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A geotechnical and environmental investigation of stabilised sulfide soils – a laboratory investigation

Investigations géotechniques et environnementales de sols sulfureux stabilisés – investigations de
laboratoire

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ABSTRACT: This paper discusses results from stabilization of sulfide soils in laboratory with two industrial waste products (Linz-Donawitz(LD)-slag and Air Blast Furnace Slag) and lime, mixed with standard Portland Cement (PC). The mechanical and chemical stability of stabilized soil samples was investigated. The results indicate that block-stabilization, with the used stabilizing agents, is an appropriate foundation method, with the exception of the stabilizing agent containing LD-slag. With its high content of Vanadine (V), as it is today, it can not satisfy environmental requirements.

RÉSUMÉ: Cet article présente les résultats de la stabilisation de sols sulfureux, en laboratoire, avec deux résidus industriels (des scories de Linz-Donawitz(LD) et de hauts fourneaux) et de chaux, mélangés avec du ciment Portland standard. La stabilité mécanique et chimique des échantillons de sols stabilisés a été étudiée. Les résultats montrent que la stabilisation en blocs avec les agents de stabilité utilisés, est une méthode satisfaisante pour des fondations à l'exception des agents contenant les scories LD. Avec son haut niveau en V, ils ne peuvent satisfaire les contraintes environnementales actuelles.

1 INTRODUCTION

Block or mass stabilization is a newly developed stabilization method, where a whole block of soil is stabilized with a stabilizing agent. As described by e.g. Huttunen, 1996, and Mácsik, 1997, the method is applicable for peat and sulfide soils down to a depth of 5 m. This method is more and more requested, due to reparations and reconstruction of old road and railway sections and building of new ones through peat and sulfide soil areas. Stabilization of clayey soils with standard Portland Cement (PC) and Quick Lime (Q) have been used for decades, Broms, 1984. However, in organic soils, stabilization is not a common method. As documented e.g. by Saitoh et al., 1996, and Kujala et al., 1996, organic contents of > 5 - 6 % in a soil, give low increase of the shear strength when stabilized with Portland Cement and lime. Portland Cement/Quick Lime stabilization has also failed in some cases when organic soils have been stabilized. At present the failures are discussed in Sweden.

In this study sulfide soil was stabilized in laboratory with three stabilizing agents: (1) Portland Cement mixed with LD-Slag, (2) Portland Cement mixed with Air Blast Furnace Slag and (3) Portland Cement mixed with Quick Lime. Earlier studies, e.g. Mácsik et al., 1995, have shown that sulfide soils can be stabilized sufficiently with an addition of different slag materials and Portland Cement. The admixture best suited for stabilization was planned to be used under field conditions.

Apart from the mechanical stability of the soil, one issue is a possible contamination of the surrounding environment. There is a certain concern about the environmental issues, as a sulfide soil is not allowed to be excavated and dumped without permission, due to environmental effects. However the estimation of these environmental effects are sometimes questionable. One other environmental issue is that slag materials, in this case from the steel industry, may contain high quantities of regulated elements.

By using an "industrial waste-product" or a "by-product" in an environmentally proper way, the benefits are double. It solves dumping problems of a by-product, and it improves the mechanical stability of a soil without exceeding regulated containment levels.

2 METHODS AND MATERIALS

2.1 Sulfide soil

Sulfide soil was sampled at S:a Sunderbyn, outside Luleå, Northern Sweden. The upper 2 m of the profile is an oxidized crust. This soil is classified as silty clay, see table 1. The underlying layer, 2 - 4 m, consists of a black sulfide soil partly without and partly with thin clay layers, classified as a silt clayey sulfide soil. The next layer, 4 - 5,5 m, is a silty clay with thin sulfide layers. This layer is underlayed by a silt. The soil was planned to be block-stabilized down to the silt layer. During block-stabilization different soil layers are mixed together. Laboratory samples were stabilized from the profile, in two series. The first series consisted of stabilized soil material from 2 to 4 meters, and the second one consisted of stabilized soil material from 4 to 5,5 m. Series one represented a stabilized sulfide soil and series two a stabilized silty clay soil with some sulfide content. Geotechnical properties of the investigated profile are given in table 1.

