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# ROBOTIZATION OF THE AUTOMATIC TUBULAR STEEL ARCH INSTALLATION: A KEY FACTOR FOR SAFETY

Atlantia

autostrade per l'italia

pavimental SpA
gruppo Atlantia

ROCKSOIL S.p.A.

MACCAFERRI

CP TECHNOLOGY

**ITALY** **Presented by :** ***Ph. D. Carla L. Zenti***

ITA AITES Miami, USA 18th November 2019

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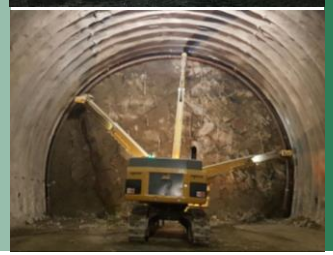
PRESENTATION OUTLINE



INTRODUCTION

- RISK Management for Health & Safety
- RISK Controlling
- RISK in Conventional Tunnelling: a focus on Primary Lining Installation
- The tubular automatic arch
- The robot: EKIP21-04
- The installation of tubular automatic arch by EKIP21-04
- Risk analysis by type of arch
- Boscaccio Tunnel Case: AS BUILT

REMARKS

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INTRODUCTION

The increase in safety levels is one of the most important considerations for innovation and research and it is one of the most common demands from the underground construction market.

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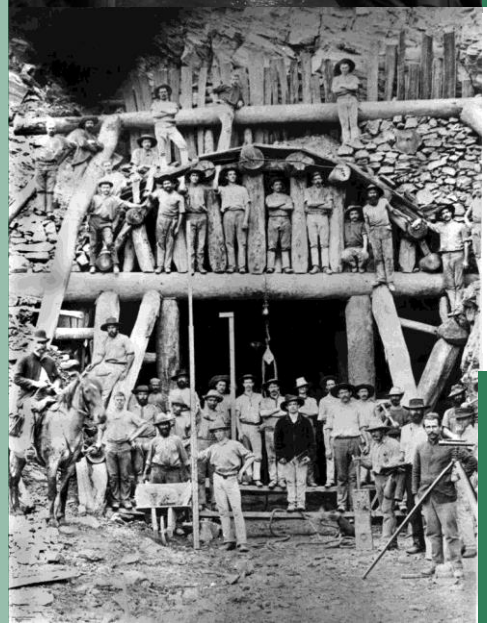
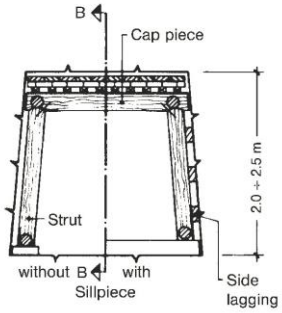
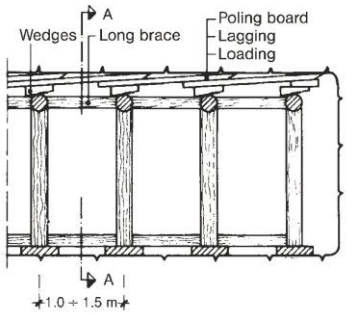
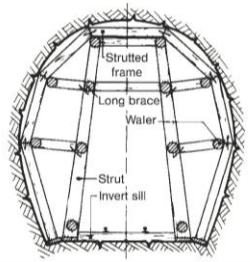
INTRODUCTION

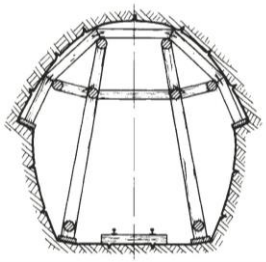
Usage of underground space is an old habit for human beings since ancient times. Our ancestors have used caves as shelters for protection from wild life and nature, and they have excavated caves to extract valuable minerals.





