Overcoming the Challenges to Complete the Central Cordillera Crossing

La Linea Tunnel

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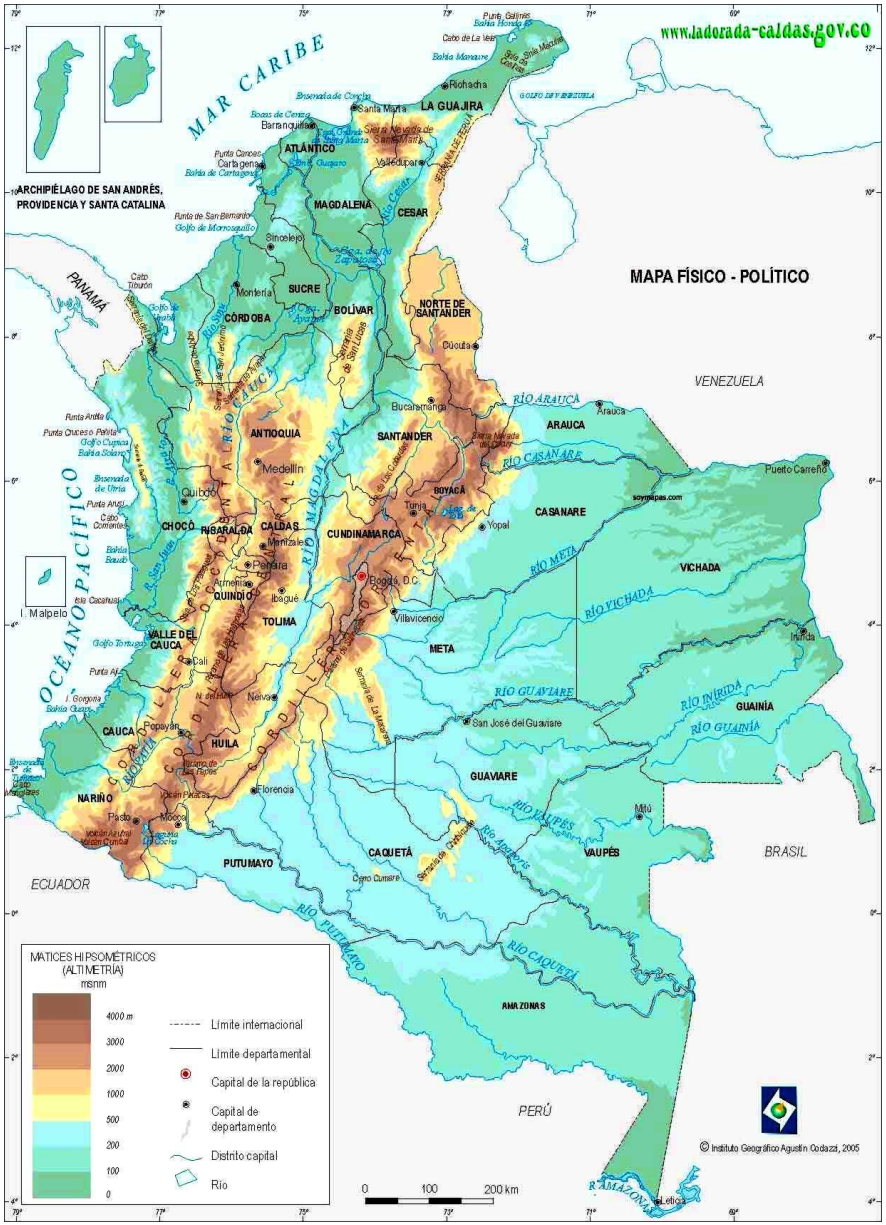
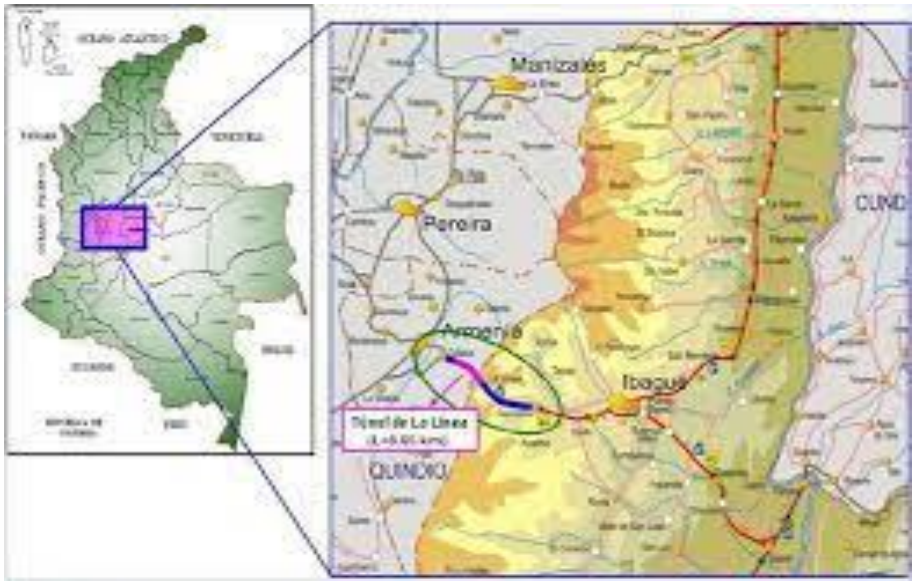
Strategic Importance of the Central Cordillera Project





Calarcá - Cajamarca
La Linea tunnel

Benefits of the Central Cordillera Crossing

Expected reduction of accidents

95%

Average speed increase

15 km/h to 60 km/h

The transit between Calarcá and Cajamarca will take

30-50 min

for light or heavy vehicles. Previously, this journey could take up to 3 hours

Reduction of

850

hours per year

of road closures

Travel savings of

12 km

due to reduction of road length

MAIN PROJECT WORKS

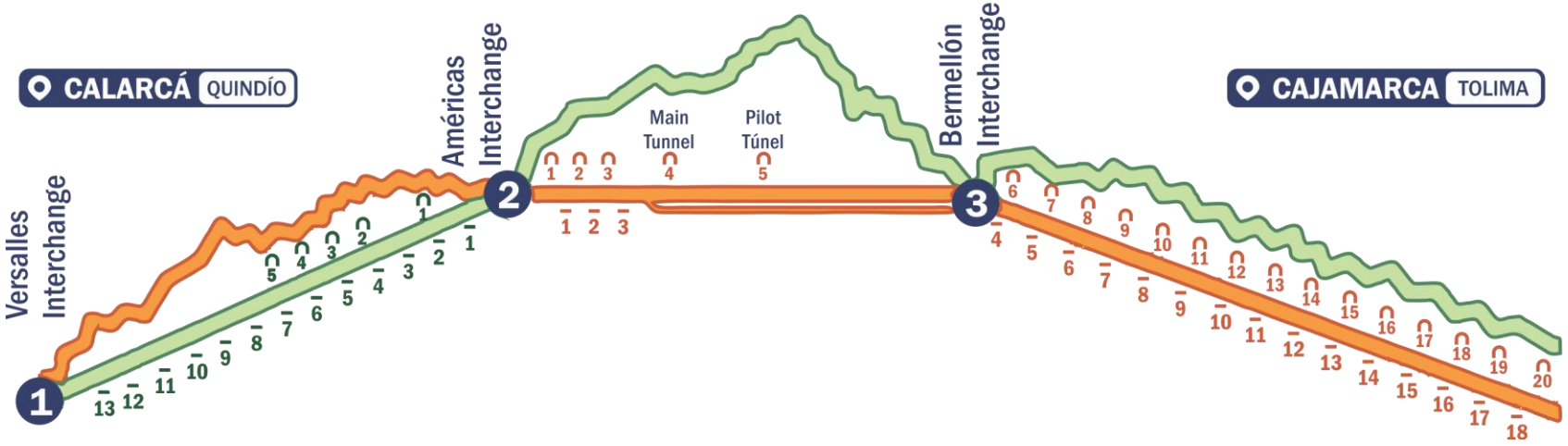
Budget = Approx.. USD $ 850 million.
La Línea Tunnel = 8.6 km – Longest road Tunnel in operation in LATAM.

CONVENTIONS

- Works in the direction of Cajamarca - Calarcá
- Works in the direction of Calarcá - Cajamarca
- Tunnels — Bridges ● Interchange

60 WORKS

- 30 km New double traffic lanes
- 40 km Of improved road
- 25 tunnels (22 km)
- 31 bridges (5 km)
- 3 Interchanges



Project timeline

Beginning

1902
First discussions to build a tunnel through the Central Cordillera

1913
First Alignment for a railroad tunnel

1980
Feasibility studies

2000
First failed tender process- No insurance policies or bonds

2005
Pilot tunnel construction

2007
Second tender process failed. LS

2008
Award of contract for main tunnel UTSG

2009
Construction begins main tunnel

2016
Contract terminated 2008.

2017
Second contract project

2020
Sept. Main tunnel completed

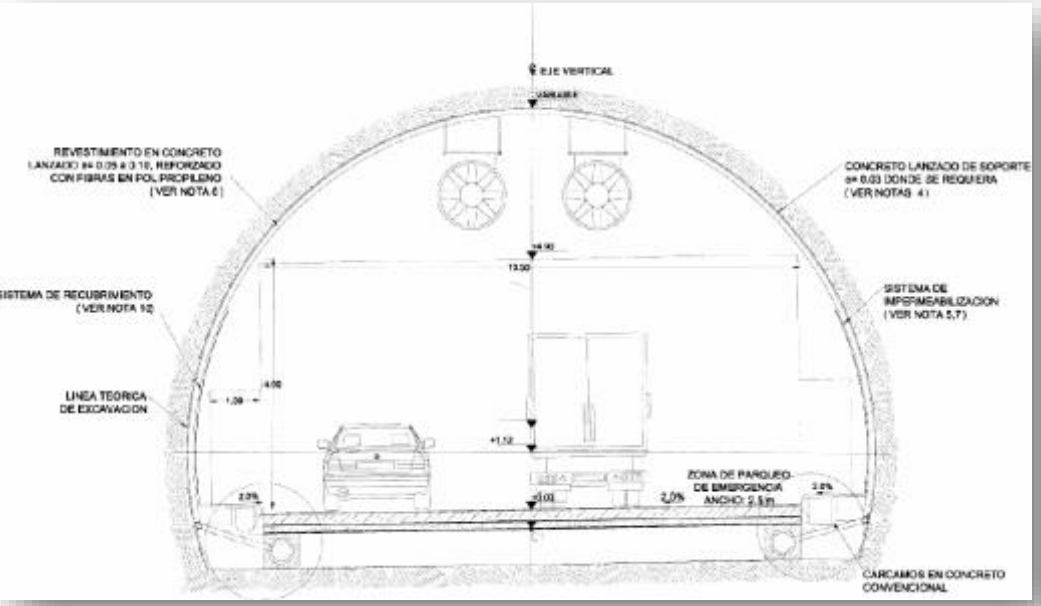
2021
Nov.
Completion of completion of corridor

