Investigation and Test for Reuse of Muck in Tunnelling

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1. General features

The possibility of reuse of the spoil coming both from conventional or mechanized tunnelling has become an interesting issue for environmental, economical and technical reasons. During last years the general and sometime combined effort of technicians, clients and planning boards has determined an increase of researches on this subject, whose topics extend from the geological description of geo-materials to the technological properties and to the plant characteristics for fitting the best recovery rate. In this frame the knowledge of the relation between the excavation method and the geo-investigations and testing can help to plan and manage the production of muck in order to reach the scope, also considering that heterogeneity in the material properties should be considered as one of the most influencing factor for success.

This note has been developed in the frame of a research activity, titled “ReMuck” whose subject is “Innovative methods for the eco-compatible and sustainable recycling of muck from tunnel excavation, also considering the potential content of noxious minerals”. The research, supported by the regional administration of Piemonte (Italy), develops in the period 2008-2010, and it is aimed to provide a common technical base for the better use of spoil material in a zone characterized by the presence of the Alpine Range, therefore with a significant number of tunnels. The research is organised in different chapters: updated applications; qualification of the muck also concerning dangerous minerals such as asbestos, radioactive minerals, quartz; excavation techniques; spoil processing and plants; lab testing procedures for the evaluation of concrete quality; reuse of the muck as granular material for embankments and base for bituminous conglomerates; reuse of the muck as raw material; health and safety and quality of the work activity. The project is developed on a base of practical data obtained thanks to the cooperation of at least four tunnel sites under construction.

2. Technical principles

It is necessary that the development of infrastructure networks - such as railways, highways, metro lines - but also of underground power or waste water treatment plans, is carried out with a comprehensive planning of the spoil for each project. This topic should consider the environmental issues, the land use, the saving of natural resources and take into account the effect that all these elements can produce on the economic balance of the project. The impact on the surrounding area can be reduced and the acceptance of an underground structure can therefore be increased. This is possible for both relevant works in mountainous area and also in urban context: it is possible to refer, as examples, the amount of muck produced in the StGotthard base tunnel project - more than $14*10^6$ m\textsuperscript{3} - and in the railway Passante of Torino Lot2 – about $2.4*10^6$ m\textsuperscript{3} - to understand the strategic importance of this subject.
The possible reuse of the muck arises from a compromise between the rock types and the relative distance of the tunnel site from the location where the spoil can be delivered to. It is therefore necessary to define which could be the possible applications of the muck; the main destinations are:

- construction of embankments, especially in road engineering or for rockfall defence; this could be the case of tout-venant, with little or no processing of the spoil coming out of the tunnel; it is not suitable for this use the presence of relevant percentage of fines neither of muck contaminated with bentonite;

- production of fragmented rock, for railways embankments or selected applications (coastal and river protection); this could be the case of muck obtained after the excavation with drill and blast (D&B) method in rock masses with good quality rock types;

- filling of sites and small valleys for the construction of yards, dumps etc; this could be the case of muck obtained after the excavation with drill and blast (D&B) method in rock masses with good quality rock types;

- reclamation of abandoned sites, quarries, landfills, harbours; in this case the quality of the muck can vary: the requirements in these cases are related to chemical properties and long term resistance characteristics to weathering, alteration etc.;

- production of aggregates for concrete preparation; this is the case when rock quality has to be very high and when the granulometric distribution represents one of the technical key elements for a profitable application; both D&B and mechanical excavation method are compatible, but a well designed plant is necessary;

- raw material, for concrete or construction material industry: this is the case of tunnelling in granitic formations, in limestone, in quartzitic masses. The method of excavation in this case is not so relevant as far as the quality of the materials is not influenced, as the composition is not altered and the material will be crushed and fragmented in any case.

