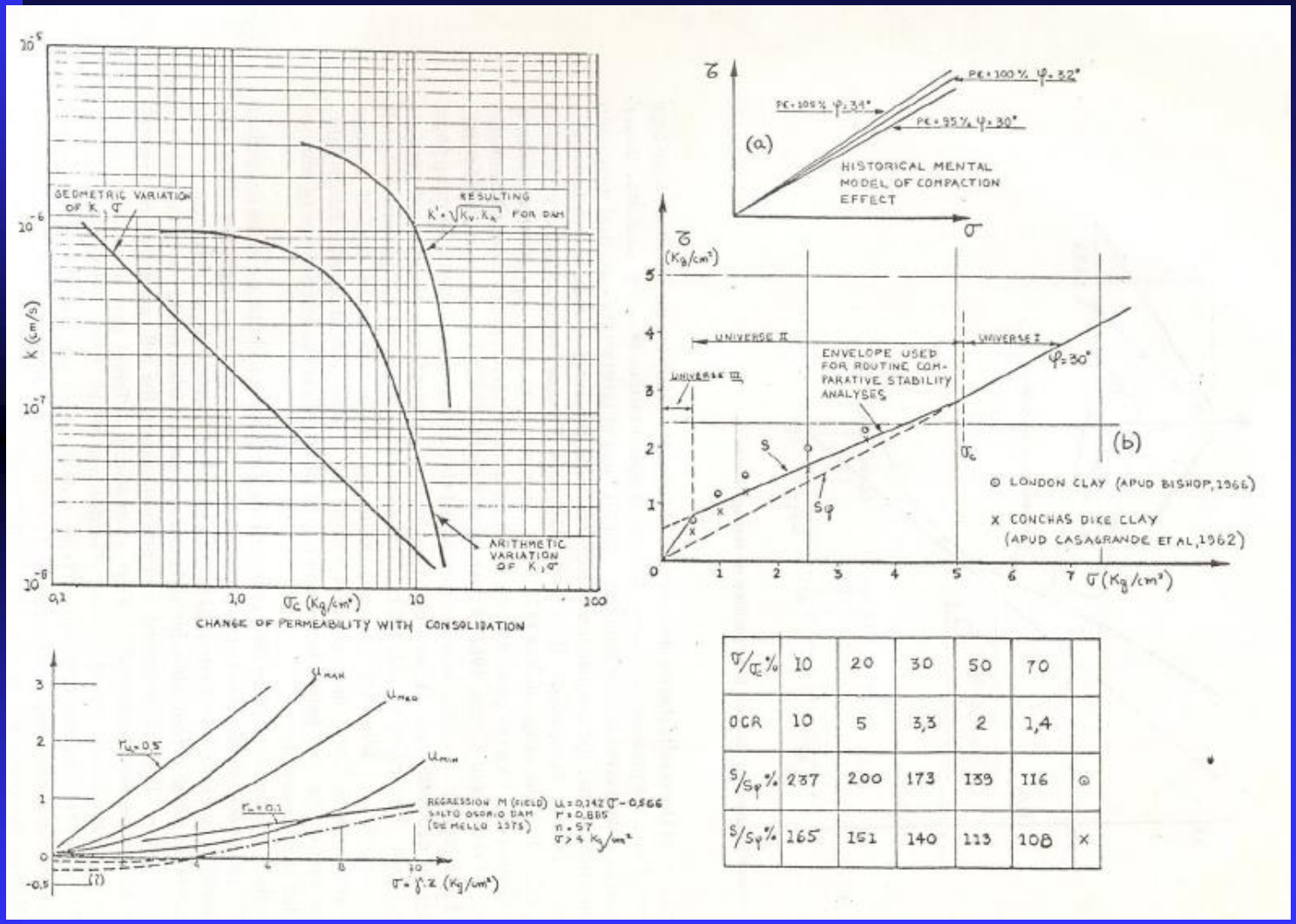






Optimized cross section and wrap around with concrete structures – 1977 Rankine Lecture

Important Contributions by Victor



σ/σc %	10	20	30	50	70	
OCR	10	5	3,3	2	1,4	
S/Sφ %	237	200	173	139	116	○
S/Sφ %	165	151	140	113	108	×

Behaviour of Compacted Clayey Materials
1977 Rankine Lecture

This lecture will discuss topics of the projects:

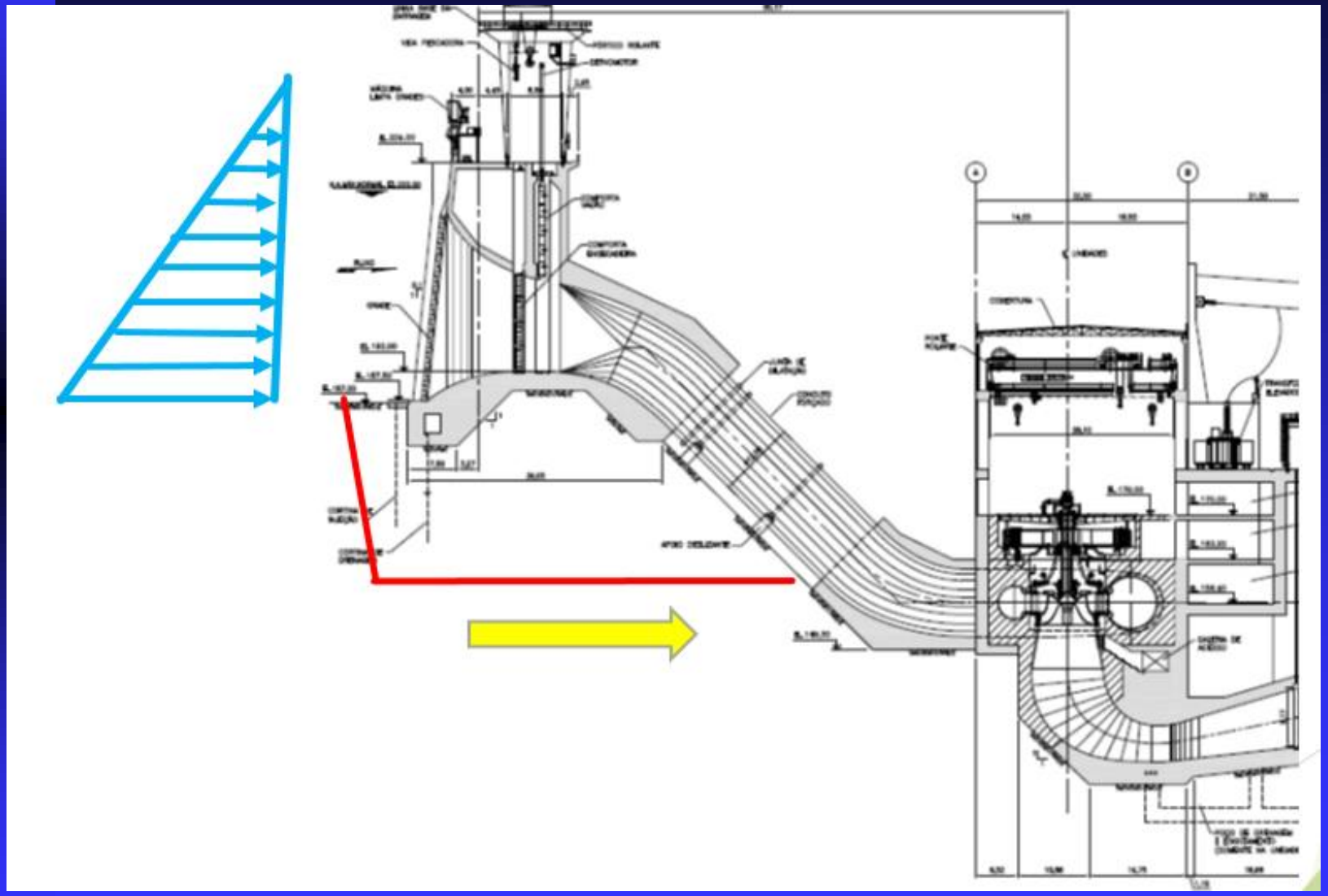
HPP Balbina – Brasil - foundation treatment

