

Scientific Paper

# Simulation method of runoff amount of rainwater from permeable pavement

Hiromitus Nakanishi<sup>1</sup>, Taesoon Park<sup>2\*</sup> and Il Hwan Kang<sup>3</sup>

<sup>1</sup>Ph.D., P.E., Executive Advisor of Taiyu Kensetsu Co, Ltd. Japan (Lifetime member of KAI)

<sup>2</sup>Professor, P.h.D, P.E., Department of Civil Engineering, Seoul National University of Science and Technology

<sup>3</sup>Ph.D Course, Departments of Civil Engineering, Seoul National University of Science and Technology

\*Corresponding author: Tel. +82-2-970-6946, E-mail. [tpark@seoultech.ac.kr](mailto:tpark@seoultech.ac.kr)

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## ABSTRACT

This paper presents the simulation method runoff amount of rainwater when the permeability pavement is used in the urban area. The urban area can be easily attacked by the sudden heavy rainfall in a short time and flooded. The reason is that the most of urban area is covered by the impervious surface layer such as dense asphalt pavement and sidewalk. This method was introduced by the Public works research institute, Japan in 2005. The field trial site was constructed and applied the simulation method to show the procedure of the calculation of the runoff amount. The result of the calculation showed that the permeable pavement was successfully protected or at least able to minimize the flood problem in case of applying the permeable pavement in the urban area.

**Keywords:** rainwater, runoff, simulation method, permeability pavement

## 1. Introduction

The year of 2019 was a year when the devastating rainfall and the urban flood were frequently taking place in Japan. As I referred in the journal, in spite of the fact that about 20 years have passed after the permeability pavements were paved, there were no severe problems especially with the structural deterioration in the pavements. We have learned water should not enter the pavement because the structural damage would take place, and we have been holding the theory for a long time. But, the results of the field trials for the permeability pavements have demolished the conventional theory and taught us the permeability pavements would be able to be sustainable and contribute to mitigating the urban flood by permeating the rainwater or storing the rainwater tentatively.



Under such circumstances, what I have to do now is to introduce and spread the calculation method of runoff amount of rainwater in the case of using the permeability pavement and to spread widely the permeability pavement itself to control the urban flood.

Regarding the calculation method of the runoff amount of rainwater through the permeability pavement, Public Works Research Institute in Japan, PWRI, has developed it in 2005, and it has been elaborated in “Road surface rainwater treatment manual (draft) (PWRI, 2005)”, “Appendix of Pavement Performance Evaluation Method (JRA, 2008)”, “Calculation Guidebook on Reduction of Environmental Loads (JRA, 2014)”. And, the calculation method has been released as an Excel file, the person who bought the book (JRA, 2014) can get the excel file free charge.

Here, I would like to elaborate on the calculation method in detail.

## 2. Runoff Coefficient & Maximum Runoff Amount Rate of Rainwater

### 2.1 Runoff Coefficient of Rainwater

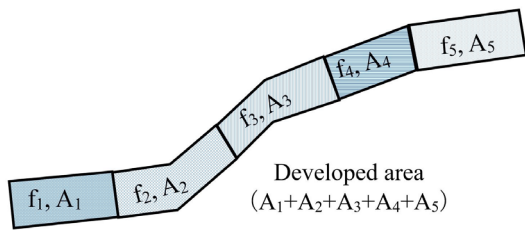
In the “Act on countermeasure against flood damage of the specific river running across cities” enacted in June 2003, the peak runoff rainwater amount in the standard rainfall intensity (10 years probability rainfall), which is the maximum runoff rainwater amount calculated every 10 minutes in the developed area, must be controlled to be the same or smaller rather than that before development.

The runoff coefficient has been designated in the Announcement No. 521 from Japanese MLIT, Japanese Ministry of Land, Infrastructure and Transport, “Announcement to determine runoff coefficient for each land use used in calculating maximum runoff”. An example is as follows (MLIT, 2009).