When no applications are possible or no solutions can be provided, it is necessary to arrange the landfilling of the spoil as waste material. This cannot be considered any longer an economic solution, because of the relevant impact from the environmental point of view, both for the necessity to find a suitable site and also for the related stability problem that could occur. In most cases, a valid muck reuse requires a processing plant, whose complexity depends on the grade and on the heterogeneity of the spoil materials, and on the eventual different simultaneous destinations foreseen for the muck coming out from the tunnel. Another fundamental element for a valid direction of the plant is represented by the temporary stocking yard or dump (Fig.1), as it allows the system to accept variation in the regular flow of the muck, variation of the quality and type of the muck, eventual stops at the processing plant or some other malfunctioning; in addition, it could be necessary to develop eventual more detailed tests on the rock properties before accepting them for processing in the plant. If the muck is destined to external uses, the temporary stocking allows to organize remote transportation.

Fig.1. Example of a temporary dump site for muck
The excavation method represents itself an important issue, as the muck obtained is quite different in the various cases; in addition, one should consider the rock mass type and the original state of fracturing in order to provide a prevision on the granulometric distribution of the muck. The main methods one can refer to are (Fig.2a,b,c,d):

a- drill and blast (D&B): usually carried out in competent rock, characterized by a wide granulometric distribution, with both fines and blocks; the natural discontinuity pattern influences the granulometric curve and the shape of the blasted rock fragments;
b- mechanical excavation in rock or hard soil (TBM): usually carried out in stable formation, also in hard soils when groundwater is not of concern; the rock fragments are rather small (few centimetres) due to the cutter action, and the shape is not isometric \[1,2\];
c- mechanical excavation in soils with soil conditioning (shield TBM): this is the case of soil formation, with or without groundwater, where the original granulometric distribution is not altered in a significative way, but some materials are additivated, such as foam, polymers, bentonite, fillers etc.
d- mechanical or conventional excavation in weak formation with the use of reinforcing/support systems at the advancing face: this is the case of use of shotcrete, eventually fibre-reinforced, fibre-glass nailing ahead the face, grouting etc.; in these cases the spoil is not homogeneous and it can be significantly contaminated by the adopted artificial materials, such as concrete or fibreglass.

Fig.2. Different types of muck produced in the various excavation methods: a) D&B in granitic mass; b) TBM fragments in rock formation; c) good conditioning of soil in EBP shield tunnelling; d) heavy reinforcing at the face by means of fibre-glass elements.
A final consideration is referred to the fact that the ground types and ground conditions can vary significantly along the tunnel: for this reason investigation, muck qualification and processing plants and spoil management could not be organized in the same way along the tunnel and in the various sectors of the tunnel.

3. In site investigation

Investigation for tunnel design purposes are carried out at the different stages of the project, both preliminary and executive. The main aims of the investigations are the definition of the geological outline of the formation, the geomechanical characterization of ground types, the hydrogeological interferences and finally the set of the excavation method. The reuse of the muck and its management can rarely be considered as binding in the decisional process for a tunnel project, but it is definitely ascertained that this issue has an enormous influence on the logistic, environmental and economic aspects of the tunnel construction. The planning of quality and quantities of the future muck of the tunnel becomes therefore one of the design features.

Drillings from the surface, drillings along the tunnel axis, geophysical surveys, geostructural surveys and hydrogeological investigation represent and provide the usual and generally sufficient set of information for the definition of the possible reuse of the muck. As the effective destination of the materials is dependant on their technological properties and on the homogeneity, during the excavation, both in advance and also at the face, drilling and sampling are scheduled: in particular at each advancing of the face it should be necessary to provide for an inspection. The daily classification of the muck is carried out just from the advancing face, by means of a visual inspection and a geological preliminary classification; this operation is based on some input data such as the speed of drilling, the advance rate of the TBM, the quality index of the rock mass etc. This preliminary information can help to arrange the laboratory tests on samples obtained on a real time basis: of course it is a matter of quick tests aimed to determine for example the carbonatic content, the abrasivity, the strength by means of point load index; more elaborated tests require a specimen preparation and can be planned and arranged on a different time basis, for example referring to core recovery ahead the face.

