Report of the Experiment Concerning Final Cover by Permeable/Waterproof Sheet（Part 1）

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Purpose of the study

At present, a final covering is placed as the uppermost layer of landfills after they are filled with wastes for the aesthetic purpose, utilization of the land and for reduction of the amount of leachate produced by the waste.　The type of the structured is represented by the soil materials that are defined by the Waste Foundation.　The soil materials are excellent in long term stability and are easily available at relatively low cost.

“Permeable/Waterproof Sheet Capping Method Research Association” (hereafter called “CP workshop”) proposed a final covering structure that uses geosynthetics in place of these soil materials (see Table - 1), and conducted verification of its possibility by performing on-site demonstration experiment and analysis of seepage flow.

Table - 1　Structure of final covering

Name of Layer	Structure of Waste Foundation	Structure of CP workshop
Erosion prevention layer (Cover soil layer)	$t \geqq 500 \sim 1,500$	Sand , t = 500 , k　1×10^{-3}
Drainage layer	t　300 , $k \geqq 1\times10^{-2}$	Geocomposite or Nonwoven geotextile
Permeation prevention layer	$t \geqq 500$, $k \leqq 1\times10^{-5}$	Permeabel/Waterproof Sheet , k　1×10^{-5}
Gas emission layer	t　300 , $k \geqq 1\times10^{-2}$	Geocomposite or Nonwoven geotextile

t : Thickness (unit : mm) , k : Coefficient of permeability (unit : cm/sec)

Equipment and method of experiment

The equipment that was used for the demonstration experiment has a structure shown in Figure - 1. Four lines of cover soil model soil baths, 6.0m long and 1.0m wide each, were made. The equipment is so simple that the water spraying nozzles (A) to (F) that are arranged on the model soil bath make artificial rain, and the water that penetrates through the layers is drained and collected by the water collecting layer and then guided to the measurement pipe. The layers consist of the water collecting layer at the lowermost part, permeation prevention layer, drainage layer, and the cover soil layer on the top, all of which are enclosed by a geomembrane sheet at the bottom and the side.

The water from the drainage layer is collected by the drainage pipe that is installed on the toe of the slope on downstream side. The water that is permeated from the permeation prevention layer is collected by the water collecting layer immediately below the permeation prevention layer, and is lead to the outside of the model soil bath by the water collecting pipes ① to ③. The water collecting layer is divided into three sections by the geomembrane sheet, and the amount of the permeated water is measured for each division individually.

For regular cover soil structures, a gas emission layer is placed below the permeation prevention layer. For this experiment, the gas emission layer is not used because the purpose is to measure the amount of water from the drainage layer and permeation prevention layer.

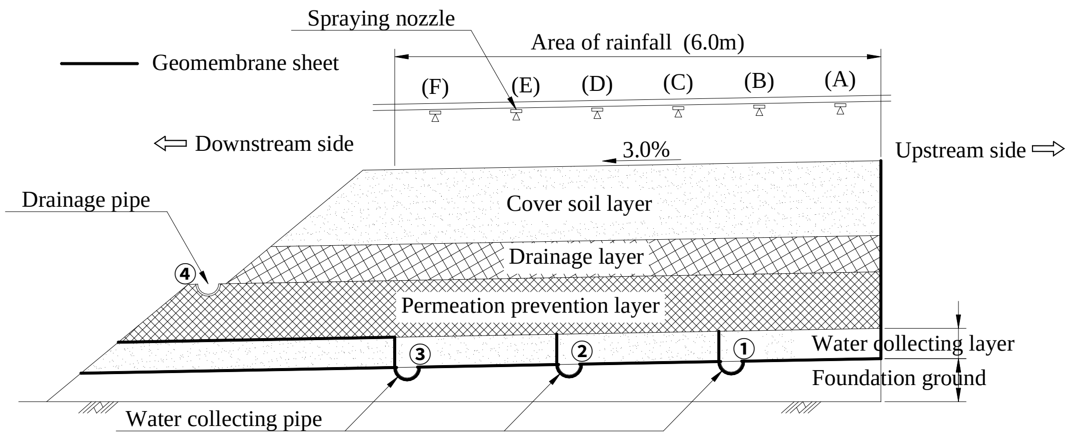

Figure - 1 Schematic view of experimental equipment (cross-sectional view of using soil materials)

