Naturally occurring asbestos in the Rocks belonging to Sestri – Voltaggio Zone (Liguria, Northern Italy). Excavation Railway tunnels management – Terzo Valico dei Giovi

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ABSTRACT: The project and construction for the new high speed railway line (connecting Genoa to Milan) faced one of the most important environmental issues: safe excavation and managing of rocks, that may contain asbestos in relevant amounts. Asbestos is a group of fibrous minerals that mainly occurs in mafic and ultramafic rocks (ophiolitic sequences). This work focuses the criteria to better evaluate the amount of asbestos fibers in the metaophiolites belonging to Sestri-Voltaggio Zone (Liguria, Northern Italy). According to Italian law, only six minerals are considered asbestos: chrysotile, actinolite, tremolite, anthophyllite, grunerite, riebeckite. Because of geological reasons, in the Western Alps the only chrysotile, actinlite and riebeckite asbestos may be found naturally. Finally the criteria for the environmental monitoring system and management of disposal materials used by Cociv for checking asbestos risk along tunnel alignment.

1 INTRODUCTION

The Terzo Valico is the new high-speed, high-capacity railway line that will improve connections between the Liguria port system and the main railway lines of Northern Italy and the rest of Europe. The Terzo Valico represents one of the strategic projects of national interest and is part of the Rhine-Alpine Corridor, one of the main corridors of the trans-European strategic transport network (TEN-T core network) connecting Europe's most densely populated and most important industrial regions.

Figure 1.The Terzo Valico Route in the Rhine-Alpine Corridor.

The General Contractor in charge of designing and building the Terzo Valico is the COCIV Consortium formed by the following major Italian construction companies: Salini Impregilo (64%); Società Italiana Condotte d'Acqua (31%); CIV (5%).

2 "GREEN STONES AND ASBESTOS"

Ophiolites complexes or "green stones" are found in many parts of the world and are constituted by mafic and ultramafic rocks (basalts, gabbros, peridotites), successively transformed in metamorphic rocks, serpentines. This kind of rocks are dark green and/or dark red coloured because of their important contents of iron and magnesium. Asbestos is the generic commercial designation for a group of naturally occurring mineral silicate fibres of the serpentine and amphibole series. The term asbestos involves a group of six minerals of the amphibole and serpentine groups (crocidolite, amosite, antophyllite, actinolite, tremolite and chrysotile) characterised by a distinctive fibrous habitus and a rather good resistance to physical and chemical attacks. The Italian national Law (D. L. 277/91), describes as asbestos the following six minerals or group of minerals:

Table 1. Group of minerals defined "asbestos".

Mineral	Formula
Chrysotile	$Mg_3Si_2O_5(OH)_4$
Crocidolite	$Na_2(Fe^{+3}Mg_3)Fe^{+3}Si_8O_{22}(OH)_2$
Amosite	$(Mg,Fe^{+2})_7Si_8O_{22}(OH)_2$
Anthophyllite	$(Mg,Fe_{+2})_7Si_8O_{22}(OH)_2$
Actinolite	$Ca_2(Mg,Fe^{+2})_5Si_8O_{22}(OH)_2$
Tremolite	$Ca_2(Mg,Fe^{+2})_5Si_8O_{22}(OH)_2$

Because of geologic reasons, in the Italian Western Alps, only three kind of asbestos may be found naturally: chrysotile, actinolite and tremolite. In the Western Alps, most of the asbestos mineralizations occur in the serpentinized ophiolites units. These units derived from the Mesozoic Piemontese-Ligurian Ocean. The SE sector of the Western Alps is known as Ligurian Alps. The Ligurian – Piedmontese units consist of metaophiolitic rocks associated to metasediments, which were involved in the Alpine tectonic events and experienced a complex and multiphase metamorphic structural evolution. The Terzo Valico layout crosses along both the metamorphic basement and the overlying sedimentary cover sequences. Particularly the first part of layout is a very complicated area, characterized by the metaophiolitic sequences of the Sestri-Voltaggio Zone.

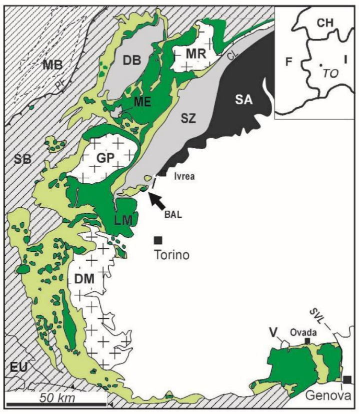

Figure 2.Simplified Alps Tectonic Sketch Map (dark green color indicates ophiolitic geological units.