HORSESHOE BRIDGE/ YARUMO BLANCO

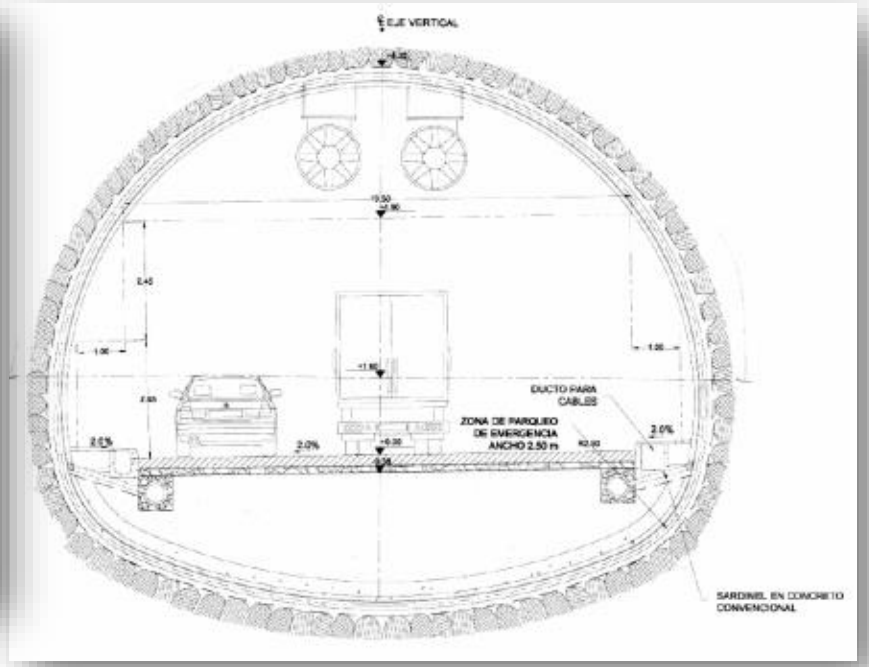
L=640M

Tunnel Cross Sections

Flat Invert Section



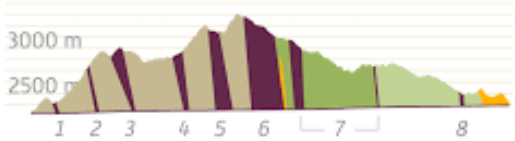
Curved Invert Section



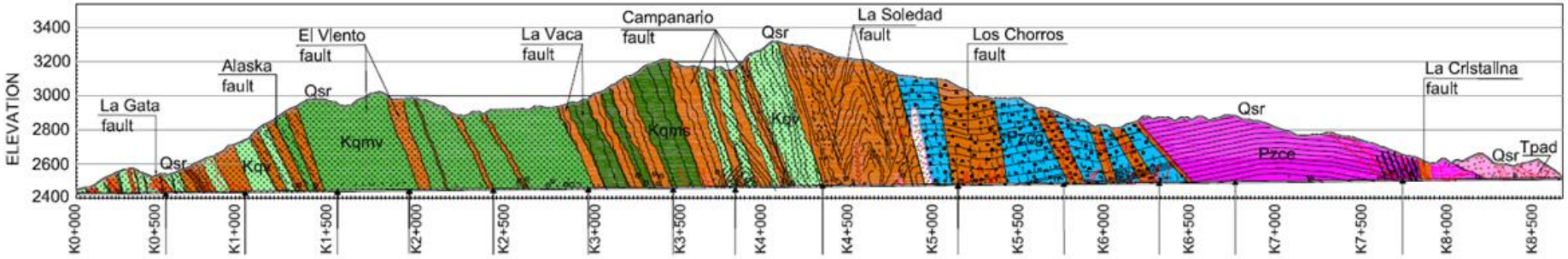
- Length= 8651,57 m
- Semi-circular section (variable radii depending on ground type)

•2 traffic lanes w=3,65 m.
•Safety zone w= 0,35 m, each lane.
• Safety parking zones with extra width of 2.5m
• 1m Sidewalks
• 4.9 m minimum clearance on on each side.

REGIONAL GEOLOGIC CONTEXT

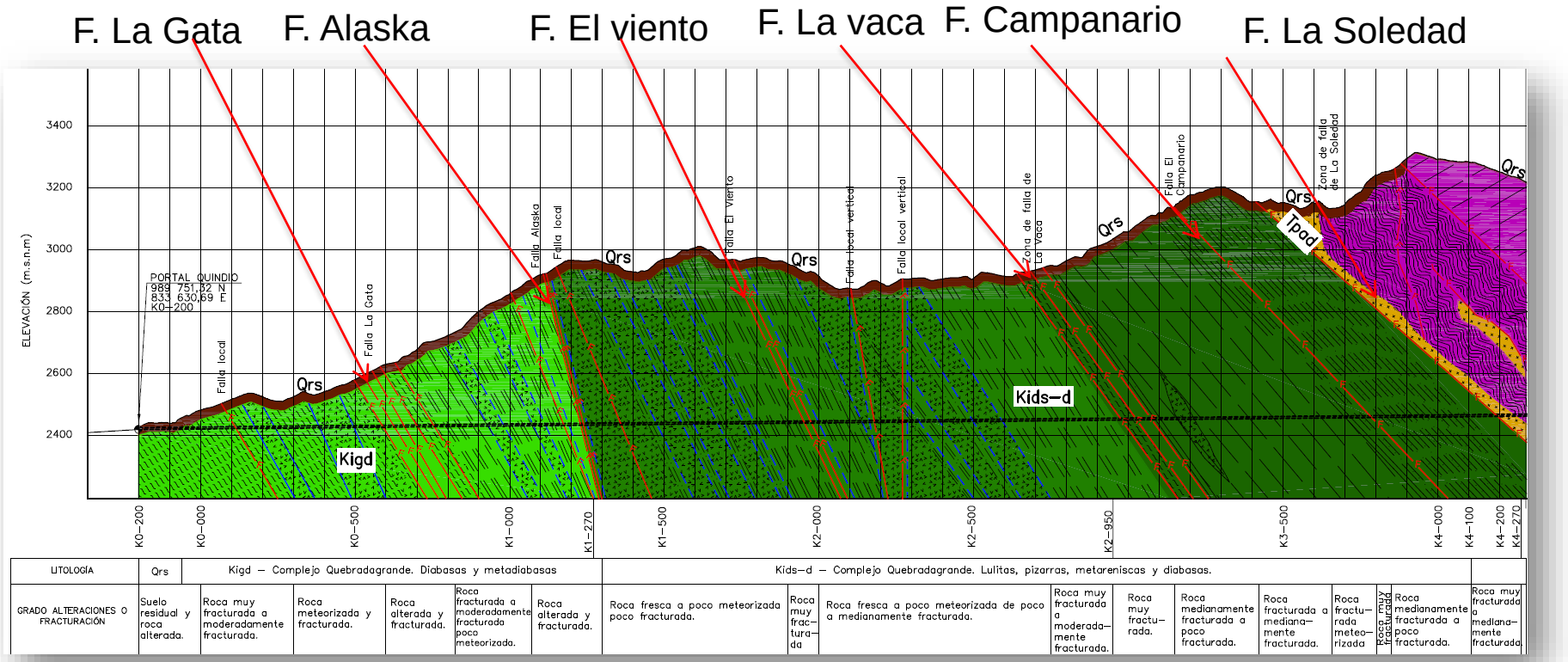


1- Zona de Influencia - **Falla La Gata**
2- Zona de Influencia - **Falla Alaska**
3- **Falla El Viento**
4- **Falla La Vaca**
5- **Falla Campanario**
6- **Falla La Soledad**
7- Zona de Influencia **Falla Los Chorros**
8- **Falla La Cristalina**



Tpad	Volcanic porphyry and andesites rocks, aphanitic texture and high hardness.	Kqms	Sedimentary volcanic unit of metadiabases (phyllites), meta shales, metasandstones, of carbonaceous quartz composition.
Kqv	Sedimentary volcanic unit of green and gray diabases and metadiabases, partially foliated.	Pzcg	Blue-green and grayish gabbros, hard with gneissic texture, with some interspersed hard gray schists.
Kqmv	Metamorphic unit of Cajamarca Grande complex chloritic quartz green schists, metadiabases, basalts.	Pzce	Cajamarca complex of green schists and sericite quartz of tin hardness, interspersed with graphite black schists.
	Fault zone		

Geologic Conditions-Western Sector



Metasedimentary – volcanic rocks

Ingetec (2008)

