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TUNNELING OPERATIONS, OCCUPATIONAL S&H AND ENVIRONMENTAL PROTECTION: A PREVENTION THROUGH DESIGN APPROACH

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ABSTRACT

The study refers on the main results of a research work that has been carried out by the Safety and Health group of the Department of Environment, Land and Infrastructure Engineering (DIATI) at the Politecnico di Torino, with reference to the substantial difference that exists between the case of an established absence of hazards due to the presence of noxious materials such asbestos, crystalline silica, in the rock mass to be excavated and the situations in which these minerals can be present. Since, when carcinogenic substances can be expected, corrective action following exposure or dispersion is clearly unacceptable, the presence of critical pollutants requires special preventive actions for the health of the workers and the muck which can introduce risks for the users (e.g., during mechanical processing involving feeding, crushing, milling, sizing and sorting operations) should not be considered for any reuse.

Keywords: Asbestos, Muck Reuse, Occupational and Environmental Risk Assessment and Management, Prevention Through Design, Tunneling, Waste

1. INTRODUCTION

The construction of mobility infrastructures requires special attention, as far as the safety of the workers and environment protection are concerned.

In tunneling operations, these aspects are influenced to a great extent by the possible presence of hazardous minerals, such as asbestos (**Fig. 1** summarizes the possible presence of asbestos in the western Alps) and crystalline silica-both classified as risk "1" by International Agency for Research on Cancer (IARC) (This classification corresponds to the A1 risk level provided by the American Conference of Industrial Hygienist-A.C.G.I.H. It should be noted that the crystalline silica is classified A2 by the ACGIH (2012)).

The risk connected to tunnel driving operations in asbestos containing formations is due to the possibility of the air dispersion of fibers, which can lead to the exposure of workers involved in both underground activities and in muck reuse plants (if the material is not recognized as hazardous and sent for land filling).

In the case of tunneling in rocks containing asbestos it should be pointed out that even though the rock winning technique involves a limited fragmentation and the percentage of asbestos is low (less than 1% in volume), the problem is not negligible; for example, in a tunnel with a cross-section of 100 m^2, even a single 10 mm thick layer of serpentinite containing tremolite asbestos can disperse a rather impressive number of fibers (about $1*10^4$) in the air of the tunnel. These fibers, if not properly managed, can certainly lead to exposure levels for the workers that exceed the Safety and Health regulation limit values (according to European Directive 2009/148 (CEC, 2009), the limit value is 100 fb/dm^3 measured by means of a Phase-Contrast Microscope (PCM)).

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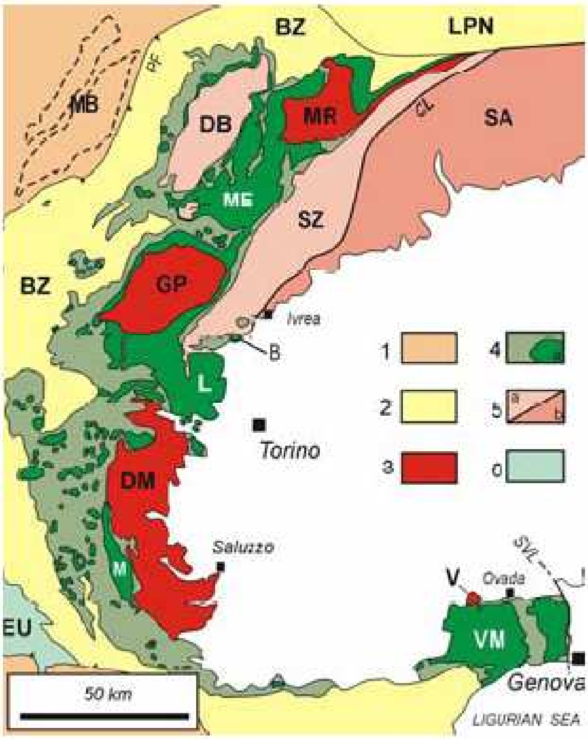

