Tensile Behavior of Embedded Geomembrane Subjected to Differential Settlement of Base Ground

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SYNOPSIS: When the base ground underlying geomembrane liner may subside partially by the cause of insufficient compaction around collection pipe for water, the geomembrane is needed to elongate and induced tensile strain. Some methods of calculating induced elongation and strain were presented, but their usefulness was not proven. In this paper, modeled tests where geomembrane was subjected to differential settlement were conducted under condition that thickness of protected layer, confining pressure and rigidity of geomembrane are constant, and shape of settlement and frictional property are varied. The measurements such as maximum tensile strain, effective range of geometric deformation and elongation were compared to calculations by Trough Model. Both observed and calculated values were very similar trend between settlement and strain/elongation, but Trough Model should be modified so that it considers the effect of a variation of a width of settling part of base.

INTRODUCTION

Recently, various types of geomembranes are installed as synthetic liner in landfill so that ground and groundwater around the landfill are prevented from being polluted by leachate. Therefore the geomembranes have to be designed not to tear or fail. When the base ground underlying geomembrane liner may subside partially by the cause of insufficient compaction around collection pipe for water, the geomembrane is needed to elongate. This behavior surely induced tensile strain within the geomembrane. In case the amount of tensile strain is enough large, the geomembrane results in tensile failure. Therefore, to predict the maximum value of strain induced within a geomembrane is very important work to estimate the safety factor for allowable tensile strain.

Relating to predicting the induced maximum value of strain, general procedure is following. First, shape of deformation of geomembrane is assumed so that it follows settling ground. Then a required amount of elongation of geomembrane is calculated geometrically. Last, strain or its distribution is estimated for the required elongation.

Current simple method to calculate the amount of elongation is Trough Model presented by Knipschild(1984). In this method, shape of deformation of geomembrane is assumed to be triangular or arc. The induced strain is estimated based on an assumption that strain distributes uniformly over deformed range. Giroud(1994) and Imaizumi et al.(1995, 1996) indicated elastic formula to calculate induced strain or stress of geomembrane which embedded in ground. According to their elastic method, the strain cannot distribute uniformly. Moreover, the amount of maximum strain and range of its distribution depend on the rigidity of gemembrane, confining pressure and frictional property between geomembrane and ground.

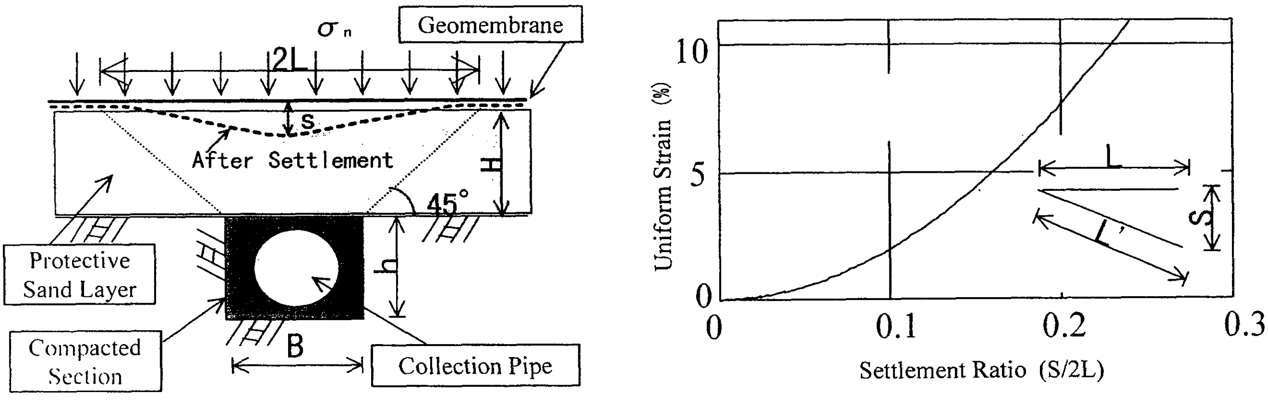
Unfortunately, we cannot find the literature that shows usefulness of the above-mentioned model and formula by conducting some experiments.

