Settlements in landfills and geomembranes induced strains

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ABSTRACT: Settlements of waste disposals induce stresses and strains in the geomembrane used as waterproofing system for capping. Analysis of settlements evolution is realised in the case of the Centre d'Enfouissement Technique de Mont-Saint-Guibert in Belgium : observations and topographic measurements realised on the site let us to modelise the evolution of municipal wastes on the base of Sowers and Gibson & Lo theoretical laws. Owing to the determination of geotechnical parameters, it is possible to calculate the strains induced into the geomembrane by geometrical and analytical developments. A particular attention is paid to the evolution of the deformations after 20 and 30 years when a decrease of wastes degradation rate is expected.

1 INTRODUCTION

The settlements observed in Zone I of the Centre d'Enfouissement Technique de Mont-Saint-Guibert represent a sollicitation that could eventually disturb the good behaviour of the waterproofing drainage system used for capping (Figure 1).

Figure 1. View of the settlement zone and the lake in zone I

The characterisation of the state and the performance of the waterproofing-drainage system and its components (drainage layer for water and for gazes, natural and synthetic waterproofing layer) is a fundamental step for knowledge of possible problems. A special attention has been devoted to the behaviour of the clay layer, to the problem of the inverted slope (drainage) and the risks in relation with a fulfilling of the pipes, to the solicitation level of the geomembrane (tear, puncture, yield stress) and its connection with peripheric geomembranes.

A theoretical calculation based on settlement measurements gives us the stress and strain state in the geomembrane and let us evaluate risk of deterioration or exceeding of the yield level.
The results presented here are concerning the evaluation of geomembrane global strains. It is indeed impossible to evaluate local deformations that could lead to an over-yield strain and, eventually, to a default in waterproofing properties.

2 PRINCIPLES OF THE WATERPROOFING CAPPING SYSTEM

The waterproofing capping system is usually composed, when it is possible (slope lower than 10-15°) with a flexible geomembrane and a 60 cm clay layer.
Relatively to the same system used in slope or in the bottom of a landfill, some different work sollicitations have to be considered (Figure 1) :

- for a capping, the geomembrane will be in contact only with rainwater; chemical resistance can be so lower important, except if there is gas production under the membrane. The membrane can also be submitted to freeze-thaw cycles during winter and higher temperature during summer;
- waste settlement can lead to large bi-axial deformations of the waterproofing system;
- the waterproofing system will be submitted to sollicitations more during service life than during construction;
- the waterproofing system can be eventually accessible and repaired if necessary. The main problem is to evaluate and to locate the default(s);
- the waterproofing system is more sensitive to roots and rodents due to its proximity to the surface.

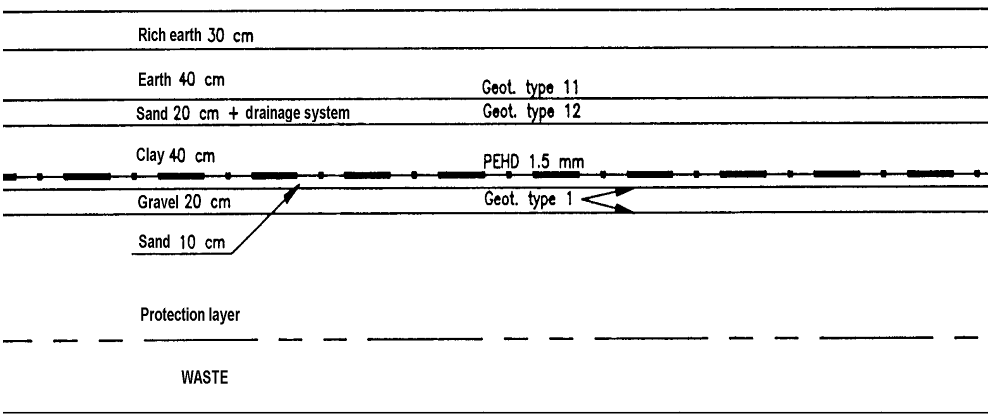


Figure 1. Waterproofing-drainage system for waste landfill capping

But the main problem is indisputably the behaviour of the waterproofing system, and particularly the geomembrane, to settlement effects.
The deformations of the geomembrane induced by settlements are function of the width and the depth of the depression as well as of its shape (circular,…). If the zone influenced by the settlement is sufficiently large in the plane, stresses and strains in the geomembrane remain relatively low.

