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LONG-TERM DEFORMATIONS OF MUNICIPAL LANDFILL BODIES AND THEIR EFFECTS ON FUNCTIONAL SAFETY OF SUPERFICIAL SEALING

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ABSTRACT

An approach to risk evaluation against the failure of waste deposit sealing layer is given. It is derived from experience gathered with municipal waste deposit closures. Such deposits were monitored in Central Bohemia in the territory of the Czech Republic. Geodetic observations on such deposits carried out for five to eleven years provided a chance to obtain and interpret continuous deformation data series. Results can increase functional reliability of their superficial sealing and can be used to optimise the time when closure and recultivation should start. The results concern superficial settlement, its development in time and irregularities that are practically very important. Definition of failure criteria that would allow evaluation of limits in irregular deposit settlement is relatively difficult and should become a topic for further investigations and discussions.

KEYWORDS: municipal landfills closure, geotechnical monitoring, settlement data interpretation, functional reliability of a deposit sealing, risk failure of a sealing layer

1. INTRODUCTION

Waste liquidation in the Czech Republic still takes mostly the form of depositioning. That is contrary to Germany or Austria where combustion is regular and deposits are almost always ashes from refuse incinerating plants. In the Czech Republic it is regular to deposit solid municipal waste (TKO), industrial waste, or dangerous toxic waste. This is the reason that such deposits are considerably different from those abroad, where the material is mostly quasi-homogeneous.

TKO deposits found in the Czech Republic contain inhomogeneous and unasotropic materials which, unlike other anthropogenous accumulations, produce considerable settlement due to consolidation and biodegradation of the organic substance whenever present in larger quantities. Regarding the fact that temperature in TKO reach up to 70 ^{0}C, such a deposit is functioning as a bio-reactor which produce depositał water and, in later stages, depositał gas, too. After several years the biochemical processes cause, in some deposits, a considerable reduction in volume. Such processes are very complex and cannot be characterised by usual geotechnical procedures when samples are taken, tested in a laboratory and then the test results implemented. Structures are complex and change in time so that any representative sample cannot be taken. Therefore, interpretation and prognosis of settlement in such waste deposit bodies calls for a long-term geodetic monitoring of survey points.

At present, there are about 360 landfills in the Czech Republic, and about 136 of them should finish operation by the end of 2009. It can be seen that deposition closures, recultivation, and further measures will be connected with geotechnical problems and will call for a good knowledge of the processes leading to deformations. Therefore, geotechnical monitoring is inevitable. Results concerning settlement will be then substantial to define risk connected with the reliability of closures.

2. ANALYSIS OF THE PRESENT STATE OF THE ART

Closure of a deposit is a process successively reaching individual stages. The process is specified normatively in standards ČSN 83 8030 and ČSN 83 8035. Closure of a TKO demands construction of an unpenetrable cover that will prevent infiltration of superficial and precipitation water. Contrary to analogical German standards which call for municipal landfill two sealing barriers (combined or a so called sandwich sealing), Czech standards for waste deposits, class S III and S IV, prescript only one sealing layer (mineral sealing, foil HDPE or another technical sheet).

There are several factors affecting the distortion of the surface of the particular landfill (partially ČSN 80 8035):

- sort of material in the landfill
- depositional technology
- the volume of material
- the length of time of depositioning
- the degree of biodegradation
- compressibility of the base
- closure technology and recultivation
- heights of survey points above the base
- period of monitoring

Evidently, any interpretation of the collected data calls for consideration about specificity of the involved factors at individual waste deposits. Research project of the Czech Grant Agency No 205/06/1666 "Long-term deformations of communal waste deposits and their effects to superficial sealing safety" was carried out in superficial deformation monitoring on five landfills in Central Bohemia, localities Ďáblice, Úholičky, Uhy, Řevnice and Chrást near Březnice, with the aim to identify and interpret

1. *extent and quantification of the settlement;*
2. *time development of the settlement;*
3. *type of settlement - regular or irregular.*

Indication of extremely irregular settlement at a certain point of the deposit calls for a discussion regarding possible failure in the sealing barrier. This can lead to a necessity to reconstruct the barrier and to admit additional costs. Assessment of the extent of failure regarding irregular settlement requires suitable criteria of failure that would be practically verified.

