Experience of MBT-Landfills and Stability Investigations

Karsten Hupe[1], Wolfgang Oltmanns[2], Kai-Uwe Heyer[1],

Fred Brandt[3], Rainer Jäger[3], Rainer Stegmann[1]

[1]IFAS – Ingenieurbüro für Abfallwirtschaft, Prof. R. Stegmann und Partner [Consultants for Waste Management], Hamburg

[2]PROF. DR.-ING. WALTER RODATZ UND PARTNER,
Beratende Ingenieure für Geotechnik GmbH [Consulting Engineers for Geotechnical Enginieering], Braunschweig

[3]AHK – Abfallwirtschaft Heidekreis,
Kommunale Anstalt des Landkreises Soltau-Fallingbostel [Heidekreis Waste Management, Municipal Institution of the Soltau-Fallingbostel District], Soltau

Stability and Operation of the MBT-Landfill Hillern

Abstract

The technical requirements for landfilling of MBT-residues on landfills in Lower Saxony are described and the realisation of the requirements on the MBT-landfill Hillern is explained. In terms of a certain compliance with the geomechanical stability of the MBT-landfill body, recommendations for the landfill operation are developed based on extensive site-specific investigations and stability calculations.

Keywords

MBT-landfill, landfill operation, stability calculation, stability proof

1 Introduction

Since mid 2005, only pretreated domestic and municipal waste may be landfilled. Due to this pretreatment, the waste material and treatment residues to be landfilled differ significantly from the waste usually landfilled with respect to physicochemical and biological as well as mechanical properties. At the time of the changeover there was still little experience regarding properties in landfill behaviour of mechanical-biologically pretreated material (MBP / MBT) on an industrial scale. Detailed guidelines had yet to be developed regarding landfilling practice and constructing corresponding landfill bodies considering site-specific boundary conditions, composition of the waste and physical as well as mechanical properties.

The present paper outlines the requirements for landfilling of MBT-residues on landfills in Lower Saxony and the realisation of the requirements on the MBT-landfill Hillern in the district of Soltau-Fallingbostel. In this context, the results of the geotechnical investigation for constructing MBT-landfills and the resulting requirements for the landfilling practice are presented.

The *Ingenieurbüro für Abfallwirtschaft* Prof. R. Stegmann und Partner (IFAS - Consultants for Waste Management) co-ordinated the attempts of landfilling MBT-residues on the MBT-landfill Hillern in mid 2005 and has been giving advice on the landfill practice since then (Hupe et al., 2006; Hupe et al., 2008). The geotechnical investigation and the geotechnical tests for landfilling MBT-residues have been carried out in collaboration with the engineering office Prof. Dr.-Ing. Walter Rodatz und Partner, Consulting Engineers for Geotechnical Enginieering (RuP) and the Institute for Soil Engineering and Soil Mechanics of the Braunschweig University of Technology (IGB·TUBS).

2 Boundary Conditions

2.1 General Provisions for MBT-Landfill Stability

Hardly any stability problems like slope failures used to arise on landfills for municipal waste, where, up to mid 2005, only untreated waste was deposited. This was mainly due to the relatively high tensile strength of fresh domestic refuse, particularly as a result of strengthening fibres, fibre cohesion (Kölsch, 1995) and some coarse components as well as the relatively high permeability owing to the heterogenous structure.

MBT-residues, on the other hand, have a fundamentally different structure and different geotechnical properties: Tensile strength, for instance, is reduced because of the elimination of reinforcing fibres; and pre-treatment makes the material much finer, more homogenous and also less permeable. The mechanical and hydraulic properties of MBT-residues vary from conventional domestic refuse in coarse fractions to fine textured sewage sludge.

Stability issues in landfills are often closely connected to the water balance and the drainage properties of the deposited waste. Rodatz and Oltmanns (1993) for instance point out the slip of 80,000 m^3 of conditioned sewage sludge (strength φ' = 34°, permeability $k_f = 1 \times 10^{-9}$ m/s) of a 19 m high slope as a result of excessive pore water pressure during disposal works.

Pore water pressure $u = \gamma_w \times h_w$ occurs in water-saturated components, especially with a high placement water content or because of water-logging and unfavourable drainage. This has to be taken into account with stability proofs (see also NMU, 2007/8). Excessive pore water pressure Δu occurs with stress increments $\Delta\sigma$ e.g. as a result of further filling steps or because of deformation of the landfill body. Undrained strength and excessive pore water pressure, inter alia, have to to be known and considered in total stress analyses.

It is customary in practice to determine the drained strength parameters angle of repose φ' and cohesion c' as well as stiffness E_S of MBT-residues in the laboratory and then deduct the characteristic stability proof and usability test values from this, using appropriate geotechnical methods. The characteristic strength values, bulk density values and water levels, if applicable, then help to determine the

- stability (here: slope failure stability) for the global safety (until 2007) or with partial safeties (from 2008 at the latest) required as well as the
- usuabilty (here: system-compatible deformation)

of the planned landfill construction.

The necessary safety values are basically in line with geotechnical situations resp. loading case.

2.2 MBT-Section of the Hillern landfill

The mechanical-biological waste treatment of the waste deposited in the Hillern landfill is carried out in the residual waste disposal plant Bassum (RABA, *Restabfallbeseitungsanlage*). The landfill area of the MBT-landfill is 5,000 m^2 at the basis. The annual increase of landfill thickness is at around 4-5 m with a disposal of 26,000-30,000 Mg/a. The MBT-landfull body will overlie the adjacent landfill segment, which, up until mid 2005, had been filled with untreated municipal waste, with two slope segments.

