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Waste Materials in Construction: Putting Theory into Practice

Mine tailings - practical experiences in filling up harbours

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Abstract

In the port of Rotterdam, old harbours are being filled up to create new sites for industrial activities. Large quantities of materials are required for these projects. Because of the mechanical, environmental and economical advantages, mine tailings are therefore used. In the past some 1.000.000 tons of this natural, inorganic residue of coal mining was used in several filling up projects in the port of Rotterdam.
The muncipality of Rotterdam has carried out an environmental impact assesment on the use of mine tailings. Conclusion was that the oxydation of the mineral pyrite is the critical aspect of the mine tailings. To prevent oxydation, it's only used below the groundwater table, in anoxic zones.
In the laboratory various experiments have been carried out on the contents and leaching of components, according to the legislation and the licences. Besides, the oxydation of pyrite is controlled in the field. At one harbour site (Beatrixhaven) the oxydation of pyrite is being monitored by measuring the pH and redoxpotential with an in-situ cone.
As the mine tailings are produced in coal mines in Germany, the environmental survey starts with sampling at the mine. In the meantime, the mine tailings are shipped to Rotterdam. At the site, the delivered material is then again sampled and examined. The mine tailings are put in the harbour and the results of the survey have to meet the standards.
The conclusion of the paper, after several years of experience with the application of mine tailings, is that the use of mine tailings is environmentally safe and meet the standards. The boundary is to use this material only in an anoxic environment (below the groundwater table). The major bottle neck in the benificial use of mine tailings is the long time, required for a licence (6 months) for a waste material, compared to those of raw materials (few days).

1. INTRODUCTION

The policy of the Municipality of Rotterdam is to stimulate the beneficial use of secondary materials. For this reason the Port of Rotterdam has adopted mine tailings in large scale projects for filling up harbours (ref. 1). Mine tailings are the anorganic residues of coal mining. They are not mined as such (they are not a primary raw material). Due to their favourable geological properties mine tailings have been used in hydraulic engineering projects in Rotterdam since the nineteen-sixties (ref. 2). As a result of their size-distribution and their high friction angle they have a good filtering action, are resistant to erosion, and can be used at a steep slope (under water). An application less specific to mine tailings is the filling of banks and harbours - for which they are also very suitable.
The annual amount of mine tailings used in the harbour area of Rotterdam depends greatly on the ongoing major projects, in particular filling up projects.

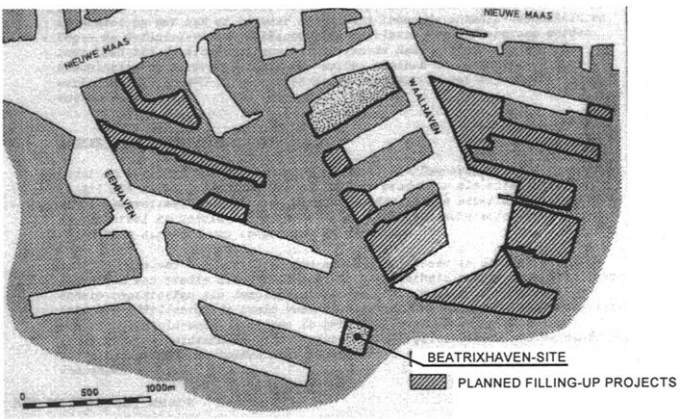

Figure 1. The Waalhaven / Eemhaven port area.

Each project requires an amount of between several thousand tons and several hundred thousand tons. In the nineteen-nineties the average annual use was about 400,000 tonnes.
Both unclassified mine tailings (0/70 mm) and classified mine tailings (10/125 mm) are used in Rotterdam. In many cases classified mine tailings are used in protective structures since these have a greater resistance to erosion in comparison with unclassified mine tailings.