A large quantity of water and gas can be entrapped from a municipal landfill during its service life. This is the evidence that biodegradation processes are decisive for the waste settlement. A complex settlement mechanism of TKO waste calls for a long-term investigation of the main involved processes. They were determined (Sowers, 1973; Edil et al., 1990; Sharma and Reddy, 2004) as follows:

1. Physical and mechanical processes which lead to consolidation of soil that comes out of reorientation of the solid particles and of the transport of the fine fraction into larger and disintegrated pores.
2. Chemical or physical-chemical processes due to corrosion, mineralization and oxidation.
3. Processes of dissolution when liquids contained in the waste percolate progressively through the waste material dissolving their soluble components.
4. Biological processes of disintegration represented by progressive decay of organic materials in the waste. Putrefactive processes are governed by temperature, humidity, as well as quantity of organic materials and nutrients in the waste.

Numerous methods of landfill settlement evaluation were published abroad on the basis of monitoring results (Dodt et al., 1987; Ling et al., 1998; Park et al., 2002 in Sharma and De (2007)). Data from a long-term monitoring of settlement movements on the landfill surface is a common provision for such models. The necessity of geodetic survey of selected municipal landfills in the Czech Republic is supported by the finding that data about rate and development of deformations collected from the foreign municipal landfills are of little use for us because the TKO composition is different in this country and so even the deformation develops differently.

Such a conclusion has been confirmed by the evaluation of deformations of the Ďáblice deposit which was under investigation in the passed years (Škopek and Kudrna, 1997; Kudrna and Škopek, 2004a, b), as well as verified by further published findings (Kudrna, 2007 a, b), (Kudrna, 2008) and (Kudrna, 2009).

3. INSTRUMENTATION PROBLEMS AND MONITORING

Instrumentation of depositional bodies with geodetic means represents installation of plastic marks of the type Harpon to reach a non-freezing depth. The number of survey points is to be chosen in respect of the area of the deposit and the period to be covered. We set ten to twenty marks as a rule. Experience shows that about one third of the points get out of operation being damaged during the life of the landfill.

In the case that monitoring has been organised before closure of the landfill, consequent recultivation results in an interruption of monitoring continuity, and new series of survey points has to be set up and a new phase of measurement is to be started. Evidently, such an interruption of continuity results in complications for interpretation of data.

Monitoring of a landfill is important not only due to operational and economical reasons but even from the point of view of safety. This is why a standard ČSN 83 8036 "Waste deposits - monitoring" puts it as compulsory.

Top ground elevation of the deposit given in the project must respect different conditions and demands, like preservation of the landscape character etc. The decision will come from the Office for regional development and environment. Such a normative regulation regarding top ground elevation may often determine possible profitability of the deposit in the given zone. The elevation given in the project should be generally understood as the elevation reached finally after stabilisation. This may be 15 to 25 years after the deposit being closed. There is an obvious move to use the deposit to the maximum

Table 1 Monitored landfills. Maximum value of the landfill height and the absolute and relative settlements of the surface.

Municipal landfill localities	Maximum landfill height (m)	Absolute settlement (m)	Relative settlement (%)
Ďáblice	34.5	4.04	14.53
Úholičky	30.2	2.63	8.74
Uhy	23.9	0.93	3.89
Řevnice	19.8	0.28	2.24
Chrást near Březnice	16.6	0.33	2.54

and deposit maximum bulk of waste in it. This aspect will call for the waste deposition project being able to define even its superelevation which after the stabilisation will satisfy final conditions. This task can be reached with the use of monitoring, too. This is also one aspect which calls for having data about landfill bodies behaviour that may help to set the necessary prognosis of the behaviour.

4. ANALYSIS OF LANDFILL SURFACE SETTLEMENT

Characteristic data about landfill surface settlements can be found in Table 1. Here, data obtained from the investigated landfills show extremes in landfill height confronted with absolute and relative settlement. Relative settlement in percentage is defined as the absolute settlement in proportion to the distance between the landfill top point and bottom.

It is evident that maximum values are not quite representative for the settlement at individual landfills. In spite of that they provide a decisive parameter for the reliability of the in function. To obtain a view of the landfill behaviour in its bulky volume one should accept an average calculated from absolute settlements. One can consider the average calculated at individual dumps in question after the last measurement of March 2009: Ďáblice 2.15 m, Úholičky 1.55 m, Uhy 0.56 m, Řevnice 0.17 m, Chrást near Březnice 0.23 m. However, the average loses its reliability in case of an insufficient number of survey points. This is the case of the locality Chrást near Březnice. Therefore, we will rather characterize behaviour of individual landfill bodies with graphs of time settlement.

