Deformation and settlement measurements on landfills

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ABSTRACT: Since the German landfill Ordinance came in order in 1993, the settlement monitoring at the landfill base became mandatory. Measuring devices had been already adapted in the late eighties. The hydrostatic elevation measurement has become the most popular exact measuring device. The measuring system enables the direct measurement of the elevation of drainage or settlement pipes. The article introduces the physical principle of hydrostatic elevation measuring and the procedure to carry out settlement measurements at landfills. Results of long-term measuring activities at several landfills are displayed. The results are related to alternative monitoring tasks such as landfill base, intermediate liners, landfill body and landfill cover. Lessons learned from 15 years of landfill settlement monitoring are provided pointing out consequences regarding monitoring frequency and required accuracy. Some suggestions towards construction of landfill components (shafts, pipes, liner systems) and landfill stability are offered. The coming up open data base on landfill settlement measurements is introduced.

1 Introduction

Landfills are still the backbone of waste disposal strategies all over the world. Countries, which are not facing space problems (like the USA), are relying more on landfilling than smaller industrial countries with a high population density do (like Germany and Japan). However, even in these countries, landfilling will not end in a foreseeable time, although the German government set the year 2020 in the political agenda as a target for final landfill closing. During the last 30 years, state authorities have spent a lot of efforts to improve the technical standards of landfills demanding base liners, gas extraction systems, landfill covers and other construction components. Despite all these measures, maintenance and monitoring of landfills often does not meet the high technical level of their construction. It literally appears that the use of modern technical methods is suspended as soon as the landfill starts operating. In terms of geotechnical monitoring, landfills face similar tasks as other huge constructions like dams and dykes. However, monitoring still remains rudimentary. The presentation addresses the state of the art of monitoring technologies for deformations of those landfill components which are not accessible for optical survey.

2 Objectives and basics of settlement measurements

Settlement measurements aim on two major objectives:

- to prove that the landfill construction works properly (liner systems, stability)
- to learn from measuring results for future construction and design

The effects of mechanical loads on the barrier systems and on the subsoil are the major points of interest, due to their significant relevance on primary protection goals. Vertical loads lead to settlements on the base and in the center of the landfill. Settlements may damage the liner systems and drainage pipes and they may create stability problems as well as difficulties to find the right moment to cover the landfill. It is a basic requirement to monitor these settlements, although landfill operators often find the measurings useless pointing on a leak of rehabilitation methods. Beside settlement measurings, the biggest need on information concerns the leachate situation. In order to support a proper leachate balance inside the landfill, the reliability of the drainage system needs to be proved. The drainage pipes are the most important part of the drainage system. They should be visually inspected every year to figure out the need on cleaning or rehabilitation. TV-inspection and settlement measurements are usually a combined activity.

Generally, landfills have two major access ports for monitoring, the surface as the easy one and – more difficult - any kind of pipes (drainage, gas extraction, settlement measuring pipes). Surface control of landfills is not that advanced task. A big range of optical methods are available. However, non-surface measurings are more important to receive information on landfill condition, because the major parts of the landfill construction (liners, drainage system) are covered by waste, hence they are not accessible. Additionally, most parts of the landfill surface change their shape and condition quickly due to waste placement making it useless for long-term monitoring. Therefore, the following presentation will focus on monitoring methods for pipes.

3 Methods

3.1 TV-inspection and related systems

Generally, TV-inspection is the basic instrument of landfill monitoring. At first, it provides visual information on the condition of the drainage pipes. This information is useful for assessing the overall leachate situation as well as the risk and the occurrence of mechanical damages of the landfill base. Figure 1 shows a severely damaged drainage pipe. The 32 mm thick wall of the PE-HD-pipe cracked completely at the crown. The crack runs over a distance of several meters. The type of damage indicates critical mechanical loads for the underlying liner system. However, the pipe still has its required hydraulic capacity, therefore without TV-inspection the damage probably would not have been detected at all.

