Research for development of Spiral bladed Drain Pipe Reinforcement method

Recherche pour le développement de Spirale bladed Canalisation Pipe Renforcement méthode

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ABSTRACT: The purpose of this research is to develop a new earth reinforcement technology "The SDPR method" having both functions of a single earth reinforcement to increases the embankment strength and a drainage pipe to lower a ground water level in embankment at the same time. This paper summarizes the field test results of pullout test and drainage test of the SDPR method. The main conclusions are as follows: 1) It is possible to install a SDPR by using a conventional boring machine. 2) It was found that by a pull-out resistance test the SDPR integrates entirely bonded to the surrounding ground and the interface resistance between SDPR and the ground had a very high correlation with the representative *N*-value of the ground. 3) It was found that by installing SDPR into embankment the hail-life of an effective rainfall to match groundwater fluctuation was shorter meaning that SDPR accelerates water pressure dissipation and drainage from embankment. 4) It was found that ultimate effective rainfall increases to improve drainage resistance of embankment by installing SDPR.

RÉSUMÉ : Le but de cette recherche est de développer une nouvelle technologie de renforcement de terre "La méthode SDPR" ayant les deux fonctions d'un renforcement de terre simple aux augmentations la force de digue et une pipe de drainage pour baisser un niveau de nappe phréatique dans la digue en même temps. Ce papier résume les résultats d'essai de terrain d'épreuve de retrait et d'épreuve de drainage de la méthode SDPR. Les conclusions principales sont comme suit : 1) Il est possible d'installer un SDPR en utilisant une aléseuse conventionnelle. 2) Il a été constaté que par une épreuve d'une résistance de retrait le SDPR s'intègre entièrement fait adhérer à la terre environnante et à la résistance d'interface entre SDPR et la terre avait une très haute corrélation avec la N-valeur représentative de la terre. 3) Il a été constaté qu'en installant SDPR dans la digue la vie de la grêle d'une chute de pluie efficace pour correspondre à la fluctuation de nappe phréatique signifiait plus brusquement que SDPR accélère la dissipation de pression d'eau et le drainage de la digue. 4) Il a été constaté que la chute de pluie efficace ultime augmente pour améliorer la résistance de drainage de digue en installant SDPR.

KEYWORDS: Earth reinforcement, Drain pipe, Disaster prevention, Road Embankment

1 INTRODUCTION

Since 40 % of current expressways in Japan have been used for more than 30 years after starting the service, it is generally known that the long use and the deterioration of expressways are becoming important on the safety of expressways.

In order to ensure the permanent safety of expressway and to maintain the functions of an expressway network prospectively, "Expressway Renewal Project" has been planned in 2016. For the expressway embankment constructed with slaking materials, cohesive soils or sandy soils with high water content, a large-scale repair such as drainage countermeasure and earth reinforcement is planning. However, to protect effectively against complex disasters caused by major earthquake and heavy rainfall, not only the countermeasure against single disaster, but also comprehensive countermeasure is required.

Therefore, the purpose of this research is to develop a new earth reinforcement technology having both functions of a single earth reinforcement to increases the embankment strength and a drainage pipe to lower a ground water level in embankment at the same time. This paper presents the development of "Spiral bladed Drain Pipe Reinforcement method", the SDPR method. In particular, this paper summarizes the field test results of pullout test and drainage test of the SDPR method.

【Installation of SDPR】 【Near view of SDPR】

Photo 1. Construction site of SDPR method.

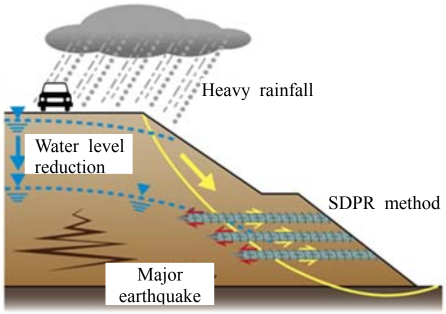


Figure 1. Outline of SDPR method.

2 SDPR method

2.1 *Overview*

The SDPR method is a method to insert a steel pipe with square slits for water drainage and spiral shape blades for reinforcement on the surface of the pipe. The SDPR method is expected to decrease the water content and pore water pressure under rainfall situation, and to reinforce the embankment stability due to the resistance of spiral blades. Photo 1 shows the construction site of the SDPR method in Miyazaki, and Figure 1 shows an outline of the SDPR method.