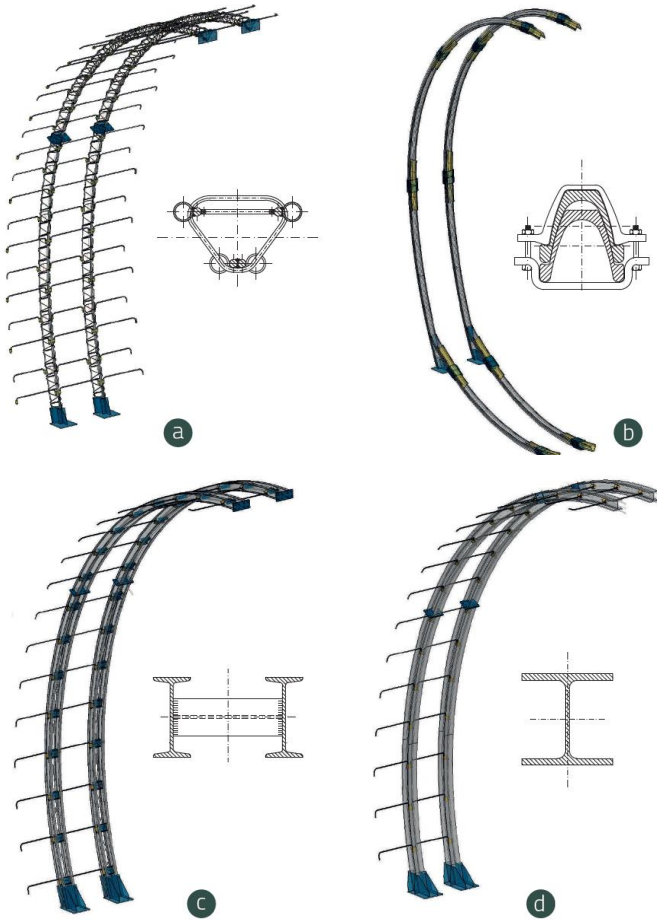



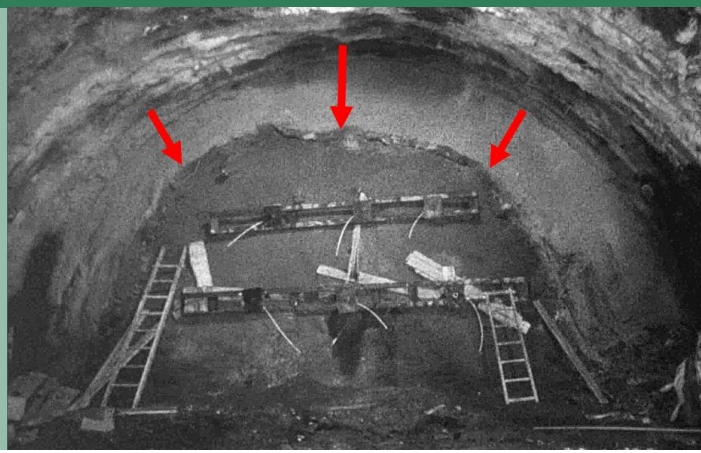
Tunnels began to be built for railroads that vastly increased both tunnel size and the need for tunnelling through difficult ground. Technology from the mining sector, such as timber supports was adopted.


INTRODUCTION




The reinforcing elements are bent, welded and bolted to form an arch that fits the tunnel profile, which is secured in place through wood packing and metal wedges to fill the gap formed because of the break. The horizontal tie bars allow the connection of adjacent arches and the relative sheets, to support the exposed back face. Even today, the most common steel supports have “I” or “H shaped section beams

San Vitale tunnel (mottled clay): the half cross section face supported by I-beams and tie rods after tunnel advance was abandoned in consequence of the core-face extrusion and cavity convergence (the red arrows underlinethe rib’s buckling), 1990



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INTRODUCTION

Risk is often measured as the expected value of an undesirable outcome. In relation to occupational safety and health, the risk is the likelihood that a person may be harmed or suffers adverse health effects if exposed to a hazard. This combines the probabilities of various possible events and the assessment of the corresponding harm into a single value. However, the actual occurrences are often more complex than a single binary possibility case. **In a real scenario, with several possible accidents, the total risk is the sum of the risks for each different accident, provided that the outcomes are comparable.**