The mine tailings are a by-product obtained during the mining of coal, and are therefore designated as a secondary construction material. Consequently from the early nineteen-nineties onwards a licence is required for their use, in accordance with the Pollution of Surface Waters Act of the Netherlands (Wvo).
Although mine tailings are a naturally-occurring material (comprised of clay and sandstone), contamination of (stored) mine tailings could not be precluded in the past due to the manner in which the material was mined and stored. Until the nineteen-seventies hydraulic oils containing PCBs were used during the mining of coal, and as a consequence there was a risk of an incidental marginal contamination of mine tailings with PCBs. There is now a (European) regulation prohibiting the use of hydraulic oils containing PCBs, and the Municipality of Rotterdam uses only (washed) mine tailings from current production from working mines.
Due to the large scale of the projects in the Waal-/Eemhaven port-area (see figure 1), the authorities asked for an Environmental Impact Assesment (EIA). In the Mine Tailings EIA (ref. 3), drawn up by the Municipality of Rotterdam in 1992, it was concluded that the use of mine tailings obtained from current production from working mines in the Ruhr region in Germany is environmentally safe in anoxic or anaerobic conditions.
The Pollution of Surface Waters Act stipulates that a licence is required for the use of mine tailings. In addition the Province of Zuid-Holland considers mine tailings to be a waste product, and that consequently a licence is also required pursuant to the Environmental Management Act (WM) of the Netherlands. The Municipality of Rotterdam is challenging this standpoint in legal proceedings. In the past Public Works have carried out several studies on the technical and environmental aspects of the benificial use of mine tailings, which are presented under chapter 2 and 3.

2. ENVIRONMENTAL ASPECTS

2.1 General

The environmental quality of mine tailings may constitute a restriction to their beneficial use. There are three decisive factors involved:

- the absence of PCBs and PCDMs
- the oxidation of pyrite
- the leaching of chloride and sulphate

Oil containing PCBs, PCDMs and/or other chlorinated hydrocarbons used in old mining techniques has been spilled in small amounts. This contaminated oil may be mixed with the coal and the residue, the mine tailings. When the coal is separated the oil could be adsorbed on to the mine tailings. Oil containing PCBs or PCDMs may no longer be used in mining. For this reason the authorities stipulate that tests be made to demonstrate that oil and PCBs or PCDMs are not present. The environmental licences contain an article which prohibits the use of batches of mine tailings containing any detectable PCBs.

The mineral pyrite is of natural origin, and is present in the mine tailings. In an aerobic environment, the redox potential is positive (>0mV) and oxygen is available. On contact with oxygen the pyrite may oxidize, ultimately producing sulphuric acid:

$$FeS_2\ (s) + 3.5\ O_2 + H_2O \text{ ---> } Fe^{2+} + 2\ SO_4^{2-} + 2H^+ \qquad [1]$$

This may result in a decrease of the pH and a serious leaching of sulphate and heavy metals, available in mine tailings and/or the surrounding soil.
For this reason it is important that oxidation of the pyrite be prevented. One of the conditions attached to the benificial use of mine tailing in infrastructural works is that exposure to air be avoided and that the redox potential is negative. The material is therefore only used below the water table.

2.2 Laboratory tests

Many laboratory tests have been carried out in the past in order to examine the environmental impact of the reuse of mine tailings. These tests consisted of the following methods:

* contents (extraction with concentrated acid)
* leaching - column test (NEN 7343)
  - diffusion test (NEN 7345)
  - shaking test (NEN 7349)

The results have been compared to standards for leaching with an height of application of 10 meters. These standards are given in legislation for constructional materials in the Netherlands ('Bouwstoffenbesluit', the Building Materials Decree). The Pollution of Surface Waters Act of the Netherlands also contains standards for leaching.
The results are shown in the following table.

Parameter	Content (n = 76)	Leaching (n = 12)	Leaching standard h = 10 m
As	12	0.371	0.83
Ba	382	0.303	1.5
Cd	0.5	0	0.022
Cr	82	0.023	0.23
Cu	47	0.038	0.37
Hg	0.3	0	0.017
Pb	31	0.007	0.99
Mn	408	0.067	-
Ni	40	0.026	0.71
Zn	118	0.135	2.3
SO_4	716	269	557
Cl	846	733	227
PAH 6 borneff	0.8	-	-
PAH 10 (VROM)	2.1	-	-
PAH-EPA	2.8	-	-
PCBs	below detection level	-	-
PCDMs	below detection level	-	-

Table 1: Average contents and leaching of trace-elements and salts (in mg/kg dry weight) of mine tailings from the Auguste Victoria Mine.

