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Spoil management: curse or blessing? Looking back on 20 years of experience

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ABSTRACT: Spoil management (SP) is an essential component of each underground engineering project. Legally spoken, excavated materials have to be recovered and not only disposed. The last 20 years show that appropriate raw material can be turned into high-quality products, which can either be selected for internal purposes or given to third parties. Aggregates for concrete and shotcrete are the major derivates. The AlpTransit projects have led to numerous innovative developments in the tunneling and the material industries. These include the production of high-tech superplasticizer concretes using mica-rich crushed sand, of concretes resistant to alkali-aggregate-reaction, to sulfates, to water and to fire as well as technical improvements such as grain rounding infrastructures and mica removal from crushed sand through a flotation technique. The experience of recent years shows possible scope for improvement in the contract processing between the awarding authority, the project engineer and the contractor. In addition, the disposal of contaminated materials and sludge represent financial risk factors that have to be minimized in the future.

1 Introduction

Spoil management plays a central function in underground engineering projects since most regulations request not only the disposal but the recycling of excavated material. Although essential, spoil management concepts (SPC) are still denied by some planning engineers and awarding authorities. This attitude can lead to dramatic logistical and financial consequences.

One reason to disregard spoil management concepts is probably the additional work needed for design and planning as well as for discussions for possible supplementary claims. Their realization is also hindered by contradictory environmental requirements for the raw material and its disposal on the one side and the produced major (aggregates) and minor derivates (sludge) on the other side.

The last 20 years of spoil management show that appropriate raw material can be turned into high-quality products, which can either be selected for internal purposes or given to third parties. Through the production of industry derivates, i.e. aggregates for concrete and shotcrete, spoil management concepts are now recognized as good tools to close the excavated material sustainable recovery loop (the entire process from the raw material to the production of aggregates for concrete).

2 Spoil management as keystone for large Swiss tunnel construction sites

In Switzerland, the concept of spoil management was first introduced during the AlpTransit Lötschberg and Gotthard projects (Figure 1, Thalmann 1999, Pralong et al. 2002, Burdin et al. 2005, Teuscher et al. 2007, Lieb 2009 and 2011). It permitted to cover the internal needs of high-quality concrete aggregates by processing adequate excavated raw material. Hence, these pioneer projects demonstrated the possibility to produce excellent quality concretes using 100% crushed rock (sand and gravel) components (Leemann et al. 1999, Kruse et al. 2003).

Figure 1. Spoil management sites with gravel plants AlpTransit. Above: Raron, Lötschberg base tunnel south; left: Amsteg, Gotthard base tunnel north (@ EBP AG); right: Bodio, Gotthard base tunnel south (@ AlpTransit Gotthard AG)

Table 1 presents key parameters for the AlpTransit spoil management concepts:

Table 1. SPC-key parameters AlpTransit (Mio. Tons)

Project	Total excavation	Processed proportion of the total excavation	Used aggregate proportion
Lötschberg	16.5 (100%)	5.2 (31.5%)	4.8 (29.1%)
Gotthard	28.2 (100%)	9.4 (33.3%)	6.5 (23.0%)

3 Spoil management as keystone for large pump storage plants

Spoil management also plays a central role for the construction of pump storage plants due to the remoteness of such building sites which makes an external aggregate supply almost impossible (logistic and finance). Hence, the suitable raw material generated during the tunnel and cavern excavation is essential to produce high-quality aggregates for the underground and the dam concretes. Table 2 presents the concrete aggregate needs for various Swiss pump storage plant projects:

Table 2. SPC-key parameters for different Swiss pump storage plants (Mio. Tons)

Project	Total excavation	Aggregate Needs
Nante de Drance	4.0	0.8
Kraftwerke Linth Limmern	1.8	0.9
Lago Bianco (in planning)	3.0	0.4
Grimsel 3 (in planning)	2.1	0.4

4 Spoil management as innovation catalyst

The AlpTransit projects have led to numerous innovative developments in the tunneling and the material industries. They stimulated the production of high-tech superplasticizers to generate high-quality concretes (fresh and hardened) even with large quantities of mica in the sand. They also promoted and encouraged the production of broken stone aggregate concretes which are accepted as a standard today. Finally, the AlpTransit projects clearly demonstrated the feasibility to create concretes made out of 100 percent crushed aggregates, resistant to alkali-aggregate-reaction, to sulfates, to water and to fire. The AlpTransit projects also accelerated technical improvements in the material processing sector and led to grain rounding (hurricane) and gravity sand-sizing devices as well as mica removal installations to optimize the fresh concrete properties (Sedrun: AlpTransit Gotthard; Cichos et al. 2004; Figure 2).