The soil chemistry of a sulfide soil depends on its degree of water saturation. Excavated anaerobic sulfide soil can oxidize if it is deposited above the groundwater table. Oxidization leads to aerobic conditions, under which the soil can release 10 000 to 20 000 mg Fe²⁺/Fe³⁺ and up to 10 000 mg of S as sulfate per kg of dry soil mass. Also pH of the leachate water from an oxidized sulfide soil will be low, < 3. As described by Mácsik, 1994, 1996 and 1999, a sulfide soil can be divided into the following three redox-environments: anaerobic, partly aerated anaerobic and aerobic. Under anaerobic conditions, below the groundwater level the release of dissolved FeS from the soil is low. Aerobic conditions, above the highest ground water level, lead to an exhaustion of the sulfide/sulfate content, and depletion iron reserves of the soil, Mácsik, 1994. In order to minimize the release of Fe²⁺/Fe³⁺ and SO₄²⁻ and the decrease of pH of the pore water, anaerobic sulfide soils should be kept under the groundwater table (under anaerobic conditions) where the soil's chemistry is stable.

Table 1. Geotechnical properties of the investigated soil profile.

| Geotechnical properties | Oxidized crust (0 - 2m) | Sulfide soil (2 - 4m) | silty Clay (4 - 5,5 m) | Silt > 5,5 m |
|-------------------------|-------------------------|-----------------------|------------------------|--------------|
| Bulk density, t/m^3 | 1,58 - 1,67 | 1,41 - 1,66 | 1,49 - 1,61 | 1,81 - 1,94 |
| Water content, % | 42 - 75 | 66 - 118 | 65 - 81 | 26 - 56 |
| Liquid limit, % | - | 83 - 101 | 48 - 58 | - |
| Sensitivity | - | 13 - 28 | 30 - 80 | - |
| Ignition loss, % | - | 5,5 - 8,1 | 3,6 - 3,7 | - |
| τ_{fu} 1 kPa | - | 17 - 38 | 12 - 20 | - |
| Texture Clay, % | 40 | 32 - 36 | 42 - 47 | - |
| Silt, % | 60 | 64 - 68 | 53 - 58 | - |

1 Falling cone test

2.2 Additives and admixtures

The stabilizing agents used in the tests were LD-Slag (L1), Air Blast Furnace Slag (L2), Portland Cement (C) and Quick Lime (Q). Both L1 and L2 were dried and sieved (< 4 mm). The main chemical compositions of the used additives are given in table 2. Three soil additives were used, (1) containing 50 % LD-Slag and 50 % Portland Cement (L1-C50), (2) containing 50 % Air Blast Furnace Slag and 50 % Portland Cement (L2-C50) and (3) containing 10 % Quick Lime and 90 % Portland Cement (Q-C90). The soil samples were stabilized with 14-weight % additive.

2.3 Mechanical properties

Stabilized samples were packed into plastic tubes (height 10 cm and diameter 5 cm). Properties like undrained shear strength and compressibility were tested after different curing times. The mechanical properties of the samples were tested according to an earlier study, Mácsik et al., 1995, where it was shown that a slag material combined with Portland Cement is a suitable technique to strengthen a natural sulfide soil and to reduce the soil's compressibility.

2.4 Analyses and leaching tests

Total Constituent Analyses (TCA) of the additives (L1, L2), of a typical sulfide soil and of the monoliths L1-C50 and L2-C50 were performed. In TCA the samples are leached under oxidising conditions in a microwave oven with 7-M Nitric Acid in sealed Teflon containers. Released metals are then analysed by plasma emission spectrometry ICP-AES, according to EPA-methods 200.7 and 200.8. The results are given in mg leached metal/kg dry soil substance.

In order to control the leachability of regulated elements, L1, L2 and L2-C50 were leached with distilled water and with acetic acid. Leachates from the selected leaching tests were analysed by the same method as mentioned above. Released metals in the leachates are given in μg leached metal/l leachate.