Table 1 shows that the amounts of trace elements leached from the mine tailings meet the standards for non-isolated use in infrastructural works. Since mine tailings are mainly used in marine environments the value for chloride, which exceeds the standard, should not be a problem. However this might be a problem when the mine tailings are used in other environments.

2.3 Field experiments

As mentioned above the possible oxidation of pyrite is a critical aspect in the reuse of mine tailings. To avoid contact with oxygen or air the Municipality of Rotterdam has committed itself to use mine tailings below the watertable only. Several hydraulic projects have been carried out in this manner in the Port of Rotterdam. The question was whether the oxydation of pyrite really occurs in practice.
Since the use of monitoring wells would promote the contact between oxygen and
mine tailings other possible methods of sampling

figure 2: the Envirocone

and monitoring have been investigated.

A survey has been carried out in which the in-situ pH and redox potential were measured in order to determine whether the environmental conditions would allow any oxidation of pyrite (ref. 4).
Measurements were made with apparatus known as an 'Envirocone' (see figure 2), a cone which is pressed into the layer of mine tailings to carry out in-situ measurements. The cone was used at the 'Beatrixhaven' site which was constructed with a large amount of mine tailings, a few years ago.
The cone was pressed into a layer of mine tailings. The temperature, pH and redox potential were measured at various times and depths in three locations. The results were recorded on-line. Sampling cones ('Pleistosonde, ref. 5) were also pressed into the mine tailing layers in order to sample the (low-oxygen) groundwater. The samples were analysed in a laboratory for the following parameters:

- pH
- redox potential
- oxygen

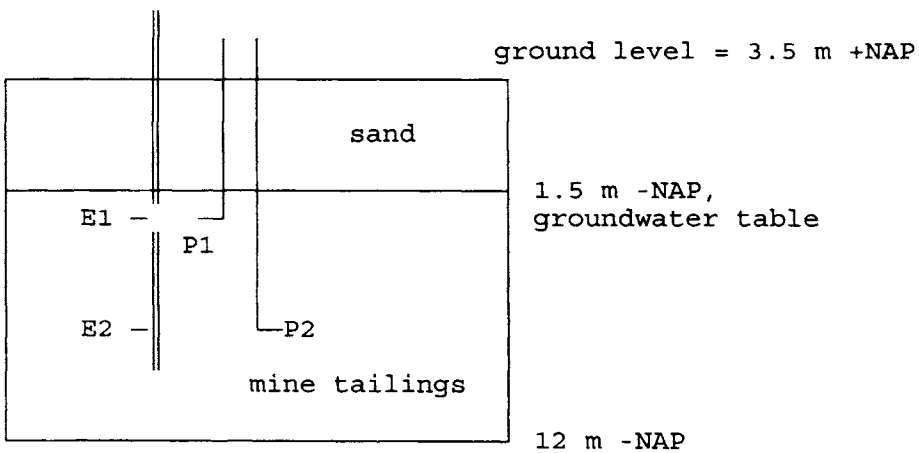

Figure 3: Measurements at one location (Beatrixhaven-site)

key:
E1, E2: in-situ measurements with Envirocone
P1, P2: sampling points of the Pleistosonde
NAP: reference level

Results

The redox potential as a function of depth is shown in the figure and the table below.

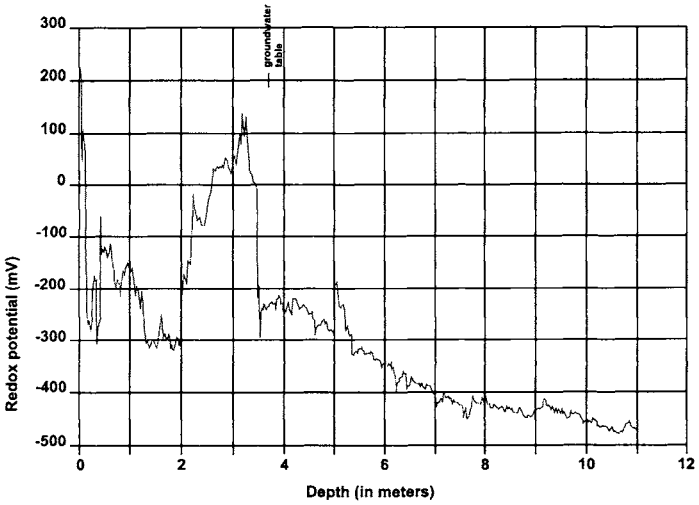

figure 3: example of the results of in-situ measurements at one location.