Figure 2. Left: grain rounding machine (Hurricane); right: flotation facility

The mica elimination technology is based on the flotation technique and works as follow: (1) The crushed sand (0/1 mm) is washed with water and chemicals (collectors) in an agitated and ventilated basin (flotation cell). (2) Phyllosilicates adhere on the collectors and segregate to the surface of the water (foam). (3) The foam is evacuated with the overflow (flotation tailing). This method permitted to eliminate more than 50% of the total mica in the 0/1 mm fraction of the crushed sand thus increasing its quality. A good sand quality is a prerequisite for good fresh and hardened concrete.

The new processing facilities enhance the recovery rate of raw material to up to 80 % by reducing excess grains to a minimum.

The high-altitude construction site Muttsee (Linthal 2015 project, Figure 3) holds a particular position in the conception of spoil management plants. The broken aggregates (including sand) used for the dam concrete are indeed not washed during their processing to limit the overall sludge production. This material was excavated during the tunnel and cavern construction. It had to be delivered via construction cableways and was temporary disposed before being processed for the dam concrete. The concrete production is stopped during the winter months.

Figure 3. Project Linthal 2012. Left: material deposit and gravel plant (dry broken); right: dam concrete

5 Quality assessment of the rock material

Only appropriate excavation material can be turned into high-quality concrete aggregates. A testing method which allows a rapid and accurate on-site control of the excavated rock and aggregate quality was developed for the AlpTransit projects (Thalmann 1996 and 2004, Kruse et al. 2003). This control tool is now used on different large construction sites internationally. Over the years, around 50 million tons of raw material and 18 million tons of aggregates were successfully inspected by our qualified geologists using this investigation procedure.

5.1 Raw material selection

The raw material (drill and blast, tunnel boring machine TBM drive, road header drive, and rock material from bores) has to meet numerous quality criteria to be used as concrete aggregate. These attributes can be directly assessed by analysing the excavated rock material. Goals of these tests are twofold. Besides evaluating the raw material quality for its processing into concrete aggregates, these investigations also act as quality control instruments. Doing so, clients, site management and contractors clearly know which raw materials can be further processed into concrete aggregates.

The quality of the excavated material is mainly based on its rock hardness and its petrography.

5.2 Rock hardness

A minimum compressive strength of 75-100 N/mm^2 is usually required for concrete aggregate. In the test procedure, the compressive strength is measured with the Point Load Index (indirect tensile strength) directly on the muck itself (TBM chips or rock fragments from drill and blast, Figure 4).

The toughness and abrasion characteristics of the aggregates are assessed by the Los Angeles Index (EN 1097-2). The wear behavior depends on the rock strength. The Los Angeles method is too time-consuming. Therefore the test procedure uses the much faster LCPC Breakability Index (French norm AFNOR P18-579) during which rock samples are subjected to a wear process by the grinding effect of a rotating small plate (Figure 4). Results of this technique linearly correlate with those from the Los Angeles Index (Thalmann 1996). In parallel, the LCPC Breakability Index determines the Abrasivity Index ABR of a sample. The Breakability test is thus used as the daily solution within the scope of quality control, whereas the Los Angeles Index is the reference and calibrating method.

5.3 Rock petrography

The petrography provides a further criterion for evaluating the raw material quality. An initial appraisal of the rock quality is done during the pre-investigatory phase of the underground project and is solely based on a macroscopic description and classification of the rock. Depending on the concrete requirements, representative rock samples (from the surface, from pilot tunnels, bore cores, etc.) should be examined and tested relative to their freeze-thaw resistance, chloride contents, sulphate components, alkali-aggregates-reaction (AAR), radioactivity of the rock material, etc. The AAR issue has been well investigated for tunnel concrete (Thalmann et al. 2004, Leemann et al. 2005). These experiences led to the publication of a Swiss AAR recommendation (SIA 2012).

A more precise petrographic analysis (unsuitable components) is required when raw sand is recycled because it may contain loads of layer silicates (mica). These are frequently <2mm in diameter and accumulate in the finer aggregate fractions during material processing. This free mica (not bonded into the rock mass) has a negative effect on the fresh and the hardened concrete properties which is proportional to the quantity, the grain size (> 0.125mm) and the type of the mica present. The larger the mica content in the crushed sand is, the more water will be needed for constant workability. Moreover only coarse-grained mica (> 0.125mm) affects concrete negatively. The evaluation of the free mica content is done on the sand sub-fraction 0.125/0.5mm by microscopy (Figure 4) which is representative for the entire sand 0/4mm. The free mica content in this sub-fraction should not exceed 35 particle-% in the concrete sand (Leemann 1999).