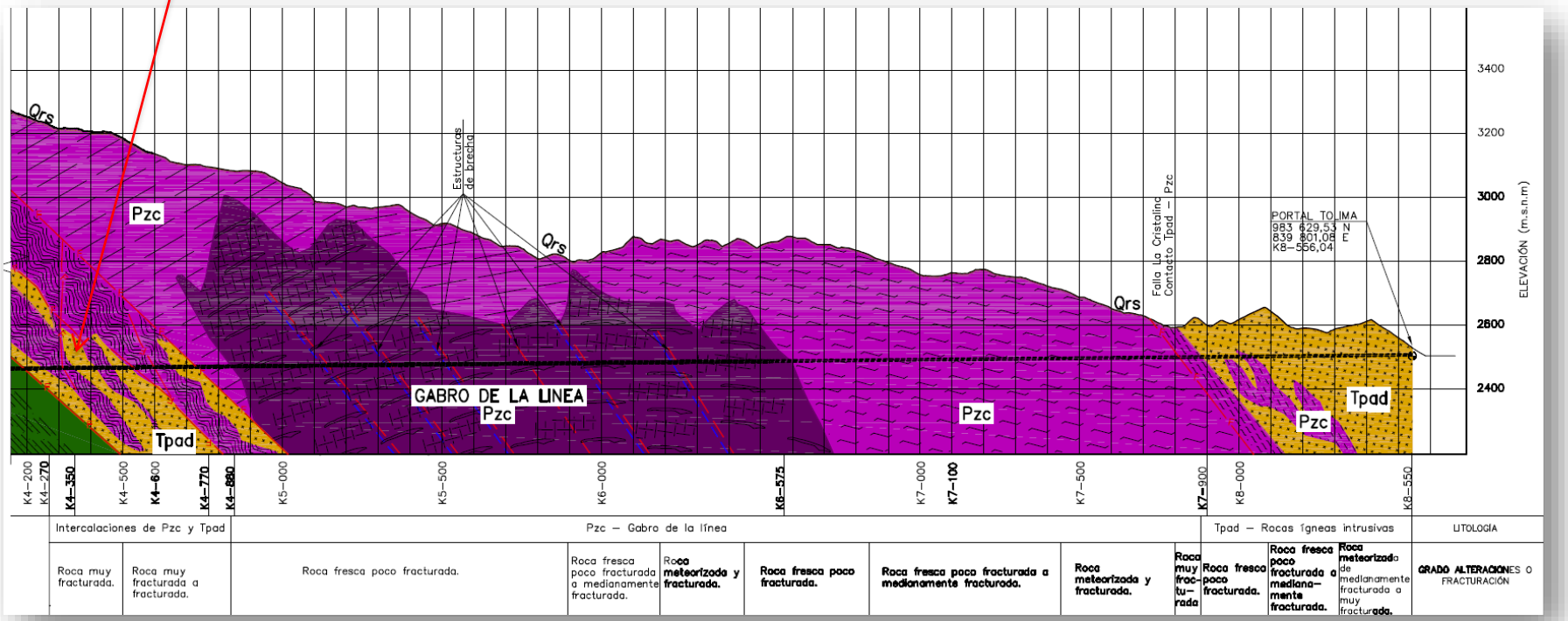
CONVENCIONES

UNIDADES LITOLÓGICAS

- **Kigd** — Complejo Quebradagrande. Cretáceo – Vólcanico tectonizado. Diabasas y metadiabasas.
- **Kids-d** — Complejo Quebradagrande. Cretáceo – Sedimentario volcánico. Lulitas, pizarras, metareniscas y diabasas.
- **Tpad** — Rocas ígneas intrusivas porfiriticas andesico dacitas.
- **Pzc** — Gabro de la Línea.
- **Qrs** — Suelo residual.

Condiciones geológicas- Sector Oriental

F. La Soledad



Igneous rocks

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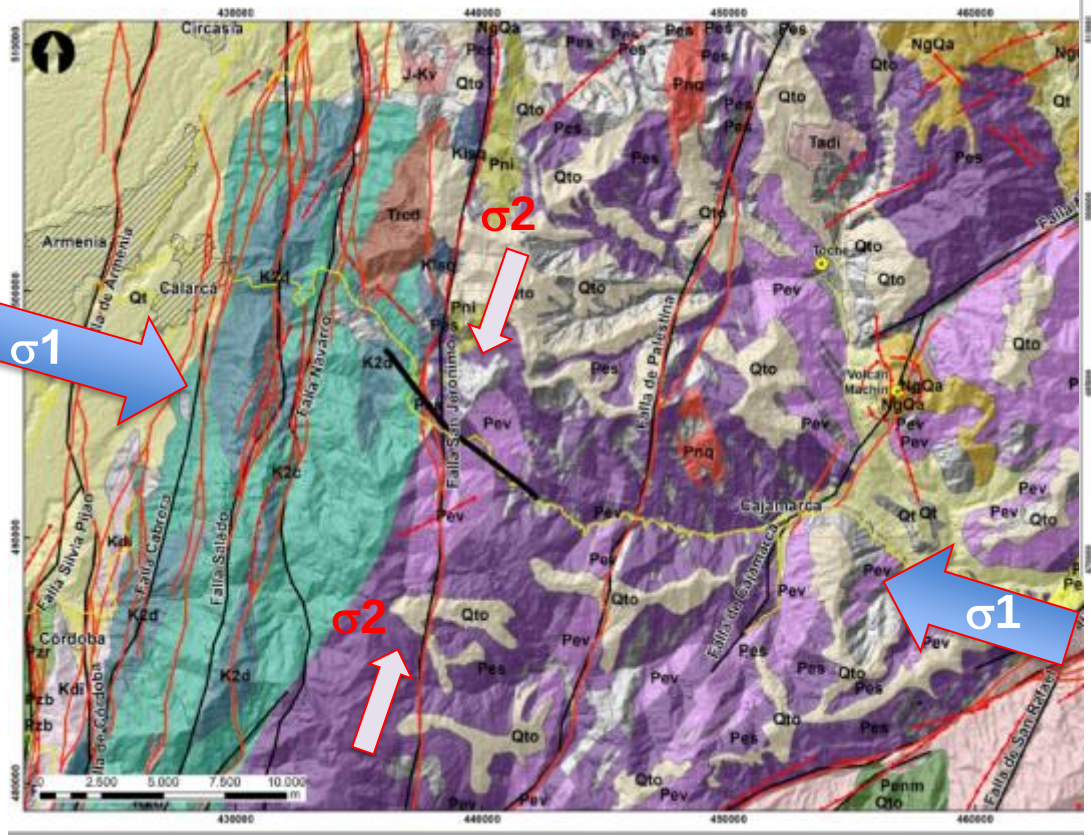
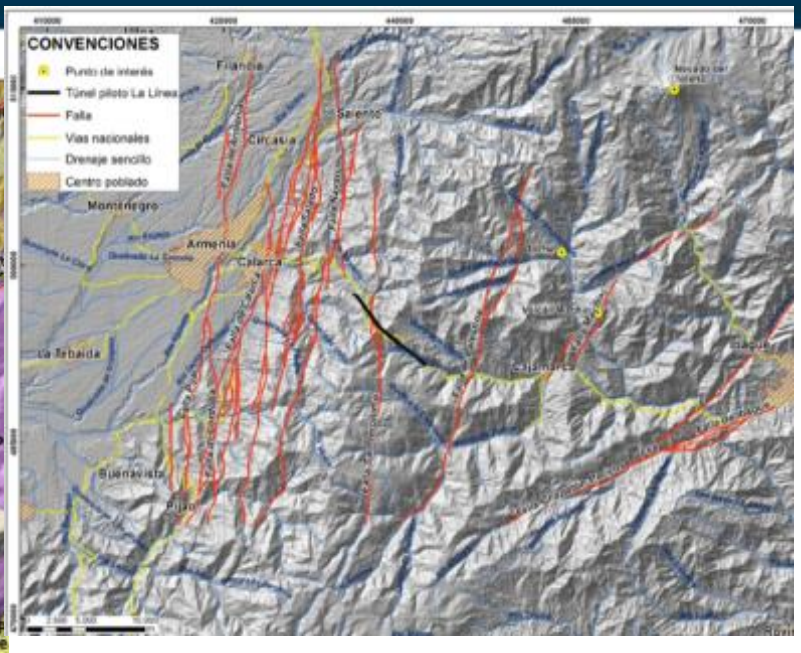
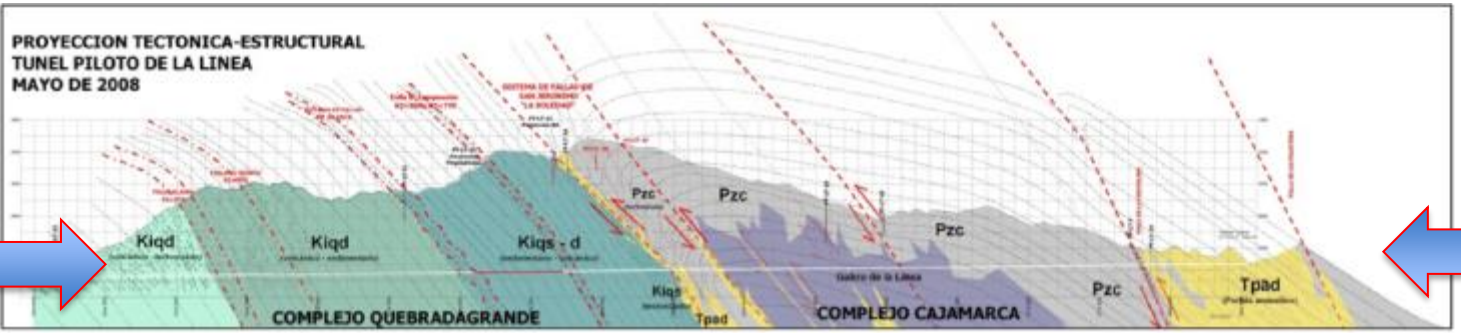
Ingetec (2008)

GEOLOGIC CONDITIONS- IN SITU STRESSES







$K = \sigma h / \sigma v$

UTSC CONTRACT (UNIÓN TEMPORAL SEGUNDO CENTENARIO) 2009

1. Turnkey type of contract. **Lump sum. All geological risk transferred to contractor.**
   Contract Value in 2008 approx. USD 315m ($629.052 million Col. Pesos. Final value of $975.511 million. Increase of $346.459 million. (55% increase of initial budget)

2. Contract initial period 70 months. Should have been completed by 2015. Four extensions, adding to 39 additional months. (55% extra time).

3. Significant quality problems. Supposedly only 12% of scope was pending.

4. The technical solutions to stabilize the most challenging fault sections were ineffective.

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Failed to Apply Good Contractual Practices for Underground Works

1. It is the Owner who will benefit from the completed project. Thus, the ground belongs to the project Owner.
2. The Owner has the responsibility to pay reasonable costs required to handle ground conditions.
3. Risk should be allocated to the party that can best control it.
4. Transferring the geological or geotechnical risk completely to the contractor gives the owner a false sense of security.

