Integrated hydrogeological and environmental restoration of landslides affecting a large asbestos mine dry tailings dump

Franco Oboni
Riskope International, Vancouver, Canada
Cesar Oboni
Riskope International, Vancouver, Canada
Claudio Angelino
Polithema srl, Turin, Italy
Bartolomeo Visconti
Polithema srl, Turin, Italy

Abstract
The Balangero asbestos open pit mine, located 35km NW of Torino (Italy), was the largest operation of this kind in Western Europe. The dry tailings were lifted by a conveyor belt from the mill and dumped over a natural slope with an approximate angle of 25 degrees, progressively reaching a maximum thickness estimated at 80 m.

By the '80s the dump was deeply scarred by various local and large scale instabilities, to the point that houses located at the toe, on the opposite side of the valley, were evacuated.

The award winning restoration project used a multidisciplinary approach including hydraulics, geotechnical, pedological and risk engineering to yield a well balanced and sustainable solution. This paper illustrates the Risk Based Decision Making (RBDM) process used through the feasibility, design and construction follow-up of the environmental restoration of the 60 Mm^3 dry Balangero asbestos tailings dump.

Introduction
The Balangero asbestos open pit mine, located 35 km NW of Torino (Italy), was the largest operation of this kind in Western Europe. In 1918, it was foreseen that the mine would extract 26,000 m3 rock per year, but in 1961 the mine extracted 1.3 Mm^3 rock. In 1966 a new mill with a capacity of 25,000 t fibres per annum was installed. The dry tailings were lifted by a conveyor belt from the mill, then through a tunnel to the opposite side of a hill, and then dumped over a natural slope with an approximate angle of 25 degrees from the altitude of about 830 m a.s.l. to the bottom of the valley at 580 m a.s.l.. As the dumping proceeded, a total surface of about 250.000 m^2 was progressively covered with tailings thicknesses going from few meters to an estimated maximum of 60 – 80 m.

Risk Based Decision Making (RBDM) was used through the feasibility, design and construction follow-up of the environmental restoration of the 60Mm^3 dry asbestos Balangero's tailings dump (Oboni et Al., 1997, 1998, Bruce & Oboni, 2000). Risk Based Decision Making (RBDM) was used by the winning project at each and every step of the design.

The project had several interesting problems related to environmental management, such as dusting and active instabilities.

RBDM showed that using innovative and unusual solutions like, for example, an aerial tramway instead of classic hauling would allow reducing dusting and project's carbon footprint meanwhile bringing an income (selling electricity produced while braking the downhill loads) and lowering general human health risks.

Overall, the integration of hydraulics, geotechnique, pedology and risk management led to a well balanced and sustainable project which will be turned into a "living museum" in the years to come.

The problem

By the '80s the dump was deeply scarred by deep seated instabilities, erosion gullies, mud slides etc., to the point that houses located at the toe, on the opposite side of the valley were evacuated. The site was furthermore recognized as one of the most serious environmental issues of Italy.

In 1992 RSA, a public company formed by the Province of Torino, the Mountain Community of the Lanzo valleys, neighbouring communities and other key stakeholders was mandated by the regional government of Piedmont to organize an international design contest for the environmental rehabilitation of the dump.

In 2000 RSA launched, on the basis of an existing preliminary design, a European design contest to find the best suitable solution for the environmental restoration and permanent stabilization of the dump slopes, orphaned since the end of the 80's. The site was potentially critical in terms of large events including mud flows, deep slides and wide spread dusting of asbestos fibres. Two communities with about 10.000 inhabitants were indeed under the influence of the dust plumes.

To win the contest two basic objectives had to be met:
a) limiting the volume of earth movements and
b) reducing the overall costs of the restoration to comply with stringent financial limitations imposed by RSA's budget.

The restoration project's alternatives selection

When engaging in the pre-feasibility of such a restoration project a wide array of design alternatives have to be carefully analyzed and compared. Risks can be used to discriminate, provided they are carefully evaluated at each specific phase of the project life (Oboni, 2006, Oboni et Al. 2001, Oboni & Oboni, 2004).

Designs based on codes or recommendations may differ quite significantly from designs based on Risk Based Decision Making (RBDM). Differences may go as deep as choosing a different material hauling system, a different drainage pattern etc. Alternatives which are perfectly code-compliant and require the same investments and maintenance may expose the owner to totally different levels of risk all along their expected life.

