GeoVirginia 2018

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Lessons Learned in Geotechnical Engineering

Series of mistakes leading to the collapse of a small dam in Colombia.

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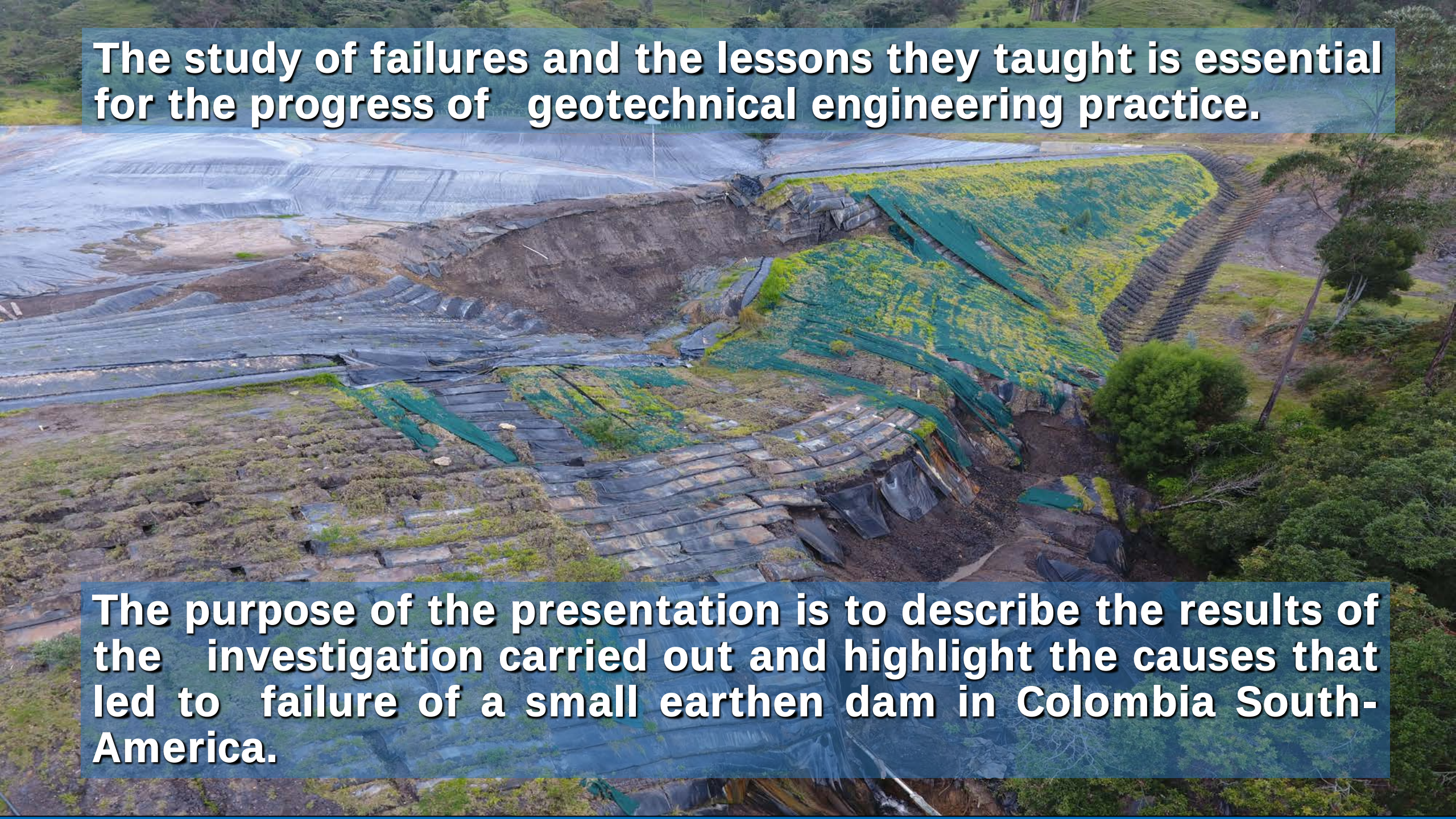
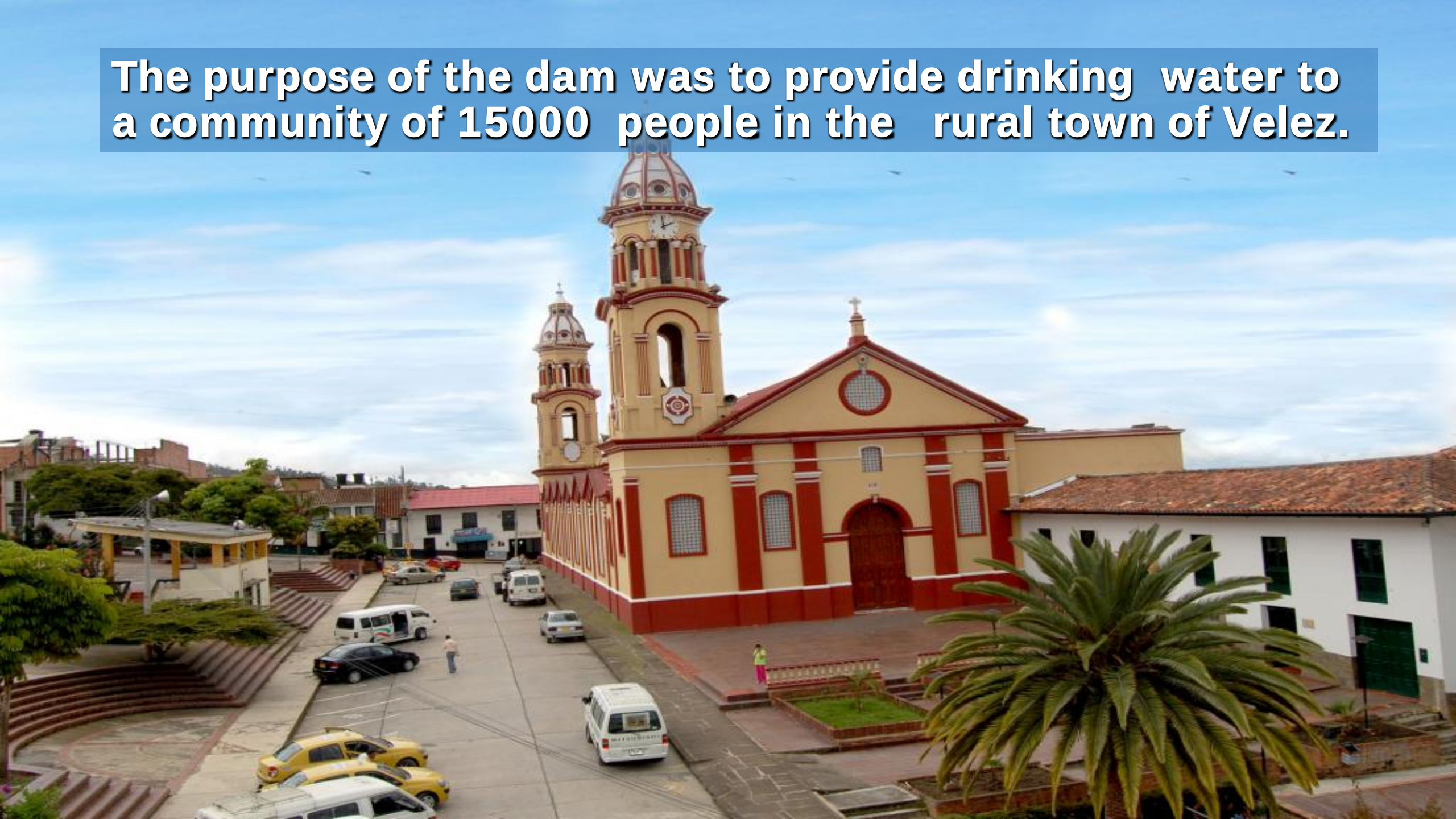
Universidad Industrial de Santander



The study of failures and the lessons they taught is essential for the progress of geotechnical engineering practice.

The purpose of the presentation is to describe the results of the investigation carried out and highlight the causes that led to failure of a small earthen dam in Colombia South-America.

The dam is located on the northern Andes in Colombia - South America.

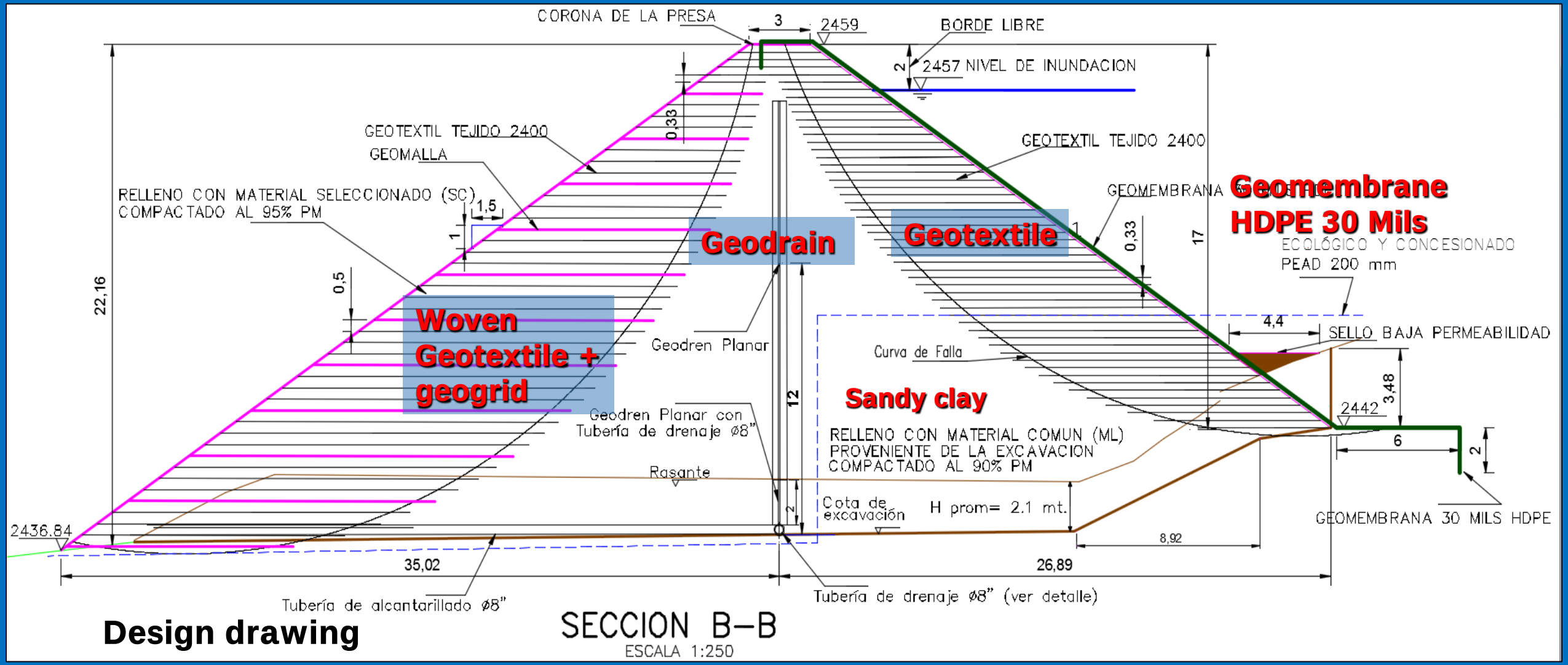

The purpose of the dam was to provide drinking water to a community of 15000 people in the rural town of Velez.