For this demonstration experiment, four types of cover soil model soil bath were used (see Table – 2). The types (1) to (3) use geosynthetics for the drainage layer and permeation prevention layer. The drainage layer were given a structure consisting of geocomposite (t=10mm, 20mm) and nonwoven geotextile (t=20mm), and the permeation prevention layer consisting of permeable waterproof sheet. The permeable waterproof sheet is a product with a structure that can control the water permeability in a certain range and pass gases without restriction. For comparison purpose, the model soil bath of type (4) was given a cover soil structure that uses soil materials defined by Waste Foundation. As may be known from Figure – 2, the adoption of the cover soil model soil bath made of geosynthetics in place of soil materials allows reduction of the layer thickness by approximately 80cm.

Table - 2 Models of different materials used for the demonstration experiment

	Type (1)	Type (2)	Type (3)	Type (4)
Cover soil layer	Sand t = 500 , k = 1×10^{-3}			
Drainage layer	Geocomposite t = 20	Nonwoven geotextile t = 20	Geocomposite t = 10	Sand (Coarse sand) t= 300 , k = 1×10^{-2}
Permeation prevention layer	Permeabel Waterproof Sheet t=1.0 , k = 1×10^{-5}			Bentonite mixture soil t = 500 , k = 1×10^{-5}

t :Thickness (unit :mm) , k :Coefficient of permeability (unit :cm/sec)

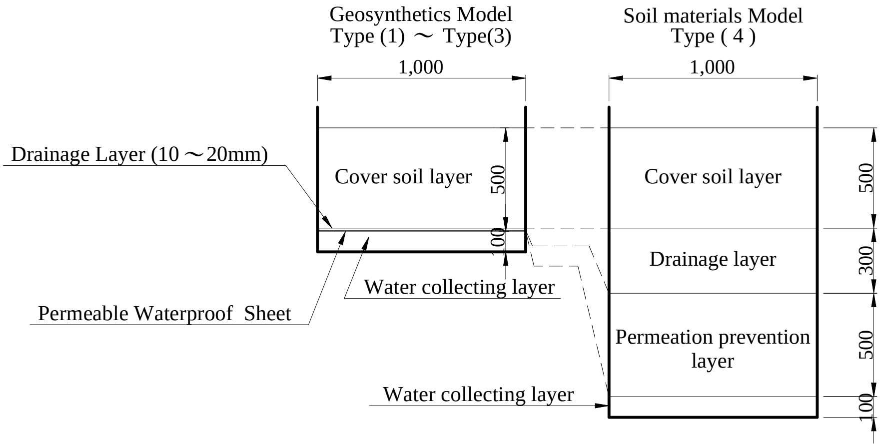

Figure – 2 Cross-sectional view of cover soil model soil bath

For the experiment, six water spraying nozzles that were arranged on the model soil bath, one unit per 1.0m^2 (see Figure - 3) , sprayed water to make artificial rain fall. The experimental equipment was covered with a sheet entirely to prevent the effect of wind (see Figure - 4). The control of water spraying amount was made based on the relationship between the water spraying pressure and water spraying amount that was measure beforehand, and in addition, the water spraying amount was verified by directly measuring the amount of water from each water spraying nozzle. The measurement was made at about three hours from the beginning of the water spraying. The amount of water spraying and the amount of permeation and draining from each layer was measured every one hour.

Figure - 3 Model soil bath for experiment

Figure - 4 Overall view of experiment equipment

Experiment and results of analysis

1）Results of experiment at water spraying rate of 30mm/hour

The experiment was performed with the artificial rain at the water spraying rate of 30mm/hour (water spraying pressure of 0.15MPa), and the amount of premeation and drainage from each layer was measured. Figure – 5 and Table – 3 show the results of the measurement by type of the bath structure. These measurement data are the collection of the data at 7th or 8th hour from the beginning of the water spraying.

For the amount of water spraying, we confirmed that the types (2) and (3) provided similar measurements, but types (1) and (4) showed increase or decrease of some 7%. This may be due to the error from the water spraying pressure and dirt and air bubbles in the water spraying pipe.

