Società Italiana Gallerie
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BEYOND A TUNNEL VISION
THE SECOND EUROPEAN CONFERENCE ON TUNNEL RENOVATION

SIG SESSION: INSPECTION, INVESTIGATION AND MONITORING
DURING TUNNEL SERVICE LIFE

Tunnelling 4.0: New Technologies and Future Perspectives for Maintenance, Upgrading and Refurbishment of Tunnels

Andrea Pigorini

Friday November 27th 2020 – fully digital

Tunnelling 4.0: new technologies and future perspectives for maintenance, refurbishment and upgrading of tunnels
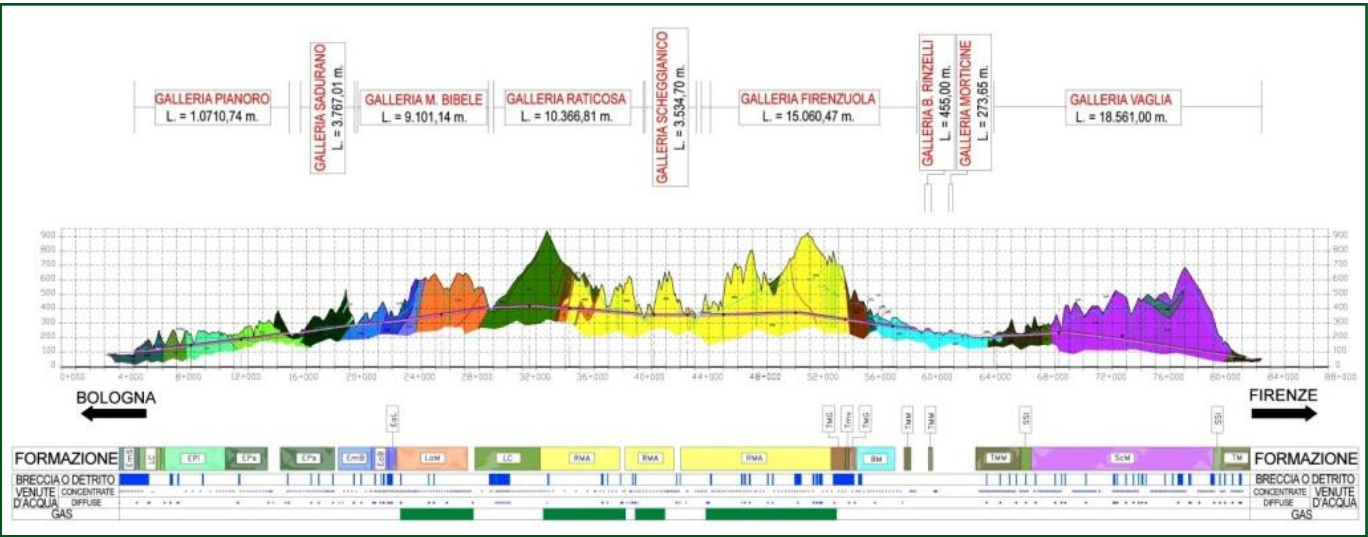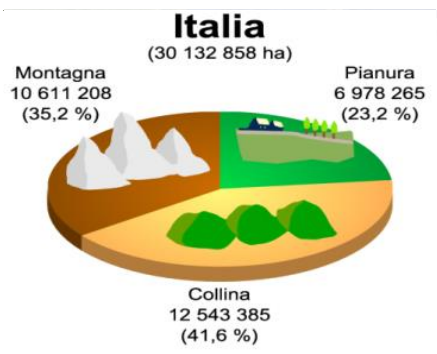

What do we need to prevent problems during tunnel operation ?

Tunnelling 4.0: Italian scenario

Without doubt, in Italy the need to build tunnels is more important than elsewhere.
This is due to the complex morphology of our country.

Profile of the railway line AV Bologna-Firenze . 72,4 km of tunnels at 300 km/h

ITALY'S OROGRAPHY

Alps Mountain chain (750 km)

Appennine Mountain chain (1500 km)

Tunnelling 4.0: Italian scenario

Tunnels in Italy (2014)
3780 tunnels for total length of 2100 km.
(metro tunnels are excluded).

Railway tunnels length (2019)

L = 100-500 m
n. = 1025
km = 246
L = 500-1000 m
n. = 309
Km = 214
L > 1000 m
n. = 348
km = 1064

Figure 1 - Total length of railway and road tunnels up to 2014 (source http://lotsberg.net/index_it.html).
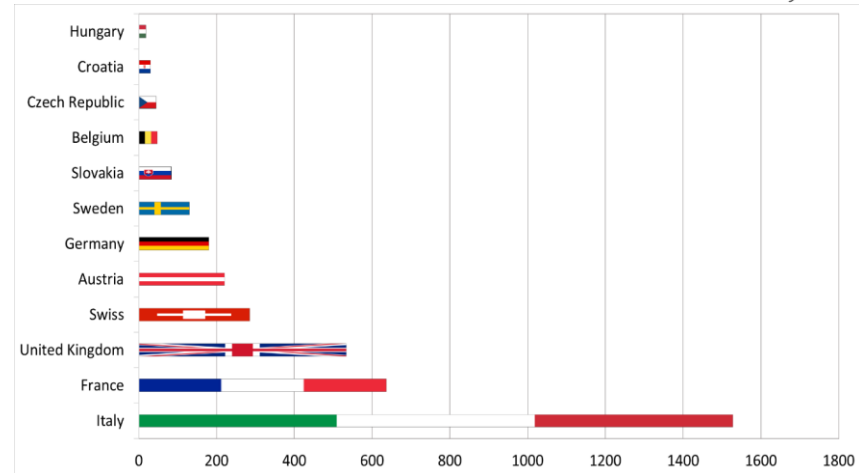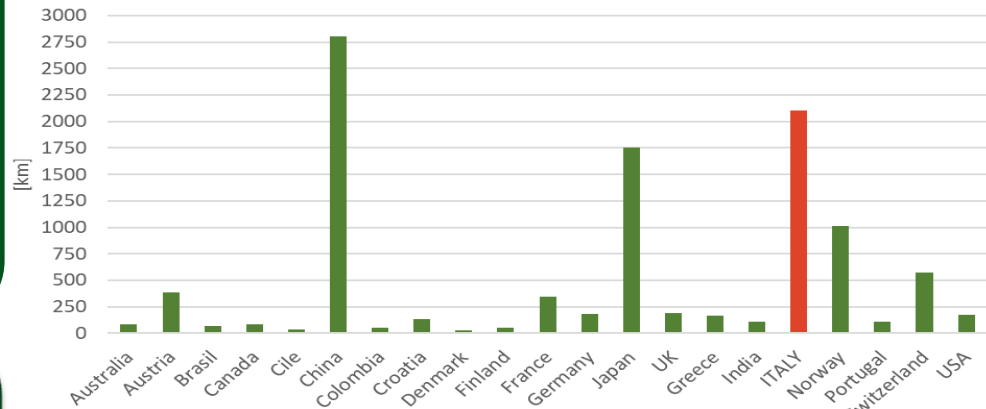

Figure 2 – Comparison of railway tunnels in several European countries updated to 2019.

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Tunnelling 4.0: Italian scenario

Without doubt, in Italy the need to build tunnels is more important than elsewhere.
This is due to the complex morphology of our country.

In Italy the first underground works were realized during the Ancient Roman Time
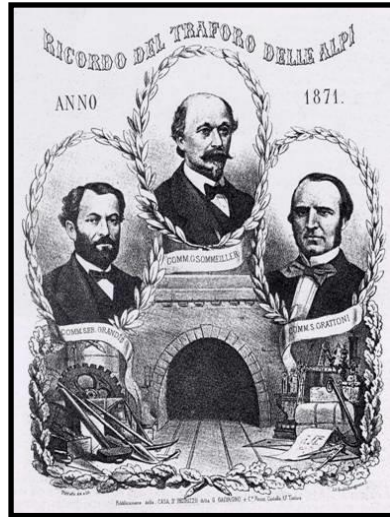
Ancient Furlo's Tunnel («Forulum-little hole») in the Marche Region, along the original Flaminia Road's layout.
It was excavated in the 76 d.C. during Vespasiano Emperor and ***still used today as road tunnel***
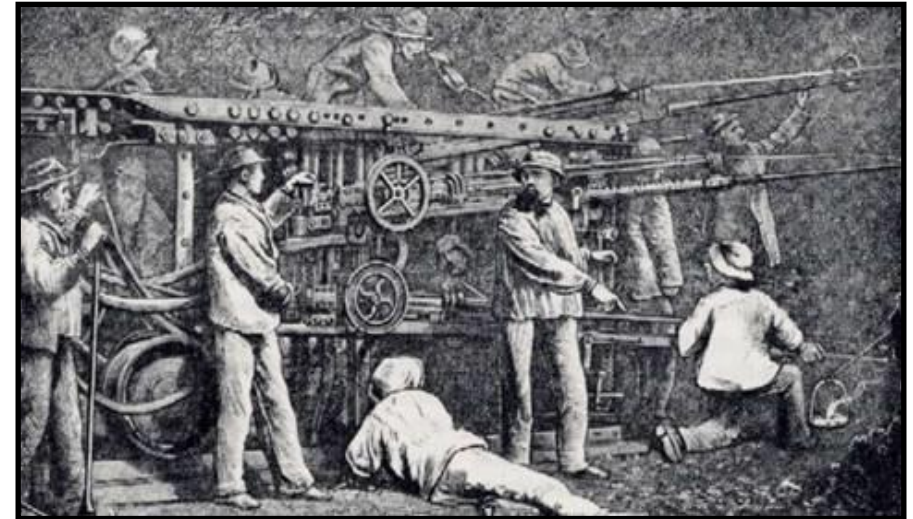
Tunnelling 4.0: Italian scenario

