Three basic topics on waste mechanics

Trois sujets fondamentaux de la mécanique d'ordures

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ABSTRACT: Three topics on waste mechanics are discussed in this paper: settlement prediction, stability evaluation of slopes and waste-structure interaction. The settlement prediction of municipal solid waste landfills is based on in-situ observations. The slope stability and waste-structure interaction are characterized by large deformations necessary to mobilize the shear strength of the waste. Due to the reinforced-soil like bearing behaviour a high bearing capacity under large deformations can be observed. Centrifuge model tests are performed to investigate the interaction between landfill shafts and waste.

RESUME: Trois sujets fondamentaux de la mécanique d'ordures sont traités dans cet essai: prédiction de pistonnage, évaluation de la stabilité de talus et interaction de la structure d'ordures. La prédiction de pistonnage pour des décharges d'ordures ménagères se base sur des observations in-situ. La stabilité de talus et l'interaction de la structure d'ordures sont caractérisées par des importantes déformations qui sont nécessaires afin de mobiliser l'effort de cisaillement des ordures. Une force portative très importante soumise à de grandes déformations peut être observée à cause de la qualité portative, qui ressemble à de la terre armée. Des tests modèles avec des centrifugeuses sont exécutés afin d'examiner l'interaction entre des puits de décharges et des ordures.

1 INTRODUCTION

The geotechnical engineer designing structures like new landfills or being involved in repair of older or abandoned landfills increasingly has to face problems including waste mechanical aspects. Often this is a challenging geotechnical task as the mechanical behaviour of wastes is of a very complex nature. Of course there are many different waste materials largely differing in composition and mechanical properties. Important geotechnical design problems in the field of waste mechanics are (Jessberger 1996):

- Static and dynamic stability of waste structures, e.g. slope stability and bearing capacity of landfills
- Deformation and settlements of waste structures, e.g. settlement prediction for waste landfills
- Constructions within waste materials, e.g. shafts or tunnels embedded in landfills
- Constructions on waste or on landfills, e.g. buildings on top of landfills for postclosure use

Figure 1 gives a schematic illustration of some geotechnical problems of waste landfills related to the field of waste mechanics (without settlements).

Depending on the composition of the specific waste material the mechanical characteristics may differ from those of typical soils and therefore require special geotechnical considerations. According to GLR (1993) waste can geotechnically be classified into two main groups:

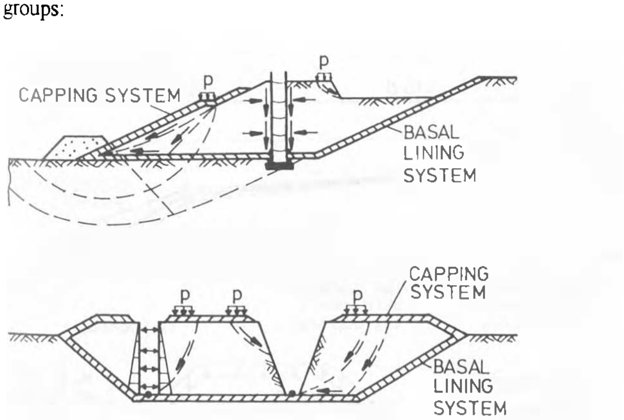

Figure 1. Failure modes with failure surfaces passing through the waste (Kockel 1995)

- Soil-like waste, defined as particulate material for which soil mechanics principles are applicable
- Non soil-like waste, defined as material for which soil mechanics principles are not or only limited applicable

A proposal for a geotechnical classification of different waste types is given in Table 1. Further recommendations for site assessment and classification of waste are described in Jessberger (1996), Kockel et al. (1996) and GDA (1994).

Table 1. Geotechnical classification of waste (GDA 1994)

Soil-like waste	Non soil-like waste
excavated soil industrial sludge road construction debris incineration residue (slag, ash, dust) construction debris sewage sludge	municipal solid waste (MSW) bulky waste "green" waste MSW-like industrial waste waste from construction sites solids residues from mechanical-biological treated wastes

As experiences with waste materials behaving non soil-like are rather few, special knowledge is necessary in the geotechnical design of waste containing structures like landfills. This paper deals with three basic topics of mechanics of non soil-like waste:

- Settlement prediction
- Stability evaluation of slopes
- Investigations on waste-structure-interaction

The following text refers to non soil-like waste deposited on MSW-landfills. This waste will be called MSW though it also consists of soil-like waste like excavated soils etc.