RBDM for Reclamation Projects requires robust and simple tools for choosing among alternatives at each and every step of a project life encompassing conceptual design, construction maintenance and then necessary performance monitoring and evaluations before reaching the end of its expected life.
The method allowing this type of comparison was specifically developed for this project and then formalized at later date under the name CDA/ESM (F. Oboni, C. Oboni, 2007). CDA/ESM has since been

used extensively, on projects all over the world, to compare alternatives considering risks and uncertainties from cradle to grave.

Material hauling, i.e. 250.000 m^3 of excavated material, had, for example, numerous possible alternatives including hauling trucks, cable car and even fluidized mud via a gravity pipe on the slope. Their specific risk profile was, however, very different in terms of duration of works, air pollution, asbestos dusting, energy consumption (the cable car allowed to produce energy while doing the job) and finally carbon footprint.

Even the choice of the slope stabilization method can be conducted with the same methodology by optimizing all the key aspects involved in the final decision: new geometry of the crest, number and gradient of the runoff system collection berms, vertical distance between berms along the slope, size of the berms.

Design goals

Beyond the basic RSA's objectives, the restoration project had to consider numerous other global and sometimes competing goals:

- Avoiding worsening of dusting during construction.
- Reducing the number of hauling trucks to limit air pollution both from engines and from dusting related to traffic on unpaved roads inside the mine area.
- Controlling the geotechnical stability of a large area including several critically over steepened sections.
- Controlling the global water runoff on the area and guiding collected water through very steep cross slopes.
- Giving a strong and immediate support to new vegetation, as vegetating the slope was considered to be the best way to control erosion in such difficult conditions.
- Implementing specially designed and sophisticated systems of reforestation/vegetation planting on sterile soils.
- Limiting the use of concrete/steel or any other artificial material given the sensitive location of the site at the footsteps of the Alps, in visible, densely inhabited area.

Resulting design's major features

Hauling

One of the major project's challenges was related to the amount of material, containing asbestos fibres to be excavated and disposed of within the old mine area, in order to unload the over steepened crest of the dump.

The 4.5 km of dirt tracks between the top and the toe of the slope were a potential source of dusting and large carbon footprint, given the foreseeable use of a fleet of small tonnage trucks. Thus the use of trucks was ultimately discarded due to environmental risks (pollution from exhaust fumes and fibres dispersion from the excavated material) and the need to upgrade the existing tracks to roads (extra costs for ancillary temporary structures).

CDA/ESM showed that the best overall results would be achieved by installing a temporary aerial tramway, designed with a single span of 960 m between the top and valley terminal stations, capable of unloading its bucket in any point along the track, at ground level (the tramway bucket could be lowered in any point of the trip to ground level), i.e. very efficiently limiting dusting. Furthermore the excavated material was wetted at excavation time and remained wet during the full trip from the source to the final resting position to reduce fibre dispersion. The aerial tramway (Figure 1) was removed after only 1.5 years of operation, having very successfully and efficiently completed the difficult task.

Figure 1: The aerial tramway loading area

Slope stability control procedures

The basic principles of the slope stabilization design can be summarized as follows:

- Unloading of the crest of the dump slope by digging three 10 m wide berms and by storing the resulting material at the toe in an artificial, 8 m high fill. Beyond its storing role, the fill was designed to protect nearby houses from possible residual mud slides in the over steepened eastern part of the slope (42°)
- Cutting a series of 8, 2.5 m wide, "path-ways berms" across the slope, each about 600 m long. The selected design allowed building these berms with only lateral transfers (no longitudinal evacuation) of the material according to the following design scheme (Figure 2). This procedure dramatically reduced downhill hauling needs and minimized the dispersion of asbestos fibres in the air. The "path-ways" also created an easy access to the slope for future maintenance and present and future monitoring activities. The stability of the "path-ways" was enhanced thanks to a double system (upslope and downslope the berm) of 0.2 m diameter driven logs. The berms are also a main element of the runoff control system, since they collect water every 20 to 30 m across the slope, thus limiting erosion.
- Build whenever deemed necessary composite wood-earth structures to retain the steepest parts of the slope, or create necessary working and maintenance platforms.

Runoff control

Deep gullies, up to 30 m deep, formed in the upper part of the slope in the past, where water concentration was higher. The remedial measures for surface water control were the following:

- Overall control of runoff through a net of small wooden channels, 50 to 100 cm wide. The small dimensions were selected for ease of construction with small equipment on the slope and to assure a capillary system to maximize erosion control. Such small wooden channels were located on the three top berms and linked to a secondary network of canals located on the "path-ways"
- Transfer of the collected water towards the toe of the slope using 4 main channels located along the steepest gradient (as shown in Figure 3): again logs and stones, natural materials, were used to build these systems.

