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From spoil to soil: Reuse of soil from TBM's in the Netherlands

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ABSTRACT: In the Netherlands several projects are underway, in which large boretunnels are planned. The excavation of them results in large quantities spoil. In most projects slurryshield TBM's are to be used. The spoil will be treated in order to be able to re-use the Bentonite slurry. The Dutch policy regarding the use of raw constructing materials is to propagate secondary materials in favor of primary materials. The digging of spoil for a bore tunnel can be regarded as secondary production. This should be resulting in such a quality that it can be used in construction works. An overview is given of the (planned) Dutch Bore tunnel projects and the quantities of soil involved. Results will be presented of relevant (research)projects concerning the reuse of spoil. The Center for Underground Space Technology (COB) carries out a research project 'Re-use of soil from boretunnels'. In this study also results of the monitoring of ongoing projects is incorporated.

1 INTRODUCTION

In the soft soil of the Netherlands a Bentonite slurry shield as well as an Earth Pressure Balance machine (EPB) will be used to realize large diameter tunnels. The quality of the out coming soil is governed by the working method and the properties of the ground.
This paper presents the Dutch policy regarding the use of out coming soil from TBM's in construction works. Also the influence of the used TBM-type on the environmental and engineering properties of the out coming soil will be treated and the potential uses will be considered. However just one traffic tunnel has been realized with a Bentonite slurry shield. Only this spring the first bored tunnel with an Earth Pressure Balance (EPB) method has been started, as well as a second project with a Slurry machine will make a 6,5 km long tunnel. The Center for Underground Construction (COB) carries out a research project 'Re-use of soil from bored tunnels'. In that study also results of the monitoring of running Dutch projects are incorporated.

2 BORE TUNNELS IN THE NETHERLANDS

In 1998 the first bored traffic tunnel in the Netherlands has been realized. This concerns the second Heinenoordtunnel, with two tubes and a diameter of 8.5 m under de Oude Maas river, south of Rotterdam. The drilling was done by a Bentonite slurry shield TBM.
The boring of the Botlek railway tunnel with an EPB TBM has been started in April '99. This Botlek railway tunnel is a part of the Betuweroute that is a totally new goods railway line that will connect the harbor of Rotterdam direct with the European hinterland.

Besides the Botlektunnel in the Betuweroute two other tunnels are planned: the Sophia railwaytunnel and the tunnel under the Pannerdensch Kanaal.
Also for the High Speed train (HSL) which connects the Netherlands with the European network of high speed trains a bored tunnel is foreseen. This tunnel the so-called "Green Hart tunnel" has a planned length of 6.5 km and passes a valuable landscape.
In table 1 the remaining planned tunnels are given. As can be seen from the map, most of these bore tunnel projects are situated in the West, the most crowded part of the Netherlands.

2.1 *The Dutch subsoil*

In the Netherlands a major part of the subsoil consists of soft to very soft soils.
Till a depth of about 250 m the soil exists of sediments from the Pleistocene and the Holocene origin. These depositions are formed under very varying regime under circumstances of rivers, sea land ice, wind and vegetation.

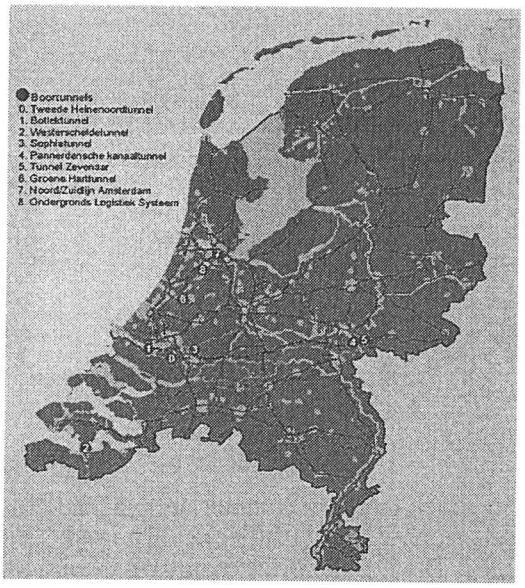

Figure 1. Map of the Netherlands with the bore tunnel projects

The Pleistocene layers of sands and clays are in general more densely packed and therefore stiffer and stronger than the Holocene layers of sands, clays and peats. The transition of the two is important level for construction purposes.

