Geodetic network design and strategies followed for drilling a 25 km tunnel in a high speed railway in Spain

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Introduction

- Two 25 km long high-speed railway tunnels (Tunnels of Guadarrama and Tunnels of Pajares) have been built in Spain, being currently the 4th and 7th longest railway tunnels in the world.
- Pajares bypass consists of two parallel tunnels and a pair of viaducts
- The technical and scientific problems that we have had to solve in these projects, in geodetic and surveying fields, have allowed us to set a methodology that optimizes the performance of this kind of works in the world of Civil Engineering.

Tunnels of Pajares

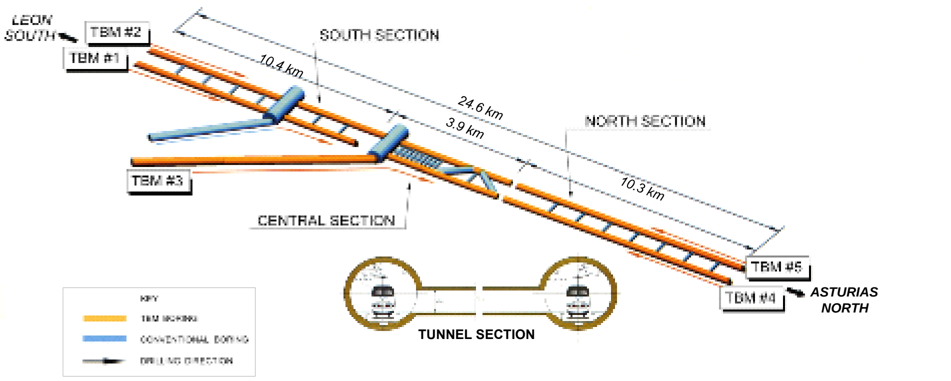
- Two parallel tubes of about 24,677m length, 9 m diameter
- The distance between both tubes of the tunnels is about 50 meters
- Cross-passages every 400 meters
- New high speed railway AVE León-Asturias
- Replace the existing railway line from end XIXth cent.
- Shortening:
  – From 57 km to 25 km distance
  – From more than one hour to 12 minutes

Track plan

Boring method

- The boring of these tunnels has been made with five Tunnel Boring Machine (TBMs).
- Two of them started from the South end (Pola de Gordón) boring with north direction
- Another one started on an intermediate zone of the project (Buiza central section), boring a 5.5 km gallery.
- The last two ones connecting the North end with the Central section from Telledo portal.

Boring method



TBM's

Geodetic objectives

- Target: methodology for design, observation and computation of the geodetic and surveying infrastructure to achieve a tolerance in the different breakthroughs of 0.2 metres.

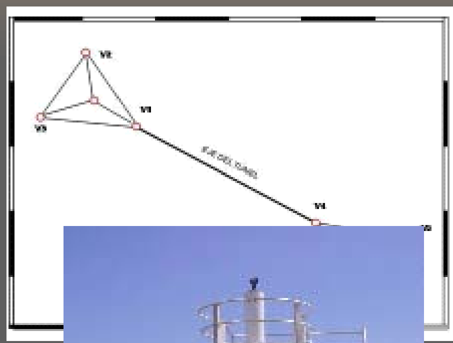
SURFACE NETWORK
- 1. Design
- 2. Geometry
- 3. Monumentation
- 4. Accuracy