In this paper, modeled tests where geomembrane was subjected to differential settlement were described. The tests were conducted with varying the width of modeled settling base and frictional property between geomembrane and protective sand layer, though the conditions such as thickness of underlying protective layer, confining pressure and rigidity of geomembrane were kept in constant. The measurements such as strain, elongation and deformation shape of settling geomembrane are discussed and compared to the calculated based on Trough Model.

BRIEF DESCRIPTION OF TROUGH MODEL

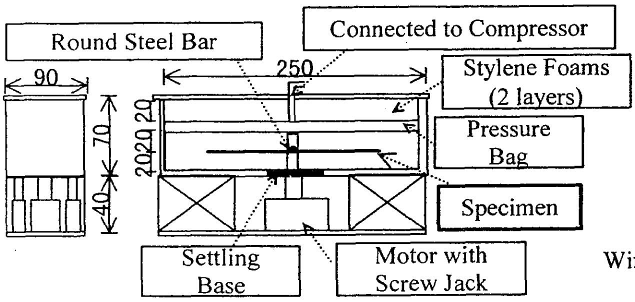
Schematic drawing of Trough Model is shown in **Fig.1(a)**. A geomembrane is spread over the protective sand layer having a thickness of H. This layer is overlaying compacted section around collection pipe that have a width of B and a depth of h. In this model, it is assumed that (1) a range of 2L of geomembrane may deform triangularly as shown in **Fig.1(a)**, (2) this effective range for deformation is equal to shearing zone of protective sand layer and (3) strains create uniformly distributed. If shearing progresses upward with angle of 45 degree from top edge of compacted section, the effective range 2L can be written

$$2L = B + 2 \times H \times \tan 45^\circ = B + 2H \tag{1}$$



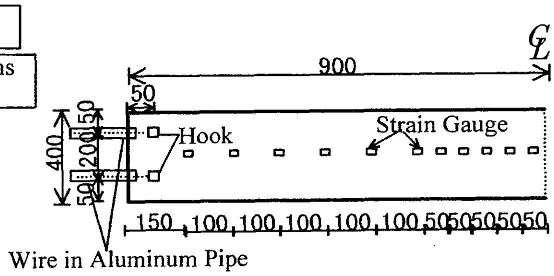
(a) Schematic drawing of Trough Model (b) Calculated Uniform Strain

Fig.1 Trough Model



(unit;cm)

Fig.2 Testing Device



(unit;mm)

Fig.3 Locations of Strain Gauges Pasted on HDPE

When the compacted section consolidates by S, the length of deformed geomembrane become L' is

$$L' = \sqrt{L^2 + S^2} \qquad (2)$$

Then the induced strain ε is given as

$$\varepsilon = (L' - L)/L = \sqrt{\{1 + (S/L)^2\}} - 1 \qquad (3)$$

The calculated uniform strain based on Eq.(3) is shown in **Fig.1(b)**. According to Trough Model, it can be seen that the strain decreases with increasing of range of L for a given settlement S. This in turn implies that wider settling section for same settlement leads smaller induced strain.

TESTING DEVICE, MATERIAL PROPERTY AND PROCEDURE

Test configuration is shown in **Fig.2**. Tests were conducted in large steel-made rectangular container with a width of 250 cm, a depth of 90 cm and a thickness of 70 cm. The bottom is separated into three parts, that is, left, center and right. The center part is placed on a screw jack which is connected to the motor. The left and right parts are stable. Differential settlement can be simulated by falling the center part. The width of settling part can be selected among 10, 20 and 30 cm. Rubber pressure bag having a width of 250 cm, a depth of 90 cm and a thickness of 10 cm is attached under the top steel cover of container. It is connected to air-compressor whose function to apply surcharge is up to 196 kPa to geomembrane through top protective soil layer.

For the center of geomembrane, to settle as same amount as settling bottom base, a round steel bar with a diameter of 10 mm is placed across over the geomembrane. The steel bar is supported H-beam which is jointed the settling part.

