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Workers safety conditions in urban underground construction: Risk evaluation, management and monitoring as applied in northern Italy

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**WORKERS SAFETY CONDITIONS IN URBAN UNDERGROUND  
CONSTRUCTION:  
RISK EVALUATION, MANAGEMENT AND MONITORING  
AS APPLIED IN NORTHERN ITALY.**

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## **1. Abstract**

On the basis of a hazard evaluation applied to underground constructions in urbanized areas, a number of problems due to the special operating context are put in evidence, a not negligible difference from the tunneling operations in mountain areas, commonly rather poorly dwelled.

As discussed, besides from the law enforced need of a careful safety analysis from the very first steps of the feasibility evaluation of the project, some typical aspects of operations in urbanized areas cannot be rigidly planned, due to a number of reasons, which can roughly be ascribed to the following topics:

- a. the narrowness of the construction site facilities, maneuvering and storage areas, and the possible interference with the common citizen activities (mainly, but certainly not only, in terms of movement and transportation), which can evolve during the construction time where important projects are considered;
- b. the often large number of contractors, each of them developing its assigned site, which, in the case of a subway, corresponds to a defined stretch of the entire line: the sites are then contiguous, this implying a careful coordination all along the construction duration.

The risk analysis approach identified as suitable for an effective risk analysis for these situations is summarized, and the basic risk management criteria and technical solutions are discussed, as applied to a subway under construction in Northern Italy.

## **2. Foreword**

In Italy, the adoption of European Community Directive 92/57/EEC of 24 June 1992 on the implementation of minimum safety and health requirements at temporary or mobile construction sites (eight individual directives referring to article 16(1) of EEC Directive 89/391) has become complete with the issuing of Legislative Decree 494/96, Updated as Decree 528 of 19 December 1999.

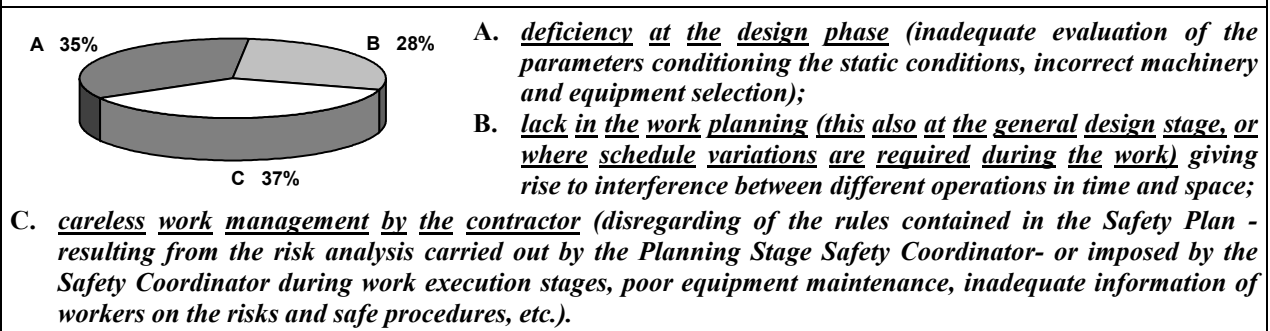
In accordance with the principles stated in the EC directive, the Italian enforcement defines the need of a careful risk analysis aimed to prevent injuries and professional diseases of the workers, and the roles of both the planning stage safety coordinator and the safety coordinator during work execution stages.

Substantially, in coherence with the analysis proposed in the official EC bulletin in 1993 as a support to the issuing of the 92/57 Directive, where the main causes of fatal injuries are summarized as shown in the following chart, the importance of a careful risk analysis, to be carried out at the very first stage of the project feasibility evaluation, and of *systematic* audits

of the interference risk along the whole work development are strongly recommended, and specially qualified people are charged of these tasks.

Finally, further dispositions on the matter of safety are contained in the 109/94 Law - commonly named “Merloni Ter”- Art.31, stating that in case of construction commissioned by public administrations, in the pre-consignment of the work stage, the company is requested to supply its Operative Safety Plan (“Complementary and Detailed Plan”) to be then inserted into the Safety Plan already developed by the Safety Coordinator during the design stage.