Frejus railway tunnel 12 km long tunnel connecting France and Italy completed in 1871
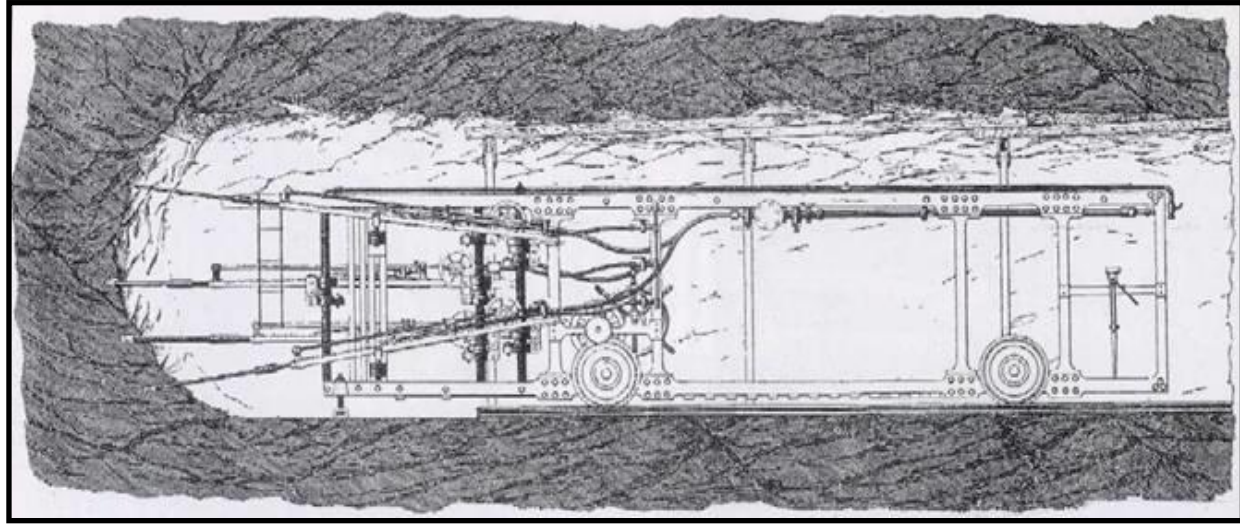
➤ the first compressed air drilling machine – the «father» of modern jumbo

➤ the excavation made by means of gunpowder (the dynamite was invented in 1866 but was still under testing)
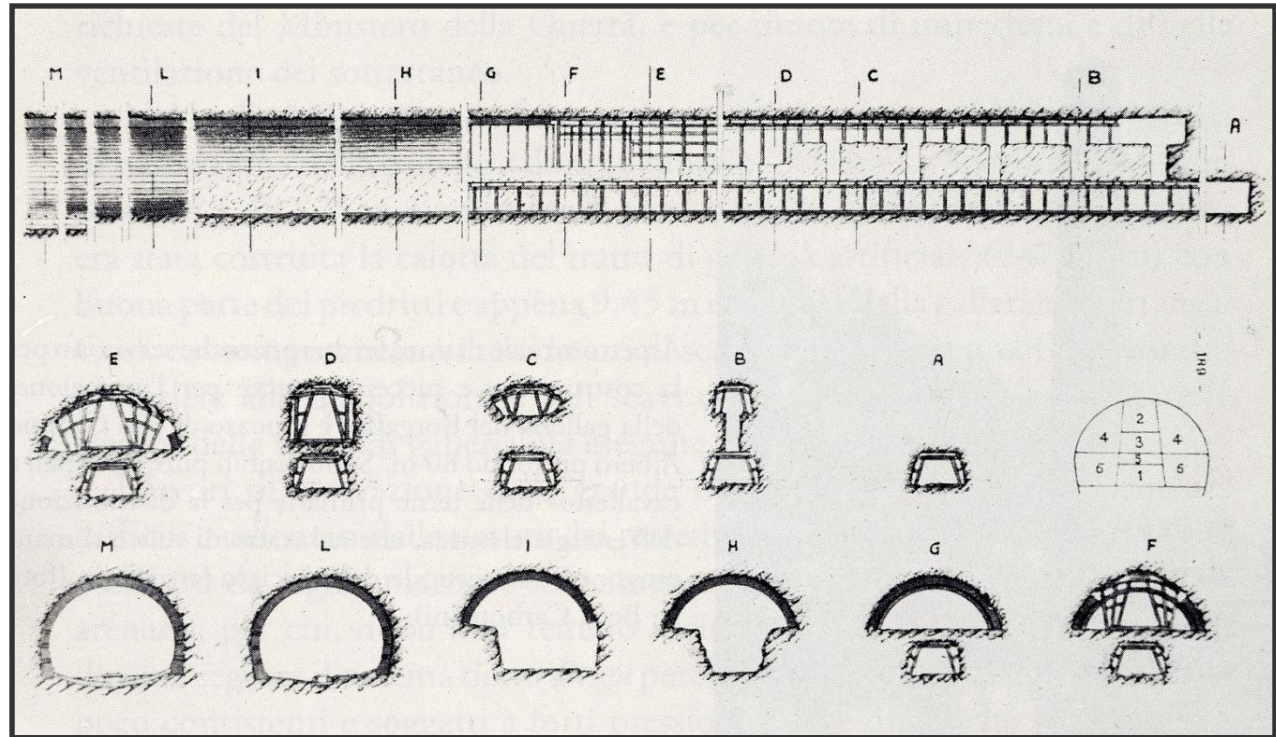
In the 1900s sequential excavation method was used with multi drift tunnels excavation, using wood for prelining and masonry and bricks for final lining.

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Tunnelling 4.0: Italian scenario

Railway Tunnels
n. = 1682
Km = 1524

* sample L > 2 km

Legend:
- Brick masonry
- Stone masonry
- Mixed masonry
- Reinforced concrete and not
- Precast lining
- Others (without lining included)

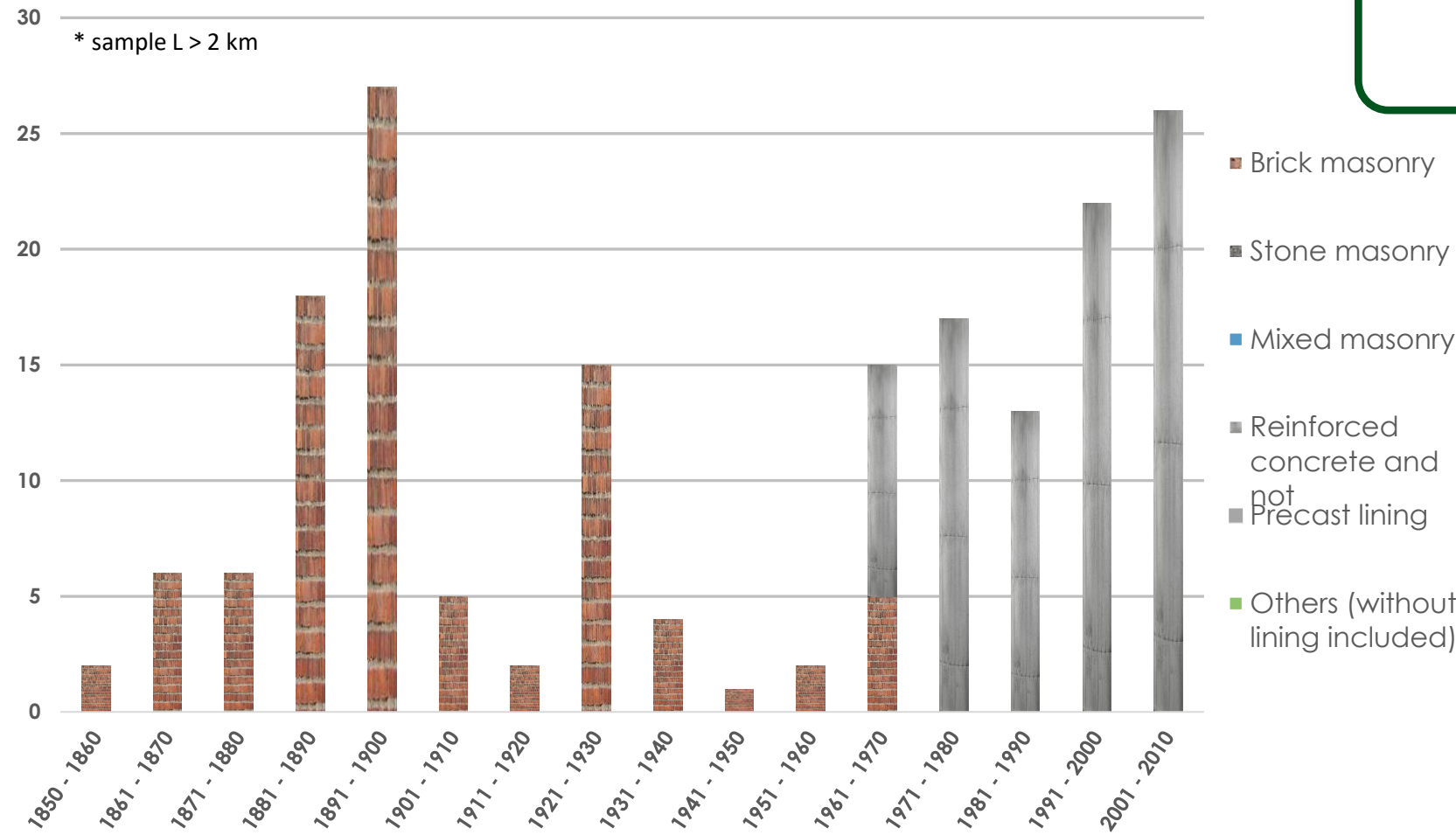Pie chart: 17,2% / 9,1% / 40,2% / 26,9% / 0,1% / 6,5%

