Drainage Effect for Embankment by Drainpipe Reinforcement

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ABSTRACT

In recent years, a number of slope failures have occurred due to heavy rain and strong earthquakes. In order to fight natural external force such as sudden rainfalls and unexpected ground motions, a reinforcement technology for the existing embankments is required. From these backgrounds, a spiral bladed drainpipe reinforcement technology (called SDPR method) has been developed. The SDPR method has three aims. First, in a normal condition, the drainpipe of SDPR can lower groundwater level in an embankment and make the embankment unsaturated. Second, the spiral blade of SDPR can resist against the sliding force of a slope failure and improve the slope stability. Third, in cases of heavy rain and a severe earthquake, the SDPR can dissipate the water pressure in an embankment. The SDPR method was experimented at a highway embankment in Tosu City, Saga Prefecture. The experiment was carried out on September 19, 2016, and the groundwater level of the embankment have been monitored for about 3 months before executing the SDPR method.

The purpose of this study is to examine the method and to reproduce the groundwater level change in the embankment by a saturated-unsaturated seepage analysis using the finite element method (FEM) and compared the water level change by having drainage-related reinforcing structure or not under the ground.

Key words: *drainpipe, embankment, reinforcement, FEM*

1. Introduction

In recent years, a number of slope failures have occurred due to heavy rains and strong earthquakes. In order to fight natural external force such as a sudden rainfall and an unexpected ground motion, a reinforcement technology for existing embankments is required. From these backgrounds, the spiral bladed drainpipe reinforcement method (called SDPR method) has been developed (Hamasaki, T *et al.*, 2017). **Fig. 1** shows spiral bladed drain pipe (SDPR). **Fig. 2** shows three aims of the SDPR method. First, in a normal condition, the SDPR can lower the groundwater level in an embankment and make the embankment in an unsaturated condition with its drain holes. Second, the spiral blade of SDPR can resist against the sliding force of slope failure and improve slope stability. Third, in cases of a heavy rainfall and a severe earthquake, the SDPR can dissipate the water pressure in the embankment.

Fig. 1 SDPR

The purpose of this study is to examine the drainage effect of SDPR method for embankment. The method is conducting saturated-unsaturated seepage analysis by changing water level using the finite element method (FEM) and compare the ground water level without or with SDPR in the embankment.

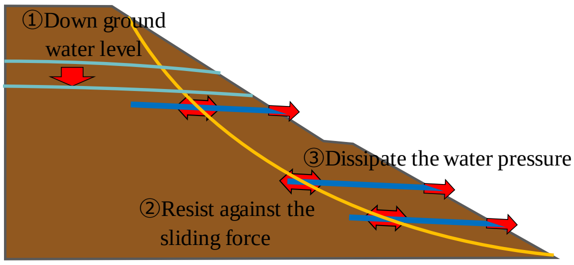

Fig. 2 Aims of SDPR method

2. Targeted embankment

The SDPR method was experimented on the south side of the highway embankment in Tosu City, Saga Prefecture. The experiment was carried out on September 19, 2016. Groundwater level, volumetric water content and suction of the embankment have been monitored for about three months before executing the SDPR method. The length of the drainpipe is 6m and the radius is 0.024m. The drainpipes were placed at 1.5m and 3.5m upper from the foot of lower slope and 1.5m upper from the foot of upper slope. The horizontal spacing of each SDPR was 3-4m. **Fig. 3** shows the actual cross section, the analytical model and where the hydrograph under the ground was. Groundwater levels were monitored every one hour.

