Società Italiana Gallerie
Italian Tunnelling Society

BEYOND A TUNNEL VISION
THE SECOND EUROPEAN CONFERENCE ON TUNNEL RENOVATION

Inspection and monitoring for tunnels maintenance: analysis of experimental data

Speaker: prof. Gianpiero Russo
University of Napoli Federico II

Friday November 27th 2020 – fully digital

Introduction: Italy a country with many tunnels

- ✓ Certainly a large number of civil infrastructure, **roads or railway tunnels among these**, are progressively deteriorating and require inspections, assessment of the state of damage (if any) and finally, if necessary, **repair and maintenance interventions.**

The nature of the problems strongly affects the design of the interventions

- ✓ The inspection phase is a very important one, to prevent serious problems and to decide on **timely and appropriate interventions.** Sometimes a timely and appropriate intervention can be quickly carried out while more serious situations may require interruptions of service that for transportation infrastructure involve social and economic impacts often of significant magnitude…

- ✓ ……………………………. recent personal experience on that …

Preventive maintenance: it avoids service interruption

«Traffic jam in Napoli: drivers in the queue for hours because of the Vittoria Tunnel stop»
Il Mattino 28.09.2020

Retrofit of existing tunnels ….

- ✓ Seismic retrofit ?

"Historically, underground facilities have experienced a lower rate of damage than surface structures. Nevertheless, some underground structures have experienced significant damage in recent large earthquakes, including the 1995 Kobe, Japan earthquake… "

Hashash et al. (2001)

- ✓ New code and regulations ask for a better performance?

"Typically problems of compliance with fire regulations, lighting, ventilation. Generally speaking, these are not structural problems directly but ... indirectly, for instance failure to comply with fire regulations exposes the tunnel to vulnerabilities, even of a structural nature. Even ventilation …

According to the AISCAT estimate: «In Italy there is about *50% of the overall amount of tunnels in Europe.»*

Important problem for Italy and not only ……..

Contents of the presentation

1. *Experience with conventional monitoring in* ***old or ancient tunnels***

2. *New technologies available for the inspection and survey:*
   need for ***«calibration»***

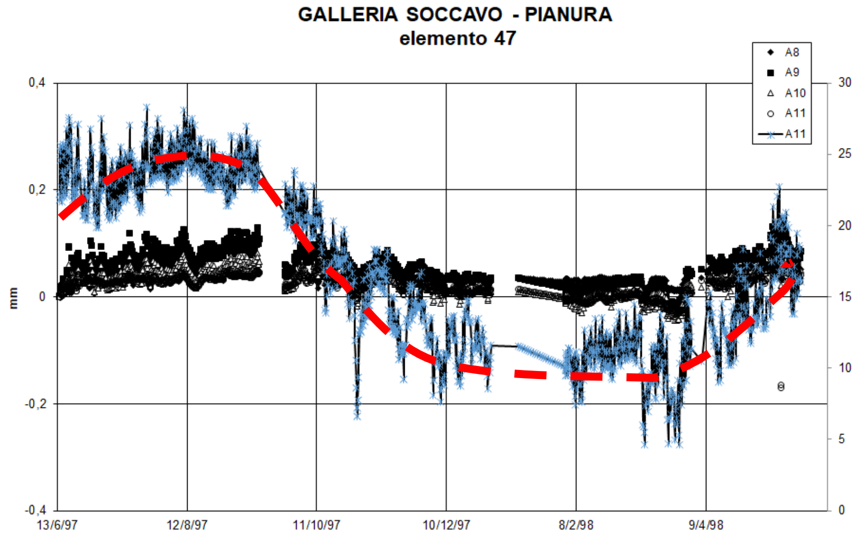
3. *Research in Napoli Federico II UNINA on the behaviour of* ***segmental lining****:*
   importance of the monitoring since the very beginning
   importance of the correct interpretation of the raw data

4. *Instrumentations and sensors: reliability, accuracy* ***and longevity***

Monitoring cracks in existing tunnels for specific troubles ……

Experience of crack monitoring in existing tunnels:

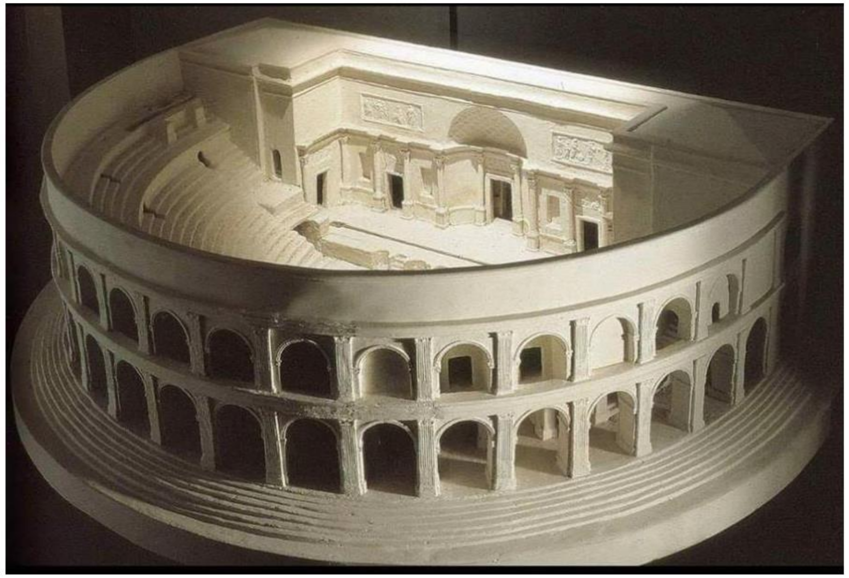
- **Napoli ring road tunnels: Cracks in the concrete lining** Epomeo tunnel (parietal tunnel; **monitoring for one year** revealed that the cracks were not evolving and the final proof was positive). **1996-1997**



- **Picture of the collapse** of a retaining wall in Salerno. **1998**
  Motorway tunnel SA-RC sidewall lining without cover …. Cracks monitored for a couple of years showed no evolution of the damage and allowed the restore works to be carried out safely

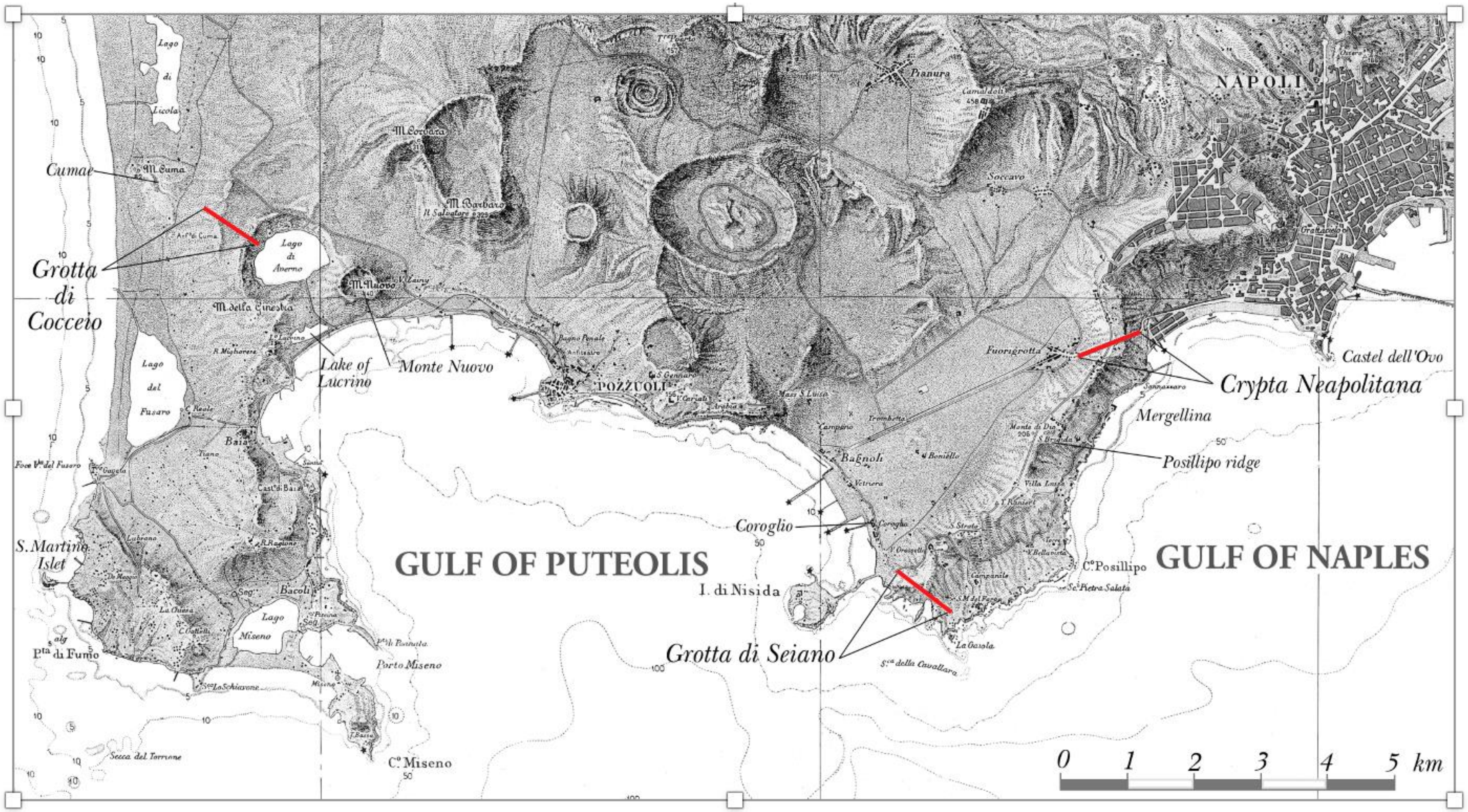
- **Natural tunnel in volcanic tuff as service tunnel for the archeological excavation of the ancient roman theater in Ercolano:** cracks in the tuff (maybe originally generated by the geological process of the tuff formation) …. Monitoring for a couple of years **(1999-2000)** …. no problems … no intervention!

Roman theater in Ercolano buried by Vesuvius eruption 79 AD

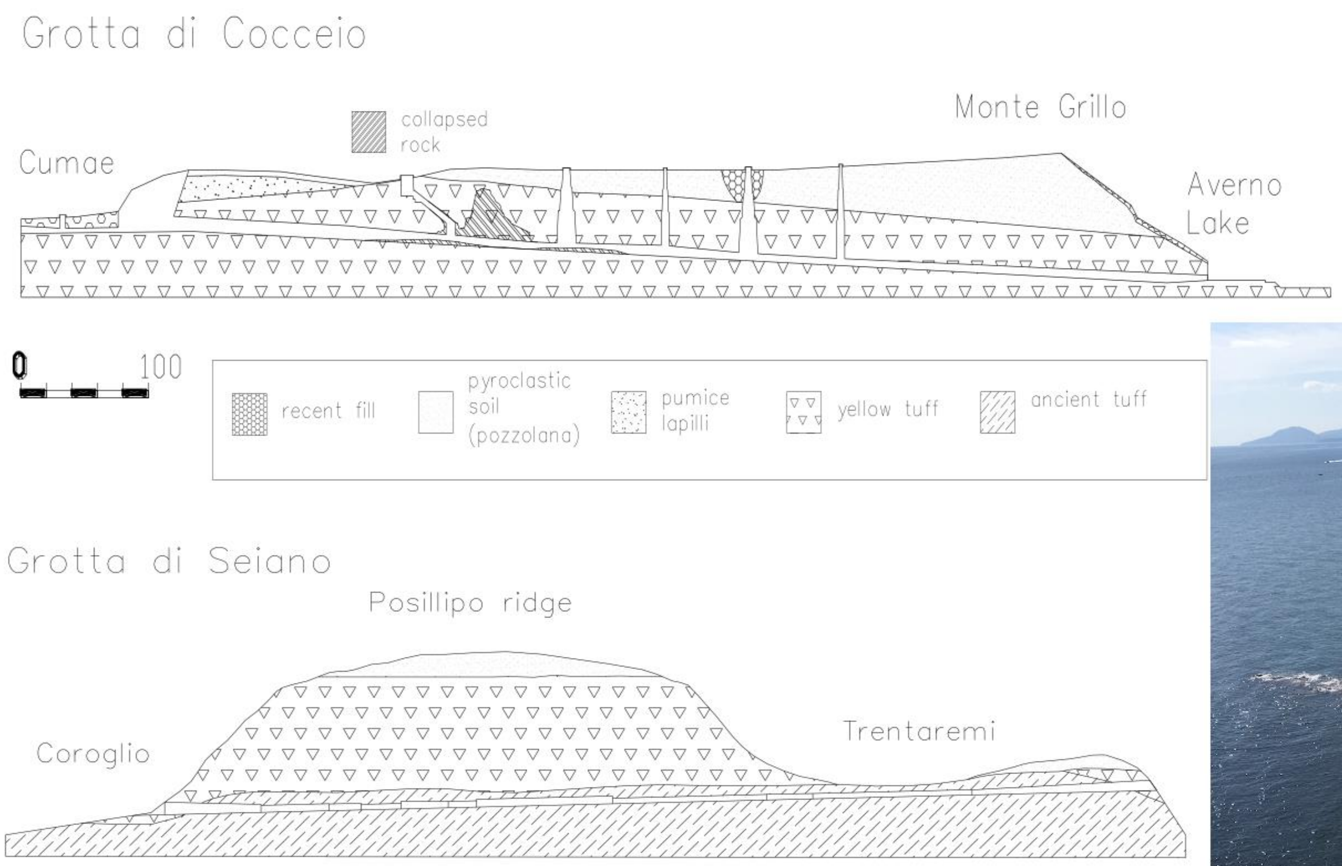


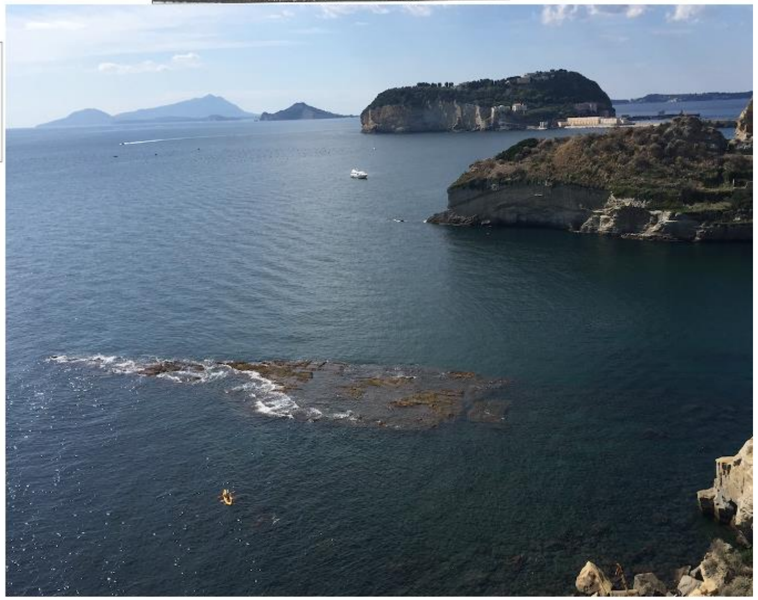
TUNNELS EXCAVATED BY CONVENTIONAL METHODS IN THE VOLCANIC TUFF

Roman ancient tunnels by L. Cocceius Architect



Roman ancient tunnels by L. Cocceius Architect





Recent regulations & codes: Italy 2020 - 1967

M_INF-GABINETTO
Uffici Diretta Collaborazione Ministro
UFFGAB
REG_DECRETI
Prot: 0000269-07/07/2020-
REGISTRAZIONE

Il Ministro delle infrastrutture e dei trasporti

Things to do:

- ✓ Quarterly/annual checks with inspection of visible surfaces for new cracks, detachments, movements, etc. ..

Simple list of new technologies

- ✓ **Not exaustive:**
  …. georadar, laser scanner, ultrasounds, endoscopics or seismic survey ..

Reliability of these new technologies ?