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5. Balanced and equitable allocation of ground related risks leads to lower cost of the works and more competitive bids.
6. A changed conditions clause should be included in underground construction contracts. Disclaimers and exculpatory language should be eliminated.
7. All available data and interpretations should be disclosed to bidders.
8. Alternative dispute mechanisms implemented

ELEMENTS REQUIRED TO IMPROVES SUBSURFACE RISK MANAGEMENT

1. Incorporate a differing conditions clause in the contract.
2. Include a Geotechnical Baseline Report (GBR) in the contractual documents
3. Consider a unit price compensation systema for items affected by ground conditions.
4. Use a contractual ground classification system that reflects the excavation and support effort and costs. Not a geomechanical classification system.
5. Implement time and cost adjustment procedures for the conditions encountered during the excavation vs. Those anticipated in the GBR.

Risk Allocation in the FIDIC Emerald Book

Risk should be allocated to the party better positioned to assume it:

Ground related risk.

Varying site conditions from those anticipated in the contract documents=> Assigned to the **Owner.**

Performance related risk (unit rates) for the anticipated conditions assigned to the Contractor.

NEW CONTRACT- CONSORCIO LA LÍNEA 2018

1 Unit Price based contract

2 First activity included a diagnosis of the Works after the termination of the UTSC contract

3 Included designs to finalize the project

4 Effective solutions implemented to stabilize the fault zones and finish the Works.

MAIN PROBLEMS ENCOUNTERED DURING THE INITIAL DIAGNOSIS

1. Main tunnel in **marginal safety condition** in fault zones. Severe convergences. Continued deformations.
2. **Much larger loads on the concrete lining than those considered in the design.**
3. No provision for reactivation of squeezing due to roc **rock creep.**
4. Deficient and incomplete documentation of the works.
5. Incomplete support. Steel arches without support. Rigid arches and incomplete round inverts in zones of squeezing.
6. Cracking and fissures in the shotcrete of the pilot due to stress distribution. Also in zones where concrete lining had already been installed.
7. Drainage and impermeable geomembrane problems @ main and short tunnels. Exposed geomembranes.
8. Deficient geologic registers. Contradictions between design and as built. Incomplete instrumentation records.
9. Deficient quality controls.
10. Short tunnels with stability problems at the portals. Insufficient lateral cover that led to inadequate confinement.

MAIN DESIGN PROBLEMS IDENTIFIED

RMR variation

Support system design based purely on empirical methods related to a variation of the RMR geomechanical classification

Failure mechanisms

Classification method did not cover failure mechanisms that usually occur in deep tunnels.

Pilot Tunnel

Findings from pilot tunnel, were not properly incorporated. Deformations >10-15% of the excavation diameter were encountered.

Anysotropy

Anisotropic or time-dependent rock mass not considered. Nor relationship between the rock mass deformation and the support, nor the effect of the construction sequence

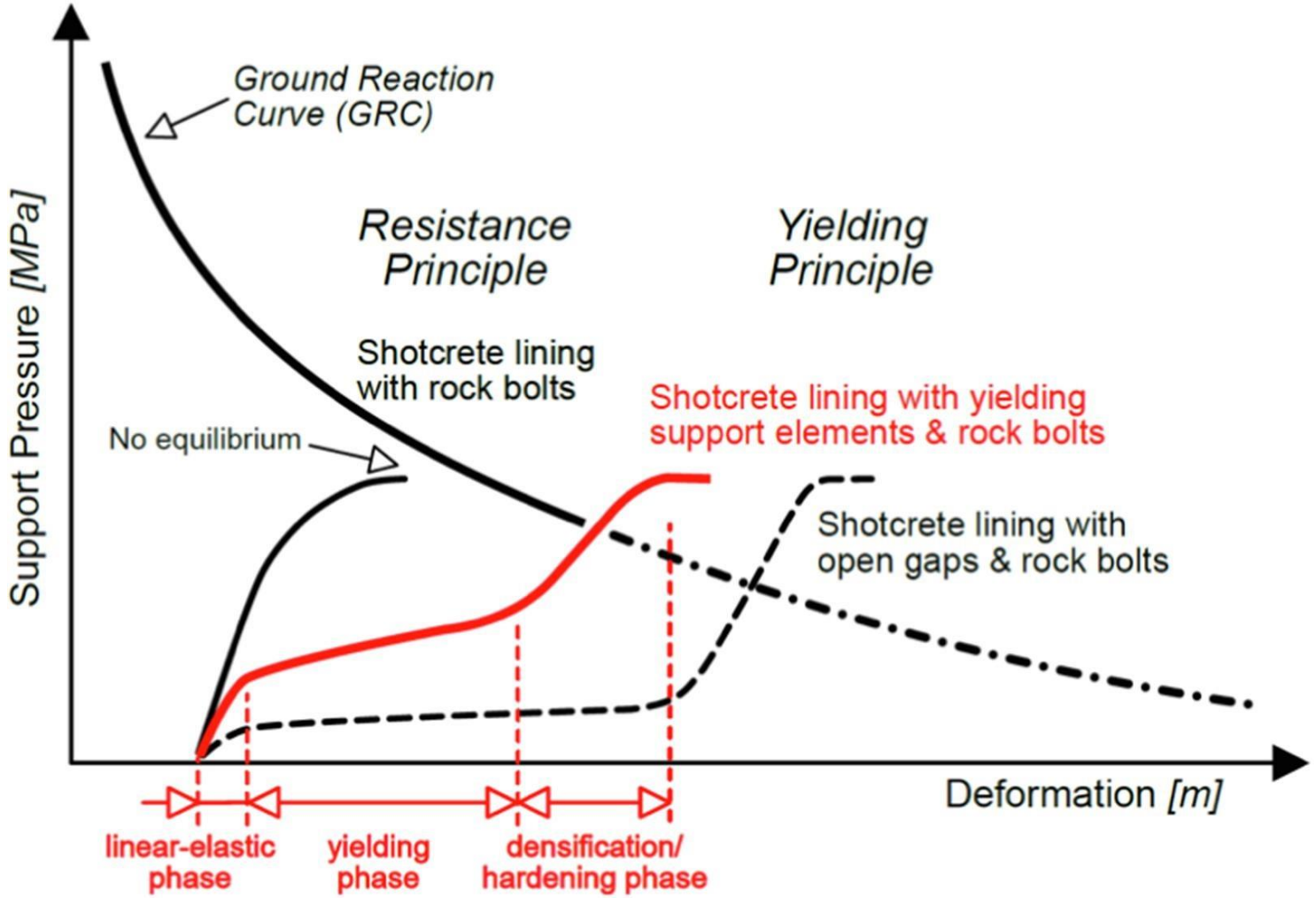
Main stresses

Geomechanical classification did not consider relationship between maximum and minimum in-situ stresses and the relationship with the type of rock, the geometry of the excavation

Rigid Support

Heavy rigid steel set become impractical to stabilize high pressures

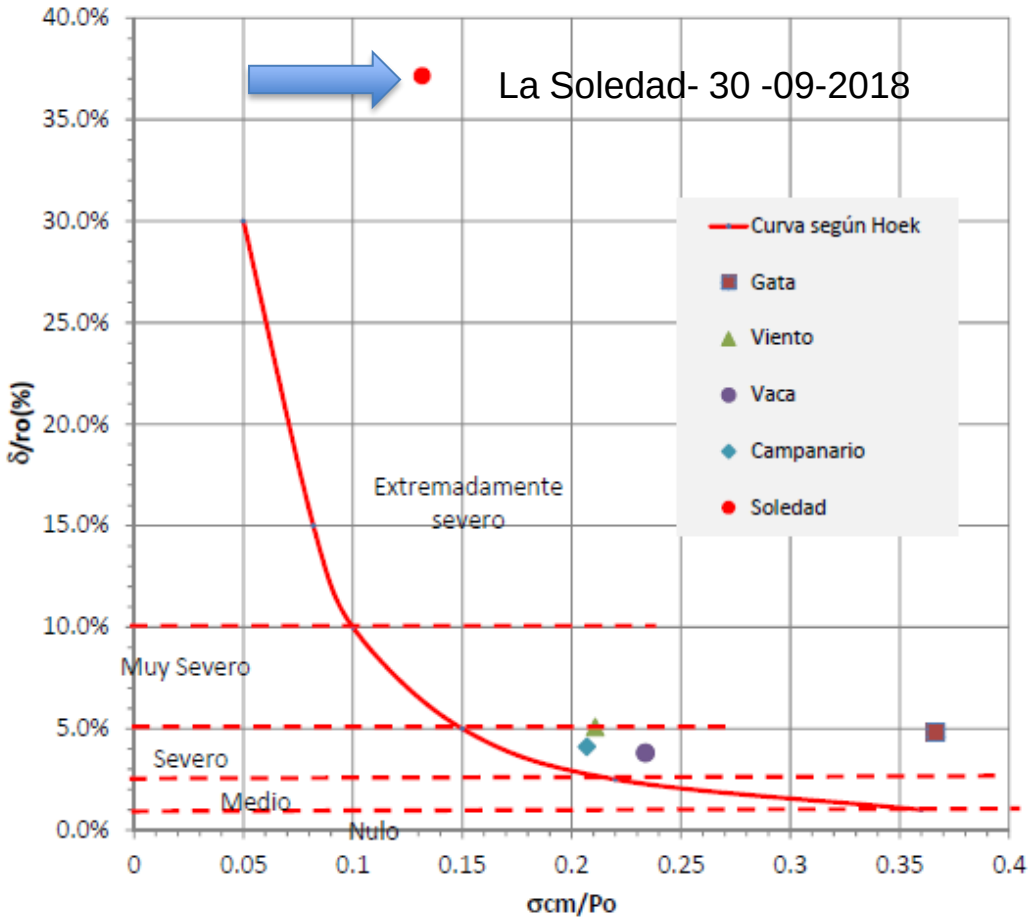
BENEFITS OF FLEXIBLE SUPPORT WERE IGNORED