$$R = \sum_{all} (probability\ of\ occurrence)\ x\ (magnitude\ of\ occurence)$$

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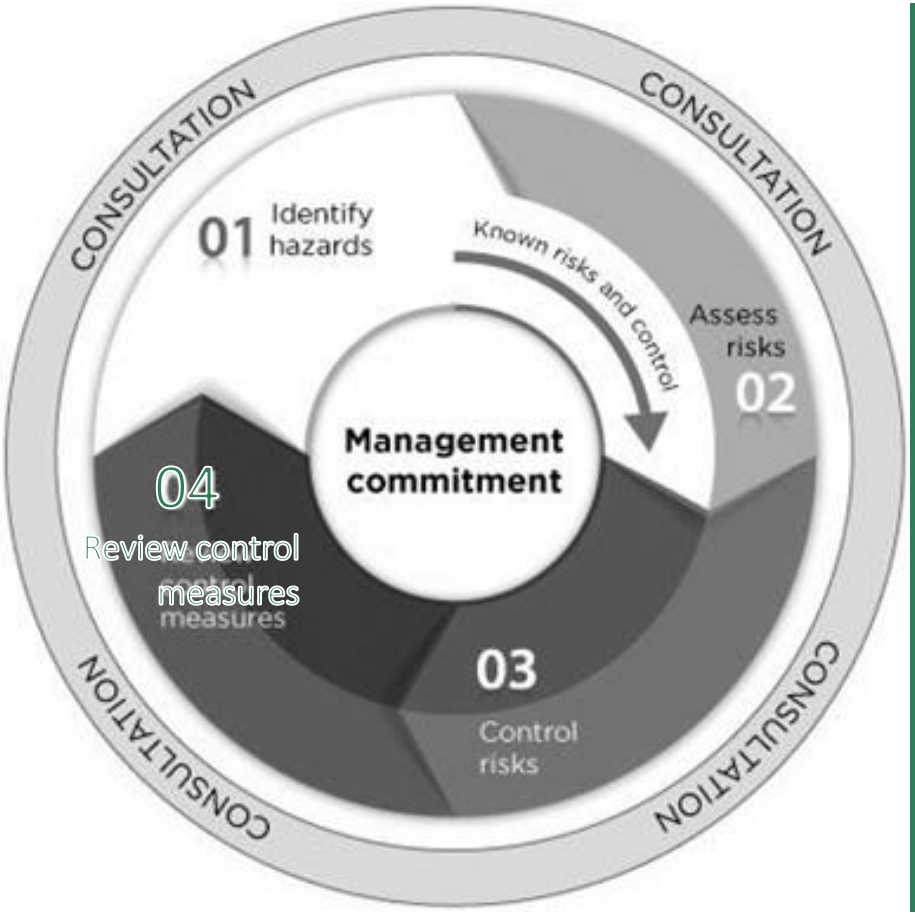
RISK Management for Health & Safety




Risk management involves mainly of four steps:

- ✓ **Identify hazards**: find out what could cause harm.
- ✓ **Assess risks:** understand the nature of the harm that could be caused by the hazard, how serious the harm could be and the likelihood of it happening. This step may not be necessary if you are dealing with a known risk with known controls.
- ✓ **Control risks:** implement the most effective control measure that is reasonably practicable in the circumstances and ensure it remains effective over time.
- ✓ **Review hazards and control measures:** το ensure they are working as planned

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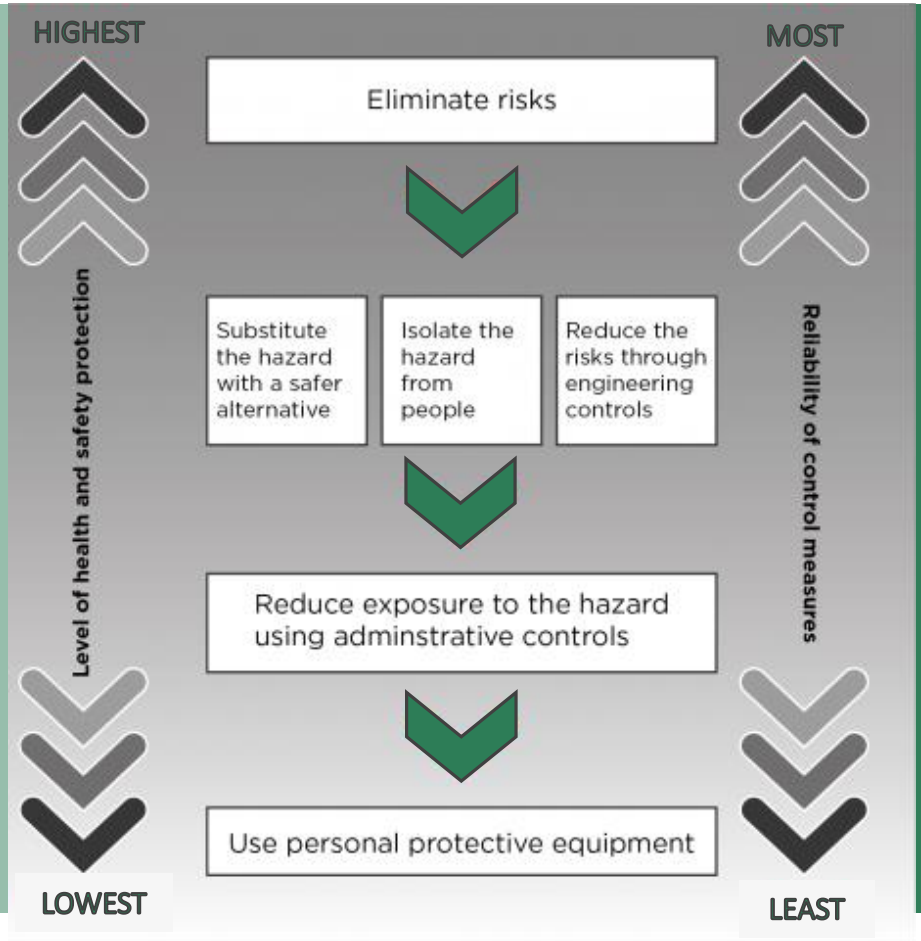
RISK Controlling