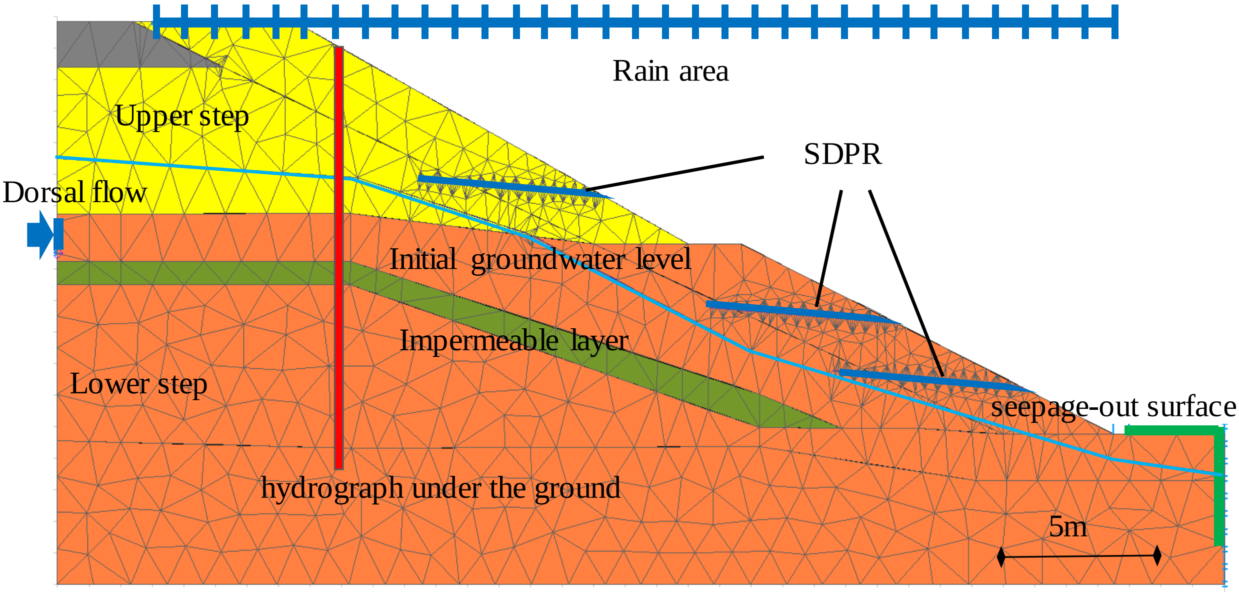

Fig. 3 Analytical model and mesh

Table 1. Soil property and analysis conditions

	Soil property		Analysis conditions			
	Wet density(g/m^3)	Dry density(g/m^3)	Coefficient of permeability (m/sec)	Specific storage coefficient (1/m)	Effective porosity	Residual volume water content
Upper section	1.472×10^6	1.098×10^6	1.250×10^{-6}	$1.000\times10^{-4*}$	0.49	0.24
Lower section	1.716×10^6	1.328×10^6	1.250×10^{-6}	$1.000\times10^{-4*}$	0.44	0.30

* General value (GODAI KAIHATU Corporation, 2013)

3. Summary of seepage analysis

Saturated-unsaturated seepage analysis were for performed for the cross section that SDPR were installed in the expressway embankment in Tosu City, Saga. **Fig. 3** shows the analytical model. It was made to fit the actual embankment. **Table 1** shows soil properties and analytical conditions. The wet density, dry density coefficient of permeability, effective porosity and residual volume water content were obtained by indoor soil test. **Fig. 4** shows the amount of rainfall and the effective rainfall used in the analysis. Targeted period was July 1-15, 2016 when there was much rainfall. In this analysis, a dorsal flow was turned on the embankment to consider water from surrounding tomographic and another slope. By changing the amount of dorsal flow, the reproducibility of the under groundwater level fluctuations were carried out. A dorsal flow was set to be a function of effective rainfall. Effective rainfall is a value representing the amount corresponding to the moisture in the earth that changes as the penetration and outflow of the falling rain over time. Effective rainfall is expressed by the following equation (1).

$$R_G = R_0 + 0.5^{1/T} \times R_1 + 0.5^{2/T} \times R_2 + \cdots + R_n \cdots (1)$$

where, R_G is effective rainfall (mm), R_n is rainfall n hour ago (mm/h), T is half life (h). In this analysis, general value of T=72(h) was used because it shows the amount of moisture contained in the soil.

An analysis was performed with SDPR set to adjust actual locations. **Table 2** shows SDPR conditions on the seepage analysis. In the part where the SDPR was actually located, holes were set in the ground whici enables SDPRs to allow free drainage. Then, the effect of reducing level and effective saturation with and without SDPR was compared. Finally, the safety factor of the embankment slope in the analysis was compared with or without SDPR.

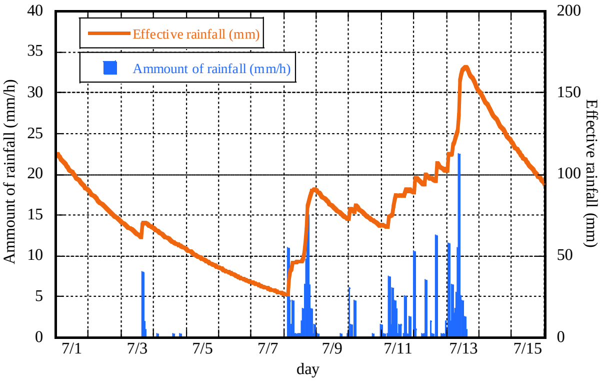

Fig. 4 Amount of rainfall and effective rainfall

Table 2. SDPR condition

Pipe radius (m)	0.024
Length (m)	6.0
Placement angle(°)	3
Horizontal spacing interval(m)	3.0
Groundwater lowering condition node interval(m)	0.078