Figure 1: Damaged drainage pipe – axial crack

TV-inspection technology has developed quickly over the past 15-20 years. Nowadays, several manufacturer offer TV-vehicles specifically adapted for landfill requirements. Basically, a TV-vehicle need to have a working range of at least 300 m, it has to fit into pipe diameters down to 200 mm (8'') and it has to be explosion proofed. A typical TV-vehicle is loaded with additional monitoring systems. Temperature sensors provide information on the temperature in the pipe, laser based measuring systems are useful for measuring the shape of the pipe offering data on mechanical loads. However, concerning the measuring of the slope and the elevation of the pipe respectively, the engineers failed. Although many manufacturers offer vehicles with ready installed inclinometers, for physical reasons, the measuring systems do not work properly– and they never will. The measuring concept bases on monitoring the angle over a small interval of distance, typically every 10 cm (4''). The signal resolution (0,01 % slope, equal to 1/100 mm elevation difference per distance interval) and accuracy (0,1 % slope, 1/10 mm per interval) of the inclination angle is excellent. However, a small measuring error remains in every interval and accumulates with increasing measuring distance. The minimum measuring error of 1 mm per 1 m distance adds up to 30 cm elevation error in a pipe 300 m long. This calculation does not include non systematic errors and reflects the optimal measuring situation. Even elevation errors of 1 m have been recorded in control measurings. Therefore, a camera based inclinometer measuring is needless for assessing settlements. However, the TV-vehicle may be used to carry external sensors like hydrostatic elevation measuring devices for settlement measuring (figure 2 and 3).

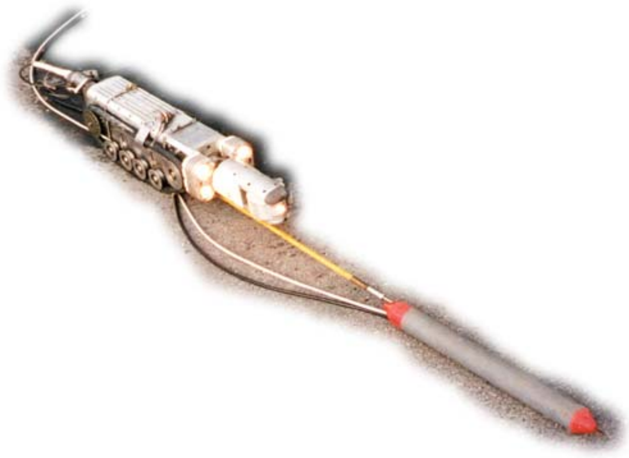

Figure 2: TV-vehicle with elevation sensor

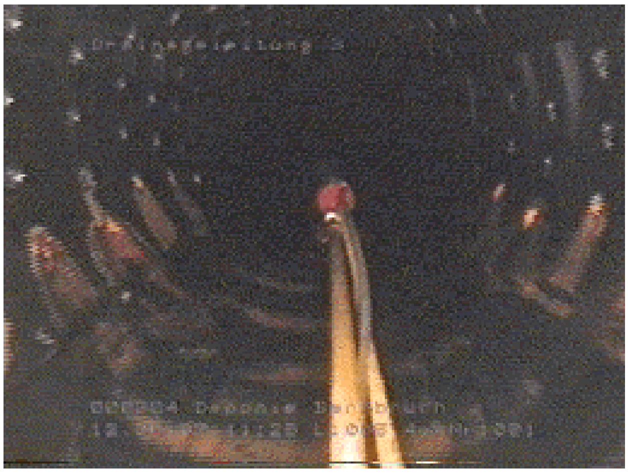

Figure 3: View inside the pipe while driving

3.2 Pipe elevation measuring

Figure 2 shows a TV-vehicle with a hydrostatic measuring device attached, figure 3 shows an image taken by the camera inside the drainage pipe. The most appropriate way to determine settlements of the landfill base is by means of repeatedly measuring the elevation of drainage pipes or a special settlement pipes. Hydrostatic elevation measuring is the only system able to measure pipe elevation exactly. Developed in the beginning of the 20th century and adapted for pipe measuring in the early eighties, it has become a well experienced and reliable technology. Hydrostatic elevation measuring bases on the physical principle that hydrostatic pressure increases linear with the geodetic depth. Figure 4 and 5 sketch the physical concept of hydrostatic elevation measurement.