2 SETTLEMENT PREDICTION

2.1 *General*

Surface settlements have to be taken into account by the design and the operation of MSW landfills. A number of mechanisms as e.g. physical compression, consolidation, biodegradation lead to a high deformability of municipal solid waste (Grisolia & Napoleoni 1996). In general a distinction must be made between load induced mechanical settlements and time dependent settlements

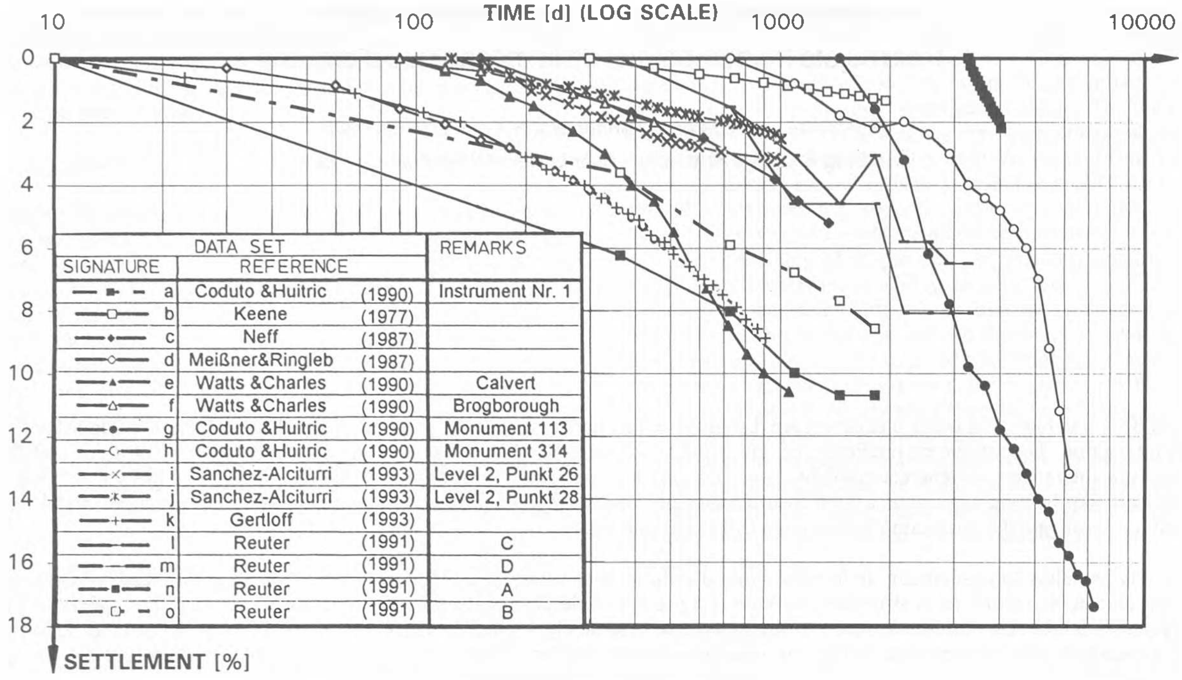

Figure 2. Measurements of surface settlement of different MSW landfills (König et al. 1996)

including biodegradation and physicochemical processes. Up to now the complex deformation behaviour of MSW is not completely investigated and it is not possible to describe all relevant processes with an analytical method. Due to this fact the prediction of landfill settlements is based in practice on existing field observations. A coupling between the gas production and the time dependent settlements is used sometimes

In this presentation we will distinguish between two methods of settlement prediction: Settlement estimation and settlement prognosis. Settlement estimation has to be performed if data from field measurements of the considered landfill are not available. In this case the settlements of the considered landfill have to be estimated on the base of observations of the settlement behaviour of other landfills.

In opposition to the settlement estimation the settlement prognosis is based on available field measurement and therefore takes into account the specific boundary conditions of the considered landfill. The time dependent settlement is predicted by extrapolation of the available data.

2.2 *Load induced settlements*

Confined compression tests are conducted in a large scale compression cell for assessing the load induced mechanical settlements of landfills. Municipal solid wastes of varying age from different landfills in Germany have been used for these tests. The constrained modulus E_s has been calculated from the results in dependence on the vertical stress σ.

It should be noticed that the constrained modulus E_s is derived from the virgin compression and therefore only yields information on settlements of waste that never before has been subjected to loads than higher of those applied in the tests. From these results a linear relationship between vertical stress σ and constrained modulus E_s can be assumed: E_s [kN/m²] = a + b · σ.

2.3 *Data base on time dependent landfill surface settlements*

Some data sets of measurements of surface settlements of different landfills are plotted in Figure 2 versus the logarithm of time. The measurements are taken from landfills located at Europe and North America with MSW of different composition. Other data sets are available by Edgers et al. (1992). The zero of the time axes corresponds to the end of filling the landfill. The settlements are defined as dimensionless relations between the measured settlements and the height of the landfills at the end of filling.

As noticed by Edgers et al. (1992) the settlement curves are characterized by two nearly linear parts showing two different inclinations. The rate of settlement related to the logarithmic time scale changes between 200 and 650 days after the end of filling the landfill from a relative small one at the beginning to a larger one. Up to the end of the observation stage (maximum 10.000 days) there is no clear hint on a further change of the settlement rate.

2.4 *Settlement estimation*

The idealized time settlement behaviour of a municipal solid waste landfill is shown in Figure 3. Concerning the scales of the axes see chapter 2.3. The time settlement behaviour is divided in 3 parts. Load induced settlements, e.g. due to the installation of a capping system, are dominating the settlement behaviour up to 10 days after end of filling the landfill. These can be described by a stress dependent constrained modulus E_s. Analogous to Edgers et al. (1992) the time dependent settlements can be described by the parameters $c_{\alpha,k}$, $c_{\alpha,l}$ and $t_{2,k} = t_{1,l}$.