4. Calculation of the safety factor

When doing stable calculations, the inside of the embankment was divided into a surface layer part, a deep upper part, and a deep lower part (**Fig. 4**). **Table 3** shows the internal friction angle ϕ and cohesion c. They were obtained from a triaxial compression test of unsaturated soil (exhaust non-drainage condition) (Matsukawa, K *et al.*, 2019). The shear resistance angle was constant at 30° regardless of saturation. The adhesive strength c was determined according to the degree of saturation obtained from the analysis. The deep part was set to a constant value because the state has hardly changed. These intensity constants below the groundwater level of the surface layer part was evaluated as a normal compaction state (c = 0). The effect of lowering groundwater was only considered in this calculation.

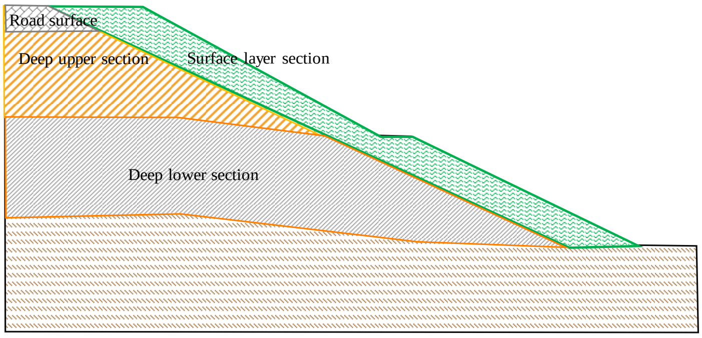

Fig. 5 Stable calculation model

Table 3. Used internal friction angle and adhesive force c in saturated and unsaturated situation

Section	Unsaturated		Saturated	
	Internal friction angle ϕ (°)	Cohesion c (kN/m^2)	Internal friction angle ϕ (°)	Adhesive force c (kN/m^2)
Surface layer section	20.0	20.0	30.0	0.0
Deep upper section	30.0	40.0	30.0	20.0
Deep lower section	30.0	30.0	30.0	20.0

5. Examination of dorsal flow rate

Fig. 6 shows changes of actual measured water levels and analysis water levels. The actual change of the groundwater levels in the analysis could be reproduced when the dorsal flow was set to the following value.

(Dorsal flow)={effective rainfall(mm) ×0.000001+0.0001} (m^3/min)

The actual groundwater level got the minimum value -4.74m on July 8 and the maximum value -2.01m on July 13. Calculated water level was got similar to the measured values. Therefore, following analyses were performed with this dorsal flow.

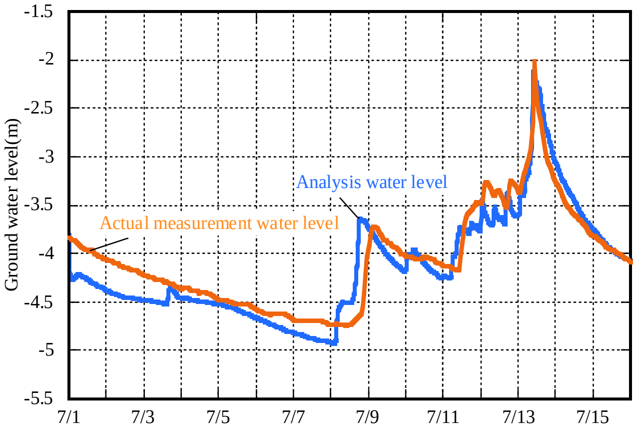

Fig. 6 Actual measured water level and analysis water level

6. Comparison of groundwater level with or without SDPR

Fig. 7 shows the groundwater levels with or without SDPR. From the results, With SDPR, the maximum groundwater level lowered about 1.5m and the average groundwater level lowered about 0.2m compared with the condition of without SDPR. The closest SDPR from the measurement point was about -4m deep. These results can be lead that indicated SDPR is effective to lower the groundwater level, especially for groundwater level over it.