The dam failed 7th June 2016
two weeks after filling up the reservoir.

After the dam failure an extensive site investigation was performed.
The investigation included:

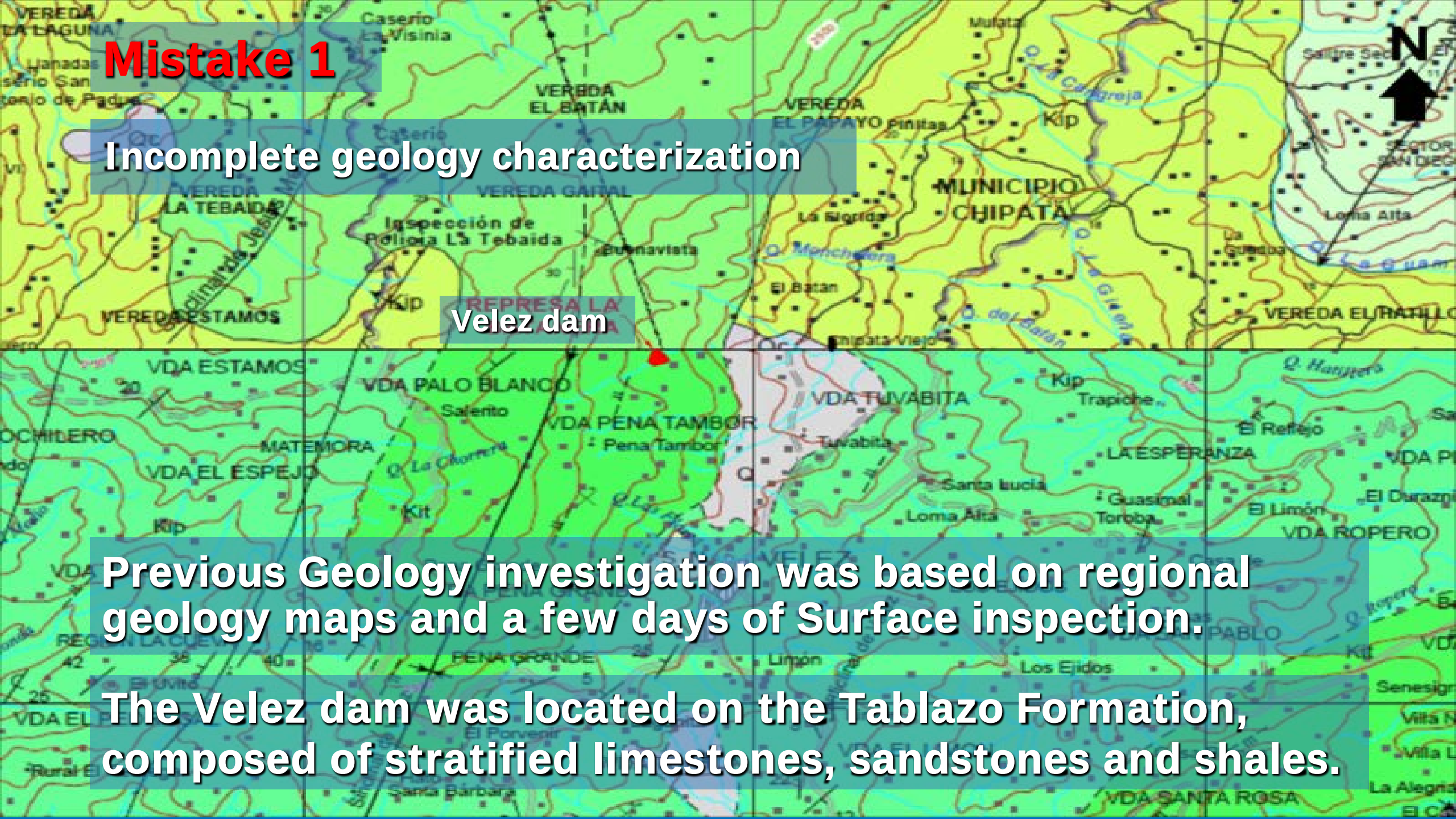
Type	Number	Maximum Length Meters	Total length Meters
Boreholes with PMT tests	9	35	153
Seismic downhole	9	35	153
MASW - Seismic Refraction	9	240	1283
Geo-electric tomography	9	480	2580
Geo-radar 50 MHZ	18	349	3015

The “Velez” dam, is a sandy clay earth-fill structure reinforced with geotextiles and provided with a geomembrane cover. This dam is 20 m high, 150 m long and provides a storage capacity of 300.000 m3.



Design drawing

SECCION B–B
ESCALA 1:250


Mistake 1
Incomplete geology characterization
Velez dam
Previous Geology investigation was based on regional geology maps and a few days of Surface inspection.
The Velez dam was located on the Tablazo Formation, composed of stratified limestones, sandstones and shales.


Geologists during the design stage identified Surface rocks as shales
Hydrochloric acid
Surface Shales ... Non karstic

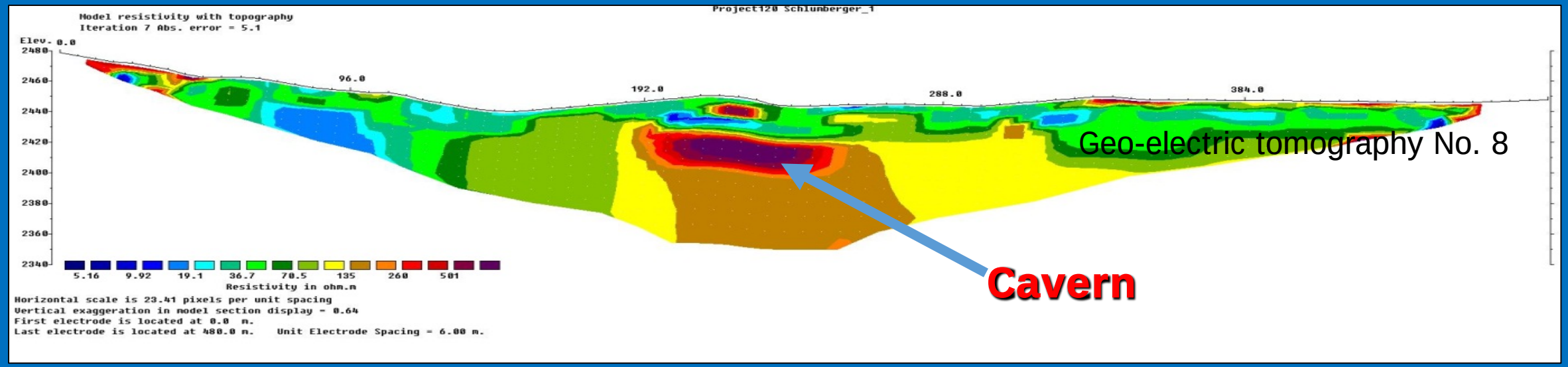
The Tablazo formation is known for the karstic behavior of the limestone rocks, but the surface rocks were shales, residual soils and some colluvial deposits.

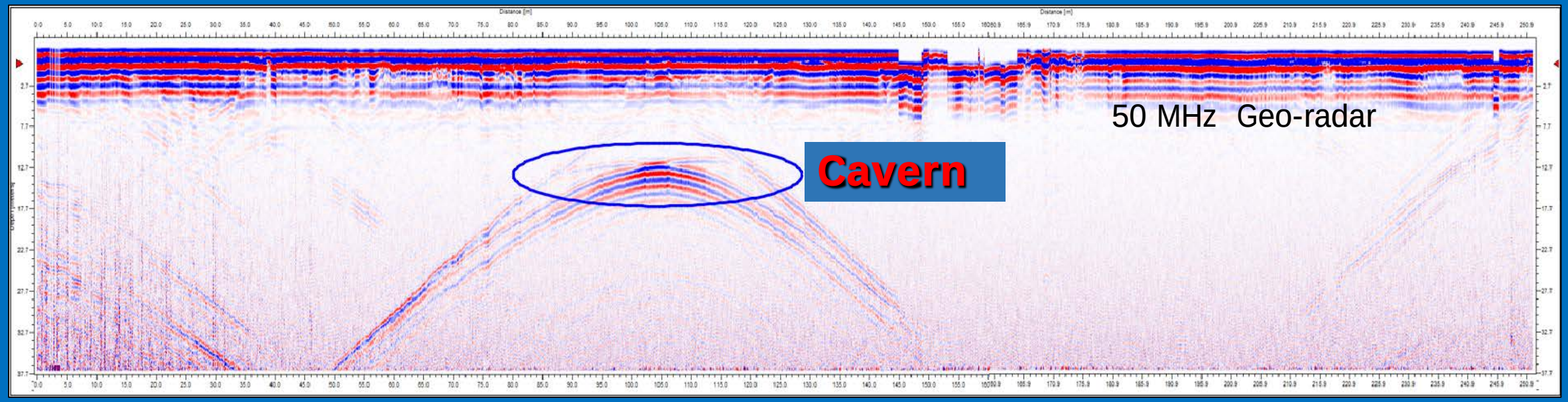
Geologists did not identified the presence of limestones.

Design Investigations did not detect the presence of caverns of disolved limestones under the reservoir.

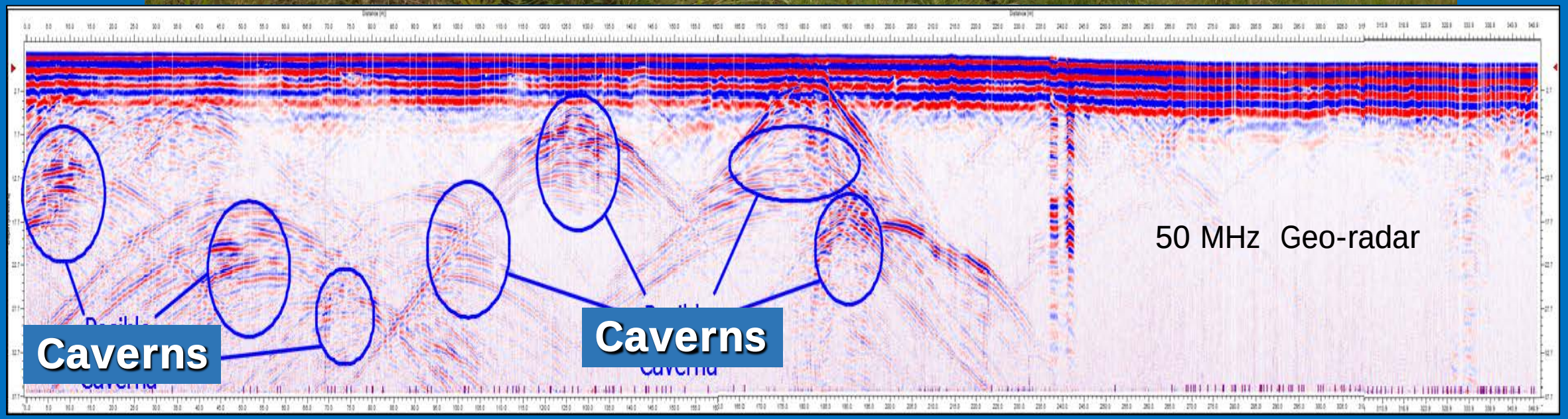
When we got to the site, for the first time, after the dam failure, we were not aware of the presence of cavers under the reservoir.