For the types (1) and (3) that uses geocomposite materials with difference thickness for the drainage layer, they did not show big difference of water flow from the drainage layer. For the amount of water from the permeation prevention layer, we confirmed that the type (3) that uses a thin geocomposite (t=10mm) provided more water. For both types (1) and (3), most of the water sprayed was collected from the drainage layer and permeation prevention layer and measured, and the water not collected were only several percent.

For type (2) which is a model using nonwoven geotextile (t=20mm) for the drainage layer, the amount of water from the drainage layer is as low as approximately 10% when compared with the case of type (1) that uses the geocomposite with the same thickness. However, we confirmed that the amount of water from the permeation prevention layer was approximately 45% of the water sprayed.

The difference may be because the amount of water supply to the permeation prevention layer located below the drainage layer is affected by the water permeability of the material used for the drainage layer. The amount of water that was not collected was approximately 46% of the overall amount of water sprayed, which may be because the steady state was not reached yet during the measurement.

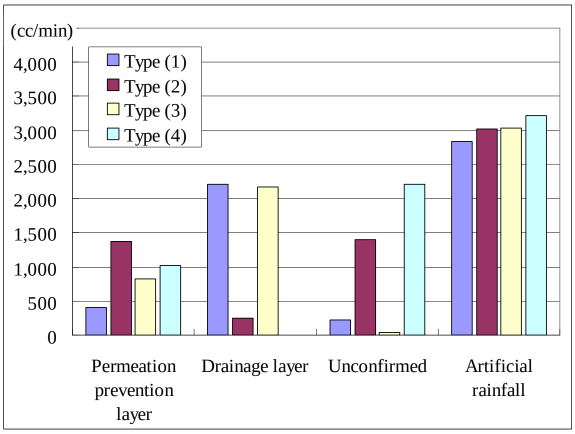

Figure - 5 Amount of water permeated from each layer (water spraying rate of 30mm/hour)

For the type (4) which uses soil materials, we confirmed that the amount of water from the permeation prevention layer was approximately 31% of the water sprayed. However, we were not able to recognize the water permeated from the drainage layer during the measurement. Also, similar to the case of type (2), the amount of water not collected was much, which was approximately 69% of the whole water sprayed. This may be because the steady state was not reached yet during the measurement, and in addition, the soil material layer was so thick that it has sufficient pore in the layer for retaining much water. Based on this matter, we determined to performed the experiment again with additional measurement pipe on the slope where the water from the permeation prevention layer exits.

Table.3 Measurements of amount of water premeated from each layer
(water spraying rate of 30mm/hour)

	Type (1)	Type (2)	Type (3)	Type (4)
Artificial rainfall = Σ [(A)～(F)]	2,844 (100%)	3,021 (100%)	3,038 (100%)	3,222 (100%)
Permeation prevention layer = Σ [①～③]	411 (14%)	1,374 (45%)	828 (27%)	1,014 (31%)
Drainage layer = ④	2,215 (78%)	245 (8%)	2,171 (71%)	0 (0%)
No measurement = Σ [(A)～(F)] - Σ [①～④]	218 (8%)	1,402 (46%)	39 (1%)	2,207 (69%)

(Unit : cc/min)

2) Results of analysis of seepage flow at water spraying rate of 30mm/hour

To reproduce this experimental model, we used FEM unsaturated seepage flow analysis software, HYDRUS-2D, to numerically analyze the seepage flow. For the model soil baths of the types (1), (2) and (3), which uses the geosynthetics for the drainage layer and permeation prevention layer, there was a possibility that the application of the formula for calculation of the unsaturated premeation can cause a problem because the capillary phenomenon does not act on, but it is considered that the effect is less because the layer is thinner as compared with the size of the model. As the amount of water sprayed, the measurements for each model soil bath were used because the amount of water sprayed at the demonstration experiment varied a little among the model soil baths. The plots of the calculation are shown in Figure – 6.

For the types (1) and (3) which use geocomposite for the drainage layer, the amount of water drained was 66% and 37% of the amount of water sprayed respectively, and the remainder is drained from the permeation prevention layer. These rates are more than the experimental values. The cause may be the effect of difference of thickness of the drainage layer because the permeability coefficient of their drainage layers is the same.