Fig. 1. Simplified tectonic sketch-map of the Western Alps. Main elements: 1: Helvetic Domain; 2-4: Penninic Domain, 2: Briançonnais Zone (BZ) and Lower Pennine Nappes (LPN); 3: Internal Crystalline Massifs of Monte Rosa (MR), Gran Paradiso (GP), Dora Maira (DM) and Valosio (V); 4: Piemonte Zone (a main ophiolitic bodies), L: Lanzo Ultramafic Massif, M: Monviso ophiolites, VM: Voltri Massif; 5: Austro-alpine Domain; 6: Embrunais-Ubaye Flysch Nappe

As a consequence, the availability of reliable input data (technical, economical and environmental) is essential from the very beginning of the project in particular in tunneling activities, in order to make correct decisions during the feasibility assessment phase and for an effective development of the project. A poor representativeness of these data can affect the results in many ways and determine deviations from the expected goal. The preliminary definition of the entity of the acceptable deviations, in each context, requires:

- The definition of the criticality of the various input parameters
- The consequent adoption of suitable techniques to quantify each parameter
- The recognition of the possible difficulties in the quantification of the aforementioned parameters and the choice of techniques directed towards limiting the resulting consequences

In the case of underground excavations (and possible reuse of muck), the design aspects are characterized by evolutionary input data due to the typical evolutionary nature of rock excavation activities and the typically inconstant characteristics of natural elements. A project should therefore be characterized by:

- Flexibility in terms of execution: the lower the quality of input data, the higher the adaptability required for the driving techniques. This involves a dynamic design approach
- Suitable confidence limits, according to the degree of knowledge of the characteristics of the rock mass. Work managers should in particular be provided with detailed instructions and the local situation should be monitored regularly

In these cases, a careful preliminary Risk Analysis is necessary and mandatory (according to European Directives 89/391 and 92/57 (CEC, 1989; 1992)). The same care is highly recommended in the PtD-Prevention through Design approach introduced by the ASSE (2009).

This analysis, which should be based on the collection of detailed information on the quantity and spatial pattern of the critical minerals, can lead to an effective choice of the tunneling techniques and technologies, in order to minimize the associated risk and to make correct decisions on the management of the excavated rock, which -apart from the impossibility of any reuse which could jeopardize the Safety and Health conditions of the workers involved- should now be considered a direct risk agent whose disposal becomes expensive.

1.1. Two Typical Poor Risk Assessment Cases

1.1.1. A Situation Involving Workers Exposure, Environmental Pollution and Important Project Modifications

A large quantity of muck, obtained from a tunneling operation and intended for reuse, showed a non-negligible asbestos content. The tunnel is part of a global project which has the aim of reducing the running distance and of making the carriage of goods by road easier. The 100 m^2 tunnel was driven in asbestos-free rock in the Dora Maira geological system (Piedmont, Italy). A variation in the nature of the rocks was neither forecasted nor identified, due to a somewhat unsatisfactory preliminary risk analysis. For these reasons, no special care was taken to deal with the situation that can be observed in **Fig. 2**.

Fig. 2. Tunnel face (intensively weathered mica schists)

Fig. 3. Asbestos elements in the fractures of heaped muck intended for reuse

Fig. 4. High Hydraulic Energy Hammer at work while a second worker provides the machine operator with visual help and "tries" to reduce the airborne dust pollution by spraying water onto the face

This can be considered a particularly serious and double problem, since the tunneling operations obviously involved uncontrolled exposure of the workers and pollutant emissions from the portals and the whole lot had to be transferred to a special dump site, with important unscheduled investments.

The whole lot consisted of 200.000 tons and the Local Environment Protection Agency measured a nonnegligible amount of asbestos minerals (tremolite and actinolite) in a relevant part of this lot as shown in **Fig. 3**.