LEVELING NETWORK
- 1. High Accuracy heights, gravimetry

UNDERGROUND NETWORKS
- 1. TBM's guidance
- 2. Underground surveying tasks

Surface network design

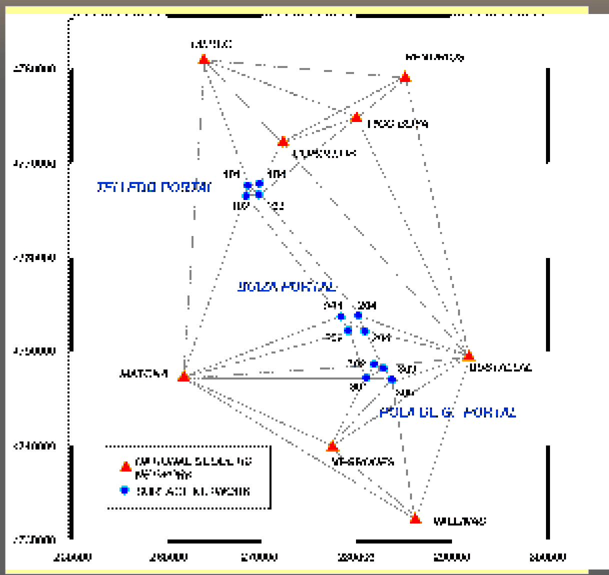
- One network on each portal, with permanent monuments and optimized geometry



Surface network observation

- GNSS observation using the available Geodetic infrastructure
- Double frequency GNSS receivers, with six hours sessions
  - Phase a. - Observation from four points of the National Geodetic Network to two survey monuments of each surface network.
  - Phase b. - Observation from four markers of the National Geodetic Network to the all survey points of each surface network.
  - Phase c. – Observation of six survey points (two of each surface network).
  - Phase d. – Observation of the remaining six survey points (two of each surface network.
  - Phase e. - Observation from five points of the National Geodetic Network to each of the main survey monuments of each surface network.

Surface network observation



Surface network computation

- Leica Geomatic Office and Geolab 2000
- Computed on ETRS89 (ITRS)
- Two different epochs with 2 year interval
  - Differences of about 4 to 5 mm
- Different computation strategies:
  - Different time span observation periods, elevation mask …
  - Kind of ephemeris: broadcast and IGS precise
  - Different strategy of baselines computation, dependent-independent
  - Alternative use of CORS stations

Surface network computation

COMPARISON BROADCAST AND PRECISE EPH

MARKERS	ΔX	ΔY	Δh	σ(X,Y)	σ(h)
305	0.002	0.000	0.000	0.005	0.007
303	0.002	0.000	0.001	0.004	0.007
302	0.002	0.000	0.000	0.004	0.007
301	0.002	0.000	0.001	0.005	0.008
204	0.001	0.000	0.000	0.005	0.007
203	0.001	0.000	0.000	0.004	0.007
202	0.001	0.000	0.000	0.005	0.007
201	0.001	0.000	0.000	0.004	0.007
104	0.001	0.000	0.000	0.005	0.008
103	0.001	0.000	0.000	0.005	0.008
102	0.001	0.000	0.000	0.005	0.008
101	0.001	0.000	0.000	0.006	0.009

Surface network computation

COMPARISON SIX hr. AND ONE hr. SESSIONS

MAKERS	ΔX	ΔY	Δh	σ(X,Y)	σ(h)
305	0.002	0.001	-0.005	0.006	0.009
303	0.001	0.003	-0.001	0.005	0.008
302	-0.005	0.002	-0.004	0.006	0.009
301	0.002	0.005	0.000	0.005	0.008
204	0.002	0.003	0.000	0.005	0.008
203	0.003	0.001	-0.002	0.005	0.007
202	-0.001	0.005	-0.003	0.005	0.008
201	0.000	0.004	-0.004	0.005	0.008
104	0.000	0.005	0.002	0.005	0.008
103	0.001	0.005	0.001	0.007	0.010
102	-0.002	0.004	0.000	0.006	0.009
101	0.009	0.005	0.007	0.007	0.009

Change of Geodetic Reference System

- As the original tunnel project was compiled on former ED50 datum, the surface network was transformed to this system from ETRS89
- A final study of azimuths was performed in both GRS's in order to analyse the error in orientation when changing the datum

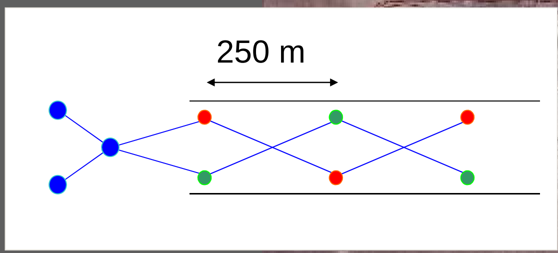
Baseline	Azimuth ETRS89 (g)	Azimuth ED-50 (g)	Difference ETRS89-ED50 (cc)
101-102	208.2708	208.2717	-8.6
201-202	164.7110	164.7115	-4.6
301-302	34.1250	34.1253	-2.8
301-303	56.8341	56.8343	-2.5
101-201	159.0928	159.0934	-5.6
101-301	163.0538	163.0544	-5.2
201-301	172.8165	172.8169	-4.0