HPP Teles Pires Brasil - stability of intake structure

HPP Chaglla - Peru - failure of the head race tunnel

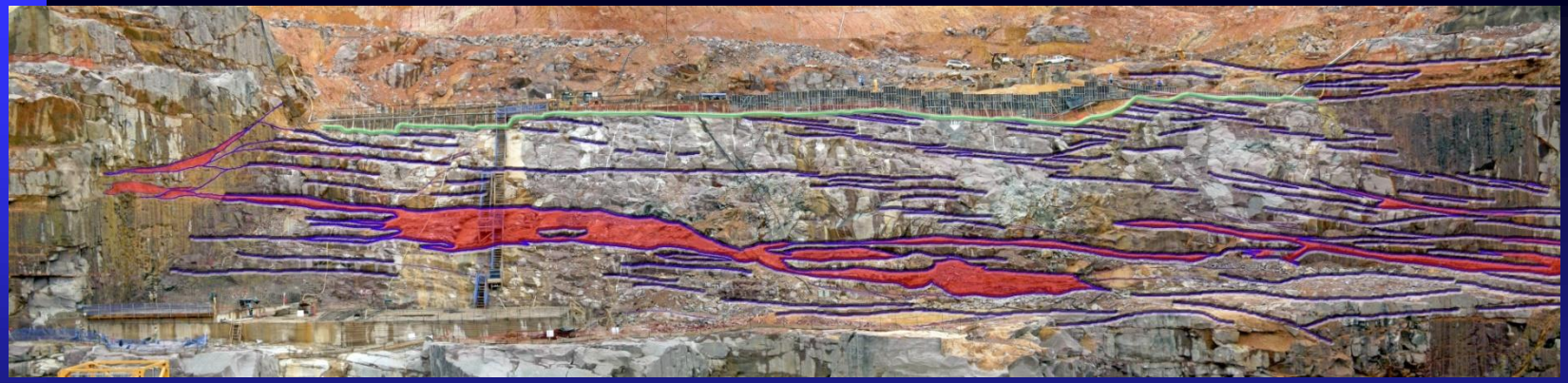
HPP TELES PIRES

HPP Teles Pires

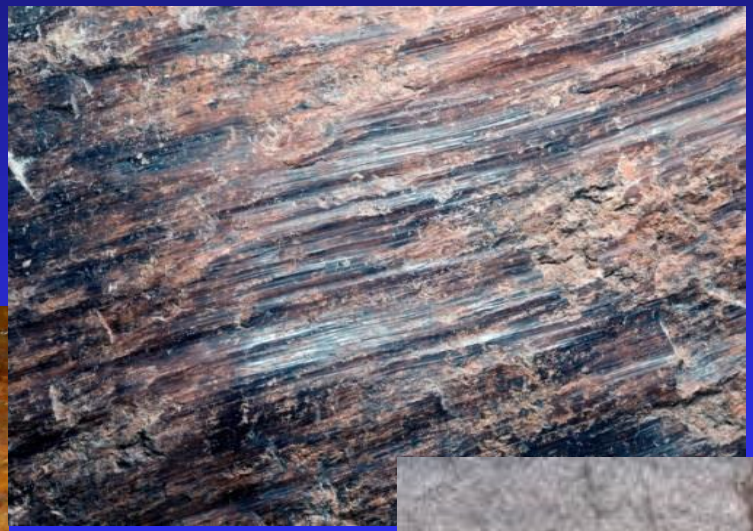


Stability of the structure as conventionally verified

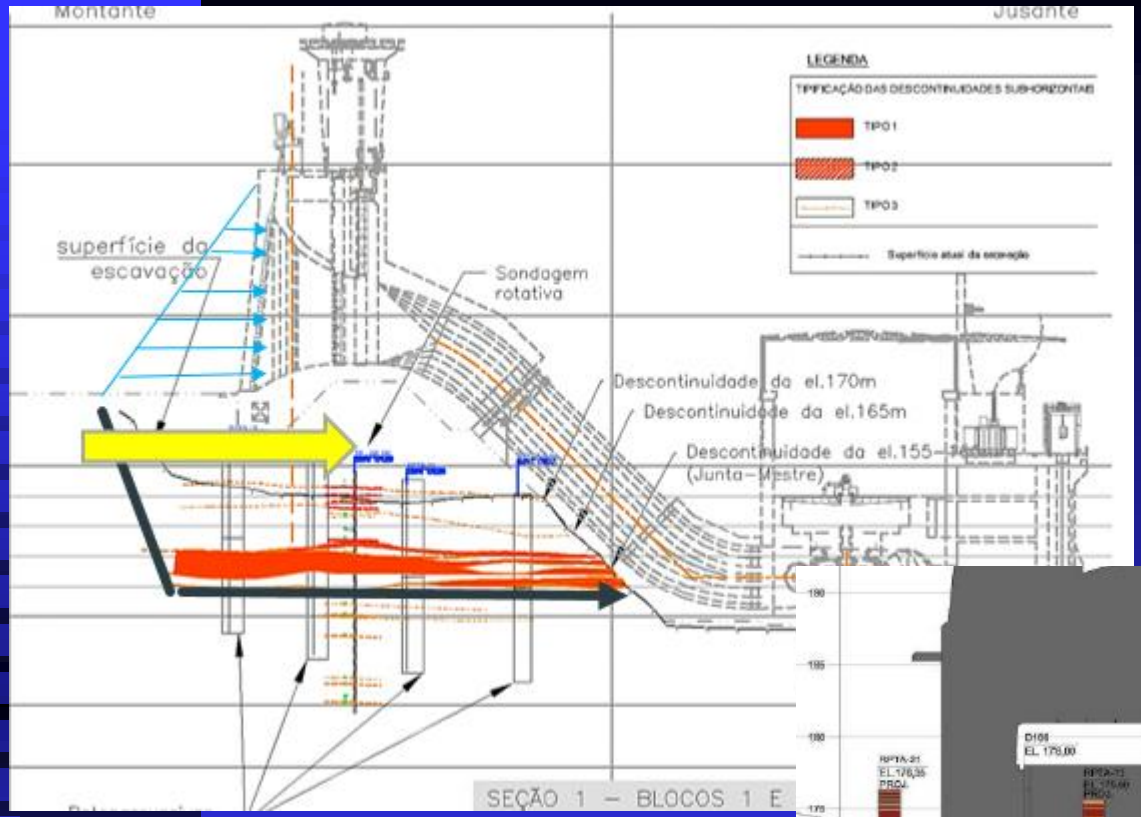
Excavation of penstocks slope



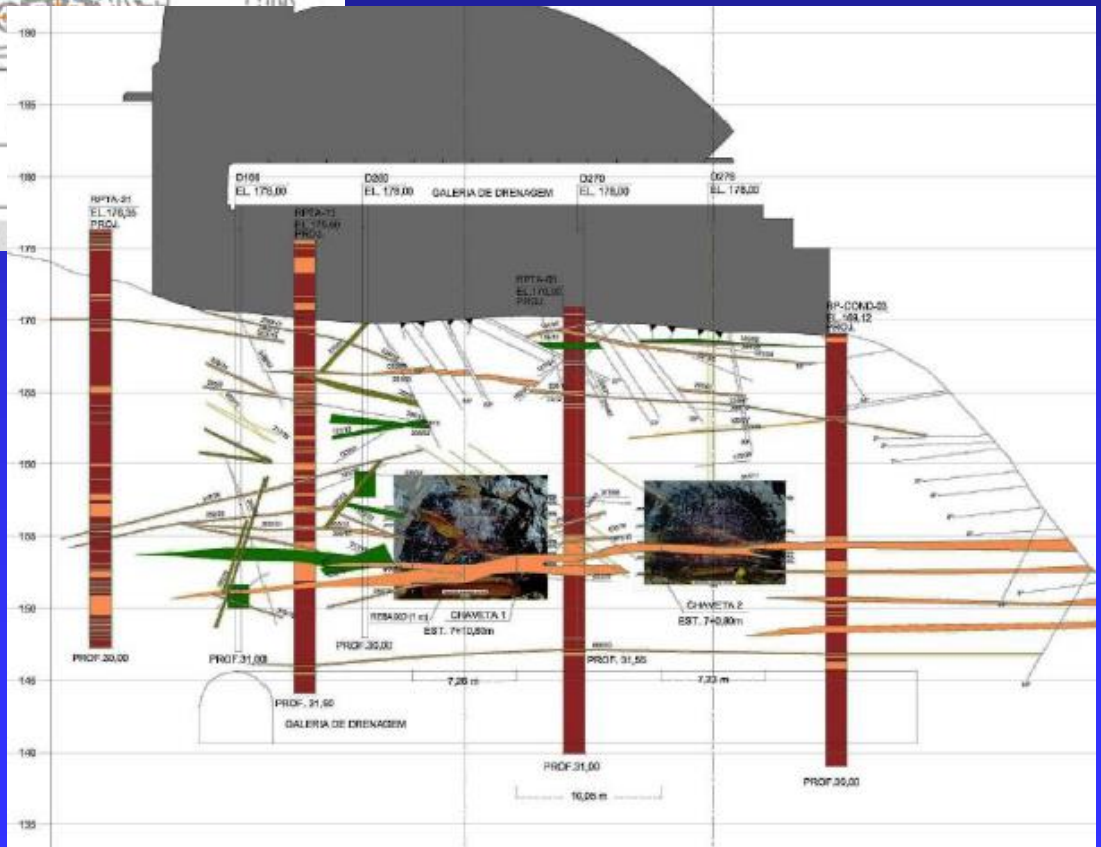
Different weathering and preserved slickensides and/or estriae



Difficulties of the stability verification with data from intense investigation campaign



Update of geological model after excavation inclusive of the shear keys



Lessons Learned

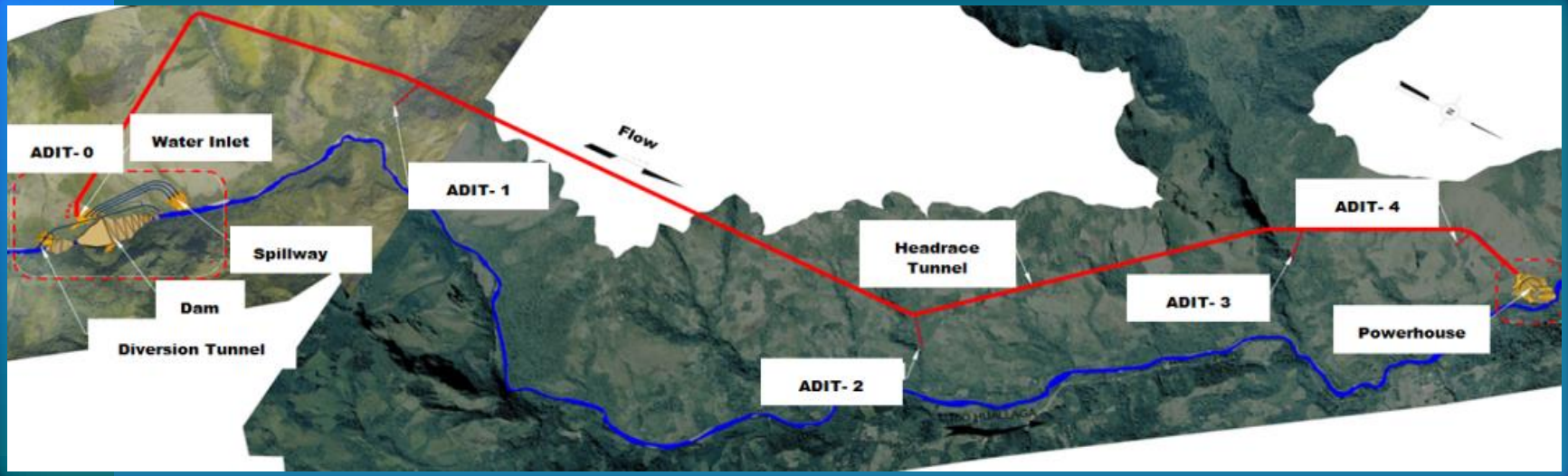
- Presence of subvertical and inclined joints was known, some of them with slickensides and polished surface.

Stress relief joints, “parallel” to the surface with evidence of hydrotermalism weathering was in tune with typical geological model.

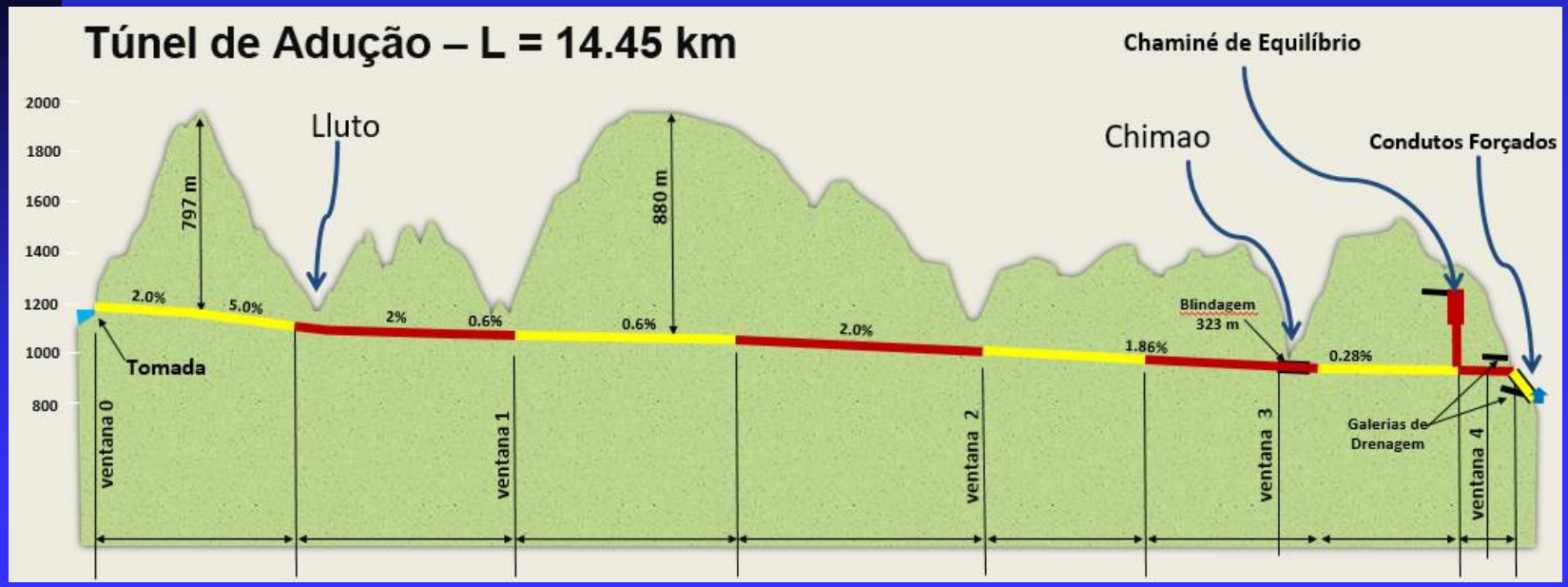
- New, not previously known, presence of persistent sub-horizontal joints associated with thrust faulting, not diminishing with depth, and at great depth, with slickensides (polishements) and/or estriae preserved.