2.5 Swedish contaminant level regulations

A high leachability of organic compounds and heavy metals can lead to exceeding natural background levels and can cause pollution of surface- and groundwater. Environmental as well as geotechnical aspects should be controlled when a new material or a new method is used in a soil. Contents, leachability of regulated elements and durability of the stabilized soil are of fundamental interest for a road construction.

The Swedish environmental protection agency (Naturvårdsverket, NV) has presented a list of maximum containment levels, MCL, Rapport 4638, 1997, for different regulated elements in a soil. In this the following three soil types, with different maximum containment levels, were given:

Table 2. Chemical compositions of the additives LD-Slag(L1), Air Blast Furnace Slag (L2) standard Portland Cement (C) and Quick Lime (Q).

| Chemical composition | L2 | L1 | C | Q |
|------------------------------------|------|------|------|------|
| CaO [%] | 31,8 | 29,5 | 63,1 | 95 |
| SiO ₂ [%] | 32,9 | 32,4 | 20,5 | 2,2 |
| Al ₂ O ₃ [%] | 13,4 | 13,6 | 4,5 | 1,0 |
| Fe ₂ O ₃ [%] | - | 0,3 | 2,3 | 0,5 |
| MgO [%] | 17,4 | 19,1 | 4 | 1,5 |
| Na ₂ O [%] | 17,4 | 0,7 | 0,25 | 0,2 |
| K ₂ O [%] | 0,46 | 0,6 | 1,4 | 0,2 |
| SO ₃ [%] | - | * | 3,1 | 0,04 |

* S content is between 1,2 - 1,5 %

- Soils, with the lowest allowable containment levels (KM), e.g. gardening, housing and groundwater protection sites.
- Soils with groundwater protection, with low containment levels (MKM-GV)
- Soils where groundwater is not used as reservoir, with the highest allowable containment levels (MKM).

There are no MCL-values presented for ground water in Sweden. Instead, a German MCL-regulation (the Berlin List), Wisser, 1993, Swedish background levels and a drinking water standard are used as comparison.

3 RESULTS AND DISCUSSION

3.1 Undrained shear strength, τ_{fu}

Figure 1 shows the results from unconfined compression tests performed on stabilized samples after different curing time. White marks represent τ_{fu} after a curing time of 10 days, grey marks after 30 days and black marks after 90 days. As shown in figure 1 a - b, an increase of τ_{fu} over the curing time is for most of the cases apparent. After a curing time of 30 days all samples had a $\tau_{fu} > 75$ kPa, which is a regulated minimum for a railroad.

The initial undrained shear strength, τ_{fu} , of the soil varies with depth in the profile, table 1. τ_{fu} of the silty clay soil was 12 to 20 kPa and τ_{fu} of the sulfide soil was 17 to 32 kPa. The stabilized silty clay soil had lower τ_{fu} compared with the stabilized sulfide soil. This variation of the initial τ_{fu} of the soil profile under the railroad section tends to give a variation in achieved stabilization effect, see figure 1.

According to triaxial tests conducted on L2-C50 samples, Mácsik et al., 1998, the stabilized soil material is dilatant under undrained conditions, which is common for dense sands and overconsolidated clays.

The oxidized layer, 0 to 2 m, mixed with sulfide soil did not give a significant increase of undrained shear strength, Mácsik et al., 1998. Stabilization of oxidized sulfide soil layers should be avoided, as oxidized sulfide soil can decrease of the achieved τ_{fu} of the stabilised soil. This is probably due to the contents of ironhydroxides, sulfates and a low pH in the oxidized zone.

3.2 Compressibility

Oedometer tests were performed on 40 days old samples, and compression curves from these tests are presented in figure 2. The results show that with 14 weight % of the additives L2-C50 and Q-C90 the compression of the stabilized samples were between 2,1 - 5 % at 320 kPa, and for L1-C50 the compression was 6 - 7 % at 320 kPa. The unstabilized sulfide soil had a compression between 12 to 20 % at 100 kPa. Addition of 14-weight % of the used additives improves the soil's mechanical stability. L2-C50 and Q-C90 gives the lowest settlement of the stabilized samples.

