Method of evaluating the durability of geomembrane in landfill

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Keywords: Geomembrane, Landfill, Durability, Field sample

ABSTRACT: Geomembranes are an important structure in landfill sealing systems, because they are hydraulically impervious and deterioration resistant. However, the durability evaluation of a geomembrane is mainly based on accelerated weatherability tests. Therefore, the Japan Chapter of the International Geosynthetics Society investigated four types of geomembranes (PVC, HDPE, TPO, EPDM) at six locations in Japan with the objective of evaluating geomembrane durability. First, several geomembrane test samples were collected from each landfill. Then, the samples were evaluated by laboratory tensile tests. Based on the test results, the relationship between total solar radiation and geomembrane elongation is discussed. The results revealed that the geomembrane elongation ratio is linearly related to in-situ total solar radiation. Finally, a durability evaluation method of geomembrane is suggested based on the results of this research.

1. INTRODUCTION

Geomembranes are an important structure in landfill sealing systems, because they are hydraulically impervious and deterioration resistant. However, the durability evaluation of a geomembrane is mainly based on accelerated weatherability tests.

It is important to grasp the deterioration factors and installation conditions to discuss the durability of the geomembrane. In addition, the concept of design life differs from demand performance according to the supply side, design side, use side, etc.

Therefore, the Japan Chapter of the International Geosynthetics Society investigated four types of geomembranes (PVC, HDPE, TPO, EPDM) at six locations in Japan. Table 1 shows an outline of the sampling investigation1). The objective of this study was to evaluate the durability of geomembranes. First, several geomembrane test samples were collected from each landfill. Then, the samples were evaluated by laboratory tensile tests. Based on the test results, the relationship between total solar radiation and geomembrane elongation is discussed. The results revealed that the geomembrane elongation ratio is linearly related to in-situ total solar radiation. Finally, a method of evaluating the durability of geomembrane is suggested based on the results of this research.

Table 1 Outline of sampling investigation

Location	East Longitude (°)	North Latitude (°)	Kind of material	Elapsed time (years)
Hokkaido	141	43	PVC	11
Iwate	141	39	HDPE	8
			EPDM	25
Ibaraki	139	36	TPO PVC EPDM	18–27
Kyoto	135	35	HDPE	12.6
Shizuoka	138	34	EPDM	16
Fukuoka	131	33	TPO	5–11
			EPDM	18

2. EVALUATION METHOD

The Japan Chapter of the IGS investigated four types of geomembranes at six locations in Japan. The samples were evaluated by laboratory tensile tests to determine the characteristic changes of the geomembrane. In this paper, it is assumed that the main factors influencing characteristic changes of geomembranes are elapsed time and total solar radiation. However, it is difficult to calculate a direct amount of ultraviolet ray irradiation of previously constructed geomembranes. Therefore, we examine

Table 2 Influence factors

Time	Elapsed time after geomembrane is installed (years)
Solar radiation	Amount of global solar radiation at sampling site (Average of data for the past 30 years)
Temperature	Annual average temperature at sampling site (Average of data for the past 30 years)
Direction	Solar radiation by difference in direction
Exposure condition	Direct, In water, Shaded (using protection mat), Indoors

the correlation between the characteristic change rate of geomembrane, elapsed time, solar radiation, temperature, direction, and exposure condition, and propose a method that uses the value at which the amount of solar radiation is corrected instead of the direct amount of ultraviolet ray irradiation. Table 2 shows a list of the influence factors used by this method.

The relationship between the characteristic change rate of geomembrane and the proposed value (Total solar radiation) is defined as follows:

$$\Delta p' = \frac{\left|p - p_0\right|}{p_0} = A \sum S \tag{1}$$

Where:

$\Delta p'$: Characteristic change rate
p : Property value of sample
p_0 : Property value of initial sample
A : Coefficient
ΣS : Total solar radiation

Total solar radiation is defined as follows:

$$\sum S \approx \left(\alpha_1 \cdot \alpha_2 \cdot \alpha_3\right) \cdot \bar{g} \cdot t \tag{2}$$

Where:

t : Elapsed time after geomembrane is installed (days)
$\bar{g}$: Amount of global solar radiation at sampling site (MJ/m^2/day)
α_1 : Coefficient considering annual average temperature
T : Annual average temperature at sampling site (Average of data for the past 30 years)
α_2 : Coefficient considering the direction of sampling site (see Table 3)
α_3 : Coefficient considering the exposure condition (see Table 4)