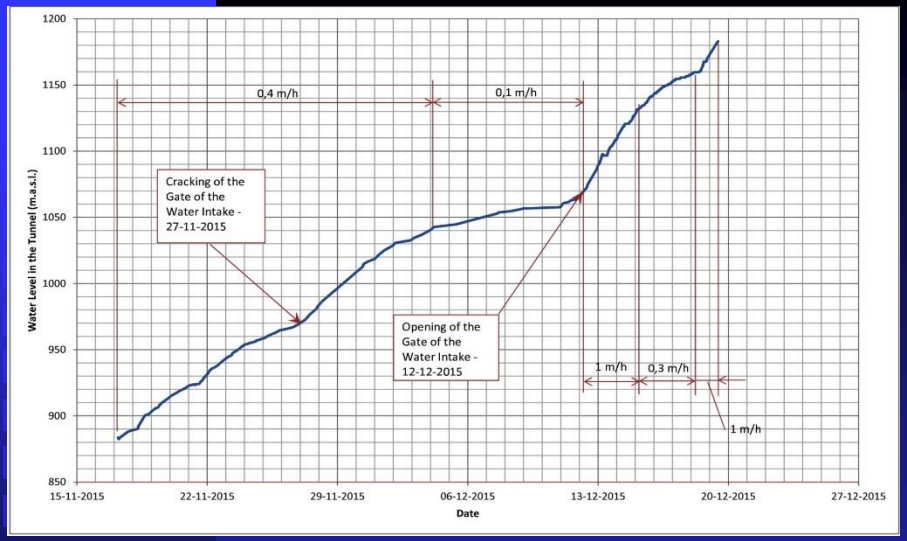
HPP CHAGLLA

HPP Chaglla



HEAD RACE TUNNEL

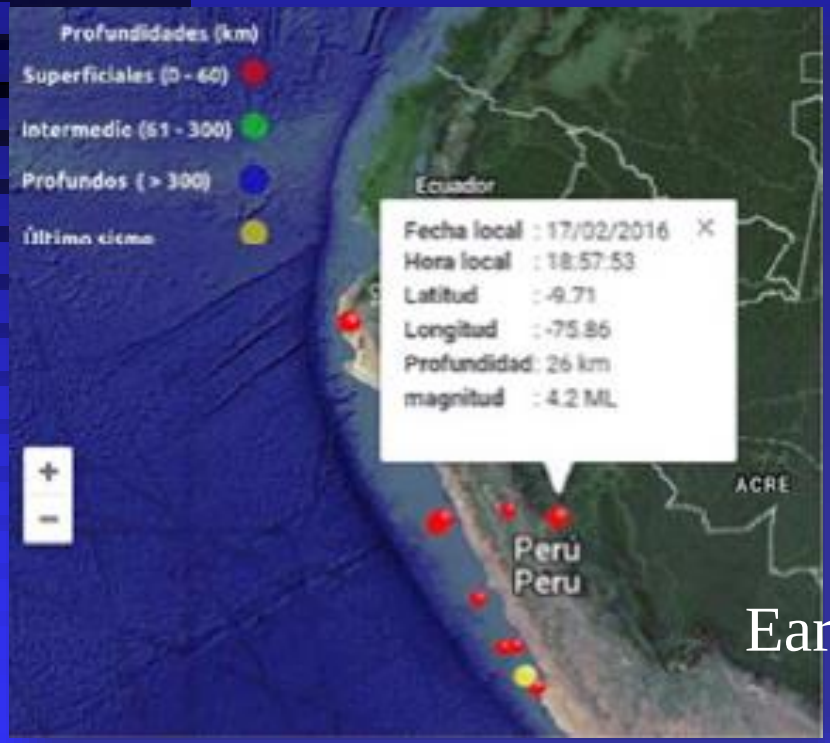


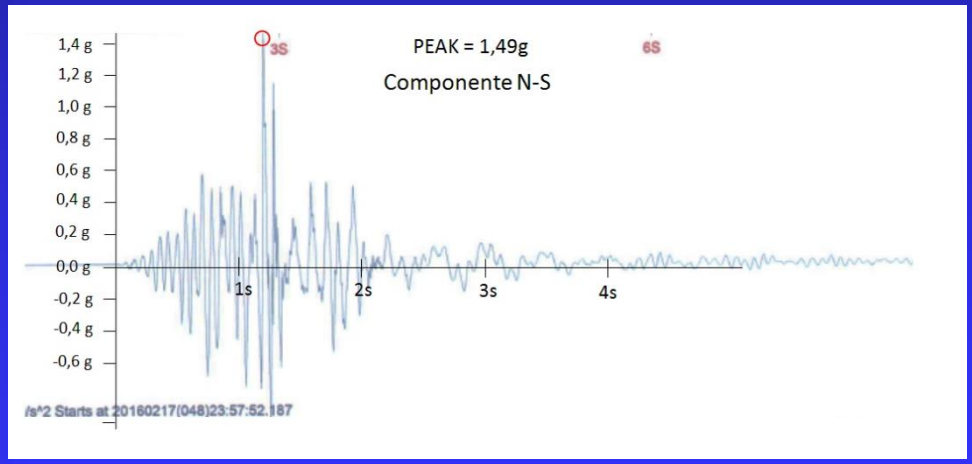


Head race tunnel pressurization

Data	Exfiltration Rate [m³/s]
Jan 15th 2016	2.45
Jan 29th 2016	2.49
Feb 5th 2016	2.83