Figure 1- this is time settlement of the Ďáblice landfill in its oldest section (points 1, 3, 7 and 9). One can observe that this section has deformed almost as one compact body and shows very low irregularities in settlement. Scatter in absolute settlement reads 1.94 to 2.32 m.

Quite different situation was found in the other section of the same Ďáblice landfill (Fig. 2 - points 11, 13, 15, 17, 19 and 20), as well as at Úholičky landfill (Fig. 5), which displayed a considerable irregularity in settlement. This section of the Ďáblice landfill proved scatter in absolute settlement 1.4 to 4.04 m, and in the case of Úholičky (points 9, 12 and 13) it was 0.55 to 2.45 m in actually recorded absolute values of settlement.

Absolute settlement in the other localities was lower and reached only several dm. Here, scatter observed in settlement values reads moderate to higher level: Uhy (points 14 to 20) – settlement 0.26 to 0.93 m, Řevnice (points 1 to 8) – settlement 0.13 to 0.28 m, Chrást near Březnice (points 8 and 9) – settlement 0.14 and 0.33 m (Figs. 7, 9 and 11).

On top of the values of *absolute settlement* ΔH *(m)* which demonstrate well the course of settlement, the interpretation works often with *relative settlement* $\varepsilon = \Delta H/H$ *(%)* at a graphical semi-logarithmical scale. Such a graph is suitable to detect transition between *short-term (primary) and long-term (secondary) development in settlement*. Detected boundary is specific for each landfill and differs according to different factors involved. E.g. Koenig et al. (1996) came to the boundary between primary and secondary settlement $t_{2,k} = t_{1,l} \approx 1$ year. Jessberger et al. (1995) analysed the behaviour of a large number of landfills an defined a mean value $t_{2,k} = t_{1,l} \approx 425$ *days.*

Our measurements at Ďáblice (Figs. 3 and 4) provide this value, too. The boundary can be found in the interval of gradient change in the course of the curve and occurs approximately between 200 and 300 days in the graph. At the other investigated localities one can find that this boundary between primary and secondary settlement develops somewhat later and appears close to 2 years (Figs. 6, 8, 10 and 12).

The period of secondary settlement allows a more competent definition of the landfill behaviour with the use of the *coefficient of compressibility* C_α which is defined as $C_\alpha = \Delta H / H \;/\; \log (t_2 / t_1)$ (Koenig et al., 1996). Jessberger et al. (1996), on the basis of a statistical evaluation, comes to a mean value $C_{\alpha,k} = 0.03$ for a short-term compressibility coefficient and a mean value $C_{\alpha,l} = 0.102$ for a long-term compressibility coefficient.

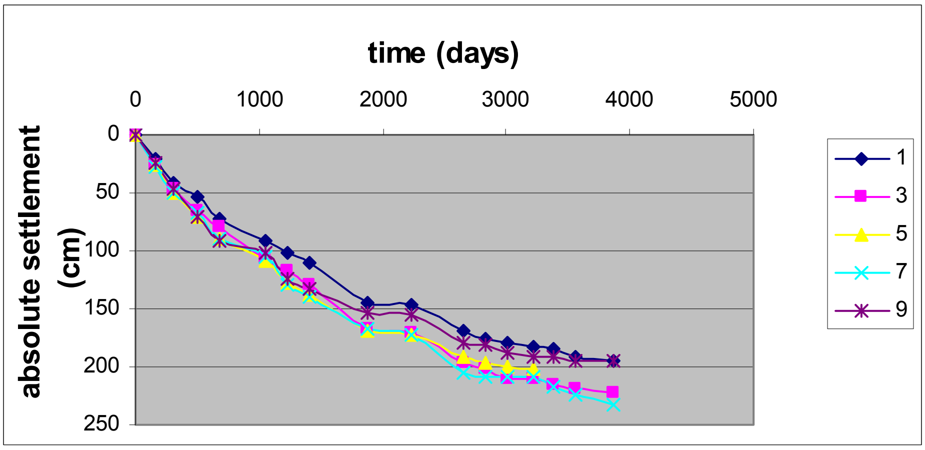

Fig. 1 Ďáblice - time development of the absolute settlement from 24.07.1998 till 19.03.2009.