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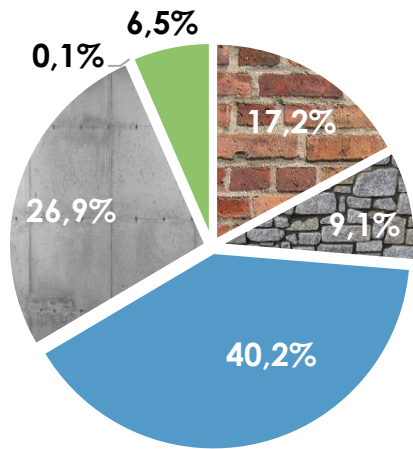
Tunnelling 4.0: tunnel life cycle

TUNNEL LIFE CYCLE

Reuse of tunnel for different purposes

Minor works needed to guarantee tunnel designed service line (example: tunnel works for water proofing)

disposal

maintenance

Tunnel asset management

upgrading

rehabiliatation

Upgrading of tunnel designed use (example: tunnel enlargement to host bigger gauges or more lines/tracks)

Tunnel lining structural problem (example: tunnel invert lifting)

Tunnelling 4.0: maintenance and refurbishment - From operator visual surveying to mobile diagnostic system
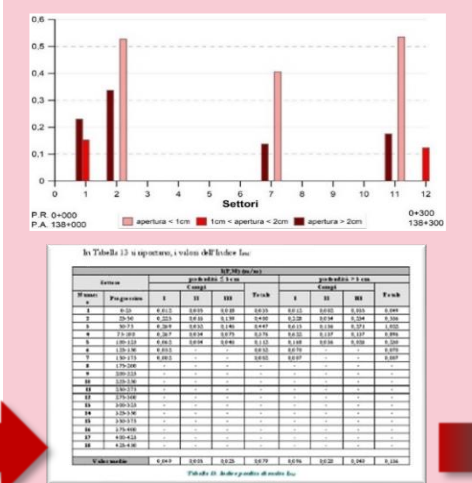
Mobile diagnostic systems

Tunnel Damage Management System

Tunnels surveys

Report and data analysis

Evaluation of tunnels damages and deterioration

Definition of refurbishment works priority

Tunnelling 4.0: mobile diagnostic system – Italian State Railway experience

Laser scanning mobile system

Use of two-mode hybrid vehicle with a mapping speed up to 30 km/h and 6/8 laser camera installed on the HV

High resolution tunnel mapping

Laser Camera

Two-mode hybrid vehicle
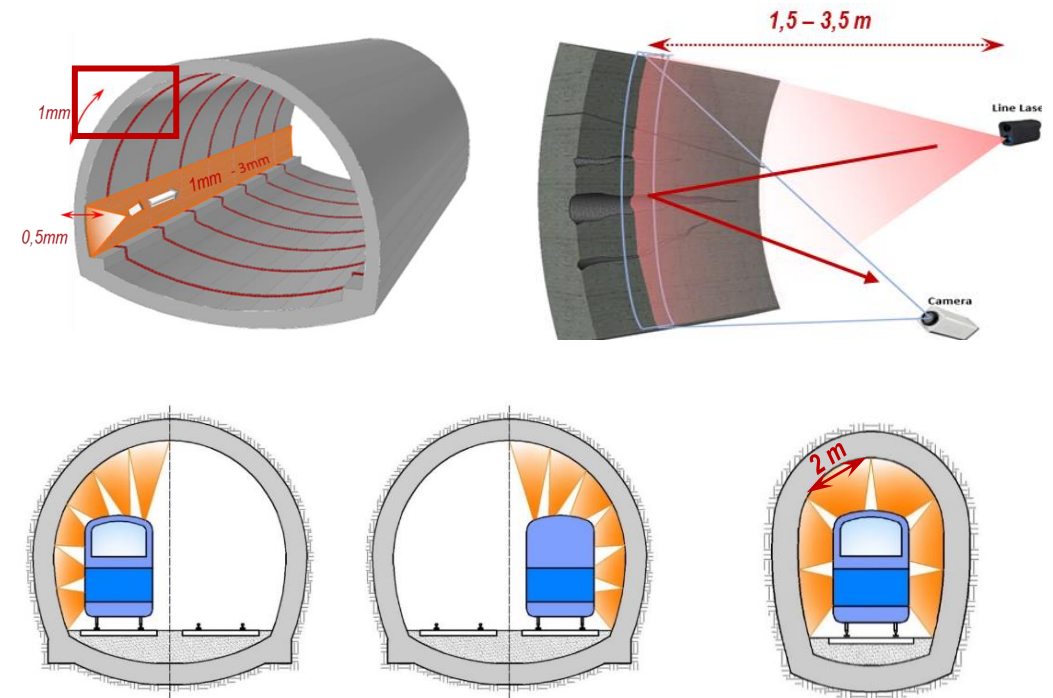
Double track

Single track

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Post processing SW to detach lining damages and wet portion of the lining.

3D View SW with virtual reality tools: more people can use VR at the same time to share information and provide instruction.

Concrete cracks measures and classification

3D scanner of the lining highlighting damages and concrete deterioration
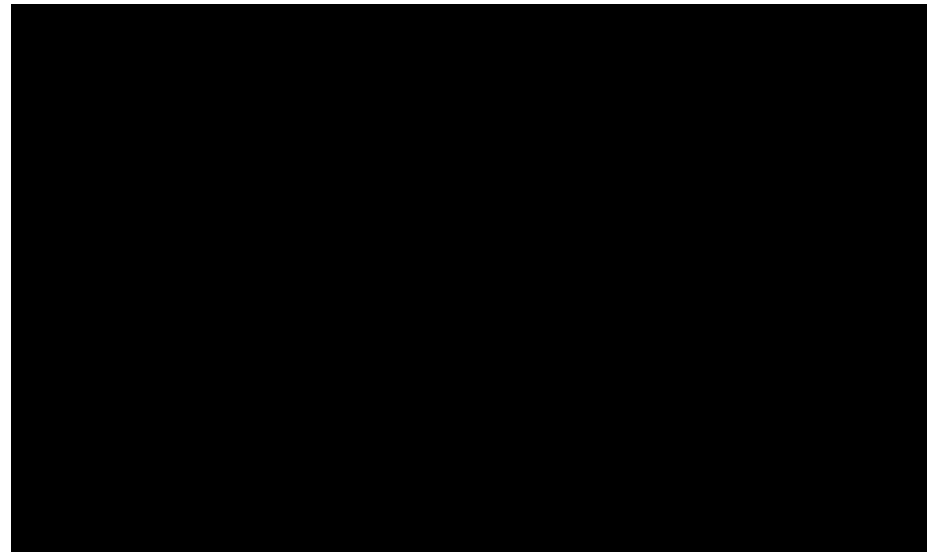
Tunnelling 4.0: tunnel damage management system – Italian State Railway experience

The Italian State Railway (RFI) together with Trento University has improoved and validated an algoritm di evaluate the tunnel lining damage from datas acquired through a mobile diagnostic system.