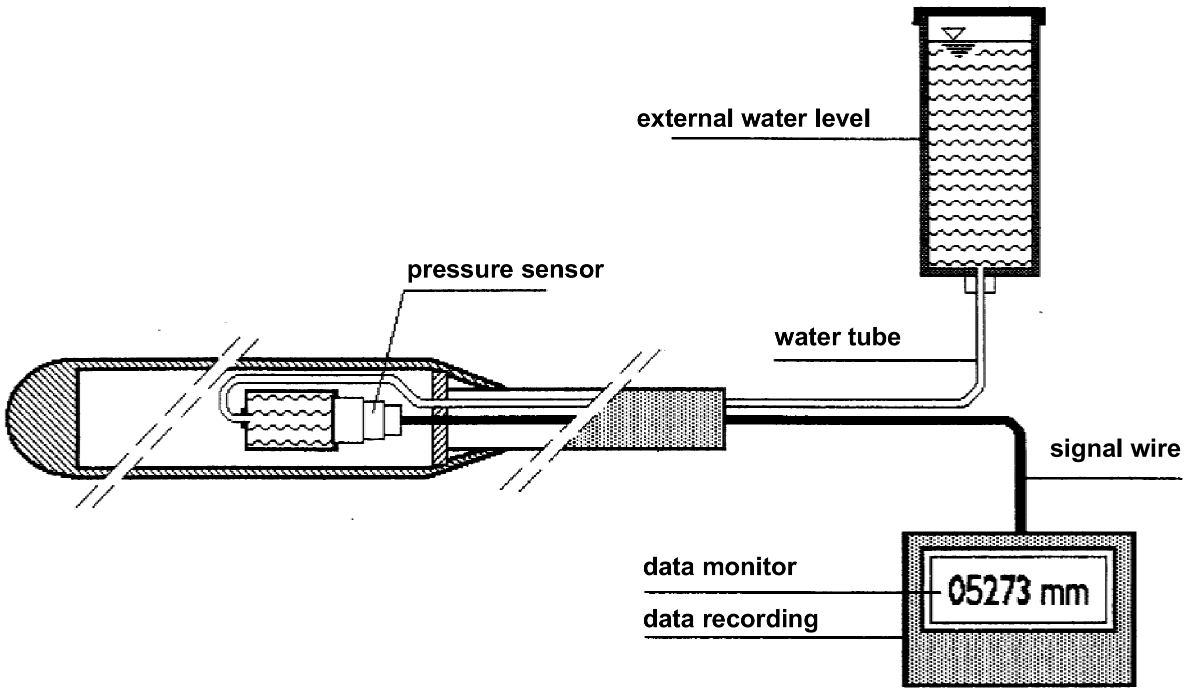

Figure 4: Physical principle of hydrostatic elevation measuring

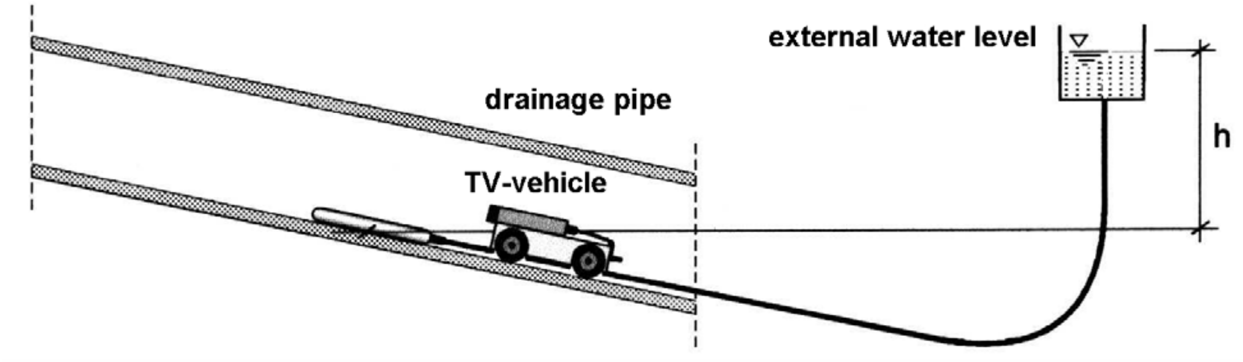

Figure 5: Measuring procedure

To enable measuring the pipe elevation, the hydrostatic sensor needs to be transported into the drainage pipe. This procedure may be realized using the TV-vehicle as illustrated in figures 2, 3 and 5. Alternative transportation systems are pulling ropes (provided both sides of the pipe are accessible) or direct pushing methods by rods. Once the sensor has been placed at the first measuring point, the elevation measurement starts immediately. The water pressure applied by the constant external water level via the water tube is proportional to the elevation difference between the water level and the altitude of the measuring point. In free selectable intervals (usually between 0,5-2 m) more data are collected. Provided the msl altitude of the water level or of one measuring point is given, the entire data can be referred to msl.