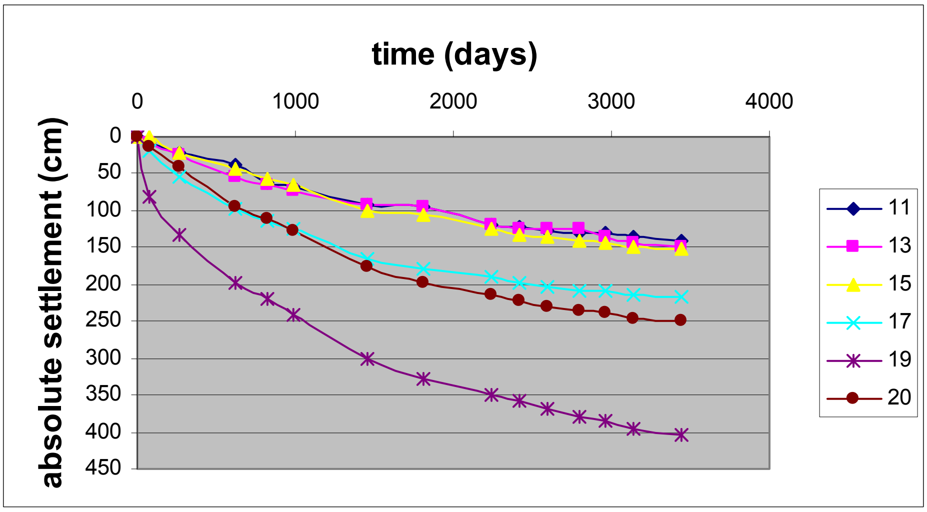

Fig. 2 Ďáblice - time development of the absolute settlement from 15.10.1999 till 19.03.2009.

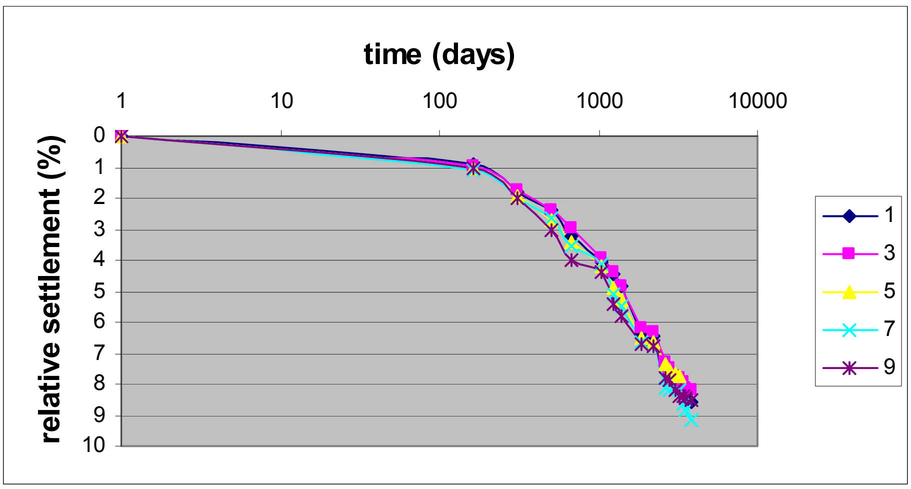

Fig. 3 Ďáblice - time development of the relative settlement from 24.07.1998 till 19.03.2009.

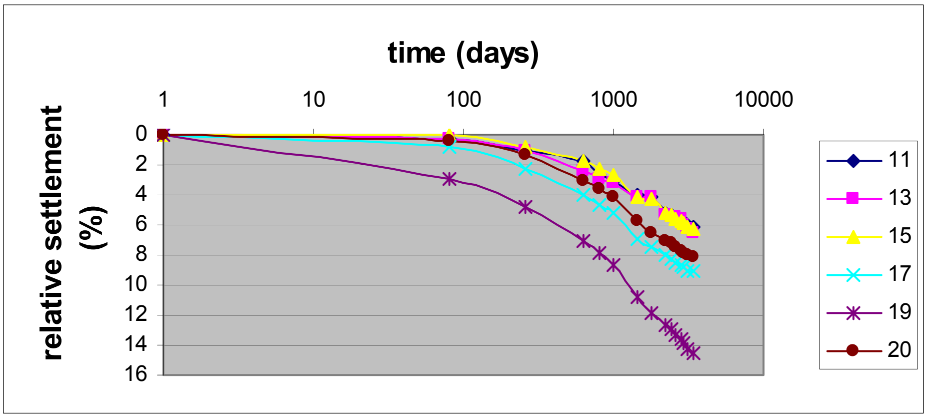

Fig. 4 Ďáblice - time development of the relative settlement from 15.10.1999 till 19.03.2009.