Subdivision of the lining in 25 m stretches

SETTORE 1 SETTORE 2 SETTORE 3 SETTORE 4 SETTORE 5

Damages classification (7 types)

Water leaching

Cracks (longitudinal, transversal, diagonal)

Loss of mortar layer between masonry

Major damage in the lining (loss of bricks, masonries, concrete deterioration)

Major lining local collapse

WORK IN PROGRESS

Definizione stato di danneggiamento della galleria

Damage Index (ID)

To evaluate the damage severity

Spread Index (I$_{DIFF}$)

To evaluate the damage diffusion

ID and **I$_{DIFF}$** index values allow to define

Priority for maintenance and rehabilitation works

Galleria A	
ID	n° settori
1	0
2	91
3	37
4	3
5	2
6	3
7	0
8	0
9	0
10	0
11	0
I$_{DIFF}$	6.24
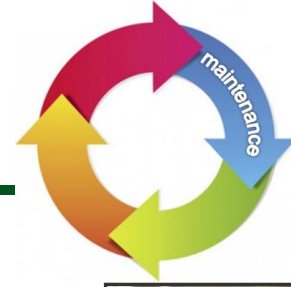
Works for tunnel water proofing and minor cracks repairing
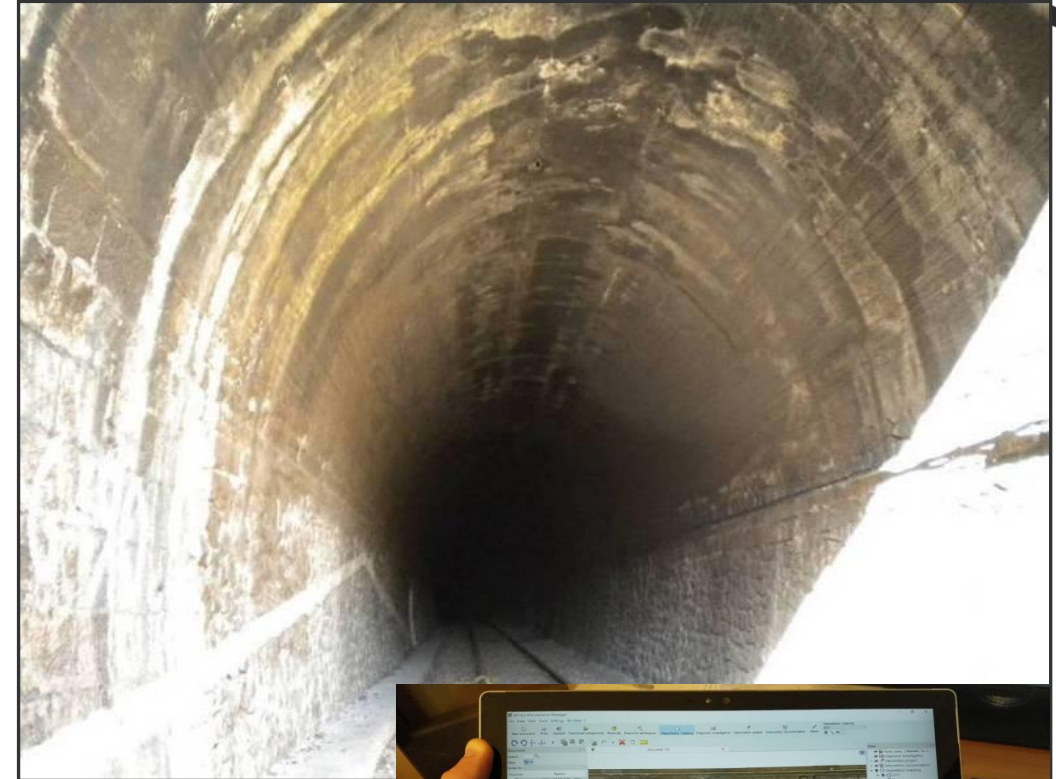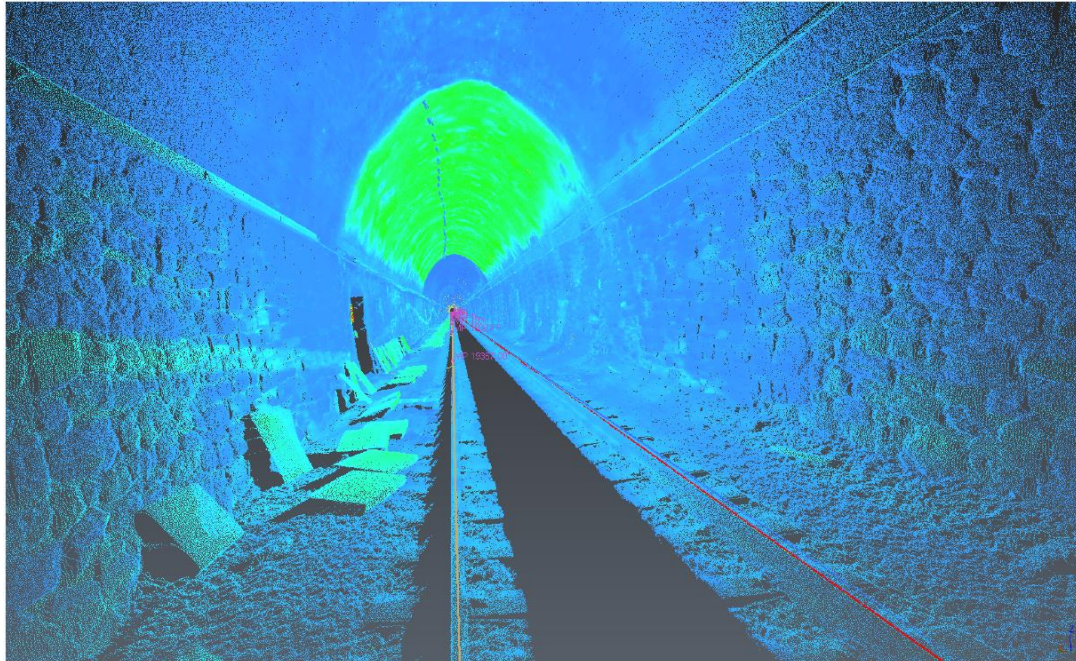
On the field check and analysis of the Damage Index
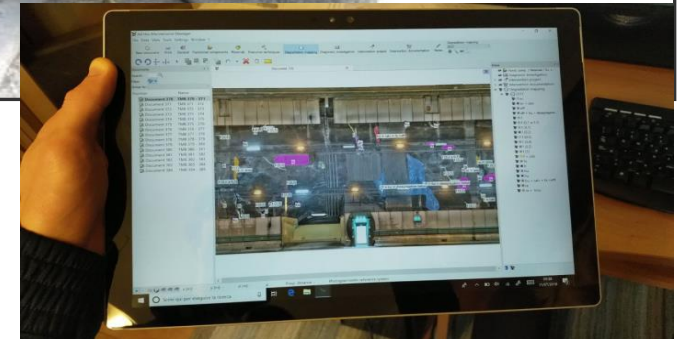
Tunnelling 4.0: maintenance works

1
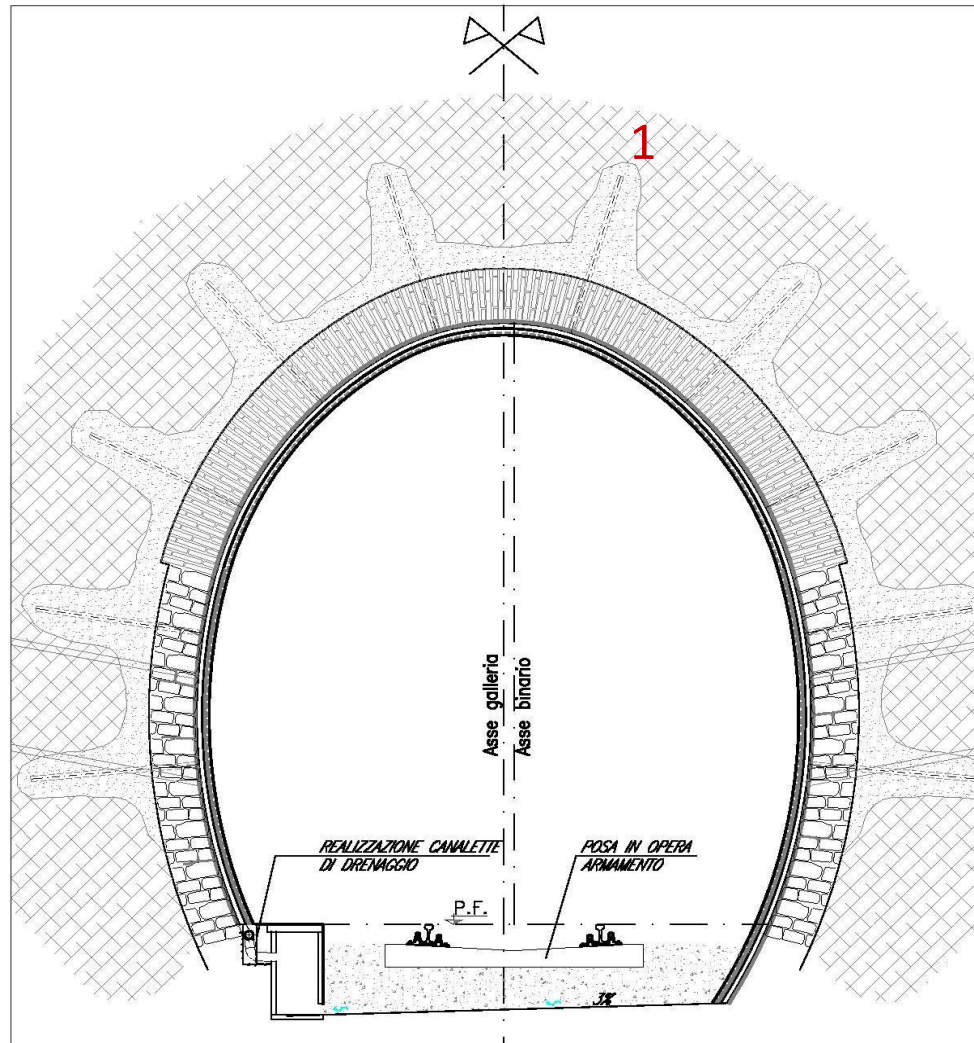
1. CONTACT GROUTING BEHIND EXISTING LINING