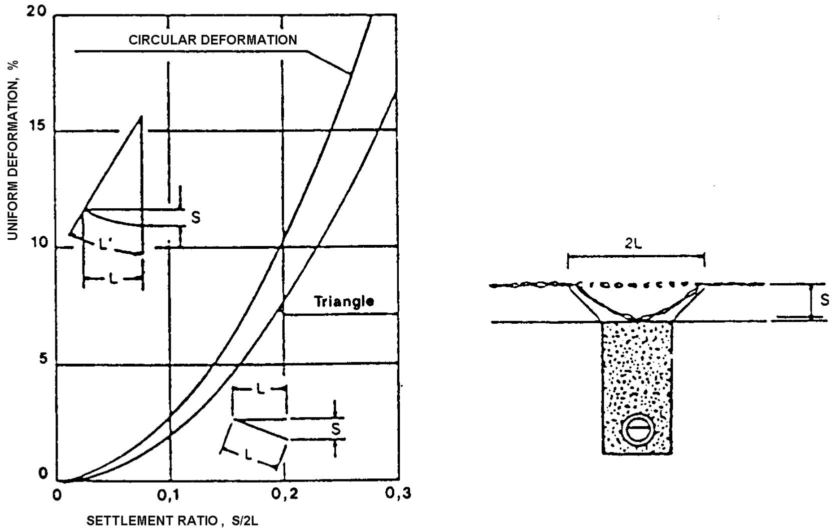


Figure 2. Deformation of the geomembranes versus settlement amplitude [1]

The model presented in Figure 2 is related to bi-dimensional deformation. When settlement is a tri-dimensional phenomenon, bi-axial deformations are induced in the geomembrane. The deformation, calculated from a geometric model, has to be compared with bi-axial deformation of geomembranes (< 20 %) and not with possible deformations determined from usual tensile tests (> 600 %), as given on Figure 3. Tests realised in different laboratories (GRI, STUVA, Steffen) [2] on samples of different dimensions, thicknesses and origins show that there is no difference in the values of yield strain due to the increase of the diameter of the sample.

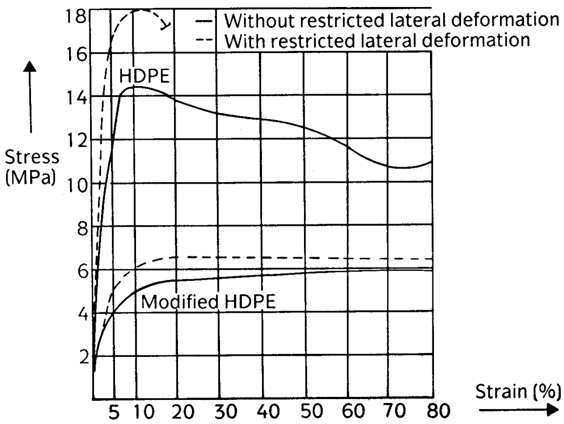


Figure 3. Stress-strain curves with or without lateral deformations [2]

Observations during these tests show also that, when the sample is of large dimension, only a central part of it is really stressed during settlement simulation (Figure 4); consequently the geomembrane in contact with the edges don't contribute to the stress release. These considerations are of course valuable for non-reinforced geomembranes as HDPE [2].

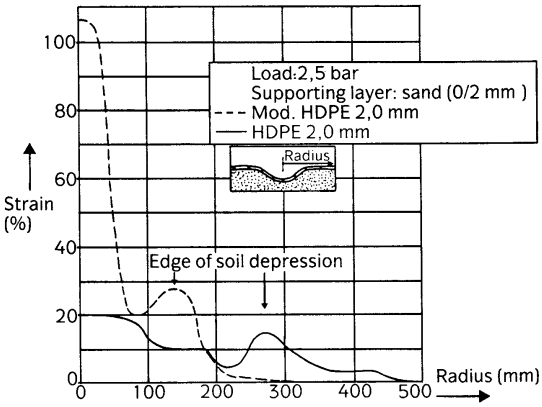


Figure 4. Deformations in the geomembrane during settlement test [2]

3 SITUATION OF THE ZONE I

The characteristics of this zone are :
- total surface of about 300000 m²;
- about 30 m high;
- low energy compactor;
- fulfilling from '85-86 to the beginning of '90.