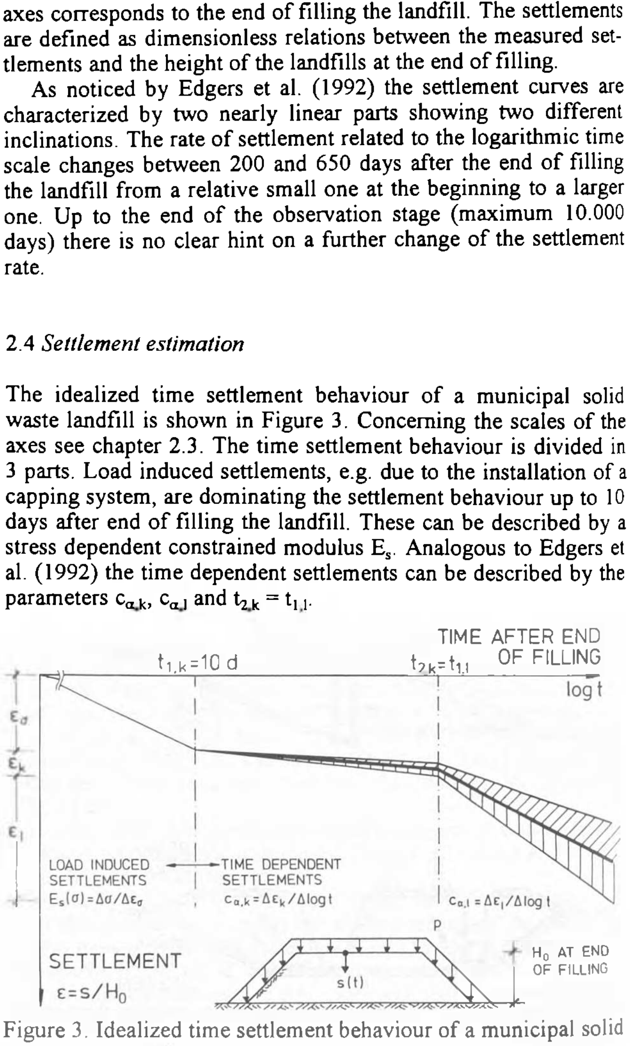

Figure 3. Idealized time settlement behaviour of a municipal solid waste landfill (König et al. 1996)

If there are no specific data available the stress dependent constrained modulus E_s can be estimated from the results of 21 laboratory tests on MSW sampled from different landfills in Germany (Table 2). The data for the parameters $c_{\alpha,k}$, $c_{\alpha,l}$ $t_{2,k} = t_{2,l}$ can be estimated in respect to the data base presented in chapter 2.3 (Table 3) and by Edgers et al. (1992).

Table 2. Prediction of E_s from confined compression tests (König et al. 1996); E_s [kN/m²] = a + b · σ.

	a [kN/m]	b [-]
Number of data sets	21	21
Mean	-200	11,7
Standard deviation	206	1,72
Upper limit of 95%-confidence interval	-106	12,5
Lower limit of 95%-confidence interval	-294	10,9

Table 3. Prediction of the parameters $c_{a,k}$, $c_{a,l}$ and $t_{2,k} = t_{1,l}$ from field measurements (König et al. 1996)

	$c_{a,k}$ [-]	$c_{a,l}$ [-]	$t_{2,k} = t_{1,l}$ [d]
Number of data sets	16	20	20
Mean	0.03	0.102	425
Standard deviation	0.017	0.077	472
Upper limit of 95%-confidence interval	0.039	0.138	645
Lower limit of 95%-confidence interval	0.021	0.066	204

This settlement estimation gives an upper and a lower limit of the expected settlements. It would be helpful for further specification of the settlements to connect the parameters determined by the data base with boundary conditions of the different field measurements, e.g. degree of compaction of the waste. Unfortunately this kind of interpretation of the field measurements leads to insufficient results due to the large number of boundary conditions influencing the settlement behaviour. However, the observation of the settlement behaviour of the considered landfill seems to be the best way to control the settlement estimation.