As shown in Figure 2, the Ligurian – Piedmontese units (metaophiolitic rocks associated to metasediments) overspread along the Western alps discontinuously. In Liguria area asbestos fibres naturally occurs in two important metaophiolitic units: the Voltri Group and the Sestri-Voltaggio Zone. Asbestos-bearing rocks are: Serpentines, derived by transformation of peridotitic rocks; Meta-gabbros and metabasalts derived by transformation (metamorphism) of mafic rocks; Prasinites, derived from transformation (metamorphism) of mafic and ultramafic rocks. As a rule, the asbestos occurs as vein-filling minerals, and is released from the hosting rock by natural physical and chemical alteration processes. As well, asbestos may occur in tectonic unit (such as Voltri group and Sestri Voltaggio Zone), in the contact portion between rocks characterized by different chemical composition: carbonatic rocks (calcschists) and metaophiolites. These particularly complexed conditions are typical of Cravasco area, in the Isoverde tectonic unit, from chainage 8+500 to 12+000. Natural asbestos occurrence is due to the following three important reasons:

- protolith chemical composition
- chemical incompatible lithologies (metaophiolites / carbonatic rocks); contact zone is characterized by metasomatic reactions
- most of the asbestos appears to crystallize under very special conditions occurring within rock formations that are undergoing intense deformation; such deformations are often accompanied by the intrusion of magmatic fluids forming dikes and sills; the fibres crystallize in high strain environments, such as within folds, shear planes, faults, dilation cavities, and at intrusion boundaries. Ophiolite complexes are highly tectonized rocks containing many of these deformation attributes, thus they present conditions ideal for fibre formation.

Asbestos is not volatile; fibres are well connected to each other; however, fibres can be emitted to the atmosphere because of the weathering of asbestos-bearing rocks or during excavation asbestos-bearing rocks.

2.1 *"Green Stones" spreading along the Terzo Valico Route*

The tunnel section of the "Terzo Valico" extended from Genoa to Tortona among two main geological units:

From Genoa to geological contact zone with Tertiary Piedmontese Basin (TPB) (chainage 19+500), the layout in entirely within the Sestri – Voltaggio Zone (ZVS); particularly this zone is characterized by the "Argille a Palombini" Formation (aP), a sequence of argilloschists, claystones and limestone lenses; between chainage 8+500 and 12+500, rockmass is highly tectonized and squeezing because of tectonic Alpine evolution

From change 19+500, tunnel stretch crosses Tertiary Piedmontese Basin Units (TPB), a sedimentary sequence constituted by conglomerates, sandstones, marls, claystones.

The ZSV represents an important tectonic area, and with the "Gruppo di Voltri" forms a complex geological context ("nodo collisionale ligure" di Laubscher at. al. 1992), interpreted as the West to East transition from Alpine rock sequences to Appennine rock sequences.

The ZSV is constituted by three different tectonic units, two of them ophiolitic (Cravasco-Voltaggio and Figogna) and the last one, Gazzo-Isoverde unit. During various stages alpine evolution, these three units experienced different temperature and pressure conditions (metamorphism) that determined the natural growth (by the original protoliths) of chrysotile, actinolite and tremolite.

The TPB represents the overlying tertiary sedimentary cover sequence of the ZVS.

The Terzo Valico tunnel section crosses this important and very complicated geological, structural and lithlogical context, because of its involvement in the Alpine Evolution Phases. The tunnel stretch passes through the contact zone between The ZVS and TPB units, too.

3 ITALIAN RULES AND CODES

In the early 1970s, it became a concern that exposure to the asbestos mineral fibres would cause asbestos-related disease. Asbestos is classified as a carcinogen and all six types of asbestos shown in figure 2 are considered hazardous. Humans may be exposed to asbestos by breathing airborne asbestos fibres, which can be deposited deep into the lungs where they persist for long periods. Italian national and local laws and regulations for asbestos contents in soil and rocks ("Terre e rocce da scavo" or TRS) have developed new operative protocols, for asbestos-bearing soils disposal an recycle. Here below the most important Italian rules: - D.L. 257/92, prohibits the extraction, marketing, and production of asbestos in accordance with European Community directives:

- D.M. 06/09/1994, analytical protocols for industrial wastes and for environmental sampling
- D.M. del 14/05/1996, defining suitability criteria for slabs, blocks and breccias using an index (index release, IR) that describes the amount of fibres released by mechanical wear. This rule is unsuitable for assessing geohazards related to natural outcrops, ophiolite-bearing sediments (e.g., beach materials), landslides, stream sediments, or rock waste within quarries. The inadequacy of the IR measure as an exclusive parameter of asbestos hazard definition has also been recognised by the Italian Council of State (Sentence 315/2012), who determined that: "the release index is not and cannot be the analytical element to define the asbestos hazard in complex geological framework".
- D. Lgs. 03/04/2006 n. 152, "Environmental Code".
- D. Lgs.09/04/2008, n. 81. Safety workers health.
- D.M. 10/08/2012, n. 161. Rules concerning "Terre e Rocce da Scavo – TRS".

4 EVALUATING ASBESTOS - ANALITYCAL METHODS

Due to the particular geological context (Sestri – Voltaggio Zone), the first analytical investigations about asbestos-bearing rocks occurrence have been performed in the Preliminary Design Stage. During geognostical investigations a number of 22 samples have been collected from the boreholes SR11, SR12, SR13, SR14 and SR15. Samples have been analysed in the laboratory of Turin Polytechnic. Mineralogical, petrographic and diffrattrometric (XRD) tests have been carried on. In five samples the occurred of asbestos minerals have been found. At that time (2004) no specific rules existed and, for this reason, the only analytical method to define the asbestos hazards was the IR method (Index Release), according to D.M. 14/05/1996. Tests showed IR values < 0.1, that means not hazardous. Asbestos minerals detected were: tremolite, actinolite (anphibole group) from boreholes SR12 and SR14.