The transition level lies on a depth of 15 to 25 m below surface near the West coast of the Netherlands. Because of its inclination from west to east it reaches the surface in the middle of the Netherlands. The depth and horizontal dispersion of layers can change from place to place very much.

During a boring the different soil layers will be mixed over the diameter of the TBM. When a separation installation is used, the soil mixture will be separated on base of particle size so that the resulting soil also can be a mix from different origin, only classified to particle size and/or mass. The quality of the released soil (moisture content, grain size distribution) defines in an important way the opportunities for reuse. The classification in clay, sand and peat seems to be sufficient to describe the ground and to look at the demands for reuse.

3 THE POLICY OF REUSE OF MATERIALS IN THE NETHERLANDS

By the boring process large quantities of spoil are produced. When one looks at the previous mentioned projects, around1 million m3 per year will be excavated in TBM drives in the Netherlands. It's of great importance that prior to the actual boring one has knowledge of the out coming soils after treatment and that the application of the soils is settled.

The dumping of these quantities has big consequences for the available space. In order to use the available space as good as possible, the Dutch have a fairly well working policy with respect to the useful application of waste materials. It's aiming at preventing both the creating of numerous big waste sites and the digging of deep pits for producing sand and gravel for construction materials. The idea is that the supply of secondary materials reduces the demand for primary materials.

When we can change the spoil from the TBM into soil, we have another secondary material that one can use in constructions, in addition to the range of developed secondary materials in the Netherlands.

Also in the crowded Netherlands with almost 16 Million inhabitants and an area of 35.000 km2 (compare to Japan with 125 million inhabitants and 375.000 km2) one has to be careful with the available space. At places were one does not want to disturb the natural environment and where the industrial and municipal activity's has to continue, railways, roads and good transport in the underground seem to be a good option.

Hereby is the slogan "Economic use of the available space". Care for the available space means also that one has to find new applications for the big quantities of out coming soil from the TBM drives, in stead of dumping them.

Because of the big quantities of soil, for each of the mentioned boring projects the principal started a study of the quality and the possible applications of the out coming soil in civil works.

In most cases the principal tries to reuse the out coming soil in the same work, for example in the construction of roads or in noise barriers. The advantage is that there is no need
to use raw materials and the chain of materials is closed.

If it will not be possible to find suitable applications for these materials, they will have to be dumped. However one of the mean reasons for boring tunnels in the Netherlands instead of digging or submerging them, is the unchanged landscape above the planned route. Dumping sites for the out coming soils are not done within the

Dutch policy. In table 1 an overview of the recent Dutch boring projects is given.

No matter what kind of TBM is used, the out coming soil has to fulfill environmental and civil demands.

Also the material has, when used for a typical application, to fulfill the demands that belong to the application - the function demands like compacting behavior or permeability.

For the two used bore method's, the Bentonite slurry shield and the EPB method, the results of the research to the possibilities of the use of the out coming soil will be discussed.

Table 1. The Dutch bore tunnel projects.

Project	Purpose	Start (year)	Boremethod	Diameter (m)	Length (m)	Excavated soil *1000 (m3)
2nd Heinenoordtunnel	road	1997	slurry	8.55	950	110
Pipeline carrier tunnel	pipelines	1998	slurry	4.90	350	7
Westerscheldetunnel	road	1998	slurry	11.25	6,600	1,300
Botlektunnel	goodsrailway	1998	EPB	9.50	1,850	260
Sophiatunnel	goodsrailway	1999	to be decided	9.50	4,200	600
Pannerdensch Kanaal	goodsrailway	1999	to be decided	9.50	1,950	270
North-Southline Amsterdam	subway	1999	mixed shield	6.50	3,800	250
Green Harttunnel HSL	railway	2000	slurry	10.85	7,010	1,300
Underground transport system Aalsmeer-Schiphol	goods	2000	to be decided	5.00	10,000	400

4 THE BENTONITE SLURRY SHIELD METHOD

By this TBM type Bentonite is used as boring agent. Bentonite is the name of natural clays that contains mainly the clay mineral Montmorillonite. This clay mineral has very important swelling properties. In contact with water the volume can increase till ten or more times the original.