Coefficient α_1 considering annual average temperature is defined as follows:

$$\alpha_1 = 2^{\left(T-15 \middle/ 10\right)} \tag{3}$$

Table 3 List of coefficient α_2 values

Direction	East (0°)	South (90°)	West (180°)	North (270°)
α_2	0.93	1.26	0.83	0.69

Table 4 List of coefficient α_3 values

Exposure condition	Direct	In water	Shaded
α_3	1.0	0.5	0.2

Coefficient α_2 considering the direction of sampling site is assumed as the ratio of solar radiation on a 30° slope to that on a horizontal plane. This is provisionally based on solar radiation from the north, south, east, and west in Hyogo Prefecture (center of Japan). Table 3 shows a list of the coefficient α_2 values.

Coefficient α_3 considering the exposure condition is assumed as shown in Table 4.

Table 5 shows a list of the results calculated using this evaluation method. The characteristic change rate adopts the breaking elongation of test samples.

3. EVALUATION RESULTS

Figure 1 shows the characteristic change rate: $\triangle p'$–total solar radiation: ΣS relationship. Particular tendencies of the material cannot be confirmed from this figure. Also, arrangement according to the kind of material is difficult, because the mixture ratio differs even in the same material. However, a linear relationship can be seen between the characteristic change rate: $\triangle p'$ and the total solar radiation: ΣS. Coefficient A is 7.38×10^{-6}.

$$\Delta p' = A \cdot \sum S = \left(7.38 \times 10^{-6}\right) \cdot \sum S \tag{4}$$

Figure 1 also shows a large difference in data when $\triangle p'$ is greater than 0.6. Therefore, one standard value of the permissible change rate is $\triangle p' = 0.6$ when the physical properties change. It is judged that the geomembrane characteristics change rapidly when $\triangle p' > 0.6$. On the other hand, due to recently improved durability, geomembranes with minimally changing characteristics over the long term can be confirmed. Therefore, when evaluating the durability of geomembrane, it is necessary to confirm the relationship between the characteristic change rate: $\triangle p'$ and the total solar radiation: ΣS based on the data from outdoor exposure tests or accelerated weatherability tests. Moreover, the relationship between the geomembrane sealing performance