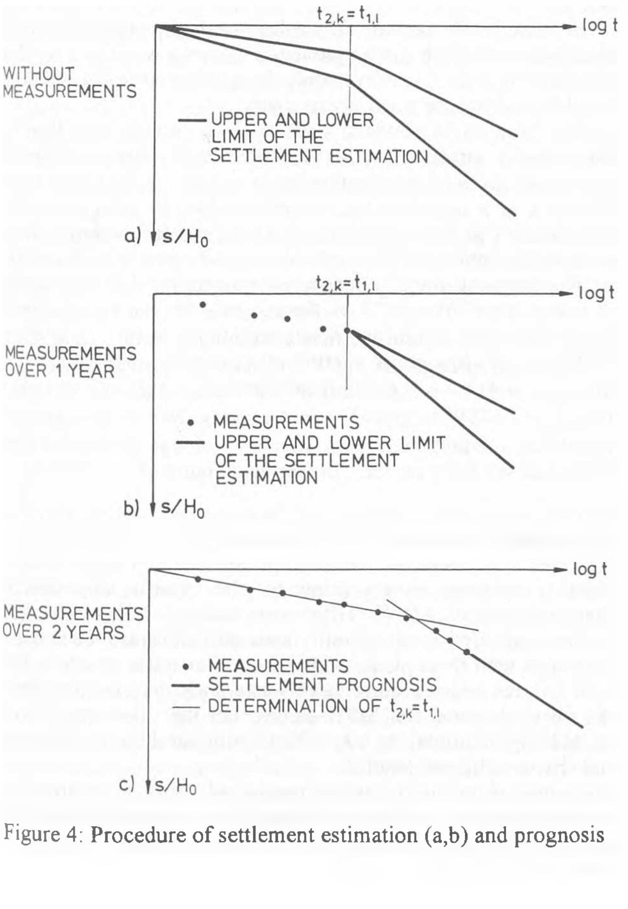

Figure 4: Procedure of settlement estimation (a,b) and prognosis

2.5 *Settlement prognosis*

The settlement prognosis is focused on the prediction of the time dependent settlements. The measurements of the surface settlements taken from the considered landfill are plotted versus logarithm of time as presented in Figure 2. First the parameter $c_{\alpha,k}$ and later the parameters $c_{\alpha,l}$ and $t_{2,k} = t_{1,l}$ can be determined by increasing number of data with time. Following this procedure there is a continuous transition from the settlement estimation to settlement prognosis as shown in Figure 4.

2.6 *Remarks*

When conducting a settlement estimation often load induced settlements due to a uniform surcharge from a capping system have to be determined. According to Figure 3 these loads are idealized as loads added immediately at time t = 0, which means at the end of filling. In the case of loads applied at a time t > 0 it should be realised that this change in stress conditions might have an influence on the rate of time dependent settlements described by $c_{\alpha,k}$ and $c_{\alpha,l}$. Here further research is necessary.

It seems to be surprising that the proposed idealization of the time settlement behaviour does not converge to a final settlement as proposed by many other authors (Sowers 1973 or Grisolia & Napoleoni 1996). This is due to the fact that the presented idealization is based on existing field measurements. The observation period of these measurements may be to short to show a significant convergence.

3 STABILITY EVALUATION OF SLOPES

3.1 *General*

When assessing the stability of landfill slopes several potential failure modes have to be considered (Figure 1). Failure modes which are related to the stability of the waste material are:

- slope failure of the waste slope itself
  failure surfaces are passing solely through the waste
  (in case of temporary slopes or excavations within the waste body the slopes may be supported)
- slope failure of the waste and surrounding soil
  failure surfaces are passing through the waste and the landfill capping/ foundation (basal lining/ capping system and subsoil)

According to E 2-19 (GDA 1995) the specific waste mechanical characteristics must be considered when conducting stability analyses with non soil-like wastes. The most important aspect is the tendency of those materials to undergo large deformations when loaded without reaching a limit state with a development of shear planes.

3.2 *Phenomenology of waste slope failures*

A suitable method for assessing the phenomenological behaviour of steep waste slopes and for understanding the realistic failure mechanisms under continously increased crest loads is the conduction of centrifuge model tests. In a centrifuge model test a 1:n - scale model of a prototype is brought into a high accelleration field of n-times earth gravity g. That means an artificial gravity field of n·g is acting on the model. Stress states of the prototype in the natural gravity field (1g) are similar to those of the reduced scale - model in the ng acceleration field. Further information can be found e.g. in Schofield (1980). The tests described below have been performed in the Bochum Geotechnical Centrifuge Z1 (Jessberger & Güttler 1988).

The tested slope models were constructed of a specially processed, 1 to 3 years old original waste sampled at a MSW landfill. For the use in the centrifuge model tests the original waste is milled and remaining oversize-particles ≥ 16 mm are seperated. After that the model slope with heights of about 20 to 40 cm is constructed by placing the "model waste" in horizontal layers.

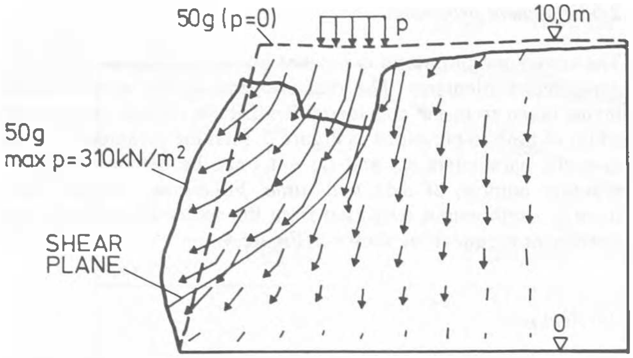

Figure 5. Deformation behaviour of a steep waste slope with steadily increasing crest load, modified from Kockel 1995

A similar stress-deformation-behaviour of a centrifuge model in the ng-acceleration field and the 1g-prototype slope requires the use of a model material with similar stress-deformation-characteristics as the original waste of the prototype. In previously conducted comparative triaxial and oedometric test series it had been proved that the stress-deformation behaviour of the model waste is almost equivalent to that of original MSW over a large range of deformation ($0 \leq \varepsilon 1 \leq 20$). Further information can be taken from Kockel (1995).