2.2 *Scale of countermeasure*

Figure 2 summarizes the dimension of rainfall-induced slope failure in Kyushu-Okinawa region from 1993 to 2012. It can be seen that the collapse volume less than 1,000 m^3 and collaps e depth less than 3 m are accounted about 90 % of the total failure. Therefore, it is effective to implement countermeasure with the depth of 3 m to prevent the medium-scale failure. From these background, the SDPR method is primarily intended as a countermeasure against these medium-scale failures.

2.3 *Design flow*

For the stability evaluation of the slope with the SDPR method, the length of single SDPR and the interval between SDPRs are calculated to match the additional tensile resistance required under rainfall and earthquake satisfying a predetermined safety factor.

Here, the tensile resistance of a single SDPR is determined by the minimum value of the interface frictional resistance between a SDPR and the surrounding ground, the tensile strength of the SDPR and the weld strength of blades and the SDPR.

2.4 *Shape and specifications of SDPR*

The shape and size of a SDPR are shown in Figure 3 and Table 1. The SDPR was used a general structural carbon steel pipe, outside diameter D_p = 48.6 mm, blade thickness t_p = 3.5 mm, blade interval P = blade diameter D_w. The spiral blades are set over its entire length. The type I is a standard type (D_w / D_p = 1.5), while the type II is a wide type (D_w / D_p = 3.0). Further, the square-shaped slit (6 mm in width × 50 mm in length) with the opening ratio of 10 % was arranged as a water drainage on the entire surface while the SDPR was hot-dip galvanized for the purpose of antioxidation.

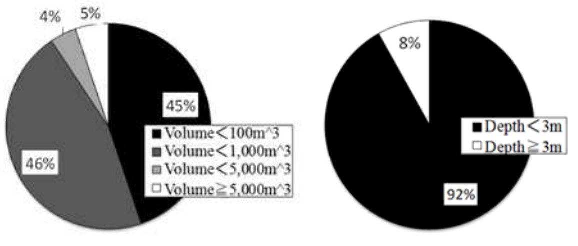
2.5 *Construction*

In the SDPR construction, using a conventional boring machine for an earth reinforcement of cut slope, a single SDPR was rotationally installed into embankment with providing vibration when necessary. As a result, it was possible to install a SDPR for L = 17 m.

3 STUDY ON INTERFACE RESISTANCE

3.1 *Pull-out resistance test description*

In order to investigate the interface resistance between a single SDPR and the surrounding ground, a pull-out resistance test in the embankments at four locations was carried out in terms of the install procedure and the shape of the SDPR. The characteristic of the embankment material is shown in Table 2. The standard SDPR length was L = 5 m while the maximum install length was used for evaluation when it becomes difficult to install due to the interposition of gravel. Pull-out resistance



1) Collapse volume (96 failures) 2) Collapse depth (62 failures)

Figure 2. Demension of rainfall-induced slope failure.

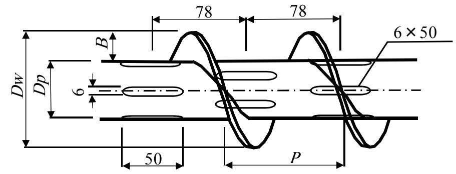


Figure 3. Overview of SDPR.

Table 1. Shape and size of SDPR. dimension; *mm*

Type	Blade diameter (D_w)	Blade width (B)	Blade interval (P)	Blade thickness (t_w)	Remarks
I	72	11.7	72	4.5-2.2	Standard type
II	148	50	148		Wide type

Table 2. Characteristic of the embankment material.

Place	Embankment material	Fine fraction content ; F_c(%)	Plasticity index ; I_p	Representative N-value*
A	sandy soil	7.9～63.2	10.7	4
B	cohesive soil	80.5	17.1	5
C	sandy soil	14.7～20.4	10.5	8
D	sandy soil	41.2	57.3	3

*It was determined by the standard penetration test and the simple dynamic cone penetration test.

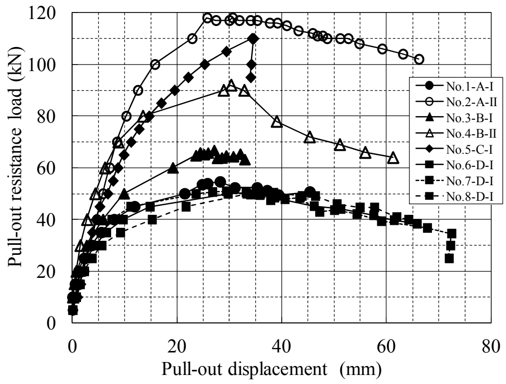


Figure 4. Load-displacement curve.

test was carried out in accordance with the lock bolt pull-out test method.