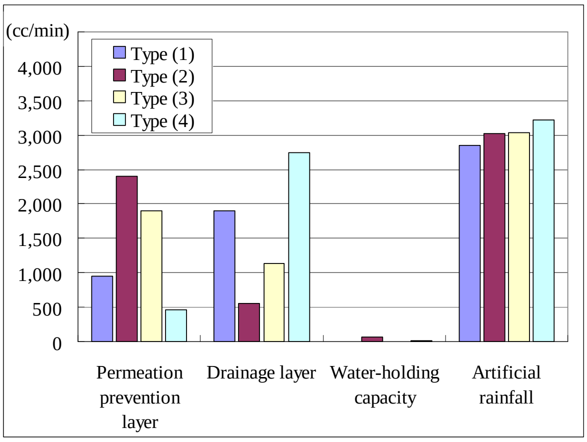

Figure - 6 Results of analysis of seepage flow
(water spraying rate 30mm/hour)

For the type (2) that uses nonwoven geotextile for the drainage layer, the results were similar to the experimental values. Because the permeability coefficient of the nonwoven geotextile is low similar to the results of the experiment, it is considered that the water that was not drained from the drainage layer was transferred to the permeation prevention layer. For the case of type (4) that uses soil materials, water 85% of the amount of water sprayed was drained from the drainage layer, which is different from the experimental values. Based on these results, it is estimated that the bentonite mixture soil was still swelling at the time of the experiment.

3）Results of experiment at water spraying rate of 40mm/hour

Since, for the previous measurement (water spraying rate of 30mm/hour), the amount of water measured did not coincide with the amount of water sprayed for type (4), we added the measurement pipe ⑤ to the toe of slope in front of the permeation prevention layer, only for the type (4), to measure the amount of water from the inside of the permeation prevention layer (see Figure – 7). This is because we took into consideration that the permeation prevention layer of the type (4) is thick, unlike the other model soil baths.

For the experiment, we sprayed the water at the rate of 40mm/hour (water spraying pressure of 0.25MPa), which is higher than the previous experiment, and measured the amount of the permeation from each layer in the same way.

Figure - 8 and Table - 4 shows the results of the measurement by type. For the type (4), the amount of water from the edge of the permeation prevention layer was added to the amount of water from permeation prevention layer, and plotted (see Figure - 8). These measurement data are also those collected at 7th or 8th hour from the beginning of the water spraying.

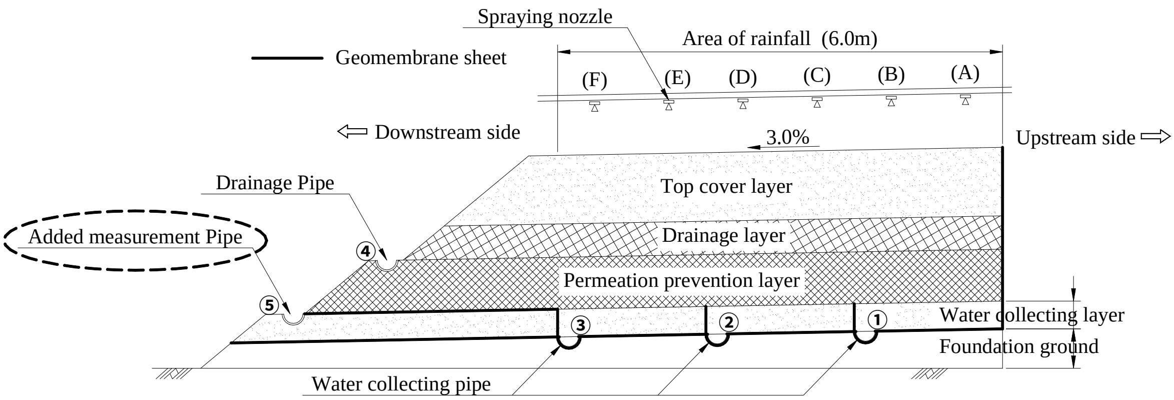

Figure – 7 Added measurement pipe (cross-sectional view when soil materials are used)

For the amount of water sprayed, though we confirmed that the amount of water was more than the targeted value by several percent, good results were obtained with similar amount of water sprayed in general.