Fig. 1 -CAUSES OF FATALITIES AT CONSTRUCTION SITES - CE RESEARCH WORK PUBLISHED IN THE CE BULL. IN 1993 (the figures put in evidence the importance of a careful design and management of the safety aspects)



### 3. An effective approach to the risk analysis and management

To get a correct evaluation and management of the risks for the safety and health of workers, the following considerations should be taken into account:

<p><i>risk = probable damage deriving from the event (M) * probability of the event occurring (F)</i></p> <p><i>WHERE A TIME REFERENCE IS ADOPTED (e.g. 1 year) THE RISK SHOULD BE EXPRESSED AS A NUMBER, THIS ONLY MAKING POSSIBLE AN EFFECTIVE RISKS COMPARISON AND A CORRECT APPROACH TO THE RISK MANAGEMENT, ON THE BASIS OF THE CRITICALITY</i></p>	
a.	probable damage M = the product of two factors, the first quantifying the worst expectable consequence of the concurrent presence of people and hazardous entities (substances, situations, etc. with the intrinsic property or quality of causing damage): death, injury, etc., which can be referred to conventional lost days, a common practice in the statistical accident analysis; the second the possibility of interference (contact factor with the hazard), as a function of the exposure duration to potentially hazardous situations or operations (commonly expressed as a percentage of the work cycle).
b.	probability of occurrence F = probability (number of expectable events on a pre stated time span) that the setting off event should occur (statistical data on the occurrence of professional injury or illness in similar operating conditions could prove valuable)
<p>in order to reduce the risk (<u>once the impossibility of removing it has been ascertained</u>) M and F should be reduced:</p> <p>⇒ acting on the probable damage M means, on one hand, adopting a solution that minimizes the consequences of the event (e.g. safety belts, PPD, etc.), on the other minimizing the duration of the critical operations through organization improvements, the use of remote control devices, etc.;</p> <p>⇒ acting on the frequency of occurrence means increasing the reliability of the system (for example through the maintenance of equipment, the identification of correct procedures etc. )</p>	

Since the statistical data on professional injuries and illnesses presently available in Italy cannot be considered sufficiently detailed, and the non observance of the law statements is not listed as a determining factor of the accident occurrence, the direct use of the described approach is often quite difficult.

To overcome this problem, it can be considered the purpose for which the provision of the law and the technical regulations on work safety and health were introduced, that is the protection of the workers: the obvious conclusion can then be reached that a situation



complying with the law statements, and in accordance to the development of the technical progress will entail the conditions of minimum probability of occurrence of hazardous events that is today achievable.

The aforesaid sentences summarize the basics upon which a well tested approach was developed /1,2,3/, based on the *relative probability of the occurrence of the event PR*, in the form:

$$PR = \frac{\text{actual probability of the occurrence of the event}}{\text{minimum probability of occurrence where the respect of law and up to date technical regulations is constantly granted}}$$

The uncertainty in the numerical quantification of the risk is so avoided where, ascertained the impossibility of removing it by means of alternative solutions, the relative probability is  $\leq 1$ .

The discussed approach makes possible the following results:

- ✓ *an unbiased numerical risk evaluation, and the resulting correct approach to the risk management on the basis of a grounded hierarchy of interventions;*
- ✓ *the minimum risk operating techniques and technologies shall be identified at the very first step of the general design, and no procedures involving higher risk conditions adopted on the basis of the obsolete approach of tradition thinking and cost analysis (as discussed in /4/, where the TBM machines are considered);*
- ✓ *a correct evaluation of the possible entity of the consequences of the damaging events, since an unexpected worsening of the consequences of an event due to other lacking (e.g. of assistance or emergency interventions means, etc.) cannot occur for situations that are surely according to the up to date regulations;*
- ✓ *the continuous updating of the risk analysis (and of the safety conditions) in accordance with the construction developments and the technology improvements being intrinsic in the discussed approach, the same proves coherent with the Total Quality Management systems of growing interest also in the construction activities. Moreover, a typical situation where excavation operations are carried on, the original unavoidable uncertainty in the rock parameters used in the preliminary static evaluations can be overcome by the use of back analysis techniques.*

The listed results are nevertheless void of practical significance where the all the possible hazards are not taken into account: as it is common knowledge, the hazard evaluation phase is quite critical in the process of risk analysis, assessment and management. At the purpose, in the case of the considered subway construction, a careful checklist was specially set up, where necessary with the What if - checklist approach: in the following table an example of the achieved result is provided (tab. 1).