On the basis of the investigation conducted by IFAS in the summer of 2005 on the disposal of MBT-residues on the MBT test site subject to regulations, the regular disposal is carried out by a caterpillar and a 30 Mg compactor, which has been used before in landfill practice. The landfill density that can be attained during regular operation is at 0.65 kg_{TM}/l (or 95 % of that value in accordance with Annex 3 of the Waste Storage Ordinance, AbfAblV) at a desirable water content of 25-30 % in relation to wet mass (Hupe et al., 2006). From 2005-2008 an average landfill density of 0.66-0.90 kg_{TM}/ at a water of 17-32 % in relation to wet mass was reached in landfilling practice. With this, the established landfill density values are within the range of densities that were determined on other sites:

- Landfill densities for a MBT waste fraction < 60 mm of 0.6-0.9 kg_{TM}/l (Kühle-Weidemeier, 2004)
- Dry densities in function of dry bulk density of the material and the chosen landfill technique: 0.75-0.88 kg_{TM}/l (Entenmann, 2007)

- Results in determining the dry density of 7 landfills 0.75-1.12 kg_{TM}/l (Entenmann, 2008)

2.3 Mechanical and Hydraulic Properties

The examination of the mechanical and hydraulic properties of waste to be landfilled is necessary for the calculation of the landfill outer slope stability and the load-time settlement behaviour. As these parameters for the MBT-residues cannot be directly deduced from the usual (geotechnically) classified parameters, project-specific laboratory tests had to be carried out. What is also important to consider is that MBT-residues are not soil-like waste material, meaning that the usual reinforcing components that take up traction present in conventional, untreated municipal waste are missing. For the stability proof and usability tests the following parameters were determined on-site by analogy with geotechnical methods (see section 4):

- Water content in accordance with DIN 18 121
- Proctor density and optimal water content in accordance with DIN 18 127
- Particle size distribution after wet sieving in accordance with DIN 18 123
- Shear parameters in shear testing with a large shear test jig in accordance with DIN 18 137
- Permeability in accordance with DIN 18 130 (k-value determination)

3 Requirements for Landfilling MBT-Residues

3.1 Requirements in Lower Saxony

In April 2007, the Ministry for the Enviroment of Lower Saxony decided on provisions regarding landfills with MBT waste material. In January 2008, the Ministry added guidelines on how to determine mechanical properties, how to monitor excessive pore water pressure and minimise lecheate formation. The following section deals with requirements for geotechnical stability and explains measure for minimising rainwater infiltration and lecheate in MBP-landfills. There are requirements that have to be met with respect to geotechnical stability for the following parameters:

- Stability
- Testing and using appropriate construction methods
- Landfilling
- Monitoring (in conjunction with backfitting during service operation)
- Documentation and evaluation of operation and monitoring

3.2 Stability and Landfilling

These are the basic requirements concerning landfilling of MBT-residues in Lower Saxony:

Stability: “Stability has to be ensured through friction within the landfill body or through supporting banks. Excessive pore water pressure can significantly result in reducing friction and consequently pose a threat to stability. Provided that there is not enough support, excessive pore water pressure is only admissible if stability is demonstrably not threatened. Otherwise measures have to be taken to prevent the creation of excessive pore water pressure in principle.”

Drainage elements within the landfill body: “The threat of excessive pore water pressure in landfills with little permeability can also be averted by shortening the flow path of the lecheate. For this both horizontal and vertical linear flat drainage elements can be installed within the landfill body. These drainage elements can also be made out of suitable waste if these comply with the provisions of the Waste Storage Ordinance (AbfAblV) or the Waste Disposal Ordinance (DepVerwV). The drainage elements are to be directly connected to the lecheate collection system of the landfill.”

Site-related laboratory test to determine shear strength, water permeability and compressibility have to be carried out to prove the stability. Alternatively, data of corresponding parameters of a joint project can be taken as a basis, if an expert confirms the transmissibility of the data to the respective individual landfill. On this basis and with reference to the landfill boundary conditions, it is then established which prerequisites have to be met to prevent excessive pore water pressure and stability threats.

When taking the tests, the construction speed of the MBT-landfill body as well as possible consequences for pore water pressure have to be considered. In this context it has to be attested that the landfill body still has a sufficient water permeability or swift consolidation, i.e. a swift reduction of excessive pore water pressure, even in compact storage, to prevent pore water pressure that can be a potential threat to stability.

As a precaution with a view to critical pore water pressure and excessive pore water pressure, intermediate drainage layers were developed for the MBT-landfill Hillern and included in the verification calculation (see section 5). Due to this constructive method for minimising potential pore water pressure, no further pore water pressure measurements have to be taken during landfill operation.

3.3 Measures to Minimise Rainwater Infiltration and Lecheate Formation

In accordance with the amendment of the Waste Storage Ordinance (AvfAblV), it is no longer obligatory to cover the surface of the landfill area for MBT-residues with materials impermeable to water. Only “where required suitable construction methods should be taken to minimise rainwater infiltration.”

In the MBT-landfilling practice of the the MBT-landfill Hillern it has proven favourable to forego a temporal cover of the current landfill area for technical as well as operational reasons. Instead of this, additional monitoring measures, inter alia, have been introduced to monitor the water balance.

Pursuant to the provisions regarding landfills with MBT waste material of Lower Saxony, lecheate formation in a MBT-landfill has to be kept to an absolute minimum in accordance with the state-of-the-art. It must not exceed 7 % of annual precipitation.

Landfiling operation at the MBT-landfill Hillern fulfils these requirements by taking the following measures:

- The open landfill area is limited to the minimum necessary for the landfilling operation to run smoothly and flawlessly.
- Areas that are not charged over longer periods of time are temporarily covered during the winter months as necessary to drain off the rainwater.
- MBT wastes are stored in relatively dry conditions and have an important field capacity, so that, even through the evaporation of the open landfill area, little rainwater infiltrates the deeper layers of the MBT-landfill body and leads to lecheate reformation.

The previsous observations concerning lecheate drainage confirm these facts. In the summers of 2006 and 2007, no lecheate drainage in the base drainage was recorded during longer periods of time. Only very little lecheate is recorded in winter. Even after rainfall, there is no significantly higher lecheate drainage, meaning that all requirements to minimise lecheate formation have been met.