The capping was realised immediately after the end of fulfilling, probably to avoid water filtration through the wastes and to reduce leaching and pollution because of the lack of ground protection.

4 MODELISATION OF SETTLEMENTS

4.1 *Theoretical laws of behaviour*

The settlements corresponding to the application of a load can be easily described by three components :

$$\Delta h_t = \Delta h_i + \Delta h_p + \Delta h_s$$

where Δh_t is the total settlement, Δh_i, Δh_p and Δh_s respectively the instant, primary and secondary settlement. The <u>instant</u> settlement occurs directly after the load application, during waste compaction procedures and after the drainage-waterproofing system. <u>Primary</u> settlement is due to water and gas expulsion from and through the wastes voids. It is in relation with overload and occurs relatively early and quickly (30 days maximum).

The <u>secondary</u> settlement is due to a synergy of secondary mechanical compression, biochemical degradation and physico-chemical action. The relation (settlement, log(time)) is usually linear. This settlement occurs for a long time (20-30 years).

4.2 *Settlements evaluation*

The calculation of parameters was realised from the analysis of settlements observed on a surface of 10 x 20 m.

Eighty reference points obtained by zone squaring were used to determined settlements for time periods corresponding to 120, 415, 850, 1176, 1499 and 1918 days. Table 1 gives an example for

D1. Original reference is time M02, that seems to be the one from which there was no more addition of ground on the surface. It is clear that primary settlement already appeared before it because there was at least one month between the end of the works and this reference. The first part of settlement phenomenon was so not observed and will be evaluated from literature informations.

Table 1. Settlement evolution Zone I - Ref. D1 [10]

Time	Settlements (m)									
(days)	1	2	3	4	5	6	7	8	9	10
0	0	0	0	0	0	0	0	0	0	0
120	0.7	0.8	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.3
415	-	2.3	2.1	1.9	1.9	1.9	1.7	1.7	1.5	1.4
850	-	3.1	2.9	2.7	2.6	2.5	2.3	2.2	2.1	1.9
1176	-	3.7	3.4	3.2	3.2	3	2.9	-	-	-
1499	-	4.2	4.1	3.8	-	-	-	-	-	-
1918	-	4.3	4.1	3.9	3.8	3.7	3.4	2.9	2.5	2.1

4.3 *Parameters calculation*

The main work is to determine the best type of law of behaviour in order to be able to predict long term behaviour.

4.3.1 *Logarithmic method*

Law of Yen and Scoulon is based on a simple logarithmic equation of the evolution of settlement versus time.
It is possible for each point to calculate equation (parameters a and b) and coefficient of regression by linear regression. Good results ($r^2 > 0.970$) were obtained by this way.

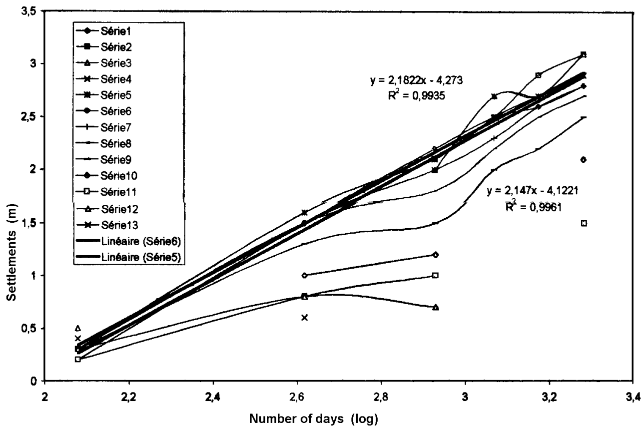


Figure 5. Linear regression on settlements versus time

4.3.2 Sowers law

The model of Sowers is based on the calculation of secondary compression ratio C_{ae} :

$$C_{ae} = \frac{S(t)}{H_p \, . \log\left(t/t_p\right)}$$

where $S(t)$ is the settlement evolution versus time,

H_p is waste thickness after primary settlement phase,

t_p is primary settlement phase duration.