2. CRACKS REPAIR BY MEANS OF ACRYLIC AND POLYURETHANE RESINS

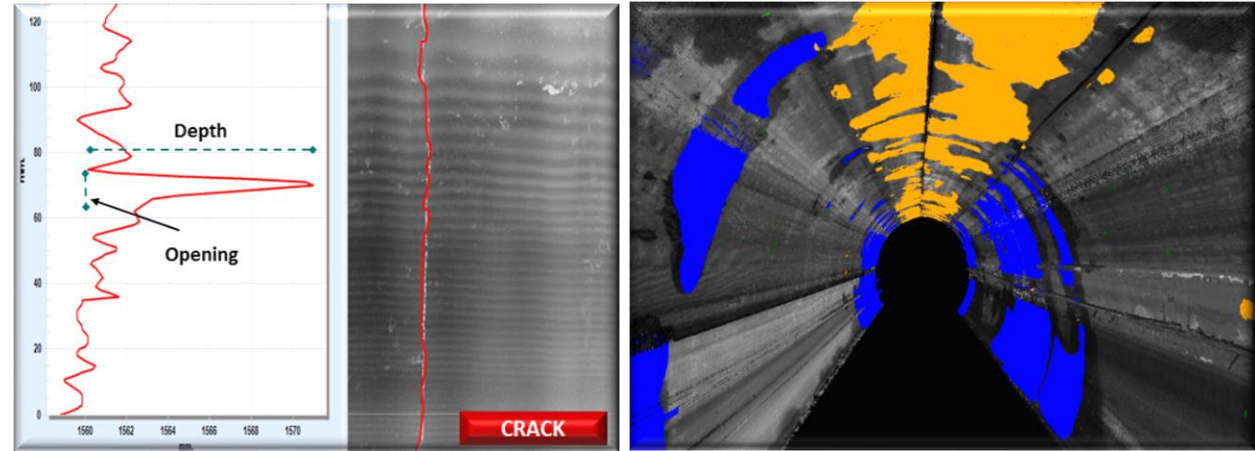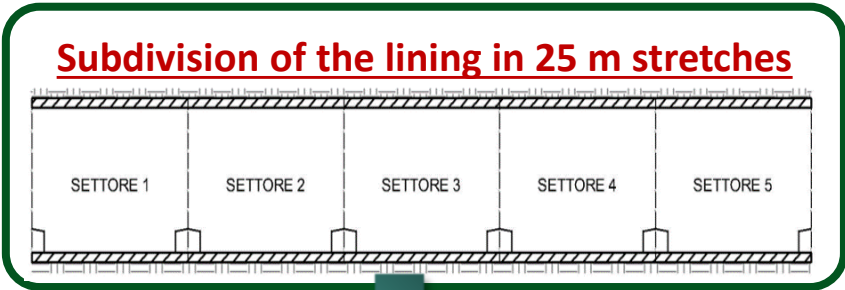3. DRAINAGE AND WATERPROOFING SPRAYABLE MEMBRANE

4. SECOND SHOTCRETE LAYER

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Tunnelling 4.0: rehabilitation works

Structural strengthening and waterproofing

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Invert reconstruction - artificial ground freezing

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7
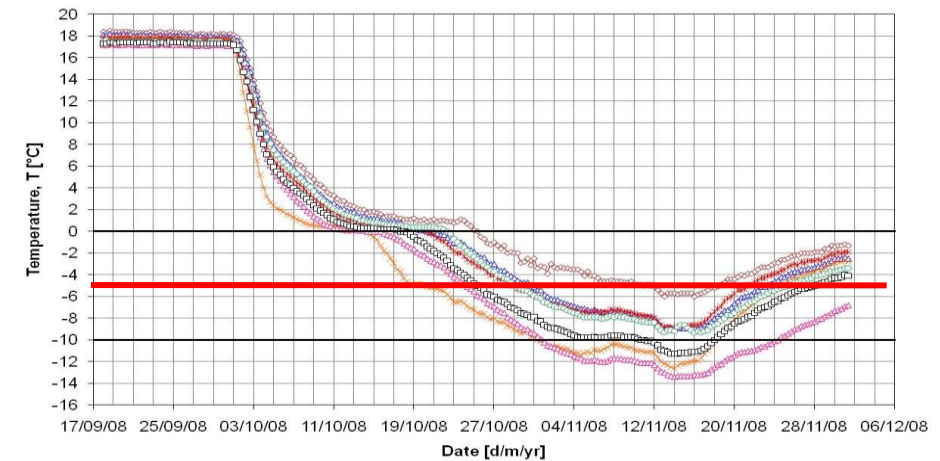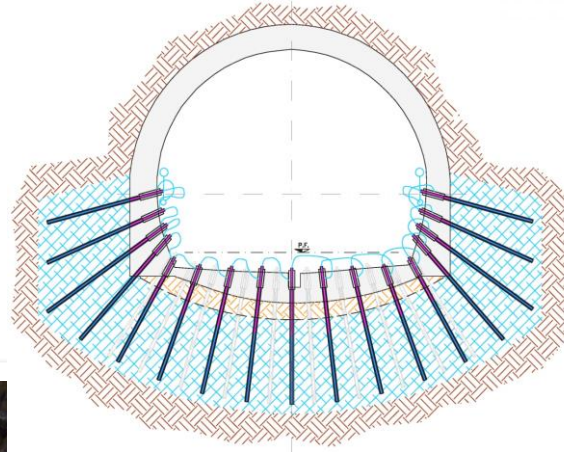
Enlarging of railway tunnels