- ✓ **Ask for cooperation with University and Research Institutions**

Recently in Italy we had the introduction of new exhaustive guidelines for bridges and viaducts checks …. (after Genova collapse)

New technology for inspection and survey

✓ **New technology for survey**

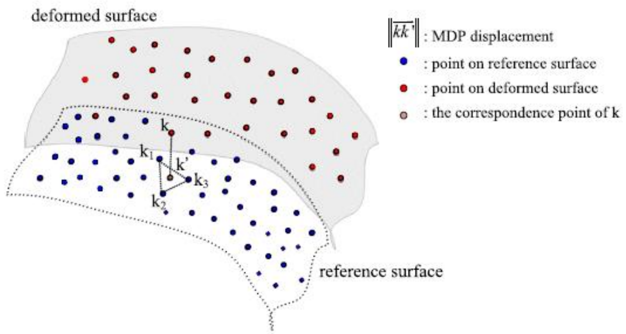
Monitoring tunnel deformations by means of multi-epoch dispersed 3D LiDAR point clouds: an improved approach (Han et al., 2013)

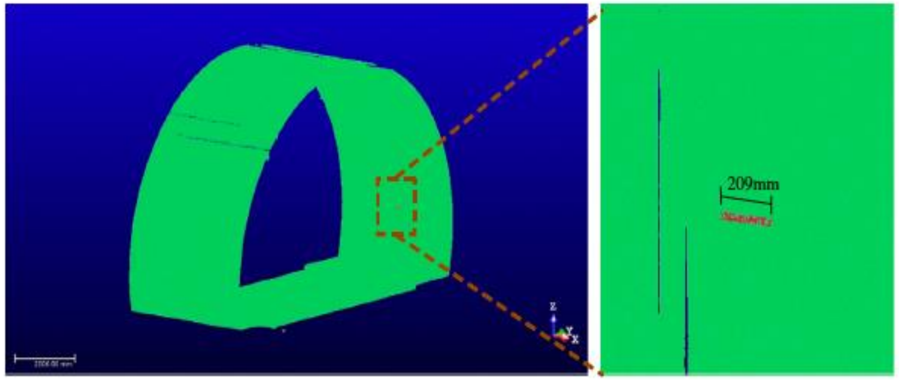
Monitoring tunnel deformations is a crucial task when evaluating tunnel stability and safety. This task requires an accurate and high-resolution spatial technique to precisely capture the meticulous anomalies on a tunnel surface. As a response, the light detection and ranging (LiDAR) technique, which collects detailed spatial data in a fast and automatic manner …..

Han et al. (2013) developed an approach to detect the deformation signals for all the points on a specific tunnel profile

LiDAR + MDP

via a minimum-distance projection (MDP) algorithm, point correspondences can be established, and the deformation signals along any profile of interest can be immediately identified.





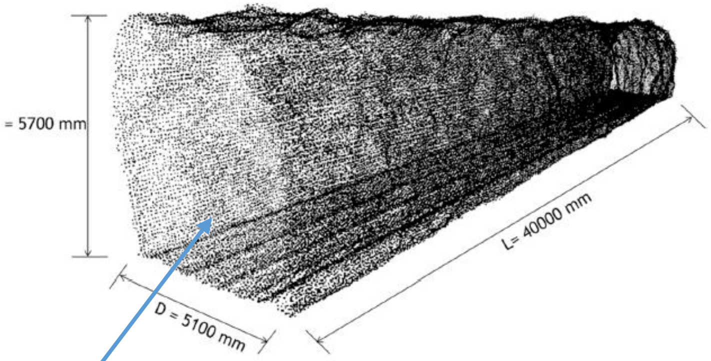
A deformation signal on the tested zone was simulated by intentionally attaching a wooden stick (6 mm in thickness) to the tunnel lining at the second epoch. The MDP displacements between two epochs were subsequently estimated.

New technology for inspection and survey

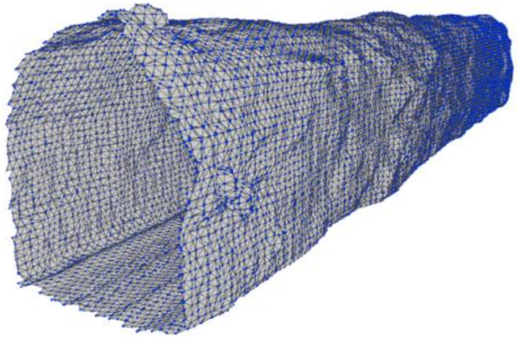
- ✓ **New technology for survey**

A coupled 3D laser scanning and digital image correlation system for geometry acquisition and deformation monitoring of a railway tunnel (Moreira et al. 2019)

In this study, a 40 m-long section of a shallow railway rock tunnel so-called "Monte Seco tunnel" located at Vitoria Minas Railway in Brazil is investigated. In the real environment, the tunnel has been scanned by a 3D Terrestrial Laser Scanning (TLS) instrumentation and its geometry was reconstructed on a point cloud. Due to the complex geometry of the irregular rock face created by drill and blast ……



a)



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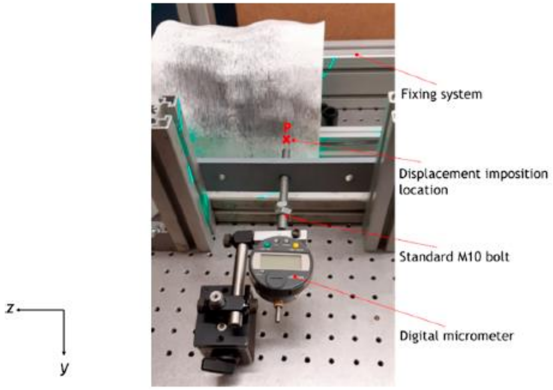
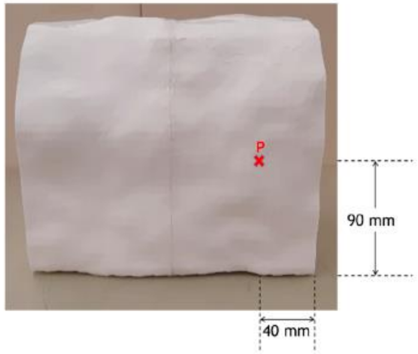


a)



b)

Most laser scanners use moveable mirrors to steer the laser beam. The steering of the beam can be one-dimensional, as inside a laser printer, or two-dimensional, as in a laser show system.

New technology for inspection and survey – non destructive test

Non destructive thermal infrared test (IRT).

It is a long time it is used to analyse the state of building facade and evaluate the quantitative need for maintenance

Since several years applications in the field of detection of concrete defects …. Example in the concrete, either prefabricated or cast in place, tunnel lining….

Different type of tests proposed on the market mainly falling into two categories:
Active or passive Thermography

Active thermography : an artificial heat source is used to create or to increase ΔT between the air in the tunnel and the concrete outer surface. Generally this method is considered as capable of investigating deeper zones (*Maierhofer et al., 2006* … about 10-20 cm)

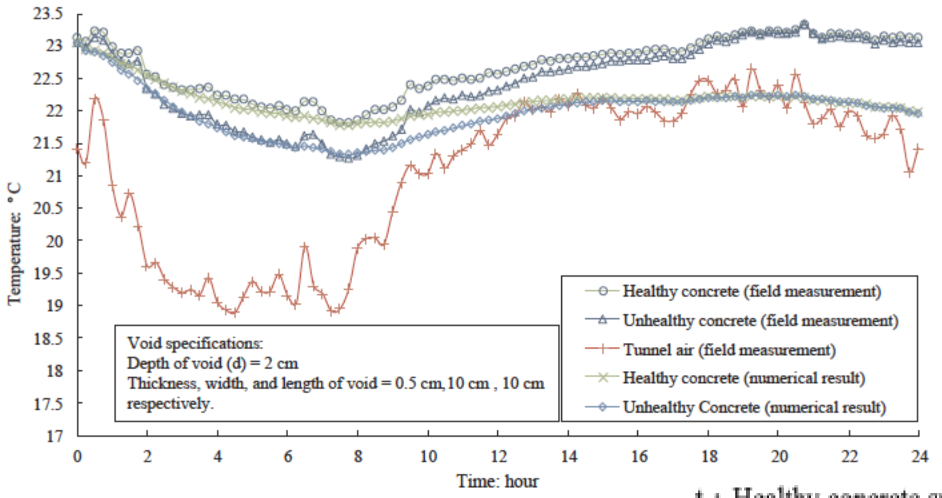
Passive thermography: temperatures are measured without any articial heat source. The method is simpler and quicker but only limited depths are investigated (5-10 cm …. *Sakagami & Kubo, 2012)*

ITR: calibration?

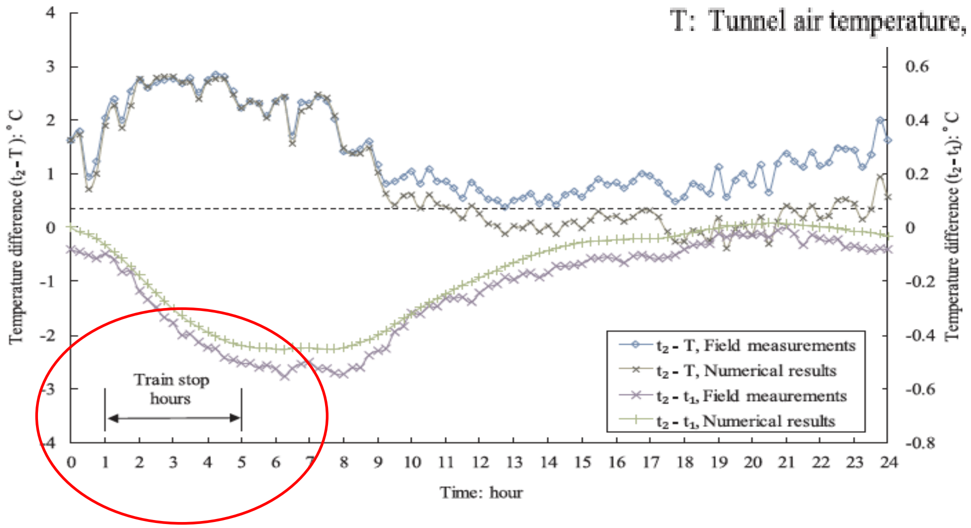
Study of infrared thermal application for detecting defects within tunnel lining
(Akagi et al., 2019)

Hyp: Voids assumed as those deduced by hammer test via expert investigators

- ✓ Need for calibration: is obvious
- ✓ Generally is better to have large ∆T to improve the readibility of the test



t_1: Healthy concrete surface temperature, °C
t_2: Unhealthy concrete surface temperature, °C
T: Tunnel air temperature, °C



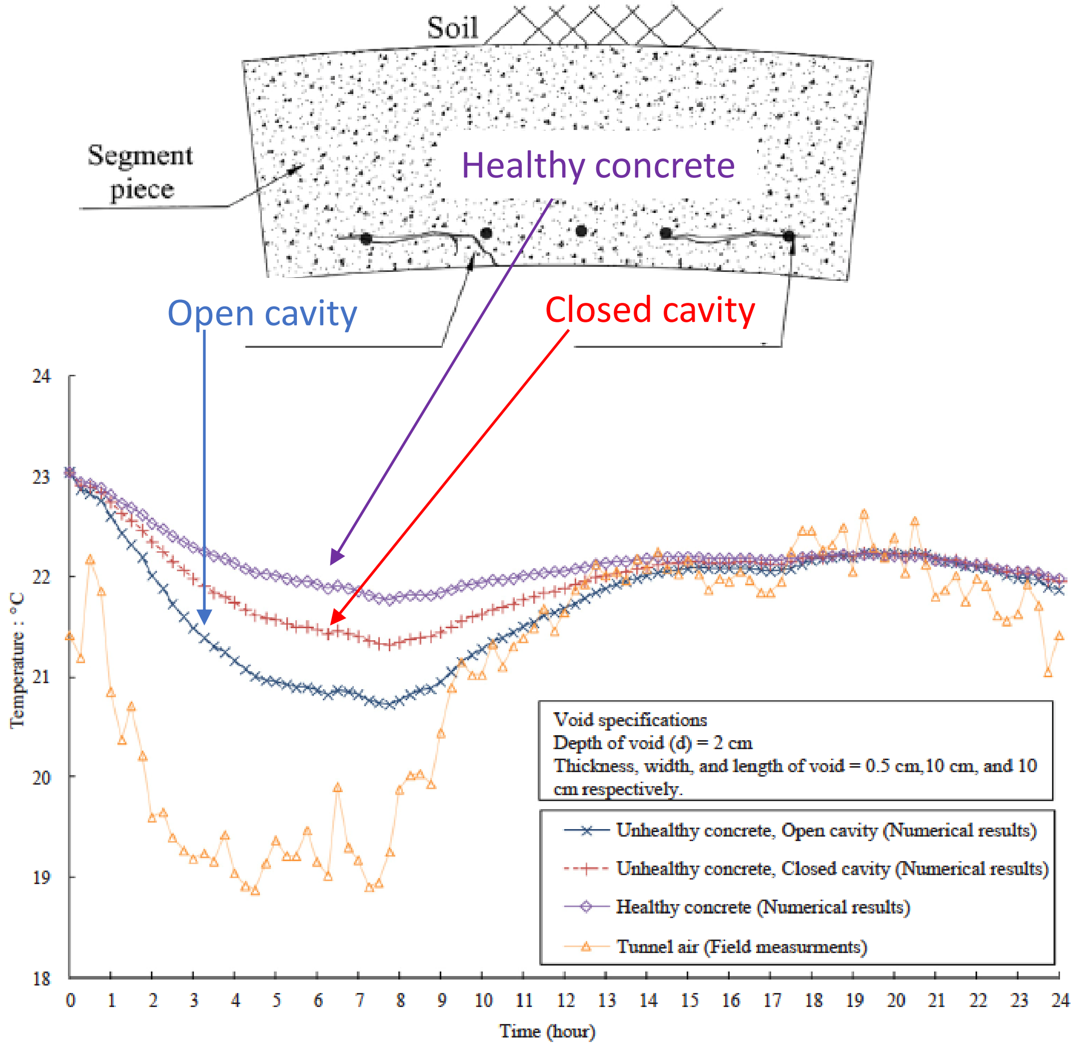
ITR: calibration?

Study of infrared thermal application for detecting defects within tunnel lining
(Akagi et al., 2019)

Hyp: Voids assumed as those deduced by hammer test via expert investigators

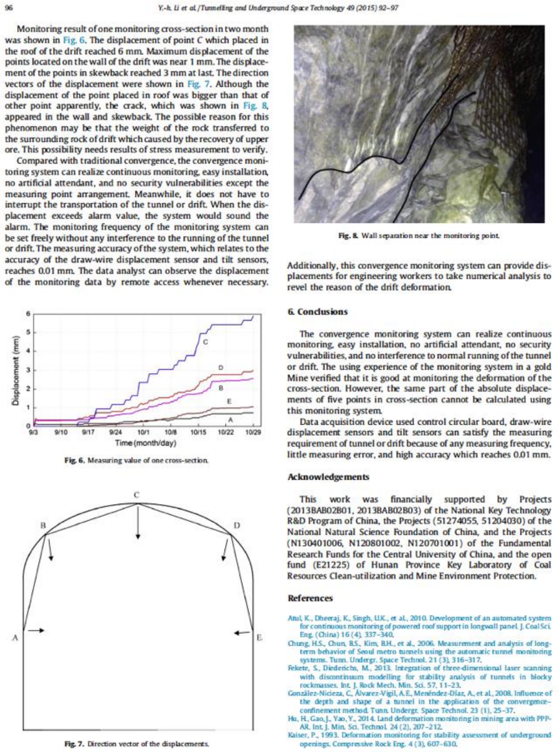
That is an example of …… calibration with numerical analysis on a well defined defect ……

Open and closed cavity …



Investigations, control or early warning monitoring

A new convergence monitoring system for tunnel or drift based on draw-wire displacement sensors (+ tilt sensors) **(2015)**



96 Y.-h. Li et al./Tunnelling and Underground Space Technology 49 (2015) 92–97

Monitoring result of one monitoring cross-section in two month was shown in Fig. 6. The displacement of point C which placed in the roof of the drift reached 6 mm. Maximum displacement of the points located on the wall of the drift was near 1 mm. The displacement of the points in skewback reached 3 mm at last. The direction vectors of the displacement were shown in Fig. 7. Although the displacement of the point placed in roof was bigger than that of other point apparently, the crack, which was shown in Fig. 8, appeared in the wall and skewback. The possible reason for this phenomenon may be that the weight of the rock transferred to the surrounding rock of drift which caused by the recovery of upper ore. This possibility needs results of stress measurement to verify.

Compared with traditional convergence, the convergence monitoring system can realize continuous monitoring, easy installation, no artificial attendant, and no security vulnerabilities except the measuring point arrangement. Meanwhile, it does not have to interrupt the transportation of the tunnel or drift. When the displacement exceeds alarm value, the system would sound the alarm. The monitoring frequency of the monitoring system can be set freely without any interference to the running of the tunnel or drift. The measuring accuracy of the system, which relates to the accuracy of the draw-wire displacement sensor and tilt sensors, reaches 0.01 mm. The data analyst can observe the displacement of the monitoring data by remote access whenever necessary.

Fig. 6. Measuring value of one cross-section.

Fig. 7. Direction vector of the displacements.

Fig. 8. Wall separation near the monitoring point.

Additionally, this convergence monitoring system can provide displacements for engineering workers to take numerical analysis to revel the reason of the drift deformation.