The phenomenology of a waste slope can be preferably shown by testing results with steep waste slopes with a steadily increasing (up to failure) crest load on top. An example is given in Figure 5. In this case a slope with an slope angle at 75° and a height of 10 m in prototype dimensions is modelized at a g-level of 50g (model height 20 cm). The crest load is increased during the test from 0 to 310 kN/m². The slope deformation is measured during the increase of the crest load.

The testing results can be summarized as follows:

- The waste slope is stable under selfweight-loads before starting the loading phase (p = 0 kN/m²)
- With increasing crest load extreme slope deformations (vertical and horizontal) are developing without reaching a failure; the "loading block" is penetrating the waste
- When reaching the limit state (p = 310 kN/m²) a shear plane develops with a shear plane reaching from the end of the loading block to the toe of the slope

Similar results had been proven for other testing conditions (Kockel 1995). It can be concluded that non soil-like waste can have a high shear strength but must undergo extremely large deformations before a shear failure occurs. Once the limit state (slope failure) is reached a shear or slope failure similar to that of soils develops. For analyzing slope failure the Mohr-Coulomb failure criterion (φ, c) may be adopted.

3.3 *Shear strength*

According to the Mohr-Coulomb failure criterion the shear parameters φ and c define the shear strength of a soil at failure. In difference to the usual soil mechanical behaviour MSW tends to show large deformation when loaded without reaching a state of failure. This can be proved by laboratory or in situ testing of MSW. In large diameter uniaxial or triaxial test series with original waste a failure cannot be observed for vertical sample compressions of $\varepsilon_1 = 0 \ldots 20\,\%$ (Kockel 1995). However, MSW reveals a high shear strength at large deformations.

Following the composite material model for MSW (Kockel 1995, Kockel & Jessberger 1995) the high strength of the waste results from the reinforcing effect of foil-like, fibrous or other mainly large waste components (fibre matrix) within the waste body.

It is important to note that large deformation is required to mobilize the material strength of MSW. In large diameter triaxial compression tests deformation dependent shear parameters. $\varphi_{\varepsilon 1}$ and $c_{\varepsilon 1}$ can be determined by applying a deformation criterion.

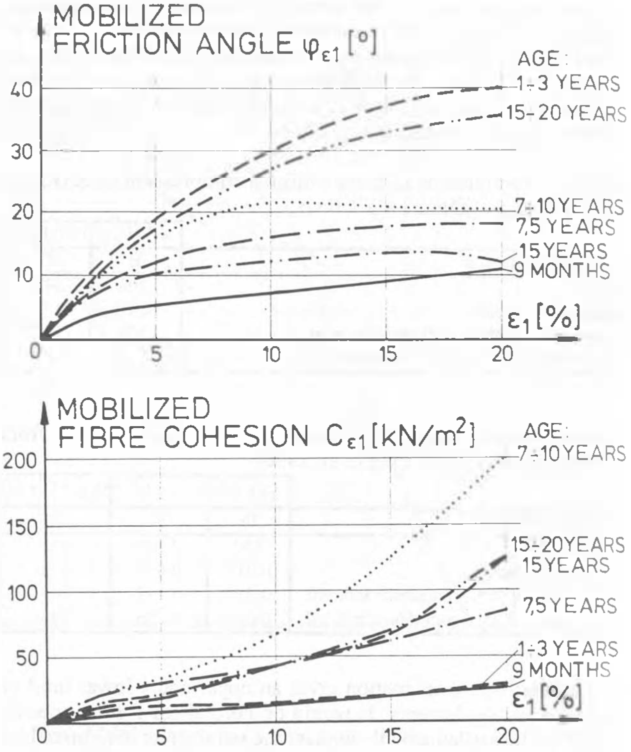

Figure 6. Deformation dependent mobilization of waste shear strength from large triaxial compression tests ∅ 300 mm (Kockel 1995)

Some results of triaxial test series with different types of MSW are presented in Figure 6. As a possible but not significant distinctive mark the age of the waste since deposition has been chosen.

Because MSW naturally is a cohessionsless material the cohesion intercept which can be proved in the tests is defined as fibre cohesion because it results mainly from the reinforcing effect of foil-like and fibrous waste components.

The limit value of the friction angle is usually mobilized at compressive strains $\varepsilon_1 \leq 20\,\%$. This limit value corresponds approximately with the friction angle at limit state (failure) and therefore is a representative material value. In comparison the mobilization of fibre cohesion needs lager deformation. A limit value of the mobilized fibre cohesion usually cannot be observed.

The range of mobilized shear parameters for different wastes is rather large. At $\varepsilon_1 = 20\,\%$ the range is for the friction angle $\varphi_{20\%} = 10 \ldots 40°$ and for the fibre cohesion $c_{20\%} = 25 \ldots 200$ kN/m²

The shear strength of MSW and its mobilization depends on the type and the composition of the waste. One pair of values ($\varphi_{\varepsilon 1}$,$c_{\varepsilon 1}$) for MSW in general is not existing. Moreover it must be noted that a reduction of shear strength with age of the deposited waste had not been proven, yet (see also Figure 6).

3.4 *Stability evaluation*

Stability analyses must account for the specific stress-strain-characteristics of MSW. Often conventional soil mechanical analyses are used in the stability assessment that are assuming a limit state with shear planes within the soil or waste structure. But such failures which require large waste body deformations have not been observed for MSW-slopes. On the other hand large waste body deformations may affect sealing or draining elements and shafts within the landfill.