4 Laboratory Examinations for the Determination of Geotechnical Parameters

4.1 Overview

Results of project-specific laboratory examinations of representative MBT solid waste (here: fresh MBT waste and three months old MBT waste from the landfill body) can be seen in table 4.1.

Fig. 4.1: Geotechnical parameters of fresh and settled MBT solid waste samples of landfill Hillern

MBT Solid Waste Sample	**Water Content DIN 18121**		**Permeability k_{10}**	**Oedometroc Modulus E_S**	**Proctor Density ρ_{pr}**	
	Mean Value [% DM]	Mean Value [% WM]	[m/s]	[MN/m^2]	Reference DM [g/cm^3]	ReferenceWM [g/cm^3]
3 months settled MBT material (MBT-A with three samples each)						
MBT-A1	58	37	n.a.	n.a.	n.a.	n.a.
MBT-A2	64	39	3×10^{-10}	1.1 – 2.5	0.862	1.411
Fresh MBT material (MBT-N with three samples each)						
MBT-N1	47	32	n.a.	n.a.	n.a.	n.a.
MBT-N2	47	32	2×10^{-6}	1.4 – 2.1	0.856	1.260

DM: dry matter; WM: wet matter; n.a.: not analyzed

4.2 Water Content

Three samples were taken from each of the four test batches and analysed with regard to water content. Both fresh samples show very homogenous water contents of approximately 47% DM or 32% WM. In contrast, samples taken after three months of settling show heterogeneous water contents that mirror the differing water contents even in small parts of the MBT-landfill body. Average values are 58-64% DM and 37-39% WM.

4.3 Compressibility (Proctor Density)

Compressibility of MBT-material was determined by carrying out a Proctor test according to standard DIN 18127 (Proctor work W ≈ 0.6 MNm/m³, test cylinder D = 20.4 cm).

Fig. 4.2: Results from laboratory examination of proctor density of MBT material from landfill Hillern (Institute for Soil Engineering and Mechanics, Technical University of Brunswick - IGB TUBS)

Parameter	**Fresh Material MBT-N2**	**Settled Material MBT-A2**
Water Content [%-WM]	32.1	38.9
Water Content [%-DM]	47.2	63.8
Proctor Density ρ_{pr} [g/cm^3]	0.856	0.862
Density of Wet Sample [g/cm^3]	1.260	1.411

WM: wet matter, DM: dry matter

Results belong to the higher range of proctor density values which were already measured at former examinations in the range of 0.77 – 0.84 g/cm³ with w_{Pr} of 47-52% for fresh MBT-material. Results are within the standard MBT range.

4.4 Permeability

Analysis of water permeability was conducted according to standard DIN 18130-1 with two solid waste samples over a period of five weeks. Permeability values k_{10} (elementary test) were:

- Fresh material MBT-N2 $k_{10} = 2 \cdot 10^{-6}$ m/s
- Settled material MBT-A2 $k_{10} = 3 \cdot 10^{-10}$ m/s

Because of the material composition with comparatively little fine material, a permeability value of $k_f = 1 \cdot 10^{-9}$ m/s (medium system permeability) was used, taking into account bibliographical reference on stability and deformation proofs for MBT-material of Hillern landfill. In addition, stability for a local permeability of $k_f = 1 \cdot 10^{-10}$ m/s was analysed as a limit case in the framework of a sensitivity study.

4.5 Stiffness

Oedometric modulus E_S was calculated according to standard DIN 18135 and under conditions specified in table 4.3. Compression tests were carried out in eight load steps σ_V = 0.02-0.25 MN/m^2 with loading and unloading cycles for simulation of in situ pressures (compression and overlay pressure) with stress increments as a result of surcharge and three time settling recordings on two MBT samples.

Fig. 4.3: Results of laboratory examinations of oedometric modulus ES on MBT material from the Hillern landfill (IGB TUBS)

Parameter	**Fresh Material MBT-N2**	**Settled Material MBT-A2**
Water content at emplacement [%-DM]	47	64
Water content at removal [%-DM]	41	48
Emplacement density $\rho_{d,E}$ [g/cm^3]	0.85	0.86
E_S [MN/m^2] for σ = 0.02 – 0.06 MN/m^2	1	1
E_S [MN/m^2] for σ = 0.06 – 0.12 MN/m^2	2	2
E_S [MN/m^2] for σ = 0.12 – 0.25 MN/m^2	7	7

DM: dry matter

At equal load steps, both fresh and settled MBT-material produced the same oedometric moduli. Both solid samples showed distinctive time settling behaviour. The (geotechnical) transition from consolidation settling (finite primary settling) to long term settling (infinite secondary settling) was not clear. For settled material primary settling stopped after about three weeks; for fresh material settling speeds after 4-5 weeks were still the same if not higher. The reason can probably be found in the more active biological chemical decomposition processes of fresh material.

For test proofs, stiffness of MBT-materials was indicated with $E_{S,k}$ = 1 MN/m^2 for $\Delta\sigma$ = 0.02-0.25 MN/m^2 to be on the safe side with regard to time settling behaviour and potential long-term settling.

4 Geotechnical Verifications

4.1 Assumptions and Boundary Conditions

Following an engineering assessment, the verifications or respectively calculations of the stability and deformation of the MBT-landfill body were carried out including proven geotechnical methods, paying special attention to

- the site-related boundary conditions,
- the results of laboratory tests,
- the provisions, standards and recommendations related to landfills and geotechnical aspects,
- a traffic load from landfilling operations on the site,
- intermediate layers as systematic surface drainages and
- the failure of intermediate drainage layers – also for the assessment of stability without intermediate drainage layers.