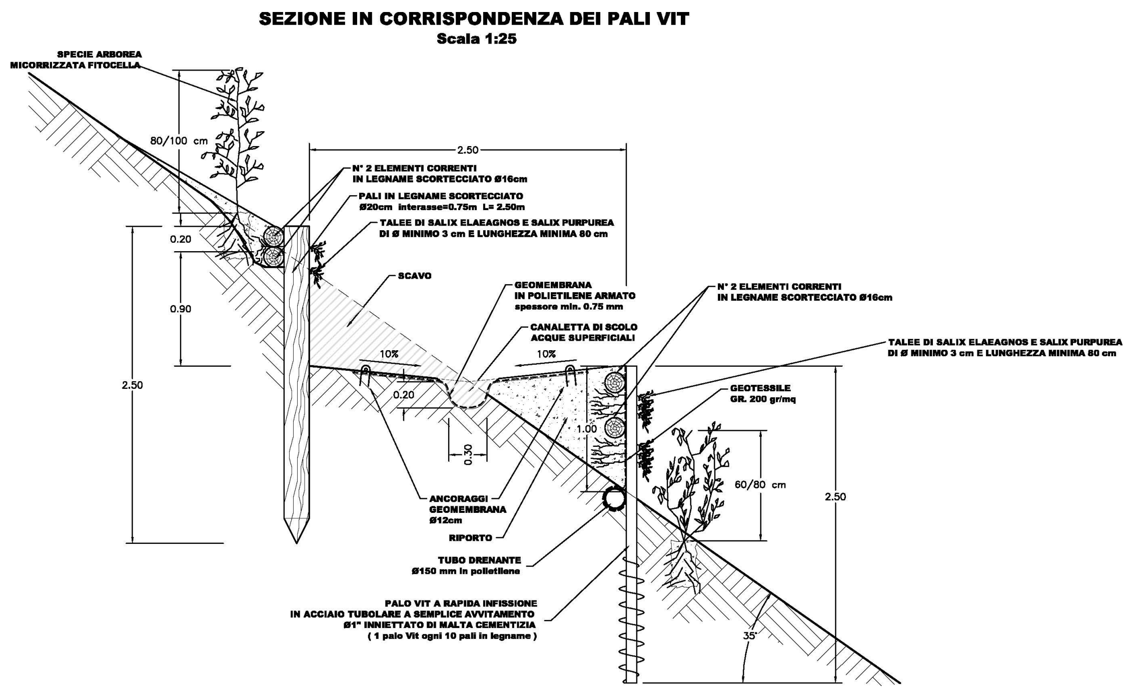

Figure 2: Path-ways berms design cross-section scheme

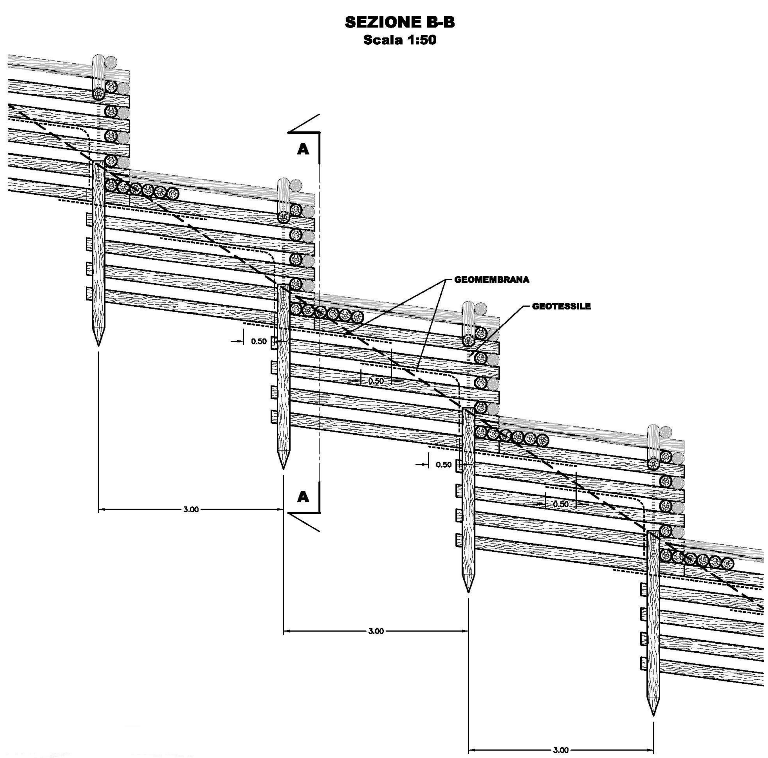

Figure 3: Main channels design longitudinal section

- Convergence of the 4 main channels in a unique main collector channel – built again only with stones and logs - allowing the water to reach the Fandaglia Creek. A decant basin, located at the very end of the collector channel, retains fine material and fibres before the water is released to the environment constituting the water quality control point.
- Control of the underground water by sub-horizontal drains drilled in critical areas along the slope.

Re-vegetation

The reforestation/re-vegetation of the area was a major challenge within the project due to the scarcity of nutrient materials in the sterile soil of the dump.
Good re-vegetation implies major achievements in the overall aspect of the dump stability:

- Erosion control.
- Water absorption and runoff limitation.
- Geotechnical stability of the surface layers of soil due to the mechanical stability given by the roots system.
- Limitation of dusting of asbestos fibres.
- Restart of an entire ecosystem not only in terms of vegetation, but also of a micro-flora and, in the future, of a fully developed natural ecosystem (deer are already back on the slope thanks to the new grass).
- And, least but not last, an important aesthetic value when local residents are looking to a newly vegetated green slope rather than to a grey dump of orphaned territory.

Success was achieved by stimulating the natural re-vegetation, restarting the pedo-genetic process and accelerating the colonization of superior species by implanting pioneer species. The use of *mycorryzae* (special fungi pre-instilled in the root system of the newly planted vegetation), specialty hydro-seeding processes and autochthonous species have allowed to reach in few years outstanding results as shown in the figure below.

Figure 4: The re-vegetated slope

The works

The approval procedure of the design took a long time, given the high number of public administrations and subjects involved in authorizations and approval.

The works started in 2003 and were completed in 2009 without any significant trouble.
The aerial tramway system proved perfect and worked properly during 1.5 years, also allowing the production of energy, to be sold to the Italian national power board, during the phases of braking of the system for the descent of the material. However work had to be suspended because of high winds and the cable car system was also badly damaged in one occasion with wind gusts recorded at 140 km/h.

Small foreseeable and foreseen damages to the construction site due to violent summer storms and prolonged rainy period were recorded through the years and caused minor delays.