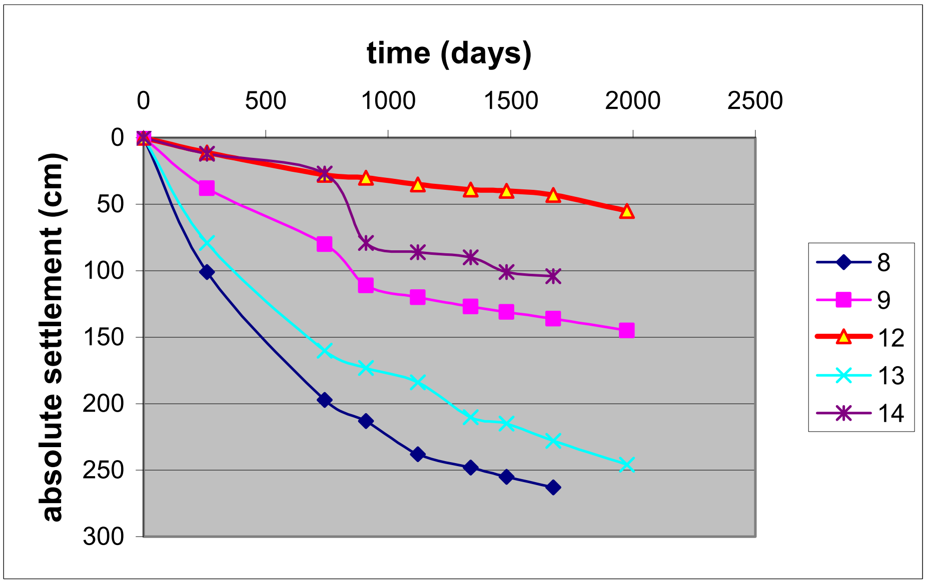

Fig. 5 Úholičky - time development of the absolute settlement from 14.10.2003 till 12.03.2009.

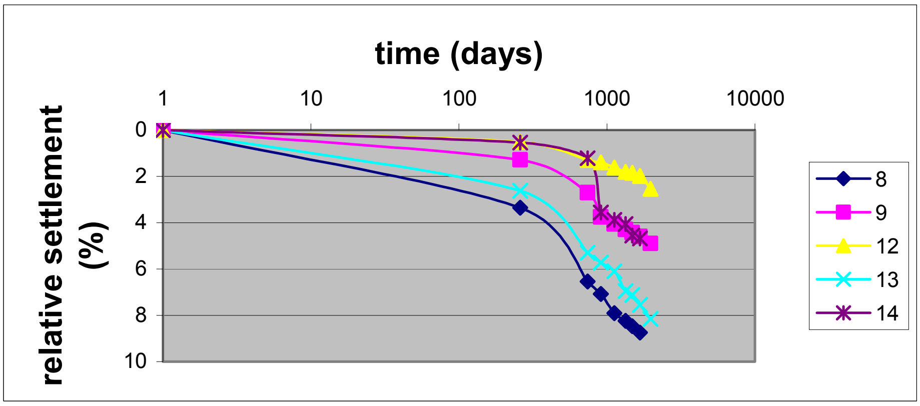

Fig. 6 Úholičky - time development of the relative settlement from 14.10.2003 till 12.03.2009.