Conventional analyses can be conducted using a deformation criterion and deformation dependent shear parameters (see 3.3) (GDA 1996). As a rule only those shear parameters of the MSW must be adopted that correspond with the expected waste body

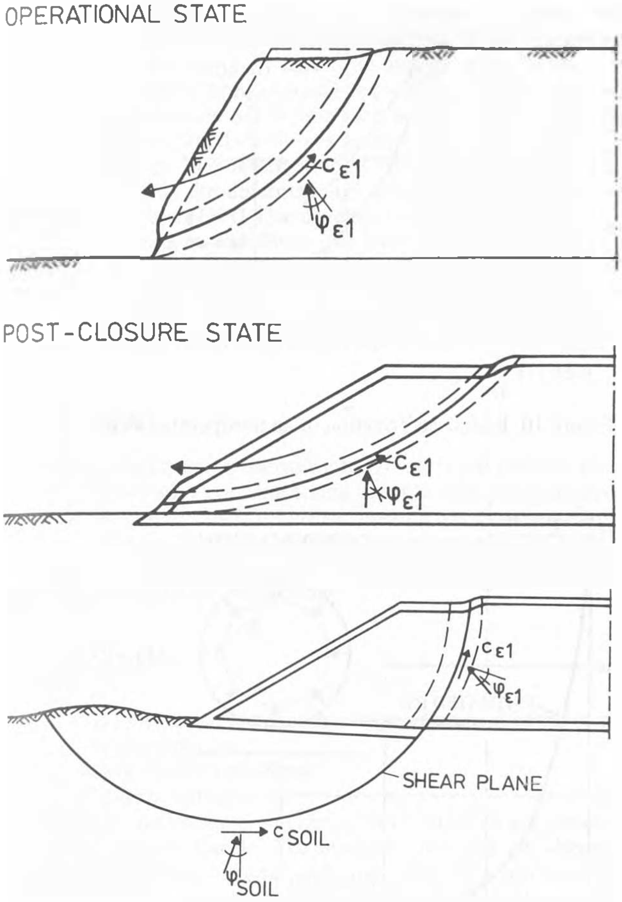

Figure 7. Failure modes and use of shear strength parameters

deformations and the relevant failure mode (Figure 7). The following aspects have to be considered:

- The magnitude of shear strain for soils to reach a shear failure is significantly less than for MSW.
- In the stability analysis for landfills shear planes may pass not only through the waste pile but also through mineral sealing layers or subsoil. In this case the compatibility of the shear strains and the mobilized shear parameters along the failure surface must be guaranteed (see Figure 6).
- Waste body deformations that are required to mobilize the shear parameters which are adopted within the calculations must not inadmissibly affect the lining systems or engineering constructions (e.g. shafts, tunnels) of the landfill.
- If large waste body deformations (e.g. operational slopes) can be tolerated, the maximum friction angle and the corresponding cohesion may be introduced in the calculation.

3.5 *Remarks*

In every stability evaluation the specific deformation criteria (state of deformation, admissible deformation) of the landfill must be taken into account. In advance it is necessary to establish the relevant geotechnical parameters (unit weight, deformation dependent shear parameters) of the waste by use of field measurements or in situ- and laboratory testing. As experiences are still rather few it is strongly recommended to verify the results of stability evaluations by means of field measurements.

When defining the critical state of landfill deformation and the deformation criterion as basis for the adoption of deformation dependent shear parameters in the stability analysis often an estimation is sufficient. For more detailed calculations further deformation analyses are necessary (GDA 1996, Reuter 1995).

Finally it should be noted that still further research is necessary on factors (age, water content, landfill gas) affecting the shear strength of MSW. The age of the deposited waste may not lead to a significant reduction of shear strength witht time (see 3.3). But results according to Kockel (1995) show that an increase of water content may lead to a reduction of the angle of internal friction of the waste. Experiences with influence of pore water or gas pressure on the shear strength of MSW are not existing.

4 INVESTIGATIONS ON WASTE-STRUCTURE-INTERACTION

4.1 *General*

The development of shear resistance of MSW is demonstrated in chapter 3 in dependency of deformations. Mobilization of shear resistance of soils with deformation is one mechanism dominating soil-structure interaction and influencing the loads on burried structures. The knowledge of interaction between waste and structures is still poor and mainly limited to field observations in special cases. Though there is often the necessity to design and construct structures embedded in the waste body of existing or new landfills (e.g. Leachate collection shafts, control tunnels).

Centrifuge model tests have been carried out to understand the principle of waste-structure-interaction and to investigate deformation induced stress redistributions within the waste body near a structure. In all cases a model waste has been used, as described in chapter 3. The longtime behaviour and effects of decomposition have not been taken into account. The investigations are focussed on the interaction between the structures and the waste body influenced by the deformations of the structure. The influence of the overall stress-strain behaviour of the landfill governed e.g. by geometry or inclination of bases and surface was neglected.