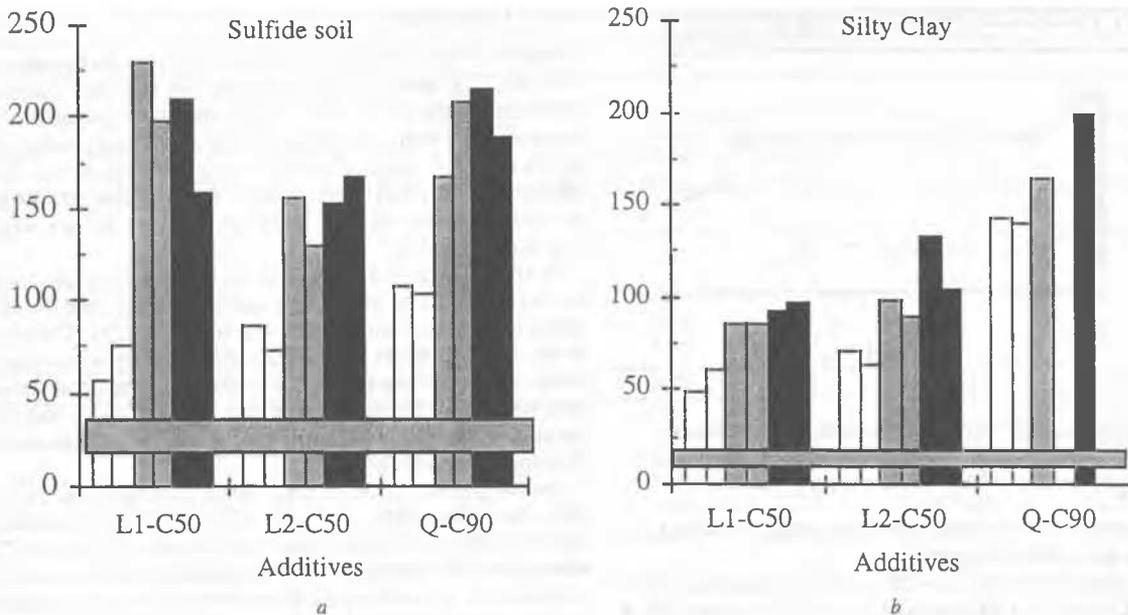


Figure 1 τ_{u} of stabilised soil samples after 10 (white), 30 (grey) and 90 (black) days of curing time (unconfined compression test). The horizontal bars represent the soil's original undrained shear strength (falling cone test). τ_{u} of the sulfide soil ranges between 17 - 32 and of the silty clay between 12 - 20 kPa.

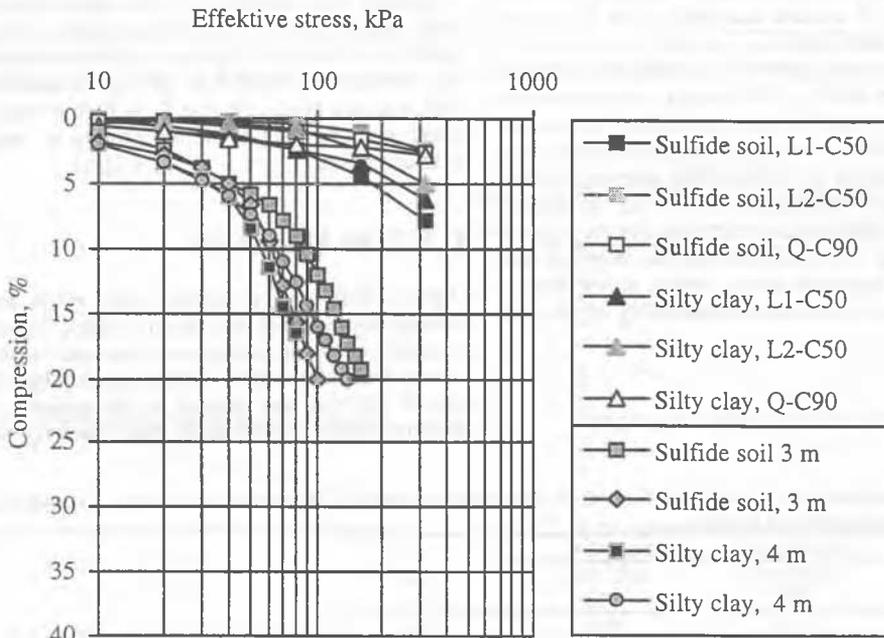


Figure 2 Compression curves of stabilised (L1-C50 – Q-C90) and unstabilised soil samples after a curing time of 40 days. The stabilized samples contained 14 weight % additives