HAZARD		CONSEQUENCE	TECHNICAL MEASURES REQUIRED BY THE LAW AND UP TO DATE TECHNICAL STANDARDS				
<i>fire in underground</i>		<i>suffocation, burns</i>	<ul style="list-style-type: none"> <li><input type="checkbox"/> <i>substantial reduction of the flammable material presence and of ignition causes (fittings and equipment selection and maintenance);</i></li> <li><input type="checkbox"/> <i>specially designed ventilation systems;</i></li> <li><input type="checkbox"/> <i>fire detection and management, and alarm systems;</i></li> <li><input type="checkbox"/> <i>escape-ways to the surface or to flame proof shelters provided with special fittings (survival kit, communication devices, etc.);</i></li> <li><input type="checkbox"/> <i>special training of people, and availability of breathing and emergency apparatuses;</i></li> <li><input type="checkbox"/> <i>special procedures for critical operations (e.g. welding, etc.).</i></li> </ul>				
worst expectable consequence	lost days	contact factor [% shift]	probable damage $M = pd \times fc$	relative probability PR	RISK (1 worker) $R = M \times PR$	n° workers involved [N]	TOTAL RISK $R \times N$
<i>suffocation, burns</i>	60	90	5400	1	5400	5	27000

#### 4. Special concern due to the urbanized area operating contest

Where underground constructions are carried on in heavily urbanized areas, which is typically the case of subways, a number of safety problems, involving workers, citizens or both rise up, due to the special operating contest (a typical situation is sketched in the following map, showing the basic layout of a subway under construction in Northern Italy).

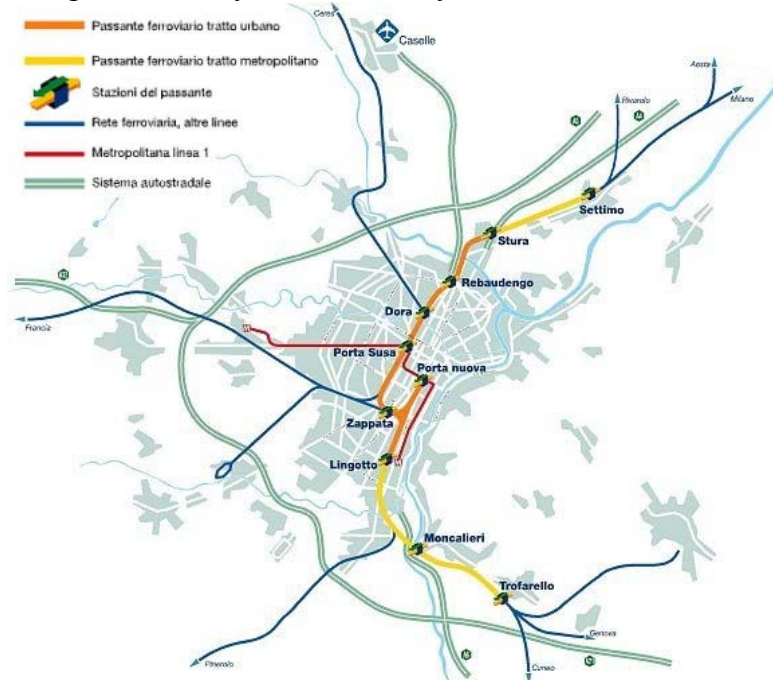


Fig. 2 example of the network of transportation systems in a Northern Italy town

An hazard evaluation brings to evidence a number of aspects directly bound to the peculiarity of the surrounding areas, which increase the complexity and condition the times and costs of the operation /5/.

These problems can roughly be ascribed to two main topics, often strictly connected, as exemplified in the following table:

- |  |
|--|
| <p>a. the narrowness of the construction site facilities, maneuvering and storage areas, and the possible interference with the common citizen life and activities, which moreover usually evolve along the construction time where important projects are considered. Some examples can be:</p> <ul style="list-style-type: none"> <li>❑ <i>the public transportation system and some private vehicular traffic should be assured, even if somehow detoured: the surface operations are then forcedly divided into different steps, and require adjustments, this typically being the case of main avenues, where some traffic lines must remain in use;</i></li> <li>❑ <i>the conditioning of productive and service activities (closing of shops and filling stations, modification of pedestrian and vehicle accesses to industrial factories);</i></li> <li>❑ <i>the removal, from the public availability, of areas destined to social activities (squares, gardens, car parks, etc.)</i></li> <li>❑ <i>the immediate proximity of the pollution sources (dust, noise, DPM, vibrations, ventilation systems exhaust, etc.) to the impactable areas;</i></li> <li>❑ <i>the setting up of sites for equipment and waste materials, and of “villages” for the workers;</i></li> <li>❑ <i>a number of buildings and artifacts of artistic or historical value are usually interested, this involving the introduction of more stringent than usual parameters, e.g. in terms of ground vibration levels,</i></li> <li>❑ <i>special operations -such as shaft sinking and surface to underground access ways excavation- can prove particularly critical</i></li> <li>❑ <i>even and particularly in difficult conditions the possible emergency situations at the construction site must be considered, together with the possible induced effects on the surrounding areas.</i></li> </ul> |
|--|