The type of geomembrane used was smooth surface HDPE with a thickness of 1 mm. Crushed stone sand of which grain size was stabilized from 74 to 840 μ was used as granular protective material. Non-woven stapled geotextile of 10 mm thick was also used as geosynthetic protective material which was installed between geomembrane and granular protective material. Their physical and mechanical properties on interface between materials are shown in

TABLE 1 Material Properties

Material	Physical property	Value
Crushed Stone	Specific Gravity	2.76×10^3
	Maximum Dry Density	1.68×10^3 kg/m^3
	Minimum Dry Density	1.32×10^3 kg/m^3
HDPE	Density	950 kg/m^3
	Tensile Strength	3.21×10^4 kPa
	Coefficient of Thermal Expantion	1.65×10^{-4} /℃
Stapled Non Woven	Density	120 kg/m^3
	Tensile Strength	1.27×10^3 kPa

TABLE 2 Frictional Properties on Interface between Materials

Interface	HDPE/ Crushed Stone	HDPE/ SNW	SNW/ Crushed Stone
Cohesion	2.5 kPa	0.32 kPa	5.2 kPa
Internal Friction Angle	19.7°	12.6°	29.0°

TABLE 3 Test Condition

No.	Surcharge	Temperature	Width of Settling Base	HDPE	SNW
1	98.1 kPa	2.6℃	10cm	O	-
2	98.1 kPa	2.7℃	20cm	O	-
3	98.1 kPa	1.1℃	30cm	O	-
4	98.1 kPa	3.6℃	10cm	O	O
5	98.1 kPa	8.6℃	20cm	O	O
6	98.1 kPa	4.3℃	30cm	O	O

O : installed, — : not installed

Table 1 and **Table 2**. Though the tensile strength of HDPE varies depending on its temperature, the value indicated in the **TABLE 1** is at a temperature of 20 ℃.

Testing procedures are following. First, crushed stone sand was poured to make bottom protective layer with a relative density of Dr=90±5 % ($\rho = (1.637\times10^3)\pm(0.022\times10^3)$ kg/m^3) and with a thickness of 20 cm. After flattening the surface of sand layer, HDPE specimen with a length of 180 cm and a width of 90 cm was spread over it. On both surfaces of the specimen, strain gauges were pasted at 21 point as shown in **Fig.3** in order to measure induced strain distribution. Then crushed stone sand was again poured to form top protective sand layer with a thickness of 20 cm. For some cases, non-woven stapled geotextiles were installed between geomembrane and sand layers. The rubber pressure bag was placed on top sand layer and steel top cover was tighten to the container through bolts. Between rubber pressure bag and steel cover, styrene foams with a thickness of 20 cm was placed to fill up the open space. The surcharge pressure of σ_v=98.1 kPa was applied. Then the center part of steel base was settled at a rate of 1 mm/min. until it settled 40 mm. In course of settling, induced strain in geomembrane were continuously measured by strain gauges and recorded on a disk through personal computer. Displacements of both ends of the specimen were also measured through a wire of which an end was fixed on geomembrane-end and other end was attached to dial gauge.

6 series of test in total were conducted. The conditions of tests are listed in **Table 3**. The temperature when the tests were conducted were 1.1 to 8.6 ℃.

RESULTS AND DISCUSSIONS

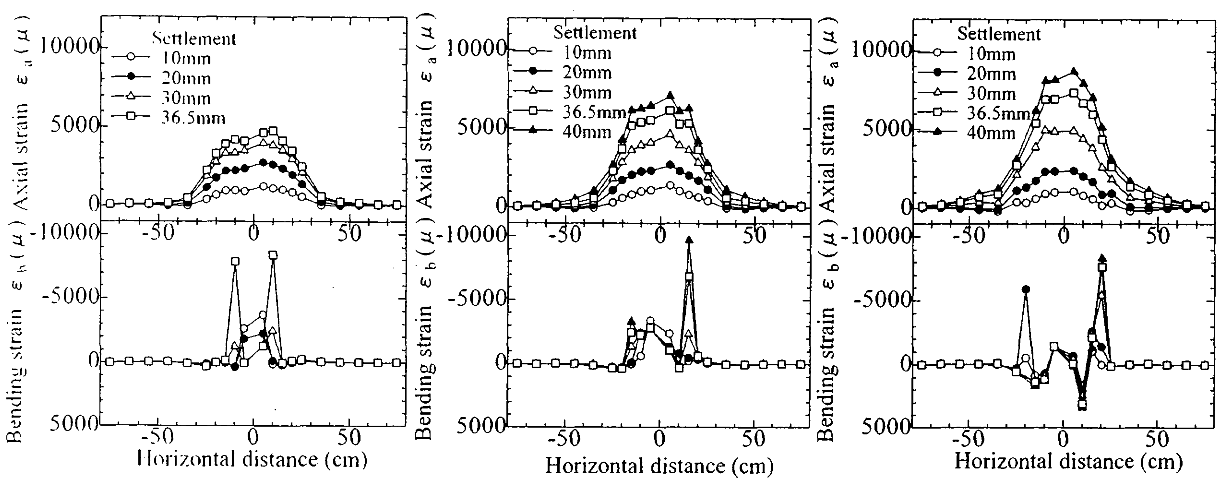
As no displacement at the ends of HDPE specimen was observed in all tests, it is clear that slipping-out behavior did not happen at its left and right ends.