3.3 The effect of freezing and thawing cycles

Sulfide soil samples, stabilized with L2-C50, were cured for 36-38 days. The samples were then exposed to four freezing/thawing cycles. Each cycle consisted of freezing at -10 °C for 24 hours and of thawing at 20°C for 24 hours. After the last cycle the undrained shear strength of the samples was tested. The results show that τ_{u} has decreased after four freezing/thawing cycles with 30 to 40 % of a non frozen sample, cured for 30 days, Mácsik et al., 1998. A conclusion of these results is that freezing/thawing can reduce the mechanical stability of a stabilized soil. Further investigation of how freezing/thawing effects the stabilized soil's mechanical stability should take place.

3.4 Environmental investigation

A soil stabilized with 14 weight % L1-C50 contains ca 1900 mg/kg V, which is almost 16 times more V than regulated by KM. The leachability of V from a pure L1-material is high at pH between 11 and 13 and at pH < 5, figure 3. Because of high leachability and high containment of V, the stabilizing agent L1-C50 is not satisfying MCL regulations as a block-stabilizing agent. L1-50 was therefore excluded from further investigations. However L1 might be of interest if its leachable content of V can be washed out under controlled forms, before it is used as a stabilizing agent.

Sulfide soil stabilized with 14-weight % of L2-C50 contains less amount of metals than permitted by Swedish MCL-regulations, table 3. Pure L2, however, contains elevated values

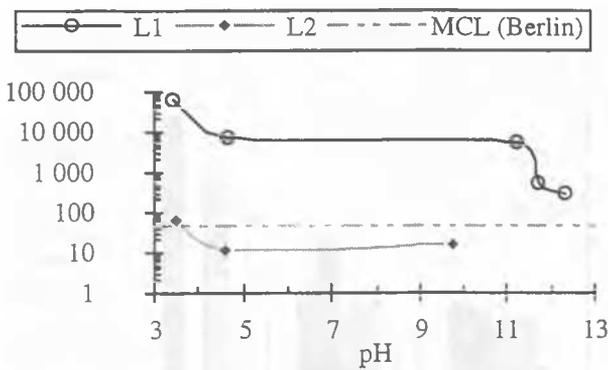


Figure 3 Leachability of V from pure L1 and L2 with an acetic acid solution, Mácsik et al., 1998. German MCL of ground water is 50 µg/l.

of V. The leachability of V from pure L2-material is low and not pH dependent for a pH > 4, figure 3.

Sulfide soil stabilized with L2-C50 contains, however, 85-92 (120) mg/kg Cr, 26 - 32 (100) mg/kg Cu, ca 30 (35) mg/kg Ni, 8 - 9 (80) mg/kg Pb, 113 - 116 (120) mg/kg V and 71 - 84 (350) mg/kg Zn, table 3. The values in the brackets represent the Swedish MCL-values in KM soils. The results indicate that L2-C50 can be used even in restricted areas according to MCL regulations. Most of the Ni content and half of the V content originates from the sulfide soil itself.

L2-C50 contains 7000 mg/kg sulfur. A typical anaerobic sulfide soil contains between 9000 - 15000 mg/kg sulfur as sulfide (S²⁻). Leaching of sulfate or sulfide from a stabilized soil will be slow due to low permeability of the stabilized soil and due to reduction of sulfate to sulfide in the surrounding anaerobic sulfide soil followed by a precipitation of e.g. FeS and CuS. An anaerobic sulfide soil can also function as a metal barrier for e.g. Cu, Pb, Cd, Mn, Fe and Ni as these can form sulfide minerals with low solubility. Another important factor, which slows down a possible leaching process, is the low permeability of the surrounding soil.