6. Conclusions

The convergence monitoring system can realize continuous monitoring, easy installation, no artificial attendant, no security vulnerabilities, and no interference to normal running of the tunnel or drift. The using experience of the monitoring system in a gold Mine verified that it is good at monitoring the deformation of the cross-section. However, the same part of the absolute displacements of five points in cross-section cannot be calculated using this monitoring system.

Data acquisition device used control circular board, draw-wire displacement sensors and tilt sensors can satisfy the measuring requirement of tunnel or drift because of any measuring frequency, little measuring error, and high accuracy which reaches 0.01 mm.

Acknowledgements

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Hu, H., Gao, J., Yao, Y., 2014. Land deformation monitoring in mining area with PPP-AR. Int. J. Min. Sci. Technol. 24 (2), 207–212.
Kaiser, P., 1993. Deformation monitoring for stability assessment of underground openings. Compressive Rock Eng. 4 (3), 607–630.

PIANO DI EMERGENZA

MONITORAGGIO DELLA GALLERIA
LINEA ROMA-NAPOLI FS spa.
TRATTO PIAZZA CAVOUR-MONTESANTO

Preparato da	Controllato da	Approvato da	Approvato da	Versione
Ing. Gianpiero Russo	F.S. spa		M.N. spa	del 01/01/1998
Ing. Gianpiero Russo	F.S. spa		M.N. spa	del 01/04/1998
Ing. Gregorio Marchese	F.S. spa		M.N. spa	del 01/11/1998

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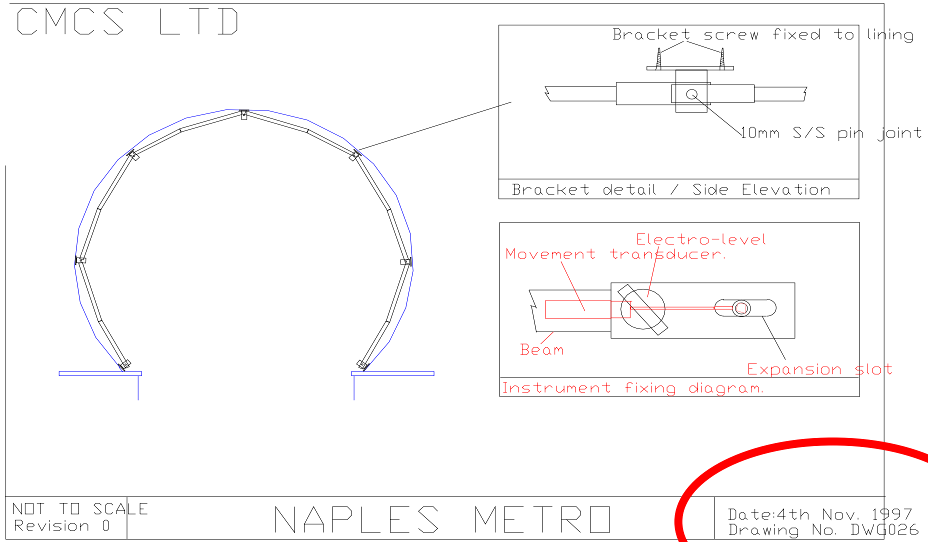
An old “similar” convergence system



…. steel rods and Kevlar wire. Each rod is instrumented by two rotation transducers and one displacement transducer. The rotation transducers used are electrolytic levels with a measuring range of ± 3° and a resolution of about one second of degree. The displacement transducers are electrically operated linear sensors with a measuring range of about 2 cm and a resolution of about 1 micron. The temperature sensors are thermocouple type with a measuring range from -10° to + 50° and have a resolution of less than 0.1 °C.

New technology for transducers: example of tiltmeters

Evolution … Micro-Electro-Mechanics sensors MEMS on the market since quite a long time.

Typical problems when choosing the right sensor are still there: …. Temperature effects, ageing of the materials, creep effects on the fixing system ..

Specifications

Sensors	
Calibrated Range	±3° | ±5° | ±10° | ±15°
Resolution[1]	0.008% full scale
Sensor accuracy	±0.05% full scale
Operating temperature	-20 to +80°C
Repeatability	±0.01% full scale
Minimum casing internal diameter	56mm
Maximum casing internal diameter	72mm
Weight (without cable)	540g
Dimensions	192mm x Ø32mm
Input voltage	10-16VDC
Signal output at full range	±2.5VDC differential
Current consumption	9mA (uniaxial) / 17mA (biaxial)
Ingress protection	IP68 to 200mH_2O (2000kPa)
Housing material	Stainless Steel

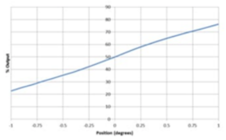
[1]Dependent on readout equipment

Part Numbers | **Specifications** | Documentation | Related Products | Sample Applications

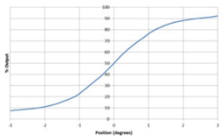
Operating Range	±30°
Communications	Analog 0.5 V to 4.5 V DC output
Linear Range	±30°
Number of Axes	2
Repeatability	±0.1°
Resolution	≤0.0025°
Supply Voltage	7 V to 35 V DC
Null Offset	±1°
Operating Temperature	-40 °C to 85 °C
Storage Temperature	-55 °C to 85 °C
Time Constant	≤55 ms
Protection Rating	IP66

Operating Range	±3°
Linear Range	±1°
Number of Axes	1
Repeatability	±0.001° (±5 arc seconds)
Resolution	≤0.0003° (≤1 arc second)
Null Offset	±0.25°
Operating Temperature	-20 °C to 50 °C
Storage Temperature	-55 °C to 125 °C
Time Constant	≤1 s

Linear Range Output



Operating Range Output



MEMS TILT SENSORS VS. ELECTROLEVELS

Predictive maintenance of …. shield tunnels

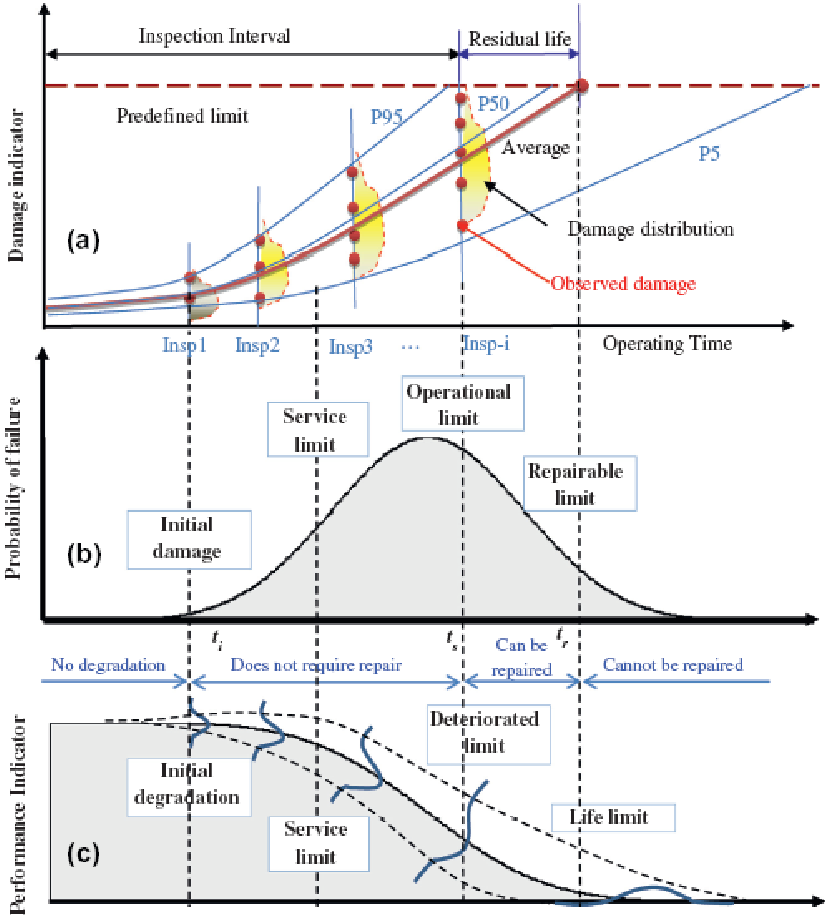
Predictive maintenance of shield tunnels (Yuan et al., 2013)

Based on the time intervals between inspections, maintenance philosophies can be classified into three categories: **corrective, preventive, and predictive.** Pinteton and Herz (2008) introduced key elements for the definition of possible maintenance definitions for engineering systems ....

A virtual dream or reality ?

Predictive maintenance is an advanced preventive approach where maintenance is deferred until it is actually needed. *The objective of this approach is to monitor the system in a way that incipient faults (such as cracks, seepage, or spalling that has initiated in tunnels) are detected, identified and tracked well before they can cause a component to have performance degradation or failure.*

The monitoring activity can be discrete (e.g., periodic inspections) or continuous (e.g., continuous monitoring of the system performance)



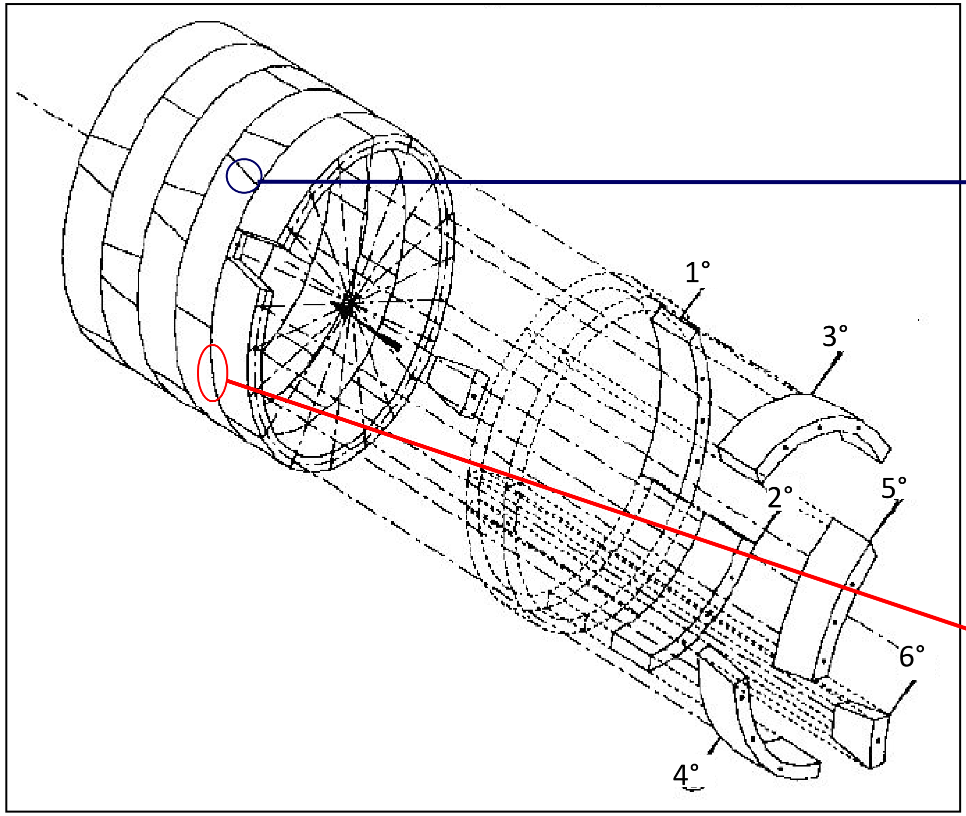
Maintenance : +/- loadings ; +/- forces +/- degradation

Monitoring is very important for :

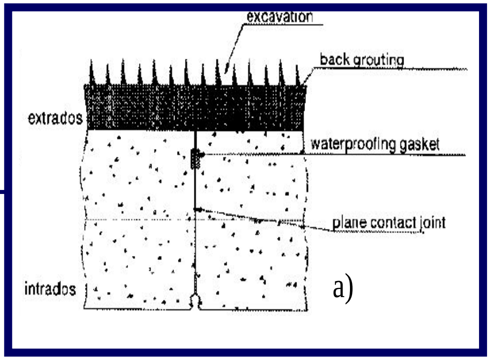
- ✓ Initial loadings (live loadings) and their variations
- ✓ Internal forces in the lining and their variations
- ✓ Degradation measured via quantitative parameters; important to know: initial conditions of the structures

Ph.D. thesis on the behaviour of prefabricated segmental lining

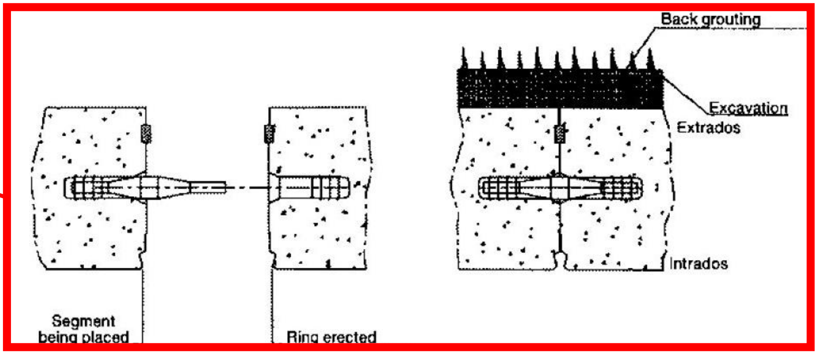
Segmental prefabricate linings



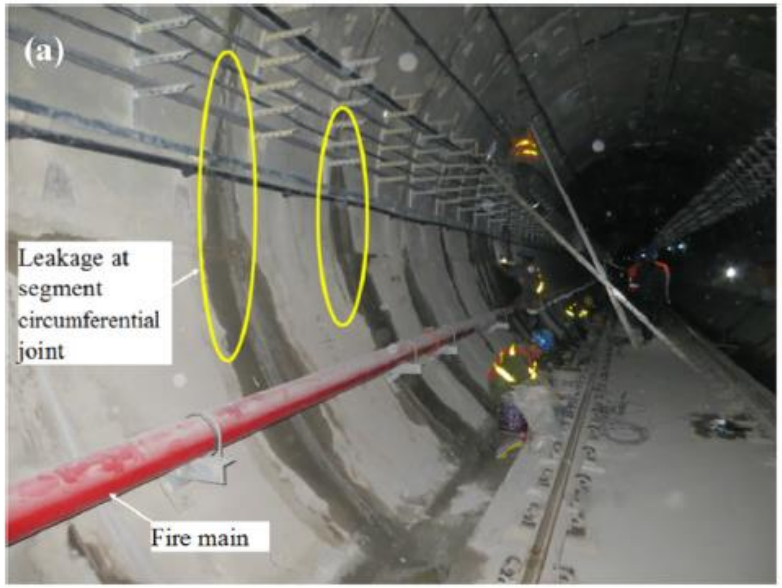
Longitudinal joints (same ring)

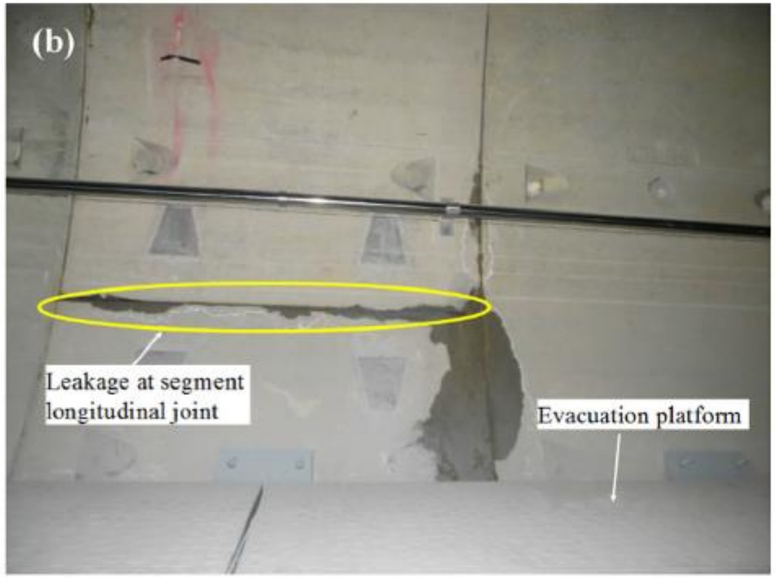


Transverse joints (adjacent rings)