- b. the often large number of contractors -and subcontractors- each of them developing its assigned site, which in the case of a subway corresponds to a defined stretch of the entire line: the sites are then contiguous, this implying a careful coordination all along the construction duration, in spite of every careful work scheduling in the project design phase. Moreover, in many cases (as shown in the above proposed map) special link areas are necessary with different transportation systems, such as railway or bus stations, etc., they also under construction.

As a matter of fact, a number of causes of unpredictable delay can occur, such as:

- ❑ *difficulties during the moving of underground service networks that are the responsibility of various management organizations (aqueducts, sewage, electric lines, telephonic and data transmission lines, gas and town heating pipes, etc.) of aerial networks, public transport lines (rails, stops, the study of alternative routes, substitution of trams with buses);*
- ❑ *difficulties in the deviation and management of motor traffic modifications;*
- ❑ *the discovery of illegal dumping areas and localized polluted situations;*
- ❑ *the presence of archaeological sites and finds;*
- ❑ *the discovery of explosive leftovers from world war II in spite of the clearing up campaigns.*

Asides from the aforesaid general considerations, it must be underlined that the experience in the safety design and management for such operations cannot be directly transferred from one site to the following, neither from a urban contest to a different one, nor even in the same town different districts, each situation requiring a special analysis and management, to accomplish as best as possible to the different local exigencies, taken into account that a no impact project is a Chimera, though: a typical example is the quite different attention devoted by the resident population to the environmental problems, somewhere focused on the protection of the public parks and gardens, or of the trees lining the avenues, somewhere else on the disturbance due to noise, dust and vibration, or to the careful preservation of sites of historic or archeological value. The same presence of a number of workers operating at the construction site can involve socioeconomic problems requiring special and different approach in different town contests.

## **5. Some examples of the difficulties met in a real case, and of their management**

With reference to the mentioned real case, some practical problems of the risk management during each operative phase are here discussed, as examples of the paramount importance of:

- a. a careful and continuously updated work scheduling, as a means to avoid unexpected hazardous situations,
- b. the collective and individual safety provisions for the working crew, both of general use and specially selected for each operation where necessary, this involving that the critical parameters are systematically monitored;
- c. a progressive improvement of the info upon which base the impact assessment of the construction areas towards the surroundings.

### ***Example 1: construction site and surface traffic management***

The need of some conservation of the traffic -especially the public transportation- in the areas interested by the construction activity, asides of the already discussed limitation of the available areas for the construction operations, and the need of effective barrages at the site perimeter. G gives rise to a series of safety problems, among which the necessity of a careful management of the insertion into the traffic flow of the machinery and muck trucks -the layout and visibility shall be carefully considered, together with signal systems, special procedures and the selection of high visibility overalls- and of a splitting of the operations in trances to be fulfilled during low traffic periods (weekends and holidays); in general, this makes the work organization much more difficult, and the safety conditions of workers cannot

be analyzed only for a secluded work site situation. A common misunderstanding is on the meaning of the site enclosure enforced by the D.Lgs.494: the goal is to impede any critical interference from the inside or the outside, this implying that a wire or light metal sheet shall be considered quite inadequate where heavy machinery is present at both sides of the enclosure (in spite of this obvious consideration, heavy lorries often run unconcernedly at 40 mph at a red plastic cone distance from excavators and crews during highway maintenance operations).

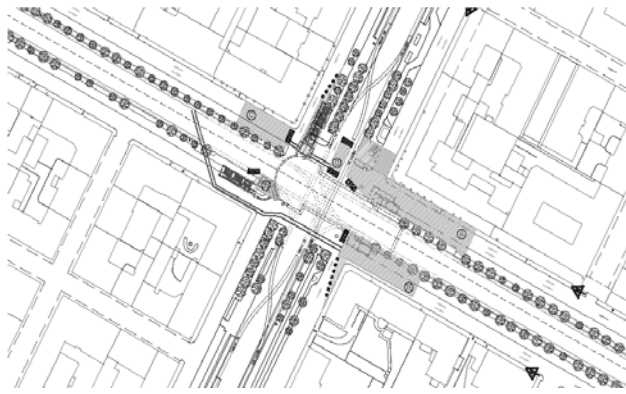
The example summarizes (see Tab.2) the various phases of the construction of a subway underground station in correspondence of the crossing of two main boulevards; in Table 3 the results of the Hazard Evaluation for such a situation are summarized:

*Tab. 2: Phases of the construction of a subway underground station in correspondence of the crossing of two main boulevards*

**Phase 1:**  
*for the preservation of the tree lines, the following operations were necessary:*

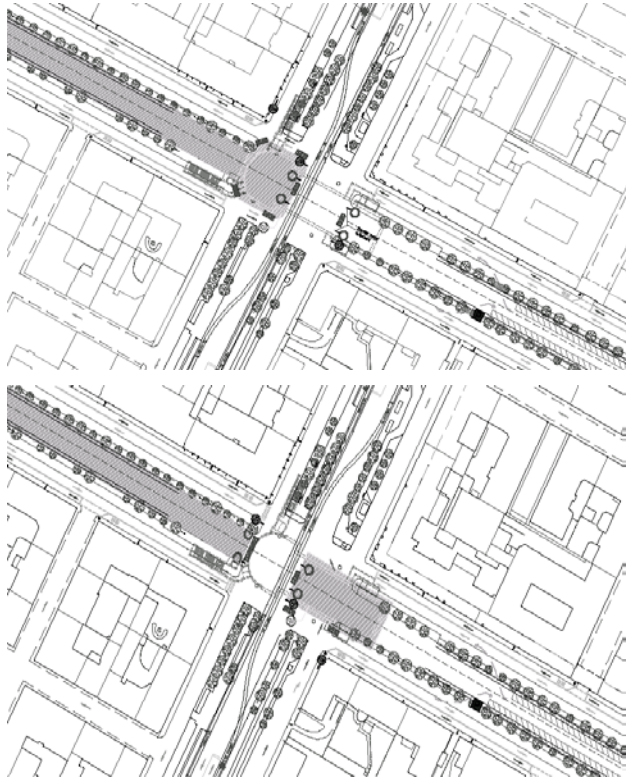
- deviation of the net of services (water, cable communications, sewers, etc.);*
- set up of special detour ways for the public transportation (this being particularly complex in the case of tramways).*

*The operations were carried out within working areas of very limited and irregular shape, in presence of traffic, and in brief time (to take advantage of periods of reduced traffic).*



**Phase 2:**  
*the main lanes will be closed to traffic, which will be detoured into the narrower side lanes. In the central lanes will be installed the site, this implying heavy problems of insertion of every machine and worker into the traffic.*

*Further problems are due to the necessity of leaving some crossing possibility to the traffic itself, this impeding the realization of a single site.*



*in both phases the lack of space obliges to a detached positioning of the auxiliary facilities (for people and machinery), this implying further problems of interference with the traffic, and to the duplication of the essential facilities (such as energy and water lines) at each site. Even the security becomes exacting, due to the large number of entrances necessary to provide easy movements from every side of the areas*

Tab. 3: Results of the Hazard Evaluation for the construction of a subway underground station in correspondence of the crossing of two main boulevards