3.5 Leachability

Samples of stabilised sulfide soil and silty clay soil were leached with distilled water. Containment of the leachate samples are presented in table 4. As a comparison metal contents of pore water samples from two typical sulfide soils (background values) are listed, one is from an aerobic sulfide soil and one is from an anaerobic sulfide soil. German MCL for groundwater, the Berlin list and a Swedish drinking water standard for private wells are also listed in table 4.

As shown in table 4, the initial metal contents of the leachates are high, especially of Ca. The contents of Cu, and Ni are decreasing with increasing liquid to solid ratio (L/S). The contents of Al, Cu and Ni are higher than the drinking water standards allow, however these elements are present in high quantities in a pore water from a natural sulfide soil. An area containing sulfide material in the soil profile is therefore not "recommended" as a drinking water resource.

The leachability of Al is lower from a sulfide soil, 187 - 315 µg/l, than from a silty clay soil, 2000- 3000 µg/l. According to the results of the leaching tests, the contents of Ni and Cu are enhanced in the leachate. The Ni content decreases, as the L/S increases, to a level which is below MCL for a groundwater protection area (according to the Berlin list). The Cu content decreases to a value below MCL for an area that does not contain an aquifer, 150 µg/l, (Berlin List).

The presented results are based on laboratory results, which exaggerate leachability due to abrasion, different solid to liquid ratios etc. However, in groundwater protection areas a stabilizing agent should be used with care, as pore and drainage water from the stabilized soil has high pH and conductivity and contains high amounts of Ca, Na and K. A field investigation will give a better understanding of the leachability of these elements under field condition.

4 FUTURE RESEARCH

Organic soils such as sulfide soils, gyttja and peat soils, are scarcely investigated soils from an Environmental/Geotechnical perspective. New investments in road and railroad systems in the coastal areas of Northern Sweden are in progress. A considerable part of the total area crossed in this region is composed of the aforementioned organic soils. This raises the necessity for inno-

Table 3 Total constituent analyses on (1) a sulfide soil and a silty clay stabilized with L2-C50-material, (2) L2 and (3) a sulfide soil. As a comparison Swedish MCL-values of a KM soil is given.

| Element | Stabilized with 14 weight % L2 | | L2 | Sulfide soil | KM |
|--------------------------------|--------------------------------|----------------|----------|--------------|---------|
| | Sulfide soil [%] | Silty Clay [%] | | | |
| SiO ₂ | 53,5 | 55,6 | 32,4 | | |
| Al ₂ O ₃ | 13,4 | 14,7 | 13,6 | | |
| CaO | 6,79 | 6,38 | 29,5 | | |
| Fe ₂ O ₃ | 7,04 | 6,85 | 0,281 | | |
| K ₂ O | 3,49 | 3,25 | 0,64 | | |
| MgO | 3,26 | 3,52 | 19,1 | | |
| MnO | 0,298 | 0,195 | 0,697 | | |
| Na ₂ O | 2,63 | 2,67 | 0,67 | | |
| P ₂ O ₅ | 0,202 | 0,37 | < 0,0123 | | |
| TiO ₂ | 0,785 | 0,616 | 2,39 | | |
| | [mg/kg] | [mg/kg] | [mg/kg] | [mg/kg] | [mg/kg] |
| As | | | | | 15 |
| Cd | | | | | 0,4 |
| Co | 12,7 | 13,5 | < 6,18 | 11 | 30 |
| Cr | 84,4 | 92,1 | 62,1 | 45 | 120 |
| Cu | 25,7 | 31,9 | 6,25 | 22 | 100 |
| Hg | | | | | 1 |
| Ni | 27,9 | 30,8 | < 6,18 | 22 | 35 |
| Pb | 8,69 | 7,98 | < 12,4 | | 80 |
| V | 113 | 116 | 458 | 61 | 120 |
| Zn | 71,4 | 83,7 | 7,01 | 69 | 350 |