With the Preliminary Design Approval, (according to Environmental Code, D.Lgs 152/2006), the Italian Ministry of Infrastructure with the CIPE 80/2006 Resolution asked to deepen investigations concerning the natural occurence of asbestos minerals and indicated some particular stretches along tunnel section. In 2012, the first construction works about Lot 1 begun. According to CIPE resolution, the Governmental (MATTM) Environmental Observatory for the Terzo Valico established a control organism named GDL ("Gruppo Lavoro Amianto" that means Asbestos Working Group). The purpose of the GDL Amianto is to define a protocol for the management of asbestos hazard during the construction works. The GDL Amianto reports its activities to the MATTM Environmental Obeservatory. The main actors are these territorials Authorities: Arpa Liguria, Arpa Piemonte, Provincia di Genova, Provincia di Alessandria, Regione Liguria, Regione Piemonte. According to survey results derived from Preliminary Design, the GDL Amianto has specified the asbestos-bearing rocks, "Green Stones" (Ophiolites and Molare Formation) and detailed a first tunnel geological longitudinal section. Geological Profile shows the probability to encounter asbestos-bearing rocks. Rules and management by the GDL Amianto has been reported in a specific document: "Protocollo di Gestione Amianto", which has been approved (18/03/2014) and adopted by MATTM with the following resolution: DVA-2014-0021283, 27/06/2014. The "Protocollo di Gestione Amianto", (P.G.A.), defined: the occurrence of Ophiolites and Molare Formation, the sampling method for the airborne and diagnostic methods, the sampling methods for soil excavation material and diagnostic methods. In the following phase of the Detailed Design, according to CIPE resolution, COCIV carried on a new deepened investigations in order to specify asbestos minerals along tunnel alignment. The new geological profile detailed the probability to find asbestos-bearing rocks:

Southern area: Monte Figogna metabasalts unit – Voltri Interconnection tunnels and Borzoli Tunnel – analyses did not find asbestos minerals amount

Cravasco area, access tunnel and main tunnel from chainage 8+500 and 11+500 - analyses founded important asbestos minerals contents.

Central area: "Argille a Palombini" unit with metabasalts, from chainage 11+500 and 19+700 - analyses did not find asbestos minerals occurrence

Northern area: Molare Formation (TPB) from chainage 19+700 and 23+700 – mineralogical and petrographic analyses showed the occurrence, no ubiquitously, of chrysotile veining in serpentines and additionally the occurrence of traces of tremolite and actinolite in sandstones.

4.1 *Analytical methods and approach*

Samples have been analysed as follows:

Qualitative analyses:_mineralogical and petrographic study on thin section allowed a first evaluation of asbestos minerals occurrence.

Quantitative Analyses:_where mineralogical and petrographic study indicated the asbestos minerals presence, the quantitative analyses have been carried on, to specify quantities and asbestos type; the analyses have been carried on by MOCF, SEM-EDS, XRD and μRamam.

Statistical Analyses:_a statistical method has been used to estimate the probability for asbestos minerals content occurrence in the analysed rocks, Molare Formation (FM) and Serpentines, Serpentinoschiscts and Ophicalcites (Isoverde tectonic and milonitic Zone).

4.1.1 *Molare Formation (FM)*

Ninety-seven (97) data results, regarding to asbestos minerals contents (ppm or "parti per milione"), from SEM analyses for samples derived from boreholes in the tunnel stretch between chainage 19+700 and 24+000. The ninety-seven samples may be described as follows: nineteen (19), matching to 19.5%, did not find asbestos minerals. The other seventy-eight (78) found fibres, mainly of chrysotile, locally of chrysotile with tremolite.

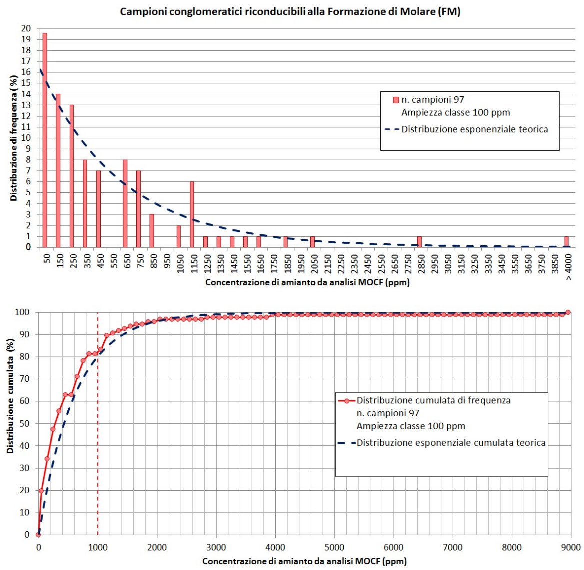

Figure 3.Analytical results

The frequency histogram shows that the 20% of the analysed samples have an asbestos content greater than 1000 ppm (19.63% according to theoretical exponential distribution, 16.50 % according to cumulative frequency distribution).