Axial strain ε_a is calculated as the average value of strains measured on top and bottom surfaces of the specimen and its positive value means tensile strain. Bending strain ε_b is calculated as deviation between top strain and bottom strain and its positive value means the shape that deforms concavely.

Fig.4 and **Fig.5** show distributions of axial strain and bending one in case of tests without geotextile and with geotextiles, respectively. From these figures, it is found that axial tensile strain does not create uniformly but has the maximum value at the center of specimen and decreases toward its end. The shape of distribution seems to be close to a triangle or a bell. It is also clear that the maximum tensile strain increases with settlement and with increasing the width of settling part of base. For example, the maximum strain at a settlement of 30 mm is about 3000 μ for a wide of 10 cm, about 6000 μ for a wide of 20 cm and about 8000 μ for a wide of 30 cm. This trend is quite the opposite to that indicated by Trough Model. The range where some tensile strain creates is almost constant with increase of settlement, but it becomes wider as the width of settling base becomes wider.

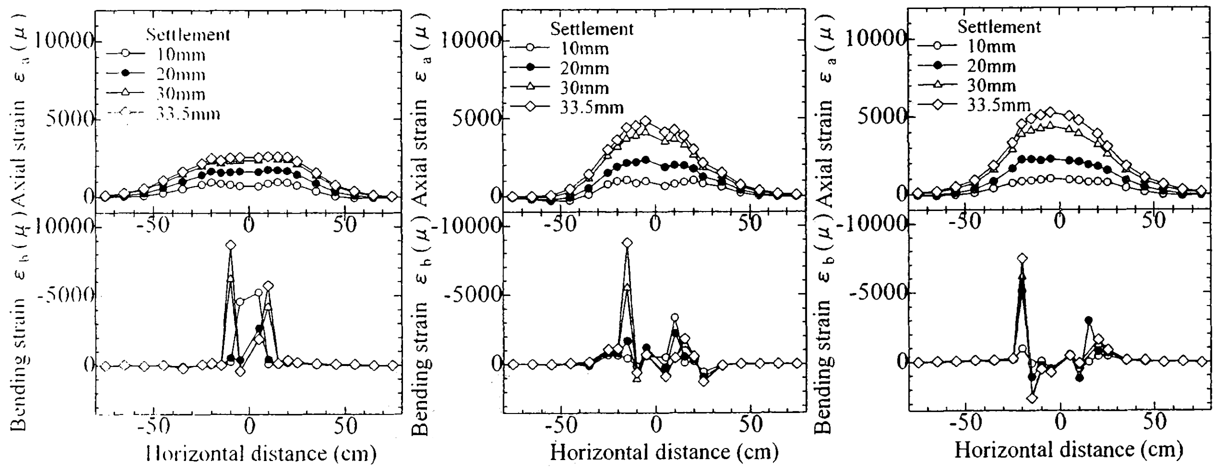
Comparing the strain distribution without geotextile to that with geotextile at a same settlement, the maximum strain with geotextile is about 60-70 % of that without geotextile, but the range of distribution in case with geotextile is wider than in case without geotextile. Based on elastic theory by Imaizumi et al., this behavior dues to the fact that geotextile/ geomembrane interface has smaller frictional properties than sand/ geomembrane interface.