Redox potential

Location	Envirocone (mV)	Laboratory (mV)	Oxygen (mg/l)
1-1 (5.0 m-bgl)	-193		
1-2 (11.0 m-bgl)	-330	-12	2.6
2-1 (5.0 m-bgl)	-330	-212	0.27
2-2 (9.0 m-bgl)	-570	-146	0.07
3-1 (5.0 m-bgl) [1])	-420	-64	1
3-1 (7.0 m-bgl)	-370		
3-2 (11.0 m-bgl)	-360	-163	0.96

[1]) measured in the covering layer of sand
bgl = below ground level

Table 2: Results of measurements of the redox potential using the Envirocone compared to laboratory analyses of the redox potential and the oxygen concentration in groundwater samples.

Table 2 shows that the redox potential is negative in both the Envirocone measurements and in the groundwater samples. The negative redox potential is lower in the samples, possibly due to an interaction with oxygen during transport and analyses.

The results of in-situ measurements show that the level of the negative redox potential in a layer of mine tailings is such that the oxidation of pyrite will not occur, according to equation [1]. The pH values lay between 6.5 and 9, indicating that sulphuric acid was not present. This demonstrates that mine tailings are environmentally safe when used below the (ground-)water table, thereby avoiding contact with oxygen.

3. LOGISTICS AND ORGANIZATION

3.1 Logistics

In the last few years most mine tailings used by the Port of Rotterdam have been supplied by just one producer, the Auguste Victoria Mine in Germany.
Mine tailings for use outside the Marl region are transported to the Marl docks immediately after they are separated from the coal. The mine tailings are transported using a covered conveyor belt, 1.8 km in length. A sieving installation at the end of the conveyor belt is used to classify the mine tailings when this is required. The mine tailings are then loaded into cargo ships using smaller adjustable conveyor belts. The ships usually sail directly to Rotterdam, where the mine tailings are in effect a return cargo.
The ships are unloaded immediately on arrival in Rotterdam, i.e. after a short delay of a maximum of one day.
The mine tailings are usually dumped directly in their final location (see figure 4), using a hydraulic crane on a pontoon. In some cases the mine tailings are to be dosed using a stone classifier, and they are then discharged at an intermediate point. These methods allow the use of the mine tailings without intermediate storage ("one-to-one production and use"). This reduces the contact with oxygen.

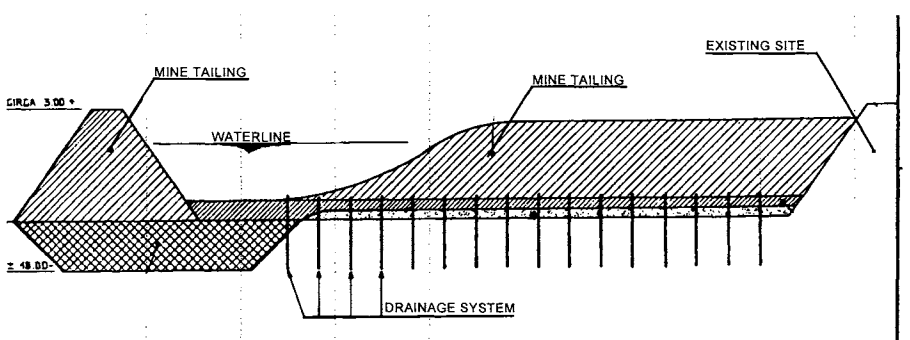

figure 4: Cross-section of a filling-up project

3.2 Organization

Once the engineering of a hydraulic engineering project has been commissioned, usually by the Port of Rotterdam, then a decision has to be made whether the use of mine tailings is a serious possibility.

Factors influencing the choice of the material are:

- material/geophysical properties;
- environmental quality;
- costs;
- availability;
- planning.