4.1.2 *Serpentinites and serpentinite schists (Se')*

The number of data refers to forty-six (46) results, regarding to asbestos minerals contents (ppm); SEM analyses have been carried on twenty-three (23) samples derived from the boreholes FCR1, FCR2 (performed from the tunnel face of the Cravasco access tunnel); five (5) samples derived from boreholes L2-CR4, L2-CR5 (performed along tunnel section, in the Isoverde Tectonic/Milonitic area); eighteen (18) samples from outcrops (these samples may be described as lizarditic Serpentine).

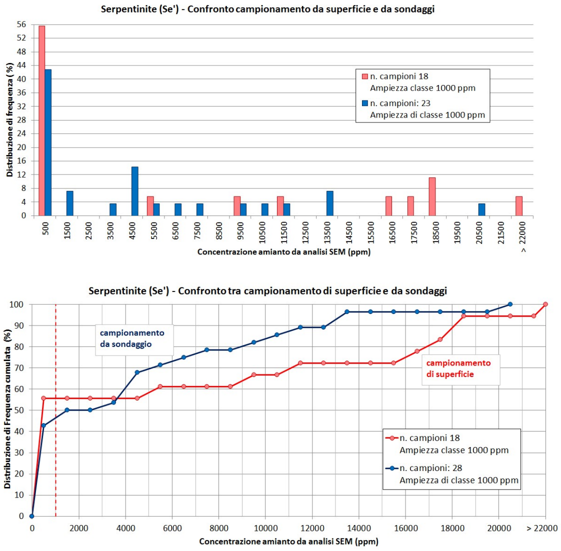

Figure 4.Analytical results

Generally for the 50% of analyzed samples, asbestos contents is greater than 1000 ppm.

4.2 *Discussion*

The check of all data, combining the analyses from outcrops, from borehole samples, from mineralogical and petrographic study at Turin and Genoa University and at Turin Scansetti Center, allowed to define the asbestos-bearing rocks ("green stones" – ophiolites) distribution along tunnel stretch of Terzo Valico from Genoa to Milan. Particularly, the analytical study shows that the only ophiolites or "green stones" with a significative content of asbestos minerals are: serpentines and serpentinoschists connected to the tectonized and milonitic zone of Cravasco; ophicalcites, in the area from Pietralavezzara and the northern Val Lemme; conglomerates and sandstones of the Molare Formation, these rocks are not ophiolites or "green stones" but they may contain boulder of them.

In these rocks the only asbestos minerals that could be find are: Chrysotile, Tremolite, Actinolite.

4.3 *Concluding remarks*

Deepening investigations provided the following important results:

- metabasalts and basaltic breccias, didn't show asbestos minerals occurrence.
- In some samples of serpentines lizardite has been found. The micro spectrometry analyses regarding asbestos minerals in vein, showed the presence of chrysotile, both cross type and slip type.
- Tremolite has been observed only in ophicalcitic rocks.
- In rocks collected from Molare Formation, chrysotile has been found: the occurrence is limited to veining in serpentines boulder, in the matrix has not been found. Locally in the matrix some traces of tremolite and actinolite has been found.

The combined analysis of the all studies allowed the review of the geological profile along tunnel section for the "Protocollo Gestione Amianto (P.G.A.)", too. In the new Profile (Figure 5) probability of asbestos-bearing rocks is limited to the following lithological groups:

serpentines, serpentinoschists and ophicalcitis rocks for the Isoverde Tectonic/Milonitic area, in the contact zone of Gazzo-Isoverde and Cravasco-Voltaggio units.

Molare Formation characterized by conglomerates, sandstones, breccias, marls, claystones.

Asbestos rocks distribution allowed to define a risk asbestos mineral prevision according to four different classes along the Terzo Valico tunnel section:

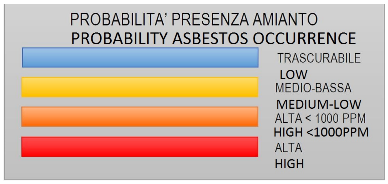

Figure 5.Asbestos along the Terzo Valico Stretch

Risk is high in two areas:

Cravasco area, from chainage 9+000 and 10+700 (L= 1700 m)

Molare Formation area (TPB), from chainage 19+500 and 23+700 (L=4200 m).

Medium risk is specified in the border of Cravasco area and in the north of Molare formation area: From chainage 8+500 and 9+000 (southern to the milonitic area), From chainage

10+700 and 12+900, 23+700 and 24+100, 15+800 and 16+200, 17+800 and 18+200 (north area of milonitic zone), From chainage 18+900 and 19+700 (north area of the Molare Formation).

High risk but with an asbestos minerals content lower than 1000 ppm from chainage 24+100 and 28+300 and in the rockmass of Serravalle tunnel.

Low risk for the remaining area.

5 CRAVASCO CASE STUDY AND APPROACH

The Cravasco Tunnel adit section, one of the four accesses tunnels to the main tunnel of the Terzo Valico, of approx. 1,260m in length. Tunnel crosses a part of this complex geological context within the Sestri-Voltaggio Zone. This area represents the core zone of Sestri – Voltaggio area and is constituted by a large number of different lithologies: from dolomites to chalk stones, from argilloschists to meta-basalts to serpentinites and ophicalcites.