The ways of controlling risks are ranked from the highest level of protection and reliability to the lowest. This ranking is known as the hierarchy of control measures. You must always aim to eliminate the risk, which is the most effective control. If this is not reasonably practicable, you must minimise the risk by working through the other alternatives in the hierarchy.

The lower levels in the hierarchy are less effective because controls that change the hazard or minimise exposure to the hazard can only minimise the risk. You cannot eliminate the risk without eliminating the hazard. Administrative controls and personal protective equipment (PPE) are the least effective at minimising risk because they do not control the hazard at the source and rely on human behaviour and supervision.

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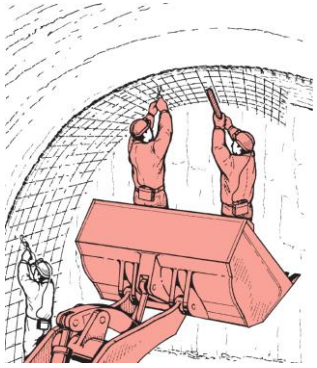
RISK in Conventional Tunnelling: a focus on Primary Lining Installation



- During the ***arch installation*** the workers are exposed to the risk related to the ***arch buckling, fall from height and face or cavity collapse***
- ***Scaling*** is necessary after excavation to proceed with arch installation, but the workers are exposed to the risk of ***fall from height*** and ***working face collapse***, for this reason the operation must be performed by machinery
- During the ***wire mesh*** and ***arch bracing installation*** in addition to the above mentioned risks there are also the ones related to ***falling*** and ***being crushed***