**Table 1.** Example of runoff coefficient (MLIT, 2009)

Classification	Runoff Coefficient
Housing land	0.90
Road (Dense-graded pavement)	0.90
Macadam road	0.50
Mountain land	0.30
Play ground	0.80
Forest land, Farmland, Wilderness, etc.	0.20

The runoff coefficient (F) for the entire development area is determined by proportionally dividing the runoff coefficient for each land use mode by the total area. An example is as shown in Eq. (1).



$$F = \frac{f_1 \cdot A_1 + f_2 \cdot A_2 + f_3 \cdot A_3 + f_4 \cdot A_4}{A_1 + A_2 + A_3 + A_4} \quad (1)$$

where, F : Runoff coefficient in entire developed area  
 $f_1, \dots, f_4$  : Runoff coefficient of each land use mode  
 $A_1, \dots, A_4$  : Area of each land use mode

Fig. 1. How to calculate runoff coefficient of original land (MLIT, 2009)

## 2.2 Maximum Runoff Amount Rate

The maximum runoff amount rate is the rate of the maximum runoff rainwater amount, which would be discharged to the rivers through the drainage facilities, against the maximum rainfall. The smaller the maximum runoff amount rate shows that the effect of restraint of runoff of rainwater is higher. The runoff coefficient shown in the former section is based on only the natural percolation and is a constant which does not depend upon the kinds of the pavement, existence or non-existence of the percolation facilities, and other (Ichikawa et al., 1984). Therefore, the entire runoff restraint performance of the permeability pavement including the water storage facilities and/or percolation facilities cannot be evaluated. Here, the maximum runoff amount rate is selected as an index that can evaluate the rainwater runoff restraint performance of the permeability pavement and others (Wada and Miura, 1995).

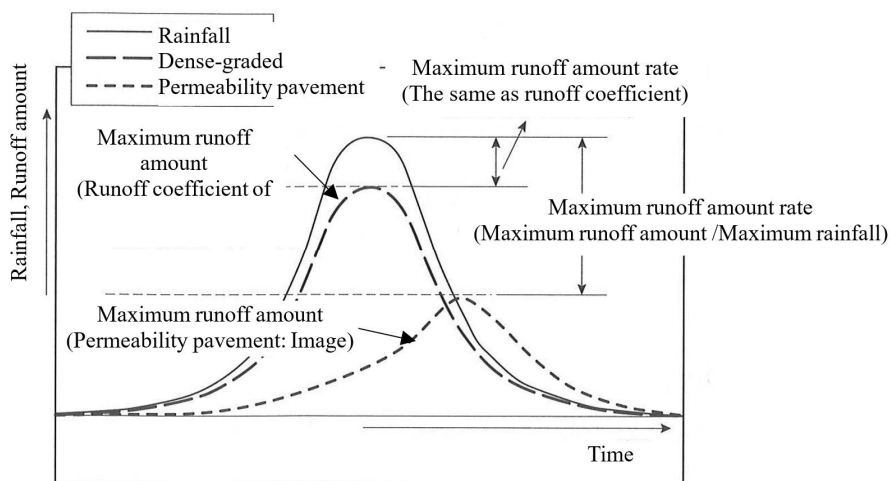


Fig. 2. Difference between maximum runoff amount rate and runoff coefficient (Image)

In the case of the impervious pavement like a dense-graded pavement, when the rainfall is the maximum, the runoff rainwater amount is also the maximum. Therefore, the maximum runoff amount rate and the runoff

coefficient become the same as shown in Fig. 2. In the case of the pavement in which rainwater can permeate or can be stored tentatively, however, the maximum runoff rainwater amount reaches the maximum after the rainfall peaks. Furthermore, because the runoff amount at each time is changing regardless of the rainfall shape, it would be inadequate to calculate as a rate of the runoff rainwater amount to total rainfall (Masuyama et al., 2001). Because the runoff coefficient cannot explain well, the maximum runoff amount rate obtained by the rate of the maximum runoff rainwater amount to the maximum rainfall shall be used.