Relating to bending strain, the position where it gives absolutely maximum value seems to be very close to just above the edge of settlement part for smaller settlement than 10 mm. However, for the more settlement, the position moves toward outside. The distance between two positions where the maximum bending strain



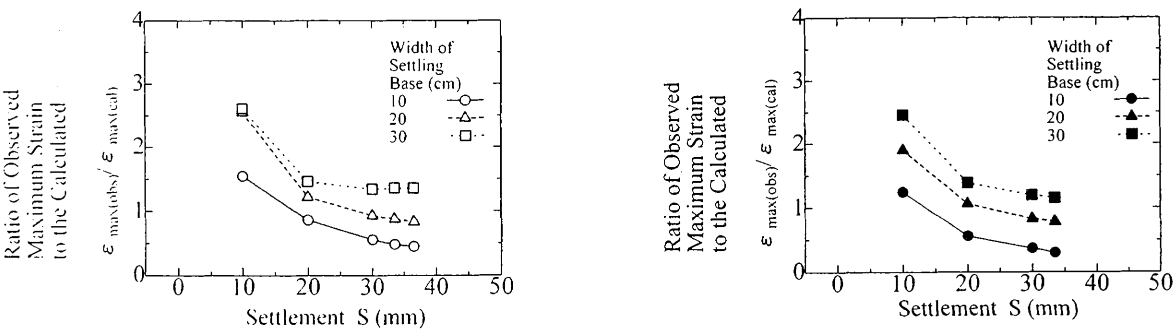
(a) Width of Settling Base:10cm (b) Width of Settling Base:20cm (c) Width of Settling Base:30cm

Fig.4 Distribution of Axial and Bending Strain in Case of without Geotextile



(a) Width of Settling Base:10cm (b) Width of Settling Base:20cm (c) Width of Settling Base:30cm

Fig. 5 Distribution of Axial and Bending Strain in case of with Geotextiles



(a) without Geotextile (b) with Geotextiles

Fig.6 Relationship between Settlement of Base and Ratio of Observed Maximum Strain to the Calculated by Trough Model

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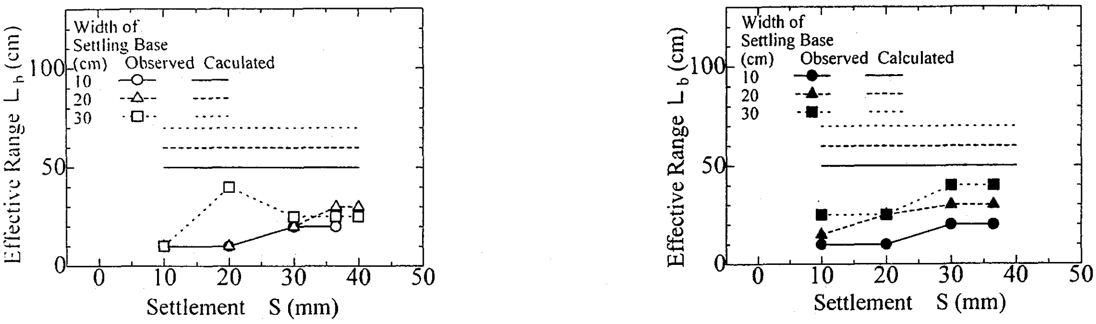
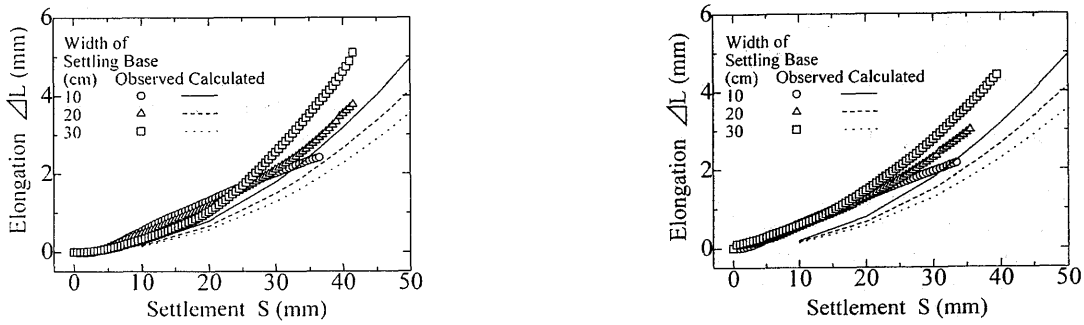


(a) without Geotextile (b) with Geotextiles

Fig.7 Relationship between Settlement of Base and Effective Range of Geometric Deformation of HDPE



(a) without Geotextile (b) with Geotextiles

Fig.8 Relationship between Settlement of Base and Elongation

creates become wider as the width of settling base becomes wider.