3.2 *Pull-out resistance test results*

Figure 4 shows the load-displacement curve obtained by the pull-out resistance test (numbers shown in the legend of the figure correspond to the numbers in Table 3). Pull-out resistance load was the maximum load in the load-displacement curve. Pull-out displacement at the maximum load was about 0.5 to 1 % of the SDPR length. Table 3 shows the result of the ultimate interface resistance τ. It is seen that τ = 45 kN/m^2 for the representative N-value = 3 while τ = 97 kN/m^2 for N = 8. In addition, the ultimate interface resistance τ of the wide SDPR type II tends to be high about 10 to 30 % as compared with the standard SDPR type I.

Figure 5 shows the relationship between the ultimate interface resistance τ and the representative N-value. As a result, there is a very high correlation (correlation coefficient by the regression analysis R = 0.96), the ultimate interface resistance τ

using the representative *N*-value was shown to be estimated by $\tau = 10 \cdot N + 13$ (solid line in Figure 5). Furthermore, we compared the estimated value of the ultimate interface resistance τ' of cohesive soil used for earth reinforcement for cut slope (dashed line in Figure 5). It is estimated that $\tau' = 0.8 \cdot c$ when cohesion (c) is quoted $c = 10 \cdot N$. As a result, the interface resistance between the SDPR and the ground was considered to estimate equal to or higher than the interface resistance of the earth reinforcement for cut slope.

4 STUDY ON DRAINAGE PERFORMANCE

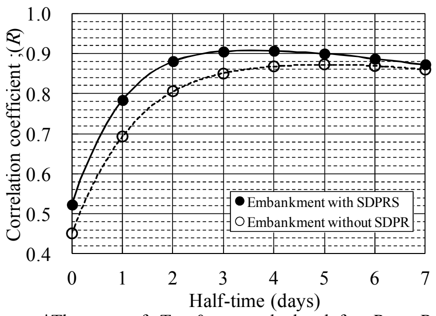
4.1 *Test site for SDPR method*

At the cut slope and embankment located in a catchment terrain as shown in Figure 6, SDPR method was constructed (refer to Photo 1). The height of two-step embankment was about 13 m while the embankment was mainly composed of gravel mingled volcanic sand. SDPR with $L = 11$ m was installed for the upper embankment and SDPR with $L = 9$ m for the bottom embankment in second step. In the stability evaluation, it is assumed to have a highest water level in embankment due to heavy rainfall and to satisfy the required safety factor during rainfall and earthquake. For original embankment without any earth reinforcement, the calculated safety factor is less than the required safety factor. In order to satisfy the required safety factor lowering groundwater level (GL-3.5 m), it was decided to install SDPRs for the interval of 3 m equivalent to the installment density was one per the area of 9 m^2.

4.2 *Groundwater level observation*

Groundwater level observation was carried out respectively at the berm step of the embankment shown in Figure 6. The observation period of this study was targeted from the April 11th, 2015 until September 26th, 2016. Figure 7 shows the observation results of rainfall and groundwater level. Maximum daily rainfall during the observation period was 167 mm/day, it is equivalent to the annual maximum daily rainfall of 2 year return period. Groundwater level had a change from GL-5.9 m to -2.4 m for the embankment with SDPRs and from GL-6.0 m to -1.5 m for the embankment without SDPR.

For the embankment with SDPRs, despite a temporarily rainfall in excess of the GL-3.5 m, groundwater level showed a tendency to decrease rapidly. On the other hand, without SDPR, groundwater level showed a tendency to exceed constantly GL-3.5 m by rainfall. There is a distinct difference between groundwater level with/without SDPR. In addition, in the case of daily rainfall more than 100 mm/day, it was confirmed that the groundwater is about 1 m lowering by installing SDPRs.



*The case of $T = 0$ was calculated for $R_G = R_0$

Figure 8. Relationship between correlation coefficient and Half-time.

Table 3. Results of ultimate interface resistance.