### 2.3 Application of Maximum Runoff Amount Rate to Evaluate Permeability Pavement

The example shown in Fig. 1 is based on the “Act on countermeasure against flood damage of the specific river running across cities”. If considering the recent devastating damages by the urban floods caused by the abnormally high rainfall intensity, however, the countermeasure that the conventional pavements should be changed into the permeability pavement should be required. That is because the improvement in the maximum runoff amount rate should be expected by changing the conventional pavement into the pavement which has the functions of subgrade percolation of the rainwater and/or tentative rainwater storage. If the calculation and/or the simulation of the runoff amount before and after changing the conventional pavement into the permeability pavement would become possible, more specific judgment about whether changing the pavement or not by the governments would become also feasible.

## 3. Definition of Relevant Technical Term

The technical terms used in this paper are defined as follows.

**Table 2.** Technical term

《Main technical terms used for the calculation of runoff amount of rainwater》	
Maximum runoff amount rate	Rate of the maximum runoff amount to the maximum rainfall.
Maximum rainfall (mm/h)	Maximum rainfall during the raining event.
Runoff amount of rainwater (mm/h)	Sum of surface runoff and drainpipe runoff amount.
Surface runoff amount of rainwater (mm/h)	Runoff amount of rainwater from the road surface to gutter etc.
Drainpipe runoff amount of rainwater ( ℓ /h)	Runoff amount of rainwater from the drainpipe.
Maximum runoff amount of rainwater (mm/h)	Maximum runoff amount of rainwater during raining.
Target maximum runoff amount of rainwater (mm/h)	The maximum runoff amount of rainwater to be set, so that the increment in the peak runoff shall be zero during raining in the developing area where roads and streets will be constructed.
Rainwater runoff suppression amount	Rainwater runoff suppression amount which would be reduced by the countermeasure action.

**Table 2.** Technical term (Continue)

Target rainwater runoff suppression amount	Rainwater runoff amount to be set so that the increment in the peak runoff shall be zero during raining in the developing area.
Rainwater runoff suppression performance	Performance to be able to suppress the rainwater runoff.
Target rainwater runoff suppression performance	Rainwater runoff suppression performance that the increment in the peak runoff would be zero during raining in the developing area.
《Constants used to calculate the rainwater runoff amount》	
Water restraint amount (m <sup>3</sup> )	Rainwater amount to be restrained in the pavement.
Water restraint rate (%)	The volume percentage of the rainwater amount to be able to be restrained in the pavement.
Water storage amount (mm)	Rainwater amount to be able to store in the pavement. Water restraint amount is also included in it.
Water storage rate (%) <sup>1)</sup>	The volume percentage of rainwater to be able to store in the pavement. Water restraint rate is also included in it.
Percolation amount (m <sup>3</sup> /h/m <sup>2</sup> )	Percolation amount for rainwater to permeate into subgrade of the permeable pavement which has a structure for the rainwater to be able to permeate into the subgrade.
Specific percolation amount (m <sup>2</sup> /m <sup>2</sup> )	Specific percolation amount is the value which is obtained by dividing the percolation amount from the permeable pavement or permeation facilities by the saturated permeability coefficient of the subgrade.
Saturated permeability coefficient (cm/s) (m/h)	An index to express the easiness of percolation of the water in the soil saturated by water.
Drainpipe drainage	To drain the rainwater in the permeable pavement to the drainage facility through the drainpipe installed into the pavement.

<sup>1)</sup> Water storage rate after water restraint=Water storage rate – Water restraint rate.

## 4. Evaluation Method of Maximum Runoff Amount Rate

The flow of the calculation method of the maximum runoff amount rate is as follows.

- 1) Setting the standard of the Maximum runoff amount rate.
- 2) Making hyetograph and calculation of effective rainfall
- 3) Pavement structure and Characteristic values of materials used.
- 4) Making Runoff hydrograph by water-balance and Calculation of maximum runoff rainwater amount.
- 5) Calculation of Maximum runoff amount rate.
- 6) Evaluation in comparison with the standard.