Table 4 Leachability of different elements from the investigated stabilized sulfide soil and silty clay soil. As comparison pore water from aerobic and anaerobic sulfide soils are presented as well as German MCL-values for contaminated ground water (Berlin list) and a Swedish drinking water standard.

| Element | Stabilised with 14 weight % L2 | | | | | | Aerobic [mg/l] | Anaerobic [mg/l] | Berlin list I/II/III [mg/l] | Drinking water [§] [mg/l] |
|----------|--------------------------------|-----------------|------------------|-----------------|-----------------|------------------|-------------------|---------------------|-----------------------------------|--|
| | Sulfide soil | | | Silty clay | | | | | | |
| | L/S=4 [mg/l] | L/S=7 [mg/l] | L/S=11 [mg/l] | L/S=4 [mg/l] | L/S=7 [mg/l] | L/S=10 [mg/l] | | | | |
| Ca | 643 | 271 | 171 | 179 | 151 | 135 | 145 | 14 | | |
| Fe | | | | | | | 68 | 10 | | < 0,5 |
| K | 133 | 39,3 | 19,6 | 91,7 | 29,3 | 16,9 | 67 | 428 | | |
| Mg | 0,89 | 0,54 | 0,31 | | | | 46 | 16 | | |
| Na | 178 | 38 | 16,1 | 127 | 24,5 | 11,6 | 286 | 270 | | |
| S | 860 | 336 | 205 | 130 | 50,4 | 29,9 | 165 | 5 | | |
| | [µg/l] | [µg/l] | [µg/l] | [µg/l] | [µg/l] | [µg/l] | [µg/l] | [µg/l] | [µg/l] | [µg/l] |
| Al | 187 | 293 | 315 | 2360 | 2520 | 3120 | 338 | 519 | | < 500 |
| As | 6,36 | 2,43 | 1,62 | 11,6 | 2,16 | 1,01 | | | 40/60/80 | <10 |
| Cd | | | | | | | | | 5/10/15 | |
| Cr | 1,35 | 1,86 | 2,01 | 2,8 | 1,85 | 2,28 | 348 | 27 | 50/100/200 | < 50 |
| Cu | 44,6 | 71,7 | 47,2 | 389 | 108 | 67,1 | 59 | 114 | 40/60/150 | < 50 |
| Hg | | 0,0251 | | 0,069 | 0,041 | 0,0216 | | | 1/2/3 | < 1 |
| Mn | 2,35 | 1,28 | 1,03 | 1,41 | | | 4000 | 1080 | | < 300 |
| Ni | 106 | 33,2 | 17,6 | 200 | 48,1 | 28,8 | 1490 | 100 | 50/75/100 | 3 [#] |
| Pb | | | | | | | | | 40/60/150 | < 10 |
| Zn | 6,54 | | | 4,26 | | | 365 | 938 | 1000/1500/2000 | < 300 |
| pH | 9,7 | 10,2 | 10,3 | 12,0 | 11,5 | 11,6 | 3 | 8 | | |
| κ[mS/cm] | 3,56 | 1,48 | 0,95 | 2,70 | 1,54 | 1,38 | | | | |

Berlin list I/II/III, where I is MCL in a water protection area, II is MCL in river valley/alluvial sediment and III is MCL for an area without aquifer. Bold stile when MCL values (from the Berlin list) are exceeded. [§] Drinking water standard (SLV 1989) for private wells "usable without remark".