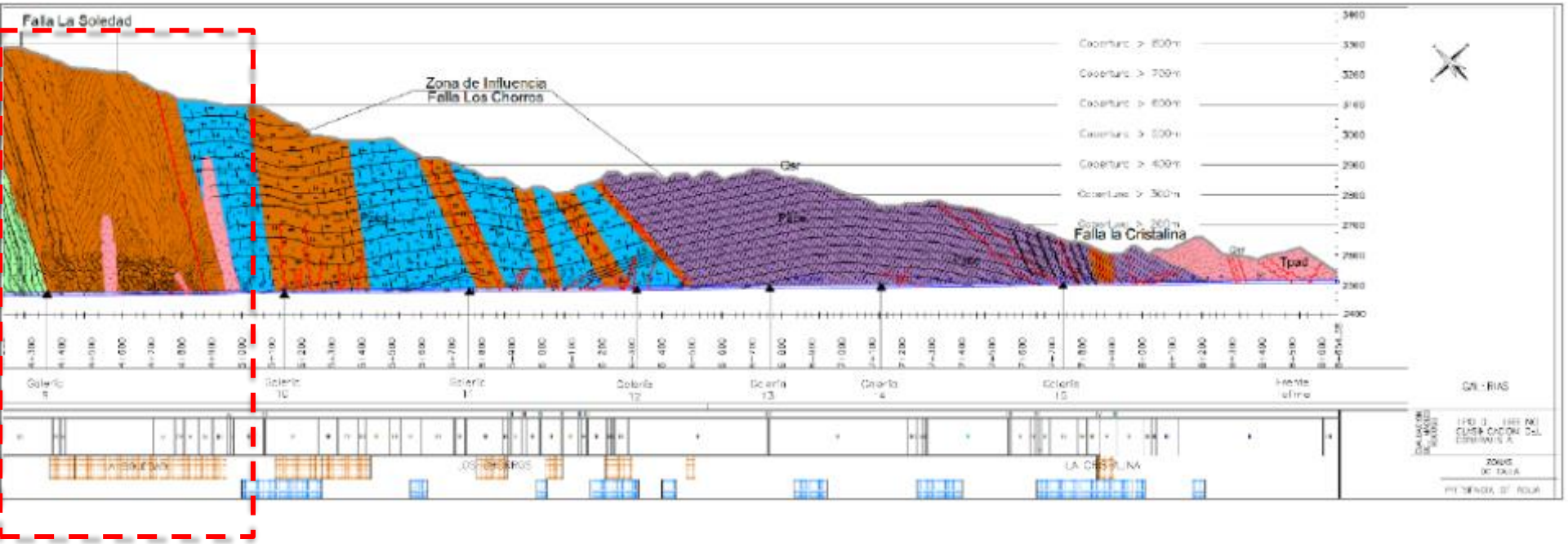
(Entfellner et al, 2023)

MAIN TUNNEL- FAULT ZONES

- Severe to extreme squeezing .
- Creep behaviour.
- Support with rigid Steel sets.
- Curved invert constructed late and incomplete.



LA SOLEDAD FAULT ZONE



DAMAGES ENCOUNTERED IN THE SOLEDAD FAULT ZONE

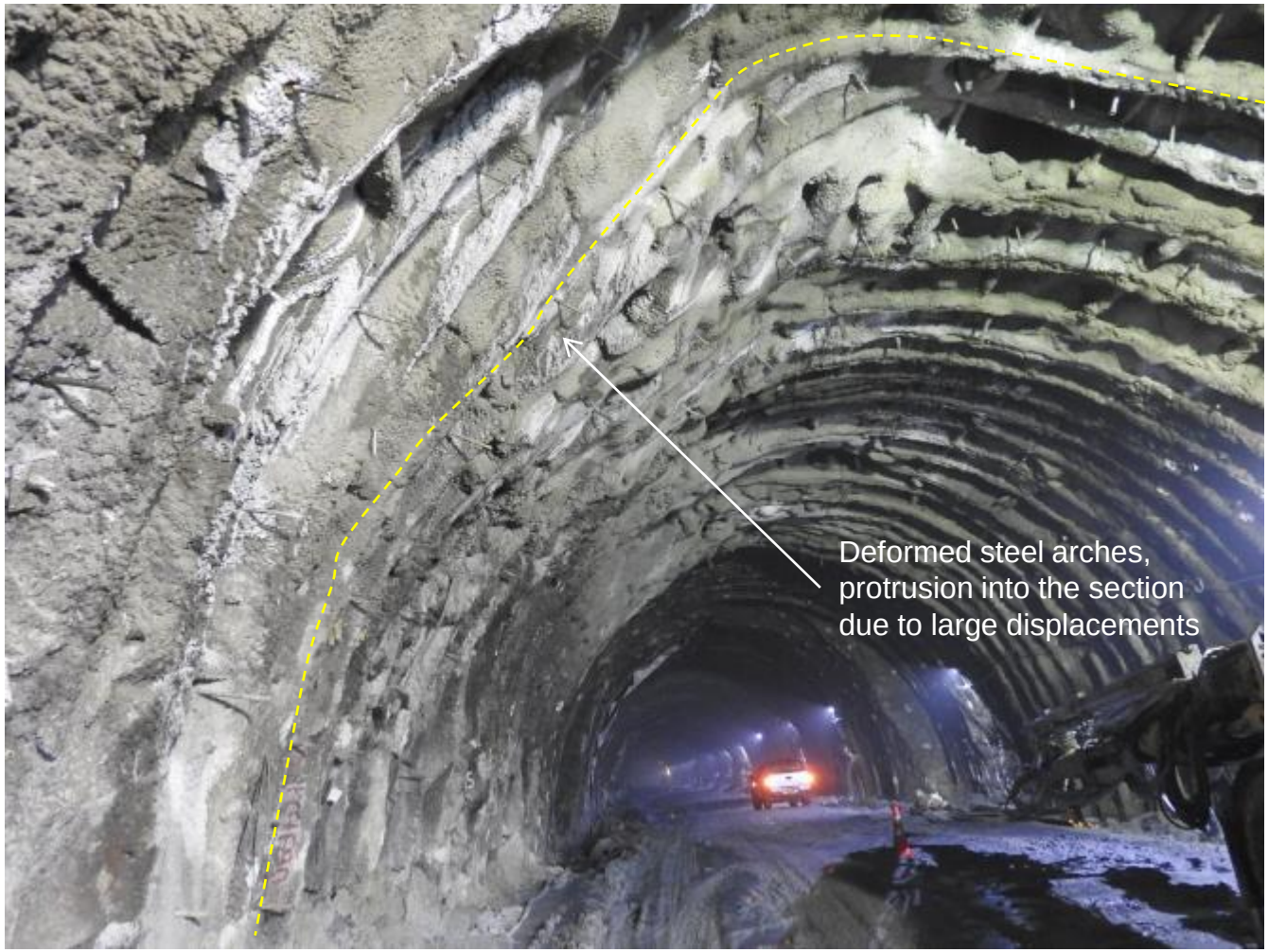
Large displacements and damage to installed support

Damages to the steel sets and shotcrete

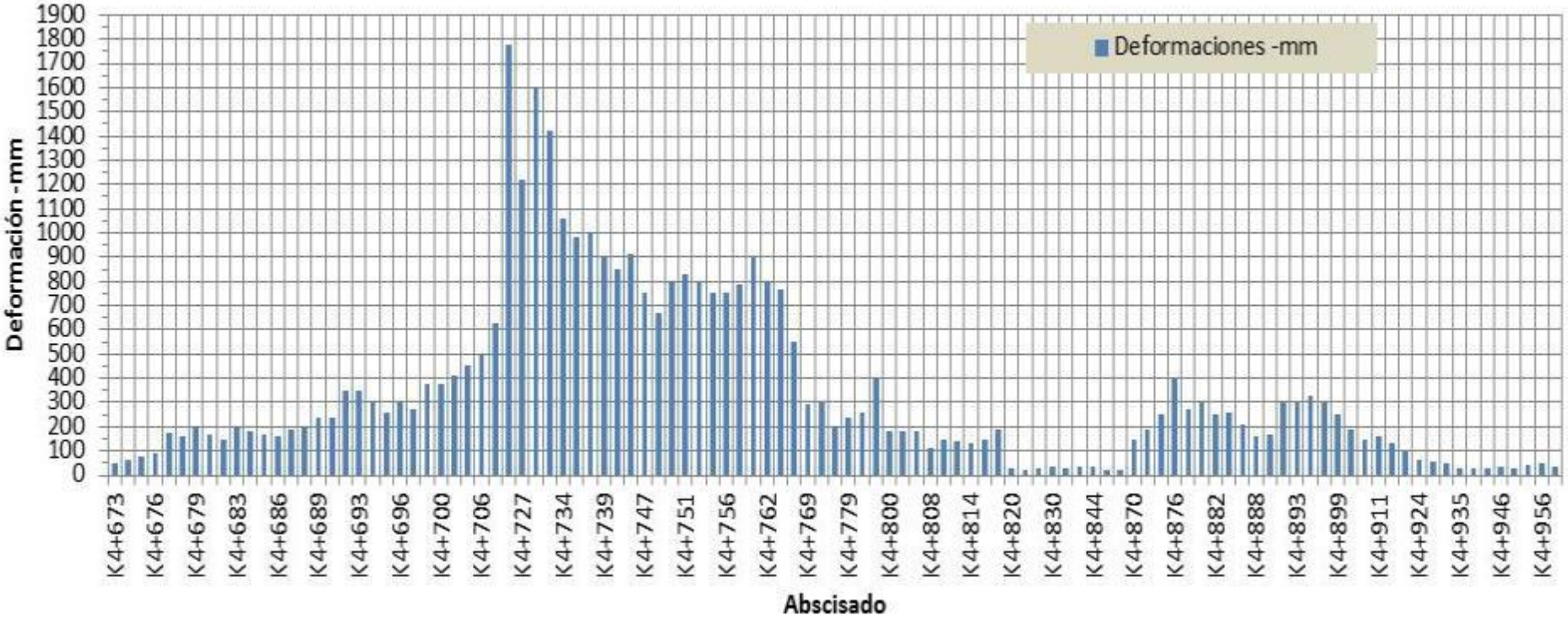
CONVERGENCE AND DAMAGE AT THE SOLEDAD FAULT