As a consequence, the construction, which should have been completed some years ago, is at present still unfinished and a complete revision of the project has been necessary, in terms of organization and equipment, to deal with the geological situation (asbestos containing layers) that was encountered during the excavation.

1.1.2. A Typical Modus Operandi Requiring very Careful Risk Analysis to Prevent Possible Undue Overexposure of Workers to Critical Pollutants

Even though the environmental conditions in tunnels in which High Energy Hydraulic Hammers -H.E.H.H.- machines (**Fig. 4**) are used are quite different from site to site, some considerations can be made on the basis of the measurement results of an extended analysis of the environmental situation at the workplaces:

- The pure blowing time of H.E.H.H. is at least similar, but often quite longer, than the blast holes drilling time. For instance, the drilling time required by a double arm boomer to prepare a "blast event" of 300 m^3 of rock is approximately 100 min. When the same quantity of rock has to be excavated by means of an H.E.H.H. machine, a blowing time of 180÷250 min can be expected
- The mean size distribution of the airborne dust at work sites usually lies in a larger particle diameter range than 25 μm, but, when the quartz content in the rock is non-negligible, the resulting concentrations should be treated with reference to the respirable dust TLV (0.025 mg/m^3 provided by A.C.G.I.H.) and this can be very problematic
- Considering that only a few carrier cabs are fitted with forced conditioning and filtered air circulation and that it is common practice to carry out the mucking operations while the H.E.H.H. machine is working, the resulting exposure of the operator can become unacceptable
- The presence of a second worker at the face is often necessary, in order to provide the machine operator with some visual help concerning the optimal positioning of the tool against the rock. The dust concentration at the side of the carrier usually

greatly exceeds the TLV values (in some occasions more than 45 mg/m^3 total dust has been recorded)

As a conclusion, the use of H.E.H.H. in rock formations containing critical minerals should be excluded at the planning phase and this exclusion should be a direct result of a preliminary risk comparison which correctly takes into account the alternative winning techniques.

2. MATERIALS AND METHODS

The techniques used to investigate the possible presence of asbestos minerals in rock masses can be divided into:

- Geological surface investigations, which are useful for a preliminary identification of the areas that potentially contain asbestos minerals
- Geognostic drilling, which is performed to characterize the material to be excavated and to determine the possible critical factors, as well as to make the resulting data useful for a refinement of the geological modeling

Even though a large amount of information can be obtained from both destruction and core drilling, the quantification of the real amount of asbestos in the investigated rock formations is a difficult task. In the first case, the analysis of the drilling fluid can lead to an overestimation of the asbestos content, due to the possibility of some over-flushing of the mineralized fractures by the pressurized fluid, while the analysis of the samples resulting from core drilling operations can underestimate the asbestos content, due to unaccountable losses in the pressurized fluid (the same phenomenon in reverse).

However, destruction drilling at present appears to be unsuitable, since, even though case hole approaches are adopted, it is impossible to establish the detailed position and thickness of the asbestos layers with such a technique. An experimental study has been carried out on a series of cores made available from geotechnical investigations. Some possible modus operandi have been identified which could be able to provide an acceptable representativeness of the asbestos content in the sampled rock on the basis of the division of the cores into tracts.

According the Authors' experience in the Italian Western Alps (**Fig. 5** shows an example of a drill cores from the Western Alps) it can be stated that surface core drills, even though essential for the characterization of large scale rock formations in terms of geological and geo-mechanic aspects, cannot be considered exhaustive for an evaluation of the asbestos content. For these reasons, progressive core drillings from the tunnel face are always necessary, regardless of the surface drilling results, to obtain information at a local scale on the expected presence of asbestos along the tunnel route.

Fig. 5. Drill cores from serpentinite bodies from the Western Alps

3. RESULTS

The following prevention criteria (technical, organizational and procedural) should be considered hierarchically as a general rule to manage environmental conditions, in particular when asbestos and silica dust can be expected (Labagnara *et al*., 2012).