During the boring process the natural soil becomes mixed over the whole diameter of the tunnel with the boring agent. When the slurry shield method is used, a Bentonite processing plant or separation installation is utilized as well.

This separation installation is based on the principle of particle size or particle mass separation. For example in the Second Heinenoord Tunnel project the soil became available after treatment as a coarse fraction (sand, clay lumps, etc.) and as a fine fraction (clay, Bentonite slurry, etc.). The volume increased with 30 to 50%, with respect to the one mentioned in table1, due to the loosening effect and the higher watercontent. Both fractions contained small percentages of Bentonite. When used in civil works, one has to know in time the environmental and civil technique consequences.

4.1 *Environmental aspects of the out coming soil*

Bentonite is a natural material that can make part from the soil en which in general contains no elements which can pollute the environment. Because of the different types of commercial Bentonite products, research on the environmental impact has to take place.

When the research has shown that the fractions from the separation installation contain no elements that can pollute the soil and the soil water, an application in civil works can be found.

4.2 *Civil engineering aspects of the out coming soil*

Bentonite is known because of his ability to take in water and to hold water. In, for example, isolation layers of dumping sites one uses these swelling properties. With a mixture of sand with 8% (mass per mass) Bentonite one can create a water impermeable layer.

For the investigations to the possibilities of re-use of the out coming soil the influence of little amounts of Bentonite on the constructive behavior should be known. Therefor one took samples at relevant moments during the separation process.

To investigate the effect of Bentonite content on material properties the out coming material with an initial level of 1.5% has been used. Because there were no samples available without any Bentonite the Bentonite content was raised.

Three levels of Bentonite have been added (+1, +2 and +4% mass to mass). Results were compared with blank samples without the extra Bentonite.

The following properties have been analyzed: Strength (with multi-stage consolidated drained triaxial tests), Compressibility (Oedometertests), Workability (proctortests) and Permeability (falling head tests). In table 2 an overview of the effects of extra Bentonite on the soil properties is given [lit 1

Looking at the table one can see that the presence of Bentonite just has relative little influence on the material quality. The presence of Bentonite has a clear unfavorable effect on the permeability.

Table 2. Effect on different properties of the out coming soil of a Slurry shield by extra added Bentonite (+1, +2 and +4 mass percent).*

property	effect of extra Bentonite on : "Coarse fractions" Clay	Sand	"Fine fractions" -
Bearing capacity			
- strength (phi)	no effect	no effect	no effect
- strength (cohesion)	no effect	no effect	no effect
Compressibility	no effect	no effect	no effect
Permeability	no effect	strong negative	strong negative
Workability			
- proctor density	small	small	small

*due to the extra added Bentonite the maximum range of total content will be around 5.5 %

Normally the permeability for moderate coarse sand is about 10 till 20 m per day. For this coarse sand from the separation installation a permeability of 1 m per day has been found; it looks as if the water is hold up by the sand. Consequently the soil fractions have a somewhat higher water content. Depending on the planned application of the fractions the presence of the Bentonite can have a positive or a negative influence on the behavior. Consequently not all the out coming material has general applications, but for all fractions there are specific applications (see table 3).

5 EARTH PRESSURE BALANCE METHOD

An EPB machine will be used in the construction of the Botlek railway tunnel. Here one plans to use additive's like foam and maybe polymers. Because of these additives the soil loses its granular structure and the out coming muck looks like a porridge. Because of the limited space at the entry shaft of the Botlektunnel, the muck of the screw auger goes into a so-called slurry box. In here the muck becomes mixed up with water (about a factor 10). After that the mixture will be pumped to the surface and transported over a distance of about 3 kilometer to the depot. The expectation is that during the hydraulic mixing and transport the foam will be broken down and thereby the ground loses its cohesion.