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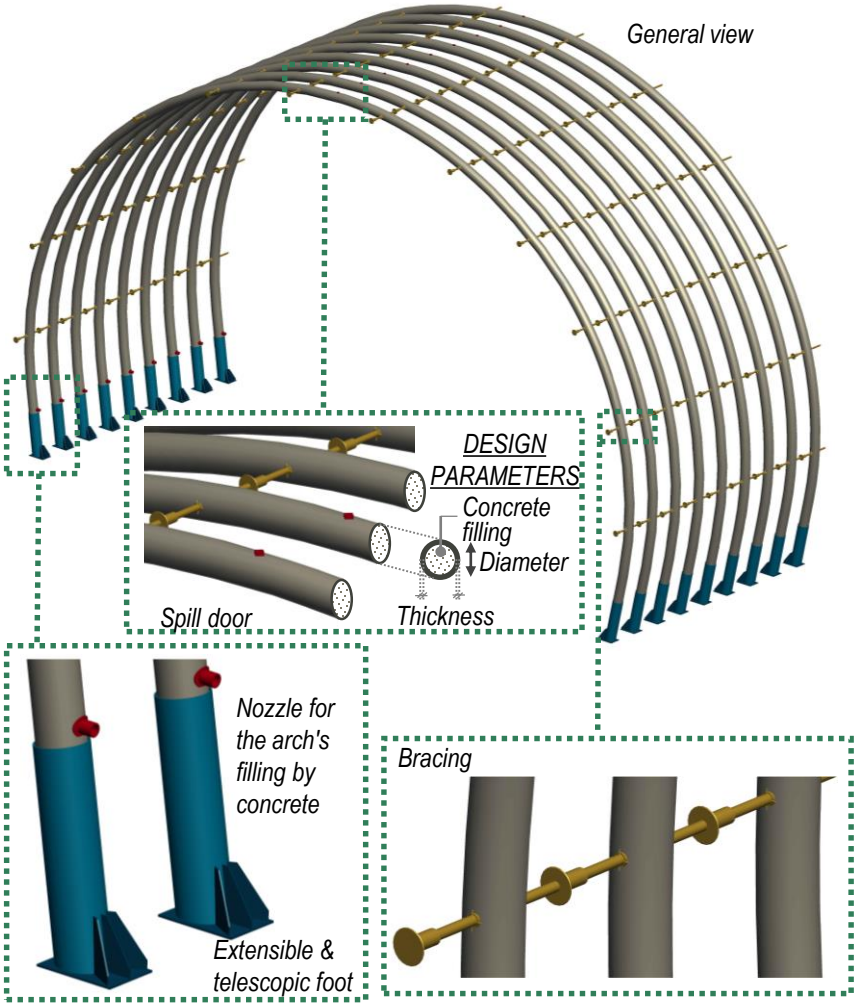
The tubular automatic arch




The open steel profiles (IPE, HE, IPN), typically used as the primary lining support, show performance weakness in their static structural properties, in directions other than the normal and central position. These problems can be solved using a profile with a symmetrical axial cross section, like a tubular rib. By substituting the open profile with a circular one, a better stress redistribution is provided.

The high stiffness along any direction of the tubular section eliminated the buckling risk of the profile during installation. This ensures a higher safety condition to the operators working in the vicinity of the excavation face. The evolution into an automatic arch required a detailed design of the innovative automatic unfolding hinges, arch-to-arch connection device and the arch foot support system. The innovation was completed by the development of a dedicated three arm erector machine for the tubular arch installation, which does not require the presence of workers close to the excavation face

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The robot: EKIP21-04

The product innovation related to automatic tubular arch had its natural completion in an important process innovation. EKIP 21-04, a special radio controlled carrier equipped with a three armed handler, has been designed. The machinery lead to install the automatic tubular arch in its final position operating far from the face. While the central arm of the robot positions the arch on the axis of the tunnel, the lateral arms hook its foots, opening and ensuring the automatic closure of the connecting plates, which allow it to be positioned in a plane parallel to the previous one already installed. The robot then pushes the arch towards the previous one and, thanks to the pre-installed rigid connecting elements, that replace the old system, ensures the connection.

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The installation of tubular automatic arch by EKIP21-04

The arch, assembled, yet folded "closed" is transported to the excavation face. When the reinforcing element is adjacent to the desired installation position is lifted by the central arm of EKIP 2104, then the lateral arms of the machine open the arch. The bracing elements are pre-installed and once in the approximate position, the machine pulls the arch towards the arches that are already in position. This procedure engages the bracing systems on the adjacent arches, locking them together at the appropriate spacing.

The final operation is the positioning of the foot of the arch to the correct level. Usually this procedure is performed by an operative inserting timber packers under the foot; this can be dangerous and is not a robust solution. To address this a special telescopic foot to the tubular arch has also been developed that can be extended by machinery, thereby enabling the positioning of the arch only with the use of a machinery arm.

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Risk analysis by type of arch

| WORK PHASE | RISK | Traditional | Tubular automatic & EKIP 21-04 | |
|---|---|---|---|---|
| *Arc lifting* | Profile buckling may causes the running over of the workers | existing risk | risk removed | The tubular profile is characterised by great stiffness in this way the buckling risk of the steel profile is removed |
| | Machinery in operation may running over the workers | existing risk | risk removed | The arch is installed by means of a single machinery operated by a single worker |
| *Arch installation* | The workers may be crushed by rock fall | existing risk | risk removed | The worker activates the radio controlled three arms handler (EKIP 21-04) from a safe zone and he dosen't enter in the danger zone close to the excavation face |
| | The workers may be buried by the collapse of the excavation face | existing risk | risk removed | |
| *Foot arch positioning* | The workers operating close to the excavation face may be crushed by the rock fall | existing risk | risk removed | The automatic tubular arch is equipped with a telescopic foot, which is positioned by the external arms of the EKIP 21-04 |
| *Arch connection by bracing* | The workers operating on a platform may fall from heights in consequence of a quick movement of the lifting machinery | existing risk | risk removed | The bracings (connection elements between two adjacent arches) are pre-installed and pre-dimensioned, respecting both structural and geometric constraints. |
| | The workers may be crushed by rock fall from tunnel crown or side wall | existing risk | risk removed | The arches are connected by means of the robot EKIP 21-04 |