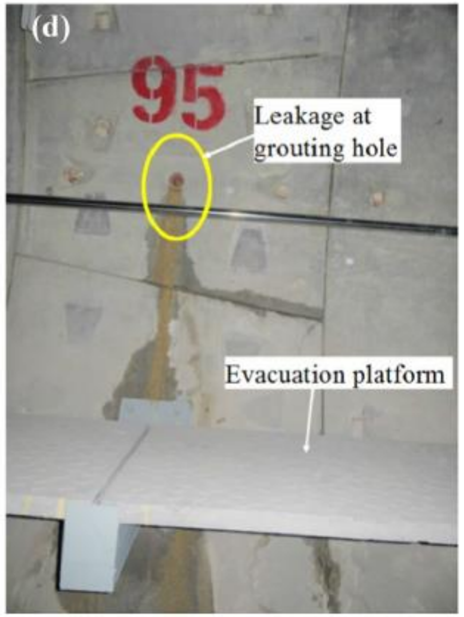


Typical damages to segmental prefabricated lining

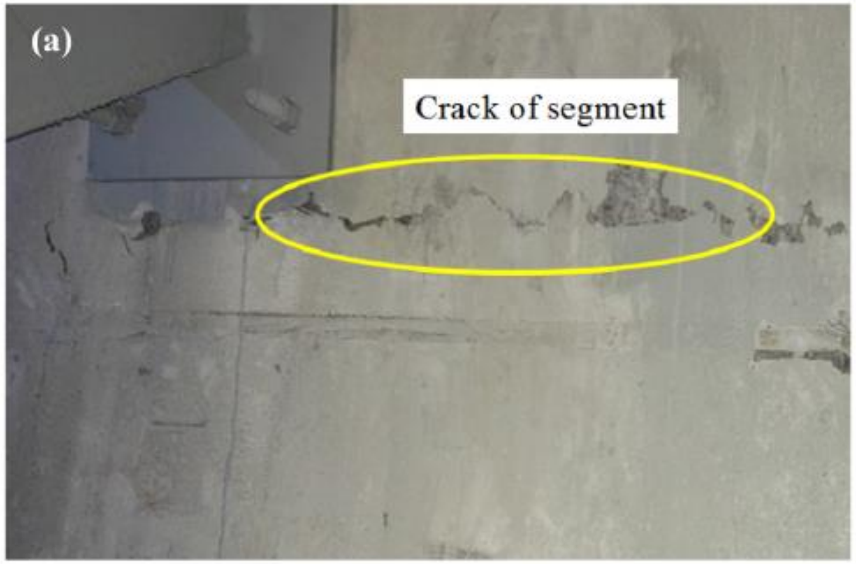


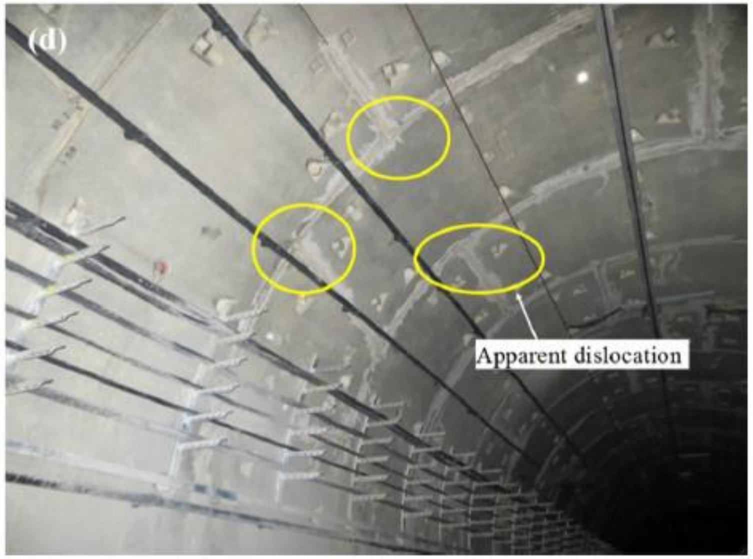


- ✓ the waterproofing of the lining is guaranteed by the right value of the compression on the rubber seals in the joints …
- ✓ leakage occurring for long time takes fine material inside and leaves loosened zones ….. a spiral getting worse with time
- ✓ need for intervention ….

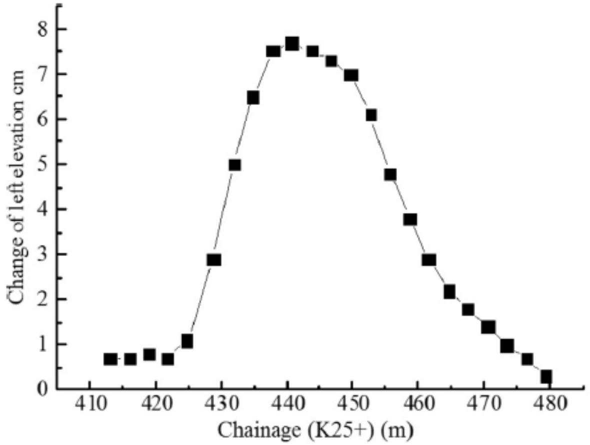


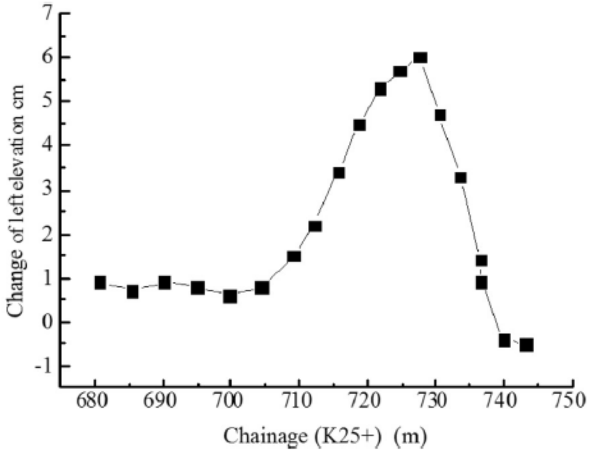
Typical damages to segmental prefabricated lining ….





- ✓ The intervention based on high pressure cement injections caused further damage to the lining …
- ✓ The lining is very sensitive to differential movements ….





Napoli underground network: LINE 1 & LINE 6

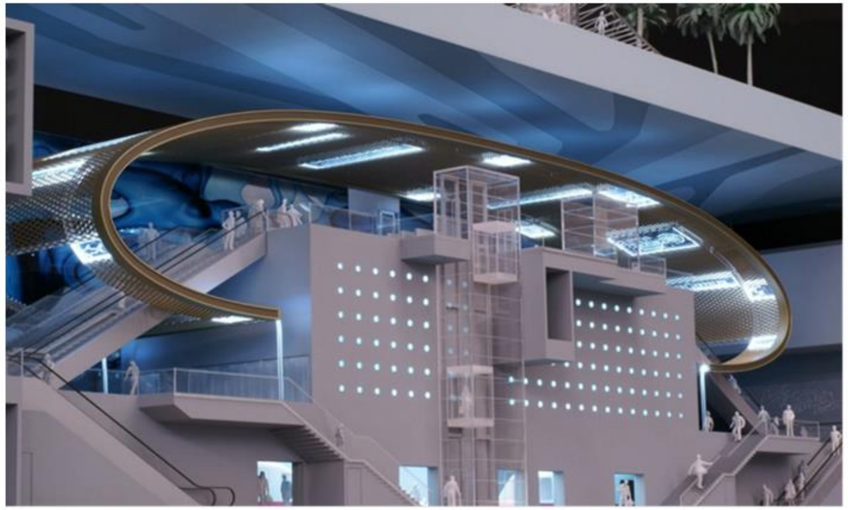
Line 1 of Napoli Underground lessons learnt and changes for Line 6.

Single tunnel with two rails (12 m diameter);

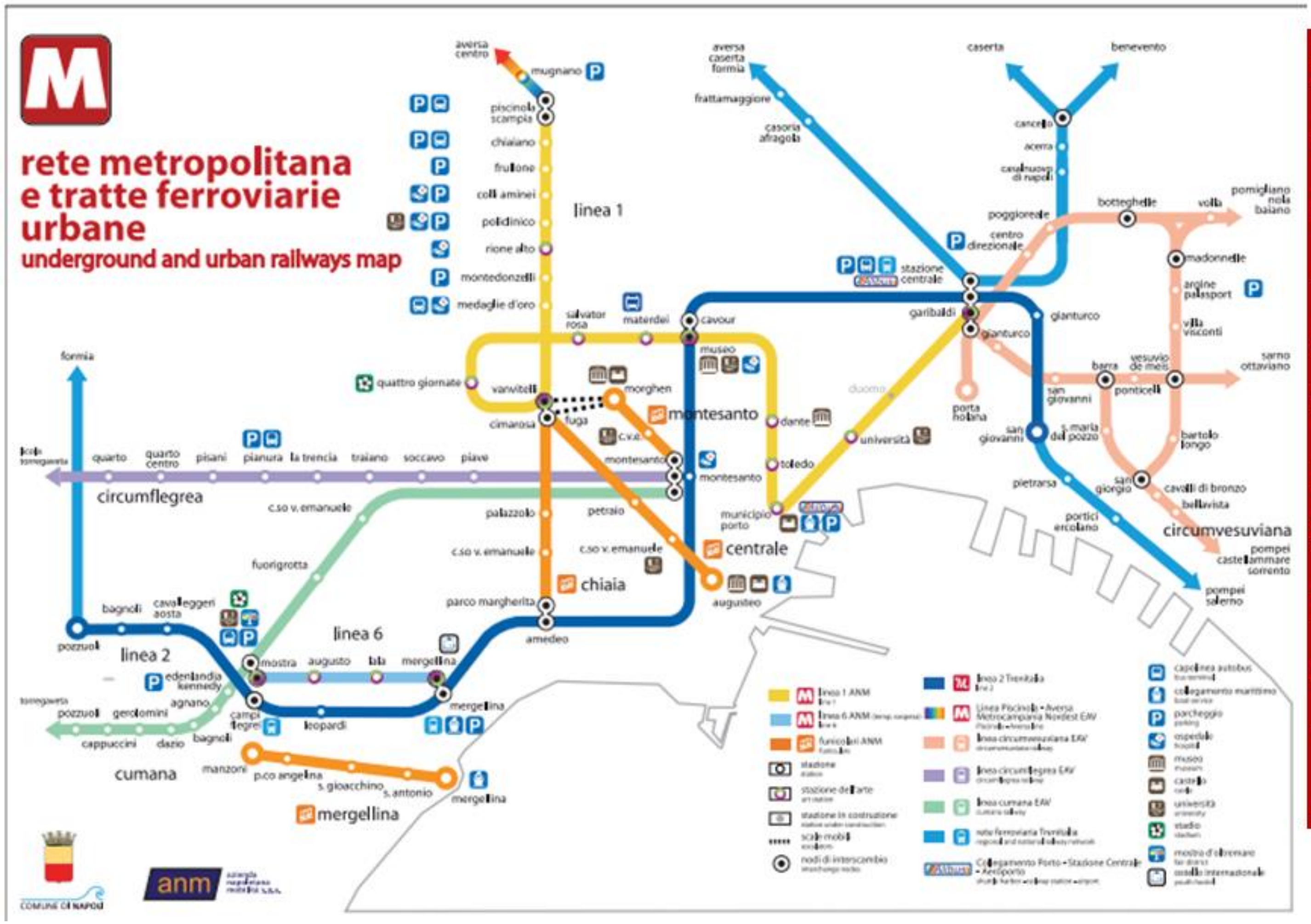
Passage of the TBM before shaft excavation;

No platform tunnels to be excavated by conventional methods and often with AGF; all included in large open vertical shaft when possible;

No ground anchors (if possible) and no ground freezing



Napoli underground network: overall development



Huge development of the undeground network in the city of Napoli in the last two decades.

2005: 22 millions of passengers/year

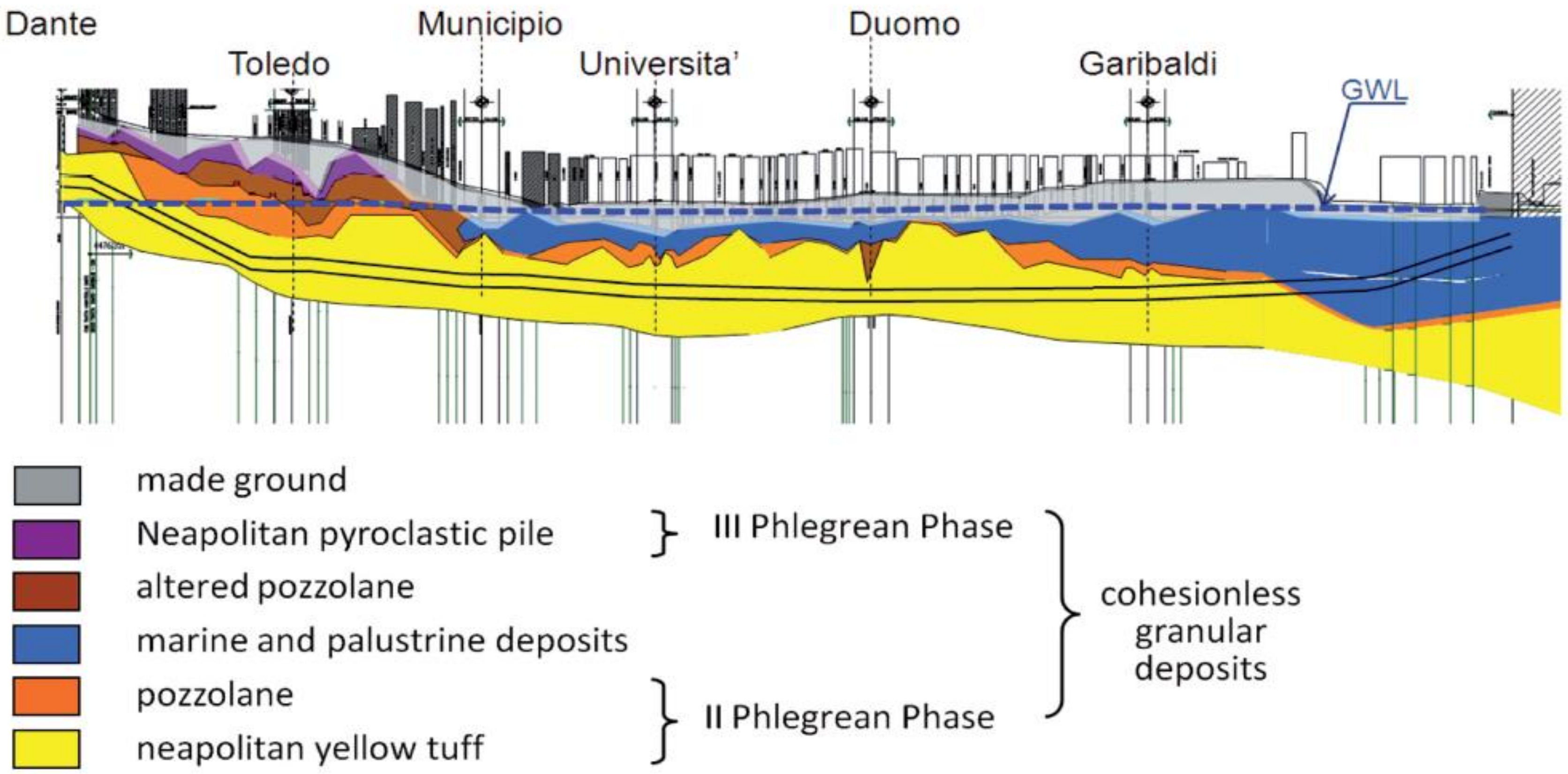
2017: 45 millions of passengers/year

At the completion: 150 millions of passengers/year

Line 1 Geology

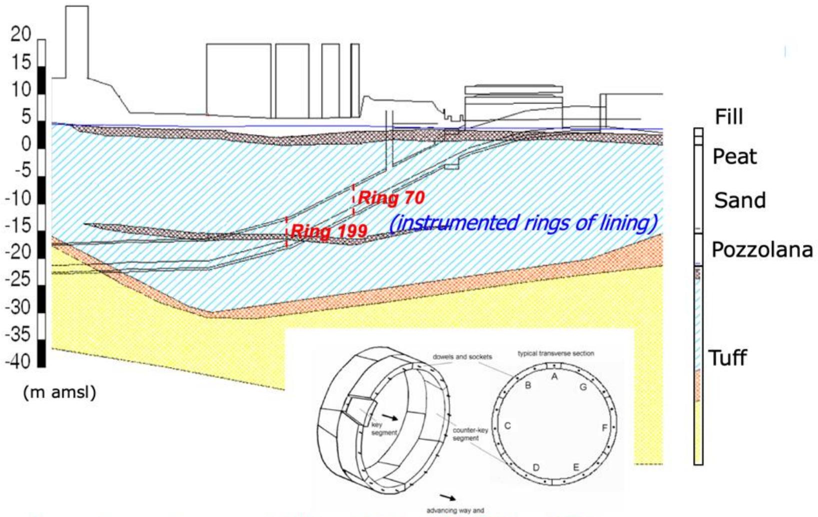
Geological profile of the lower stretch of Line 1 in Napoli

G. Russo/C. Viggiani/G.M.B. Viggiani - Geotechnical design and construction issues for Lines 1 and 6 of the Naples Underground