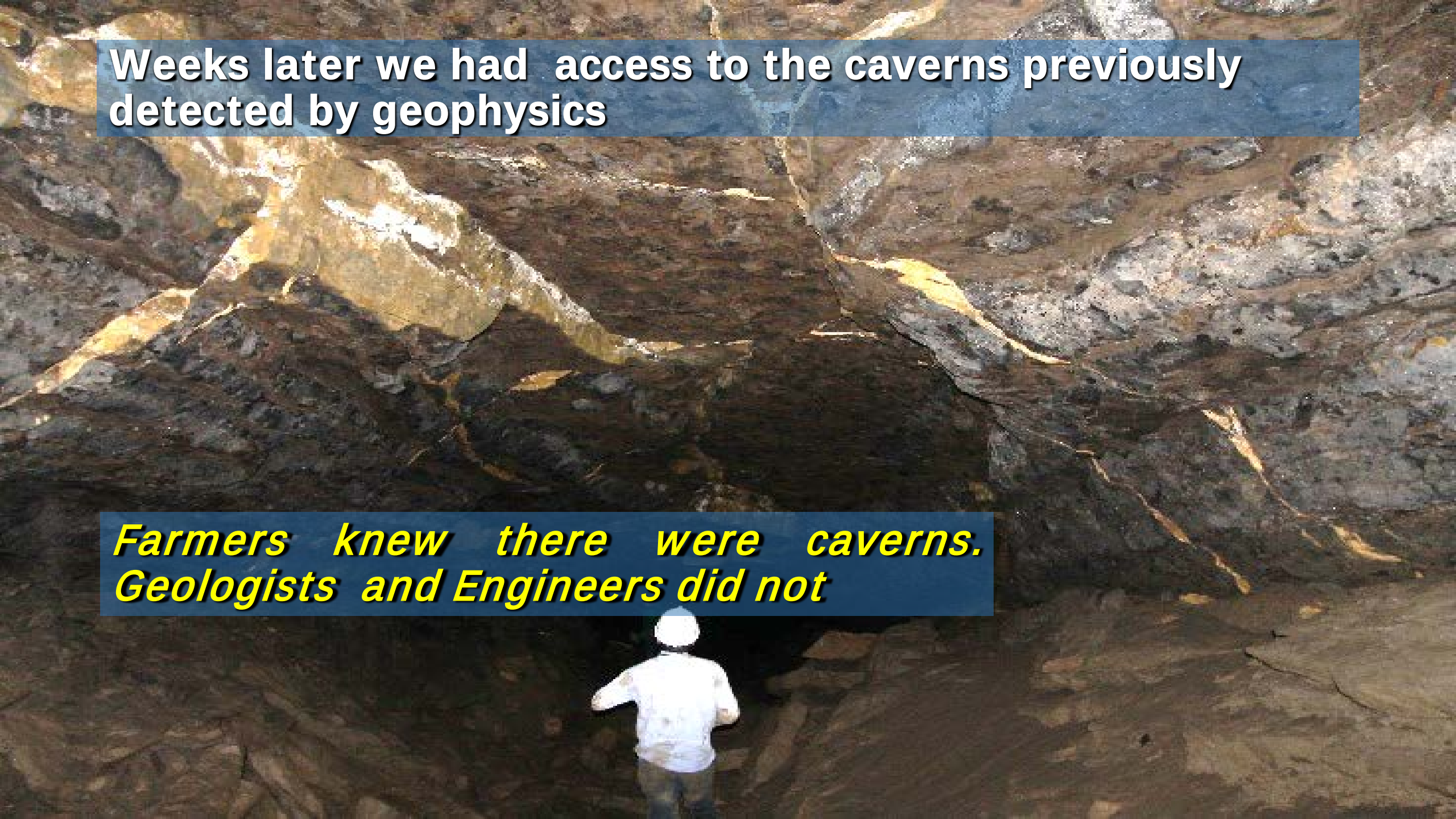
Caverns were detected using a combination of geo-radar, geo-electric tomography and seismic MASW.





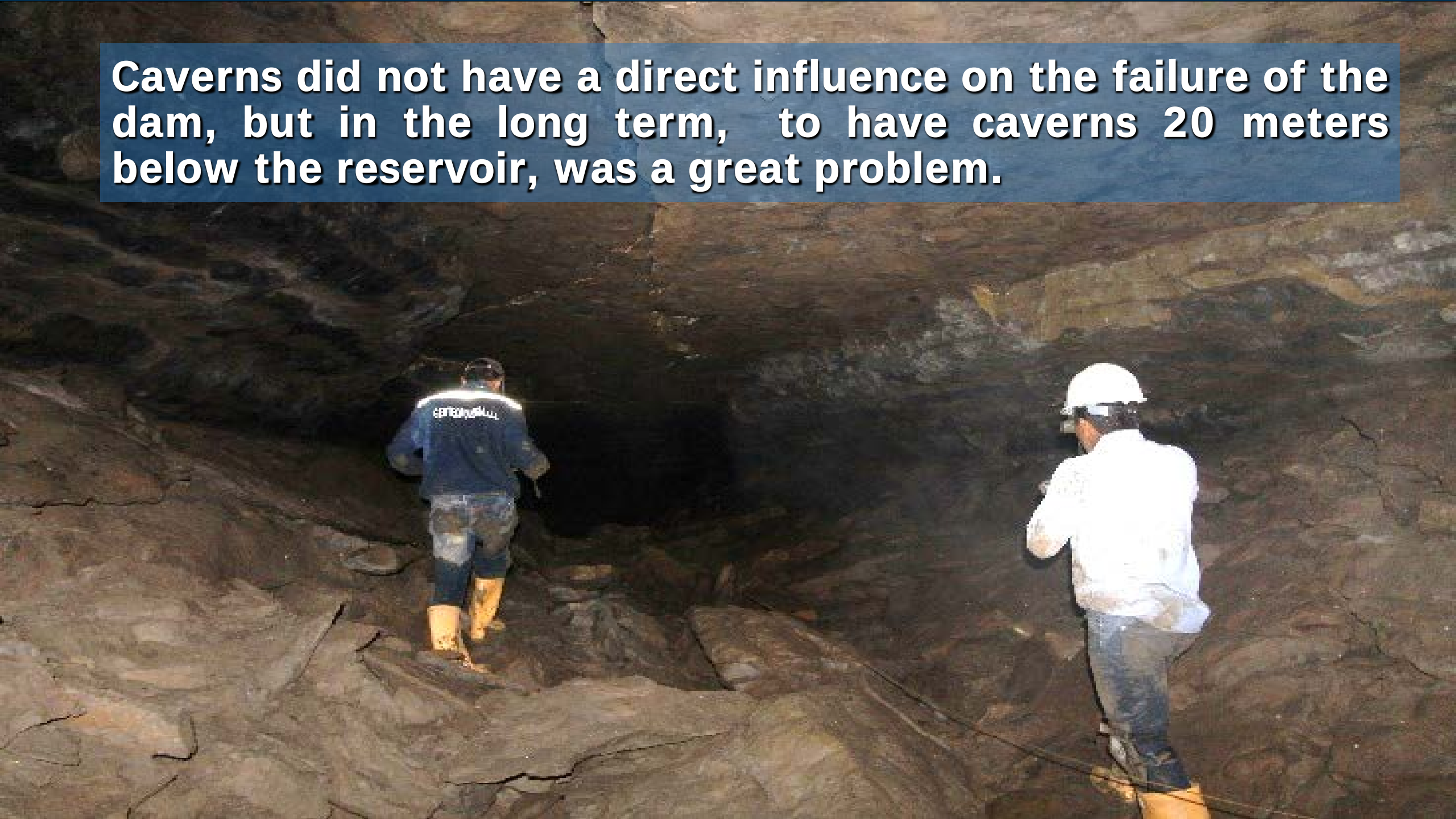
The 50 MHz geo-radar was especially effective.





Weeks later we had access to the caverns previously detected by geophysics

Farmers knew there were caverns. Geologists and Engineers did not


Caverns did not have a direct influence on the failure of the dam, but in the long term, to have caverns 20 meters below the reservoir, was a great problem.

Mistake 2

Insufficient geotechnical investigation during the design stage

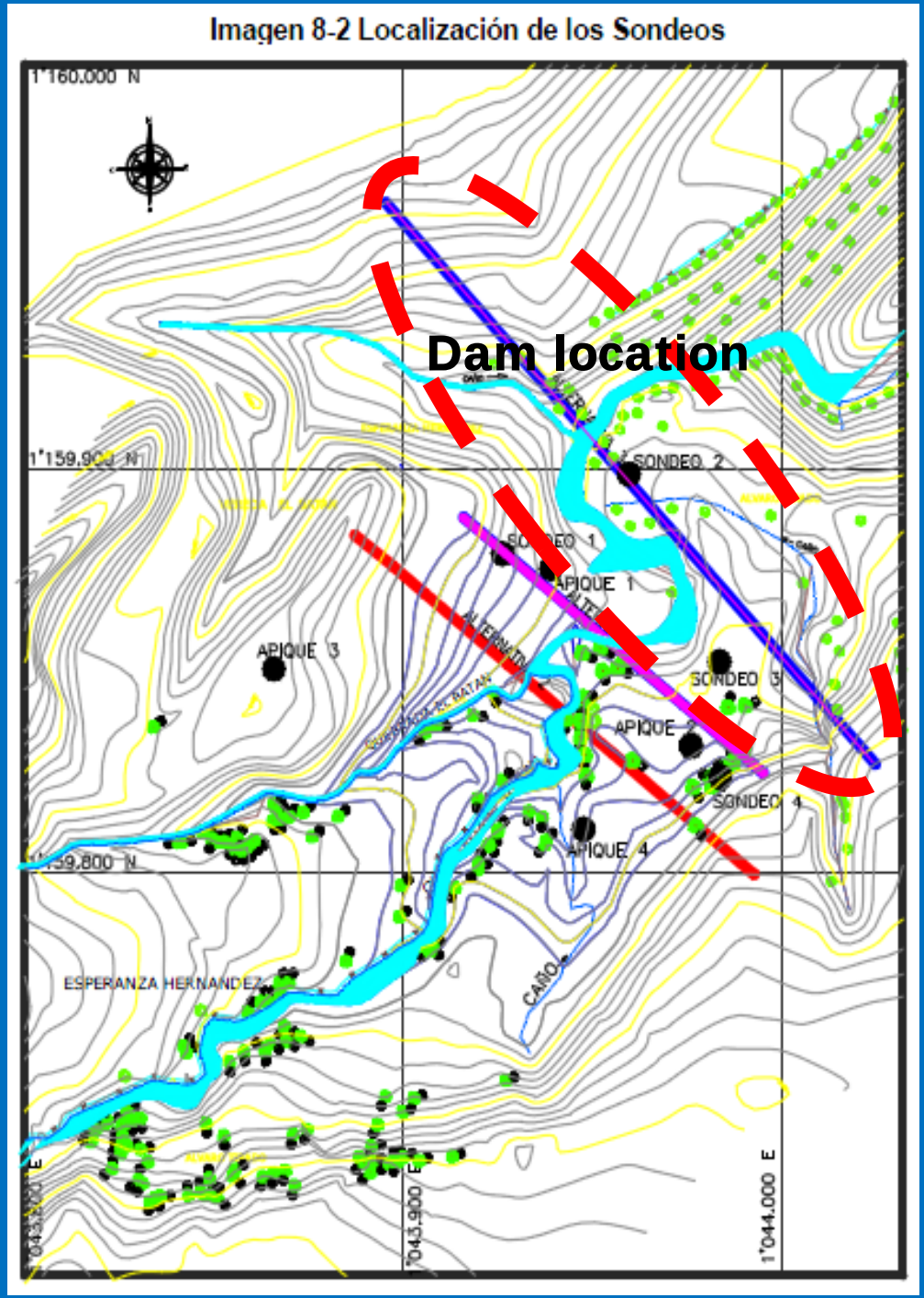
The initial site investigation consisted of:

Four boreholes at a máximum depth of 5 meters. (only one along the dam)

Four test pits.