Boscaccio Tunnel Case: AS BUILT


## *THE PROJECT VARIANTE DI VALICO*

Motorway A1 Milan-Naples. Extension of the third lane, section Barberino-Firenze Nord

**DESCRIPTION:** Expansion of the 62.5 km of the Apennine stretch of the A1 between Sasso Marconi and Barberino, with the construction of the Variante di Valico, is a priority intervention to improve traffic conditions and reduce e travel times between Bologna and Florence: the infrastructure inadequate for existing traffic levels.

**BOSCACCIO TUNNEL:** 1.962 m long

The solution has been officially approved by the client **AUTOSTRADE PER L'ITALIA**

Contractor: **PAVIMENTAL S.p.A.** applied this solution inside Boscaccio Tunnel.

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Boscaccio Tunnel Case: AS BUILT

## STEEL ARCH INSTALLATION: TIME ANLYSIS

| ARCH TYPE | Handling to the Excavation Face [minutes] | Lifting, installing and connection to previuos arch [minutes] | Total Length Boscaccio Tunnel [m] | Installation Step [m] | Steel Arch Number [n°] | Total Time [hours] |
|---|---|---|---|---|---|---|
| TRADITIONAL | = | 45,0 | 1962,0 | 1,00 | 1962 | 1472 |
| TUBULAR AUTOMATIC | = | 15,0 | 1962,0 | 1,00 | 1962 | 491 |

Δ time saving for each arch - 30 minutes → -67%

Total time saving due to arch installation
Δ 981 hours = 40 days & 21 hours

## SHOTCRETE ANALYSIS - MATERIAL QUANTITY & TIMING

| ARCH TYPE | Average Consumption for 6 m section [mc] | Average Consumption for Linear Meter [mc] | Total Length Boscaccio Tunnel [m] | Total Consumption Boscaccio Tunnel [mc] | Shotcrete Pump Production [mc/h] | Total Time [hours] |
|---|---|---|---|---|---|---|
| TRADITIONAL | 181,67 | 30,3 | 1962,0 | 59405 | 20 | 2970 |
| TUBULAR AUTOMATIC | 156,00 | 26,0 | 1962,0 | 51012 | 20 | 2551 |

Δ Total shotcrete saving [mc] -8393

Total time saving
Δ hours 420 = 17 days & 12 hours

## ACCIDENTS ANALYSIS

| | Variante di Valico (VAV) 52 km of conventional tunnelling | Boscaccio Tunnel 2 km of conventional tunnelling |
|---|---|---|
| Accidents caused by rock fall from excavation face, tunnel crown or side wall | 43 | 0 |

*Boscaccio Tunnel*
*No fatalities recorded*

## SAFETY LEVEL INCREASE + ECONOMICAL BENEFIT

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Boscaccio Tunnel Case: AS BUILT

**BOSCACCIO TUNNEL**
Contractor: **Pavimental S.p.A.**
Tunnel length: **1'942 m**
Full Face Excavation: **190 m²-210 m²**

**SAFETY VALUE:**
NO WORKER AT THE EXCAVATION FACE
1 worker for the radio-control of the machinery

**HUMAN RESOURCE SAVING: - 80%**
*Shift Composition for Arch Installation*
*Traditional arch: 5 members*
*Automatic tubular arch & Ekip 2104: 1 member*

**ECONOMICAL VALUE**
INITIAL EXTIMATION OF TOTAL CONSTRUCTION TIME: 1000 DAYS (DIRECT COSTS+OVERHEADS)
TIME SAVING → ARCH INSTALLATION 40 days & 21 hours
→ CONCRETE SPRAYING 17 days & 12 hours