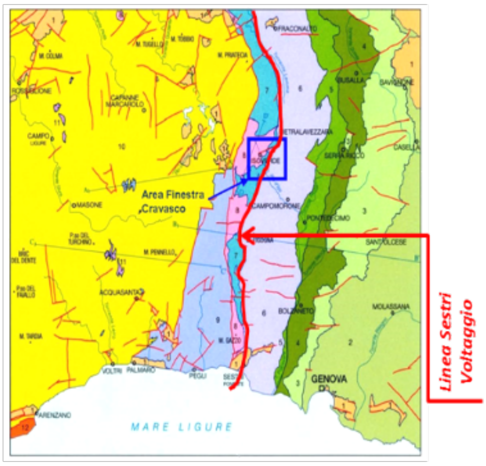

Figure 6.Cravasco plan

During the tunnel construction, near chainage 0+706 approx., in the argilloschists excavation, tunnelling work bump into an ophiolite rock sequences usually defined as "Green stones". These rocks are not continuously at the face scale, but contain important amounts of asbestos fibres. This new and important event led the COCIV Consortium to review technical and procedural system to allow excavations and reduce, as much as possible, the risk to exposure for workers. As well, a management procedure for removal and disposal asbestos-bearing soils has been produced according to the Italian "Environmental Code". The Cociv Consortium efforts are very important because this experience is unique in modern tunneling excavation in rockmass with asbestos-bearing occurrence. All existing asbestos rules and codes are referred to industrial sites contaminated by asbestos products. Until today, no rules or procedures have been defined for tunnel excavation in "green stones". The Cociv Consortium according to GDL Amianto requirements and, additionally, operating with Arpa Liguria and Genoa University, well-defined a new procedure to manage tunnel excavation, to safe its workers, to handle asbestos-bearing soil disposal. According to the current national regulations, work conditions and, most of all, the workers "Exposure risk" have been defined and planned with accuracy.

During tunnel excavation, with conventional methods, in asbestos-bearing rocks, the fibers content in the work environment (the so-called "airborne particulate") is a variable. The fiber amount depends on the distribution and content of asbestos fibers because of a great rockmass heterogeneity. Asbestos fiber content heterogeneity depends on the different mineralization conditions of the rock mass.

During excavation, it has been found that the softer the rock is, the greater the risk of fibers spreading is, as a result of the higher specific surface of the excavation material produced. According to modern technology the specific number of airborne fibers spread into the work site can be detected with a certain time delay (usually of 12÷24 hours). For this reasons it is necessary to proceed with maximum caution with respect to "workers' prevention" and "protection measures". The reference value for fibers "airborne particulate" in work environments is 2 fibers/liter evaluated by SEM analyses (according to Italian Ministerial Decree 06/09/1994). This value represents the threshold value: above it all possible active and passive protection measures must be activated. First of all, after analysing standard tunneling procedures with conventional methods, the breaking of the rock at the excavation face was identified as the "cause" of the potential spread of asbestos fibers. Underground ventilation air, tunnel waters, excavation soils and rocks were identified as the "scatterers" of the potential spread of asbestos fibers into the work site and the external environment.

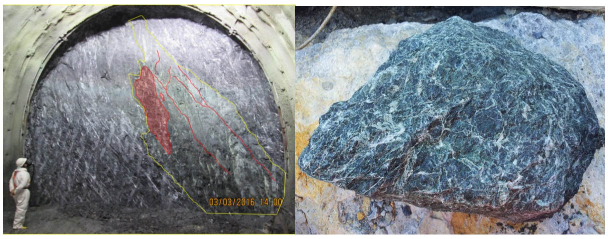

Figure 7.Excavation face with the "source" of fiber spread (left); Serpentine rock containing asbestos (right)

After identifying the “cause” and any potential “scatterers” for the fibers spread, the Cociv Consortium established and implemented technical and procedural solutions to carry on tunnel excavation under asbestos-bearing rocks occurrence: “risk reduction” of the activities concerning protection measures for workers; Importance of protection measures “collective” and “individual”; “partition” of the excavation area from the rest of the underground tunnel; guaranteeing productivity in tunnel excavation; the defined procedures must be easy to reproduce in other sites, too, potentially affected by excavations in asbestos-bearing rocks.

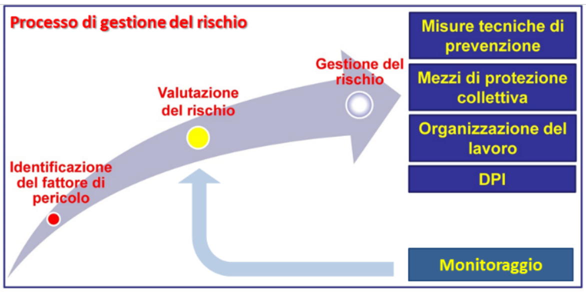

Figure 8.Risk management process adopted for the excavation of the Cravasco tunnel access

Processo di gestione del rischio: Risk management process

Identificazione del fattore di pericolo: Identification of hazard factor

Valutazione del rischio: Risk assessment

Gestione del rischio: Risk management

Misure tecniche di prevenzione: Technical prevention measures

Mezzi di protezione collettiva: Collective protection equipment

Organizzazione del lavoro: Work organisation

DPI: DPI

Monitoraggio: Monitoring system

As a first step, tunnel was divided into 3 physically separate areas. Each one has been related to a specific risk concerning the potential contact to airborne asbestos fibers during excavation and tunnel activities.