Some basic soil tests

This was not enough to identify the depth and characteristics of the materials for the foundation of the dam

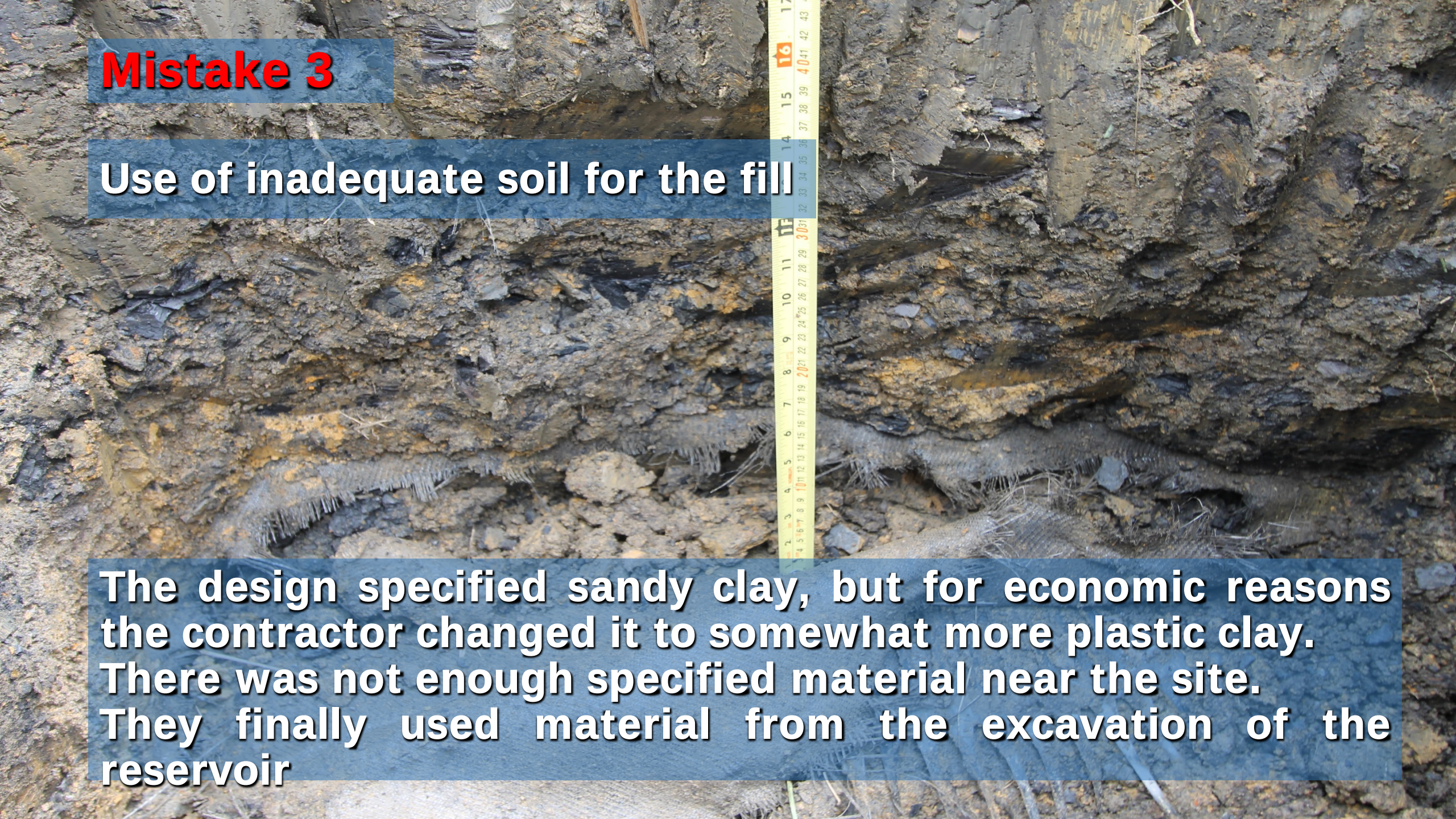


Argument for the poor site investigation :

There were not Access roads to the site and the transportation of equipment was too difficult.

Geophysics was not used for design

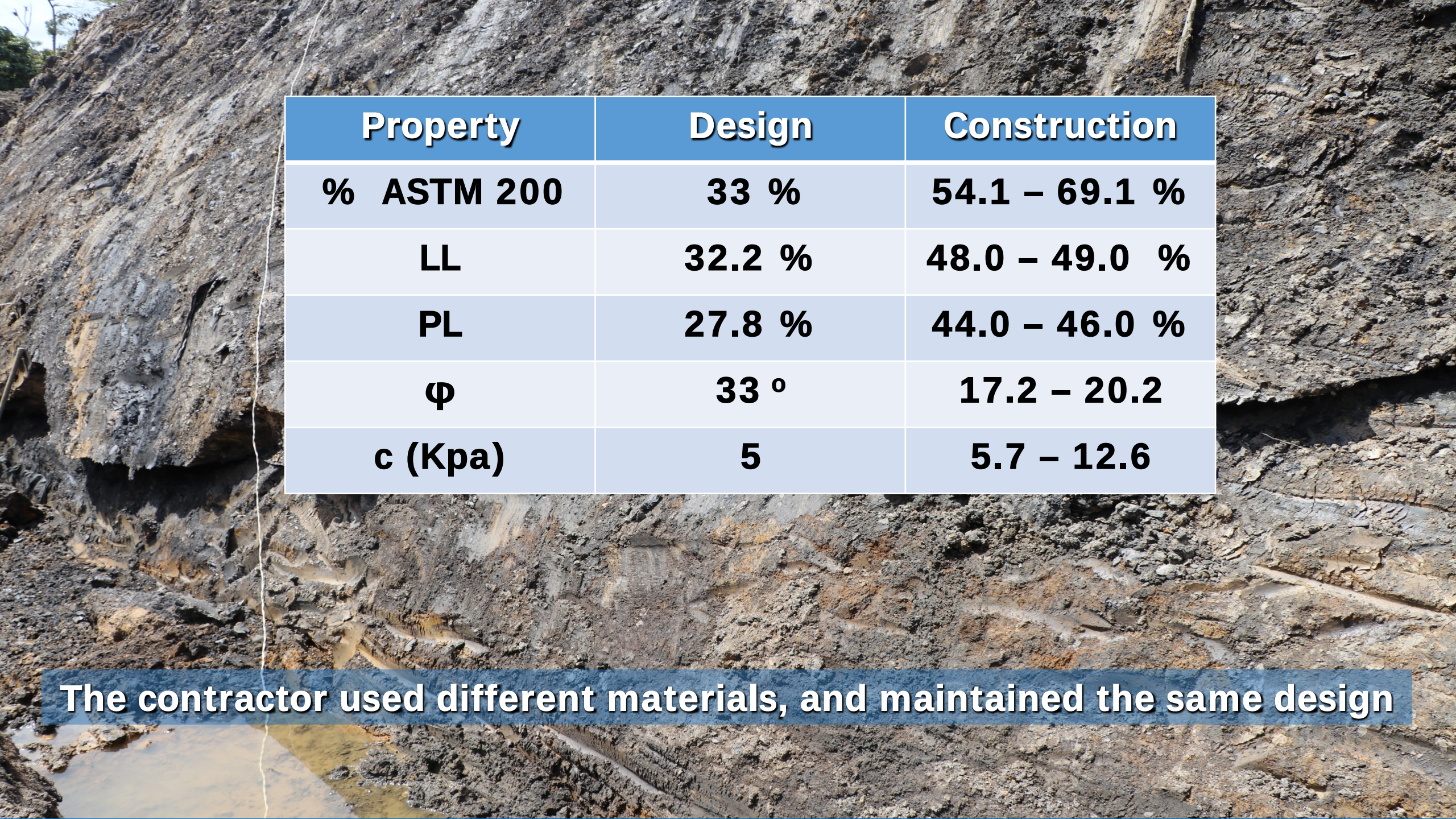
Geophysical tests are an excelent alternative in mountainous terrain.



Mistake 3

Use of inadequate soil for the fill

The design specified sandy clay, but for economic reasons the contractor changed it to somewhat more plastic clay.
There was not enough specified material near the site.
They finally used material from the excavation of the reservoir



Property	Design	Construction
% ASTM 200	33 %	54.1 – 69.1 %
LL	32.2 %	48.0 – 49.0 %
PL	27.8 %	44.0 – 46.0 %
φ	33 º	17.2 – 20.2
c (Kpa)	5	5.7 – 12.6

The contractor used different materials, and maintained the same design

Mistake 4

Excesive and inadequate use of gesynthetics for the type of soil.

In South America we frequently use geotextile reinforcements in small dams and generally they do not pose any problem.
In this case the use of geotextiles and geogrids to reinforce a "plastic clay" fill was not adequate.

The design was influenced by the geo-synthetics supplier
- ✓**Geotextiles**
- ✓**Geogrids**
- ✓**Geodrains**
- ✓**Geomembranes**
- ✓**Geocelds**

They used most of the available geosynthetics in the market.

Product dealers offer “free” technical consultancy.

From a sellers brochure:

“Consulting in choosing technical and economic "custom made" solutions, free technical assistance for designing, installation or free technical assistance to installation and quality control of the executed works, supply of materials. Technical assistance in the design is performed to a high standard of quality due to special dimensioning programs for different types of engineering works.”