5.1 *Environmental aspects of the out coming soil*

By the re-use of the out coming soil, it is important that before the start of the boring process one has knowledge of the environmental aspects of the biodegradable additives. However in general the producer and the contractor do not want to give this information! The next procedure has been followed: The contractor has in collaboration with the producer selected a few alternatives of additives. These additives all have been examined. When these materials will full fill the environmental demands the contractor can make a decision.

To investigate the biodegradability the alternative additives are checked in the laboratory. At the laboratory the additives were mixed up with the ground from the boring profile. In this case it was Holocene clay, Holocene sand and Pleistocene sand. The boring process, EPB-shield with hydraulic transport, is imitated in the laboratory in a way that a slurry is obtained.
Because the additives will go in the water phase, ecotoxicologic research has been carried out on the water phase. The conclusion of this was that the examined additives all (except the mixture with the Pleistocene sand) become broken down within 15 days under airy circumstances. Under non-airy circumstances the additives will brake down in 100 days, so in that case they can pollute the environment during that time.

5.2 *Civil engineering aspects of the out coming soil*

The way of transport of the out coming soil from the EPB at the Botlek project is unique: in this case the mixing with water and the hydraulic transport from the EPB to the depot. When the mechanic properties are known before the slurry is mixed up (straight after leaving the screw) and also in the depot, one can check the influence of the transport. First experiments have shown that by this way of transport the muck loses its cohesion. What is left is a material that can be used as construction material. Definite results of the constructive behavior will come later this year.

6 SUMMARY

In the Netherlands not only research has been conducted to the technique of boring in soft soil and the geotechnical effects on the surrounding, also a lot of research has done into the re-use of the out coming soil. In each tunneling project the re-use of the soil is a point of attention.

Comparing the Slurryshield method with the

Table 3: Overview from the effects of the used TBM on the re-use of the out coming soil

TBM type	Spoil	Description	Applicability environmental	civil engineering	Potential use of the soil
Slurry	'coarse'	i.e. sand, clay-lumps	yes	yes	i.e. fill material for embankments and road constructions, etc.
	'fine'	thin slurry	yes	no	capping layer waste site
EPB	one mixture	pulpy muck	not direct, (additives will not be broken down fast)	not direct,	
EPB (with hydraulic transport)	one mixture	granular	yes (additives will be broken down fast)	yes	fill material for embankments

Earth Pressure Balance method gives the following points:

- when using a Slurry machine one needs a Bentonite Separation Installation and different fractions from coarse to fine are the result, all with a little amount of Bentonite;
- when using an EPB just one flow of soil comes out. If used, the hydraulic transport will brake down the foam for the most part and there remains no or a very little additives after 28 days in the deposited soil.

Both the remaining Bentonite with a slurry machine and the little amount of additives in case of the EPB does not pollute the environment.

Because of the Bentonite, the sand in the fraction has lost a little of its permeability. The other properties of the out coming material are only changed very little, therefore can these fractions be used as construction materials

Using hydraulic transport in addition to the use of an EPB machine results in out coming material that can be stored or applied directly in constructions.

General remark

Of course re-use of the out coming soil is not only a question of fulfilling the environmental and engineering demands. As often it also has to weigh out financial. If the effort to make a new material is very high, or no application could be found in a radius of about 20 km, the costs for re-use would get to high. In the case of the Westerschelde tunnel the following solution has shown to be the most economic. The fine fraction will be dumped in the Westerschelde River and the coarse fraction will be re-used in constructions.

Future developments

Re-use of soils can only become a success when the quality of the out coming soil is known in an early stage of the project preparation. This is a necessity to create useful applications. Therefor the effects on the out coming soil of the TBM, the additives, the transport, and the separation plant have to be known. Recently activities have been started to model these effects on the on the out coming s(p)oil.

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