We determined a ΔH of 1.5 m during primary settlement (30 days). Calculation of coefficient was realised for different reference points after 1176, 1499 and 1518 days.

Table 2. Secondary compression ration C_{ae} [10]

Reference point	C_{ae}
D1	0.077
D2	0.072
E1	0.069
F1	0.079
G1	0.079
G2	0.064

These results are in accordance with litterature
[6, 10] and let us to calculate the law of settlement, according to Sowers model.

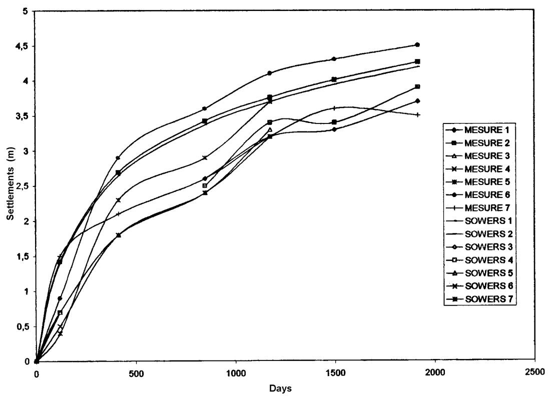


Figure 6. Comparison between on site measurements and Sowers model - ref. G1 [10]

Gaps between theory and practice may be evaluated and seems to be more important in the beginning with a decrease versus time.

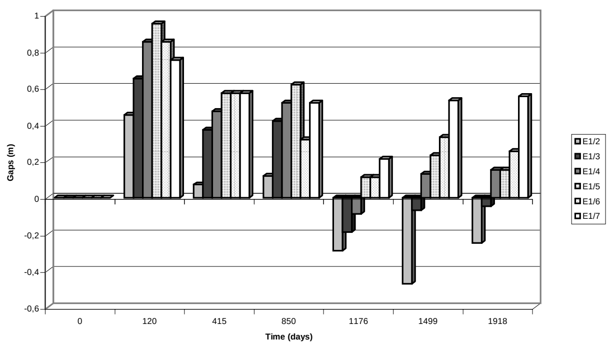


Figure 7. Gaps between Sowers model and on site measurements - Ref. E1 - measurements 1 to 7 [10]

4.3.3 Gibson and Lo's law

On the contrary of Sowers, Gibson & Lo purpose an exponential law, that induces settlement evaluation larger than with logarithmic laws.
Estimations realised on the base of the law of Gibson & Lo, with calculation of different parameters [10] let us to evaluate settlement evolution at the different reference points.

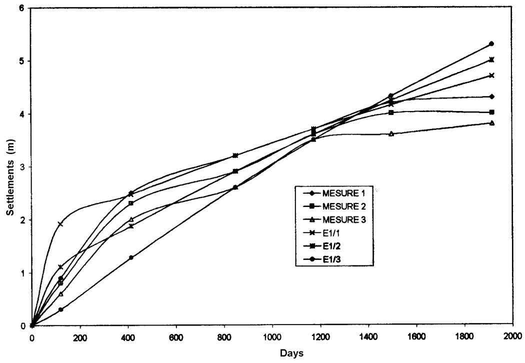


Figure 8. Comparison between on site and Gibson & Lo model

4.3.4 Comparison of theoretical models

Comparison between theory and on site measurements let us to make the next observations :

- the shape of the curves for settlement is clearly logarithmic and it seems to Sowers model is better adapted to describe the behaviour of wastes and the evaluation of settlements for a long time : settlements trend to stabilise with time;
- primary settlement has not been taken into account and has to be add to the calculated values.

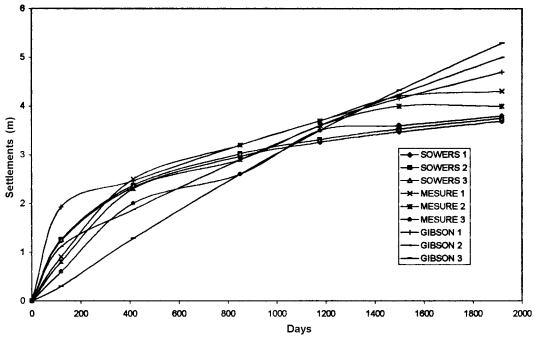


Figure 9. Comparison of models of Sowers and Gibson & Lo - Ref. D1

These two models will however be considered for the evaluation of the geomembrane deformations, taking into consideration that calculations made with Gibson & Lo are probably giving maximum values.