![Fig. 3. Indication on the percentage of drilling to get a minimal base of knowledge (left). This rate cannot be considered absolutely, because the increasing burden of the tunnel requires drillings ahead the face (right) or, in some important cases, also directional drillings from the surface.](image)
Particular care is due when noxious minerals can be found, such as asbestos, quartz, radioactive minerals. In these cases – especially when free fibres occur - special arrangements for the site organisation, for the drilling operation and also for subsequent sampling and testing must be adopted, in order to avoid undesired contamination and for health protection.

Fig. 4. Samples enveloped to avoid fibres dispersion (left) and example of fibre coating on a joint.

4. Regulations and standards for testing and materials

National regulations should provide a clear distinction between “waste” materials and “secondary product” for the spoil of a tunnel excavation. As example, in Italy in recent years national laws have introduced this concept, so allowing a new way to reuse and to locate the muck. These laws (Law 443/2001, D.Lgs. 152/2006, D.Lgs. 4/2008, Law 2/2009) allow the spoil to be considered secondary products if the material is:
- not originated by a direct exploitation,
- suitable for a complete reuse, both on site or in another clear destination,
- characterized by environmental and technological properties suitable for the proposed application;
- characterized by the required properties from the beginning, without the need to adopt particular treatment;
- the economic value is not negligible and all the involved parties, client, contractor and public administration have demonstrated the intention for reuse.

After these statements, the laws consider that it should be necessary:
- the reuse of the muck should be preferably directly at the site or in well identified areas;
- the complete amount of the muck has to be evaluated and destinated;
- the mechanical treatment should have a light environmental impact;
- the muck is not contaminated on the basis of acceptance range for components.

Materials obtained from the muck have therefore to be identified, they should pass through a technical and environmental qualification, then the suitable process for optimisation should be assessed and the various flows and quantities should be calculated and negotiated. For example it is important to verify the amount of additives in the muck obtained through a soil conditioning by means of foams (EPB method) and the relative bio-degradability, or the degree of separation of the bentonitic mud from the spoil coming from diaphragms excavation; this can be done with large scale sampling, on the temporary piles. It is also necessary that during the classification, treatment and selection this materials do not determine undesired pollution to the environment or to the groundwater flow, neither they can involve stability problems. Another relevant testing is today dedicated to the alkali – aggregate reaction control, for example referring to the microbar test following AFNOR P18-588 and the concrete behaviour following AFNOR P18-454 [3].
There are two basic characterisations and qualifications that have to be carried out: the first is aimed at the spoil material as originated at the tunnel face, the second is referred to the material produced after the treatment. This last testing and classification is arranged to guarantee the quality of materials – that is the technical properties – following available standards. As example it is possible to refer to StGotthard plant in Bodio, where at least 10 tests have been usually carried out in order to ensure the quality of processed materials from granitic and gneissic rock formations, as in table 1 (aggregate classes production at Bodio plant: 0-1 mm, 1-4 mm, 4-8 mm, 8-16 mm, 16-22 mm) [4,5]:

<table>
<thead>
<tr>
<th>Test system</th>
<th>Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fragmentation index</td>
<td>Modified AFNOR p18-579</td>
</tr>
<tr>
<td>Point load index</td>
<td>ISRM</td>
</tr>
<tr>
<td>Los Angeles test</td>
<td>EN 1097-2</td>
</tr>
<tr>
<td>Petrographic analysis</td>
<td>SIA</td>
</tr>
<tr>
<td>Granulometric analysis sand</td>
<td>SIA 162.311</td>
</tr>
<tr>
<td>Granulometric analysis gravel</td>
<td>SIA 162.311</td>
</tr>
<tr>
<td>Shape of elements</td>
<td>EN 933-6</td>
</tr>
<tr>
<td>Alkali aggregate reaction</td>
<td>AFNOR p18-588</td>
</tr>
<tr>
<td>Unit weight</td>
<td>EN 1097-6</td>
</tr>
<tr>
<td>Water content</td>
<td>EN 1097-6</td>
</tr>
</tbody>
</table>

Table1: main tests carried out at StGotthard, Bodio treatment plant.