## 4.1 Set of the Standard of the Maximum Runoff Amount Rate

In the basin of the river designated as the specific river running across cities, when the development, which is regarded as the development blocking the rainwater percolation like paving work larger than a certain scale, would be done, the standard shall be set up so that the maximum runoff rainwater amount after development does not exceed that before the development.

## 4.2 Making Hyetograph and Calculation of Effective Rainfall

In making a hyetograph (rainfall waveform), the probability rainfall intensity formula is used. The probability rainfall intensity formula is normally expressed shown in Eq. (2) and the formula is determined in each local government.

$$r_t = \frac{a}{t^n + b} \times 100 \quad (2)$$

where,  $r_t$  : Probable rainfall intensity (mm/h)

$t$  : rainfall continuation time (min)

$a, b, n$  : constant

Here, taking an example of  $a=1452$ ,  $B=7.5$ , and  $n=0.7$ , the explanation would be continued. In the “Act on countermeasure against flood damage of the specific river running across cities”, 24-hour centralized rainfall waveform of 10-year probability rainfall intensity is supposed to be made at the interval of 10 minutes. Using the 10-year probability rainfall intensity, the probability rainfall amount from  $t_1$  minute to  $t_2$  minute since the start of the raining can be obtained by Eq. (3).

$$R_{t_1-t_2} = \frac{r_{t_2}}{60} \times t_2 - \frac{r_{t_1}}{60} \times t_1 \quad (3)$$

where,  $R_{t_1-t_2}$  : probable rainfall amount from time “ $t_1$ ” to time “ $t_2$ ” (mm)

$r_{t_1}$  : Probable rainfall amount at the time “ $t_1$ ” (mm/h)

$r_{t_2}$  : Probable rainfall amount at the time “ $t_2$ ” (mm/h)

If inputting the time at the 10 minutes interval into Eq. (3), the equation is as shown as follows;

$$R_{0-10} = \frac{r_{10}}{60} \times 10 - \frac{r_0}{60} \times 0 = \frac{\frac{1452}{10^{0.7} + 7.5}}{60} \times 10 = 19.34$$

$$R_{10-20} = \frac{r_{20}}{60} \times 20 - \frac{r_{10}}{60} \times 10 = \frac{\frac{1452}{20^{0.7} + 7.5}}{60} \times 20 - \frac{\frac{1452}{10^{0.7} + 7.5}}{60} \times 10 = 11.6$$

.....

$$R_{1430-1440} = \frac{r_{1440}}{60} \times 1440 - \frac{r_{1430}}{60} \times 1430 = \frac{\frac{1452}{1440^{0.7} + 7.5}}{60} \times 1440 - \frac{\frac{1452}{1430^{0.7} + 7.5}}{60} \times 1430 = 0.47$$

In the case of making the rainfall waveform for 24 hours (1440 minutes) at an interval of 10 minutes, the number of the data is 144. To arrange the data into 24-hour centralized rainfall waveform,  $R_{0-10}$  of the probability rainfall intensity which is the heaviest shall be put to the center (No.72), the next heaviest probability rainfall intensity ( $R_{10-20}$ ) shall be put to the No.73, and the next one ( $R_{20-30}$ ) shall be put to No. 71. Hereinafter, the processing of alternately arranging left and right in the descending order of rainfall is repeated.

The hyetograph which was made in such a way is shown in Fig. 3.