Measured convergence in the main tunnel

ZONES OF THE MAIN TUNNEL WITH CROSS SECTION INVADED AND DAMAGED TO STEEL SETS



MEASUREMENT CONVERGENCE DISPLACEMENT AT LA SOLEDAD



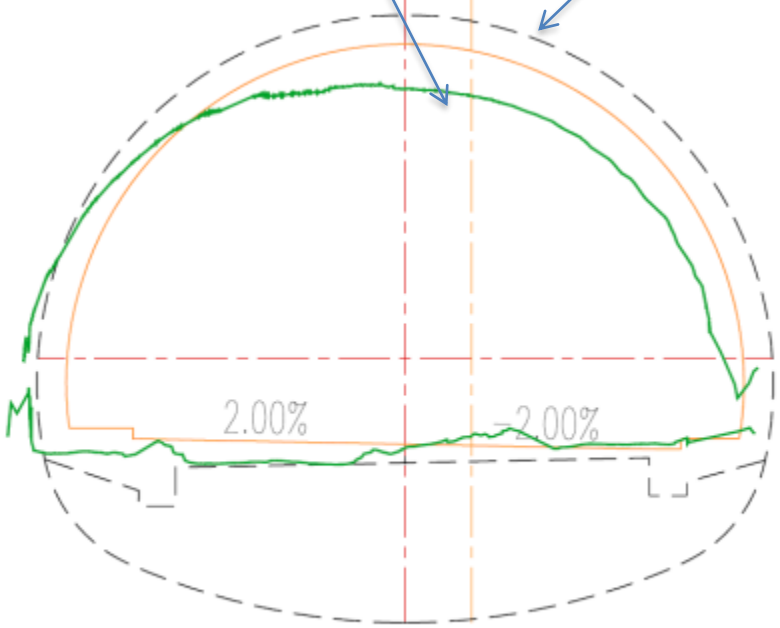
SECTOR OF LARGEST MOVEMENTS

View towards Quindio

CROSS SECTIONS ENCOUNTERED AROUND THE SOLEDAD FAULT

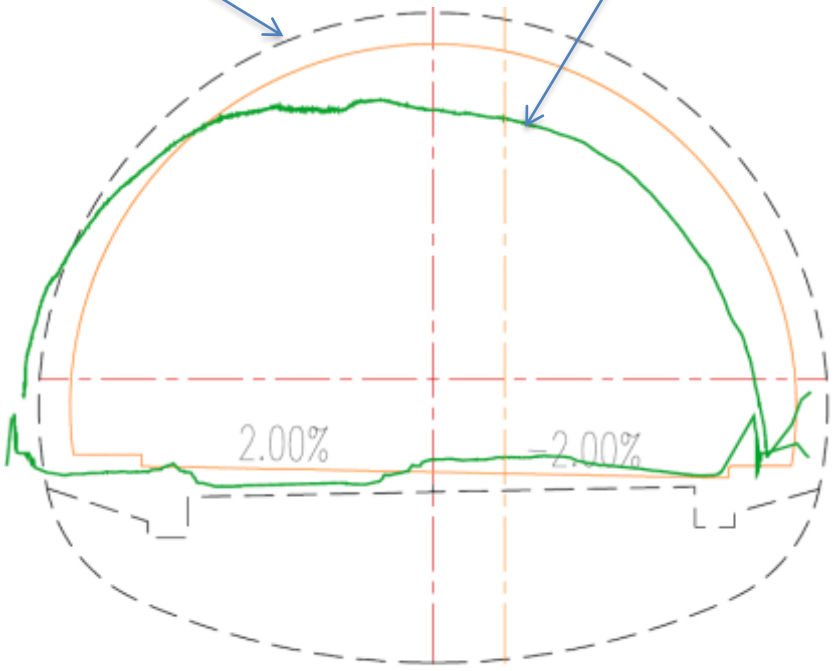
Theoretical Cross Section

Encountered Section



4+705.00
FALLA LA SOLEDAD

Encountered Section



4+710.00
FALLA LA SOLEDAD

FISSURES AND CRACKING IN THE CONCRETE LINED SECTORS

CRACKING IN THE CONCRETE LINED SECTORS

WHERE DO WE START?

RETHINKING THE PROJECT

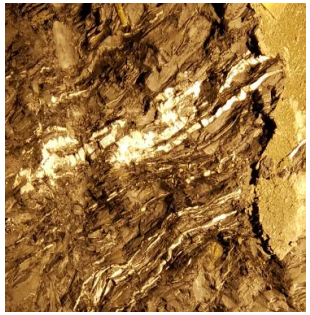
Pilot Tunnel

Analyze Instrumentation

Understand effects of construction sequence

Rock mass Parameters

New tests, Understand anisotropy, back calculate parameters



Detail of the rock mass in the La Soledad Fault Zone.

Creep

Acknowledge creep and time dependent behavior

Flexible Supports

Yielding Supports and closely controlled construction sequence.

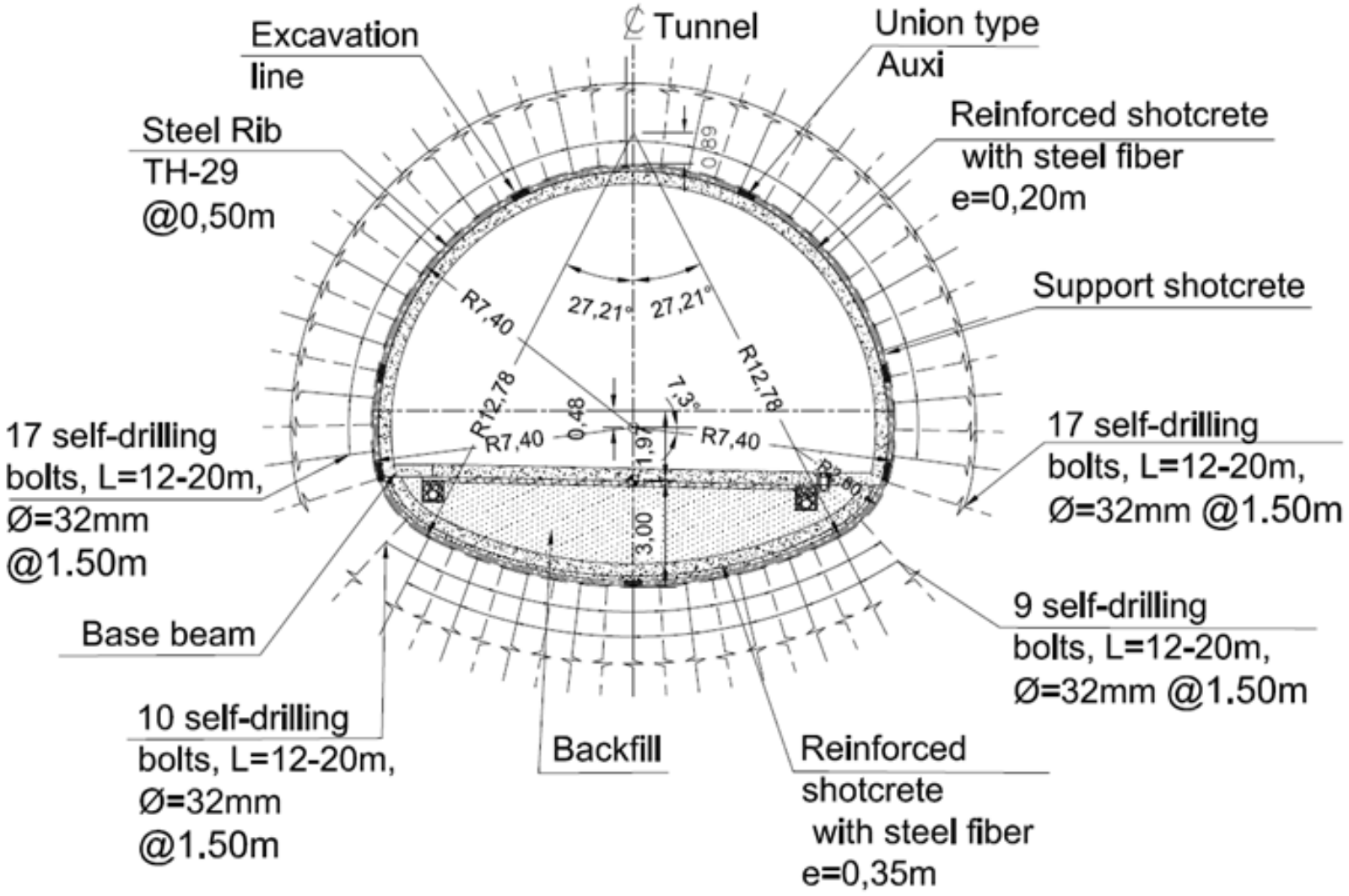
Observational Method

Extensive instrumentation. Analysis and adjustment of support and construction sequence.

BASIC CATEGORIES TO DEFINE THE STABILIZATION PROCEDURE

Qualitative Evaluation	Maximum Displacement mm	Section Invasion cm	Damage to Support
Very High (A)	>300	>30	Bent and damaged steel sets, fissures in shotcrete, rockfalls
High (B)	150-300	15-30	Steel sets partially bent and/or fissures in shotcrete.
Medium(C)	50-150	5-15	Steel sets derailed and/or fissure in concrete
Low (D)	0-50	0-5	Small fissures in shotcrete
Null (E)	0	0	No damage