On the basis of tests in the context of literature research, the following values were chosen for the geotechnical verifications:

- mean moisture density γ_k = 12 – 15 kN/m^3
- saturation degree S_R at a mean particle density of ρ_s = 2.0 – 2.5 g/cm^3 for
  - fresh MBT-material S_R = 65 – 75 % at w = 47 %
  - settled MBT-material S_R = 85 – 95 % at w = 64 %
    with regard to the max. pore water pressure on the safe side
  - MBT-material Hillern S_R = 100 %

Further boundary conditions of MBT-tipping on the Hillern landfill:

- emplacement area at base: approx. 5,000 m^2
- emplacement volume per year: 26,000 – 30,000 Mg/a
- raise of emplacement height per year: approx. 4 – 5 m/a
- fluctuation of emplacement volumes or respectively discontinued emplacement due to seasonal or weather-induced fluctuations or respectively varying emplacement velocity

Horizontal intermediate drainage layers with 5 m vertical spacing, 30 cm thickness and a min. outward slope of 1.5% are planned for the MBT-landfill body. In conjunction with a saturation of the MBT-material of up to S_R = 100% and at normal traffic loads with a successive built-up of the landfill body, this, inter alia, results in a load-induced excessive pore water pressure due to the 1 m thick emplacement layer with consolidation of 5 m thick layers with unpressurised draining into the surface drainage.

4.2 Slope Stability

The stability of the slope at N = 1 : 3 was calculated pursuant to standard DIN 4084 with varying possible circular and polygonal slip planes under special consideration of the built-up by layers with overlapping consolidation of the layers. The (in 2007: global) stability to be proven was $\eta \geq 1.3$ for the operating state (LF 2: construction state) and $\eta \geq 1.4$ (LF 1) for the final state. For the case of a "failure of the intermediate drainage layers", a safety factor of $\eta \geq 1.2$ (LF 3) was considered tolerable.

According to the partial safety concept pursuant to DIN 1054-2005, which has been applicable since 2008, effects E are multiplied with partial securities γ and resistances R are divided by partial securities γ. It has to be verified that E ≤ R, inter alia, for the serviceability limit state (GZ 1C) or respectively an efficiency factor of

$$\mu = E/R \leq 1.0$$

At first, due to a lack of more detailed tests, partial security values γ following the values given in DIN 1054-2005 were assumed for the MBT-material and examined for the load case combinations LF 1, LF 2 and LF 3.

		LF 1	**LF 2**	**LF 3**
Permanent effects	γ_G	1.00	1.00	1.00
Harmful variable effects	γ_Q	1.30	1.20	1.00
Coefficient of friction tan φ'	γ_φ	1.25	1.15	1.10

Based on the tests, the following values were assumed:

Mean permeability of the MBT-material	$k_f = 1 \cdot 10^{-9}$ m/s
Density	$\rho_k = 1.2$ t/m^3
Stiffness	$E_{S,k} = 1$ MN/m^2
	with $\Delta\sigma = 0.02 – 0.25$ MN/m^2
Angle of friction	$\varphi'_k = 35.0°$

Since the documents evaluated so far did not provide sufficient evidence for a potential cohesion c' of the MBT-material, it was assumed that $c'_k = 0$.

The simulated emplacement velocities (development of the landfill height over time) are shown in figure 5.1. The maximum emplacement velocity proven to be safe starts at max. v ≈ 8 m/a and then decreases to max. v = 6 m/a when reaching the final height, or respectively

H_{MBT} = 0 – 3 m v_{MBT} = 0.7 m/month
H_{MBT} = 3 – 13 m v_{MBT} = 0.6 m/month
H_{MBT} = 13 – 18 m v_{MBT} = 0.5 m/month