4 Monitoring results

Figure 6 illustrates the result of settlement measuring in a drainage pipe. The pipe elevation has been measured three times between 2000 and 2006. To evaluate the overall settlement, the results were compared to the elevation after construction. Total settlement ranges between 10 cm and 30 cm. From 2000-2006, the front stretch (between end of pipe and 60 m) shows settlements which corresponds to higher normal loads in this area. The different subsidence may cause a critical mechanical situation around the area located at 60 m distance. The distribution of settlements is illustrated in figure 7. The maximum subsidence was found next to the end of the pipe (point 10 m).

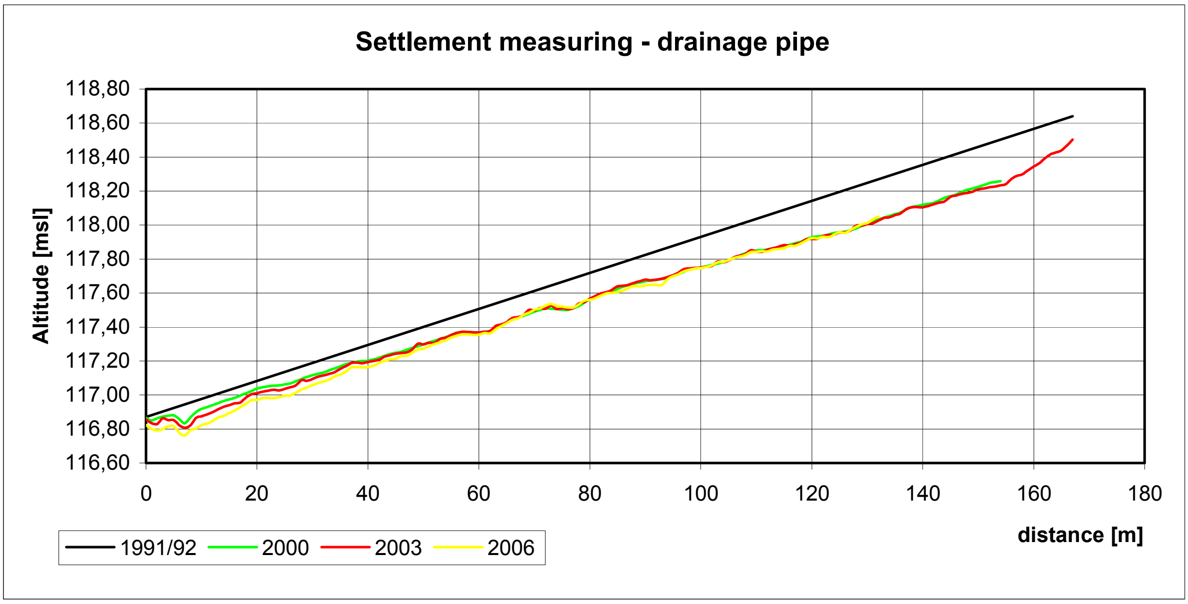

Figure 6: Results of settlement measurings in drainage pipe

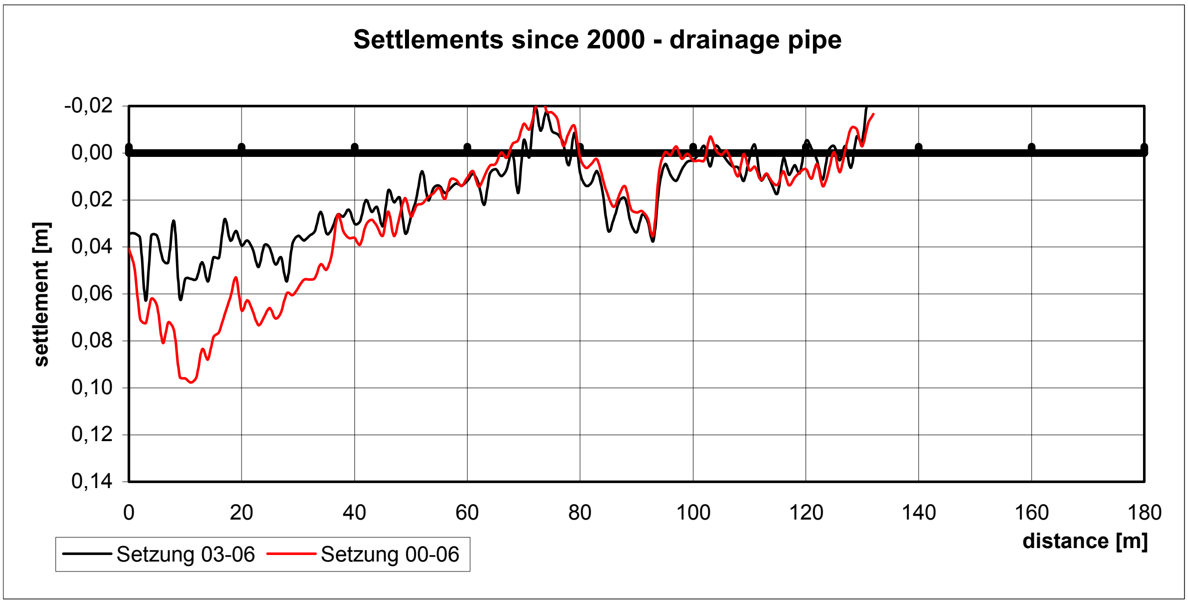

Figure 7: Settlements in drainage pipe

Settlement measuring is also possible inside the landfill, provided an access is available, e.g. via a settlement measuring pipe. Figure 8 shows the result of a almost 20 year monitoring of a settlement pipe (figure 8). The pipe has been installed in 1988, when the landfill was filled with a waste layer of 5 m. Meanwhile, the landfill has grown up to 20 m height. The load on the settlement pipe has reached 15 m waste (equal to 120-150 kN/m^2).