Winter conditions, including work suspensions from December to March due to icing of the surface layers, impacted the construction site but only required shifting of certain operations to a later date.

All the solutions expressly designed for this particular project ended up being "dynamically adapted" as the restoration progressed and experience of the site was gained by all the project's stakeholders.
Slight modifications to the initial designs allowed to improve construction sequences and final performance.

The reforestation process was intensely monitored and scrutinized; as matter of fact, at the end of the works, the first trees and shrubs, hydroseeding had already undergone 3 or 4 vegetative seasons and allowed a "real time" control of the success of the operation. In total the re-vegetation effort was quite intense and included: 450,000 m^2 of hydro-seeding, 15,000 shrubs, 7,300 trees and 267,000 live cuttings.

During the entire construction strict air quality monitoring campaigns were carried out both on the construction site and in the two neighbouring communities: during violent wind storm work was stopped to avoid excessive (additional) dusting and the resulting potential public opinion scrutiny.

Strict worker's safety protocols were adopted including particular protective masks with a high filtration capacity, special protective working dresses. Furthermore workers were not allowed to leave the site without a proper changing of clothes and personal shower within a special decontamination unit.

The overall budget for the project was 5.5 M €. The Figure 5 shows the state of the slope after two seasons.

Conclusions

The use of natural construction materials available within easy reach from the construction site and the adoption of a hauling system via an aerial tramway to dispose the excavated material allowed to carry out highly difficult geotechnical works in a very sensitive area meanwhile limiting the pollution from heavy truck and the dispersion of asbestos fibers in the built and inhabited environment.

Risk Based Decision Making (RBDM) procedures at every step of the design process were used for the environmental restoration bid, allowing the best engineering compromise in terms of technical results and budget limitations.

The integration of geotechnique, hydraulics, pedology and risk management within the designers' multidisciplinary group led to a well balanced and environmentally sustainable project allowing the gradual recovery through natural processes of an otherwise highly compromised area.

Figure 5: The final slope, after two seasons

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