4.2 *Trap door tests*

In a first test design a trap door mechanism is used to investigate the activation of the waste's bearing capacity by simulating a realistic stress-strain state comparable to large prototype dimensions. These tests were conducted in the Bochum geotechnical centrifuge Z1. The tests were performed at 1/30 of prototype size and were carried out at 30 g simulating a waste body of about 30 m height. The tests were performed in a rectangular strong box (175 x 900 x 582 mm (w x l x h)). A piston is centrally located in the floor of the strong box. A rectangular plate extends the full width of the strong box and has a length of B = 100 mm. During a controlled downward movement s_v the load acting on the plate is measured.

In figure 8 the vertical stress acting on the trap door is drawn versus vertical settlement of the trap door. At the beginning (s_v=0) vertical stresses at rest conditions can be observed ($\sigma_v = \gamma \cdot h$). By settling the plate this vertical stress will be reduced immediately. At a settlement of about s_v/B= 10 % a minimum value can be measured that will not be influenced by further settlement. This value corresponds to the self weight of the waste mass forced out just below the generated arch.

4.3 *Radial stress acting on a landfill shaft lining*

To understand the dependence of the radial stress acting on a shaft lining on the radial deformation the investigations on two systems will be presented. First the radial stresses acting on a very stiff shaft lining preventing all radial deformation of the waste body (s_r= 0) have been observed. Secondly the deformation behaviour of an unsupported radial symmetrical excavation was studied. In this case free radial deformation and therefore the activation of the full bearing capacity of the waste (σ_r= 0) is allowed.

Several series of centrifuge model tests have been performed to investigate the loads acting on different stiff shaft systems The influence of the placement of gravel between the lining and the

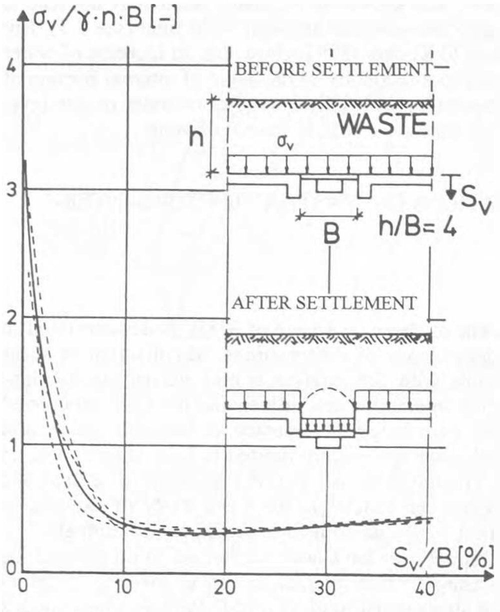

Figure 8. Results from trap door tests

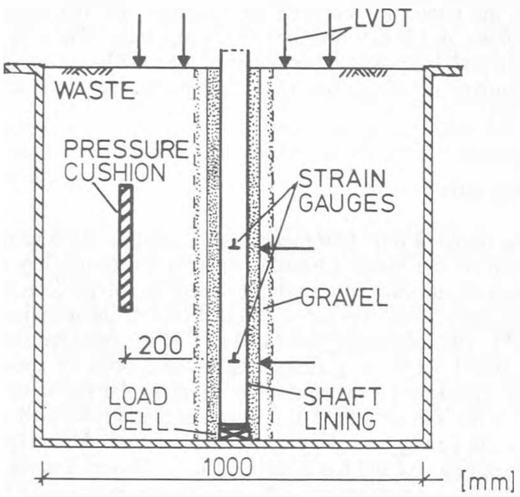

Figure 9. Test design to investigate loads acting on stiff shaft systems

waste on the shear stresses due to negative skin friction and on the radial stresses have been studied (Figure 9). Ununiform loads have been applied on the system by a pressure cushion. However, in the following we will discuss the results concerning the radial stress acting on a stiff shaft lining without gravel between shaft lining and waste under radial symmetric boundary conditions. Further informations on investigated aspects on leachate collection shafts can be found in Syllwasschy et al., 1996.

To simulate a stiff shaft lining a brass shaft model equipped with strain gauges is placed in the middle of a strong box (Figure 9) surrounded by model waste. The complete model fixed in the centrifuge bucket is accelerated to the selected g-level of 40 g. In this way a shaft of 25 m in depth and 3 m in diameter is simulated.

The waste body consolidates due to the acceleration of the model. The settlement and horizontal deformations can be measured by displacement transducers. Shear stresses caused by negative skin friction and radial stresses are acting on the lining and measured when nearly no increase in settlement can be observed.

The test results show that the radial stress of the waste acting on the stiff lining is characterized by K_0-conditions. The ratio between radial stress and the theoretical vertical stress is found to be about 0.3, which is similar to stress ratios at rest K_0 found in laboratory tests.