**TOTAL TIME SAVING: -58 DAYS + 9 HOURS ≈ -6,0 %**
reference 1000 days → *influence on DIRECT COSTS & OVERHEADS*

**MATERIAL SAVING: - 8393 m³**
*Shotecrete* **-14,1%**


Boscaccio Tunnel Case

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REMARKS

THE FEEDBACK OF CLIENTS

- Autostrade per l'Italia included the system in its operative procedure. The owner of road and railway infrastructures in Italy are updating their operative procedure to include the first lining system (Automatic Tubular Arch & EKIP2104)
- Italian Health and Safety Departments are updating their guideline considering the system. [NIR 37 «Safety During Excavation» & NIR 41 «operation close to the excavation face»]

LONG TERM IMPACTS PROMPTED BY THE INITIATIVE

- The initiative is a no-return point in terms of safety for the first lining and its installation procedure. The risks have been deleted because no miner work anymore close to the excavation face. Pavimental S.p.A. decide to adopt the solution as common practice for tunnel excavation.

DOCUMENTED RESULTS AND HOW SAFETY HAS IMPROVED THE PROCESS

- The number of the fatalities related to the installation of the first lining during the excavation of 52 km of tunnel (conventional excavation) of the Variante di Valico was of 43 cases. No fatality related to the same work phase has been recorded during the excavation of Boscaccio Tunnel (2 km conventional excavation)

THE INITIATIVE GOES BEYOND NORMAL PRACTICES

- The combination of automatic tubular arch & radio-controlled handler eliminate the risks related to the installation of first lining, reduces the number of workers, without affecting the quality of the project and its progress, as a consequence of the complete automatization of the system & of its installation

THE SYSTEM HAS BEEN INCORPORATED INTO WORKING STANDARD PRACTICES.

- Autostrade per l'italia included the system for its tender

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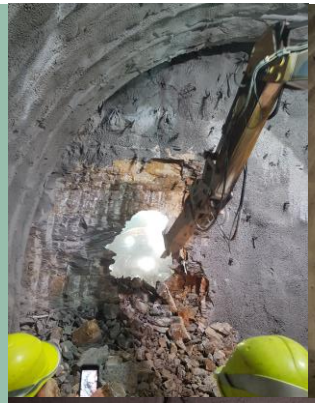
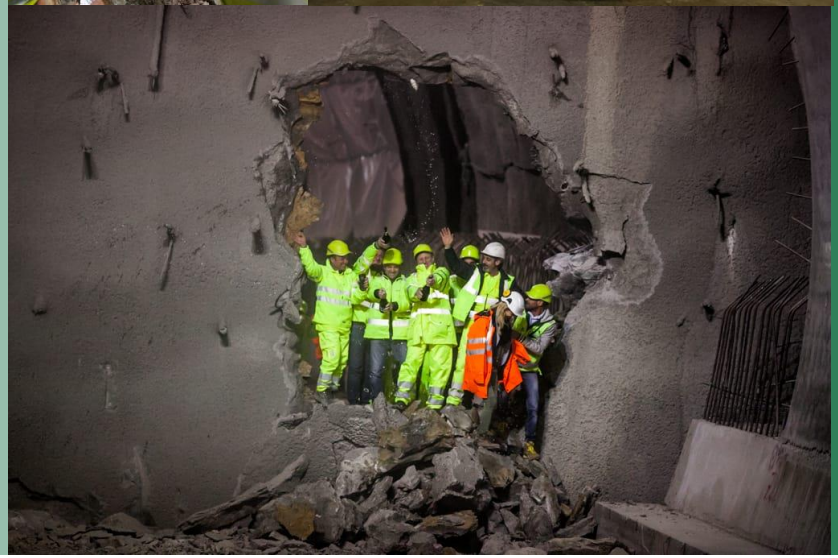
REMARKS





## ROBOTIZATION OF THE AUTOMATIC TUBULAR STEEL ARCH INSTALLATION: A KEY FACTOR FOR SAFETY

*"It is a right of employees to work in a safe place, it is a duty of the contractor to ensure it happens, but it is a responsibility of the industry to provide solutions that achieve both objectives"*
*(C.L. Zenti, 2015)*

**04.12.2018 BREAKTROUGH BOSCACCIO TUNNEL**

2 km of excavated tunnel → 0 fatality

*EVERYONE BACK HOME SAFELY AT THE END OF TUNNEL EXCAVATION*

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