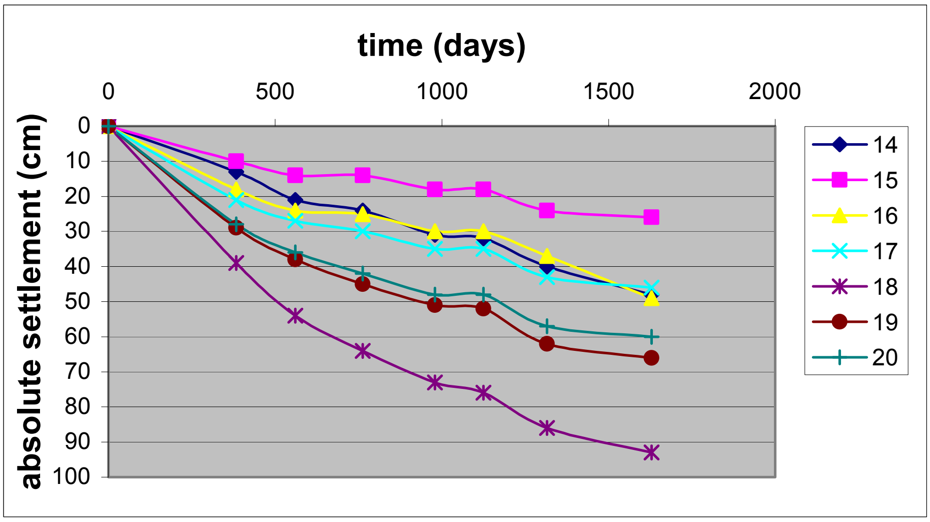

Fig. 7 Uhy - time development of the absolute settlement from 07.10.2004 till 24.03.2009.

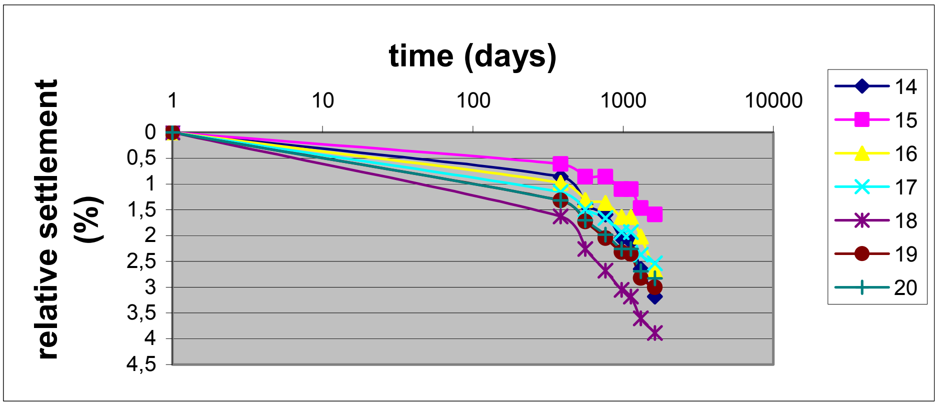

Fig. 8 Uhy - time development of the relative settlement from 07.10.2004 till 24.03.2009.

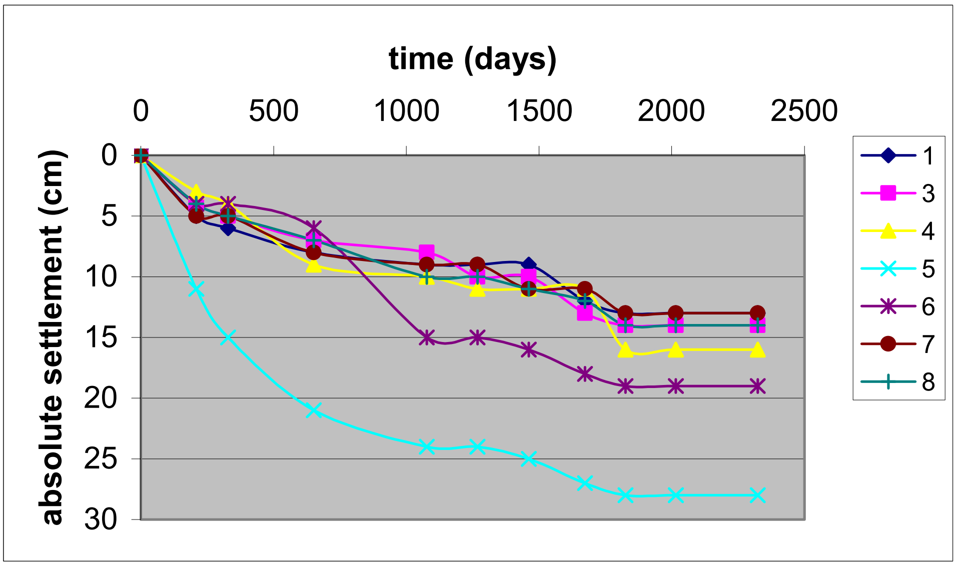

Fig. 9 Řevnice - time development of the absolute settlement from 13.11.2002 till 25.03.2009.