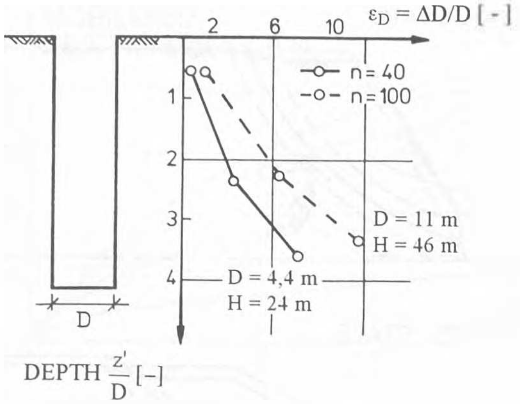

Figure 10. Radial deformation of an unsupported shaft

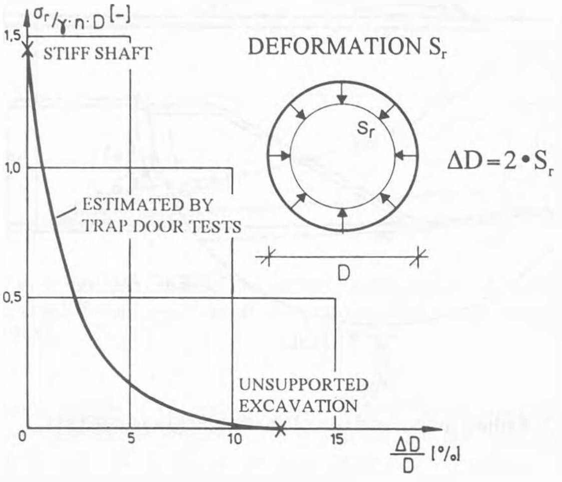

Figure 11. Estimated relationship between radial stress and deformation for landfill shafts (z'= 39 m)

To simulate an unsupported excavation a shaft dummy is placed in the middle of the strong box surrounded by model waste. The shaft dummy will be removed just before the beginning of the centrifuge model test. The radial deformation s_r has been observed during increasing the g-level up to 100 g. By this procedure different prototypes with increasing depth and diameter are modelled.

The reduction of the diameter ΔD of the shaft, measured at two g-levels - 40 g and 100 g -, related to the initial diameter D is plotted versus the dimensionless depth z'/D (z'= actual depth) in figure 10. At 40 g the model simulates a prototype shaft of 24 m in height and 4.4 m in diameter, at 100 g it is 46 m in height and 11 m in diameter.

The shaft model without lining shows even at an acceleration of 100 g no tendency to fail. Large deformations can be observed, from about 2 % of the diameter near the surface (z'= 5.5 m at 100 g) up to 12 % near the bottom (z'= 39.0 m at 100 g) of the shaft. The bearing capacity of the waste is mobilized by these large deformations analogous to the activation of shear resistance as mentioned in chapter 3. The mobilization of the bearing capacity is a presupposition to stabilize the unsupported excavation.

The different test results show that radial forces acting on a shaft lining seem to be dependent on the radial deformation of the lining. A very stiff system (e.g. concrete lining) does not allow significant radial deformation (ΔD/D=0) and the stresses acting on the shaft lining are acting at the state of rest. If large deformations are permitted the bearing capacity of the waste can be activated and the radial stress reduced to σ_r=0.

It may be possible to describe the relationship between radial stress and radial deformation between these two limit states using the results of the trap door tests. The dimensionless radial stress acting on the shaft lining $\sigma_r/\gamma \cdot n \cdot D$ is plotted in Figure 11 versus the radial deformation $\Delta D/D$ for a shaft with a depth of $z' = 39$ m. The radial stress at $\Delta D/D=0$ was measured in the tests using a stiff shaft lining. The deformation $\Delta D/D=12$ % ($\sigma_r = 0$) is taken from the tests on the deformation behaviour of the unsupported excavation (Figure 10). The development of the radial stresses with deformation between these two limit states is estimated from the load-displacement relationship observed in the trap door tests (Figure 8). However each depth z' will have different amounts of radial stress and deformation but nevertheless the general relationships between radial deformation and stress will be the same.

4.4 *Remarks*

The radial deformation necessary to reduce radial stresses has to reach quite a high value concerning the stiff shaft lining materials as e.g. concrete or PE-HD. Further research has to concentrate on the investigation of waste-structure interaction and the lapse of deformation dependent activated earth pressure where this chapter showed some first assumptions.

5 *Conclusions*

Three basic topics on waste mechanics are discussed in this paper:

- settlement prediction
- stability evaluation of slopes
- waste-structure interaction

Methods for settlement prediction of MSW landfills are presented which are easy to handle. The methods are based on laboratory tests in case of load induced settlements and on in-situ observations in case of time dependent settlements. If available measurements on the considered landfill have to be taken into account (settlement prognosis). Otherwise the settlement has to be estimated by the help of a data base of field observations.

The slope stability is characterized by large deformations necessary to mobilize the shear strength of the waste. Due to the reinforced-soil like bearing behaviour MSW shows a high bearing capacity under large deformations. Conventional slope stability analysis can be cunducted using a deformation criterion and deformation dependent shear parameters.

The fact that large deformations are necessary to mobilize the bearing capacity of the waste has to be taken into account analysing waste-structure-interaction. In case of the design of shaft systems the deformation of conventional shaft materials (concrete, PE-HD) is to small to activate stress conditions in the waste different from the state of rest.

However the long time behaviour and influence of biochemical decomposition on the bearing capacity have to be studied more intensive and the overall deformation behaviour of the landfill has to be taken into account considering waste-structure-interaction. In all cases the instrument of field measument observing the overall behaviour of landfills including a complete description of boundary conditions seems to be helpful to understand the complex mechanisms.

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