Tunnelling 4.0: upgrading works

ENLARGEMENT OF AN HIGHWAY TUNNEL UNDER OPERATION - 2 EXAMPLES: NAZZANO and MONTEDOMINI TUNNELS

Nazzano Tunnel (Highway A1) - with vehicular traffic during work
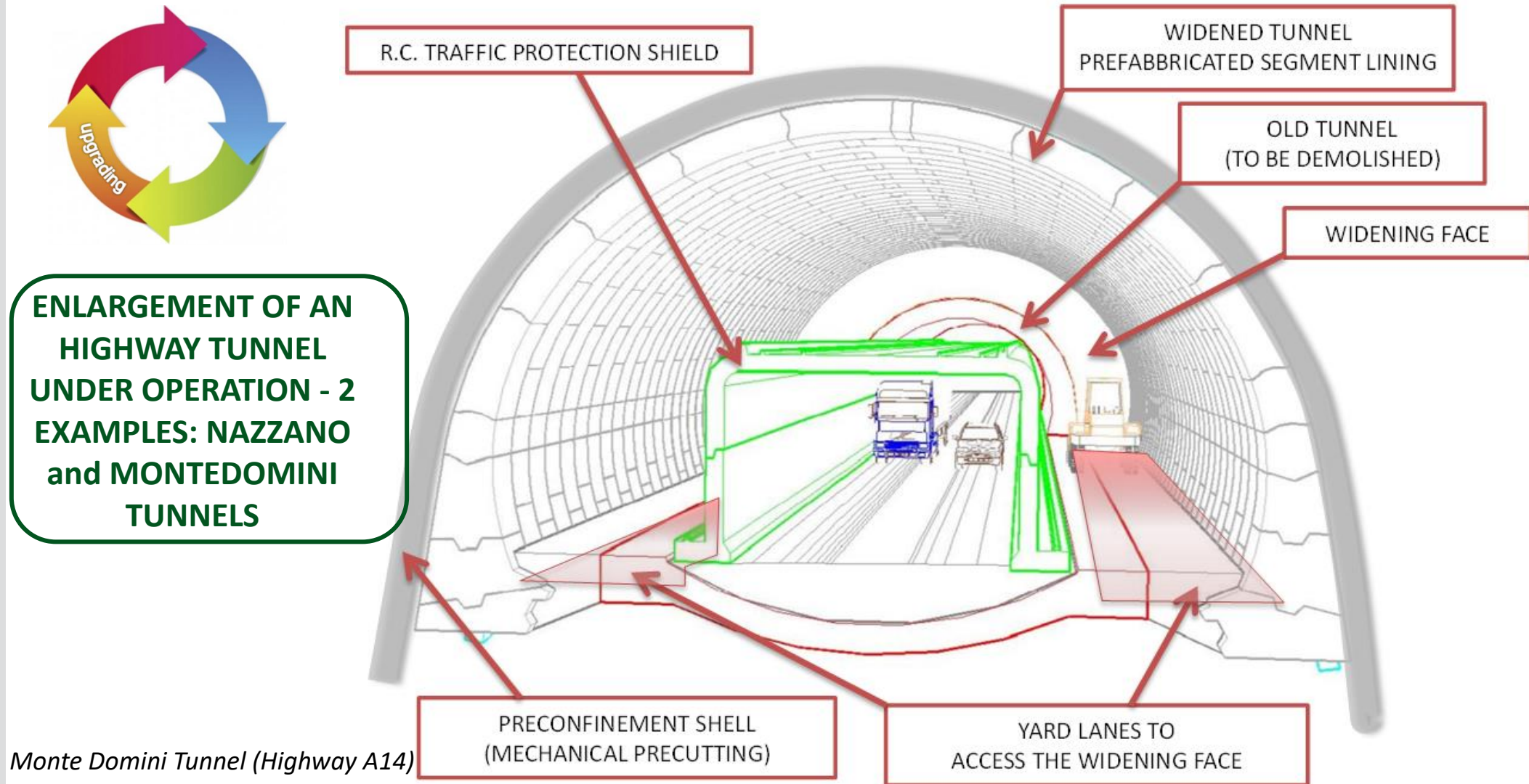
ENLARGEMENT OF AN HIGHWAY TUNNEL UNDER OPERATION - 2 EXAMPLES: NAZZANO and MONTEDOMINI TUNNELS

R.C. TRAFFIC PROTECTION SHIELD

WIDENED TUNNEL PREFABBRICATED SEGMENT LINING

OLD TUNNEL (TO BE DEMOLISHED)

WIDENING FACE

PRECONFINEMENT SHELL (MECHANICAL PRECUTTING)

YARD LANES TO ACCESS THE WIDENING FACE

Monte Domini Tunnel (Highway A14)

Tunnelling 4.0: upgrading works

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Tunnelling 4.0: disposal or better a clever reusing
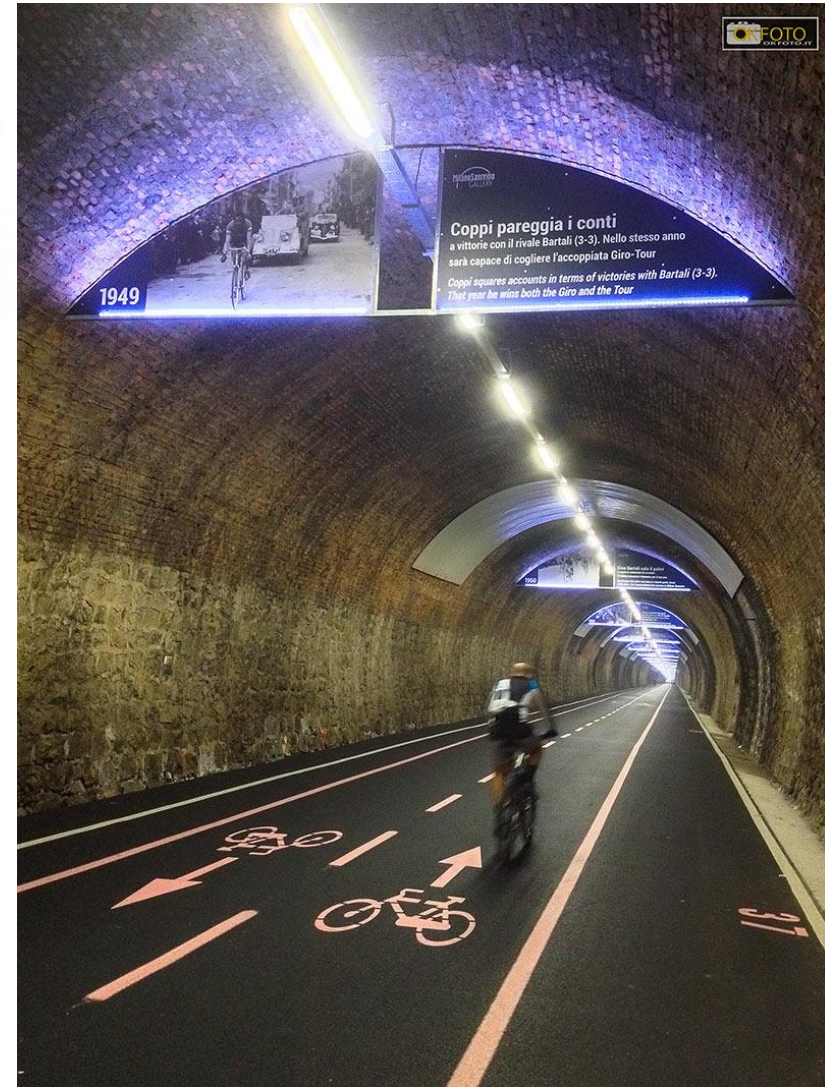
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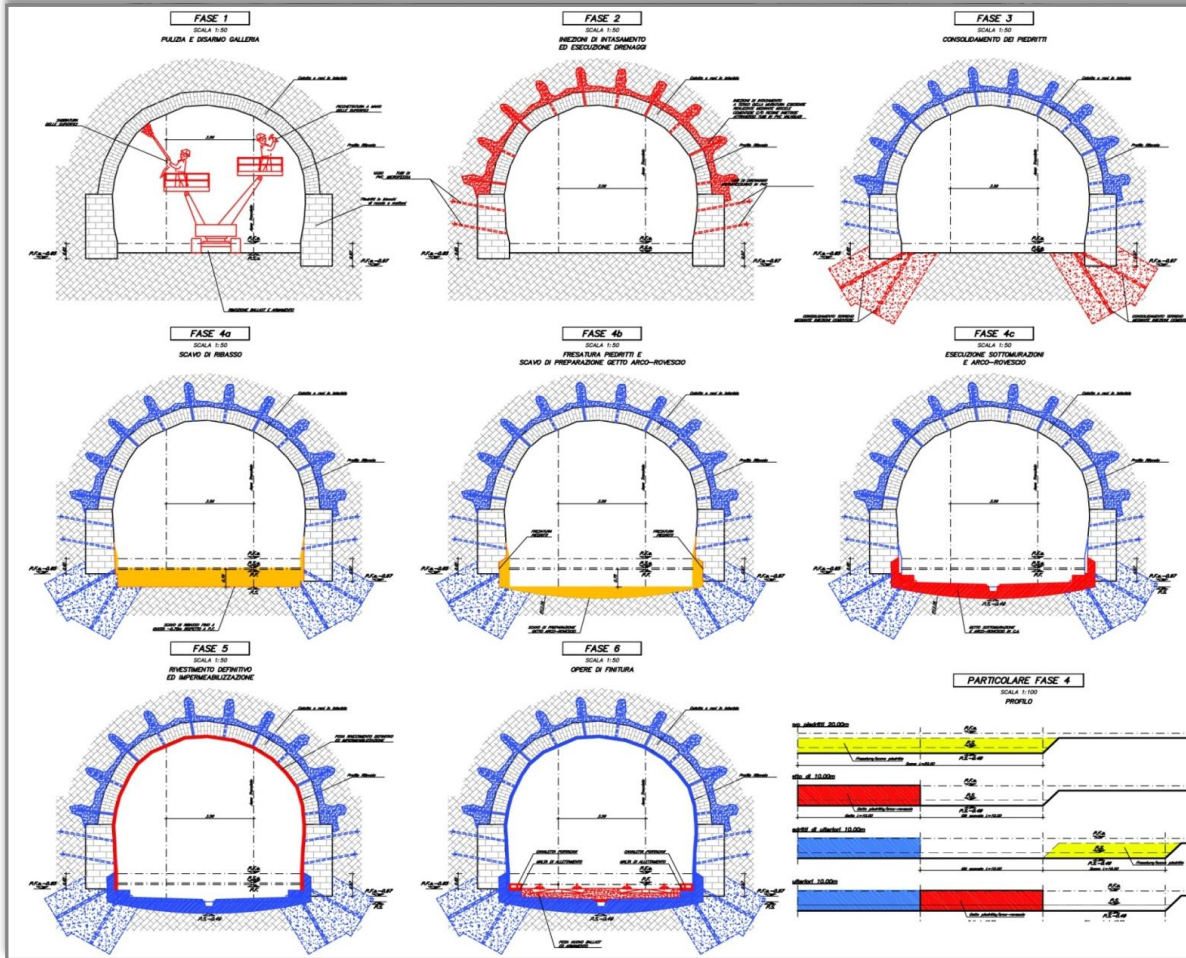# Tunnelling 4.0: intermediate remarks

Tunnels are a resilient infrastructure and usually their service life is much higher than their designed nominal life. This has increased the number of existing tunnels still in operation with an average service life of more than 50 years.