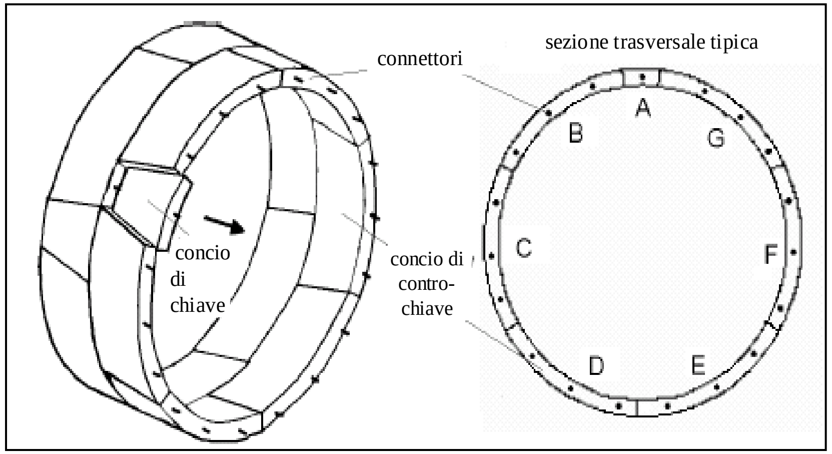
Line 1: Experimental investigations on the segmental lining

Longitudinal profile in the stretch from Directional Center to Garibaldi Station

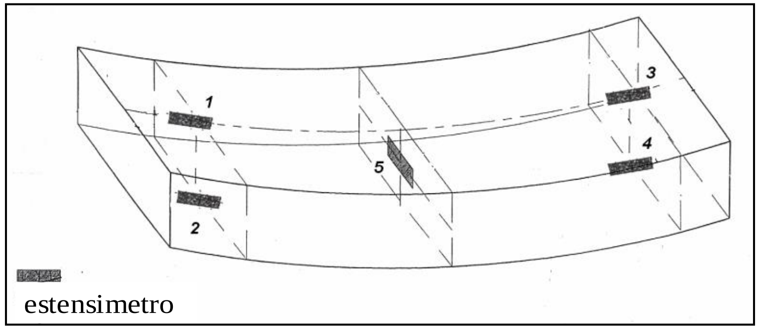


- *Pre-cast concrete segmental lining (5.85 m I.D., 6.45 m O.D.)*

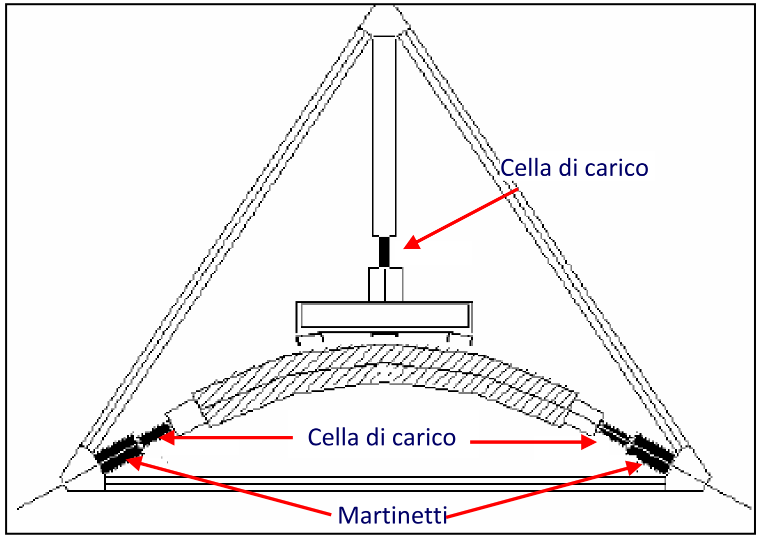
Typical cross-section



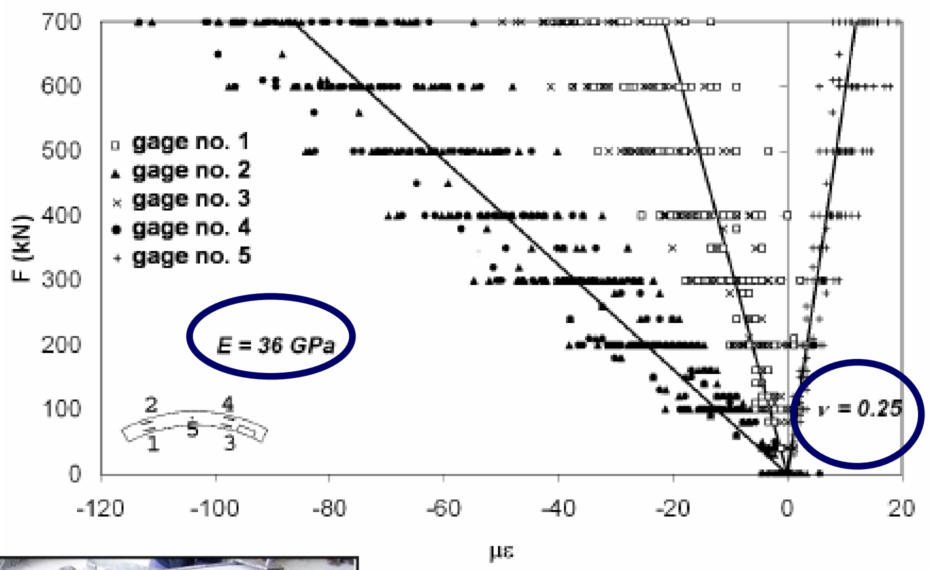
in the instrumented segment

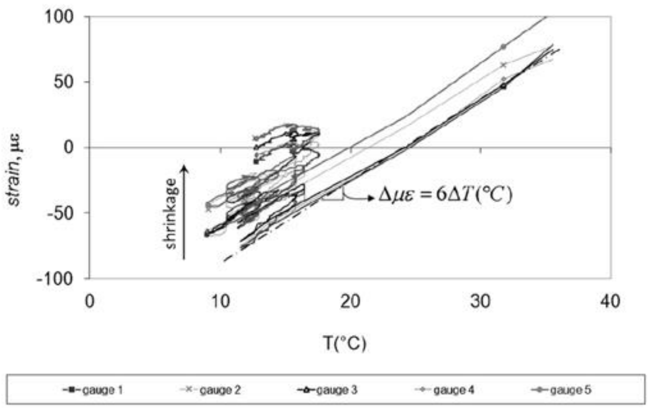


Line 1: Experimental investigations on the segmental lining



Results of load tests

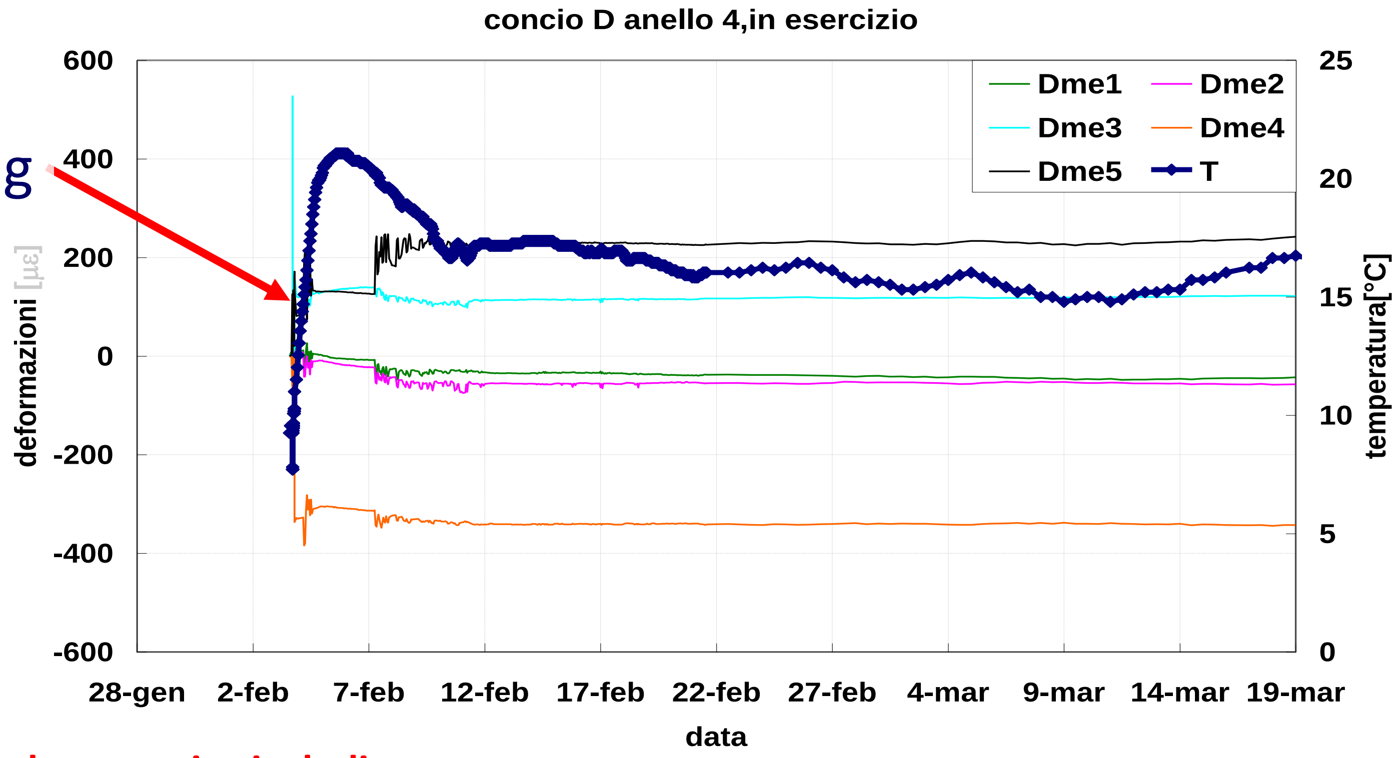




Line 1: Experimental investigations on the segmental lining

Line 1: Experimental investigations on the segmental lining

Start Mounting



Convention used: POSITIVE COMPRESSIONS

During assembly, large strains including tensile strains

After exiting the shield, changes in strains are very limited

Bending Moment

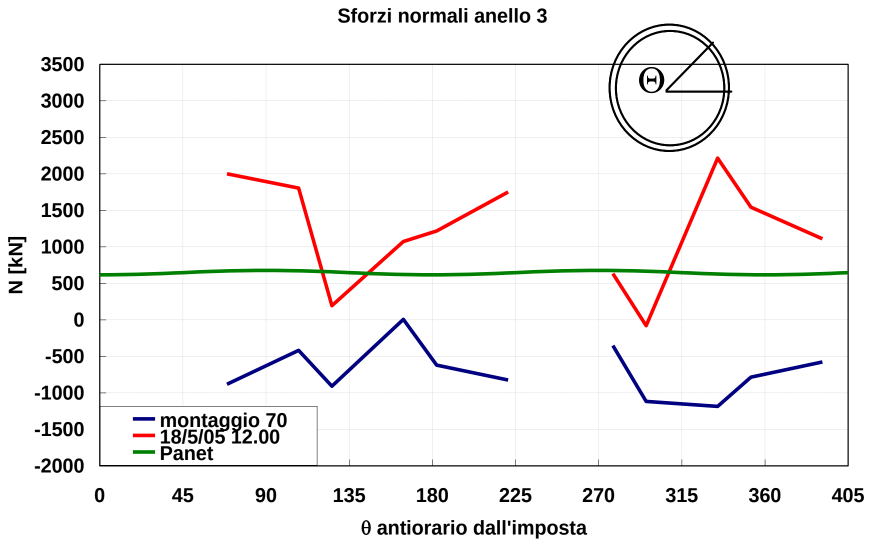
$$M = \frac{\varepsilon_{sup} - \varepsilon_{inf}}{2 \cdot b} \cdot EI$$

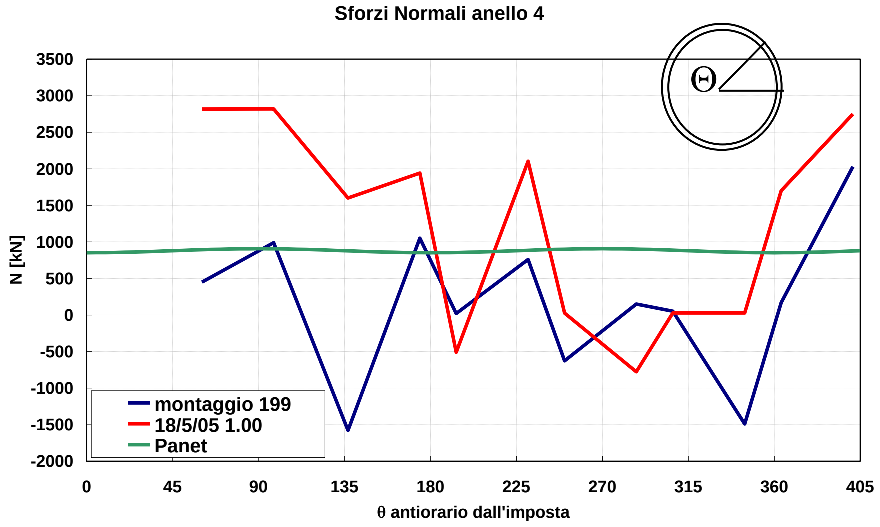
Axial Thrust

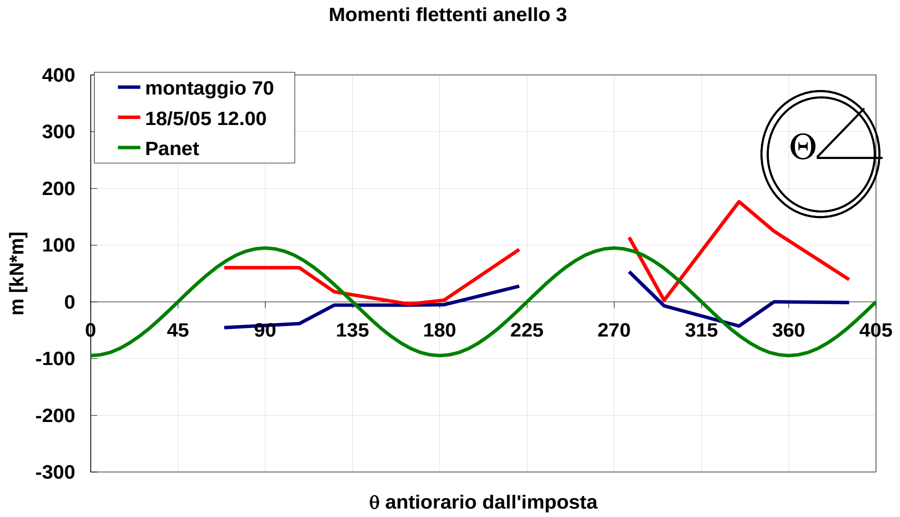
$$N = \varepsilon_{media} \, EA$$

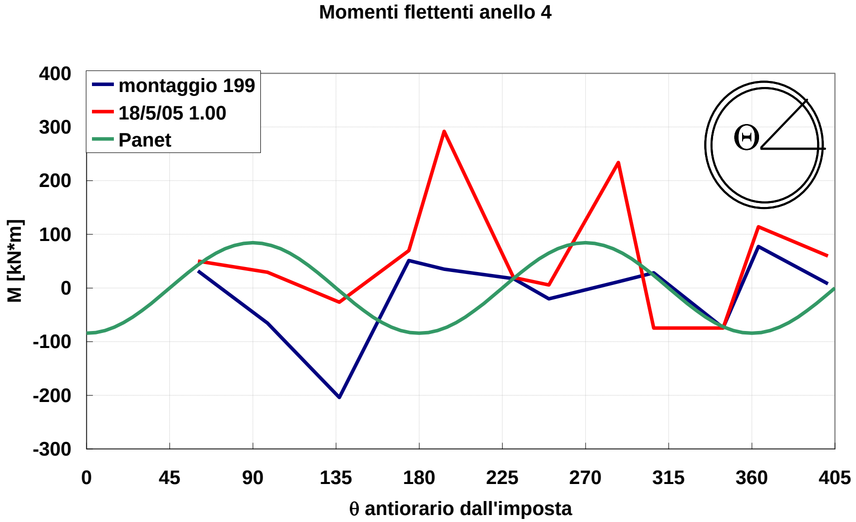
I attempt Simple beam theory

Line 1: Experimental investigations on the segmental lining









Line 1: Experimental investigations on the segmental lining

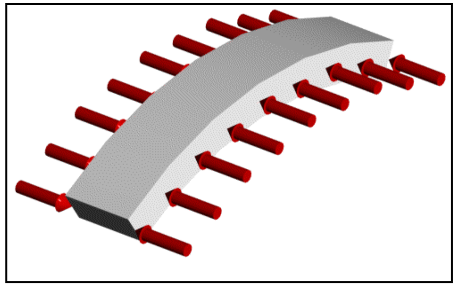
II attempt

- ✓The problem is 3D
- ✓The calculation of stresses from the measured deformations must be carried out via an incremental procedure because during the assembly of the various segments the constraint conditions change (geometric source of non linearity)