Exfiltration from the tunnel





Earthquake happened on Feb 17th 13:00hrs

Effects of the earthquake

Feb 18th

Feb 18th

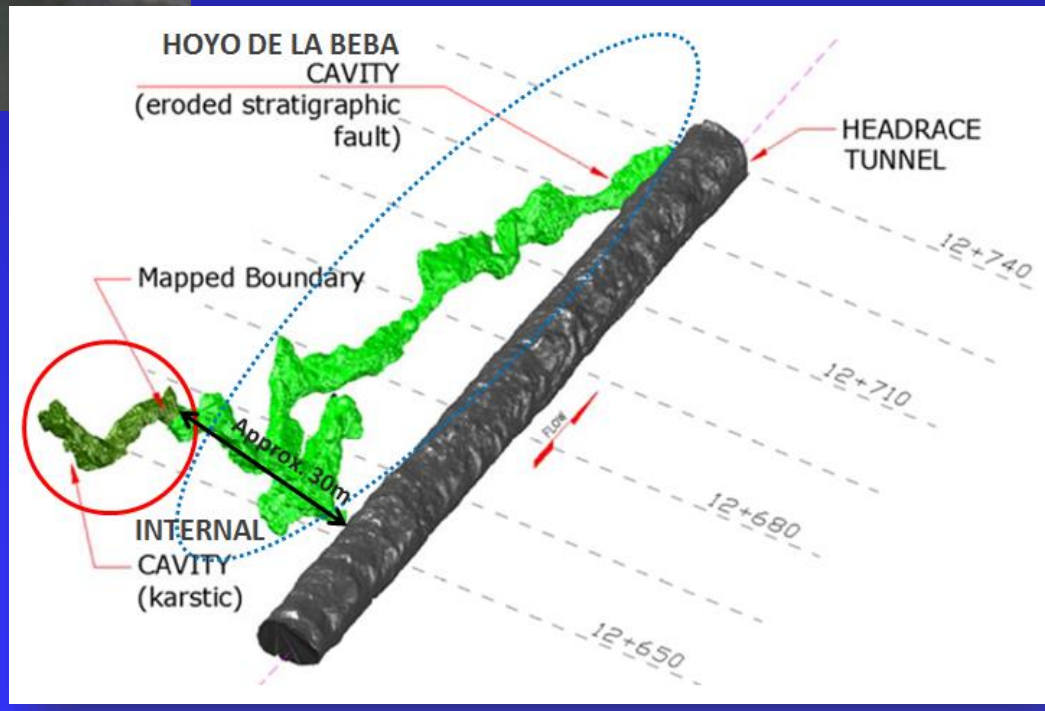
Quebrada Chimao

Feb 19th

Exfiltration on Feb 20th = 11.4m^3/s; 403% increase

Collapse of tunnel support as seen from the tunnel when dewatered

Topographic mapping of erosion cavity by speleologists/geologists



Interpretation of the Cause of Failure

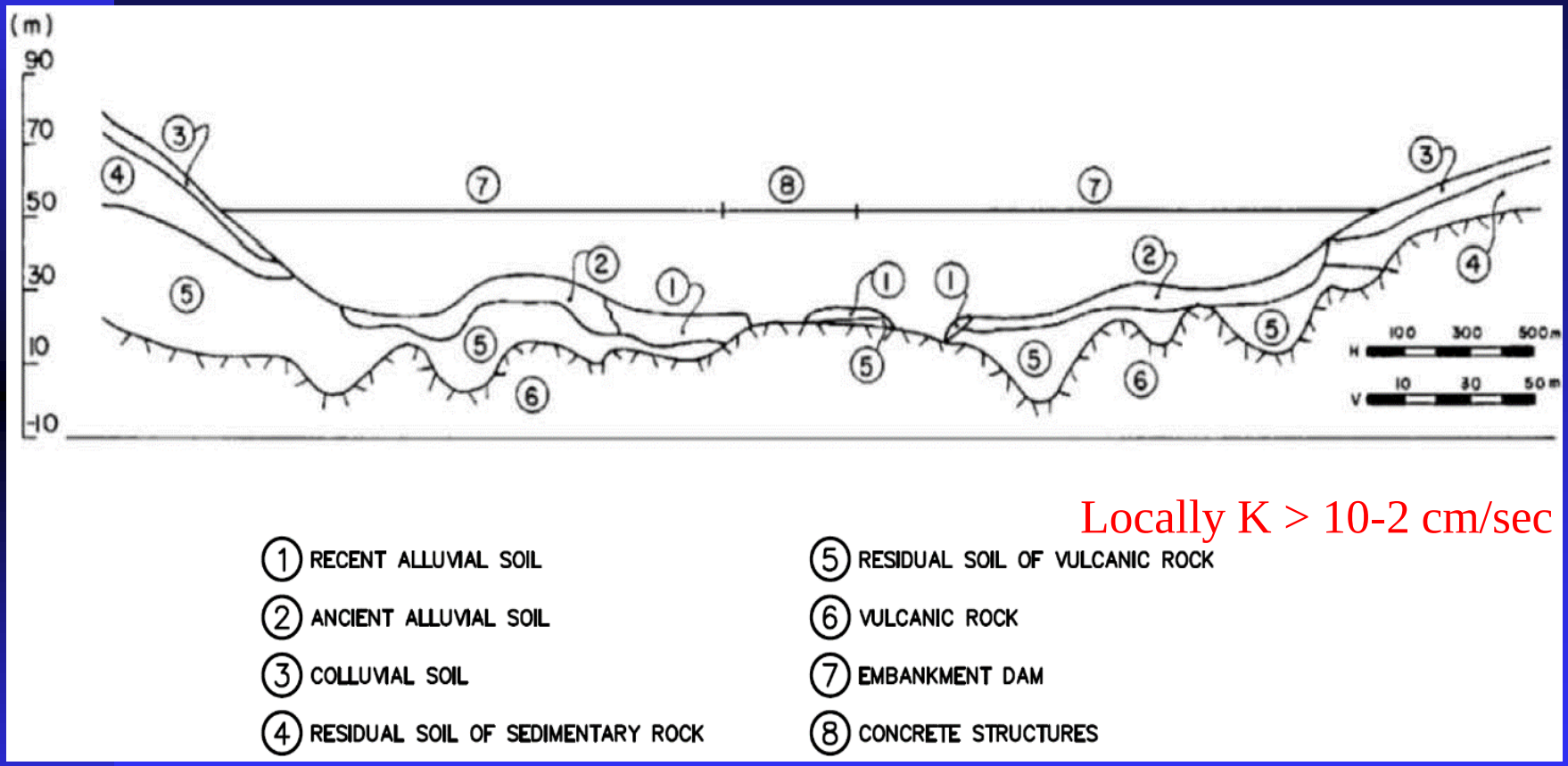
- Earthquake generated the disarticulation of the very fractured and saturated stratigraphic fault rock mass;
- Retrogressive erosion developed from a distant karstic feature till the vicinity of the shotcrete, drastically reducing its passive support, leading to the failure inside out of the tunnel lining and support.

HPP BALBINA

HPP Balbina


Balbina
Balbina
© 2018 Google
Image Landsat / Copernicus
Image © 2018 CNES / Airbus
AM-240
Google Earth

Geological longitudinal profile



Attention to Material 5 – Residual Soil of Vocanic Rock: presence of particularities that would condition design decisions related to the dam's foundation

Ancient termites - micro and macro canaliculae

Facts

Criss-crossing the soil matrix, tubular cavities / canaliculi ranging in diameter from 2 to 30mm are present, conditioning flow of water with Kequiv locally reaching values as high as 10^{-2} to 10^{-1} cm/s.

No determination of length, interconnections, continuity, and preferential direction could be made.

Interconnection between the canaliculi demonstrated by the excavation and dewatering adjacent trenches; the addition of tracer – outcrop in other in only 20sec.

Concern wrt stability of the canaliculi's walls when submitted to a continuous flow of water.

Genesis

The action of termites was proposed by the portuguese biologist Machado A.B (1983), confirming the activity of these insects in all the samples, through traces, essentially composed of faecal and oral pellets, found inside the canaliculi.

Canaliculi developed in the last glacial quaternary era (12.000 to 18.000 years ago) - region had dry climate, decisive vegetation formations propitious for the proliferation of termites.

Canaliculi of > Φ correspond to roots, eaten by termites, and those with Φ < 0.8 mm the disintegration of thin roots.

Investigations

Layer of low density (γd 5 to 10 kN/m^3) saprolitic soil - areas with high occurrence of tubular cavities / ‘’canaliculi’’, typical diameters of a few mm to 2 cm, exceptional cases up to 10 cm.

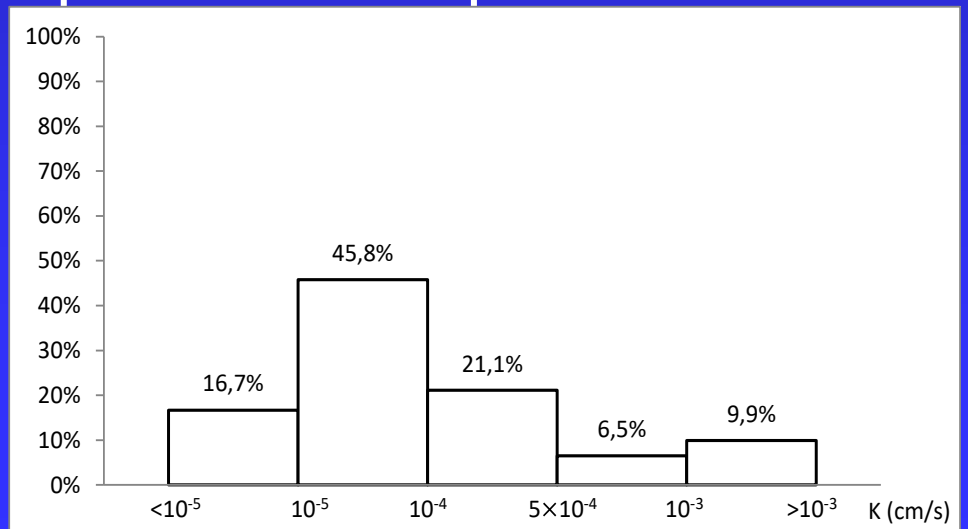
Constant level permeability lab tests and in situ tests performed in trenches.

38% of values > 10^{-4} cm/s, and 10% > 10^{-3} cm/s, - not compatible with the existing experience in saprolitic soils.

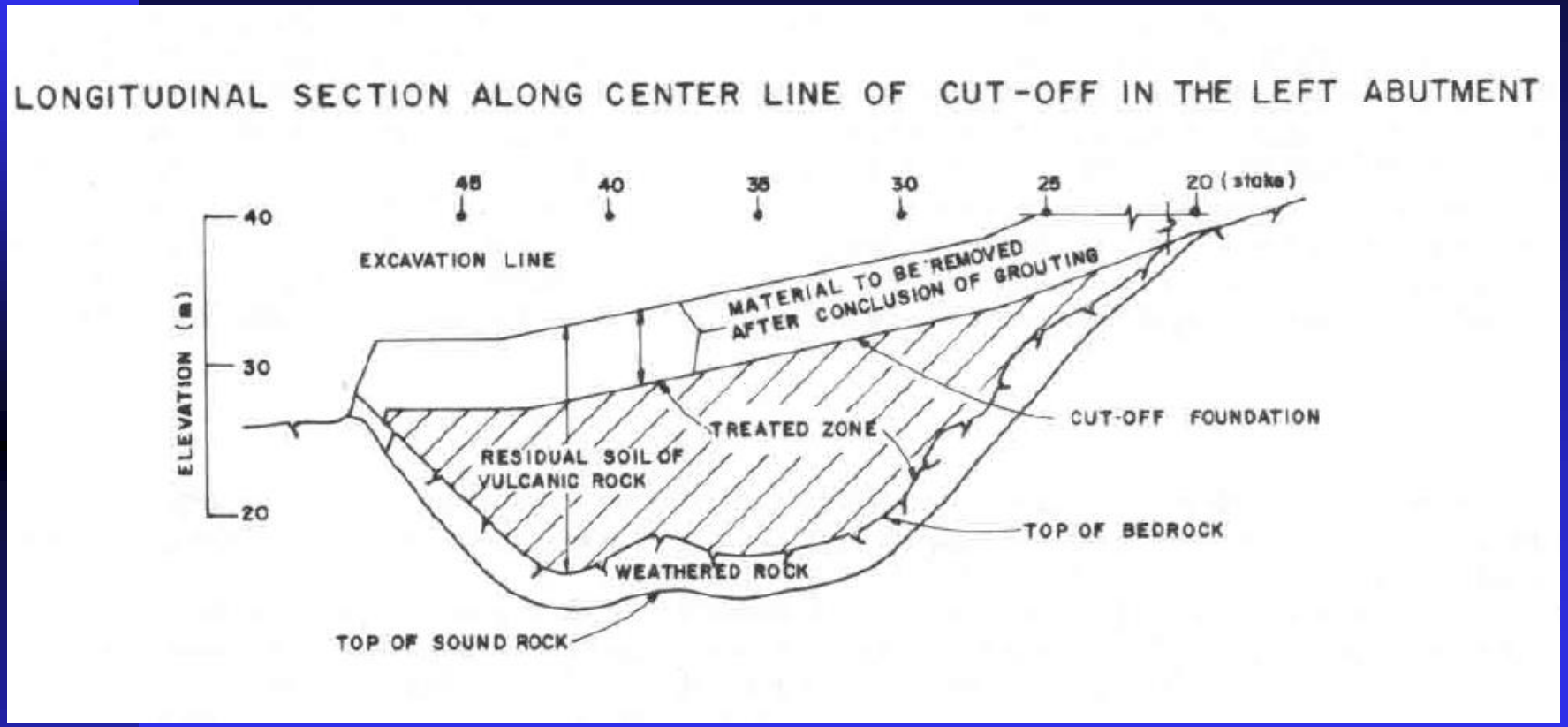
Frequency of canaliculi:

Φ cm: 1 or 2 per m2,

2 mm Φ: 100 per m2



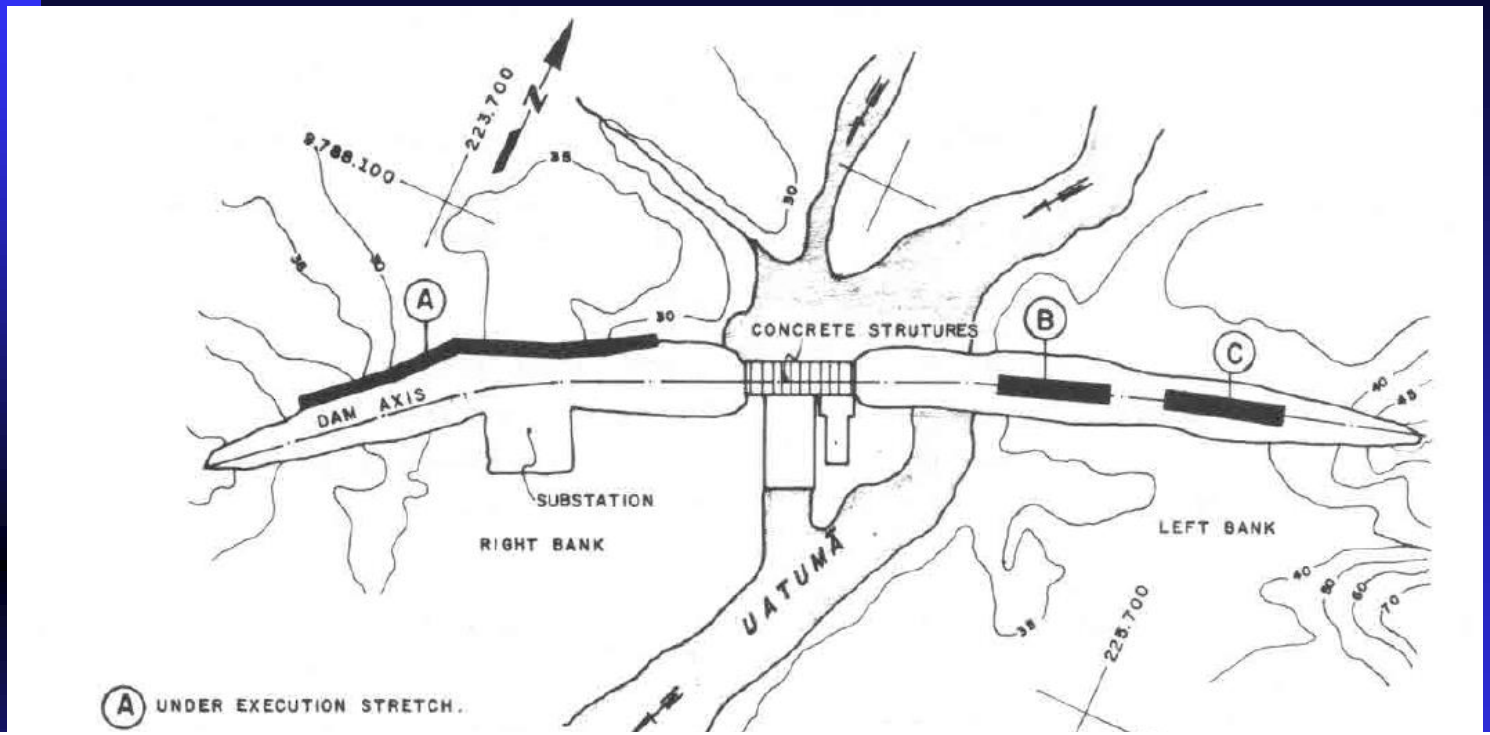
Concept of Foundation Treatment



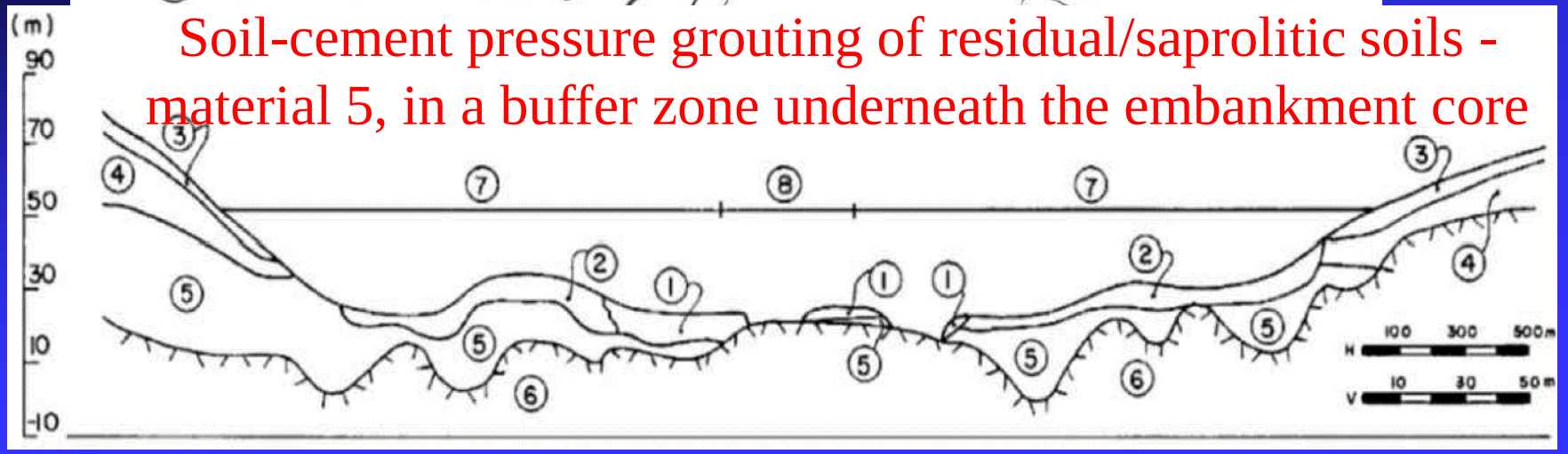
Removal of 20 to 25 m of residual/saprolitic soil in a conventional cut off would generate an “inverted” embankment dam, with serious impact in the construction schedule, and on costs.

Other conventional solutions like a cut off implemented with diaphragm wall equipment impossible due to logistic contraints

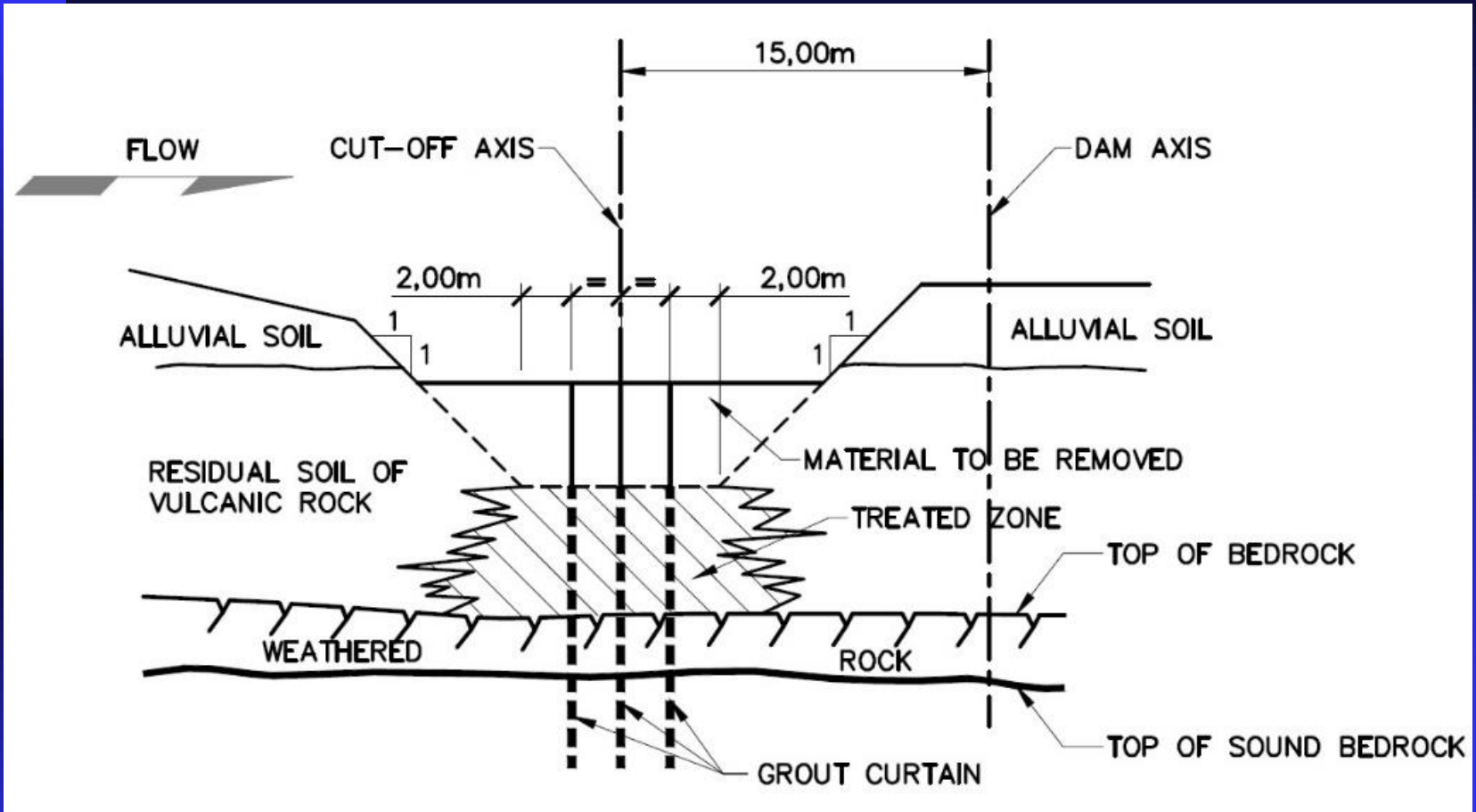
Proposed Solution

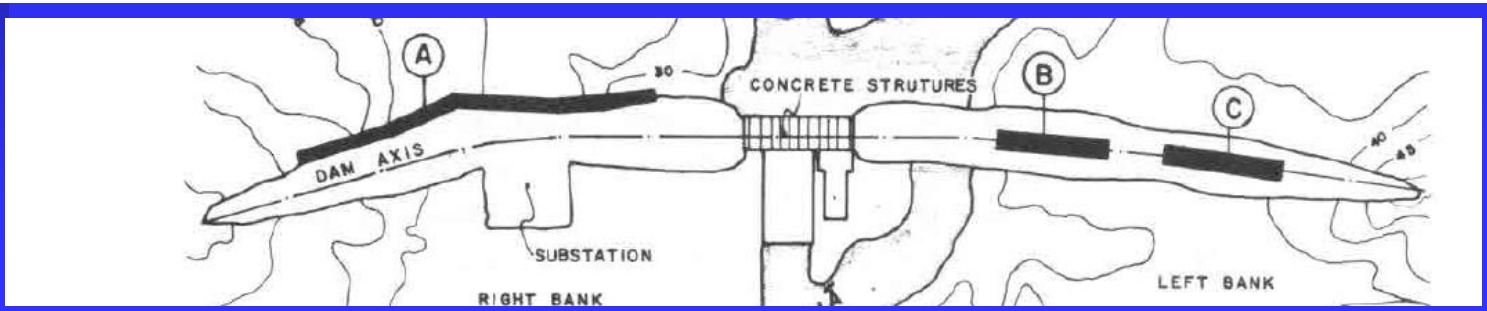


Soil-cement pressure grouting of residual/saprolitic soils - material 5, in a buffer zone underneath the embankment core