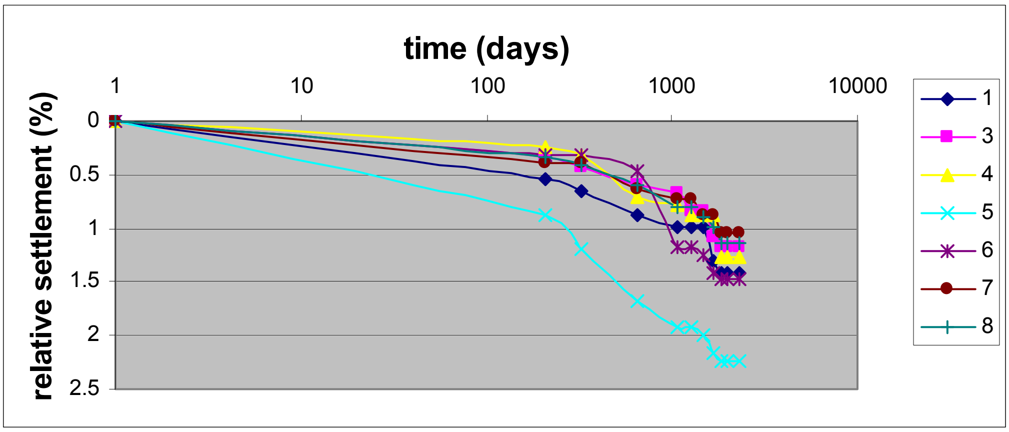

Fig. 10 Řevnice - time development of the relative settlement from 13.11.2002 till 25.03.2009.

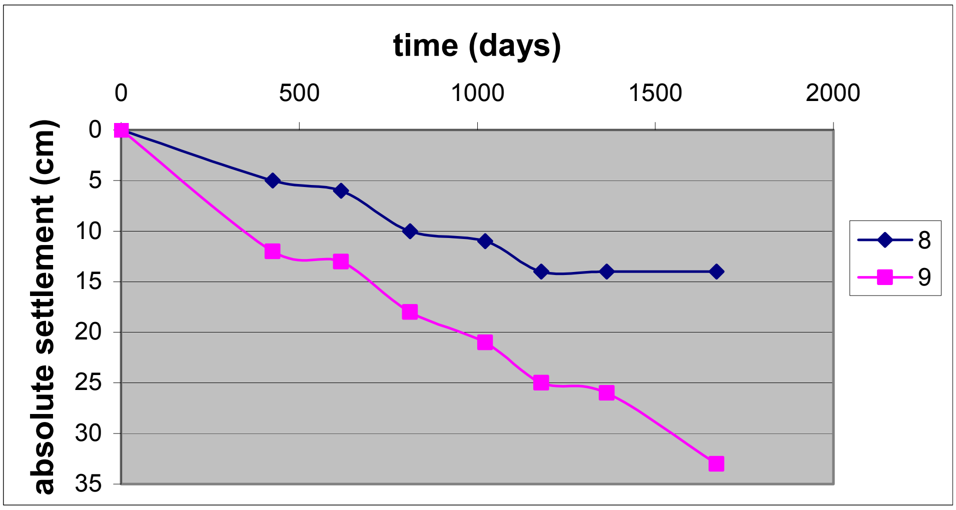

Fig. 11 Chrást - time development of the absolute settlement from 26.08.2004 till 25.03.2009.

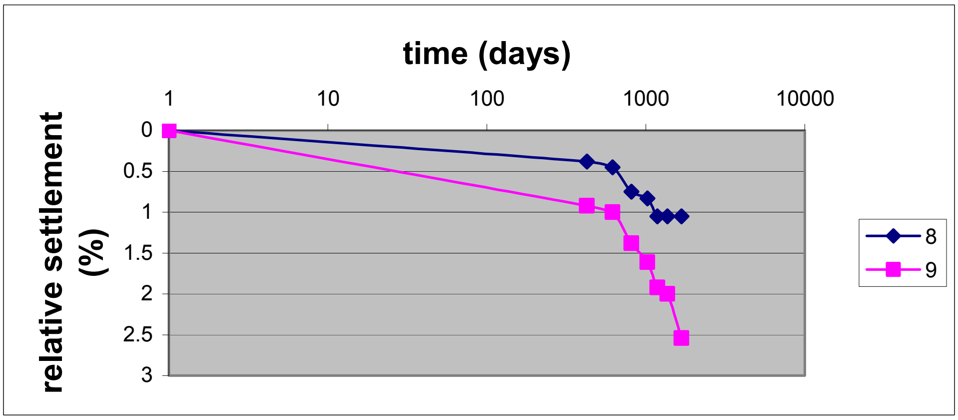

Fig. 12 Chrást - time development of the relative settlement from 26.08.2004 till 25.03.2009.