Line 1: Experimental investigations on the segmental lining

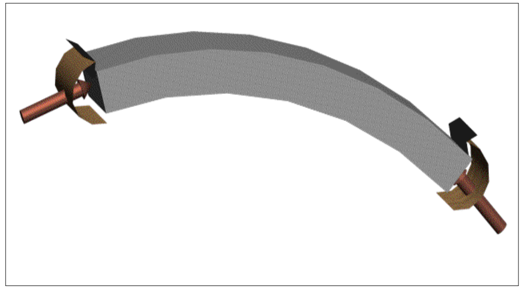
Jack thrusts and reaction of the back ring

Distributed loadings



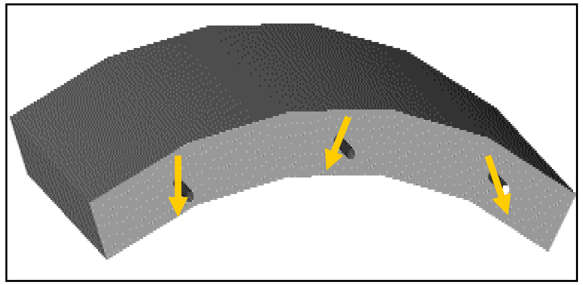
Interaction between adjacent segments

Distributed loads on the side faces



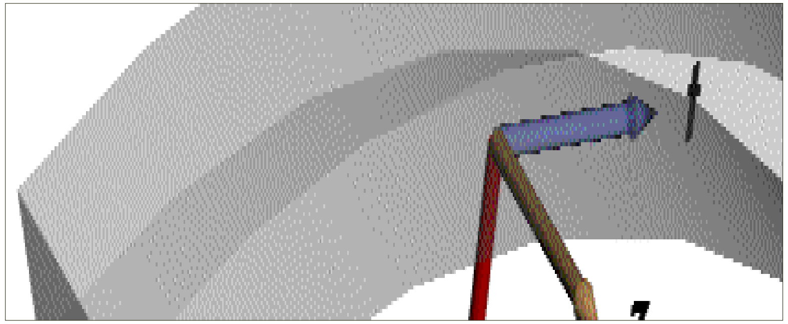
Forces transmitted from connectors to the segments

Concentrated loadings



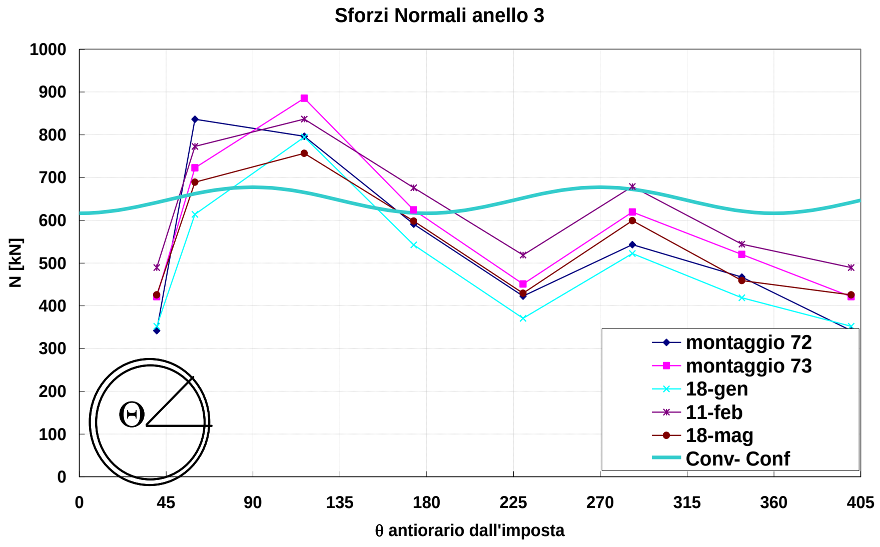
Equilibrium equations

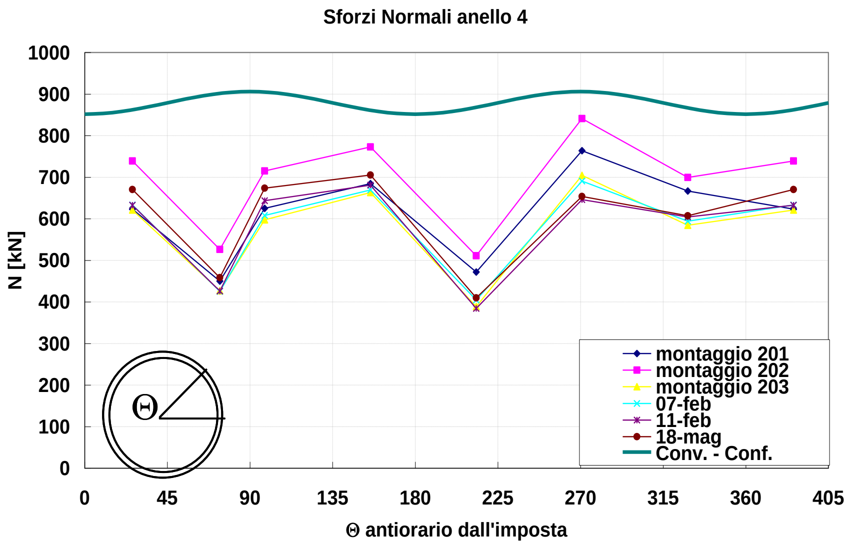
$$\left\{\begin{array}{ll} \Sigma\Delta F_{ri}=0 & \Sigma\Delta M_{ri}=0 \\ \Sigma\Delta F_{ti}=0 & \Sigma\Delta M_{ti}=0 \\ \Sigma\Delta F_{zi}=0 & \Sigma\Delta M_{zi}=0 \end{array}\right.$$

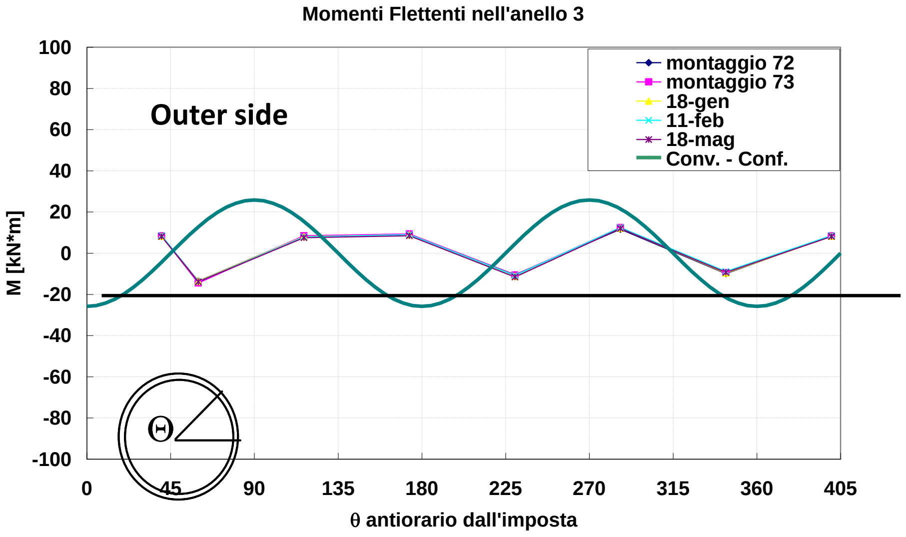


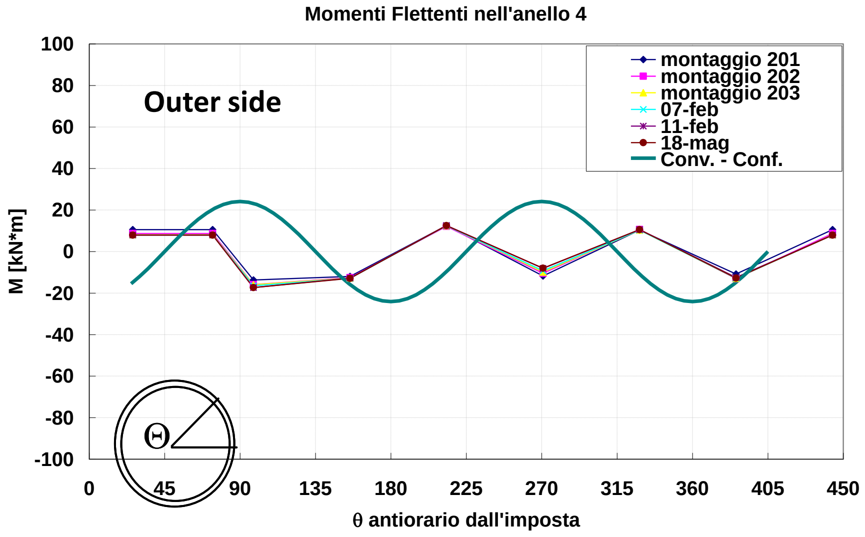
Compatibility equations $\Delta\varepsilon_{mis\ i} = \Sigma\alpha_i F_i$

Line 1: Experimental investigations on the segmental lining









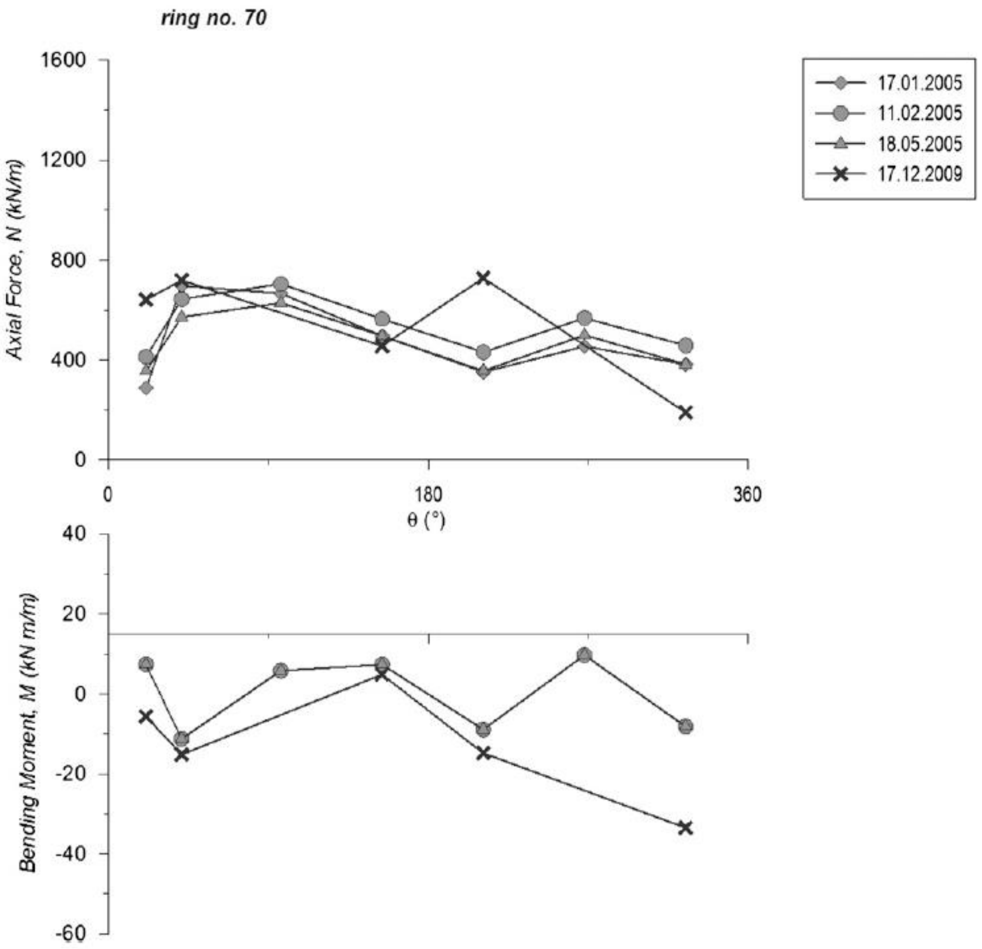
Line 1: Experimental investigations on the segmental lining

MORE DETAILS ON THIS
PROCEDURE IS AVAILABLE ON
.....

Internal Forces Arising in the Segmental Lining of an Earth Pressure Balance-Bored Tunnel

Emilio Bilotta, Ph.D[1] and Gianpiero Russo, Ph.D.[2]

J. Geotech. Geoenviron. Eng. ASCE 2013.139:1765-1780.



Line 1: Experimental investigations on the segmental lining

We are not alone ... to bang our heads...

Although on average the magnitude and distribution of the bending moments is well predicted by the 2D and 3D analyses (however, differences may be observed locally as high as 300% or more), they all fail in the prediction of hoop forces.

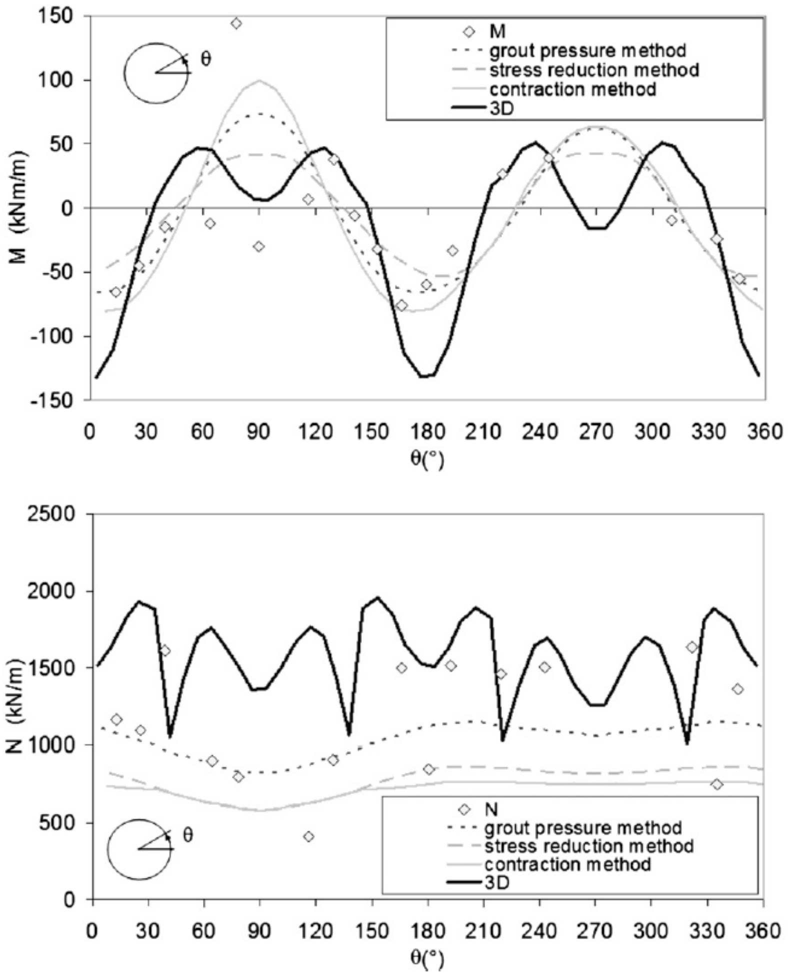


Fig. 1. Back-calculated and predicted values of the bending moment and hoop force in the Second Heinenoord Tunnel (modified after Koelewijn and Verruijt 2001; Möller and Vermeer 2008)