Station N.				
Location				
Main hazards due to the presence of the construction site	Hazards for the site workers	Hazards from the construction site	Main consequences	Main countermeasures
1 - General			1 - General	1 - General
- Traffic	X	X	Interference with the construction machinery	Planned detourings Special organization on the way used by the construction machinery into the traffic
- Presence of unauthorized people in the working areas	X	X	Collision and crashes, run overs	Set up of New Jersey and other enclosure Overseeing of the construction site
- Intrusion of derouted vehicles into the working area	X	X	Collision and crashes, run overs, falling down into excavation areas	Set up of New Jersey and other enclosure Planned detourings
- Presence of visitors	X	X	Collision and crashes, run overs	Identified of the site to be visited and info of the workers Info of the visitors The visitors should be accompanied by members of the staff
- Presence of facilities non previously identified	X		Irrushes of gas and water	Overseeing of the excavation areas Definition of emergency procedures
- Presence of bombs	X		Explosions	Overseeing of the excavation areas Reclamation of blombs
- Presence of toxic industrial wastes	X		Poisoning	Procedures for emergency situations Overseeing of the excavation areas
- Presence of toxic industrial wastes	X		Poisoning	Reclamation of industrial wastes
- Presence or irrushes of gas	X		Poisoning and explosion	Overseeing of the excavation areas and monitored presence of gas Procedures for emergency situations
- Presence of waste water	X		Poisoning and biological risk	Overseeing of the excavation areas Definition of scavenging and reclamation procedures
- Polluting of impacter immissions		X	Environment pollution	Monitoring of the environment pollution Cleaning the tax leaving the construction area Water spraying of the site routes
- Presence of unmovable facilities	X		Irrushes of gas and water	Observation of the planned excavation techniques Definition of emergency procedures Overseeing and monitoring of the excavation areas
2 - Due to the contiguity or different essays			2 - Due to the contiguity or different essays	2 - Due to the contiguity or different essays
- Presence of newspapers, news and other stands and kiosk		X	Collision and crashes, run overs	Planned detouring, speed limits
- Presence of dehors		X	Collision and crashes, run overs	Planned detouring, speed limits
- Presence of gases stations			Explosion, toxic gas irrushes	Planned detourings Info on the scheduled on the refueling Procedures on the refueling operations Procedures for emergency situations
- Presence of tram ways	X	X	Interference with the public transportation	Planned detourings
- Presence of schools, hospital etc...(*)		X	Collision and crashes, run overs	Planned detouring, speed limits
Underground facilities identified :	APS, AAM, ITA, WIN, ENE, AEM, ATC			
Sewers movement:	1)APS_145 (waste water): trench with micropiles 2)APS_146 (waste water) trench with micropiles 3)APS_147 (sewage water) trench with micropiles			
(*) Present buildings (detail)	PRESENT BUILDINGS		LOCATION	BUILDINGS
		0415		Intercity railway station
		0414		Hotels and other shops
		0416		Hotels and other shops

### Example 2: the importance of a careful adjustment of the work schedule

Even if, according to the UE directives, the operation schedule must be planned in the very design stage, where important construction operations are being carried on, it is of paramount importance that –where necessary- even substantial modifications are introduced. This can be due to the necessity of a better use of time and space, as previously discussed, or to unexpected time shifts in the development of workings in adjacent sited developed by different contractors or, finally, to recently acquired info or decisions modifying the input design data.

The new work safety situation shall be carefully analyzed by the Safety Coordinator(s) during work execution, who will revise the Safety Plan, in cooperation with the main site contractor.

Such a problem had to be faced during the excavation of a tunnel linking the underground of a station and a service shaft which will be used to set in operation a Tunnel Boring

Machine; the station and the tunnel/shaft system are part of two different sites (developed by different contractors).

The original safety plan stated linking tunnel to be excavated from the base of the shaft, to minimize the interference risk at the station site. This being impossible due to unexpected delays, a substantial revision of the general operations scheduling in the station was necessary, in order to take into account a new series of operations, what's more carried out by workers employed by a different contractor.

The revision work, carried out by the Safety Coordinator (in the case the same for the two sites, this somehow simplifying the problem), was based upon a careful analysis of the original work program, upon which the new operations were imposed: two different kinds of interference in time and space were then identified, manageable by means of special technical provisions or requiring some time shift respectively. Thanks also to the use of a 3 D representation of the different working phases, a new time scheduling of the operations was formulated -and commonly agreed- as shown in Fig. 4, together with the most representative 3 D drawings.