No.	Place	SDPR type	Blade diameter (D_w; mm)	Test body length (L; m)	Pull-out resistance load (P; kN)	Ultimate interface resistance* (τ; kN/m^2)
1	A	I	72	5	54	48
2	A	II	148	4	118	63
3	B	I	72	5	66	58
4	B	II	148	3	92	66
5	C	I	72	5	110	97
6	D	I	72	5	51	45
7	D	I	72	5	51	45
8	D	I	72	5	50	44

*$\tau = P/L(Dw \cdot \pi)$

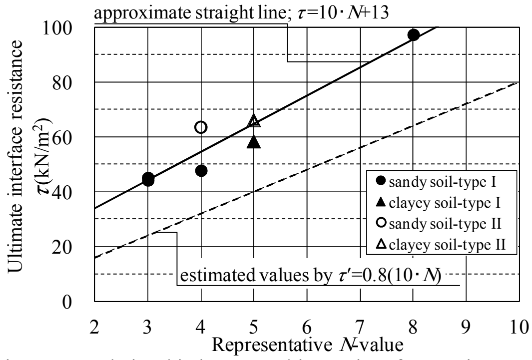


Figure 5. Relationship between ultimate interface resistance and representative *N* value.

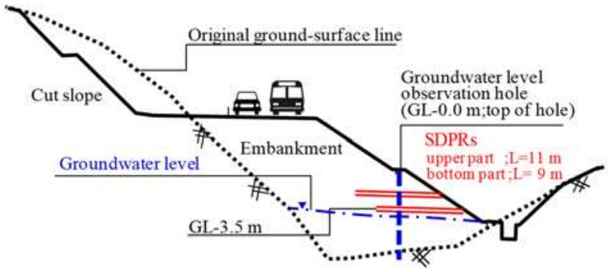


Figure 6. Overview of test site.

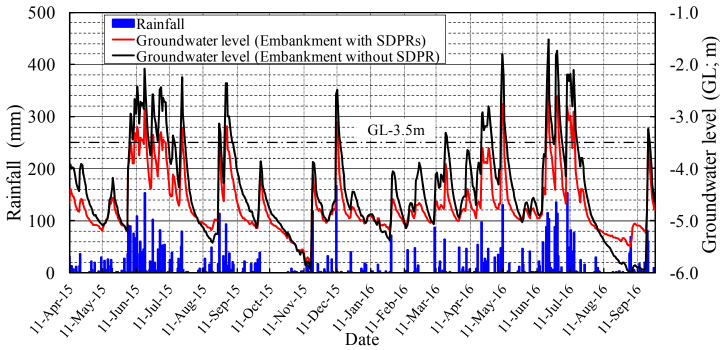


Figure 7. Observation result of rainfall and groundwater level.

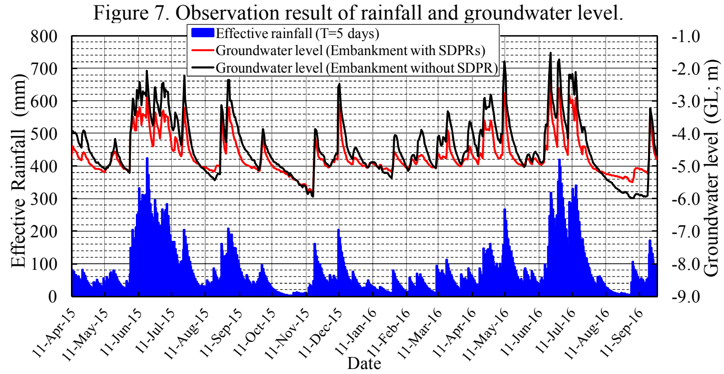


Figure 9. Fluctuation of effective rainfall and groundwater level.

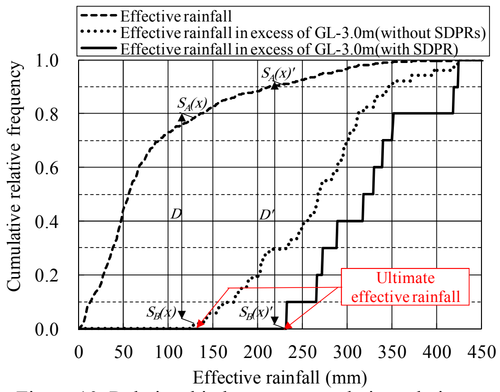


Figure 10. Relationship between cumulative relative frequency and effective rainfall (T = 5 days).

4.3 *Effective rainfall*

In order to quantitatively examine the drainage effect, we tried to evaluate on the effective rainfall considered the effect of preceding rainfall. The effective rainfall is a value of rainfall which showed how much remains in the ground for the sake of convenience. The effective rainfall is expressed by the following equation (1). The half-life T represents a time period to half effect of the rainfall.

$$R_G = R_0 + \Sigma R_n \cdot (0.5)^{n/T} \quad (1)$$

where, R_G is the effective rainfall (mm), R_n is the rainfall before n days (mm), and T is the half-life (day).