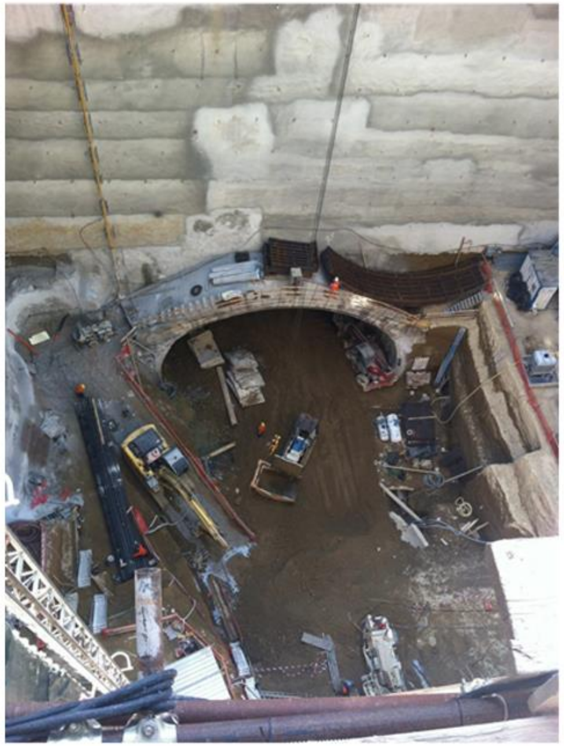
LINE 1 …. & LINE 6 – Napoli underground

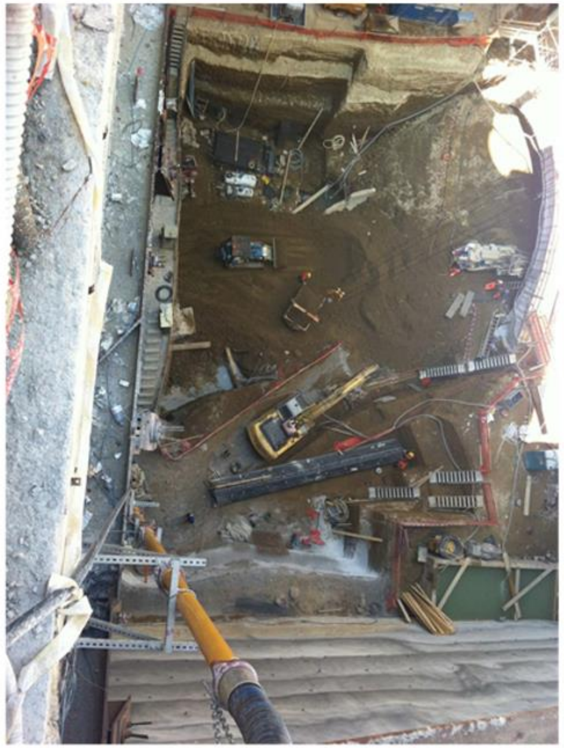
DIFFICULT WORKS IN URBAN ENVIRONMENT

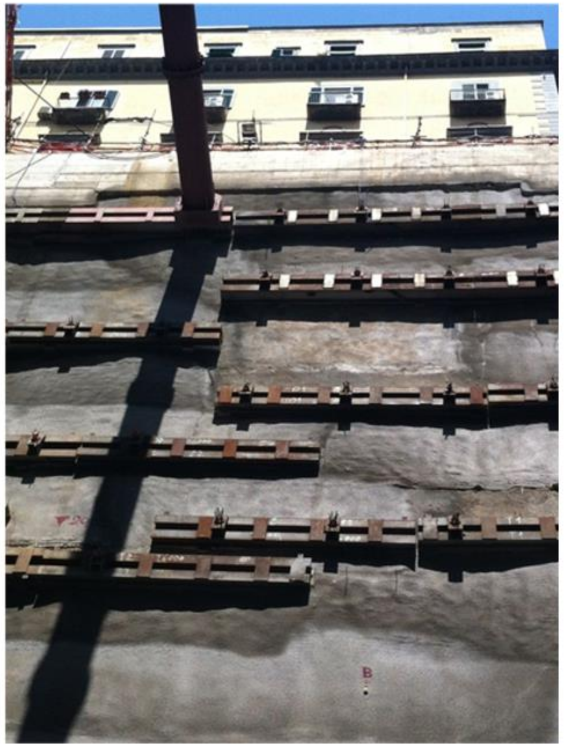
Lining structural monitoring in the new underground service of Naples (Italy)

Emilio Bilotta ⇑, Gianpiero Russo

Tunnelling and Underground Space Technology 51 (2016) 152–163







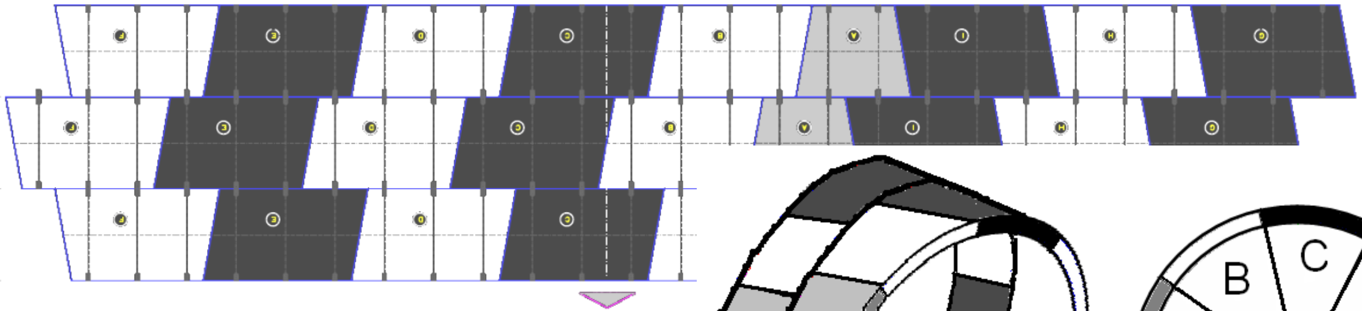
LINE 6 – Experimental investigations on the segmental lining

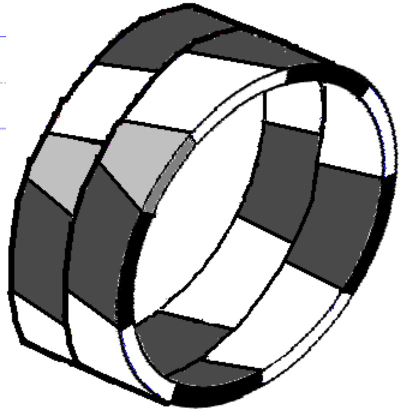
EPB shield machine

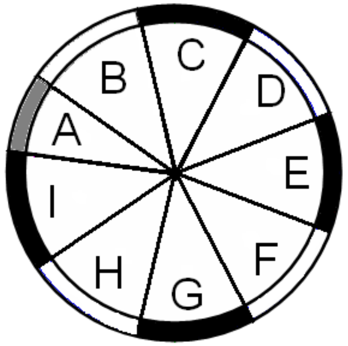
- D=8.16m

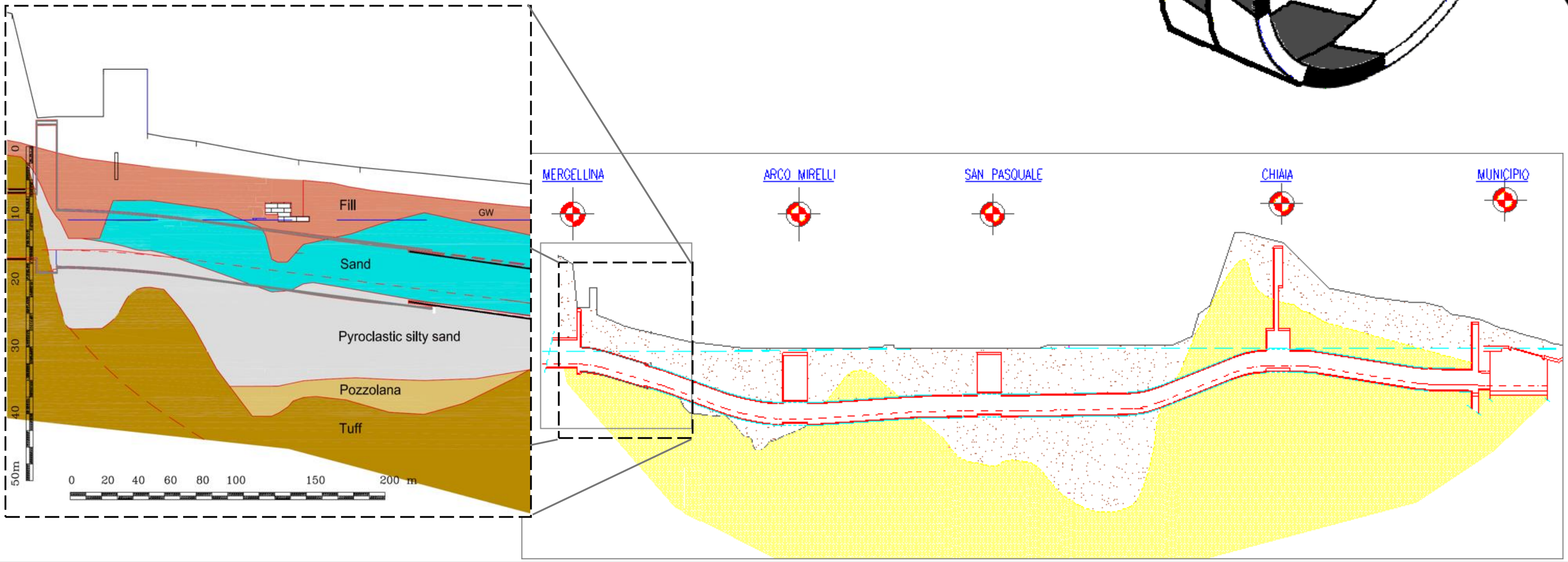
reinforced concrete lining:

- OD = 7.85 m
- ID = 7.25 m
- thickness, t = 30 cm
- width, w = 1.70 m
- 9 segments per ring

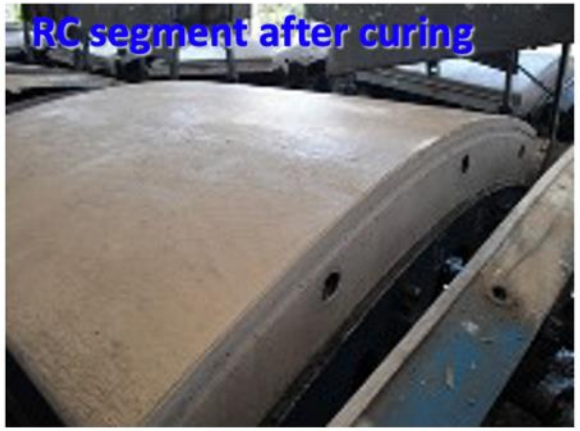








LINE 6 – Experimental investigations on the segmental lining

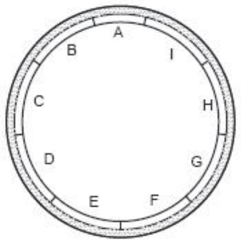


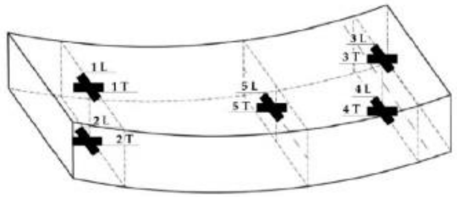
LINE 6 – Monitoring the strains in the lining

EURO:TUN 2017, Innsbruck University, Austria

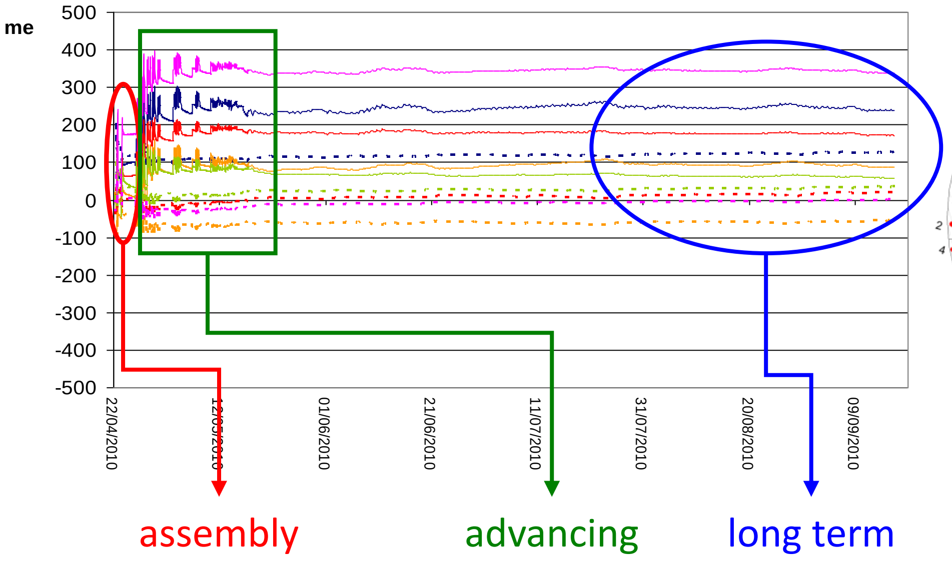
Numerical back-calculation of strain measurements from an instrumented segmental tunnel lining

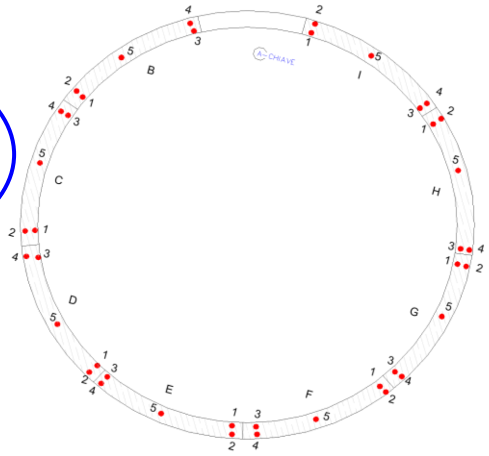
S. Fabozzi[1], E. Bilotta[1], G. Russo[1]



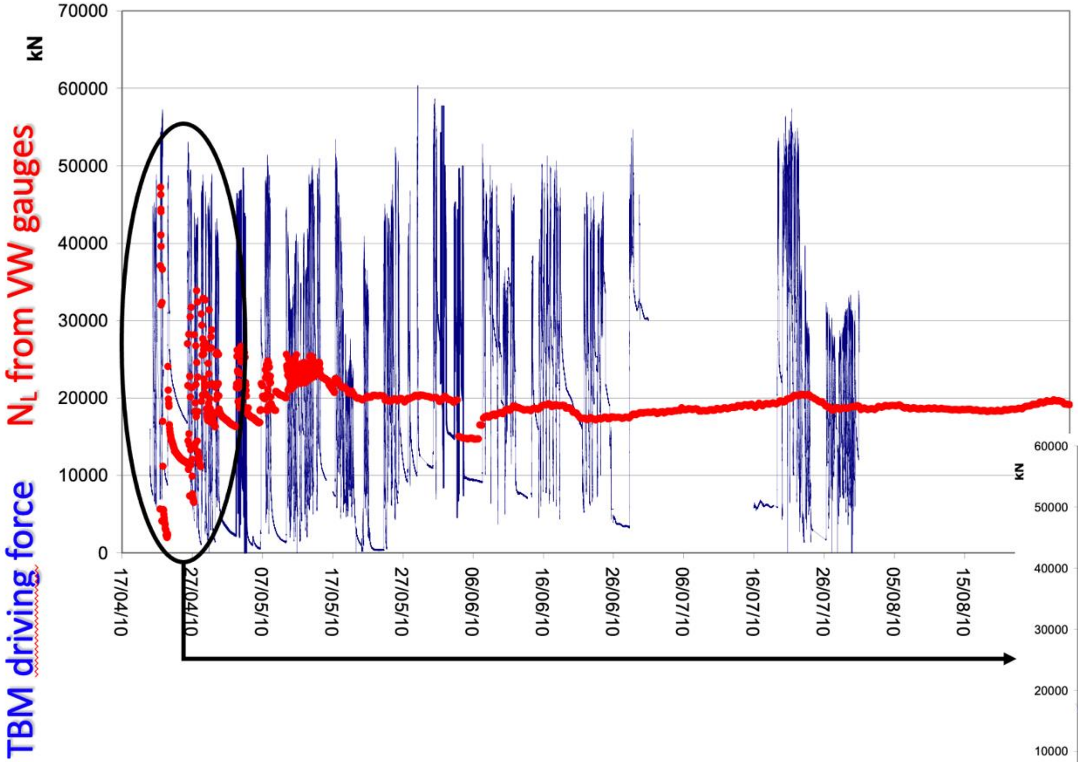


More sensors allowed more accurate interpretation and for instance the overall equilibrium check



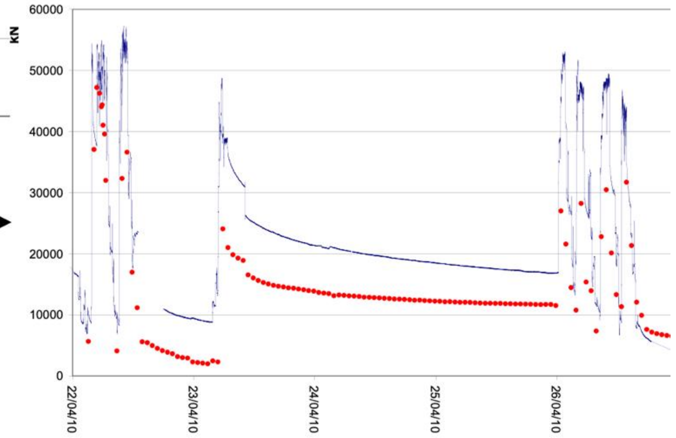


LINE 6 – Monitoring the strains in the lining



Longitudinal Axial Force N_L

EQUILIBRIUM CHECK



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S. Fabozzi, E. Bilotta, G. Russo

http://www.eurotun2017.com/de/home/

3D ACCURATE MODELING – MAIN STEPS:

1) TBM advancement : a nearly cylindrical rigid plate to simulate the shield (holding the trunk-conical shape -diameter variation 0.3%); a face pressure on the front for obvious stability issue;
2) Installation of the lining: the last ring placed under the shield protection is loaded longitudinally by forces equals to the measured thrusts;
3) *Grouting*: on the second ring - outside the shield - the pressure of the grout (fluid state) is applied as a hydrostatically increasing radial pressure with the depth (mean value deduced from pressure measurements at the nozzles);
4) Grout consolidation: the gap between the lining and the soil is "filled" by solid elements representative of the hardened grout and the elements of the interface grout-r.c. and of the grout-soil are activated (their mechanical parameters have been calibrated using the deformation measurements in the linings....)