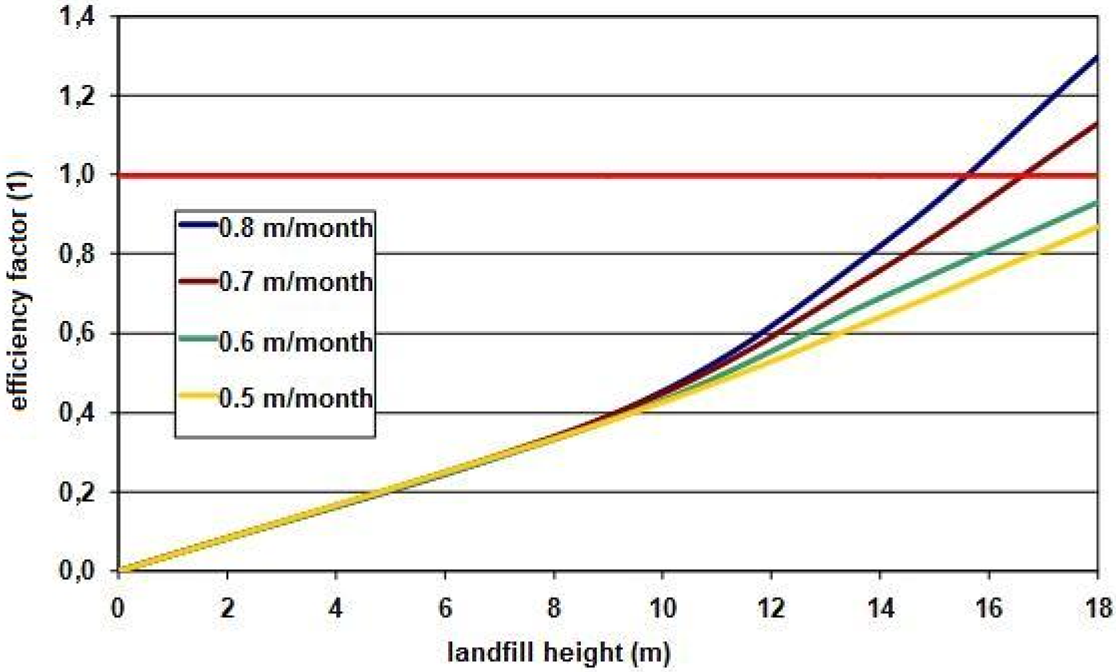

Figure 5.1: Efficiency factor (emplacement velocity) vs. emplacement height

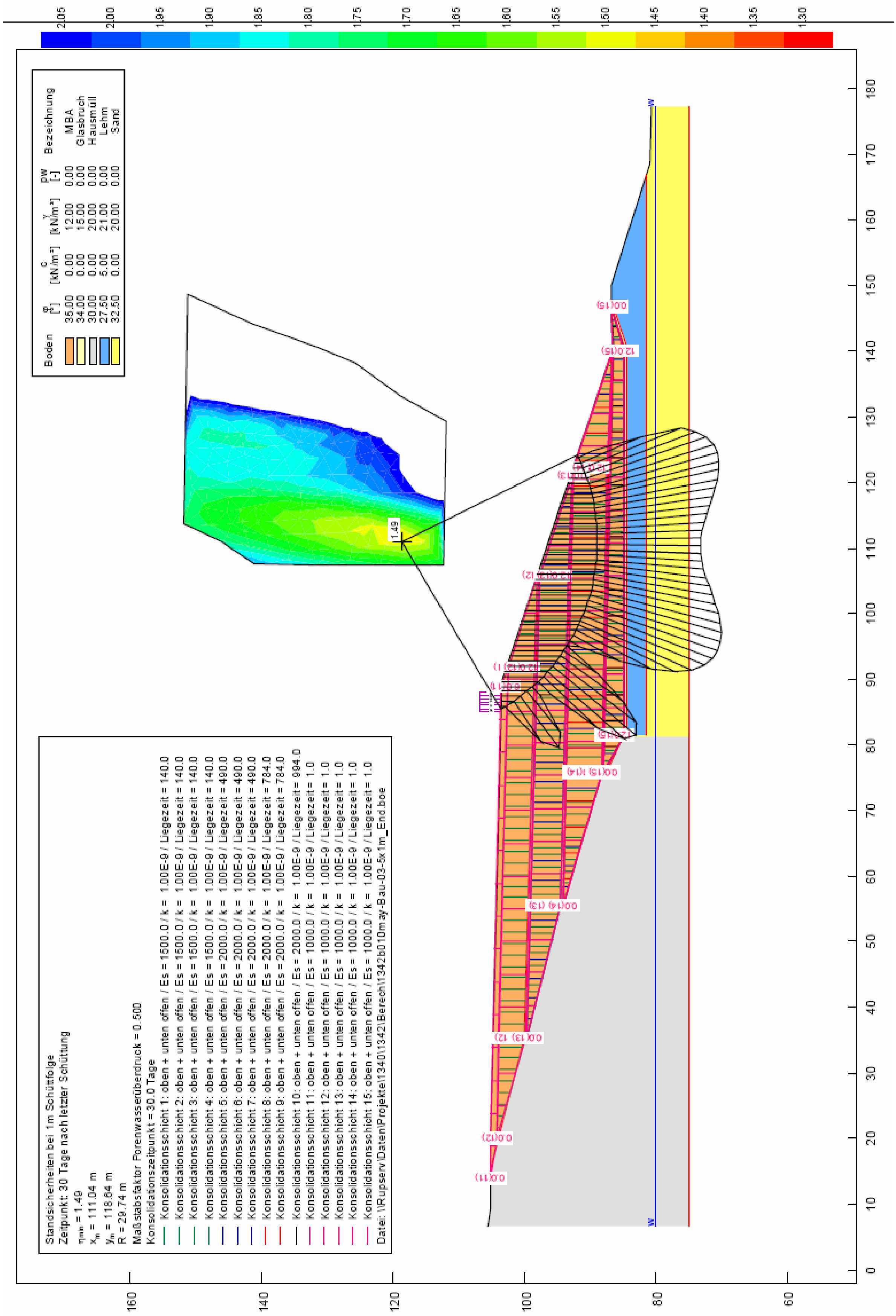

Fig. 5.2: Slope stability verification for the MBT-landfill body in its final state

Legend to fig. 5.2:

Slope stabilities at 1m emplacement layer
Time: 30 days after last filling
η_{mn} = 1.49
x_m = 111.04 m
y_m = 118.64 m
R = 29.74 m
Scale factor excessive pore water pressure = 0.500
Consolidation period = 30.0 days

Consolidation layer 1: top + bottom open / Es = 1500.0 / k =1.00E-9 / settlement period = 140.0
Consolidation layer 2: top + bottom open / Es = Es = 1500.0 / k =1.00E-9 / settlement period = 140.0
Consolidation layer 3: top + bottom open / Es = Es = 1500.0 / k =1.00E-9 / settlement period = 140.0
Consolidation layer 4: top + bottom open / Es = Es = 1500.0 / k =1.00E-9 / settlement period = 140.0
Consolidation layer 5: top + bottom open / Es = 2000.0 / k =1.00E-9 / settlement period = 490.0
Consolidation layer 6: top + bottom open / Es = 2000.0 / k =1.00E-9 / settlement period = 490.0
Consolidation layer 7: top + bottom open / Es = 2000.0 / k =1.00E-9 / settlement period = 490.0
Consolidation layer 8: top + bottom open / Es = 2000.0 / k =1.00E-9 / settlement period = 784.0
Consolidation layer 9: top + bottom open / Es = 2000.0 / k =1.00E-9 / settlement period = 784.0
Consolidation layer 10: top + bottom open / Es = 2000.0 / k =1.00E-9 / settlement period = 994.0
Consolidation layer 11: top + bottom open / Es = 1000.0 / k =1.00E-9 / settlement period = 1.0
Consolidation layer 12: top + bottom open / Es = 1000.0 / k =1.00E-9 / settlement period = 1.0
Consolidation layer 13: top + bottom open / Es = 1000.0 / k =1.00E-9 / settlement period = 1.0
Consolidation layer 14: top + bottom open / Es = 1000.0 / k =1.00E-9 / settlement period = 1.0
Consolidation layer 15: top + bottom open / Es = 1000.0 / k =1.00E-9 / settlement period = 1.0

soil	φ [ ]	c [kN/m²]	γ [kN/m³]	pw [-]	type
	35.00	0.00	12.00	0.00	MBT-material
	34.00	0.00	15.00	0.00	cullet
	30.00	0.00	20.00	0.00	domestic waste
	27.50	5.00	21.00	0.00	loam
	32.50	0.00	20.00	0.00	sand