A zone – “Contamination Area” is the tunnel section close to the excavation face, spanning max. 80lm. In this area, all procedures defined for the asbestos-bearing rocks excavation are performed. The specific risk equipment required refers to all excavation activities is concentrated in the A Zone.

B Zone – “Decontamination Area” is the tunnel section close to contamination Zone A, with variable length from 90m to 140m. in this area decontamination activities for everybody, for tools and equipment used in Zone A during excavation activities, are carried out.

C Zone – “Contamination-free Area” means the remaining area of the tunnel from the end of the B decontamination Zone and the tunnel entrance. This area is intended for the activities not directly connected to the excavation of asbestos-contaminated materials. No subject to the risk exposure to asbestos fibres (such as waterproofing and final shotcreting of the tunnel).

The physical separation of the three areas was achieved by creating two “Physical Compartments” between the A/B and B/C Zones, making use of quickly removable metal structures. Both compartments were fitted with automated gates to enable the entry and the exit of staff and vehicles along the tunnel and equipped, at their top, with flat spray nozzles in order to produce an effective water blade for the entire time the gate is open. This mechanism guarantees the effective partition of the areas. At the same time, the pressure ventilation system works as an extraction ventilation system, to capture the maximum number of airborne asbestos fibres spread in the A Zone during tunnel excavation. This method gives the opportunity of a quickly environment decontamination in A Zone after ending excavation activities and securing the tunnel face for other activities. The ventilation system was designed in such a way as to guarantee constant airflow in the tunnel. The air, running through the entire length of the tunnel, from the entrance to the extraction point close to the excavation face, may effectively contribute to prevent the spreading of fibres to the different areas of the tunnel and to the external environment.

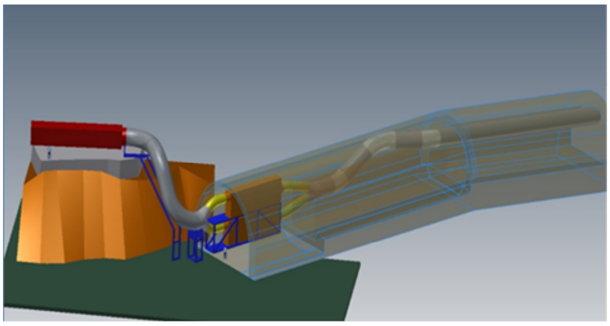

Figure 9 - Layout of extraction ventilation system

The air removed by the ventilation system, conveyed by a rigid metal pipe, runs through the entire length of the tunnel. In a second time the removed air is given back to the atmosphere after undergoing a filtration treatment that captures any asbestos-carrying fibres.

Starting from the entrance of the tunnel and progressing to the excavation face, the new extraction ventilation system consists, specifically, in two fans fitted on an external metal support, with a power of 200 kW each, capable of extracting up to 60 m³/s of air from the tunnel.

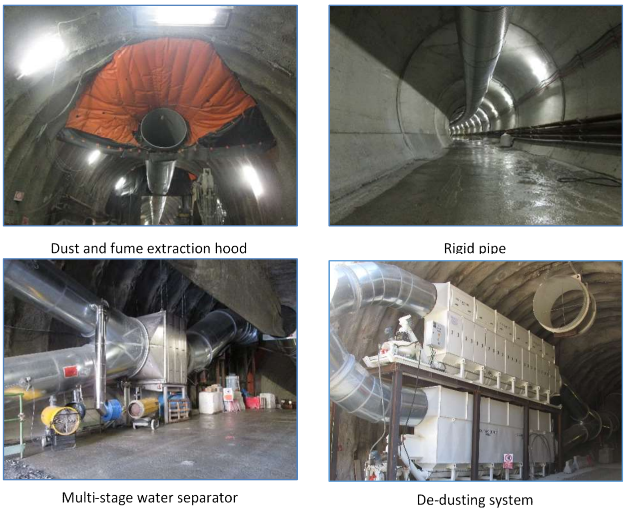

Figure 10 - Components of Extraction ventilation system

The "B Zone – Decontamination Area ", has been designed for all decontamination operations for staff, vehicles and equipment used in the A Zone during excavation activities.

Figure 11.Vehicle wash tunnel

Vehicle decontamination was designed and executed by making all vehicles coming from the A Zone go through a “wash tunnel”, through a number of fan nozzles installed on the side walls. For the decontamination of all staff working at the excavation face, as well as of everybody who have had access to the A Zone, according to the Health Authorities Control Bodies, a dedicated “decontamination unit” has been planned. Decontamination Unit was built making use of modular units. It consists of 3 rooms installed in this order: Clean changing room, Shower room, Dirty changing room.