Proposed Solution





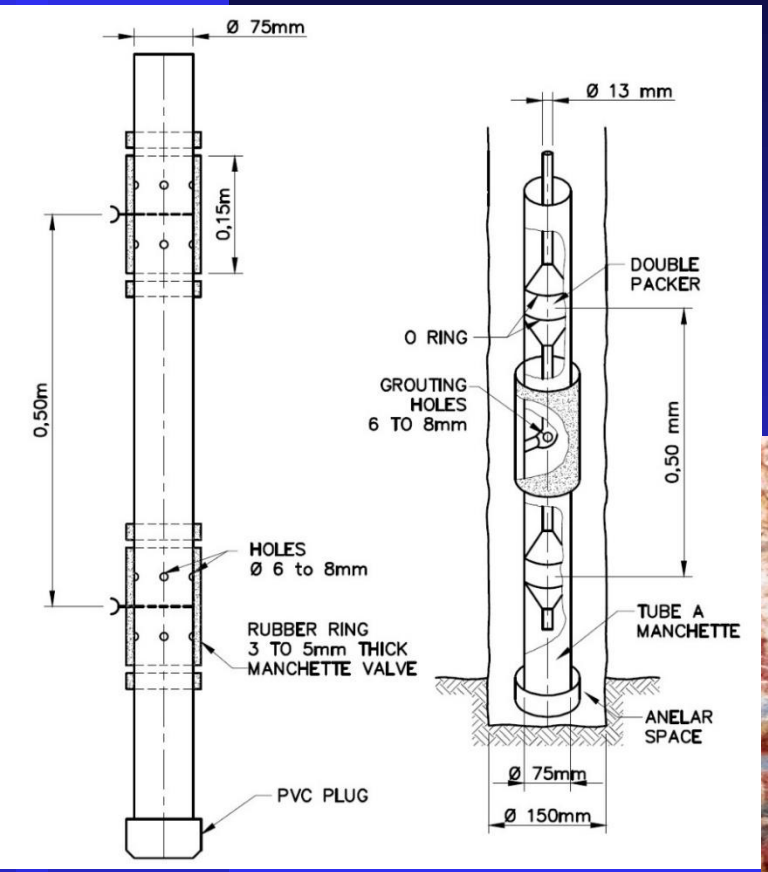
Concept and Advantages of Solution

Advantages of this concept of treatment:

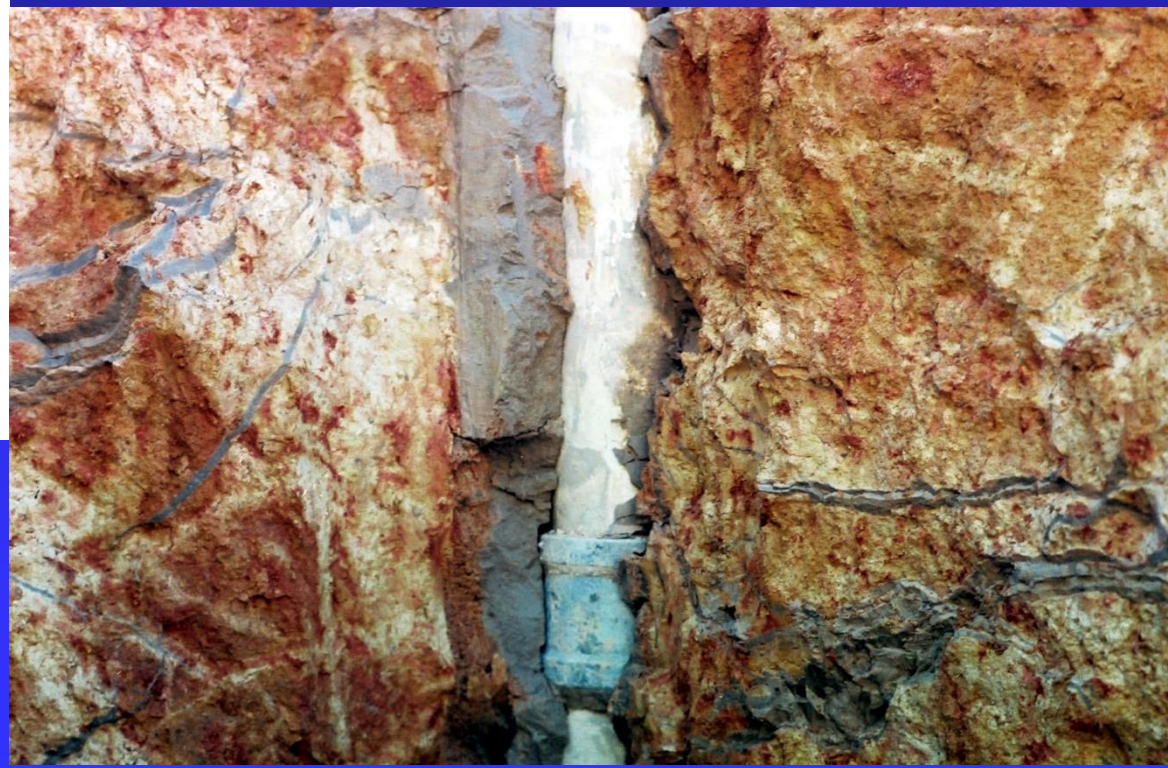
- grouting intensified in regions with higher intake;
- treatment all year round, despite of climate;
- use of conventional equipment;
- same boreholes can be used to treat the weathered and sound rock underneath the saprolitic soil

Experimental initial stretch already in the dam foundation to understand behaviour and performance, to refine specifications and provide information for design calculations

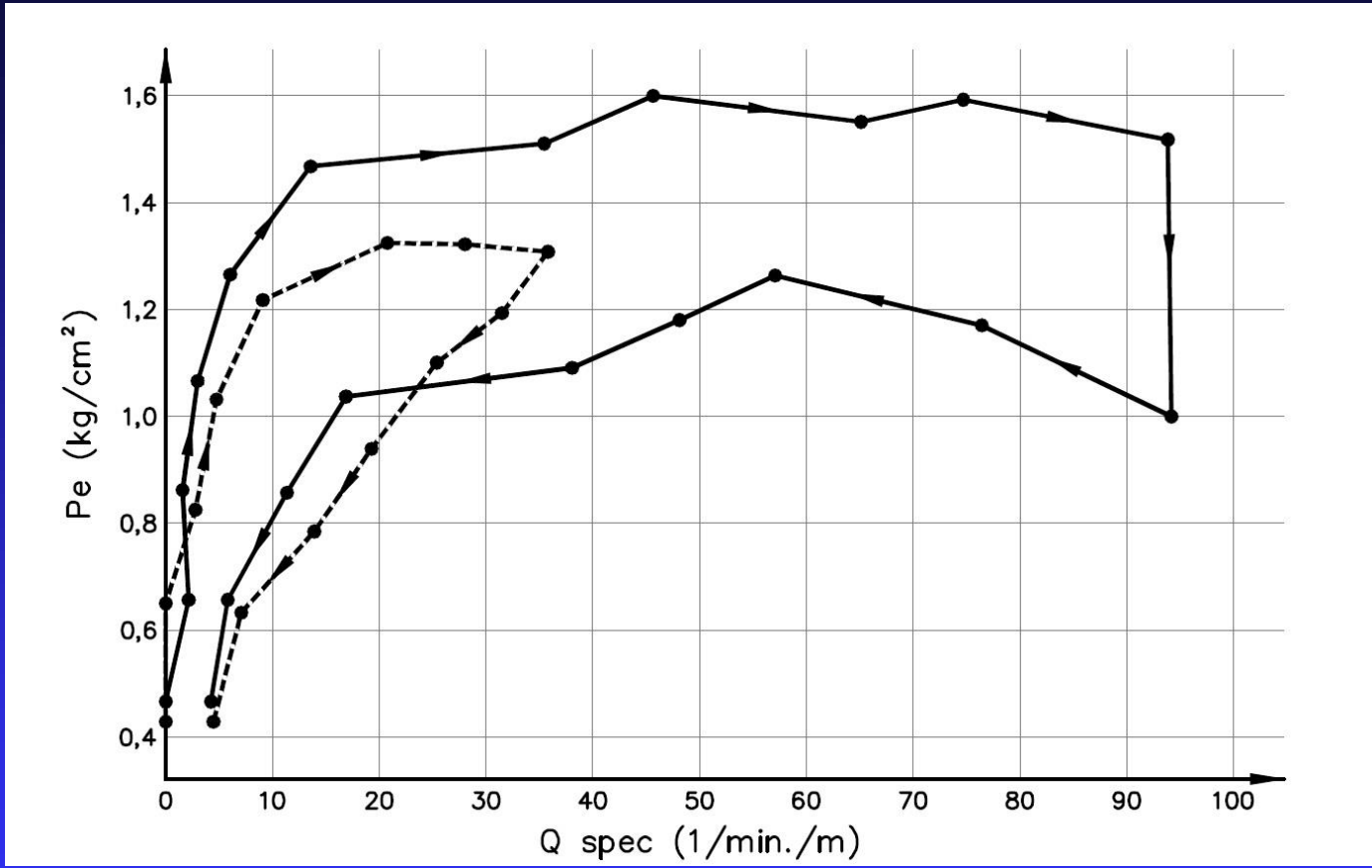
Details of Tube a Manchete



Special details developed in order to be able to grout through tube a manchete, isolating stretches/depths with packers in residual soils, needing reaction from the soil to the packers