3.1. Intervention on the Hazard Factors

This involves the adoption of materials that are NOT (or less) capable of emitting pollutants or which are suitable for pretreatment.

When tunneling operations are considered, this intervention can lead, in a PtD approach, to a modification of the tunnel route in order to avoid critical geological areas. This can obviously be unacceptable if there are extensive asbestos containing formations (**Fig. 1**).

3.2. Control the Pollutant Emissions

If the previous approach is not feasible, the pollutant should be "stopped" as close as possible to the source, in order to control pollutant emissions and to prevent the general pollution of the working environment; this often heavily conditions the choice of driving technique (**Fig. 6**), fittings, machines and procedures.

3.3. Control the Pollutant Dispersion in the Working Environment

In order to control pollutant dispersion in the working environment and to avoid the spread of pollutants, it is necessary to separate the area into sections.

If there are non-negligible consequences, in terms of safety and health, systems in as close circuit as possible should be adopted when hazardous minerals are present.

Fig. 6. Roadheader fitted with a de-dusting system used as a possible winning means in critical formations

When a full-face technique is used in the tunneling excavation, it is important to note that some types of machine, such as the hydroshield and slurryshield, intrinsically remove the excavated materials, with a hydraulic close circuit, from the excavation chamber.

Other types of machine, such as EPBs, allow the muck to be managed in a confined zone (cochlea) where the material is conditioned, in this way minimizing the dispersion of pollutants.

The subsequent transportation of the mined rock out of the tunnel should be managed with closed pipe conveyors: on the basis of the results of a number of sampling campaigns carried out by the Authors, the mean inspirable dust concentration measured in proximity of open and closed conveyors (with comparable flow rates), range from 10 mg/m^3 to 0.1 mg/m^3, respectively.

3.4. Environmental Pollution Management

Environmental pollution management by means of ventilation systems is perhaps the most convenient and cheapest arrangement for the underground pollution management, but should not be considered as the primary or even sole prevention means (particularly in the presence of hazardous minerals).

The aim of tunnel ventilation systems is to ensure both the safety of underground workers, through an effective management of the pollutants in the underground environment and the control of the emissions at the portal.

A number of different layouts are currently available for tunnel ventilation systems. Apart from the basic layout, the ventilation system should be considered as an integrated part of different subsystems which operate together to accomplish the target of an effective management of the underground environmental conditions, both in normal and critical situations.

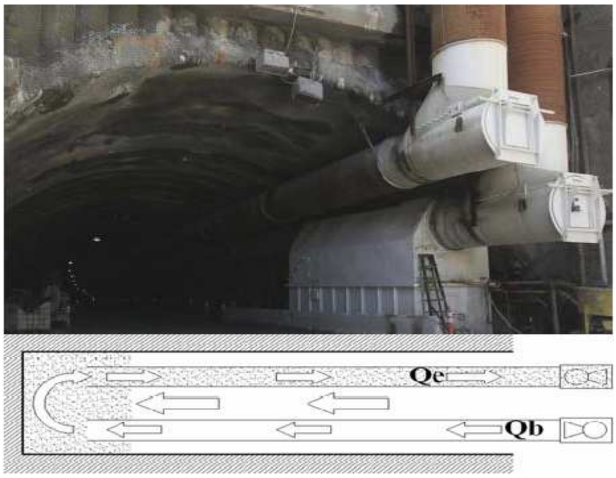

Fig. 7. The double flow ventilation system and its simplified layout used during the construction of the Caldecott Tunnel in Orinda California, fitted with an exhaust filter. Qe should be greater than Qb to produce an airflow toward the tunnel face. (http://www.sfgate.com/bayarea/article/CaldecottTunnCaldecott-dig-toward-tomorrow-2309547.php#photo-1816773)

In the case of the possible presence of asbestos containing formations along the tunnel route, a double flow ventilation system should be considered as the correct ventilation layout, **Fig. 7**, because it makes it possible to collect the polluted air directly in the proximity of the face and restitute filtered air to the portal.