In line with current regulations, excavation earths and rocks that, after specific characterization, show an asbestos content greater than 1 g per each kg of material, are classified as “special hazardous waste” (CER 17 05 03*) and must be sent to suitable waste disposal sites after management, treatment and bagging. An “Automated bagging line” has been prepared for the packaging of large quantities of excavated material in big bags weighing 1 ton each. The big bag production was of about 800 big bags per day, equal to 2 m of excavation face. In total, no. 22,580 big bags - equal to approx. 26,783 tons - of earths and rocks containing asbestos above the legal threshold were bagged and disposed of (CER 17.05.03* - earths and rocks containing hazardous substances). During all excavation, loading and transport operations of soil and rock material, everybody is protected from exposure to asbestos fibers by suitable PPE provided. All staff members who accessed A and B Zones, apart from having to wear the aforementioned full double Tyvek suits, were issued with rubber boots and gloves with long over sleeve, both easily washable, as well as high-visibility jackets and hard hats. With respect to respiratory tract PPE, ground staff operating mainly in A and B Zones were issued with

TMP3 full-face APRs equipped with P3 EN143/02 filters, characterized by an FPN2000 Nominal Protection Factor and a FPO400 Operational Protection Factor, i.e. capable of "reducing" the concentration of airborne fibres in the usage environment by 400 times.

Figure 12 - Personal Protection Equipment

In order to contain and further reduce the workers risk of exposure, the organization of activities was reorganized and based on two guiding concepts: limiting the number of workers in the A Zone to the absolute minimum (4 max.) during excavation and loading/transport of excavated material; introducing a sub-shift of approx. 4 hours for the staff working in A Zone during the excavation and material removal/transport stages.

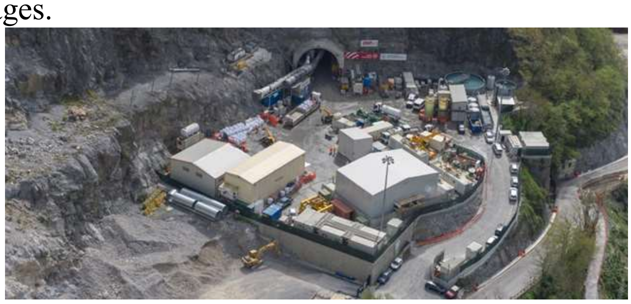

Figure 13.Cravasco Site: aerial view

In order to verify the suitability and the effectiveness of the aforementioned procedures and system solutions to be implemented, during the entire excavation through the asbestos geological formation, the airborne asbestos was subject to intensive monitoring in all work areas (A, B, C Zones and apron), in the cabs of the vehicles used for material removal/transport, as well as in clean and dirty changing rooms of the staff decontamination unit. The monitoring stations were located in the most representative way to capture actual workers' exposure, monitoring up to 6 samplings in parallel for the most at-risk activities for a total of approx. 700 samples during the entire time asbestos excavation was performed. In order to detect asbestos fibers, it was decided to use Scanning Electron Microscopy (SEM), which can provide morphology, composition and structure information with respect to the various components of the sample and can identify the number and type of individual fibers in a precise way.

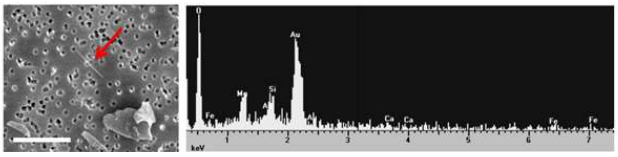

Figure 14 - SEM tests

The alternative method for fiber identification uses the PCOM (Phase-contrast Optical Microscopy) technique, which, even if more widespread, quicker and cheaper, suffers from significant technical constraints which do not allow the certain and univocal identification of asbestos fibers. The analysis of progressive and numerous sampling data enabled a significant increase in the level of knowledge and awareness of the spreading of asbestos fibers during work processes and, therefore, the identification and suitable adjustment of all the solutions adopted during operations including, where required, the adoption of corrective measures. The ongoing monitoring of the excavation stage revealed how the concentration (fibers/l) of airborne fibers detected in the A Zone was variable and independent from the effective asbestos content in the mass (mg/kg).

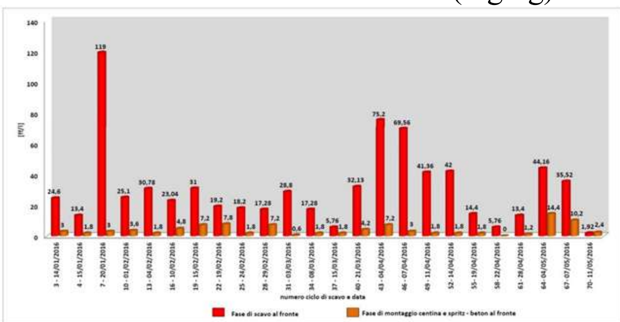

Figure 15 - Monitoring of airborne fibers: A Zone data

During excavation work, the highest airborne fiber peaks were detected for particularly soft rock areas with an asbestos content of around 4,000 mg/kg. Lithological sections with over 13,000 mg/kg didn't evidence disparate airborne spread. By sampling all excavation stages for a single face (excavation, excavated material removal/transport, preliminary shotcreting, installation of ribs and final shotcreting), it was also possible to determine how the fibre concentration detected in the A Zone during the most critical stage of excavation work corrupted very quickly (approx. half an hour) thanks to the extraction ventilation system.