Typical section for Treatment A

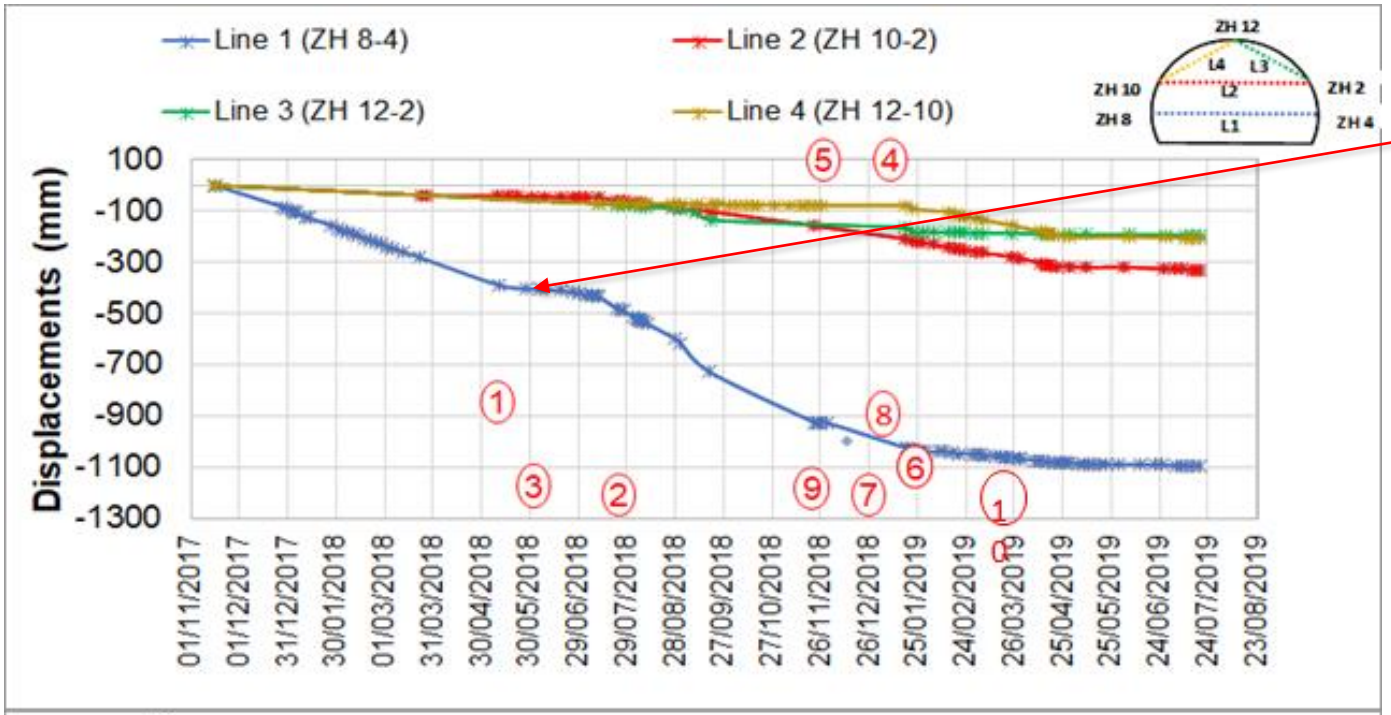


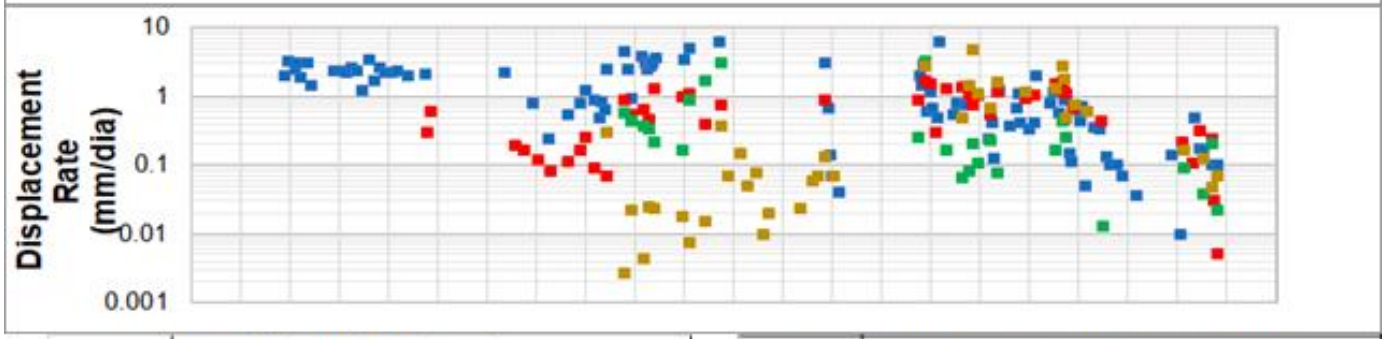
COMPLETION OF SUPPORT ELEMENTS INCLUDING YIELDING GAPS

Alternative Treatment Classes

Treatment	Bolts	Reprofilling	Shotcrete (1st layer)	Steel Sets	Shotcrete (2nd Layer)	Shotcrete (3rd Layer)	Invert
A	L=12m @1.5x 1 (Selfdrilling)	Theoretical Line +0.1.5m	0.05+ fiber	Th-29 @ 1m	0.1+ fiber	0.05 @vault and walls+0.16 at invert+fiber	Curved with 2.15m
B	L=6m @1.5x 1 (Selfdrilling)	Theoretical Line	0.05+ fiber	Th-29 @ 1m	0.1+ fiber	0.05	Curved with 2m
C-1	NO	Theoretical Line	0.05+ fiber	HEB160 @1m	0.1+ fiber	0.05	Curved and straight
C-2	L=6m @1.5x 1 (Type A)	Theoretical Line	0.05+ fiber	HEB160 @1m	0.1+ fiber	0.05	Curved and straight
D	NO	Theoretical Line	0.05+ fiber	No	No	No	No

Convergence displacements recorded @ K4+724 fault during rehab. works.



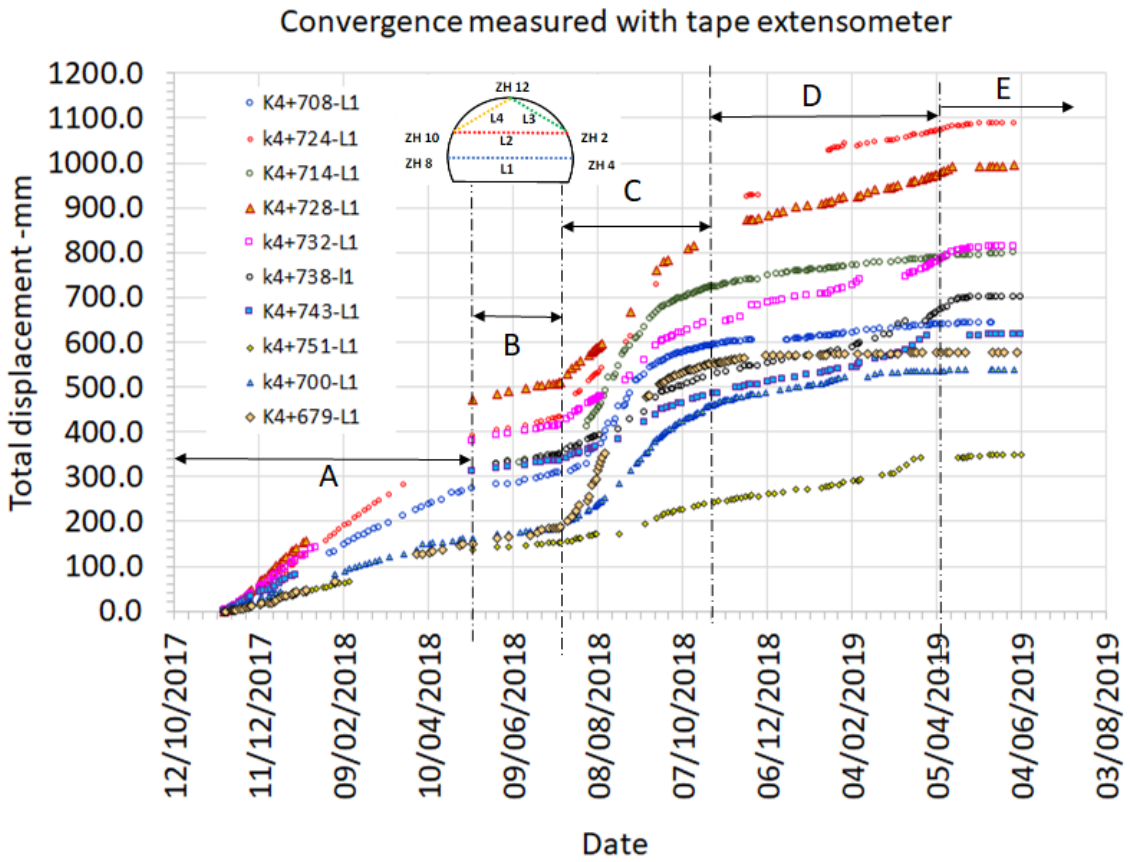


1	Demolition of the base beam
2	Reprofiling
3	Bolts in vaut and walls
4	Steel Rib
5	Curved invert excavation

6	Steel rib in the invert- Right wall
7	Steel rib in the invert- Left wall
8	Bolt in the invert
9	Bolts - 20 m Long (Vault)
10	Closure of joints or windows

Activation of displacements upon removal of the base beam due to lack of support and joint action with curved invert.

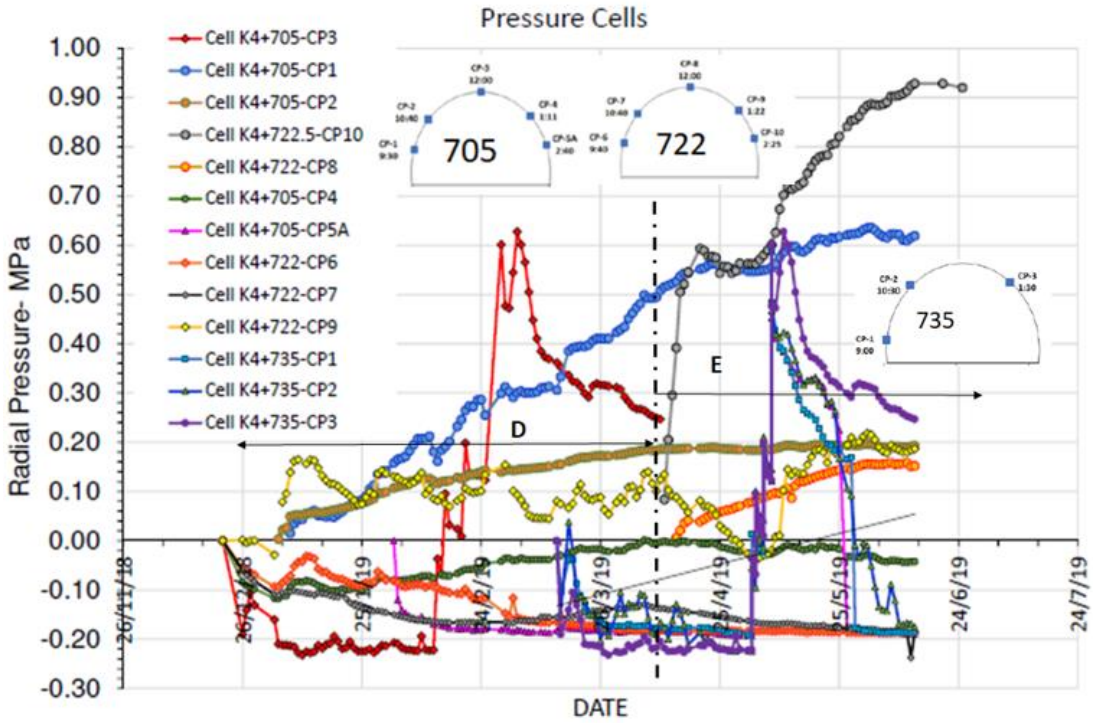
CONVERGENCE MEASUREMENTS DURING THE STABILIZATION PROCEDURE



The behavior of the displacements allowed to distinguish five periods:

- (A) before intervening the tunnel with the rehabilitations works and since the beginning of the instrumentation measurements with tape extensometer in October 2017
- (B) when self-drilling rock bolts were installed.
- (C) when the base beam was removed and the reprofiling started.
- (D) during invert construction works
- (E) when yielding gaps were completely closed in May 2019.