Table 5 List of tensile test results

No.	Material	Time	$\bar{g}$	$\bar{g} \cdot t$	T	Coefficient			ΣS	Δp'
		t (day)	(MJ/m^2/day)	(MJ/m^2)	(°C)	α_1	α_2	α_3	(MJ/m^2)	
1	PVC (P1)	4015	12.0	48180	8.7	0.65	1.10	1.00	34090	0.183
2		4015	12.0	48180	8.7	0.65	1.10	1.00	34090	0.333
3		4015	12.0	48180	8.7	0.65	1.05	1.00	32534	0.238
4		4015	12.0	48180	8.7	0.65	0.76	1.00	23661	0.150
5		4015	12.0	48180	8.7	0.65	0.76	1.00	23661	0.183
6		4015	12.0	48180	8.7	0.65	1.05	1.00	32534	0.207
7	HDPE (H1)	2920	11.9	34748	11.1	0.76	1.10	0.20	5803	0.124
8		2920	11.9	34748	11.1	0.76	1.10	0.20	5803	0.002
9		2920	11.9	34748	11.1	0.76	1.05	0.20	5538	0.024
10		2920	11.9	34748	11.1	0.76	1.05	0.20	5538	0.040
11		2920	11.9	34748	11.1	0.76	1.05	0.20	5538	0.166
12	EPDM (E1)	9125	11.9	108588	11.1	0.76	0.93	1.00	77012	0.633
13	TPO (T1)	6935	13.0	90155	13.6	0.91	1.26	1.00	103305	0.908
14		6935	13.0	90155	13.6	0.91	0.83	1.00	68050	0.863
15		6935	13.0	90155	13.6	0.91	0.69	1.00	56572	0.337
16		6935	13.0	90155	13.6	0.91	0.93	1.00	76249	---
17	TPO (T1)	8760	13.0	113880	13.6	0.91	1.26	1.00	130490	0.800
18		8760	13.0	113880	13.6	0.91	0.83	1.00	85958	0.812
19		8760	13.0	113880	13.6	0.91	0.69	1.00	71459	0.362
20		8760	13.0	113880	13.6	0.91	0.93	1.00	96314	0.544
21	PVC (P3)	8760	13.0	113880	13.6	0.91	1.26	1.00	130490	0.944
22		9855	13.0	128115	13.6	0.91	0.83	1.00	96702	0.934
23		9855	13.0	128115	13.6	0.91	0.69	1.00	80391	0.846
24		9855	13.0	128115	13.6	0.91	0.93	1.00	108353	0.879
25		6570	13.0	85410	13.6	0.91	1.26	1.00	97867	0.770
26		6570	13.0	85410	13.6	0.91	1.26	1.00	97867	0.925
27		6570	13.0	85410	13.6	0.91	1.26	0.50	48934	0.574
28	TPO (T3)	6570	13.0	85410	13.6	0.91	1.26	1.00	97867	---
29		6570	13.0	85410	13.6	0.91	1.26	1.00	97867	0.654
30		6570	13.0	85410	13.6	0.91	1.26	0.50	48934	0.244
31	TPO (T4)	6570	13.0	85410	13.6	0.91	1.26	1.00	97867	---
32		6570	13.0	85410	13.6	0.91	1.26	1.00	97867	---
33		6570	13.0	85410	13.6	0.91	1.26	0.50	48934	---
34	EPDM (E2)	6570	13.0	85410	13.6	0.91	1.26	1.00	97867	0.527
35		6570	13.0	85410	13.6	0.91	1.26	1.00	97867	0.529
36		6570	13.0	85410	13.6	0.91	1.26	0.50	48934	0.307
37		6570	13.0	85410	13.6	0.91	0.93	1.00	72235	0.473
38		6570	13.0	85410	13.6	0.91	0.93	1.00	72235	0.521
39		6570	13.0	85410	13.6	0.91	0.69	1.00	53594	0.552
40	EPDM (E3)	6570	13.0	85410	13.6	0.91	0.69	1.00	53594	0.467
41		6570	13.0	85410	13.6	0.91	0.83	1.00	64468	0.600
42		6570	13.0	85410	13.6	0.91	0.83	1.00	64468	0.586
43		6570	13.0	85410	13.6	0.91	1.26	1.00	97867	0.665
44		6570	13.0	85410	13.6	0.91	1.26	1.00	97867	0.572
45	HDPE (H2)	4599	11.8	54268	16.1	1.08	1.00	0.20	11714	---
46		4599	11.8	54268	16.1	1.08	1.26	1.00	73795	---
47		4599	11.8	54268	16.1	1.08	0.69	1.00	40412	---
48	EPDM (E4)	5840	13.6	79424	16.2	1.08	0.76	0.75	49096	0.325
49		5840	13.6	79424	16.2	1.08	0.76	0.75	49096	0.349
50		5840	13.6	79424	16.2	1.08	0.93	0.75	60078	0.497
51		5840	13.6	79424	16.2	1.08	0.93	0.75	60078	0.434
52		5840	13.6	79424	16.2	1.08	1.10	0.75	70737	0.533
53	TPO (T5)	4015	13.0	52195	16.8	1.13	1.26	0.78	58169	---
54		4015	13.0	52195	16.8	1.13	1.26	0.78	58169	---
55		4015	13.0	52195	16.8	1.13	1.26	0.78	58169	---
56	TPO (T6)	1825	13.0	23725	16.8	1.13	1.00	0.20	5368	0.075
57		1825	13.0	23725	16.8	1.13	0.83	1.00	22278	0.055
58		1825	13.0	23725	16.8	1.13	0.83	1.00	22278	0.064
59		1825	13.0	23725	16.8	1.13	1.05	1.00	28048	0.019
60		1825	13.0	23725	16.8	1.13	1.05	1.00	28048	0.070
61		1825	13.0	23725	16.8	1.13	1.10	1.00	29390	0.085
62		1825	13.0	23725	16.8	1.13	0.81	1.00	21741	0.064
63	EPDM (E5)	6570	13.0	85410	16.8	1.13	0.93	0.73	65899	0.394
64		6570	13.0	85410	16.8	1.13	0.83	0.73	58813	0.455
65		6570	13.0	85410	16.8	1.13	1.26	0.73	89282	0.565
66		6570	13.0	85410	16.8	1.13	0.69	0.73	48893	0.435

PVC: Polyvinyl Chloride; HDPE: High Density Polyethylene; EPDM: Ethylene Propylene Diene Monomer; TPO: Thermo Plastic Olefin.