Mistake 5

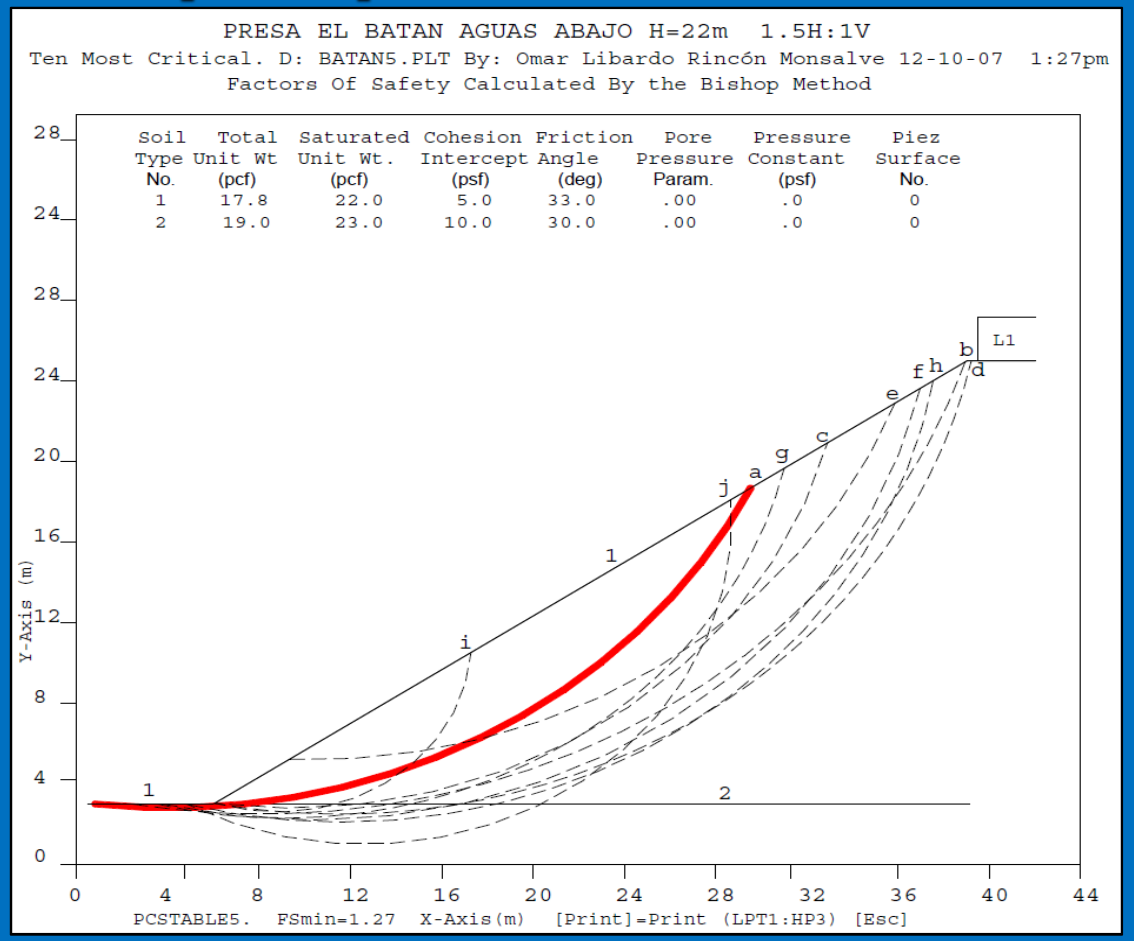
Mixing reinforcements of different deformation modulus.

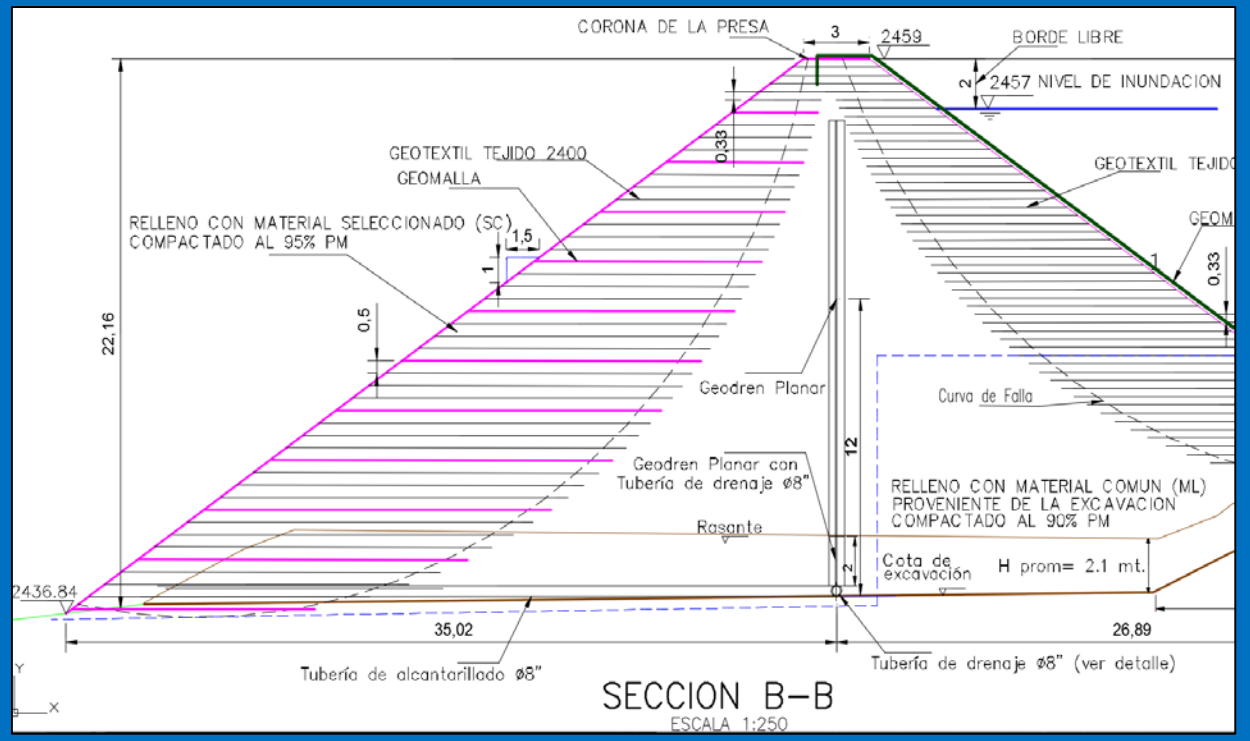
Geotextiles + Geogrids

In some places geogrids broke and geotextiles deformed without breaking.

Mistake 6

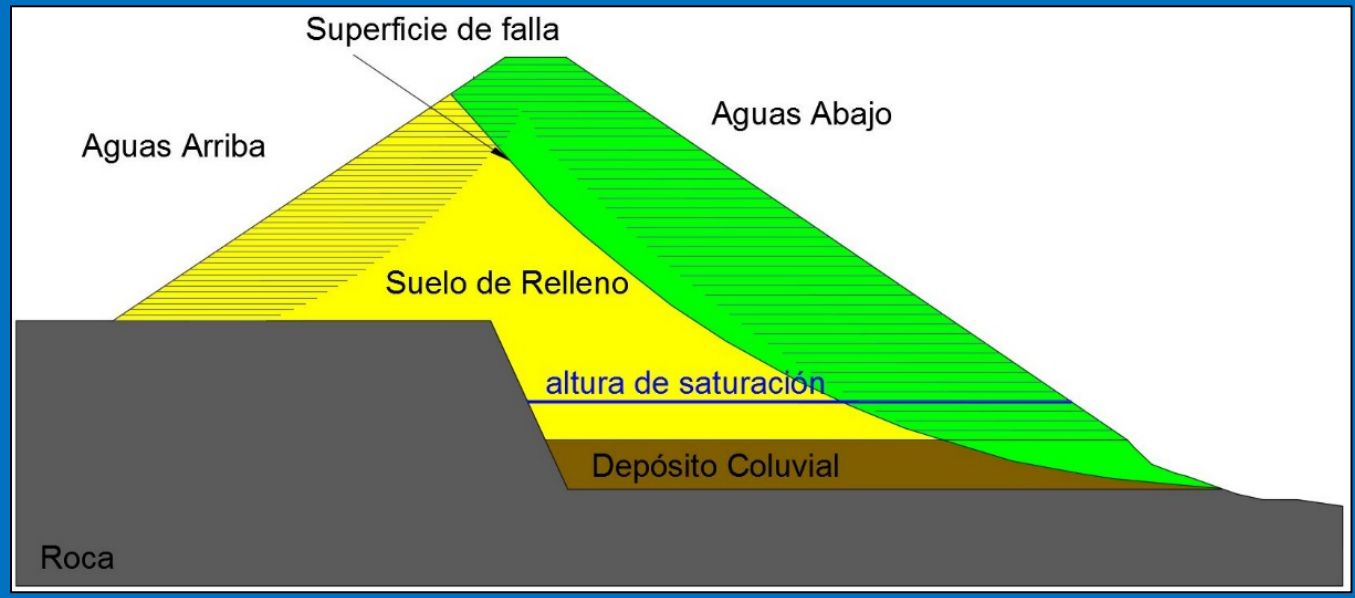
Deep slope failure was not considered in the design