4.4 *Theoretical evolution of settlement*

The principal information deduced from models of Sowers or Gibson (Figure 9) is the estimation of the evolution of settlements with time.
It is generally considered that this evolution decreases after 20 or 30 years [5, 6], versus the characteristics of wastes and maturation conditions. The evaluation of settlements after 30 years could give a view of the topography of the site.

Table 3. Evaluation of settlements after 20 and 30 years according to models of Sowers and Gibson & Lo

References *	Settlements after 20 years (%)		Settlements after 30 years (%)	
	Sowers	Gibson & Lo	Sowers	Gibson & Lo
D1	18.4	31.1	19.8	35.2
E1	16.5	33.5	17.8	37.1
F1	18.7	40.9	20.1	47.1
G1	18.8	32.8	20.1	35.6

* references are corresponding to representative points of the general profile of the surface.

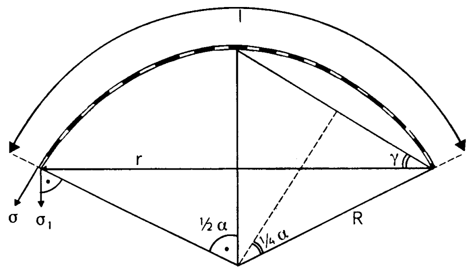
If we add the 5 % corresponding to the primary phase of settlements we obtain a total settlement of :

- after 20 years, Sowers : 23.1 %
  Gibson : 39.6 %
- after 30 years, Sowers : 24.5 %
  Gibson : 43.8 %.

According to the theory of Sowers, settlements after 30 days should correspond to about 25 % while Gibson and Lo's estimation is about 45 %.

5 SOLLICITATIONS FOR THE GEOMEMBRANE

The effects of the settlements on the geomembrane may be estimated for geometric considerations. If we suppose a spherical deformation of the geomembrane, without fixation of the edges, strain ε (%) and stresses σ (kN/m) may be estimated according next considerations :



$l = 2\,\pi.R.\alpha / 360 = 0.01745\, R.\alpha$

From available data

H = maximum height of settlement
r = radius of the settlement zone
l_o = diameter of the settlement zone
d = thickness of the geomembrane

all necessary parameters

R = radius of
l = length of circle segment
ε = strain
σ = stress

can be calculated. Particularly, it is possible to evaluate $\varepsilon = \left(\ell / \ell_o - 1 \right) .100$. Calculation is realised at 30 years' date for a value of settlement of 25 % (H = 7.5 m) and 45 % (H = 13.5 m).

Table 4. Parameters and deformation of the geomembrane

H (m)	2r (m)	ε (%)	Safety coefficient
7.5	120	1.01	12
7.5	80	2.30	5.2
13.5	120	3.32	3.6

Safety coefficient results from the ratio between the calculated deformation and deformation at yield (12%).
Results show that, if there is a decrease of the safety coefficients, yield strain shouldn't be attempted after 30 years, even with most critical settlement models (Gibson & Lo).

6 CONCLUSIONS

Modelisation let us to know how could evoluate the geomembrane deformations with time, depending on the waste settlements. It is clear that a large part of waste degradation and mechanical compression already occur and that the rate of settlements will largely decrease. Estimations based on theoretical developments lead to the conclusions that, until now and for 20 or 30 years, the geomembrane used in the water-proofing system of the capping, is able to support such a global waste settlement. However, any particular behaviour leading to localised settlement (reduced surface and increase of settlement coefficient) could induce larger deformations, eventually out of yield strain. It is consequently impossible to guarantee "zero defaults".

Moreover, some important local sollicitations, like in the anchorages, may induce stress into the membrane. In our situation, this is potential risk, considering the contact between clay and geomembrane, without geotextile for slipping. Due to settlement and if friction between clay and geomembrane is greater than between geomembrane and underface geotextile, stresses may develop into the geomembrane.

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