Table 6 Calculated total solar radiation

	t (day)	$\bar{g}$ (MJ/m^2/day)	α_1	α_2	α_3	ΣS (MJ/m^2)
Hokkaido	1825	12.0	0.65	1.26	1.00	17831
	3650	12.0	0.65	1.26	1.00	35661
	5475	12.0	0.65	1.26	1.00	53492
	7300	12.0	0.65	1.26	1.00	71322
Tokyo	1825	11.8	1.08	1.26	1.00	29345
	3650	11.8	1.08	1.26	1.00	58690
	5475	11.8	1.08	1.26	1.00	88035
	5475	11.8	1.08	0.69	1.00	48209
	5475	11.8	1.08	0.83	1.00	57991
	5475	11.8	1.08	0.93	1.00	64978
	5475	11.8	1.08	1.26	0.20	17607
	7300	11.8	1.08	1.26	1.00	117136
Fukuoka	1825	13.0	1.13	1.26	1.00	33866
	3650	13.0	1.13	1.26	1.00	67732
	5475	13.0	1.13	1.26	1.00	101598
	5475	13.0	1.13	0.69	1.00	55637
	5475	13.0	1.13	1.26	0.20	20320

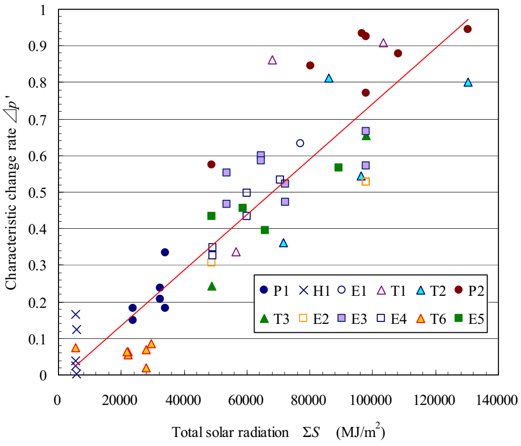

Fig. 1 ⊿p' – Σ*S* relationship

and the characteristic change rate: ⊿*p*' used by this method has not yet been clarified.

Table 6 shows an example of calculated total solar radiation for Hokkaido, Tokyo and Fukuoka. Thus, when the region (amount of global solar radiation, annual average temperature), direction, exposure condition, and elapsed time are set, the total solar radiation can be calculated using Eq. (2). Figure 2 shows the calculation results of four cases using Eq. (4). For example, when the upper bound of the permissible change rate is ⊿*p*' ≤ 0.6, one standard value of total solar radiation becomes Σ*S* = 80,000 MJ/m^2. As a result, the period that exceeds the upper bound value of the characteristic change rate is about 12 years under conditions of direct exposure from the south in Fukuoka. On the other hand, the characteristic change rate does not exceed the upper bound value for at least 15 years by using the protection mat (shaded condition).

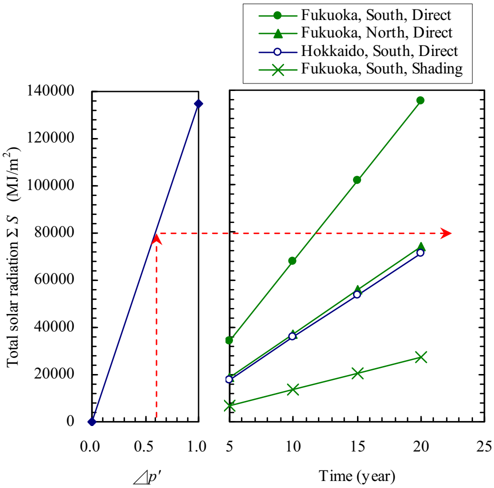

Fig. 2 Example of trial calculation results

4. CONCLUSIONS

The following conclusions are drawn from this research:

(1) The characteristic change rate ⊿*p'* and total solar radiation Σ*S* are linearly related.

(2) One standard value of the permissible change rate is ⊿*p'* = 0.6, because the difference in data is large when the characteristic change rate is greater than 0.6.

(3) When the region (amount of global solar radiation, annual average temperature), direction, exposure condition, and elapsed time are set, the total solar radiation and the period that exceeds the upper bound value of the characteristic change rate can be calculated.

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