Figure 4. Left: point-Load device; middle: breakability and abrasivity machinery; right: microscopy analysis

6 Aggregate production

The raw material must be processed through an optimal multi-stage preparation procedure (including crushing, screening and washing processes) to ensure that the end-product aggregates meet the requirements for the production of quality concrete. Raw material processing starts in the excavation area, where the raw material is pre-crushed in order to reach the necessary 250 mm to be evacuated with conveyor belts. In the gravel plants, the raw material is transformed into sand and gravel by means of different crusher systems before being washed and screened into their respective size groups. The crushed sand has to be prepared with an appropriate equipment.

The sand washing procedure produces large quantities of fine particles (< 0.063mm) that have to be removed with powerful dewatering presses (mud production). TBMs produce larger quantities of mud than a drill and blast drive since more fine particles are generated (10-15% vs 8-10%).

7 Spoil management bottlenecks

Our 20 years experience shows that spoil management is not limited by technical issues but is rather hindered by the contract processing between the awarding authority, the project engineer and the building company and by environmental paradoxical legislations.

7.1 Anthropogenic contaminations

In Switzerland, the raw material disposal (temporary and definitive) is subjected to strict environmental directives which can dramatically increase the overall construction costs. This is particularly true for the sludge produced during sand processing in which contaminants add up. For example, the nitrate, nitrite and hydrocarbon concentrations of the muck and especially of the mud may exceed the tolerance limits during conventional drill and blast drive. The sludge cannot be disposed with unpolluted excavated material but has to be either collected separately at licensed landfill sites (inert or reactive landfills) or reused as substitutes in the brick and cement industry. Waste recovery is requested, when it is technically possible, ecologically meaningful and economically feasible.

Determining the contamination level of muck or sludge faces different problems. The measurement and sample procedure represents one of the major ones. It is indeed frequent that different laboratories obtain distinct results. These discrepancies are probably related to the lability and instability of the contaminants which can concentrate in some parts of the landfill and disappear in others. The nitrate concentration of the sludge can be diminished by adding thiosulfate. The outputs of this technology depend largely on stable and special conditions (i.e. optimal pH-value) which are hard and expensive to obtain. The use of solid explosives instead of liquid ones also represents a alternative to minimize the muck and sludge nitrate contamination. The introduction of natural bacteria to decontaminate sludge is currently tested.

The hexavalent chromium (Cr^{VI}), abundant in cement, is another problematic source of contamination because the allowed Chrom-(VI) concentration for muck or sludge is lower than that tolerated for cement. This contradiction may trigger large additional costs: while the cement meets the Chrom-(VI) concentration requirements, the raw material and especially the sludge may not and thus have to be deposited in reactive landfills. The Chrom-(VI) concentration can be monitored in cement by adding ferroussulphate to the clinker. This solution could not be tested on sludge so far.

During AlpTransit a substantial part of the mud produced by TBM-drives was dumped in inert landfills. As soon as explosive drives started, the mud was disposed in special landfills or recycled in the cement industry (Hitz et al. 2006). Due to the importance of this project, the disposal of the contaminated sludge got constantly optimized. This enabled an almost complete recycling of the sludge in the cement industry.

7.2 Geogenic contaminations

Geogenic minerals are considered as environmentally irrelevant by the Swiss environmental guidelines. Exceptions are radioactive and asbestos minerals which are harmful for the environment and/ or human health.

7.2.1 Asbestos minerals: Example of the Lötschberg base tunnel

At the end of March 2002, asbestos veins were discovered in the rock during the Steg/Raron TBM drive. The SUVA (Swiss National Accident Insurance Fund) asked to interrupt the drive to protect the crew.

During nine days measurements were undertaken in the tunnel and in the vicinity of the tunnel portals (installation yards, living quarters, canteen, depots, material management etc.). Although the quantities of asbestos detected were extremely low, the subsequent underground excavating operations were executed under special measures such as wearing of protective masks, changing working clothes daily and using spray water curtains (Dustex dispersion system). In parallel, measurements in the tunnel and in external areas were accomplished (Teuscher et al. 2002).