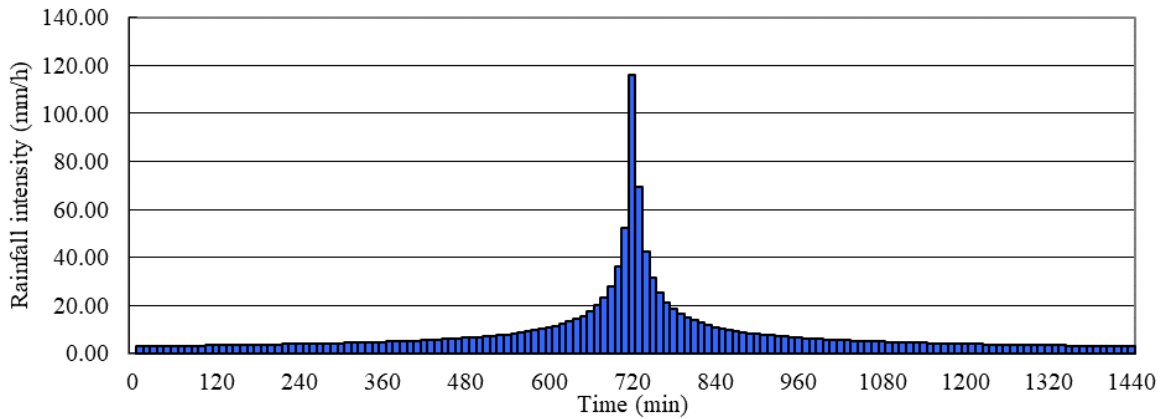


Fig. 3. Hyetograph

There is rainfall which is not coming to the pavement by blocking by trees and so on in the rainfall shown in the hyetograph. Therefore, when calculating the water-balance in the permeability pavement, the effective rainfall obtained from Eq. (4) shall be used.

$$M = 0.9 \times R \quad (4)$$

where, M: Effective rainfall, R: Rainfall from hyetograph

### 4.3 Pavement Structure and Characteristic Values of Materials Used

Using the core samples taken from the paving site, the characteristics values like water restraint rate and water storage rate of each layer of the pavement and the saturated permeability coefficient of subgrade shall be obtained. Furthermore, a specific percolation amount is needed in the case of subgrade percolation is expected, the information, like the diameter and the runoff coefficient of drainpipe, and the collection water area (interval of drainpipe x width of the pavement) per a drainpipe, is collected when the drainpipe is used.

### 4.4 Making Runoff Hydrograph and Calculation of Maximum Runoff Rainwater Amount

Preparation of runoff hydrograph and calculation of the maximum runoff rainwater amount can be easily done by using the program incorporated in Excel. Here, the basic idea and calculation method for the water-balance are briefly introduced.

#### 4.4.1 Calculation Method of Water Restraint Amount and the Maximum Water Storage Amount

The water storage rate shown in Table 3 includes the water restraint rate. The maximum storage amount is calculated by subtracting the water restraint rate from the water storage rate as shown in Table 4.

**Table 3.** Data information needed for calculation of maximum runoff amount rate

	Explanation/Test method	Note (reference value, formula etc)
Water restraint rate [ $R_i$ (%)]	Based on the test method, "Test method of permeability performance to determine the water restraint rate and water storage rate" (JRA, 2008)	Open graded As. Mix.: $R_i=1.5\%$ Granular material: $R_i=0.5\%$
Water storage rate [ $\alpha$ (%)]		Open-graded as. Mix: $\alpha$ =Air void-6% Granular material: $\alpha$ =Air void-3%
Saturated permeability coefficient of subgrade [ $k_0$ (cm/s)]	Base on the test method, "Test method of permeability test to determine the permeability coefficient of subgrade" (JRA, 2008) or "Test method of Borehole test to determine the permeability coefficient of subgrade" (JRA, 2008)	
Specific percolation amount [ $K_f$ (m <sup>2</sup> /m <sup>2</sup> )]	Specific percolation amount ( $K_f$ ) is a function determined by the shape of the ground and water-level and it is regardless of soil property.	$K_f = 0.014H + 1.287$ where, $H$ : water level (m)
Percolation performance of subgrade [ $Q$ (m <sup>3</sup> /h/m <sup>2</sup> )]	$Q = 36 \times K_f \times k_0$	