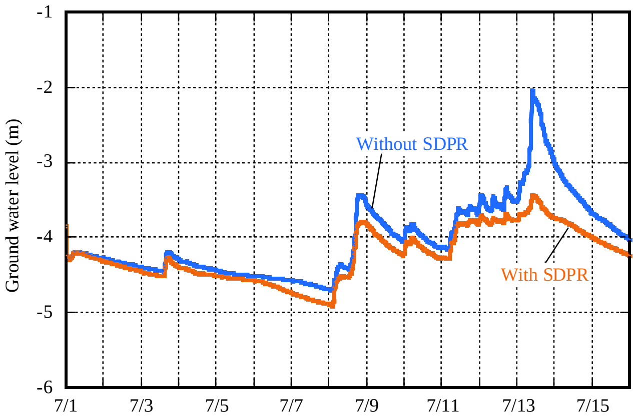

Fig. 7 Ground water level without or with SDPR

7. Relative temporal change of safety factor with or without SDPR

Fig. 8 shows the relative temporal change of safety factor with or without SDPR. The safety factor was obtained by repeating arc calculation. In repeated arc calculation, the center position and radius of arc slip showing the minimum safety factor were obtained by trial calculation. The value at 24 o'clock was used each day. The values were relatively evaluated based on the safety factor at 24 o'clock on July 1 without SDPR. A sliding surface with a depth of 1 meter or more was used. The rate of change of safety factor was about 0.5 times on July 11 without SDPR, but it was suppressed to about 0.8 times with SDPR. Therefore, SDPR had the effect of improving stability.

Fig. 9 and **10** show the groundwater levels and sliding surface with the lowest safety factor on July 11 with or without SDPR. The groundwater level declined much more near SDPR in the lower section. The depth of sliding surface without SDPR was 1.58m and with SDPR was 1.00m. The sliding surface with SDPR got deeper than without SDPR owing to decline the groundwater level.

8. Conclusions

The purpose of this study is to examine the drainage effect and stabilizing effect of SDPR method for embankment. As a result, following conclusions are obtained.

(1) The actual change of the groundwater level in the analysis could be reproduced when the dorsal flow was set to following value. (Dorsal flow)={effective rainfall(mm) × 0.000001+0.0001}(m^3/min)

(2) SDPR is effective to lowered the groundwater level, especially for groundwater level over it. With SDPR, the maximum groundwater level downs about 1.5m and the average groundwater level lowered about 0.2m compared to without SDPR.

(3) SDPR has the effect of improving stability. The change rate of safety factor was about 0.5 times on July 11 without SDPR, but it was suppressed to about 0.8 times with SDPR.

Therefore, the drainage effect and stabilizing effect of SDPR method for embankment could be confirmed.

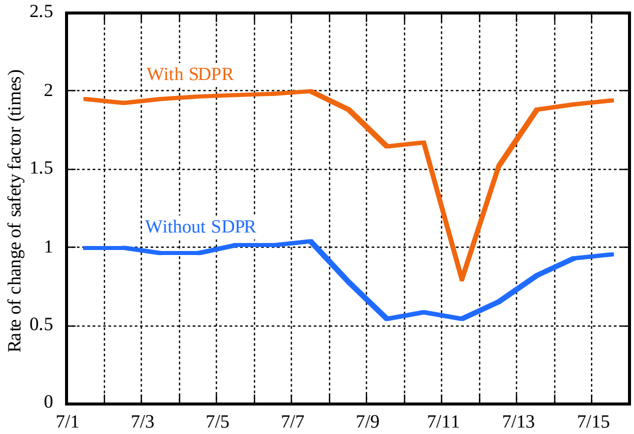

Fig. 8 Relative temporal change of safety factor without or with SDPR

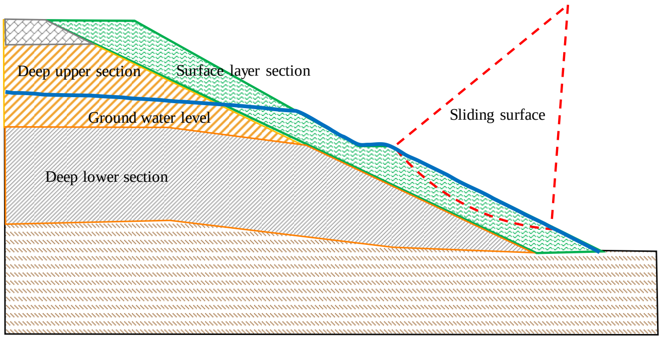

Fig. 9 Ground water level and sliding surface without SDPR

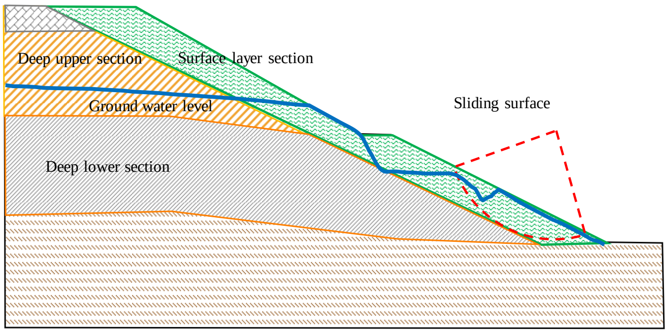

Fig. 10 Ground water level and sliding surface with SDPR

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