Recent cases of tunnel lining local collapse have highlighted the necessity that future investments in underground infrastructures have to also foresee maintenance, refurbishment and upgrading works of the existing ones.

New technologies can help to manage the entire life cycle of tunnels by using large scale monitoring, automatic process of tunnel lining scanning to realize the "tunnel digital twin" to which apply algorithm to detect lining structural problems and damages.

When dealing with existing tunnel geological and geotechnical models are still very important to understand the causes of the detected problems.

The industrialization of rehabilitation works is an issue still to improve.

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Engineering & Construction in a post Covid world: weathering the storm - a focus on Italian Market, the priority of maintenance investments and the potential of new technologies

Marco Ranieri

Friday November 27th 2020 – fully digital

State of art – Italian economy during Covid-19

High economic slowdown

- **GDP reduction** in 2020 estimated at **about 12%**, equivalent to the loss of about 2 million jobs

- **Strong uncertainty about the economic recovery** over the next 24 months will guide business strategy

- **The system of social / economic relations** and value creation will be **deeply modified and accelerated**

Restart and recovery

- Demand and supply of goods and services will be strongly impacted due to **limits on mobility**, increased costs linked to **supply chain restrictions** and the country's debts.

- The success of the post-emergency recovery will be driven by some "**flywheel sectors**", such as the implementation and management of major infrastructure projects

"The new word will never be the same"

"

The E&C industry in 2019 is worth about 7% of the Italian GDP with more than 2.2 million employees, despite the sharp contraction in public investment that has caused the loss of more than 600 thousand direct jobs in the last 10 years.

The launch of a major infrastructure investment programme is the key intervention to counter the strong reduction in GDP caused by the Covid-19 and drive the recovery phase.

Main contractors and subcontrator, client and authorities, the financial system and the Government will have to make a decisive contribution to the implementation of the "Major Infrastructure Investment Programme" aimed at **sustainable value creation in the long term, boost of the employment and productivity**.

Marco Ranieri, Engineering & Construction in a post Covid world: weathering the storm - a focus on Italian Market, the priority of maintenance investments and the potential of new technologies

Key numbers of E&C sector in Italy

84 bn€
Deficit in 10 years and over 50% cutting on expenditure for *major projects* investments planned

16 years
Average duration for *major projects* construction *(> €75M)*, of which 50% classified as "administrative crossing times"

2.200 k
Employees in E&C sector, with a reduction of 25% in the last 10 years

24° place (EU)
In 2019 Italy spent only 4.8 bn€ out of 51.9 bn€ of the available european funds

8.500
Number of contracting authorities listed from ANAC, with a clear need of centralizing the procurement management

>60 %
Revenues of the main Italian companies in the E&C sector comes from abroad

Source: ANCE, Rapporto Osservatorio Congiunturale sull'industria delle costruzioni (2019)

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Understanding market needs – 4 priority areas

1 Define investment priority areas and unlock public and private economic resources

2 Rebuild a key sector with new resilient and stronger players

3 Thinking circular and acting sustainable along the entire project life cycle

4 Start a digital transformation and innovation process to improve productivity and safety

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EU Funds – Focus areas

Infrastructure: major maintenance programmes, extension of the HS rail network, safety of bridges and tunnels on secondary roads, local public transport, renewal of vehicle fleet

Digital transformation: support for the **technological upgrade of businesses**, reduction of the digital divide and strengthening of distance learning

Environment and natural resources: hydrogeological risk mitigation, reservoir system and water sector reinforcement, river banks consolidation, water pumping plants, irrigation channels, soil consolidation, reforestation

SMEs: promote enterprises with a view to **supporting employment**, with a social cohesion function

- A **strategic vision** for the activation of European funds is essential, involving the European financial institutions with appropriate planning.

- New collaboration scenarios could open up with access to the **Recovery Fund's resources**.

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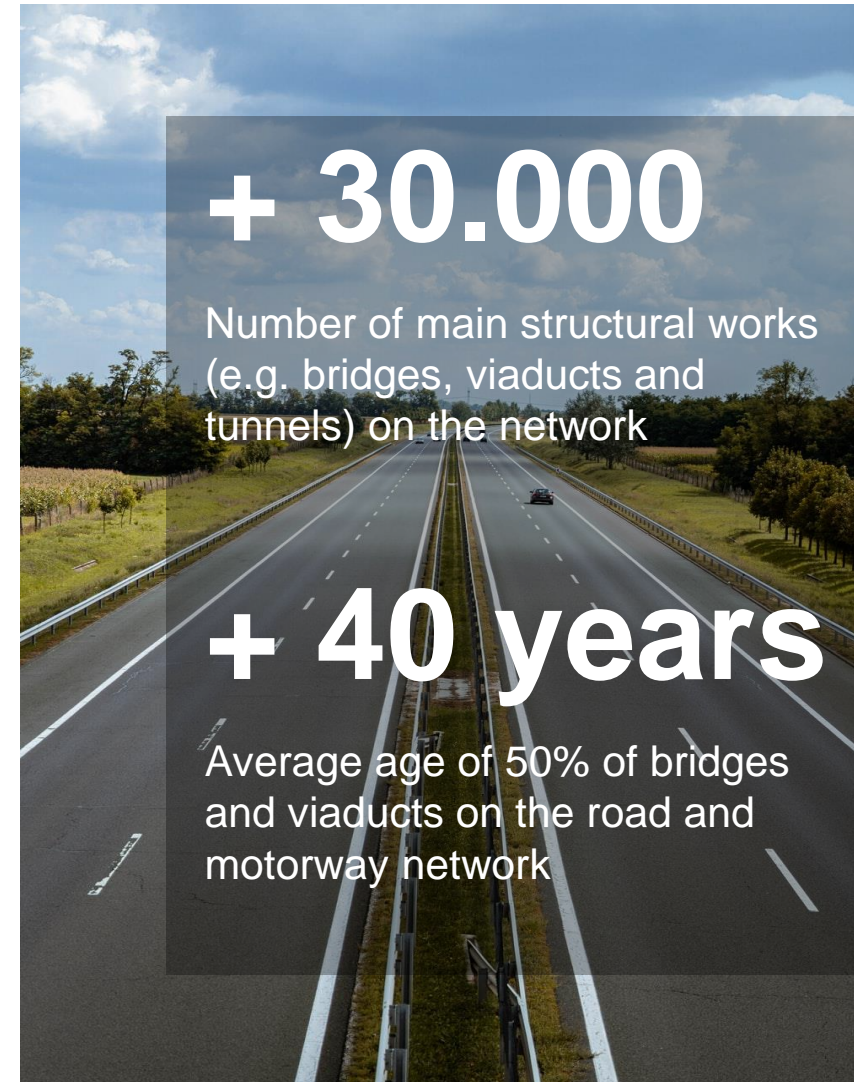
Overview on the road infrastructure network in Italy

According to the latest **National Account for Infrastructure and Transport 2018-2019**, the italian road network covers over 235,000 km, divided as follows:

- **6,966 km of motorways**, including those managed by ANAS;

- **23,335 km of roads of national interest**;

- **135,691 km of regional and provincial roads**;

- **69,098 km of roads belonging to the Municipalities of the Province or Metropolitan City**.

Considering that the total development of the municipal network can be estimated at around 700,000 km, the **cumulative total is almost 1 million km of infrastructure**.

+ 30.000

Number of main structural works (e.g. bridges, viaducts and tunnels) on the network

+ 40 years

Average age of 50% of bridges and viaducts on the road and motorway network

The value of infrastructure maintenance

The annual expenditure in the maintenance of land transport infrastructure is higher than **150 bn€,** with a growth of **+50%** since 2000.

Further growth is expected in the next years, due both:

- the **obsolescence of existing networks**;
- the **development of new infrastructure** that shall be maintained**.**

In the last 20 years, the average annual expenditure in infrastructure maintenance has reached the amount of **15 bn€** (about **0,8%** of **GDP**), in line with the UE 28 trend.

*«Literature data show that the **lack of ordinary maintenance** produces a **reduction in the asset useful life** of about **50%** and a consequent **increase in the maintenance costs** itself, which varies on average between **30% and 60%.»***

Maintenance & repair strategy in the finance model

The **financial modelling results** (e.g. IRR) is quite dependent on the forecasted values and cycles of M&R.

However, in most cases the analysis is quite «basic» on such aspects, with typically two kind of estimating approaches:
- **Benchmarking**
- **Data from the engineering design studies** (if available)

More in-depth analysis would be required for complex infrastructure such tunnels, also considering:
- the **specific M&R needs** of the different sub-systems
- the **need to optimize the financial profile** of the project.