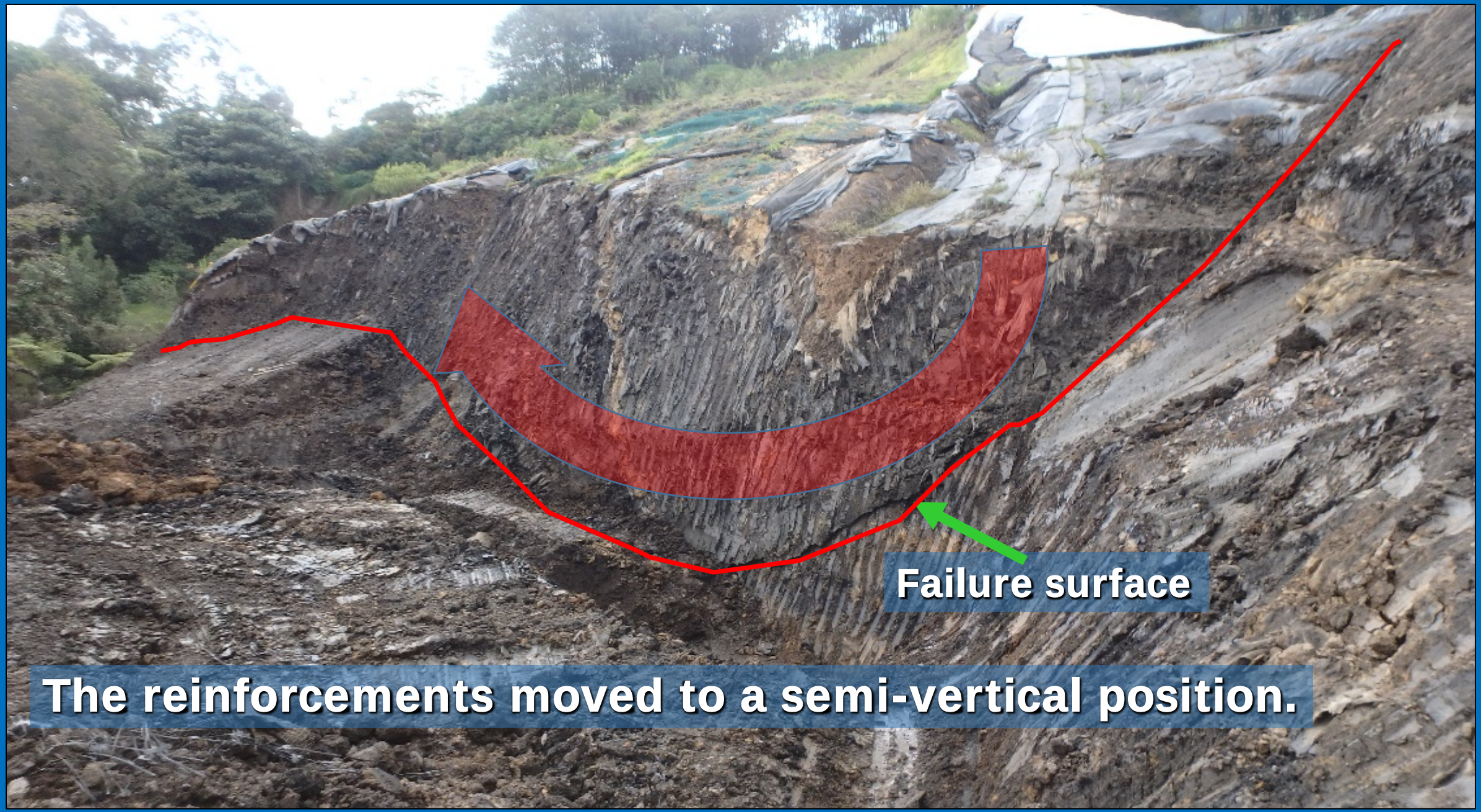




Length of reinforcements was not enough to control deep slope failure

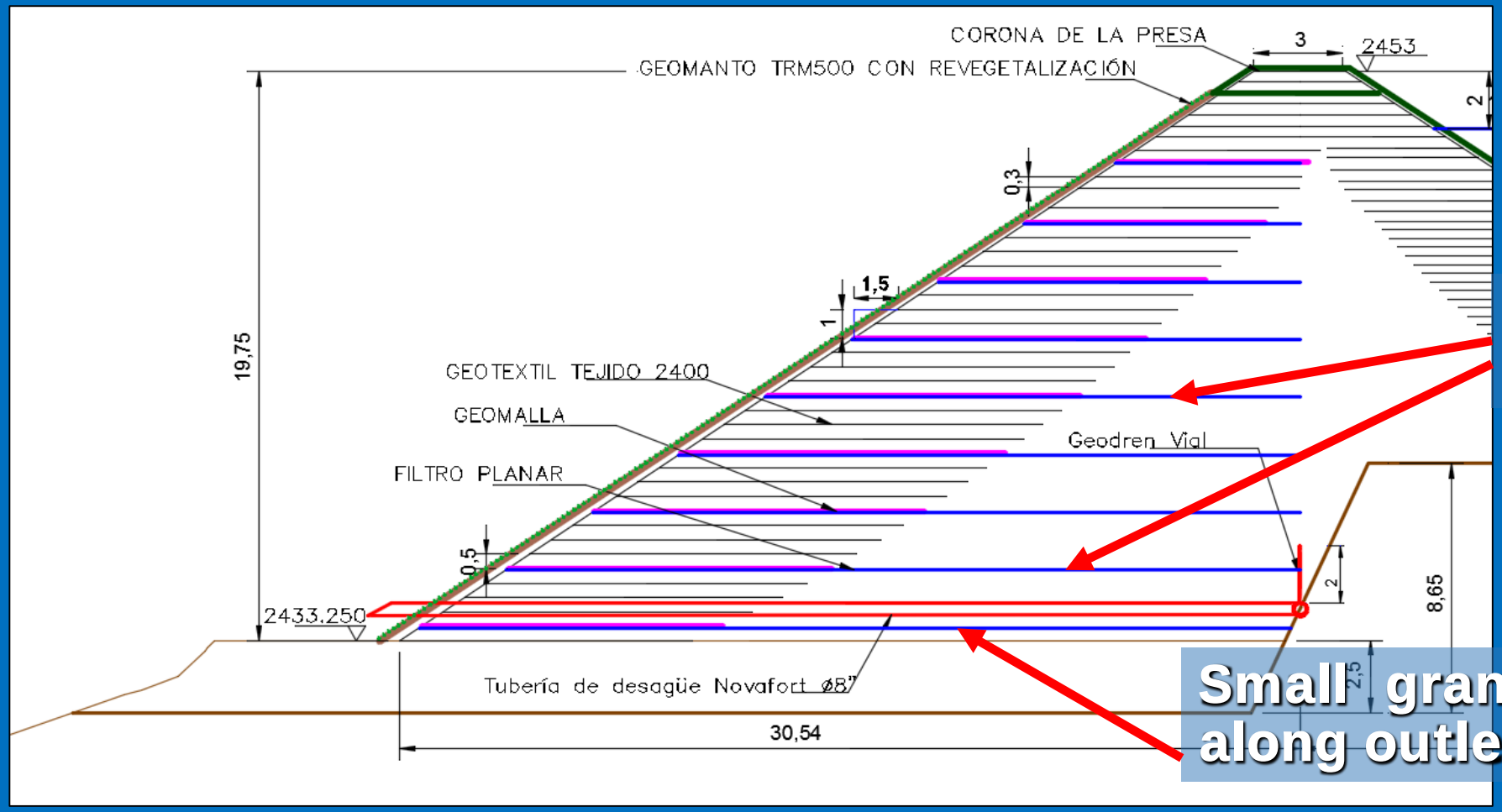
Actual failure occurred behind the reinforcement




Failure surface
The reinforcements moved to a semi-vertical position.

Mistake 7

Poor internal drainage



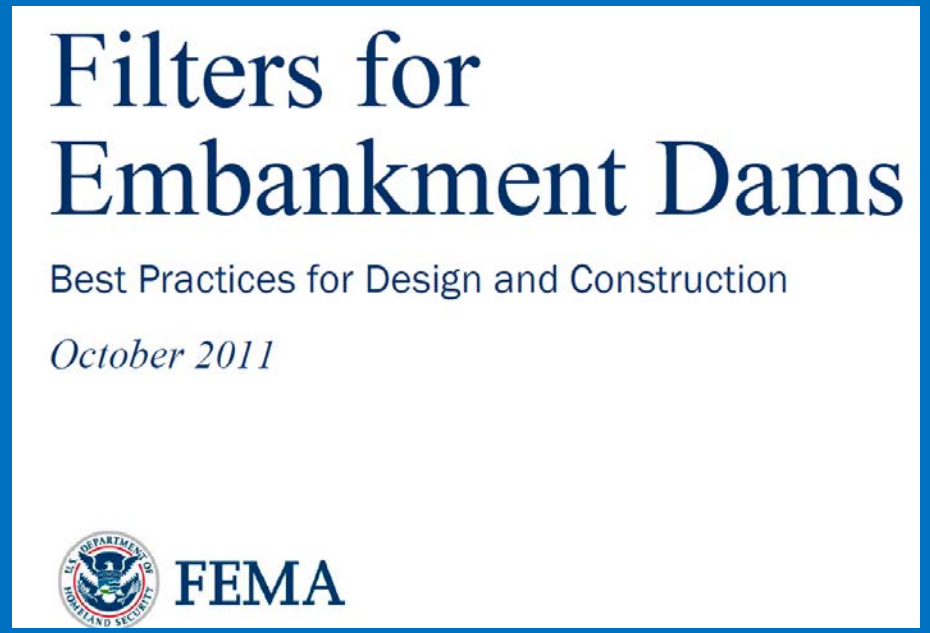
Geosynthetic drains

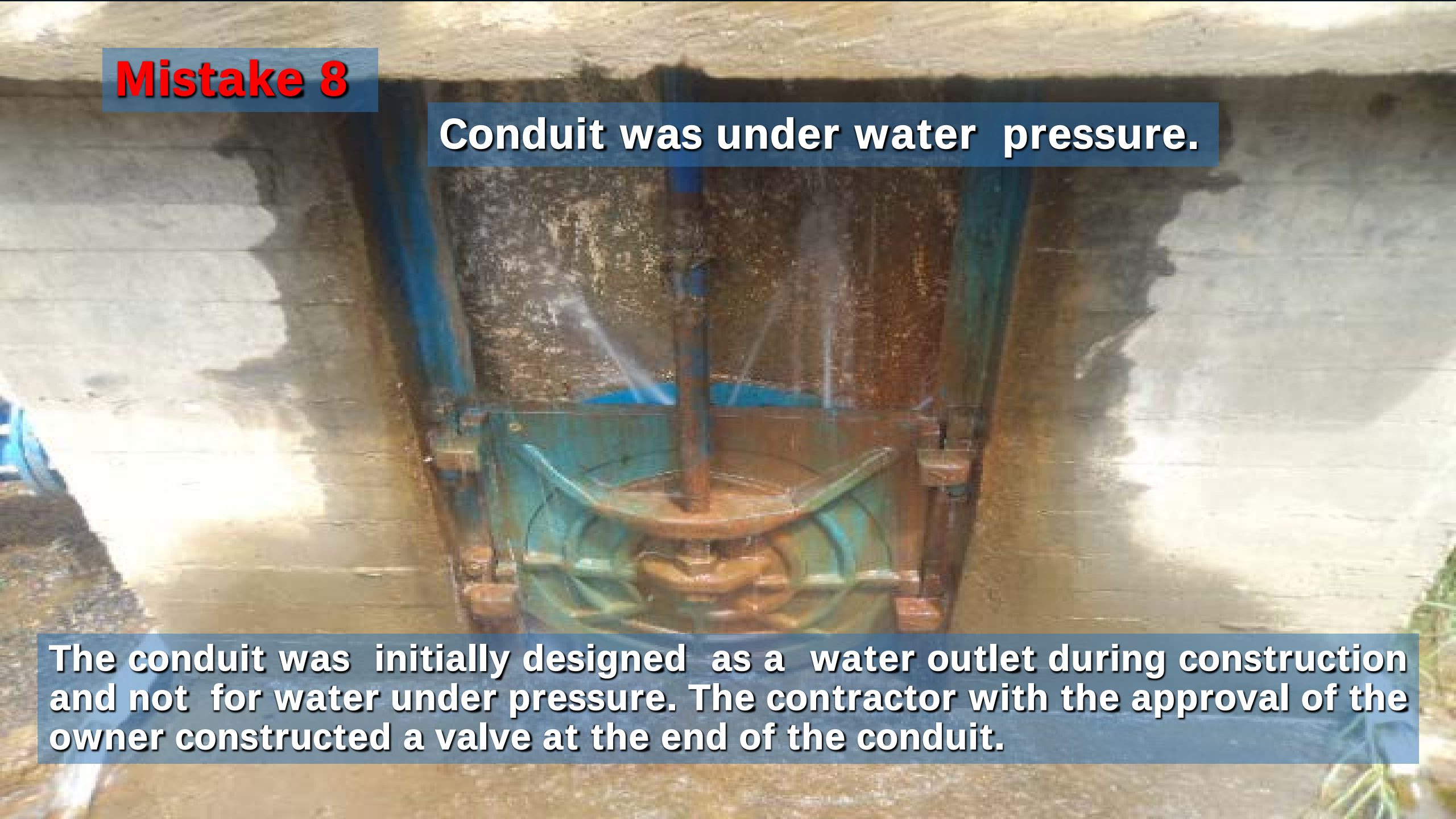
Small granular drains along outlet conduit

Most drains were Geo-synthetic drains
They did not have enough capacity to manage the water filtrations.

Some organizations reccomend not to use geosynthetics in drainage systems of earthen dams.

FEMA: "geotextiles should only be used in non-critical areas of embankment dams."





Mistake 8

Conduit was under water pressure.

The conduit was initially designed as a water outlet during construction and not for water under pressure. The contractor with the approval of the owner constructed a valve at the end of the conduit.