Table 2 Classification of irregular settlement on the investigated municipal landfills.

Municipal landfill localities	Survey point pair	Difference *s* between settlement (m)	Distance *l* between the survey points (m)	Ratio *(s / l) x 100* (%)	Failure criterion *s / l*
Ďáblice	19-11	2.64	121.40	2.17	
	19-13	2.56	92.27	2.77	
	19-15	2.52	128.25	1.96	
	19-20	1.54	123.62	1.25	
Úholičky	12-8	2.20	63.25	3.48	
	12-13	1.91	39.53	4.83	0.80 %
Uhy	18-15	0.67	66.13	1.01	
	18-17	0.47	31.22	1.51	
Řevnice	5-4	0.12	16.29	0.74	
	5-6	0.09	13.92	0.65	
Chrást	8-9	0.19	40.36	0.47	

5. INTERPRETATION OF THE RESULTS REGARDING FUNCTIONAL RELIABILITY FOR A LANDFILL CLOSURE

From the point of view of service life and functional reliability of a landfill it is the irregular settlement which must be given the first order attention. The time course of the settlement in the selected points (Figs. 2, 5, 7, 9 and 11) can be used to derive the ratio between the difference in settlement and the distance between two respective survey points. The ratio represents the measure of the irregular settlement (Table 2). Then, indicated maximum irregular settlements have to be compared with *failure criterion*.

There were considerations to accept failure criterion which would set a limit value of irregular settlement at a level of 1 : 400 (0.25 percent). Appropriateness of this value was verified during the extensive maintenance work on an old dump for toxic waste at SPOLANA Comp., Neratovice (Jánoš, 1999).

One must note that this value was prescribed by the designer as a limit for the new cover of the old dump under maintenance which was to be loaded with additional waste. In this case the cover of the old landfill represented also a basal sealing of the new landfill and was composed of mineral seal one meter thick (5 layers, 20 cm each) and of a sealing foil from HDPE 2 mm thick. Obviously, the application of this criterion cannot stand for all the different landfill types and respective ČSN standards do not specify any particular approach to this *risk problem of irregular settlement*.

Regarding this fact the criterion was approached and defined in respect to possible tensile failure, and defined for fine-grained soil at a level of 0.80 %, after verified results of LaGatta et al. (1997) in Heerten and Koerner (2008). From the work of the cited authors one can see clearly that specification of this criterion is an uneasy task since, on the top of other aspects, it depends on the soil humidity and on its plasticity.

A more detailed discussion regarding this theme must be expected in near future to specify a more *correct value of this failure criterion* and to find an expert opinion about limits in irregular surface settlement of municipal landfills. The discussion may affect standards in the field of the actual problem of waste dumping.

In spite of doubts that were discussed above one can, on the basis of the accepted criteria, account for the functional reliability of the dump closure at the investigated municipal landfill. Landfills Ďáblice, Úholičky and Uhy provided irregular settlements which override the failure criterion. In case of Ďáblice and Úholičky the value calculated on the basis of monitoring results gets even several times over. Therefore, one can see overriding of the criteria confirmed and assume origination of actual tensile failures. Landfills Řevnice and Chrást may be seen clear from such tensile failures, at least for the present time.

6. CONCLUSION

It is the pair of indication points 12-13 on Úholičky landfill (Table 2) where irregular settlement was found most critical. At this landfill the ratio between the difference in settlement and the distance between the two respective survey points reached 4.83 %. It comes out therefore that the limit value of the derived irregular settlement failure criterion has been surpassed here six times and the risk of failure is at maximum.

Further research should be oriented to verification of the limit value set for the failure criterion. Methodically, it is suggested to use an excavator and produce survey trenches centered between individual pairs of indication points. The trenches should reach the surface of the gravel-sand degasifying layers. Then a detailed documentation of the failure character in the sealing and recultivation layers found in the walls of survey trenches should be studied.

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