In this study, in order to evaluate the water drainage of SDPR, the half-life was calculated to maximize the correlation coefficient between effective rainfall and groundwater level fluctuation as shown in Figure 8. As a result, the half-life for the embankment without SDPR was T = 5 days (correlation coefficient by the polynomial regression analysis; R = 0.87), while the hail-life was T = 4 days for the embankment with SDPRs (R = 0.91). It was shown that the hail-life was shorter meaning the water drainage from embankment accelerated with installing SDPR.

In addition, showing the effective rainfall fluctuation in the case of T = 5 days, in Figure 9, it suggests that it's a very high correlation with the groundwater level fluctuation.

4.4 *Calculation of ultimate effective rainfall*

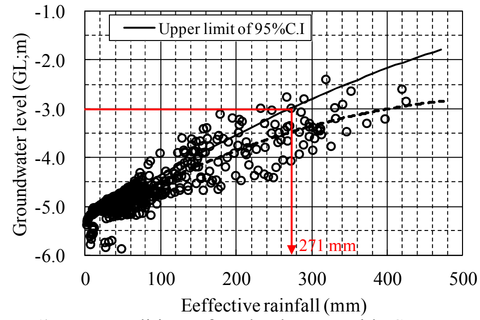
In order to quantitatively examine the improvement of the drainage performance of SDPR, an ultimate effective rainfall was defined as the effective rainfall in excess of the GL-3.0 m which is a condition to satisfy the safety factor F_s = 1.05 for the embankment without SDPR during heavy rainfall.

The calculation was carried out as follows: Under the same conditions of T = 5 days, we counted the frequencies of effective rainfall and excess of GL-3.0 m during the observation period. After that, as shown in Figure 10, ultimate effective rainfall was taken when the effective rainfall became the maximum difference among the two cumulative relative frequency. Then the significance of them was confirmed at the level of 5 % test, using Kolmogorov-Smirnov test (refer to Formula (2)).

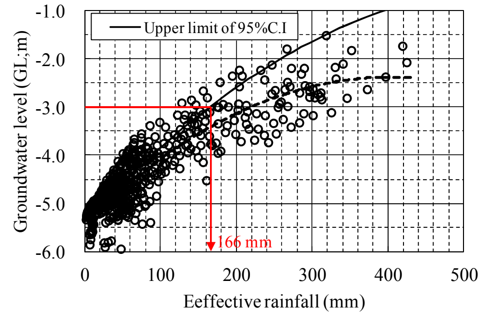
$$D = max \mid S_A(x) - S_B(x) \mid \geqq 1.36 / \sqrt{n} \quad (2)$$

where, D is KS test statistic, S is the cumulative relative frequency, x is the effective rainfall (mm), and n is amount of data. As a result, the ultimate effective rainfall was 232 mm for embankment with SDPRs while 138 mm for one without SDPR.

In addition, as shown in Figure 11, the regression coefficient



1) For condition of embankment with SDPRs



2) For condition of embankment without SDPR

Figure 11. Relation between groundwater level and effective rainfall (T = 5 days).

within 95 % confidence interval was calculated with the relation between the groundwater level and the effective rainfall, to estimate the ultimate effective rainfall with the approximated curve. As a result, the ultimate effective rainfall was 271 mm for embankment with SDPRs while 166 mm for one without SDPR.

Therefore, it is very useful to install SDPRs into embankment for increasing ultimate effective rainfall and decreasing the half-time meaning that there is rapid dissipation and drainage of groundwater due to rainfall.

5 CONCLUSIONS

The main conclusions are as follows:

1) It is possible to install SDPR by using a conventional boring machine when the representative N-value of embankment is 10 or less.

2) It was found that the SDPR integrates entirely bonded to the ground and the interface resistance between SDPR and the ground had a very high correlation with the representative N-value of the ground, and the ultimate interface resistance τ could be estimated by the representative N-value of the ground.

3) It was found that by installing SDPR into embankment the hail-life of an effective rainfall to match ground water fluctuation was shorter meaning that SDPR accelerates water pressure dissipation and drainage from embankment.

4) It was found that ultimate effective rainfall increases to improve drainage resistance of embankment by installing SDPR.

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