RADIAL PRESSURE CELL MEASUREMENTS ON THE SUPPORT



- In the period prior to the windows closure (Period D) an increase in pressures was noted in several of the cells.
- After the gaps closure, there was a reduction in pressure rates and a general stabilization in most of the radial loads.
- In each of the stations there was an anisotropy of radial earth loads applied to the support.

- (A) before intervening the tunnel with the rehabilitations works and since the beginning of the instrumentation measurements with tape extensometer in October 2017
- (B) when self-drilling rock bolts were installed.
- (C) when the base beam was removed and the reprofiling started.
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CONSTRUCTION SEQUENCE-REPROFILLING

CONSTRUCTION SEQUENCE

Reprofilling @ the Soledad Fault- K4+682 a K4+686

Reprofilling to install TH-29 Steel sets. @K4+687

CONSTRUCTION SEQUENCE

Installation of self drilling bolts

CONSTRUCTION SEQUENCE

Installation of TH-29 Steel set– K3+175- K3+176

Installation of self drilling bolts @ invert K4+670

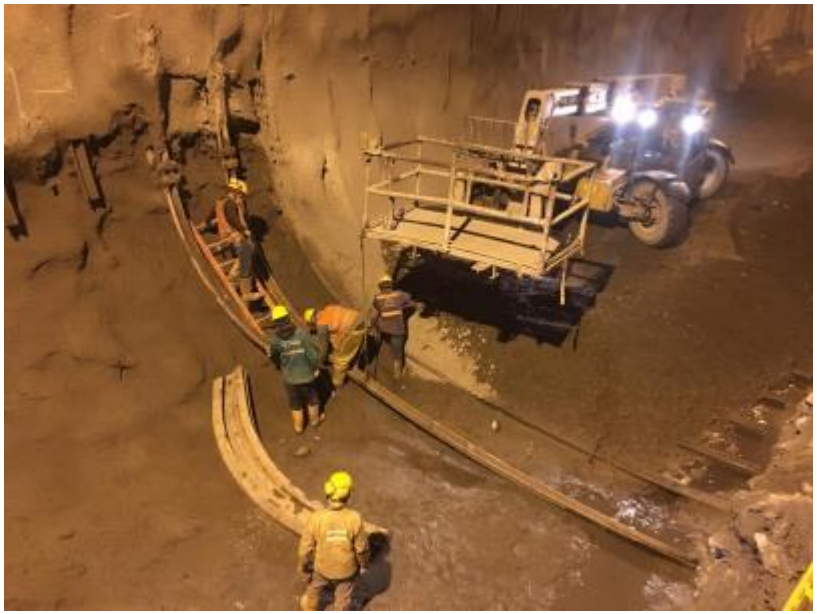
CONSTRUCTION SEQUENCE

Reprofiling and demolition of base beam @– K4+534

Installation of Steel sets @ curved invert.

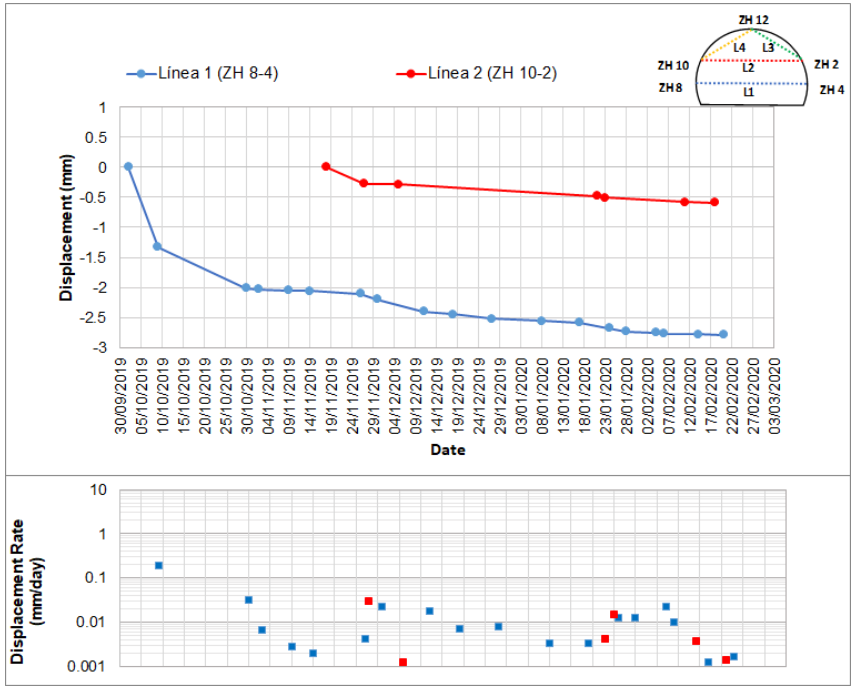
CONSTRUCTION SEQUENCE

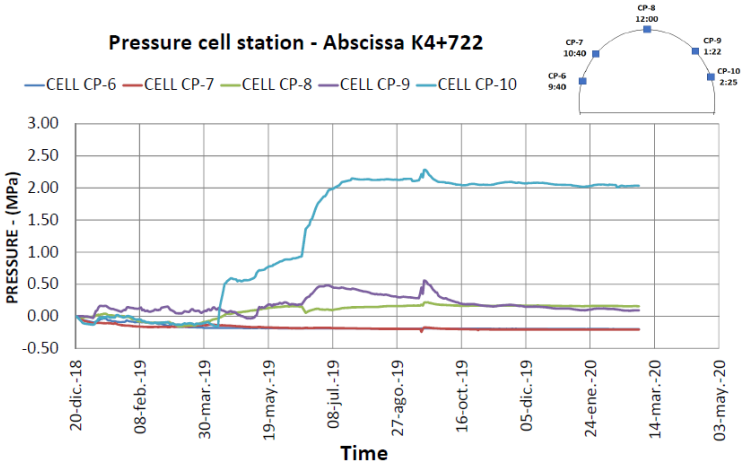
Initial Shotcrete and Steel sets for invert @ K3+890 - K3+896

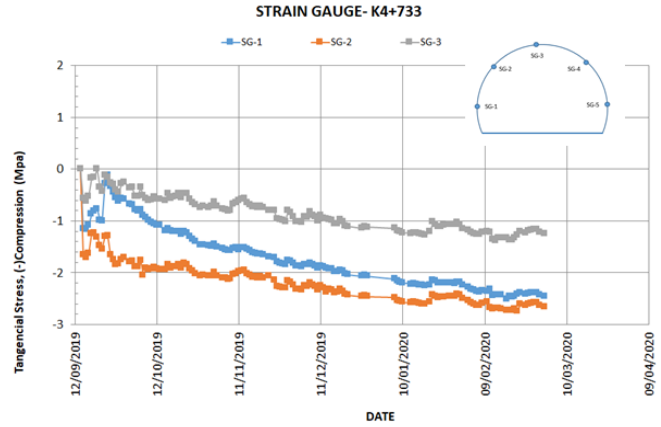


Shotcrete and invert Steel Sets K4+683 a K4+685

CONCRETE LINER

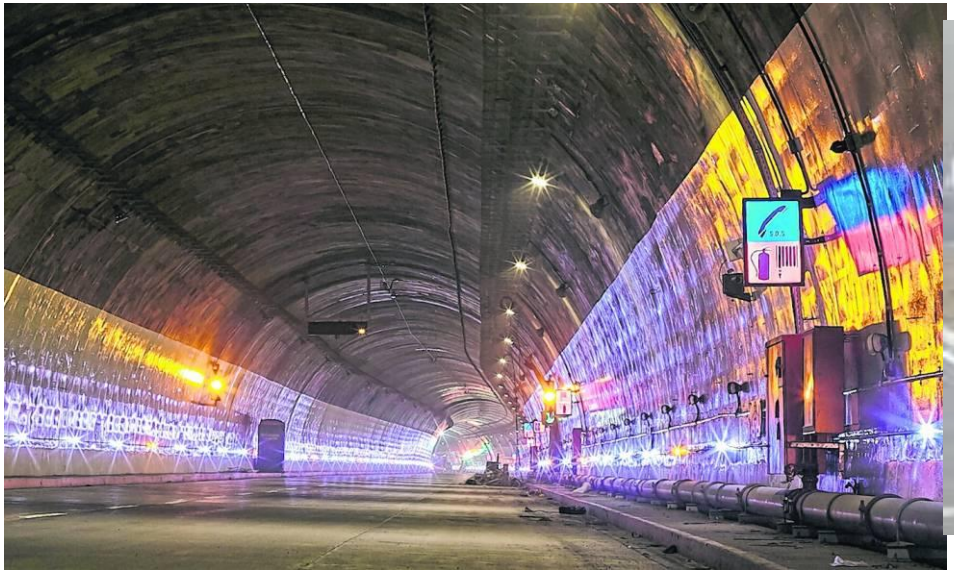






Tangential stress deduced with vibrating wire strain gauges

Finally! Inauguration Sept. 2020/ Complete Corridor Nov. 2021



The la Linea Tunnel is a relevant case study of the problems that arise from poor project structuring and contracting a tunnelling project as lump turnkey Project.

Underground Works demand special contractual provisions to be successful. Efficacy of design and construction methods are also linked to contractual provisions.

The Project Owner should own the ground related risk

The contractor should assume the performance related risk for a set of ground conditions defined in the GBR.

This the balanced and equitable risk distribution behind the ITA/FIDIC Emerald Book

Flexible non-rigid support are required to support the ground mass when squeezing ground is encountered.

Thorough geotechnical instrumentation properly and timely interpreted with the construction sequence can be fundamental for defining the required support even in extreme conditions and great uncertainty.