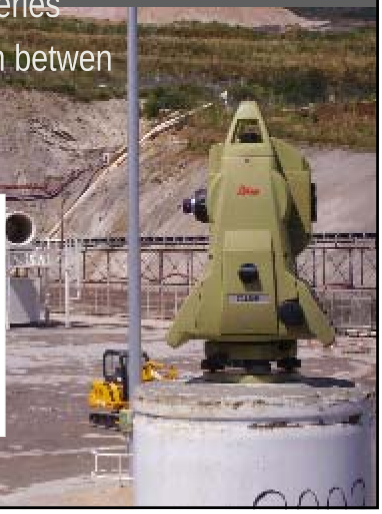
Underground network design

- Use of Leica TCA 2003 robotic stations with ATR
- Gyromat DMT 2000 gyroscope
- Different simulations for:
  - Number of series for measuring angles and distances
  - Diferent geometry (following the axis or zig-zag traverses)
  - Different distances between the network control points
  - Use of gyrotheodolite and different distances between gyro observations
  - Maximum lenght of tunnel without gyrotheodolite assistance
- Simulations and final computations made with Geolab 2000

Underground angular and distance observations

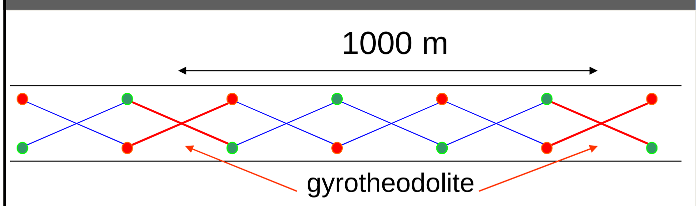
- Six Leica TCA angle and distance series
- Double zig-zag traverses with 250 m betwen control points





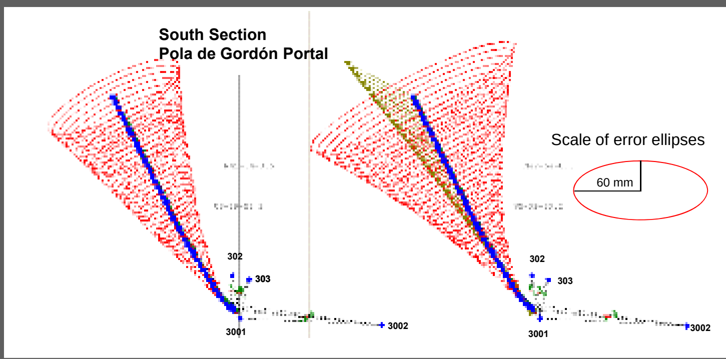
Underground gyrotheodolite obs.

- Two series of DMT 2000 gyrothedolite on each azimuth
- Vertical deflection correction
- Crossed azimuths each kilometre of traverse



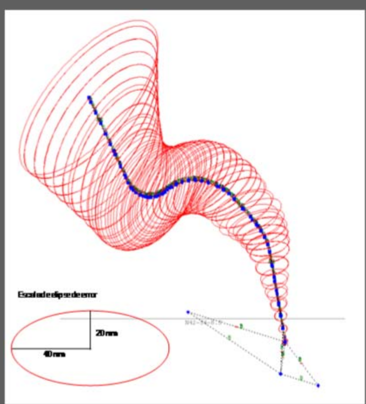
Underground network results

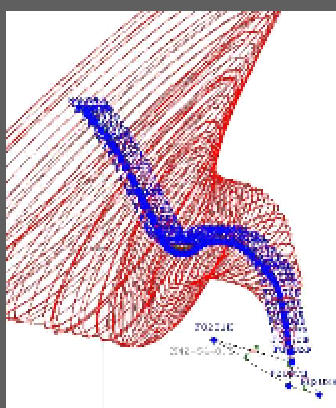
- South section network
  - Computation with and without gyrotheodolite observations