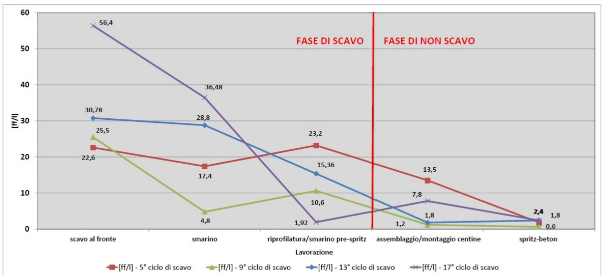

Figure 16 - Ongoing monitoring of airborne asbestos in the A Zone

It was established that, during all excavation stages (74 excavation face cycles - approx. 500 data points) the fibers spread were almost completely confined to the “contaminated” A Zone, their concentration in the other areas (B and C) was not relevant because of the efficiency of the physical partitions installed.

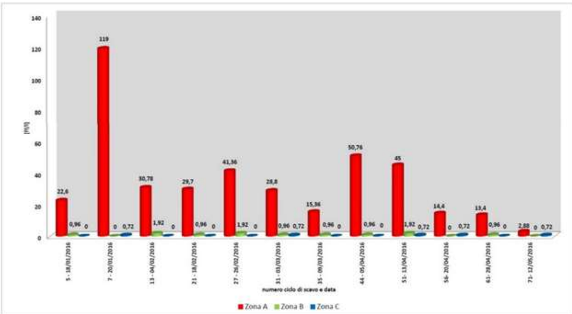

Figure 17 - Monitoring of airborne fibres: comparison of data for A, B and C Zones during the excavation stage

Positive results were obtained by the monitoring performed inside the cabs of excavation face machinery at the tunnel face.

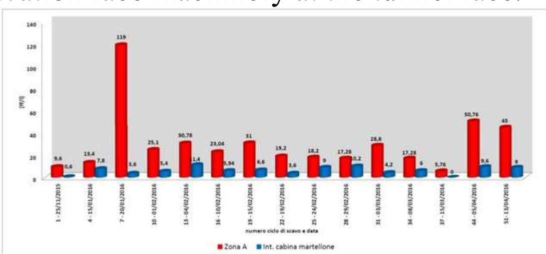

Figure 18 - Monitoring of airborne fibers: comparison between the A Zone and the cab interior of excavator with hammer during the excavation stage

Excellent results were obtained by monitoring the cab interior of dumpers used during the removal and transport of excavated material, too.

Excellent results were achieved in the clean changing room of the personnel decontamination unit. Additional monitoring was carried out at stations located close the tunnel entrance and close to residential dwellings located around the site at pre-set distances (“bands” or “rings”) from it. The several data collected (approx. 1,200 samples) underlined asbestos contents below 1 fibre/l and in line with natural environmental concentrations for the area.

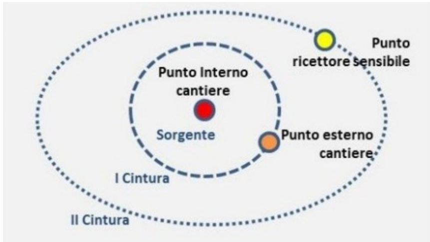

Figure 19. Criterion for the location of "Asbestos - Living environment" monitoring stations and "source" monitoring stations

6 CONCLUDING REMARKS

The “Cravasco Site”, the first experience of Tunneling in asbestos-bearing rocks for the Terzo Valico, was successfully concluded with the achievement of important milestones and provided key information for the development and improved management of future tunnel sites with comparable features.

First of all the most significant target was achieved: “minimization" of the risk exposure to asbestos fibers for all workers involved, thanks to intensive awareness-raising, information and training activities at all levels on such an important matter. Another important target was the reaching of “zero impact” on external environment - the so-called “living environment”. Finally, the most important results obtained were undoubtedly the carrying out of procedural solutions that could be easily “reactivated” at the same excavation site and “replicated” at other sites of the Terzo Valico project potentially affected by the excavation of rocks containing asbestos. Despite operational issues arising from newly introduced plant equipment and the adoption of non-standard work procedures, a “sustainable” level of productivity was obtained, achieving a daily excavation progress of 2m (excavation section of approx. 85m2) and a monthly progress of up to 35-40m. These important results were impacted by many operational difficulties:

- limited work site areas;

- daily (from 7:00 to 19:00 hours) and weekly (Monday to Friday) limitations for the delivery of big bags to waste disposal sites which had been authorized to process special hazardous waste;
- circulation restrictions (both size and weight-related) for the only access road to the site.

Finally, it should be noted how the major results obtained were also reached thanks to the professional, positive and practical input of Control Authorities, ASL 3 Genovese and ARPAL, which, as part of the relevant roles and responsibilities, effectively contributed to the achievement of a successful outcome.

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