3.5. Special Working Environments

Finally, a reduction of the pollutant to an acceptable level is sometimes not possible; in this case, it is obviously necessary to adopt special working environments (remote control from a safe position) to separate workers from the environment in order to ensure safety and healthy conditions through the use of remote control devices.

4. DISCUSSION

Availability (ability to be able to perform a required function under certain conditions, at a particular time or during a given period of time, assuming that the needed external resources are provided) should be considered a key aspect in the design of the safety systems. Unfortunately, at present, these considerations are seldom taken into due account.

The Authors have conducted a research project to identify -on the basis of tests or real situations-the most suitable Hazard Identification techniques to analyze the ventilation system for tunnel driving operations.

Among a number of tested Hazard Identification techniques (CCPS, 2011), the combination of Recursive Hazard and Operability Analysis -HAZOP(r)- and Fault Tree Analysis -FTA- have proved to be the most effective in order to provide good suggestions for the ventilation plant design in terms of reliability improvement with particular reference to the layout definition and the hardware (fans and ducts), monitoring/detection/response systems dimensioning and redundancies.

The application of the HAZOP(r) has confirmed the importance of a continuous monitoring of:

- The air flow rate, which should be carried out in the ventilation ducts in at least two points: immediately downstream of the fans and close to the terminal section of the duct. The measured values should be consistently detectable (for example, with a display screen) on the control panel and automatic data recording is required; a difference in the measured values in the two measurement locations is an index of an accidental loss of flow due to duct leaks or breakages. The knowledge of these values allows one to immediately recognize possible critical situations and to properly manage the maintenance operations
- The pressure head, which should be carried out in the ventilation ducts immediately downstream from the fans (automatic data recording is recommended) to check the flow-rates
- The air velocity along the tunnel, considering that the same ventilation system setting can lead to different air velocity profiles, depending on the geometry of the tunnel and on possible obstructions (e.g., due to the presence of machinery, scaffoldings, in order to verify the efficiency of the system

The FTA, on the other hand, has confirmed the importance of maintenance, organization and management choices: In the case of poor choices of maintenance, organization and management, the analysis of the reliability of mechanical components would in factbe useless. The FTA has also clearly highlighted the paramount importance of the backup systems in order to obtain significant improvements in reliability.

Finally, the research has pointed out the difficulty of finding in literature structured and detailed databases on failure rates of the various components, special for tunnel ventilation systems.

5. CONCLUSION

On the basis of the obtained results, it is possible to confirm that a careful Risk Assessment should be carried out during the very first phase of a project and, in the case of tunneling, it should be based on input data as reliable as possible. The subsequent Risk Management should obviously lead to the Prevention through Design approach, which is commonly recognized as the only approach capable of effectively minimizing the occupational and environmental risks; moreover the maximum flexibility should be introduced, so that the "special" safe -and quite expensive-modus operandi is activated if only strictly necessary.

The selection of different underground organizations, even including hazardous areas zoning and of special winning and mucking techniques and technologies can dramatically reduce the tunneling velocity (down to less than 1/3) and increase the cost. But, it must be considered that a not forecast incident, such as a gassy atmosphere or the presence of asbestos layers involves-asides from the possibility of accidents, health impairments and environmental pollution-a forced stop in the operations, claims, sentences and administrative sanctions, resulting sometimes in more than a 1 year interruption of the operations, which will be started again only after the necessary organization and technical modifications: The resulting costs can result increased of more than 10 times, as recently occurred.

Finally, in order to avoid unscheduled stops and to ensure the correct working operation of the safety facilities and in particular of the ventilation plants for the management of underground pollutants, such as the presence of critical minerals in the rock formations, it is necessary to study the reliability of all the components of the system, both in normal and emergency conditions.

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