Mistake 9

Small trench drains parallel to the outlet conduit

INSTALACIÓN DE GEODREN PARALELO A LA TUBERÍA DE 36" QUE DESAGUA EL GEODREN CENTRAL

CAPA DE TRITURADO EN EL GEODREN PARALELO A LA TUBERÍA DE 36"

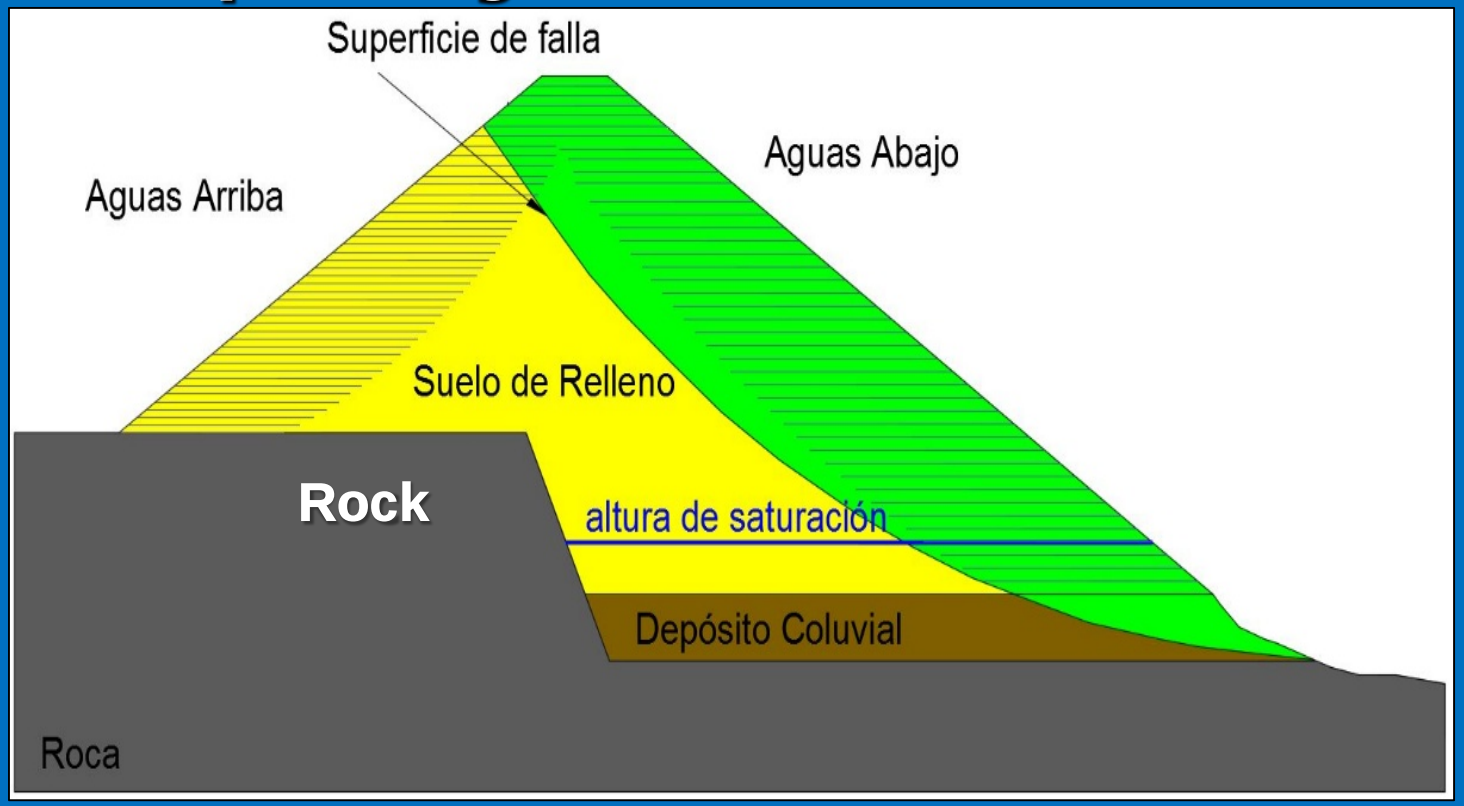
The contractor built small gravel trench drains along the reinforced concrete conduit.

The behavior of the conduit was investigated

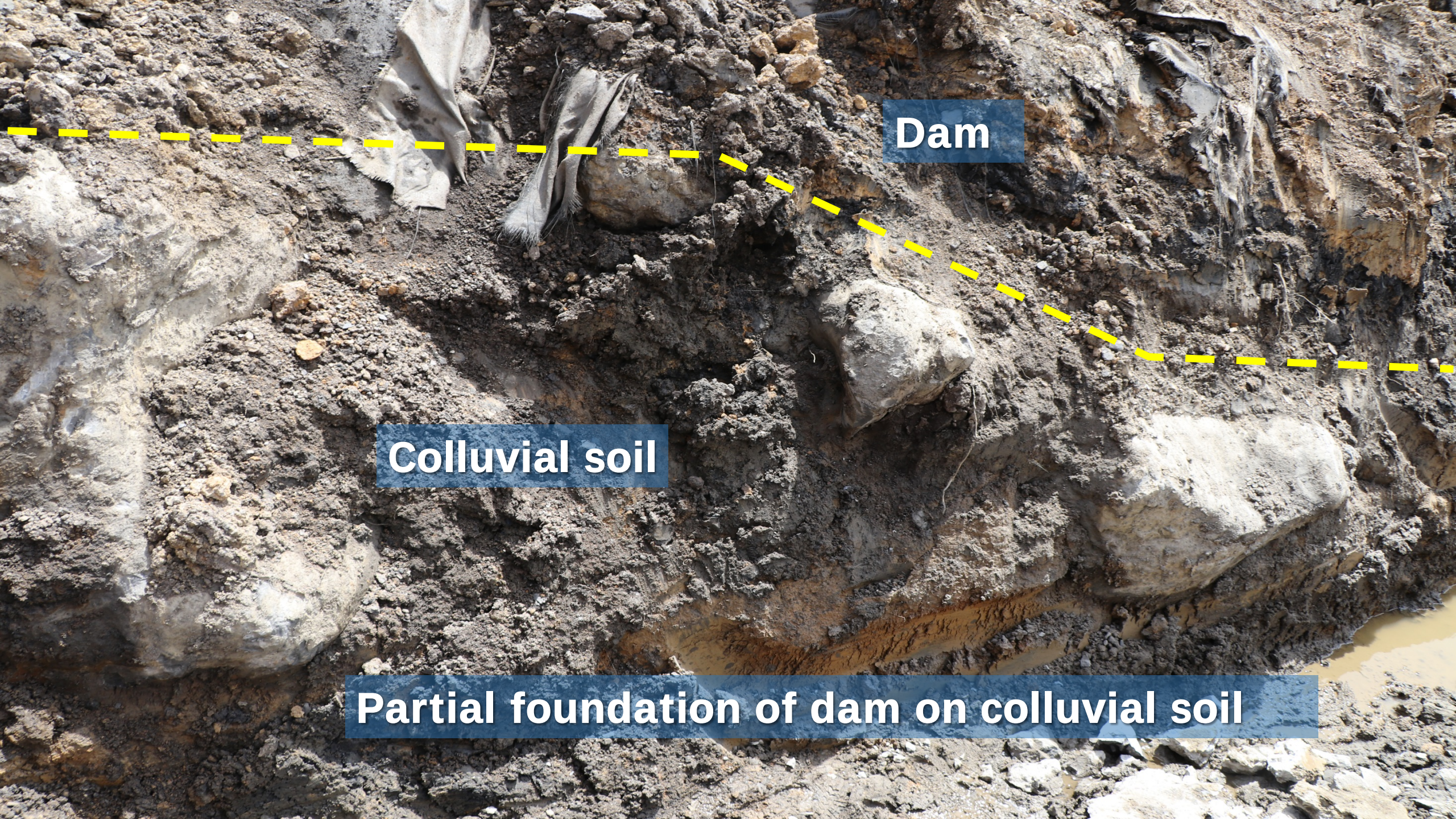
Excavation for conduit investigation

Mistake 10

Non uniform and not deep enough foundation.



The dam foundation and the conduit was partially on rock and soil. This produced non-uniform settlements of the dam and the conduit.