For example, for the operating states H_{10} = 10 m + 1 m (emplacement height) = 11 m total height, H_{15} = 16 m and max. H_{18} = 19 m total height with $k_f = 1 \cdot 10^{-9}$ m/s and a reduced permeability $k_f = 1 \cdot 10^{-10}$ m/s, the efficiency factor μ immediately after emplacement is:

H_{10} = 11 m total height	$k_f = 1 \cdot 10^{-9}$ m/s	μ = 0.37	
H_{15} = 16 m total height	$k_f = 1 \cdot 10^{-9}$ m/s	μ = 0.59	
H_{18} = 19 m total height	$k_f = 1 \cdot 10^{-9}$ m/s	μ = 0.84	(LF 2)
H_{18} = 19 m total height	$k_f = 1 \cdot 10^{-10}$ m/s	μ > 1.0	(LF 2)

With increasing landfill height, the efficiency factor increases successively or respectively the stability decreases; however, stability is still verified in the final state. By way of calculation, with a reduced permeability $k_f \approx 1 \cdot 10^{-10}$ m/s, slope stability could no longer be verified in a layer of only 5 m immediately after reaching the final height and with fully saturated MBT-material. According to plan and without further verifications, e.g. for a – in terms of stability: positive – slower emplacement or partially saturated landfill material, the permeability of the material must be $k_f \geq 1 \cdot 10^{-9}$ m/s.

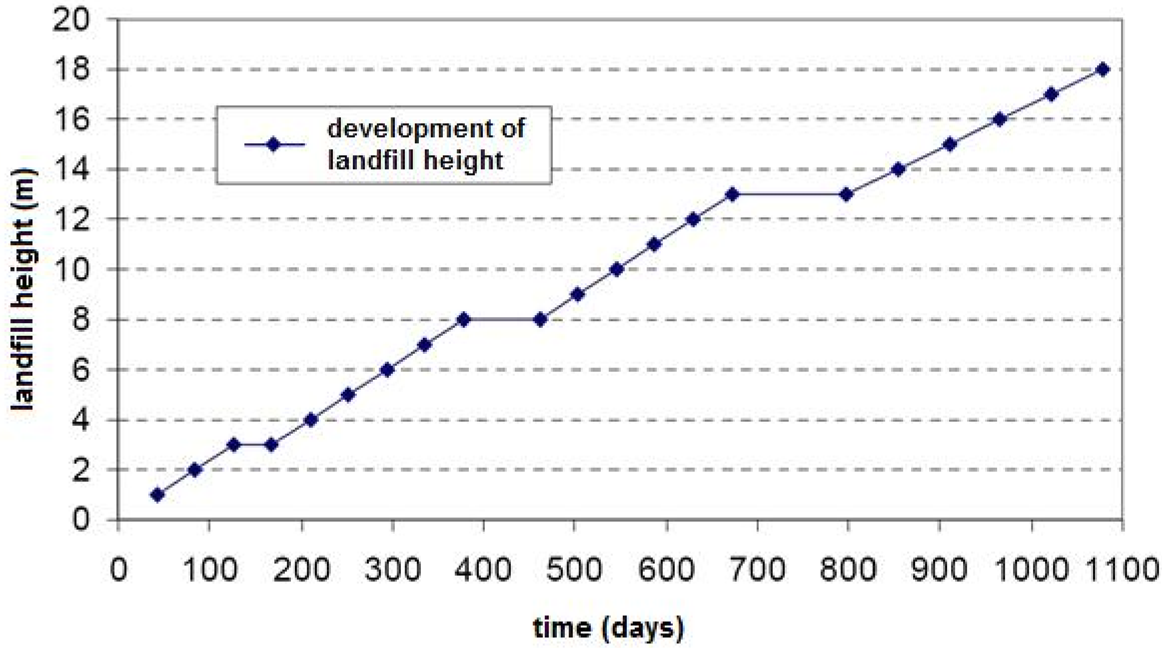

Fig. 5.3: Landfill height vs. time

A conservative estimate for the stability verifications assumed a high emplacement velocity of v_{MBT} = 0.7 – 0.5 m/month. Only <u>one month after completion of the filling process</u> on the final level, the slope stability already increases or respectively the efficiency factor decreases from μ = 0.84 to μ = 0.75.

H_{18} = 19 m final height (1 month) $k_f \approx 1 \cdot 10^{-9}$ m/s μ = 0.75 (LF 1)

In case of failure of one of the intermediate drainage layers, the stability or respectively the efficiency factor would be μ = 0.97 instead of μ = 0.75.

The calculations demonstrate the positive effects or respectively the need for intermediate drainage layers in MBT-landfill construction with relatively shear-resistant, but compressible MBT-material with a very low permeability.

A strength parameter of φ'_k = 35.0° was used for the calculations. Under otherwise unchanged conditions (permeability $k_f \approx 1 \cdot 10^{-9}$ m/s, density ρ_k = 1.2 t/m³, saturation S_R = 100 %, max. emplacement velocity v_{MBA} = 0.8 m/month up to 19 m landfill height at a slope angle of 1 : 3), and with the material of the MBT Hillern at μ ≤ 1.0, the minimum shear strength for the required slope stability is $\varphi'_k \geq 30°$. This strength – and the permeability – should be validated.

Further comparative calculations with higher emplacement velocities demonstrated e.g. that filling velocities significantly above 1 m/month and, at the same time, unfavourable water balance as well as a low water permeability of the refuse (by way of calculation) would cause an extensive slope rupture shortly after emplacement. At the MBT-landfill Hillern, this scenario is prevented by operational and constructive measures.