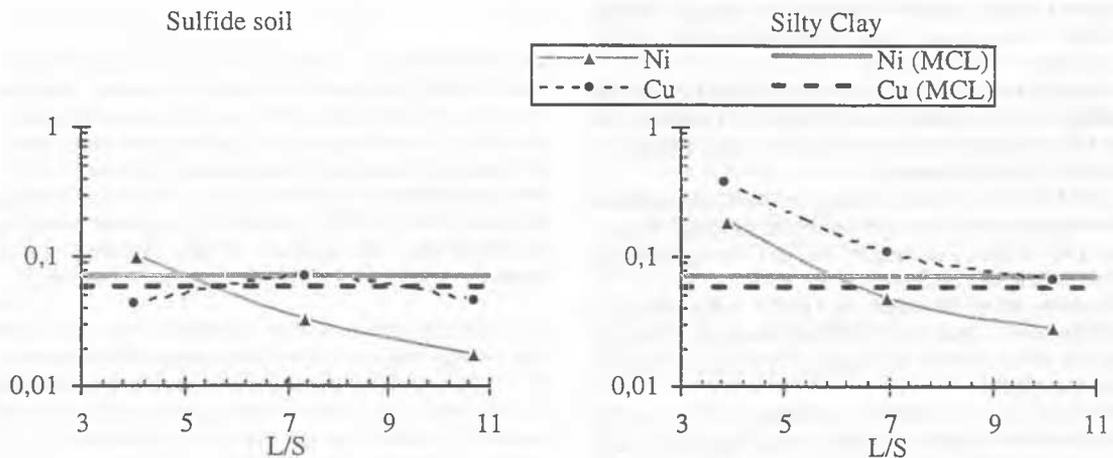


Figure 4 Leachability of Ni and Cu from L2-C50 stabilised soil samples. Distilled water was used as extractant.

vative methods to deal with problems related to drainage, road foundation, etc. The environmental and geotechnical interest in organic soils will increase in the near future.

New standards for laboratory and field investigations are needed for the whole range of organic soils. Soil chemistry as well as traditional geotechnical parameters, must be taken into consideration in these new standards. Soil chemistry and the way it can alter the soil's geotechnical parameters, is a future research area.

Excavation and drainage of sulfide soil and peat-land is restricted. Block-stabilization of these soil types is therefore an alternative soil stabilization method. However, long term stability of stabilized organic soils, subject to leaching, freezing/thawing behavior and biological degradation have not been investigated, and the need for field-data collection is great.

A development of quality control methods for stabilized sulfide soil and peat is needed. In order to assess the stability of stabilized soil samples, development of new sampling devices and appropriate laboratory and field tests is needed.

5 CONCLUSIONS

Air Blast Furnace Slag (L2) mixed with 50-weight % Portland Cement (L2-C50) is an alternative stabilizing agent to Portland Cement/Quick Lime in sulfide soils. The used amount of the additives was 14-weight % dry soil. L2-C50 is a cheaper material than Q-C90 even if the amount added to the soil can be decreased for the latter material. Before stabilization, the investigated sulfide soil had a τ_{ru} between 12 and 50 kPa. After stabilization and a curing time of 30 days the soil samples had a $\tau_{ru} > 75$ kPa. L2-C50 gives a satisfying mechanical stability to the stabilized soil, without neglecting Swedish MCL-regulations for a sensitive soil. Containment of regulated elements in the leachates from laboratory samples is also in the vicinity of German regulations (Berlin list) for ground water.

Also L1-C50 is a material which gives sufficient stabilization effect, $\tau_{ru} > 75$ kPa, however it contains high amounts of V. The leachability of V from pure L1 is high and pH dependent. Leach-

ability of V is high for pH between 11 and 13 and for pH < 5. This material might be improved as a stabilizing agent, from an environmental point of view, if its content of easily leachable V can be lowered by pre-treatment.

Inhomogeneities in geotechnical properties and in element containment of a sulfide soil in the profile can influence stabilization results greatly. Sampling and laboratory testing give important information about achievable stabilization effects as well as inhomogeneities in a profile and along a section of a road or railroad. Stabilization of oxidized sulfide soil layers should be avoided, as this material can decrease the achieved τ_{fu} of a stabilized soil.

The block-stabilized soil in this case is surrounded by semi- to impermeable soils, sulfide soil and a silty clay soil. The only drainage way is upwards in the direction of the surface of the stabilized area. Due to settlement, excess pore water and trapped air will be pressed out from the stabilized block. This settlement will take place during the first 10 to 14 days after stabilization. This excess water will contain dissolved elements, mostly Ca, K and Na, but it may also contain some Ni and Cu. Stabilization with a stabilizing agent should be done with care in restricted areas with groundwater protection as the drained water will have high pH and high conductivity.

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