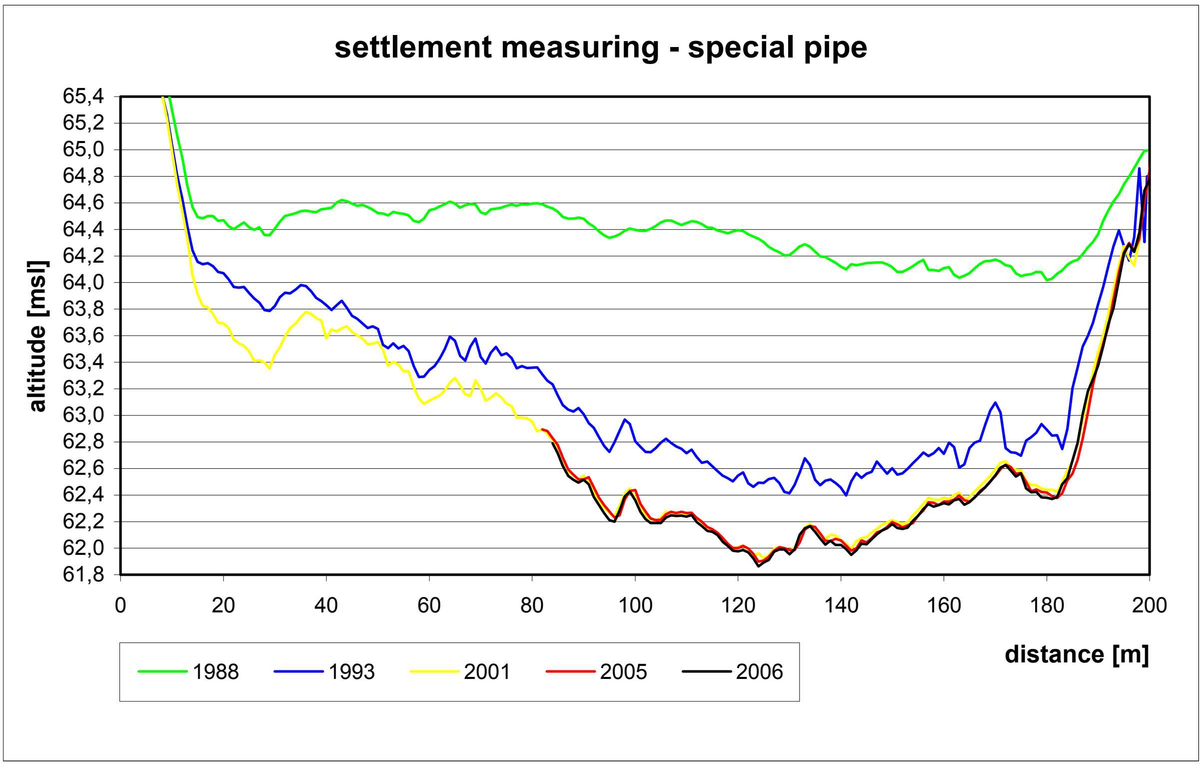

Figure 8: Settlement measurement in special pipe

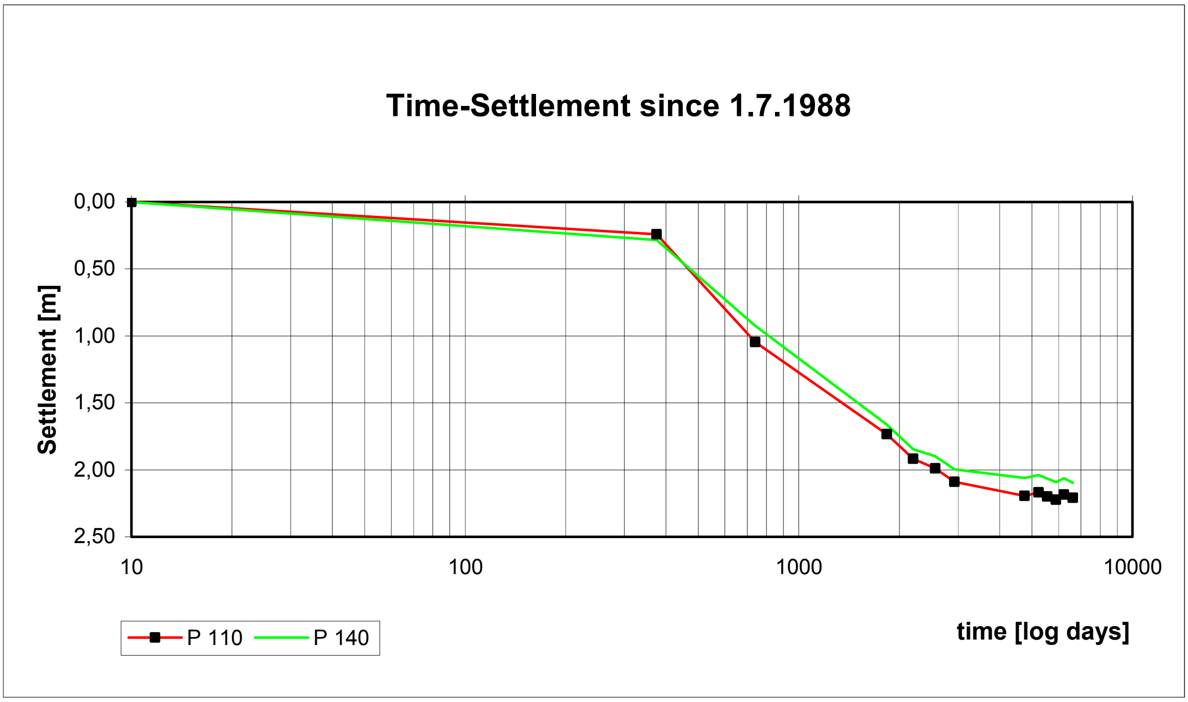

Figure 9: Time-settlement line

The maximum total settlement exceeds 2,50 m or 50%. Figure 9 illustrates the time-settlement line for 2 different measuring points in the pipe. The line shape corresponds to consolidation theory. Although under heavy load and large vertical deformations, the 80 mm (3'') PE-HD pipe, pressure level PN10, is still in function. A camera inspection in 2002 obtained that the shape has changed from round to oval, but still an effective diameter of at least 50 mm is available. The result demonstrated impressively, that the waste settlement can not be monitored from the surface, where the huge settlements had not been recognized at all.

5 Consequences

In 1993, settlement monitoring has become mandatory for landfill operators in Germany. In some places, monitoring measures had started even earlier. Subsequently, a huge data base is available from monitoring activities at German landfills. However, this unique data base probably will not help landfill operators outside Germany. In 2005 German government started an extensive closure program for landfills; research activities had been already stopped. Finally, public interest in those data is limited; hence activities on data evaluation and publishing are small.

Dr. Kölsch GmbH is one major provider for geotechnical measuring services at German landfills. The company serves more than 40 landfills for up to 20 years. Data evaluation is usually not part of monitoring services, since it is in hands of the operator, local consultants or authorities. To make the data base available for international users, Dr. Kölsch GmbH has initiated a national project to collect all data for publishing purposes. Landfill operators will be requested to deliver missing information (landfill height, subsoil condition a.s.o.). All data will be merged and published at

www.dr-koelsch.de

The website will extended by a enhanced section for settlement data of landfills. This project ensures that the results of 20 years of landfill monitoring are not getting lost. It may help landfill operators abroad to learn from other operators. This may avoid that everybody has got to make his own bad experiences.