7.2.2 Radioactive minerals: Example of the Gotthard base tunnel

During the Gotthard base tunnel, the radioactivity of the excavated material and the concentration of Radon in the tunnel were analysed regularly because it was assumed that a geological unit of 150 m length (Giuv syenite intrusion) containing radioactive minerals would be encountered during the drive. The way to handle radioactive excavated material was defined in an action plan. Under a radioactivity of 1 µSv/h, the raw material was considered as inert and was reused to produce concrete aggregates, or was recycled in housing and road constructions. Above a radioactivity of 1 µSv/h, the excavated material had to be disposed on hot dumps or sealed in containers before being buried in lateral galleries of the tunnel. Such material has not been encountered during the Gotthard base tunnel project.

7.3 Other elements of concern

An integral spoil management concept has to minimize noise, dust and machine emissions that might affect negatively the surrounding population and environment. A way to rapidly reduce conflicts is to introduce so-called “crisis or help hotlines”, which can be used by the concerned population to report a problem.

8 Contractual and construction specific aspects

Spoil management is a service provider which is able to handle at any time the accumulated muck and which guarantees the production of suitable aggregates needed on-site. In Switzerland, the client is responsible for the subsoil and therefore also rock quality. Thus the client plays an active role for the raw material supply. The project coordinator has to determine during feasibility studies that the excavated stone fits for the production of high-quality concrete or mortar aggregates. The concrete has to be ordered as designed concrete according to EN 206-1 in the tender documents. For such concretes, the required properties and additional characteristics are specified to the producer who is responsible for providing a concrete conforming to the required properties and additional characteristics (fresh concrete). Gap-graded aggregates have to be avoided. The way of the raw material internal processing will also depend on the geological and geographical situation of the construction site.

Spoil management can either be defined as an independent lot or as a combined lot, in combination with the tunnel construction. Advantages and disadvantages of an autonomous lot are presented in Table 3.

Table 3: Advantages and disadvantages of independent SMC-lot

Advantages	Disadvantages
Influence on the allocation of the SM-works	Additional interfaces
‘Neutral‘ material supplier	Client and project manager strongly involved
Lead-time for time-critical assembly	Tunnel builder with little interest in SM
Chance for the local stone/earth industry (specialists)	Excess production of different size fractions

Delays and adjustments in the building program are common especially when no requirements have been set on the workmanship. Moreover, the underground construction is usually uncoupled to the drive and thus starts normally after the excavation work. This has dramatic repercussions on the dumping performance, on the intake capacity and on the volume of the raw material temporary storage facilities.

In this case, the beginning of the underground construction also browbeats the production output of the gravel and the concrete plants. Irregular working hours at the gravel plant represent an additional difficulty. The aggregate and concrete quantities to be produced daily are hard to forecast. Experience shows that the sand quantity is always underestimated by a factor of 2 over the entire construction period. Gap grading is sometimes chosen by some building contractors to produce excess components.

Most of these problems can be minimized with a combined lot since the whole responsibility regarding excavation and underground construction is that of the tunnel builder.

9 Lessons learned

Over the last 20 years, spoil management has been recognized and accepted as one of the central objectives of large construction projects aiming to recycle the excavated raw material into high-quality aggregate for their own concrete production. Spoil management is not only cost-efficient but also offers a way to limit sound, dust, transport and environmental emissions.

The following key points should be followed to better implement spoil management concepts in large construction projects:

- Spoil management is a service provider for the tunnel constructor. It intends to minimize the generation of excavated material to what is actually needed on-site and to find a recycling strategy for surplus materials. Spoil management has to be accepted and recognized as a major component of the site management. It should also be involved in all conceptual and planning decisions because they considerably influence material flows (performance) and surface requirements.
- Combined lots are actually preferred to individual lot because they reduce the responsibility of the client and permit to overcome assumed problems and interfaces. In any case, the work of the tunnel builder has to be controlled.
- The temporary storage of the raw material and of the processed aggregates requires large surface areas which have to be integrated by the planners at the beginning of the project.
- The client must rapidly start feasibility studies (material and concrete tests) to test if the on-site excavated material can fulfill the concrete requirements. The client should also promptly obtain information about material balances and potential yields. These estimations are very important parameters when natural resources are limited.
- The concrete is specified as designed concrete (consideration of the exposure classification and requirements). In this case, the building company is responsible for concrete quality controls and for the certification of the gravel plant, of the concrete components and of the concrete plant.
- The client controls on-site (in a construction site laboratory) the quality of the raw material and that of the aggregates produced from it. The control intervals are defined in a quality control plan.
- The client has to solve as soon as possible problems related to contamination of raw material and of sludge with the competent authority. Maximal pollution value may vary from state to state and even sometimes from one construction site to another.
- Universal sample methods and pollution limits for contaminated materials and sludge should be defined for Europe.

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