Lesson learned: **new «modern» infrastructure tends to have lower maintenance costs in the first operating period.**

Comparison of
**MRO costs
vs
Construction Costs**
(Net Present Value)

Long tunnels
Up to **10-15%** of the construction costs

Railway lines
Up to **5-8%** of the construction costs

Unlocking the potential of technology to boost productivity

The **slow and poor spreading of technologies within the E&C sector**, and more generally within industry, has been one of the main causes of low productivity of companies in recent decades.
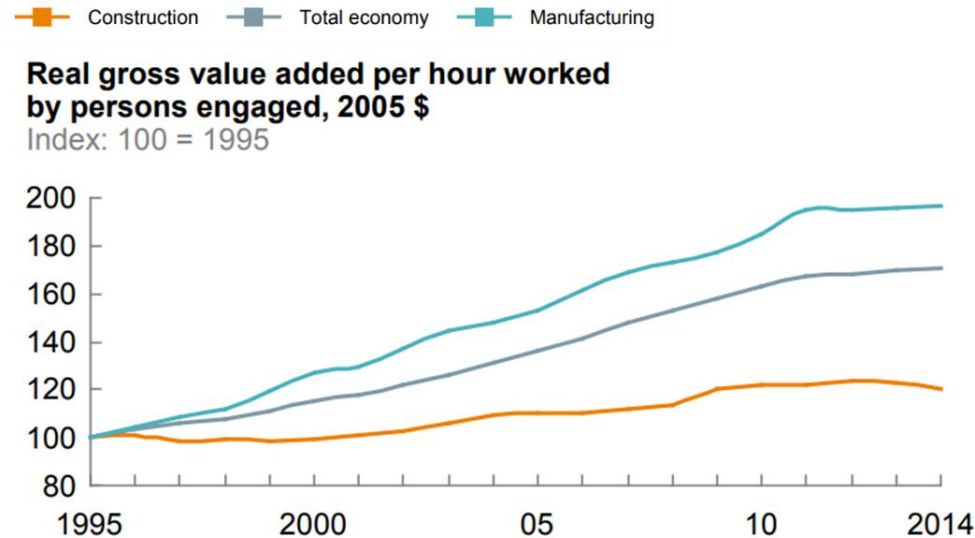
The actual situation due to the Covid-19 emergency has provided an **important boost** to the sector, strongly accelerating the diffusion of technologies. In such conditions, they represent:
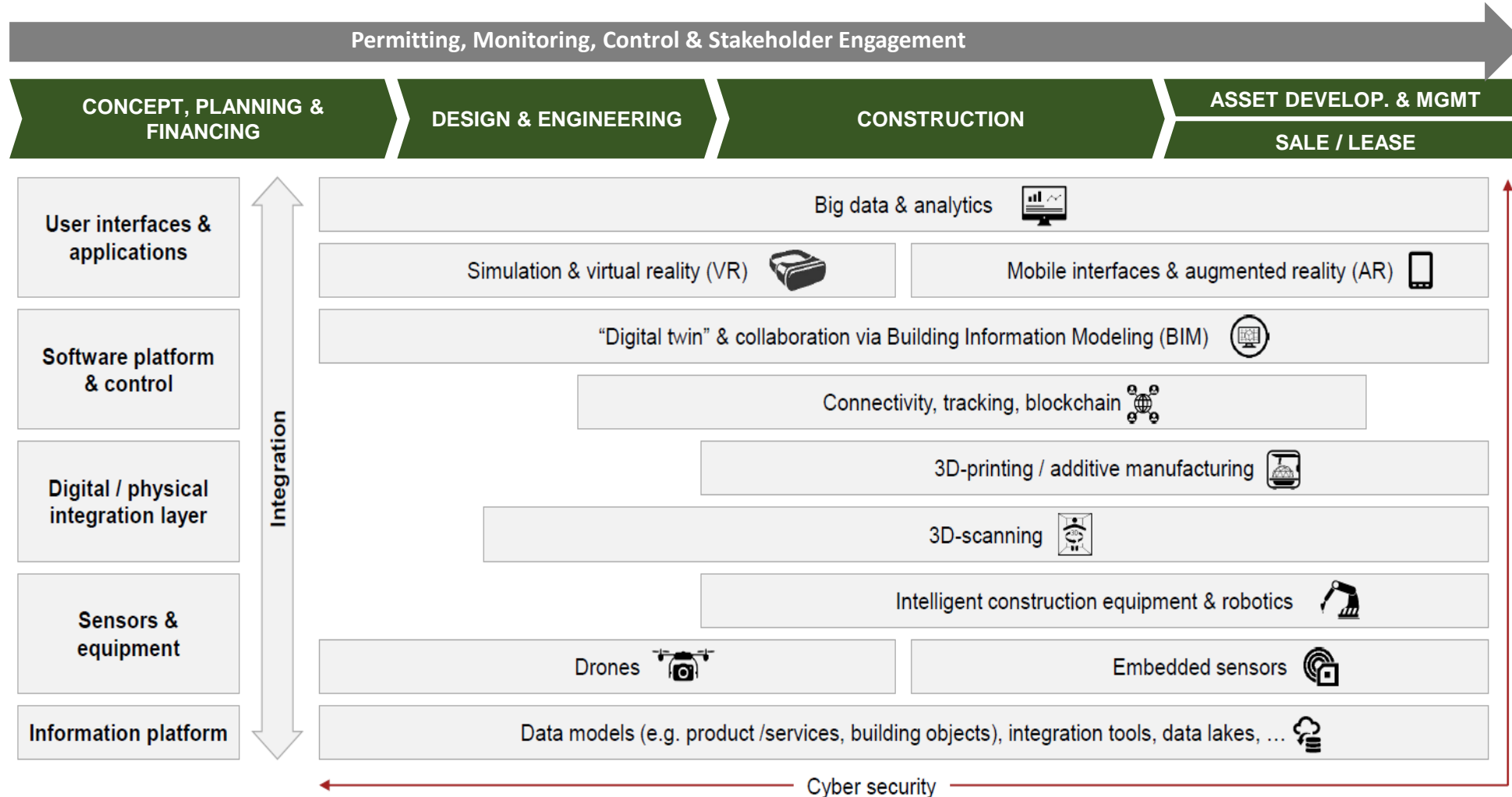
Enabler for the recovery of productivity through new ways of complex man-machine interaction (e.g. robotics, advanced automation, RPA)

Tool for improving standards of **communication, safety and security, interoperability**

- Construction - Total economy - Manufacturing

Real gross value added per hour worked by persons engaged, 2005 $
Index: 100 = 1995

200
180
160
140
120
100
80
1995 2000 05 10 2014

1% average annual growth

Main technologies overview on projects lifecycle

Main technologies in asset maintenance sector

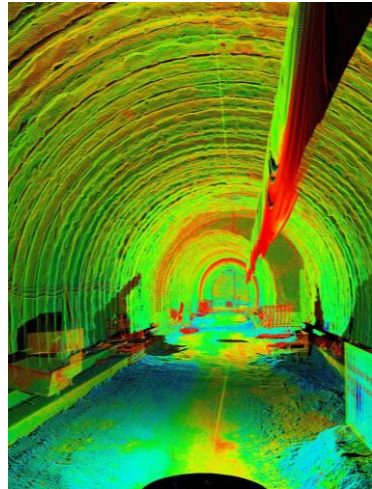| Automation		Monitoring & Control		
1 Digital mapping of pavement degradation conditions	**2** Immersive digital inspection for tunnels	**3** AI monitoring systems for structures	**4** Satellite control of structural failures	**5** Digital twin and augmented reality for inspections
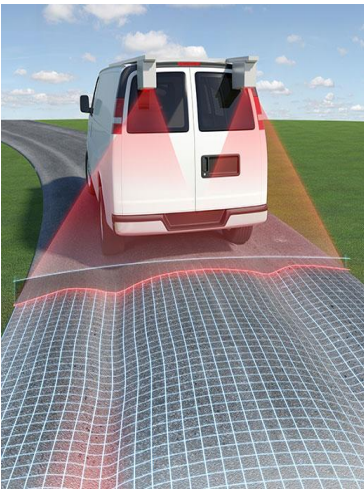
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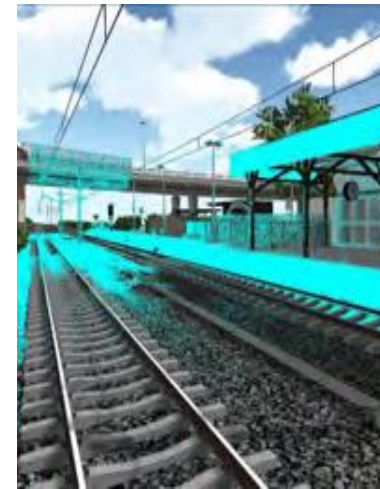
Thank you

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