With the exception of the planning these factors have already been mentioned above. In the planning, the time needed for the licensing procedures stipulated by the environmental legislation will determine whether mine tailings will be used. A period of 7½ months between the application for an environmental licence (Environmental Management Act) and the date that this comes into effect should be taken into account. The planning should also take account of the time needed to draw up the application for the licence, and for invitations to tender.
In practice a period of about a year between the first plans to use mine tailings and their actual use should be borne in mind.
The time delay involved may mean that it is necessary to abandon the principle of using secondary construction materials and opt for primary materials, not requiring a licence.

3.3 Monitoring

In accordance with licences issued under the Environmental Management Act and the Pollution of Surface Waters Act a wide range of tests must be performed before and during a construction project which uses mine tailings. This means that detailed plans for the organization of the work should be drawn up in good time:

- prior to the execution of the construction, project information must be available from extensive and lengthy tests carried out on samples of mine tailings sampled at the mine;
- during the execution of the construction, project samples must be taken regularly for the purposes of a limited number of rapid tests. This involves the manager (on behalf of the licence holder), the competent authority, the supplier, and the laboratory.

Prior to the commencement of the construction project, a monitoring programme is drawn up indicating which samples will be taken. However, in practice the original monitoring programme often has to be amended continually during the execution of the work due to changes in the progress, i.e. the supply of the mine tailings. The manager plays a vital central role in the monitoring programme. He is also responsible for the administration and provision of information (amounts used, results from the monitoring programme) to the competent authority. In other words the use of a secondary material such as mine tailings requires a lot of extra knowledge, organization and time from the manager.

Examination programme for mine tailings (§ 2.2)
admittance examination (sampling at the mine): a minimum of 3 sets of analytical data per year, at most 1 year old, composition (complete) tank leaching test column test cascade test
preliminary examination (sampling at the mine): every 100,000 tonnes composition (complete) tank leaching test
check examination / monitoring (sampling at the work): every 25,000 tonnes composition abridged tank leaching test column test

4. CONCLUSIONS

In the last decade several million tons of mine tailings have been used in Rotterdam. The Ministry of Housing, Spatial Planning and the Environment of the Netherlands has laid down uniform regulations with regard to the use of raw and secondary building materials, which contain simple procedures (a statement is sufficient). The Department of Public Works have carried out many studies to assess the environmental impact of mine tailings. From these studies and our experiences, the following conclusions can be drawn:

-It has been shown that neither the content and amount of trace elements and salts leaching into the water should constitute a problem. This means that, in practice, mine tailings can be used in an environmentally safe way, provided that the oxidation of pyrite is prevented.
-In spite of jurisprudence and the results from all the monitoring programmes within the scope of licences the authorities still consider mine tailings to be a waste material. This means that a licence has to be obtained, involving a procedure which takes six months. The bottlenecks in the implementation of a policy for the beneficial use of secondary materials might then be the time required to follow the necessary procedures as compared to those for traditional materials (2 days), and the number of laboratory analyses involved (composition and leaching).

-The restriction of the use of mine tailings below (ground-)water level has been shown to be satisfactory. Attention should be given to the leaching of chloride from the mine tailings. An extra washing stage in the coal mining process might reduce this problem.

Two processes could improve the chances for the beneficial use of mine tailings:

* the introduction of national certification of the quality (including simple procedures)
* the use of adequate monitoring techniques (e.g. the Environcone instead of monitoring wells)

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REFERENCES

1: Dassen W.G. et al Reuse of waste materials in constructional works, experiences in the city of Rotterdam; in "Environmental Aspects of Construction with Waste materials" (WASCON-proceedings), (1991)
2: Gijt, J.G de et al, Results of pile load tests in mine tailings, proceedings of 'Piling, European practice and worldwide trends' (1992).
3: Gemeentewerken Rotterdam (Public Works), 'MER-Mijnsteen', (Mine Tailings Environmental Impact Assessment with regard to the use of mine tailings for large scale filling of harbours in the Waal-Eem haven area of Rotterdam) (in Dutch), (1992).
4: Gemeentewerken Rotterdam & AP vd Berg Machinefabriek, Report of the investigation into the operation of the Envirocone (in Dutch), (1994).
5: Zandbergen R.R. and J.L.M. van Leeuwen, The sampling of anaerobic groundwater in proceedings of TNO/KfK-congres Contaminated Soil '95 (1995).