4.3 Prediction of Deformation

For the intermediate drainage layers (layer thickness 0.3 m, one layer per maximum MBT filling height of 5 m, outward slope N ≈ 1.5%) and under consideration of the landfilling process and overlapping consolidation of the horizontal layers, the settlements S were determined. For the aforementioned emplacement velocities, consolidation ratio of U = 50% (= 50 % remaining subsidence) of the lower MBT-layers for the laying of the surface drainage or respectively the upper MBT-layers were taken into account. Furthermore and as a point of reference, the settlements for the respective consolidation ratio U = 100%, solely resulting from the compressibility of the MBT-material due to further built-up, were determined as the settlement to be expected.

For the MBT-material, permeability was assumed to be $k_f \approx 1 \cdot 10^{-9}$ m/s, stiffness $E_{S,k}$ = 1 MN/m^2 and mean moisture density ρ_k = 1.2 t/m^3. Pursuant to DIN 1054-2005, for the verification of the serviceability limit state (GZ 2) – in this case: verification of the settlements of the surface drainages – the partial securities for permanent and varying effects were set at $\gamma_G = \gamma_Q$= 1.00.

The result of the subsidence calculation is shown as a cross-sectional outline in figure 5.4. Accordingly, the maximum settlements above the slope bottom of the existing landfill or respectively at maximum filling height are:

$H_{Drain} \approx$ 3 m	max. $S_{Drain} \approx$ 0.64 m	min. $S_{Drain} \approx$ 0.60 m
$H_{Drain} \approx$ 10 m	max. $S_{Drain} \approx$ 1.27 m	min. $S_{Drain} \approx$ 1.06 m
$H_{Drain} \approx$ 15 m	max. $S_{Drain} \approx$ 1.42 m	min. $S_{Drain} \approx$ 0.86 m
$H_{LFS} \approx$ 19 m	max. $S_{LFS} \approx$ 1.07 m	

H_{Drain} Height level of the intermediate drainage layer
H_{LFS} Height level of the landfill surface (final level MBT-landfill body)
S_{Drain} Subsidence of the intermediate drainage layer

In view of the target slope of N ≥ 1.5 % in the final state, the calculated settlements of the drainages must be compensated with surcharges during emplacement. The calculated settlements of the landfill surface, which is sloped for the (partial) run-off of precipitations, can be compensated with surcharges during emplacement or with post-shaping measures.

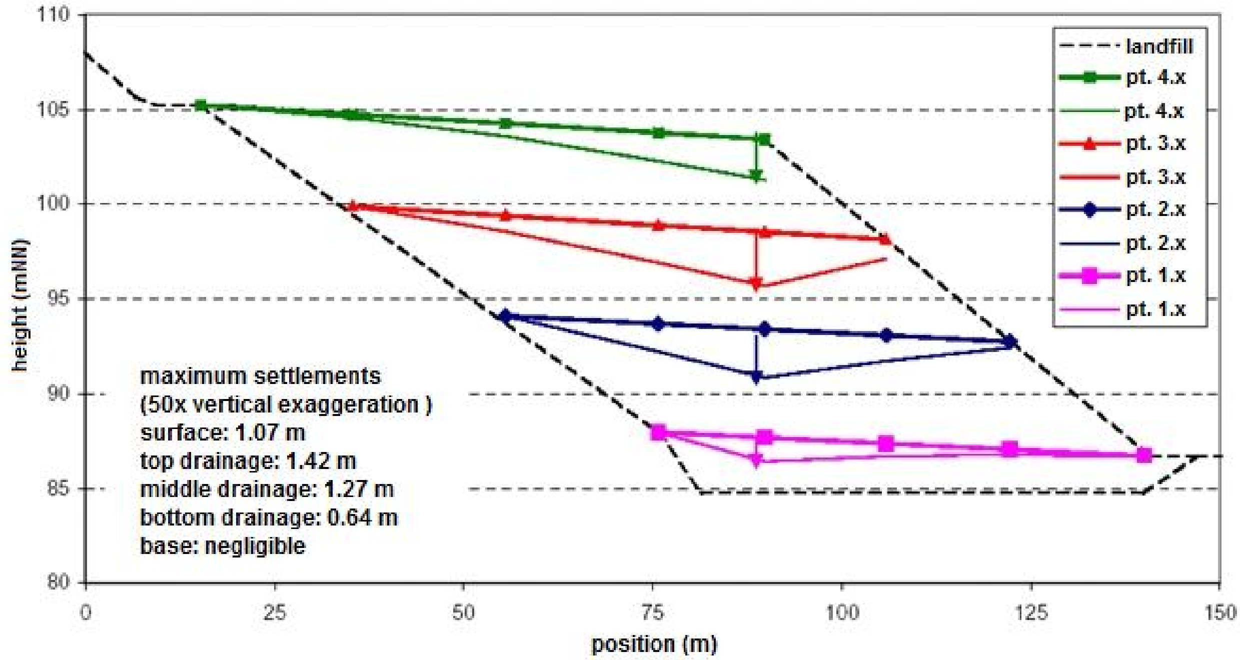

Fig. 5.4: Prediction of Settlement for MBT-landfill

Consolidation ratio: 50% (inherent and currently induced settlements)

Settlement calculation for the MBT-landfill body Hillern, based on the intermediate drainage layers, settlements are shown in vertical exaggeration

5 Recommendations

The mechanical-biological treatment of municipal solid waste changes the composition of the landfilling material as well as its chemical-physical, biological and waste-mechanical properties. Hence geotechnical verifications must be given for new MBT-landfills and new requirements for the emplacement of MBT-material must be taken into consideration.

This report discusses the provisions of Lower Saxony for the landfilling of MBT-material and illustrates their realisation on the example of the MBT-section of the Hillern landfill which is run by Heidekreis Waste Management in the Soltau-Fallingbostel district.