Underground network results

- Central Link network
  - Computation with and without gyrotheodolite observations

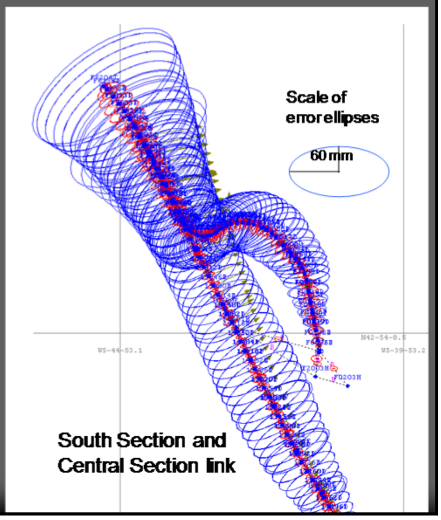




Underground network results

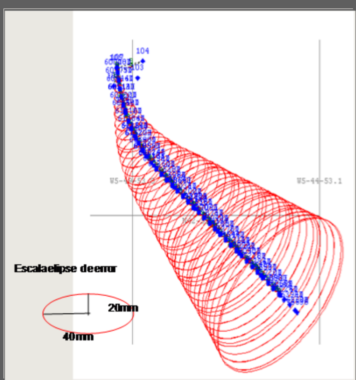
- South and Central Sections breakthrow

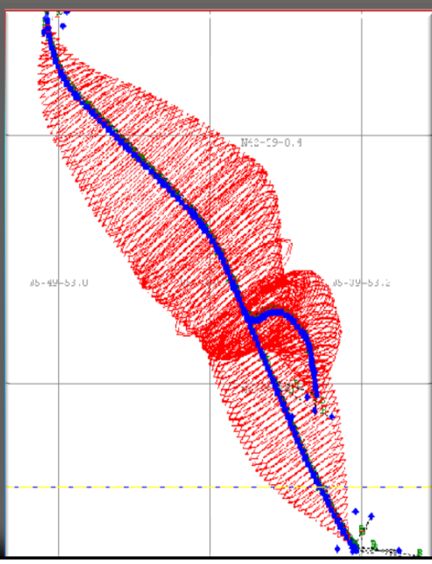
LINK SOUTH WEST TUNNEL AND TUNNEL OF BUIZA				
COORDINATES DISPLACEMENT				
Points	NORTH (m)	EAST (m)	σ North (m)	σ East (m)
FG024D	-0.052	-0.006	0.02	0.027
FG024I	-0.048	-0.005	0.02	0.027
DISPLACEMENT ALONG TUNNEL AXIS				
Points	FORWARD (m)	TRASVERSAL (m)		
FG024D	0.044	0.029		
FG024I	0.040	0.026		



Underground network results

- North Section and complete Underground Network





Conclusions

- The values of the different breakthroughs done and checked have a maximum value of about 60 mm. These values are also consistent with the uncertainties previously computed.

- Given the results presented in this communication, the best suitable methodology for this type of work may have the following characteristics:
  - 1 Surface network observations must be done by GNSS techniques. Static method in each survey point must have multiple observations of at least 1 hour which guarantee repeatability and reliability. No improvement is achieved when using precise ephemeries
  - 2 If a geodetic datum change is required, a study of azimuths, in both systems, on the surface network must be performed to evaluate the loss of accuracy

Conclusions

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  - 3 As the axis of the tunnel has to be free, the underground network must be designed as zig-zag traverses, in order to minimize lateral refraction error. Optimal traverses will have 250 m length legs. At least six sets of observations have to be performed.
  - 4 Gyrotheodolite observations are needed to reduce the loss of accuracy on the transmission of azimuths in traverses of this length. For more than 4 km tunnel length the gyro observations should be performed every kilometre, observing two crossed axes, in order to minimize lateral refraction error. On critical areas, such as curves, the observations must be performed on each traverse axis.
  - 5 Traverses along tunnel axis with legs of 375 m. are most suitable to control the underground network but the observation is restricted to be done when technical stops of drilling.


Thank you for your attention