Dam
Colluvial soil
Partial foundation of dam on colluvial soil

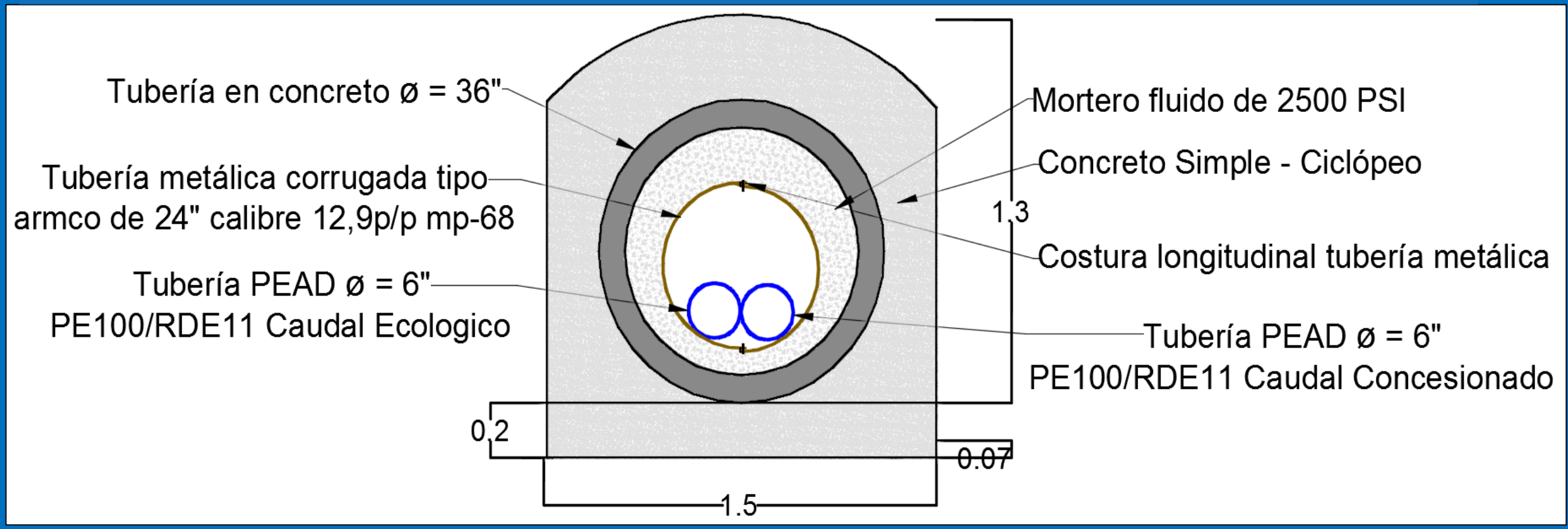

During construction the conduit broke due to non-uniform settlements

Reinforced concrete conduit affected by non-uniform settlements

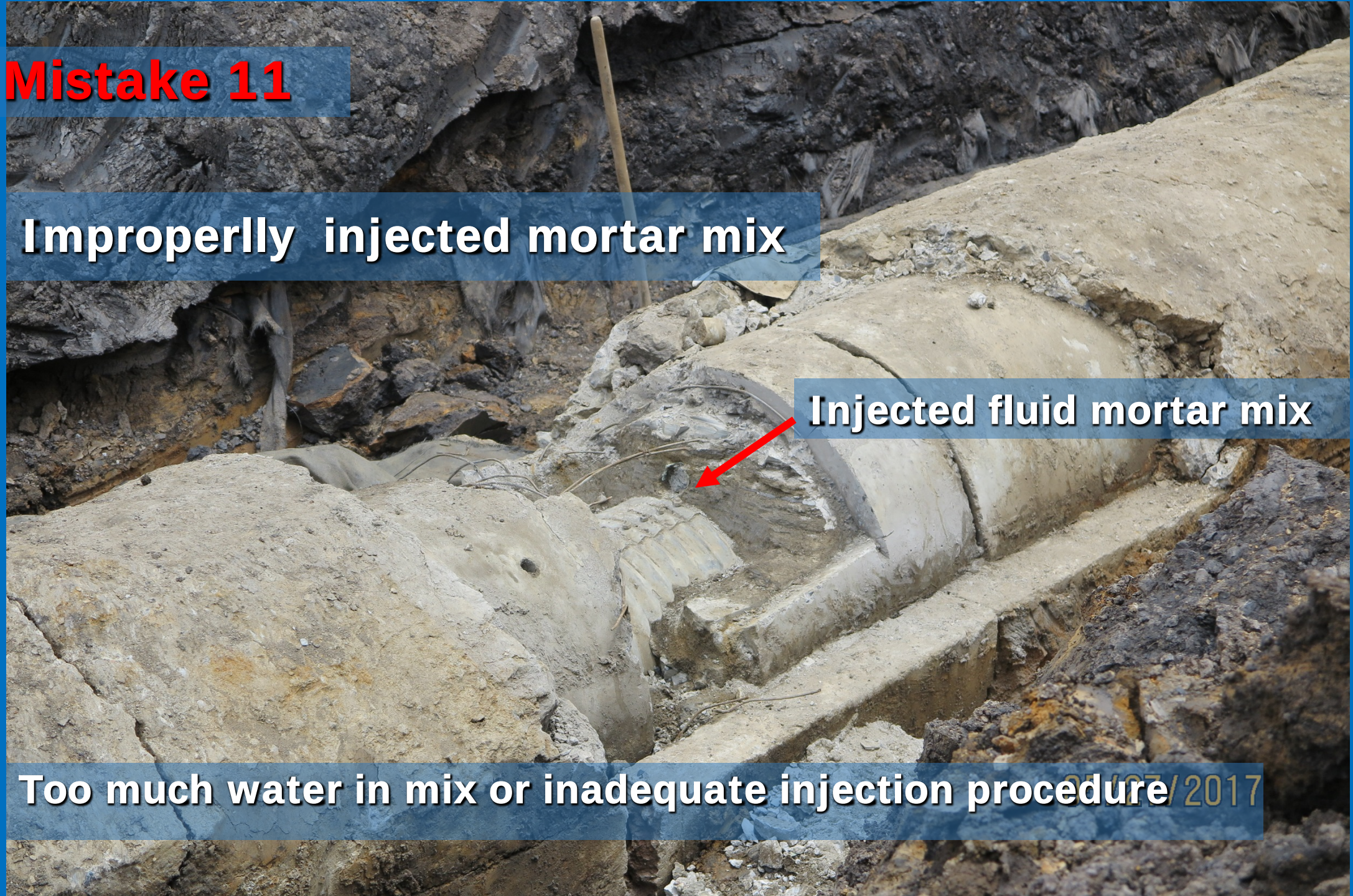

Cracks on the conduit

Solution implemented by the contractor:

The contractor introduced an additional smaller metallic conduit with fluid concrete between the two tubes

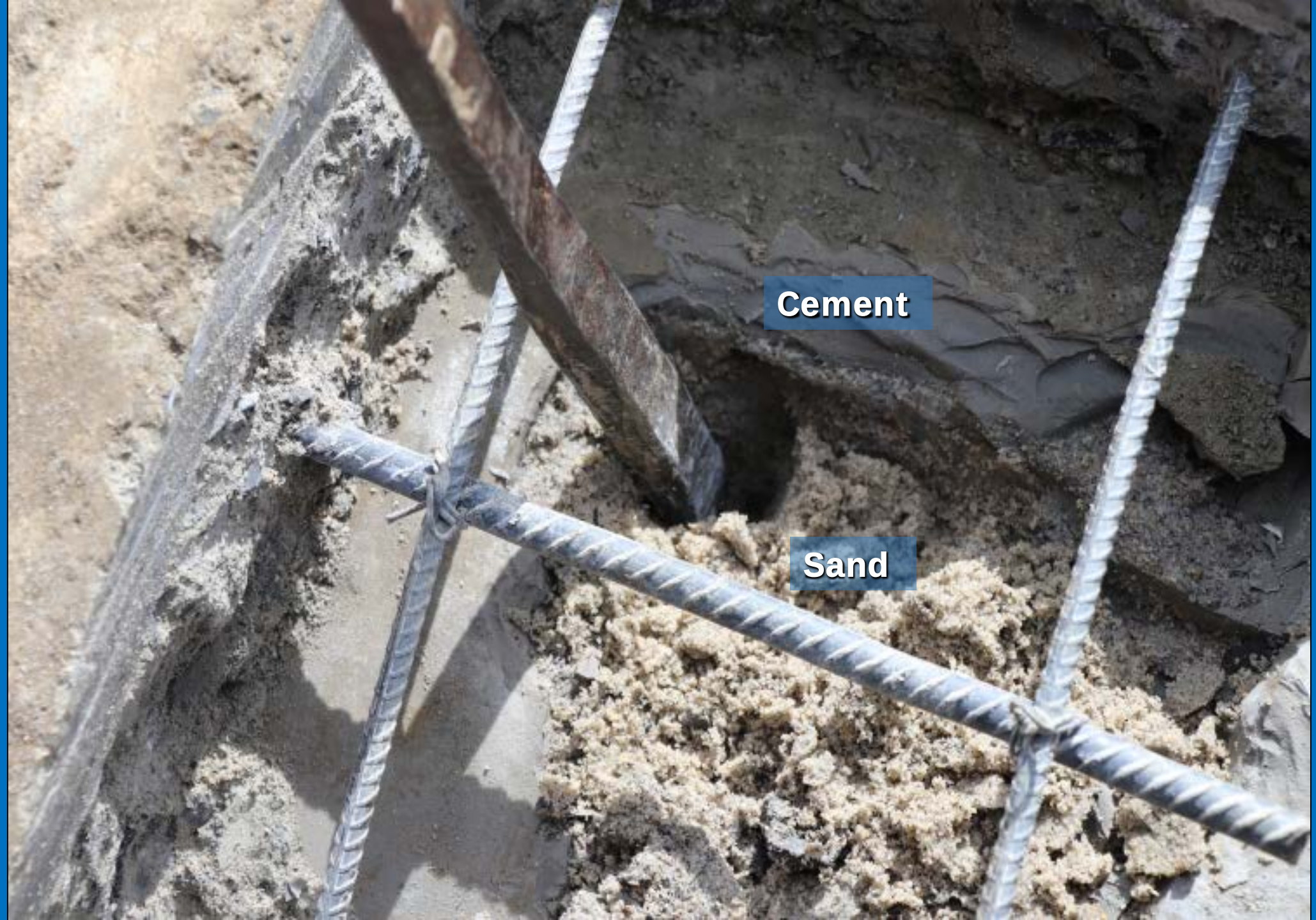



Concrete cover
36 inches reinforced concrete conduit
Injected fluid mortar
24 inches Metallic conduit


Mistake 11
Improperlly injected mortar mix
Injected fluid mortar mix
Too much water in mix or inadequate injection procedure

There was sedimentation in the fluid concrete and the solution did not work.

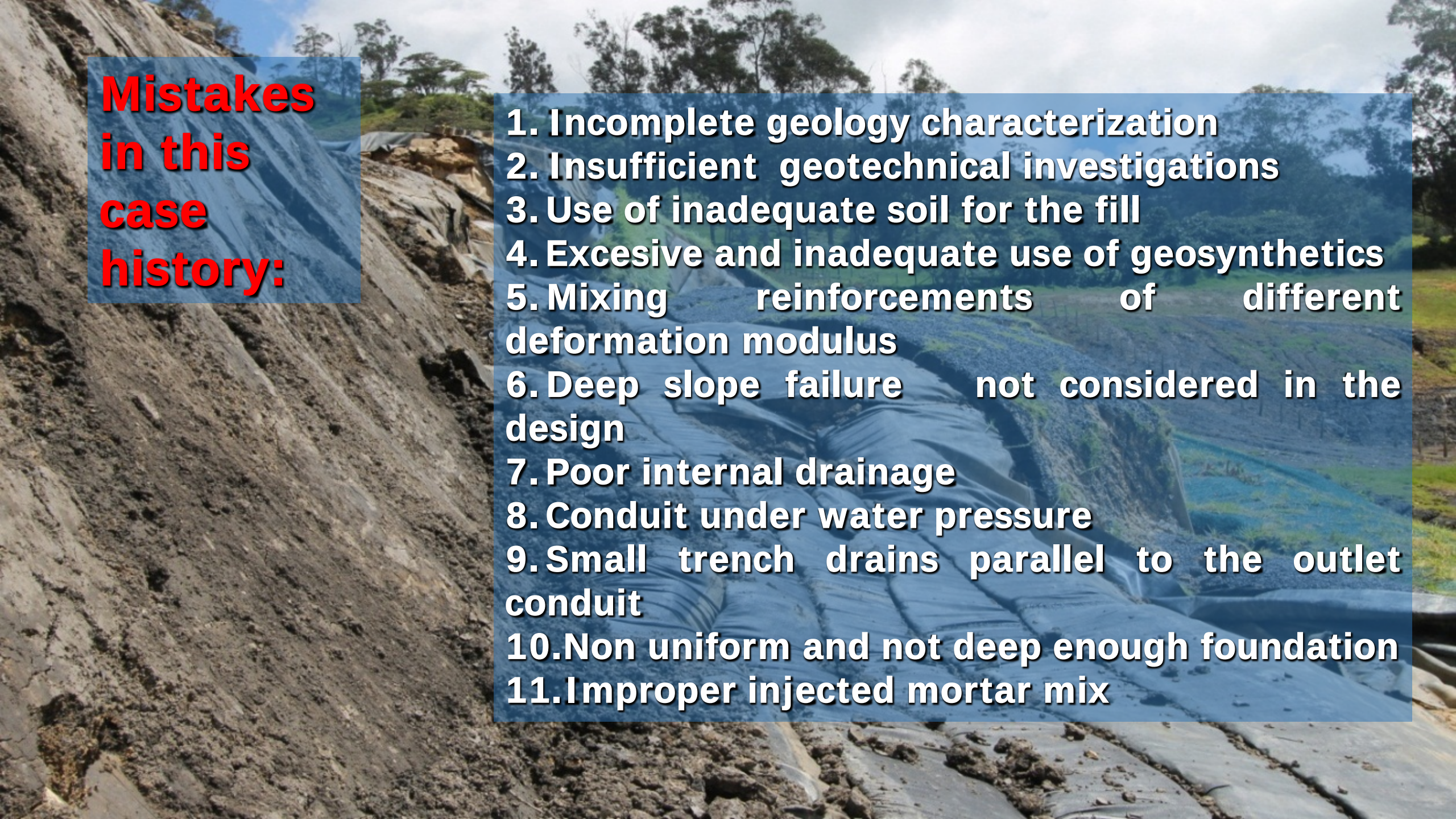

Sedimentation of fluid mortar
Cement
Sand


Cement
Sand

Summary

Mistake: “An act or judgement that is misguided or wrong”

Some of the most valuable engineering lessons have come from projects where errors have been made clear in retrospect



Mistakes in this case history:

1. Incomplete geology characterization
2. Insufficient geotechnical investigations
3. Use of inadequate soil for the fill
4. Excesive and inadequate use of geosynthetics
5. Mixing reinforcements of different deformation modulus
6. Deep slope failure not considered in the design
7. Poor internal drainage
8. Conduit under water pressure
9. Small trench drains parallel to the outlet conduit
10. Non uniform and not deep enough foundation
11. Improper injected mortar mix

Failure retrospective

Picture one week after filling the reservoir

Water escaped from the broken conduit to the longitudinal drains.

Video one week before failure

Flow on the white conduit comes from drains along the main conduit.


Small amount of water flowing from geosynthetic planar drains.

Two weeks after the reservoir fillep up slope failure started.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Thank you for inviting us to share this lesson with you.


And a special gratitude to our research team
Muchas gracias
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