Similar example is represented by the railway Passante of Torino, where the alluvial coarse material has been divided in two classes: grey material, about the 47%, with a production of 31% of very high quality aggregates for concrete and 16% for embankments, and the red material about 53% of the excavated volume, for external destination, due to a more relevant percentage of fines.

5. Requirements for spoil treatment plants

The treatment plant should be adapted – in terms of complexity - to process the muck of the pertinent sectors of tunnel, so the type of muck process and the quantity of materials become the input element for the technical choice. In order to reach a sustainable process, a compromise between the highest reuse of the muck, the overall economical balance of the spoil management and the environmental issues has to be arranged. For example, in the case of StGotthard base project, some operative principles have been implemented: maximum reuse of the muck for the aggregates for the internal production of concrete; transportation based on low emission methods, such as belt conveyor and railways; protection against noise, dust and pollution of the surrounding environment. The overall economic balance is expected to be positive, as if there is a consistent cost for the treatment plant and for the detailed investigation, testing and qualification, on the other side there is a saving in terms of landfiling, surface consumption and cost for the purchase of the aggregates, especially if no quarries are located in the vicinity of the tunnel. It should be observed that in case of high quality rock types, the production of aggregates could create a lack of balance with the eventual local production of aggregates; this fact could request a specific agreement with resident producers and regional authorities in the management of the spoil, in order to avoid damping phenomena.

At the treatment plant it is necessary to separate the material that can usefully be processed from the waste or from the muck of different quality: the plant has to be designed on the basis of the treatment phases, such as washing, fragmentation, classification, modification of the shape, and on the basis of the average flow of the muck; eventual differences can be compensated by the temporary deposits. As example, in the case of D&B in granitic formation a primary fragmentation
is necessary, while in the case of TBM production of chips a significative percentage of fines has to be removed, so washing and classification will be emphasized. In the plant it is nevertheless possible to recover concrete aggregates, if the rock type is adequate, also in the case of TBM excavation, when the chips fragments are usually flat and long, by reaching an isometric shape, with subangular or rounded elements, depending on the workability required for the casting of the concrete or for the shotcreting application. In some cases some parts of the process should be aimed also to physical-chemical separation (floating) and not only to hydro-mechanical operation: that is the case of the mica components, if these are considered undesired.

In order to organize the information coming from the investigations for a profitable use of the treatment plant it is necessary to finalise the data, both in terms of quality and quantity of the removed muck, referring to the tunnel chainage: this approach will allow to compare the, availability with the capacity of the plant and to assess the balance for the internal reuse of muck as concrete aggregate; the last fact represent a strategic point for the tunnel construction, so its importance should be emphasized. For long tunnels it arises the necessity to provide more that one treatment site, thus organizing the muck treatment in different comparts.

Another interesting issue is represented by the differences between urban sites and mountain sites. The spoil from urban tunnel can be easily characterized well in advance, thanks to the low overburden; it is possible that in this case the treatment plant assume a particular importance in order to process the conditioned soils; more difficulties arises from the lack of available space on surface.

Fig. 5. Plant for the separation of bentonitic mud from the alluvial soil (left) and crushing and classification plant for clean coarse soil (right) at Passante of Torino.

Finally, it is necessary to provide investigation and technical treatment for the water coming from the tunnel and so for the humidity of the muck and also for the wastewater produced in the treatment plant. It is usual to re-use in the internal processes the same waste water, thus obtaining only a residual mud to be definitely disposed in landfills.

6. Conclusions

Reuse of muck from tunnelling excavation is today a fundamental issue in a tunnel project. Investigations for ground characterization are useful for the assessment of spoil previsions, while for the definition of aggregate properties for qualified application some standards are also available, as reported in bibliography [6]. Treatment plants need to be designed for crushing and separation both for rock and soil muck, even when additives are adopted for excavation.
7. References