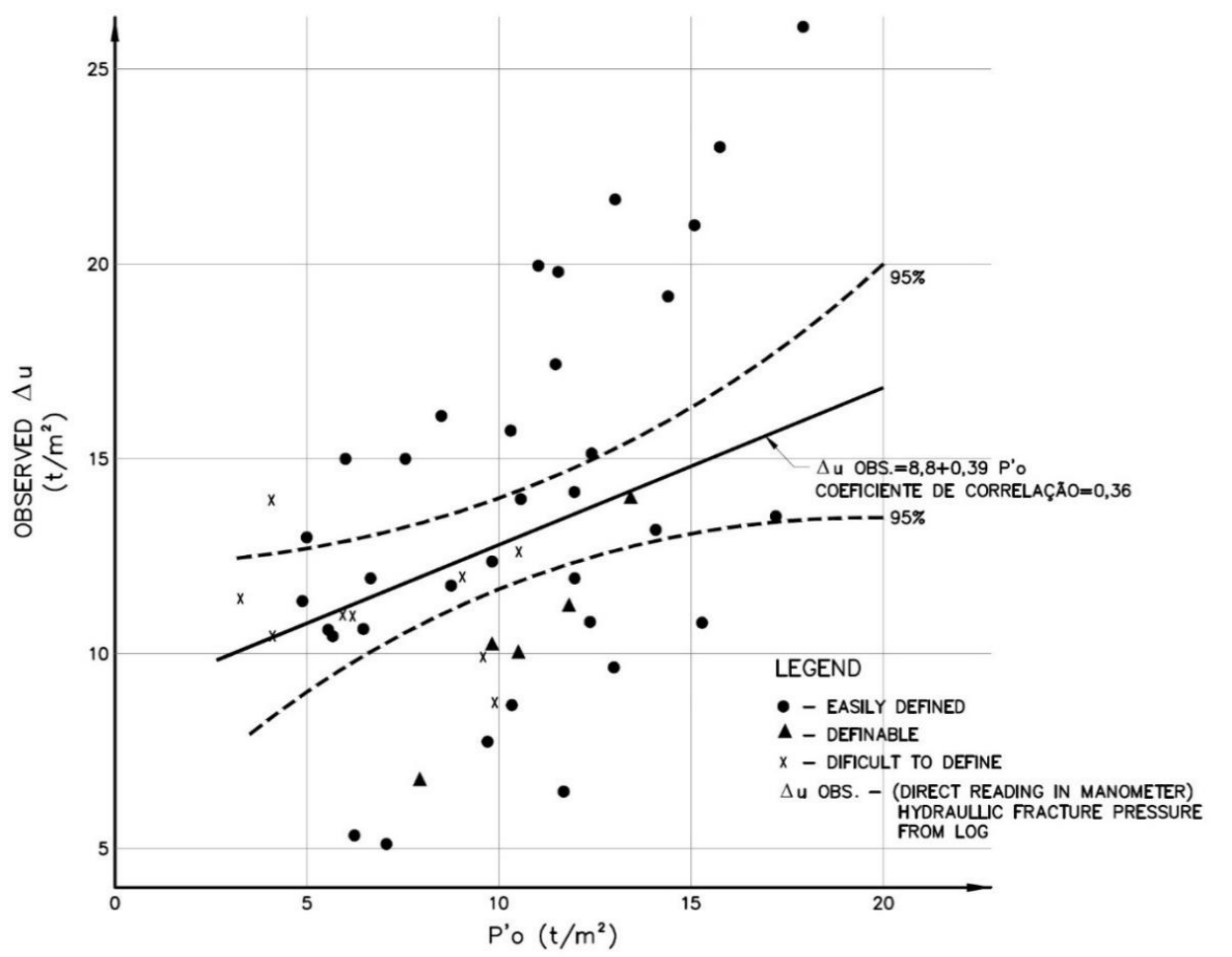


Hydraulic Fracture Tests of Soil



- Carefully performed to determine initial coef. Permeability K, pressure of hydraulic fracturing, minor principal stress σ3 and k0
- Grouting with different pigments and inspecting trenches confirmed orientation of σ3

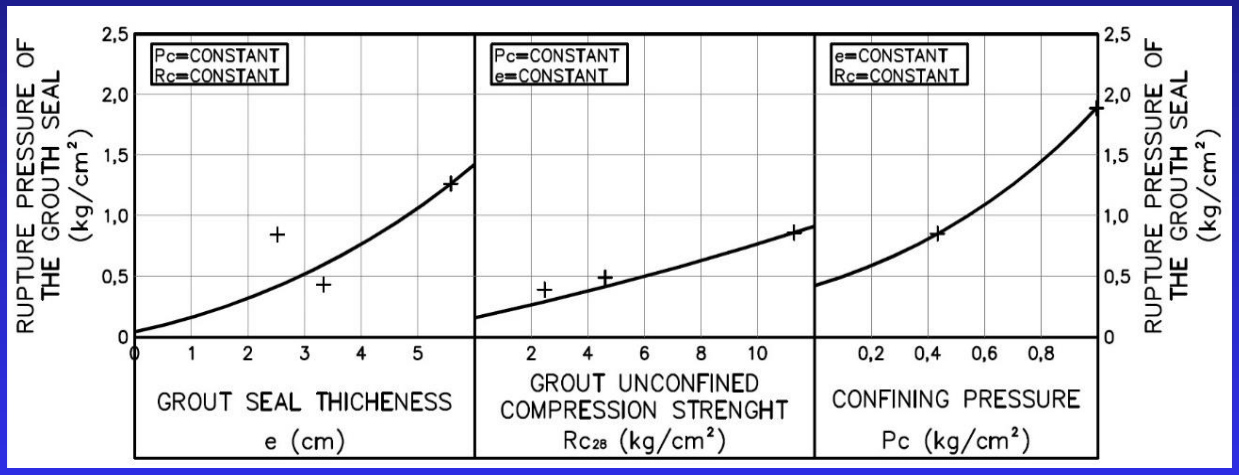
Hydraulic Fracture Tests of Soil



Relationship between the increase of pressure to generate hydraulic fracturing and effective stresses in water loss tests

Soil-Cement Grouts

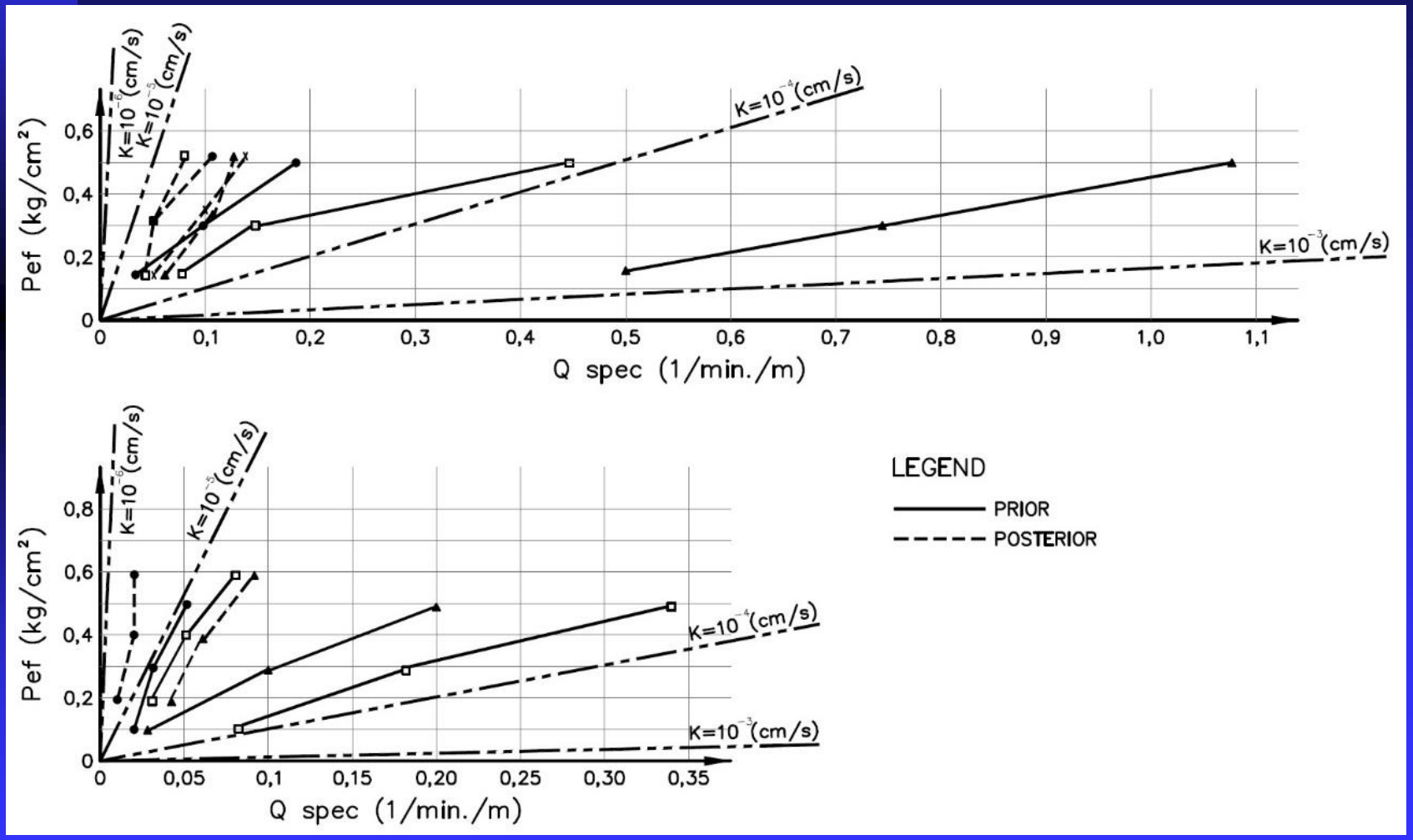
- Used local residual soil in the mixture.
- Different from used for the annular seal space between soil and PVC pipe. To fix PVC pipe grout had to be weak to allow future fracturing.
- Tests simulated rupture processes of the annular seal grout, as a function of its thickness, grout strength and confining pressure



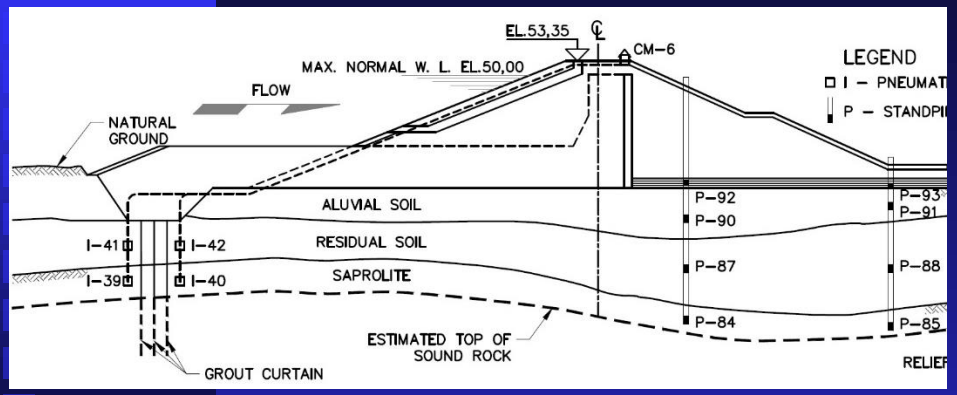
- Based on these results, a grout mixture for the annular seal:
  cement: 285kg / soil: 290kg / water: 805l
- For foundation soil: UCS at 28days of 150 kN/m^2; Viscosity $\leq$ 50cP; Sedimentation factor $\leq$ 5%; Fluidity in Marsh cone of 40s to 45s.
  cement: 375kg (reduced during works)/ soil: 290kg / water: 805l

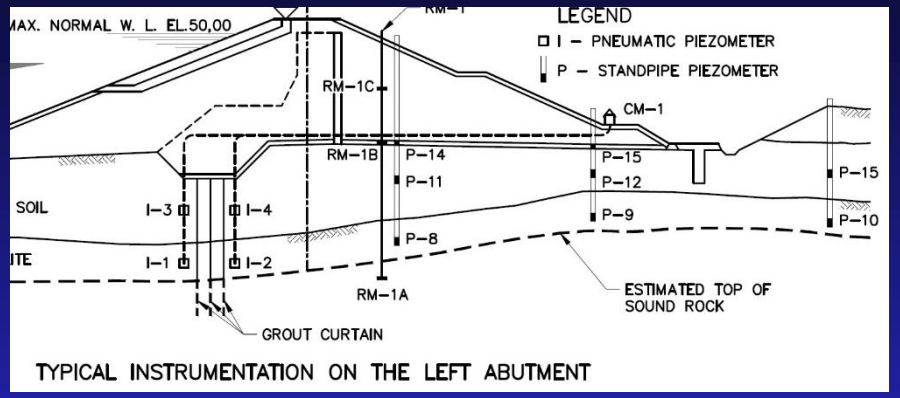
Investigation Trenches in Experimental Area