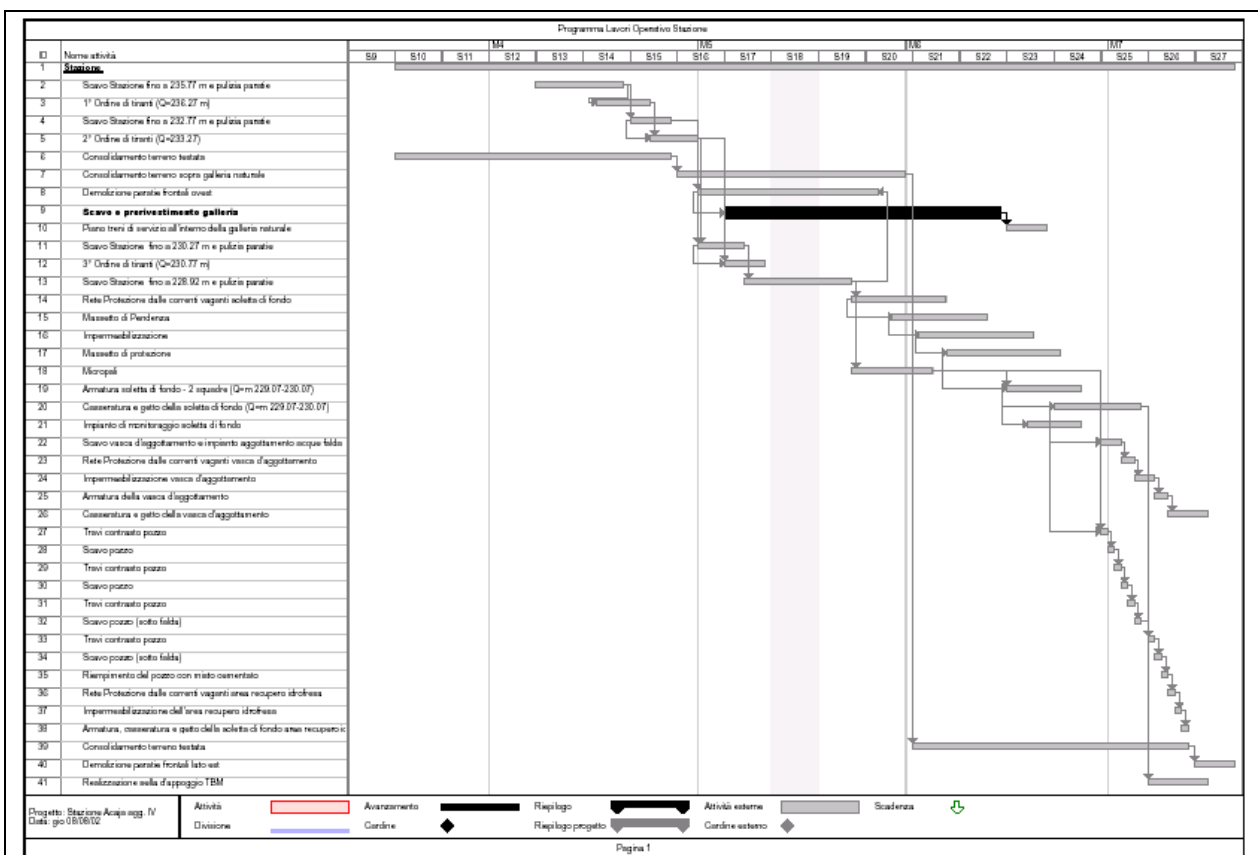
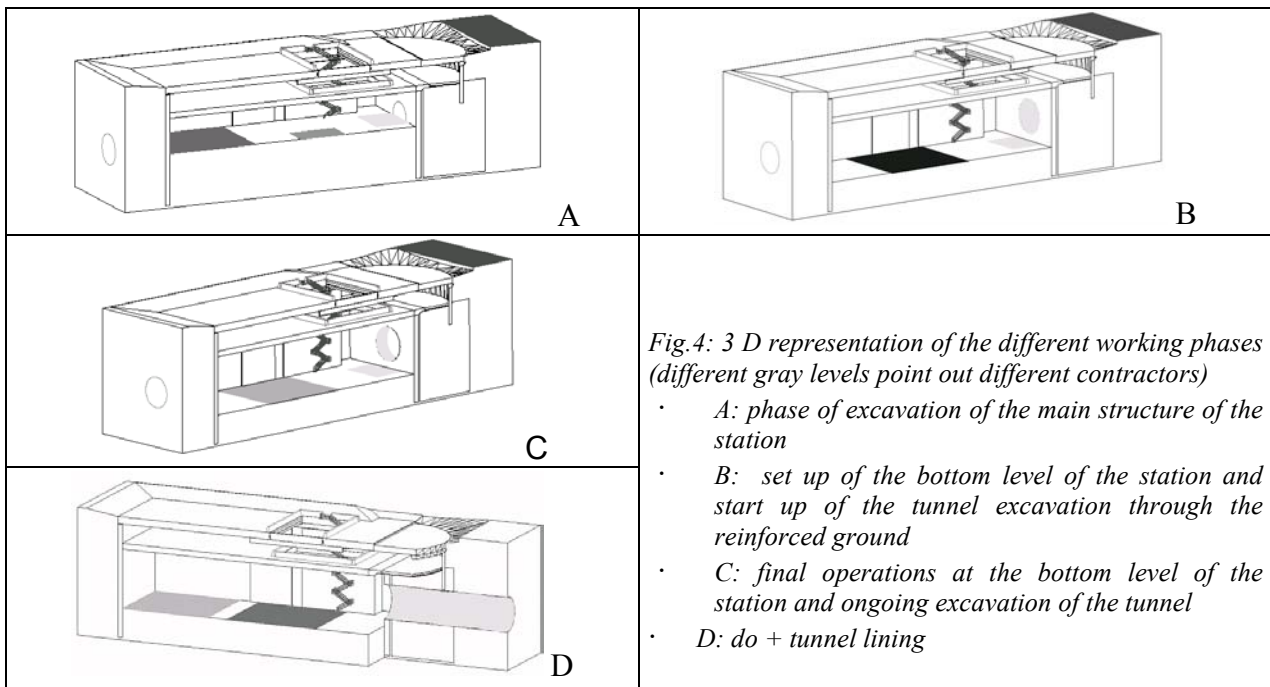
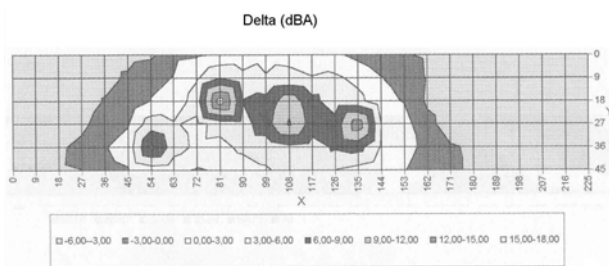