Fig.6 shows relationship between settlement and ratio of observed maximum strain to the calculated using Eq.(3) based on Trough Model. It can be seen that the ratio of $\varepsilon_{max(obs)}/\varepsilon_{max(cal)}$ is higher than 1.0 for smaller settlement of about 20 mm, but for the settlement larger than 20 mm, the ratio is larger than 1.0 in case of a width of settling base of 30 cm, smaller than 1.0 in case of a width of settling base of 10 cm and almost equal to 1.0 in case of a width of 20 cm. This means that Trough Model gives slightly higher tensile strain in case of smaller width of settling part of base. In case the width of settling base is larger than 20 cm, to use Trough Model seems to be critical in design because it underestimates the maximum strain.

It seems reasonable to consider that the position giving maximum bending strain corresponds to the position where geomembrane deforms remarkably in geometry. So, the distance between the two positions with maximum bending strain was estimated as effective range L_b of geometric shape. **Fig.7** shows change of the observed L_b with settlement. L_b calculated based on Eq.(1) of Trough Model are also drawn. From the figure, it is found that the observed L_b increases with settlement less than 30mm though the model shows constant values. The amount of the observed is 40-60 % smaller than the calculated. In both of observations and calculations, the effective range depends on the width of settling part considerably. Roughly speaking, effective range L_b is proportional to the width in this tests.

Integrating the axial strain shown in **Fig.2** results in elongation that required to follow deformation of bottom protective sand layer. **Fig.8** shows relationship between settlement and elongation. It is obviously found that elongation increases with settlement. The trend is almost same among three different widths till settlement is up to about 25 mm. Comparing the calculated to the observed, the former gives about 70 % smaller than the latter within a settlement of 25 mm.

Beyond 25 mm in settlement, larger width of settling part creates more elongation in experiment, but larger width estimates smaller elongation in Trough Model. Therefore in case a width of settling base is larger than 20 cm, Trough Model seems to give critical estimation of elongation. The practical point of Trough Model that is found from **Fig.8** is that it gives similar trends between settlement and elongation, especially for larger width. So, if we can modified the Trough Model so that a variation of a width of settling part effects on elongation correctly, it may be come practical model.

CONCLUSIONS

A series of base partially settling tests were conducted to find how the induced strain distributes in the geomembrane and how much the maximum strain is. The obtained results were discussed from the view of comparing with those calculated based on Trough Model.

The following were main conclusions.

1. Axial tensile strain does not create uniformly as assumed in Trough Model but has maximum value at the center of specimen and decreases toward its end. It is also clear that the maximum tensile strain increases with settlement and with increasing the width of settling part of base.
2. Comparing the strain distribution without geotextile to that with geotextile at a same settlement, the maximum strain with geotextile is about 60-70 % of that without geotextile, but the range of distribution in case with geotextile is wider than in case without geotextile.
3. Relating to bending strain, the position where it gives absolutely maximum value seems to be very close to just above the edge of settling part for the settlement less than 10 mm. However, for the more settlement, the position moves toward outside.
4. Trough Model gives slightly higher tensile strain in case of smaller width of settling part. This is conservative from a view of design. But in case of the width of settling base larger than 20 cm, Trough Model seems to be critical in design because it underestimates the maximum strain.
5. In both of observed and calculated, the effective range L_b depends on the width of settling part considerably, and effective range L_b is somewhat proportional to the width in observed.
6. Relating to elongation, the trend between settlement and elongation is almost same till settlement is up to less than about 25 mm, though the calculation gives about 70 % smaller than observation. But beyond 25 mm in settlement, the larger width of settling part creates more elongation in experiment while larger width estimates smaller elongation in Trough Model.

So, the Trough Model should be modified so that a variation of width of settling part effects on amount of strain and elongation correctly.

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