With a view to safeguarding the geomechanical stability of the MBT-landfill body Hillern and similar MBT-landfills, the following recommendations can be made:

- The permeability of the MBT-material shall be checked, especially in the event of changes in the delivered MBT-output.
- The shear strength of the MBT-material shall be checked, especially in the event of changes in the delivered MBT-output.
- Geotechnical methods (particle distribution, water content, compactibility) act as a reference in the classification of MBT-material and should not be over-interpreted, especially with regard to strength, stiffness and permeability.

- In order to lessen potential excessive pore water pressure through settlement compensation, intermediate drainage layers with surcharge shall be installed in relation to the dimensioning; at the Hillern landfill, drainage layers are located as follows:
  - in the slope between the MBT-landfill body and the adjacent domestic waste (existing landfill body) and
  - in the MBT-landfill body with a vertical distance of $\Delta H \approx 5$ m with a maximum MBT-layer thickness of $D \approx 5$ m
  - with a drainage layer thickness of at least 30 cm and
  - with an inclination of the drainage subsequent to final settlements of at least 1.5%.
- The maximum emplacement velocity shall not exceed 5m/year at normal operation.
- The landfilling shall be documented in a space-time waste register.
- The geotechnical verifications shall be checked and updated if necessary, especially in the event of changes in the technical boundary conditions at the landfill or the quality of the delivered MBT-output.
- For landfilling operations, further fundamental aspects must be considered:
  - Low emplacement water contents and functioning drainages as well as a low built-up velocity can minimise the occurrence of excessive pore water pressure. This increases the stability and reduces deformation.
  - Sloped, smooth MBT-surfaces in the construction state minimise water-logging through precipitations and therefore unfavourable saturation.
  - Landfill areas that are not charged over a longer period shall be temporarily covered in order to drain surface water.
  - In the operating state, slopes shall have a maximum inclination of 1:3.

In view of the operation of the MBT-section of the Hillern landfill, it can be stated that the provisions of the Ministry for the Environment of Lower Saxony and the ZUS AWG are met with in terms of

- Stability,
- Testing and using appropriate construction methods,
- Landfilling,
- Monitoring (in conjunction with backfitting during service operation),
- Expected limitation of leachate and
- Documentation and evaluation of operation and monitoring.

6 Bibliography

Hupe, K., Heyer, K.-U., Stegmann, R.	2006	Einbauversuche mit MBA-Reststoffen – Erfahrungen von der Deponie Hillern. In: Deponietechnik 2006 (Hrsg.: Stegmann, Rettenberger, Bidlingmaier, Bilitewski, Fricke), Hamburger Berichte 29, Verlag Abfall aktuell, Stuttgart, 111-130.
Hupe, K., Oltmanns, W., Heyer, K.-U., Jäger, R., Stegmann, R.	2008	Standsicherheit und Ablagerungsbetrieb der MBA-Deponie Hillern. In: 3. Praxistagung Deponie 2008 „Zwischenlager, Deponien, Nachsorge“. (Hrsg.: Wasteconsult international), Cuvillier Verlag, Göttingen, 57-72.
Kölsch, F.	1996	Der Einfluss der Faserbestandteile auf die Scherfestigkeit von Siedlungsabfall. Mitteilungen Heft 133/1996, Leichtweiss-Institut für Wasserbau der Technischen Universität Braunschweig
Rodatz, W., Oltmanns, W.	1993	Rutschung einer Klärschlammdeponie bei Sanierungsmaßnahmen. 8. Christian Veder Kolloquium, Institut für Bodenmechanik und Grundbau, TU Graz
Kühle-Weidemeier, M.	2004	Konstruktion und Betrieb einer MBA-Deponie unter Berücksichtigung der rechtlichen Vorgaben und aktueller Erkenntnisse. In: AVL-Workshop „2005“ – Deponien stilllegen – Deponien weiterbetreiben – am 05.05.04 in Ludwigsburg
Entenmann, W.	2007	Einbau von MBA-Material und anderen Reststoffen auf Deponien. In: Müll-Handbuch (Hrsg.: Bilitewski, Schnurer, Zeschmar-Lahl), Erich Schmidt Verlag, Berlin, 4350
Entenmann, W.	2008	Einbau von MBA-Material – Anforderungen, Monitoringmaßnahmen, Emissionen, Erfahrungen. In: Deponietechnik 2008 (Hrsg.: Stegmann, Rettenberger, Bidlingmaier, Bilitewski, Fricke, Heyer), Hamburger Berichte 31, Verlag Abfall aktuell, Stuttgart, 249-263.
Niedersächsisches Umweltministerium	2007	Ablagerung von mechanisch-biologisch behandelten Abfällen: Umsetzung AbfAblV Anhang 3 Nr.2 Satz 3“; ZUS AWG, Dezernat 32 – Abfallwirtschaftliche Beratung, 10.04.2007
Niedersächsisches Umweltministerium	2008	Annahme und Einbau mechanisch-biologisch behandelter Abfälle: Ergänzende Hinweise vom 16.01.2008 zum Erlass vom 10.04.2007

Address of the authors

Dr.-Ing. Karsten Hupe, Dr.-Ing. Kai-Uwe Heyer, Prof. Dr.-Ing. Rainer Stegmann
IFAS – Ingenieurbüro für Abfallwirtschaft, Prof. R. Stegmann und Partner
Schellerdamm 19-21
21079 Hamburg
Germany
Tel.: +49 40 / 7711 0741 (42)
E-mail: info@ifas-hamburg.de

Dipl.-Ing. Wolfgang Oltmanns
PROF. DR.-ING. WALTER RODATZ UND PARTNER
Beratende Ingenieure für Geotechnik GmbH
Nußbergstraße 17
38102 Braunschweig
Germany
Tel.: +49 531 / 70 136 11
E-mail: info@rup-geotechnik.com

Dipl.-Ing. Rainer Jäger, Dipl.-Ing. Fred Brandt
AHK – Abfallwirtschaft Heidekreis
Kommunale Anstalt des Landkreises Soltau-Fallingbostel
Bornemannstraße 4
29614 Soltau
Germany
Tel.: +49 5191 / 970 681 (631)