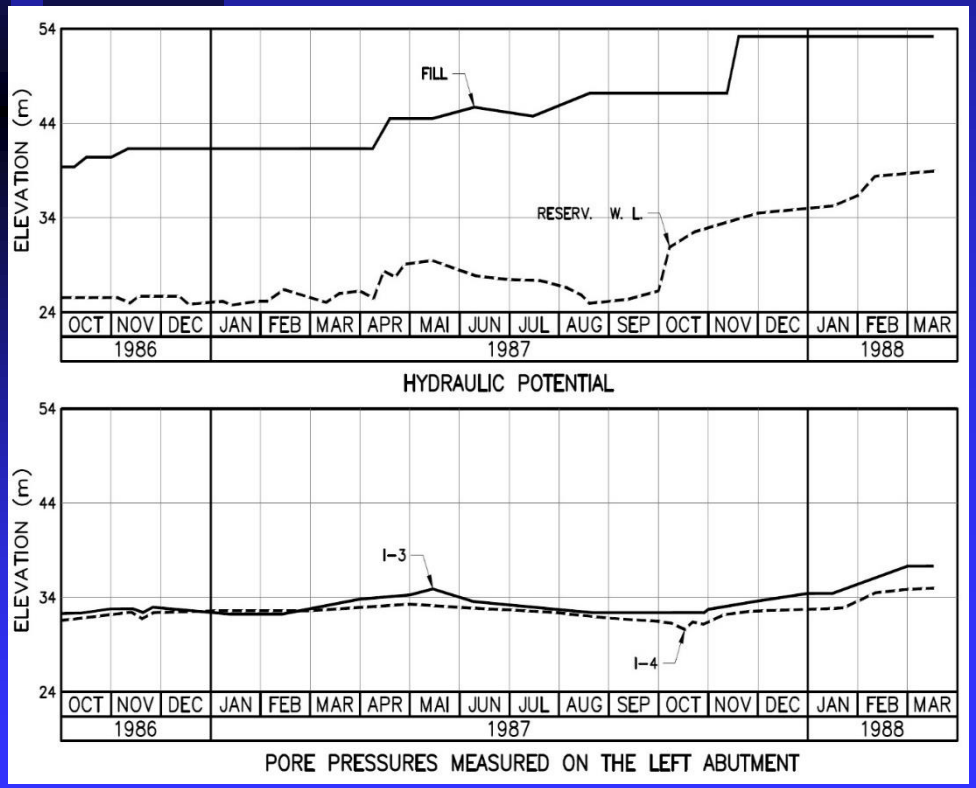
Comparisson of Water Loss Tests Prior and Posterior to Treatment

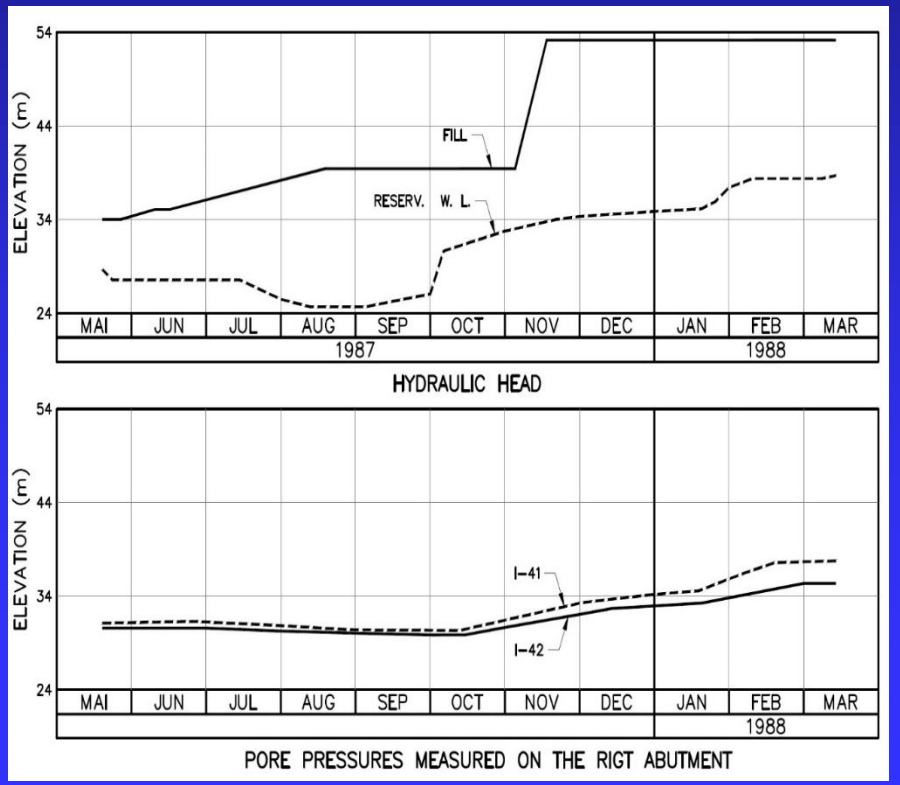


Initial Filling Monitoring Data

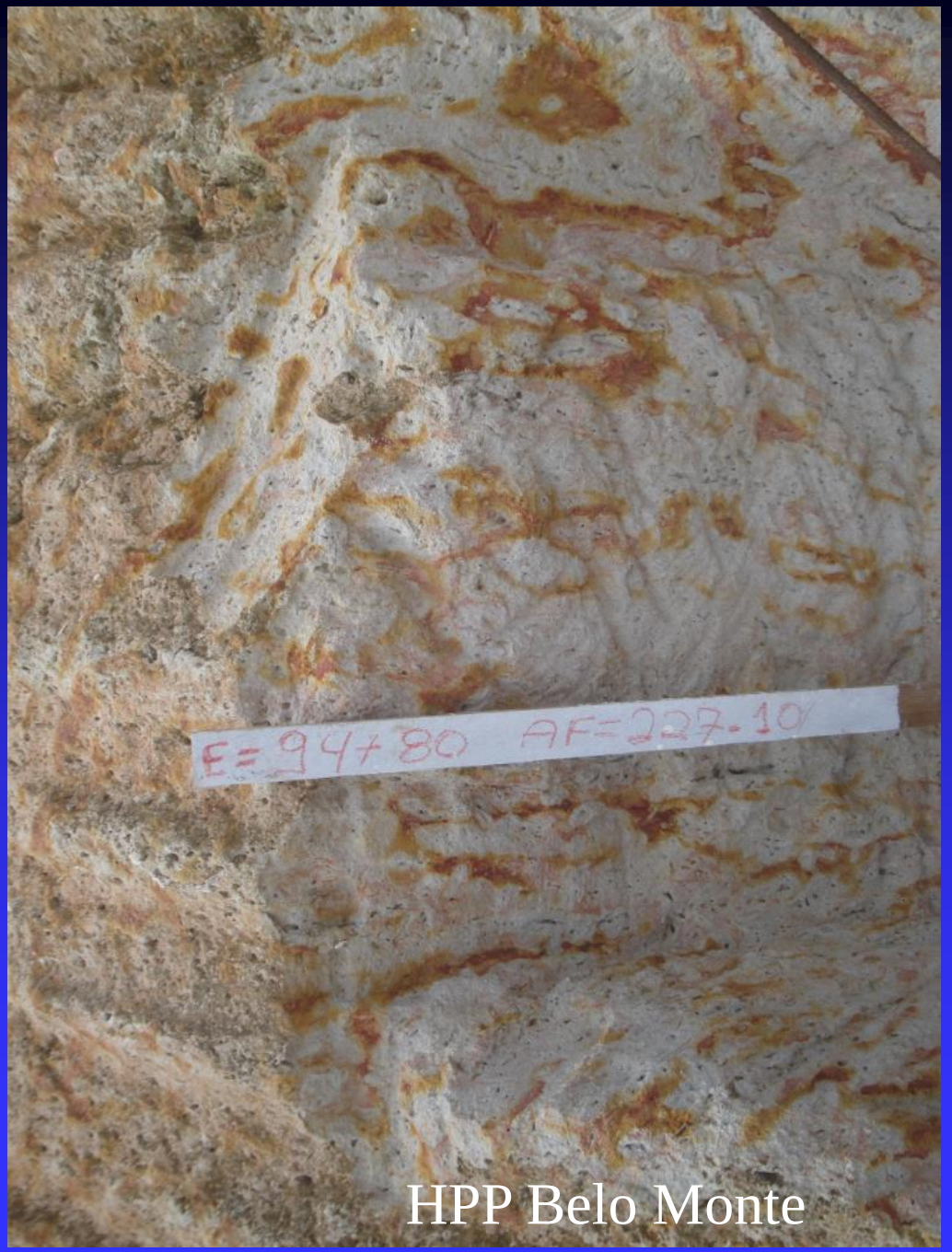








HPP Belo Monte 2015



Concluding Remarks

- Prof. Victor de Mello's perspective on how to use soundly based creativeness is seen as present in all 3 case histories presented, eventhough he only conducted the HPP Balbina case.
- The importance of a sound geological model to support the design studies is emphasized.
- Difficulties in budget and time constraints add an important factor in some contract models, but should not restrain or divert engineers involved from the right path

One of Victor's most used sayings:

"He who knows not, and knows not that he knows not - He is a fool, shun him.

He who knows not, and knows that he knows not - He is simple, teach him.

He who knows, and knows not that he knows - He is asleep, wake him.

He who knows, and knows that he knows - He is wise, follow him."

Last statment reviewed by de Mello and Burland to:

"He who knows, and knows that he knows – He is insufferable, use him

He who knows, and knows when he knows not – He is wise, follow him".

Acknowledgments

Our gratitude to many colleagues, especially to Profs G.Sadowski and C.Wolle, Mr. C.M.Nieble and Dr. W.Bilfinger, as well as Construtora Odebrecht and Construtora Andrade Gutierrez.

I also have to acknowledge the fact that numerous of Victor's friends incorporated me as their friends, sharing with me their enormous experience in life through geotechnical engineering; special gratitude is shared with Prof. Michele Jamiolkowski, Dr. David Carrier, Prof. John Burland, and Prof. Harry Poulos.

Acknowledgments

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The gratitude is extended to all members of the Goa Chapter and to the Indian Geotechnical Society.

THANK YOU VERY MUCH

AAPKA BAHUT BAHUT DHANYAVAAD

DEV BHOREM KHORUN

All Victor de Mello's writtings,
as well as the de Mello Lectures and
other technical material
available to download from:

www.victorfbdemello.com.br