LINE 6 – Monitoring the strains in the lining – FEM backcalculated M,N

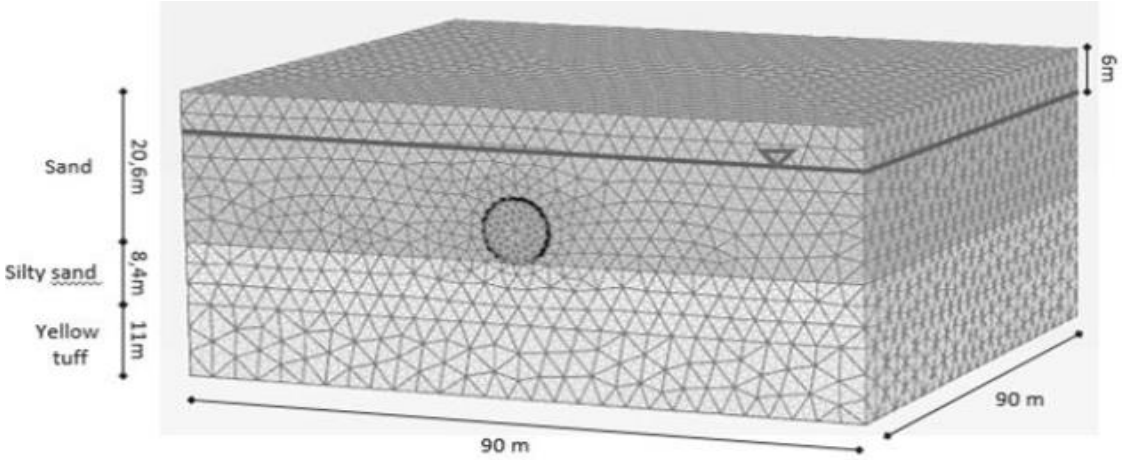
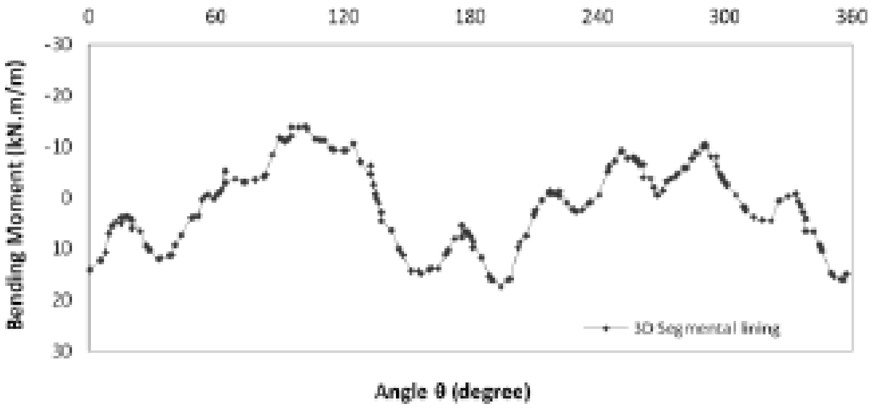


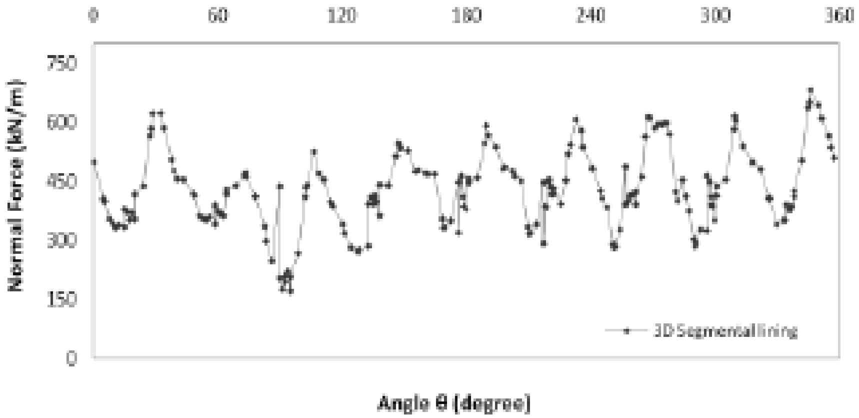
Table 1. Soil parameters.

	γ_{sat} kN/m^3	ν -	φ °	c' kN/m^3	E^{50}_{ref} E^{oed}_{ref} kN/m^2	E^{ur}_{ref} kN/m^2	$\gamma_{0.7}$	G_0^{ref} kN/m^2	p_{ref} kN/m^2
Sand	18	0.3	37	0	40E^3	85E^3	0.13E^{-3}	88E^3	115
Sity sand	16	0.3	37	0	47E^3	100E^3	0.19E^{-3}	182E^3	170
Yellow tuff	16	0.3	27	500	-	-	-	-	-

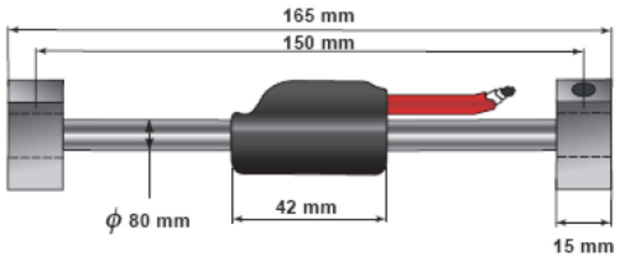
Transversal strains	*ε (10^{-3}) Measured*	*ε (10^{-3}) Calculated*
T1	0.080	0.076
T2	0.070	0.068
T3	0.070	0.063
T4	-0.170	0.028
T5	0.010	0.013

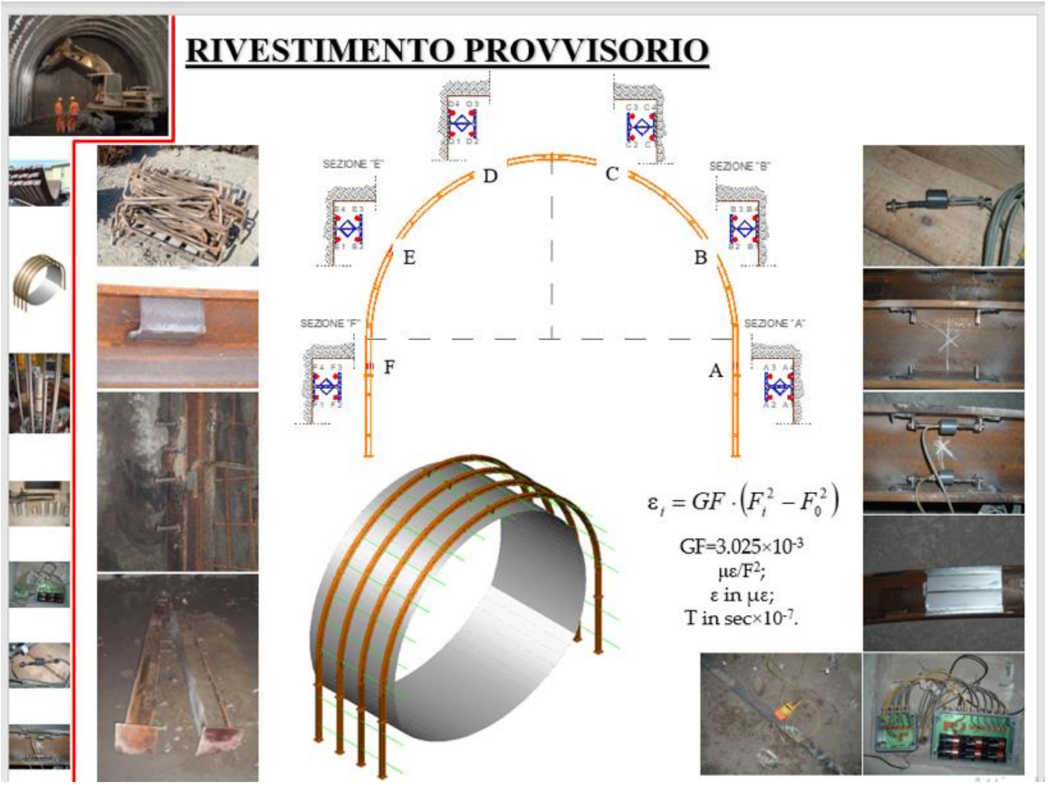
longitudinal strains	*ε (10^{-3}) Measured*	*ε (10^{-3}) Calculated*
L1	0.200	0.105
L2	0.050	0.092
L3	0.110	0.145
L4	0.001	0.128
L5	0.070	0.141
Average	0.108	0.122



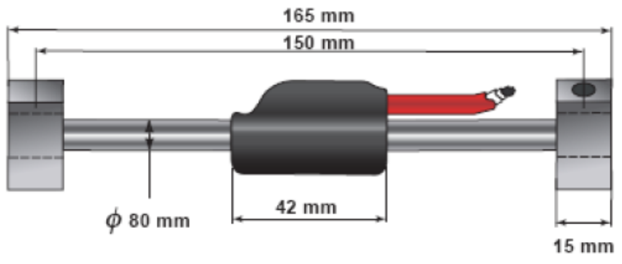


RELIABILITY IN THE LONG TERM OF SENSORS : VIBRATING WIRE GAGES

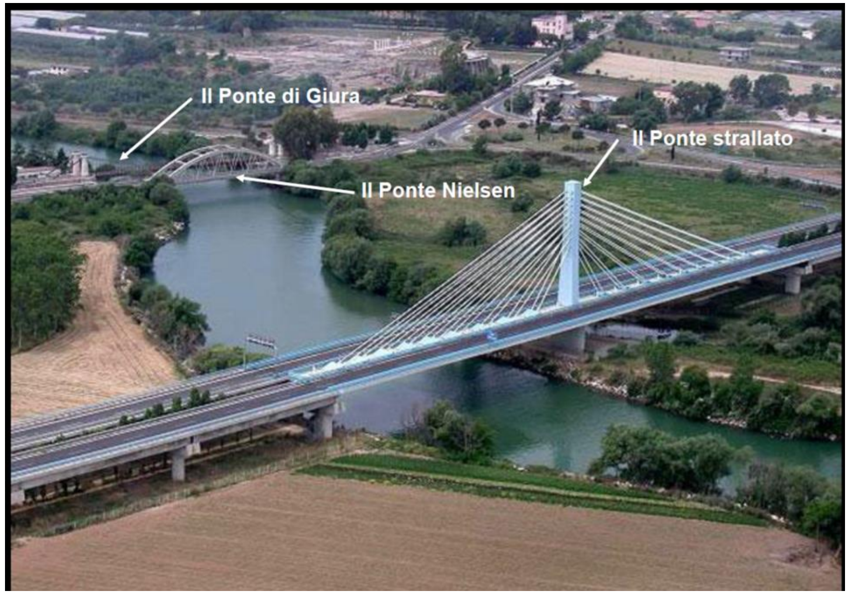


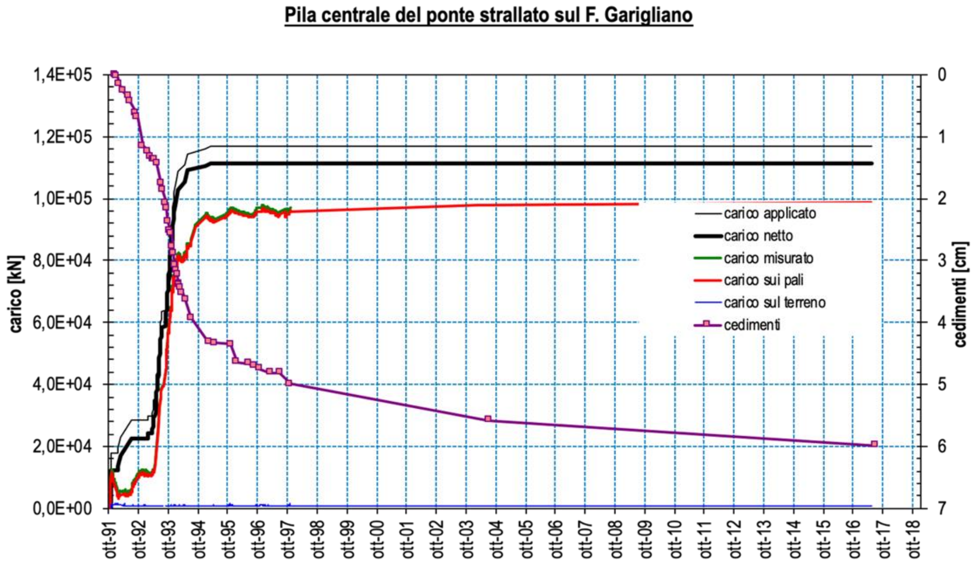


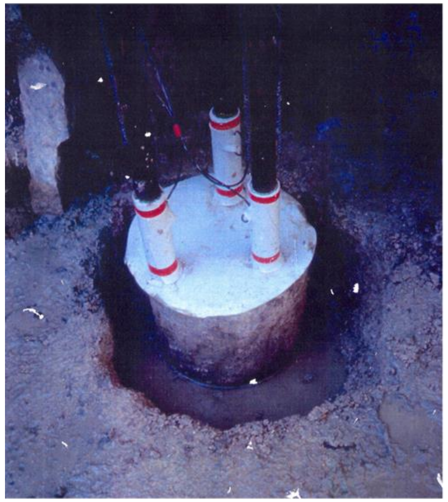
RELIABILITY IN THE LONG TERM OF SENSORS : VIBRATING WIRE GAGES

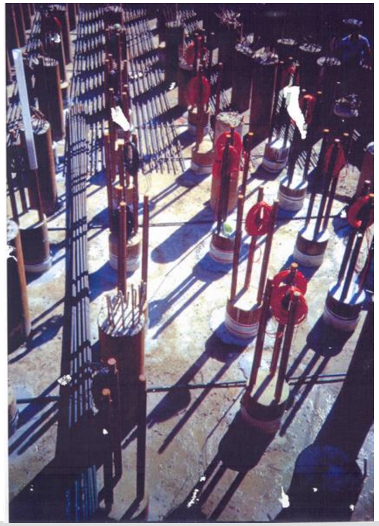


25 + 2 years of honoured work









TUNNELLING: New technologies and new perspectives

- ✓ **EXISTING TUNNELS REQUIRE INSPECTIONS AND CONTROLS:**

NEW TECHNOLOGIES ARE USEFUL BUT ALWAYS UNDER MAN SUPERVISION – ENGINEERING JUDGEMENT
WHEN YOU HAVE TO FACE WITH CONSTRUCTIONS FROM 10 YEARS TO 100 YEARS OR MORE AND THESE CONSTRUCTIONS ARE STILL ON THE «MARKET» THERE IS NOT A UNIQUE SOLUTION GOOD FOR ALL THE PURPOSES

AI APPLICATIONS ARE BECOMING MORE AND MORE POPULAR IN A NUMBER OF FIELDS AND ONLY FOR LIMITED ASPECTS THEY CAN BE VERY INTERESTING ; …. FOR INSTANCE ON GUIDING TRIAL AND ERRORS PROCEDURES **AI** APPLICATIONS CAN BE VERY USEFUL AND PRODUCE TIME SAVINGS;

NEW SENSORS AND NEW TRANSDUCERS ARE AVAILABLE (MEMS - LORAWAN TECHNOLOGIES AND SIMILAR THINGS) (OLD SENSORS AND OLD TECHNOLOGIES SHOULD BE ABANDONED ?)

- ✓ **EXISTING TUNNELS NEEDS DECISIONS:**

PREDICTIVE MANTEINANCE CAN BE AN EFFICIENT ANSWER TO THESE NEEDS.

LAST BUT NOT LEAST: ONCE DETECTED A DEFECT A CO-RELATION BETWEEN THE DEFECT OR THE DAMAGE AND THE PERFORMANCE OF THE TUNNEL SHOULD BE DEFINED AND ASSESSED – NOT AN EASY TASK