Fig.3: the new time scheduling of the operations resulting from the revision of the original Safety Plan, in the new situation of excavation of the linking tunnel starting from the station instead of from the shaft



**Example 3: improvement of the info upon which base the impact assessment of the construction areas towards the surroundings.**

Some forecasting of the noise emission from the station construction sites have been carried out, in order to get a preliminary evaluation of the expectable disturbance in the surrounding areas. The results got comparing the preexistent traffic noise to the output of computer simulations applied to the first phases of ground reinforcing (hydromills, earth moving machines and supporting facilities) show a moderate increase of the noise level at the facing buildings at ground level, and some reduction of the noise level reaching the top floors: this is due to the detouring of the heavy traffic previously interesting the avenue (see Fig 5)



*Fig.5 – Variation of the expectable sound level due to the first phases (preliminary ground reinforcing) of the construction operations in a station area at 1,5 m above the ground level*

It can be expected a worsening of the situation where massive excavations from the surface will take place, due to the increased number of heavy machines in limited areas. Where the further excavation phases will be started, some evaluations of the expectable noise level at the surrounding areas will be necessary, taken into account also the localized source represented by the station top opening (11.5 \* 16.5 m<sup>2</sup>), e.g. according to the EN 12354-4/2000 (Building Acoustics - Estimation of acoustic performance of buildings from the performance of elements - Part 4: Transmission of indoor sound to the outside).

Since the noise emission data can vary from the Manufacturer data due to the machine age, use and maintenance conditions, the preliminary input data shall be considered as a first and quite approximate approach: some campaigns based on sound intensity measurements will be started in '02 fall, to get a direct evaluation of the sound power of the main machines in use.

## 6. Conclusion

On the basis of the experience drawn from the analysis of the difficulties met in the real case of the construction of a subway in Northern Italy, the following considerations can be drawn:

- a. *as stated, a careful risk analysis, and the deriving management solutions are a must since the very beginning of the construction design, and both normal working conditions and emergency situations should be taken into account;*
- b. *the risk analysis shall consider not only the protection of workers at the workplaces, but also the possible problems due to the interference of the town activities on the site, and vice versa;*
- c. *nevertheless, in the case of important construction operations in urbanized areas, some flexibility is necessary with regards to the possible solutions of the safety problems, so that the minimal risk conditions can be granted even if some unexpected modifications in the work development or organization become necessary (the Safety Coordinator during work execution and the site contractor are involved);*
- d. *due to the limited areas available, and to the peculiarity of the subway construction operations, both rough and extremely specialized activities are necessary, this worsening the difficulty –typical of excavations- of careful operations to be carried out with high kW/man ratios;*
- e. *the aforesaid activities are often carried on by different subcontractors, and some overlapping can occur even between contiguous sites, developed by different contractors, so that the task of the Safety Coordinator during work execution cannot be considered a really relaxing one, requiring technical, organizing and also human capabilities);*
- f. *in spite of any careful safety analysis and management, some unexpected event may nevertheless occur: it is then particularly important that the people operating at the construction sites prove remarkable common sense and quick reflexes.*



*young elephant looking for freedom  
in a construction area (27 05 02) →*

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