**Table 3.** Data information needed for calculation of maximum runoff amount rate (Continue)

	Explanation/Test method	Note (reference value, formula etc)
Maximum runoff amount through drainpipe [ $Q_{out}$ (m <sup>3</sup> /h)]	When $H \leq 1.2D$ , $Q_{out} = 1.7 \sim 1.8 \times B \times H^{3/2}$	
	When $H \geq 1.8D$ , $Q_{out} = C \times A \times \left[ 2 \times g \times \left( \frac{H-D}{2} \right) \right]^{1/2}$	
	where, $Q_{out}$ : Maximum runoff amount through drainpipe (m <sup>3</sup> /h)	
	B: Width of drainpipe (Radius in case of circular section) (m)	
	D: Height of drainpipe (Diameter in case of circular section) (m)	
	A: Cross area of drainpipe (m <sup>2</sup> )	
	g: Gravity acceleration (9.8 m/s <sup>2</sup> )	
	C: Flow coefficient (0.85-0.95 in case of with bell mouth, 0.6 in case of without it)	
	In the case of $1.2D < H < 1.8D$ , $Q_{out}$ shall be calculated in proportional allotment using $Q_{out}$ at 1.2D and $Q_{out}$ at 1.8D.	
Runoff amount permissible per unit area [ $Q_p$ (m <sup>3</sup> /h/m <sup>2</sup> )]	$Q_p = \frac{R_{max}}{1000} \times F_s$	
	where, $Q_p$ : Maximum runoff amount permissible per unit area (m/h×m <sup>2</sup> /m <sup>2</sup> )	
	$R_{max}$ : Maximum probable rainfall in Hyetograph for 10 minutes.	
	$F_s$ : Standard value of maximum runoff amount rate	
Maximum runoff water amount per one of drainpipe [ $Q_m$ (m <sup>3</sup> /h)]	$Q_m = Q_p \times W \times L$	
	where, $Q_m$ : Maximum runoff water amount per one of drainpipe (m <sup>3</sup> /h)	
	W: Width of pavement (m)	
	L: Interval of drainpipe (m)	
	Calculation of rough interval of drainpipe shall be as follows;	
	$Q_c \leq Q_m$ $Q_c \leq Q_p \times W \times L$ $\therefore L \geq Q_c / (Q_p \times W)$	

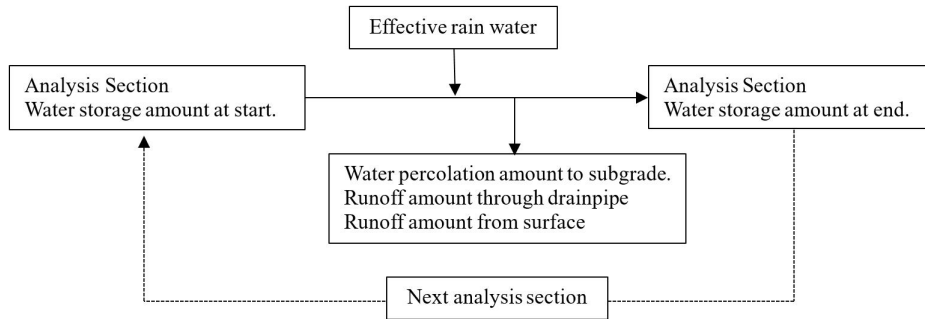
**Table 4.** Calculation example of the maximum water storage amount

(a)	(b)	(c)	(d)	(e)	(f)=(c)×(d)	(g)=(c)×((e)-(d))
Name of layer	Material used	Thickness of layer (mm)	Water restraint rate (%)	Water storage rate (%)	Water restraint amount (mm×m <sup>2</sup> /m <sup>2</sup> )	Maximum water storage amount (mm×m <sup>2</sup> /m <sup>2</sup> )
Surface	Mixture	50	1.58	13.9	0.79	6.16
Intermediate/Binder	Mixture	50	1.58	13.9	0.79	6.16
Base course	Mixture	105	1.58	13.9	1.66	12.94
Sub-base course	Granular	410	2.60	7.1	10.66	18.45
Total	-	615	-	-	13.9	43.71

#### 4.4.2 Outline of Calculation Procedure for Water-balance

Regarding the permeability pavement targeted to the evaluation, the water storage rate and the water restraint rate are different by the materials used for the layers. And, the change in the water-level from the subgrade to the surface cannot express by the simple mathematical formula. Therefore, the water storage

amount in the permeability pavement shall be sequentially calculated by calculating the water-balance in each time section as shown in Fig. 4.