For the types (1) and (3) that use geocomposite of different thickness for the drainage layer, we confirmed that the amount of water from their drainage layers is the same, but the amount of water from the permeation prevention layer of the type (3) was higher. Though the qualitative results are similar to the previous case as a general trend, the measurement of the amount of water of type (1) was less than the estimation. And, the amount of water that was not measured was only several percent of the whole amount of water sprayed, which is good result of the measurement. However, though the amount of water sprayed was increased, we confirmed that the amount of water from the permeation prevention layer was decreased, which is a problem to be solved in the future together with issues such as clogging.

On the contrary, for the type (2) that uses nonwoven geotextile for the drainage layer, the amount of water from both permeation prevention layer and drainage layer was increased as compared with the results of the previous experiment, and the ratio with respect to the amount of water sprayed was near equal to the previous measurement results. But, the amount of water that was not measured was as high as 36% of the whole.

For the type (4) which uses soil materials, addition of the measurement pipe to the slope of the permeation prevention layer resulted in reduction of the amount of water that was not measured, which is qualitatively similar to the case of type (2) that uses nonwoven geotextile. But the amount of water that was not measured was the same as the case of type (2). It is estimated that the cause is that, for both types, the steady state is not reached in the present measurement time.

After the experiment, we disassembled the model soil baths to verify the state of damage of the geomembrane sheets and connection of the measurement pipes and checked them if leak and/or damage that can cause occurrence of the amount of water that was not measured exist, but no such situations were identified. As a result of laboratory permeability test, the permeability coefficients of the bentonite mixture soil that was used for the permeation prevention layer were in the order of 10^{-5} to 10^{-6}cm/sec.

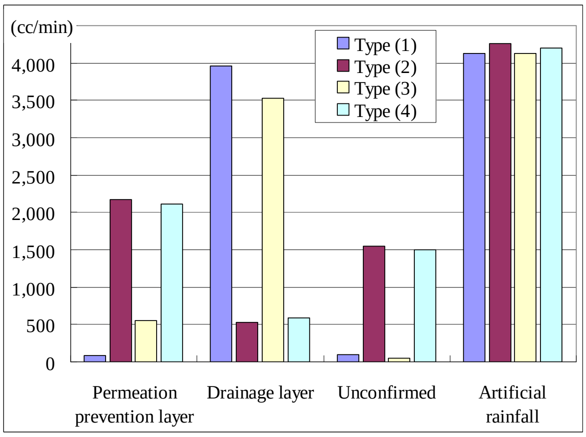

Figure - 8 Amount of water premeated from each layer (water spraying rate of 40mm/hour)

Table.4 Measurements of amount of water premeated from each layer (water spraying rate of 40mm/hour)

	Type (1)	Type (2)	Type (3)	Type (4)
Artificial rainfall = Σ[(A)～(F)]	4,133 (100%)	4,255 (100%)	4,125 (100%)	4,198 (100%)
Permeation prevention layer = Σ[①～③]	87 (2%)	2,176 (51%)	555 (13%)	981 (23%)
Drainage layer = ④	3,956 (96%)	531 (12%)	3,527 (86%)	587 (14%)
Toe of slope within permeation prevention Layer = ⑤	----	----	----	1,133 (27%)
Unconfirmed = Σ[(A)～(F)] - Σ[①～⑤]	91 (2%)	1,548 (36%)	43 (1%)	1,497 (36%)

(Unit : cc/min)

Summary and future issues

As a result of the above experiments and analysis of seepage flow, we confirmed that;

① The use of geosynthetics in place of soil materials for the structuring of each layer can still provide a function that get rids of excessive rain water and permeate the remainder to the waste layer.

② The amount of water permeated into the waste can be adjusted by the thickness of geosynthetics used for the drainage layer.

③ As a result of these experiments, we were not able to confirm the correlation between the amount of water sprayed and the amount of water from the drainage layer and permeation prevention layer.

The future issues are as follows.

① To increase the patterns of the amount of water sprayed so that the amount of water permeated into the waste can be controlled, we should accumulate the measurement data.

② The effect of clogging of the geosynthetics should be verified through demonstration experiments.

③ The cause of unbalanced water budget for the drainage layers with low water permeability should be studied.

④ The method for designing the most suitable cover soil structure should be established by comparing and examining the results of analysis of the values obtained from demonstration experiments.

Acknowledgements

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Refferences

“Improvement of waste landfill; planning and design procedures” (Japan Waste Management Association)