**Fig. 4.** Steps of water-balance sequential calculation

#### 4.4.3 Explanation of Calculation Process

Although the calculation is very easy if using an Excel file, here, the calculation process is explained. Table 5 shows the calculation conditions.

**Table 5.** Calculation conditions

Item	Input value
Maximum runoff amount rate targeted	0.41
Probability rainfall intensity equation	$r_i = 1452 / (t^{0.7} + 7.5)$
Coefficient of Effective rainfall	0.9
Layer thickness of pavement	See Table 11
Water restraint rate & water storage rate in each layer	See Table 11
Type of Permeability pavement	Subgrade percolation + Runoff through drainpipe
Permeability coefficient of subgrade [ $k_0$ (cm/s)]	$1.879 \times 10^{-5}$ cm/s
Specific percolation amount [ $K_f$ ( $m^2/m^2$ )]	$K_f = 0.014 \times H + 1.287$
Width of pavement	W=10 m
Drainpipe	Diameter: 5 cm
	Flow coefficient: C=0.6
	Interval of drainpipe: L=35 m

##### 4.4.3.1 Calculation of Subgrade Percolation Capacity and Drainpipe Runoff Capacity

Table 6 shows the calculation example of the subgrade percolation capacity and the drainpipe runoff capacity and demonstrates the process to calculate the subgrade percolation capacity and the drainpipe runoff capacity based on the water-level at the start of analysis.

**Table 6.** Calculation example of “Possible subgrade percolation amount” and “Possible runoff amount through drainpipe” (MLIT, 2009)

Analysis time section: from 730 to 740 (minute)						
Start time	End time	Water-level at the start of analysis	Specific percolation amount	Subgrade percolation capacity	Drainpipe runoff capacity per one	Drainpipe runoff capacity
(min)	(min)	$H_{t-Start}$ (mm)	$K_f$ (m <sup>2</sup> /m <sup>2</sup> )	$Q_r$ (mm.m <sup>2</sup> /m <sup>2</sup> )	$Q_{p1}$ (litter/sec)	$Q_p$ (mm.m <sup>2</sup> /m <sup>2</sup> )
			Calc.-1	Calc.-2	Calc.-3	Calc.-4
730	740	502.50	1.29	0.15	3.6	6.17

Calc.-1:  $K_f = 0.014 \times H_{t-Start} \div 1000 + 1.287 = 0.014 \times 502.5 \div 1000 + 1.287 = 1.29$

Calc.-2:  $Q_r = K_f \times (\text{Permeability Coeff.}) \times 10 \times 600 = 1.29 \times 1.879 \times 10^{-5} \times 10 \times 600 = 0.15$

Calc.-3:  $H \geq 1.8D$ :  $Q_{p1} = C \times A \times [2 \times g \times (H - D \div 2)]^{0.5} \times 1000$   
 $= 0.6 \times (\pi \times 0.05^2 \div 4) \times [2 \times 9.8 \times \{(502.50 \div 1000) - 0.05 \div 2\}]^{0.5} \times 1000 = 3.6$

Calc.-4:  $Q_p = Q_{p1} \div (\text{Area to collect water}(m^2)) \times 600 = 3.60 \div (35 \times 10) \times 600 = 6.17$

#### 4.4.3.2 Calculation for Water-balance

Table 7 shows the example of water-balance calculation, it demonstrates the process to calculate the water storage amount at the end of analysis time and the surface runoff amount. By subtracting sequentially “water restraint amount at end”, “subgrade percolation amount” and “drainpipe runoff amount” from the total of “water restraint amount at start”, “water storage amount at start”, and “effective rainfall”, both of “water storage amount at end” and “Surface runoff amount” are calculated.

**Table 7.** Calculation example of “Water balance”

Analysis time section: from 730 to 740 (minute)								
	Water restraint amount at Start	Water storage amount at Start	Effective rainfall	Water restraint amount at End	Subgrade percolation amount	Drainpipe runoff amount	Water storage amount at End	Surface runoff amount
	$r_{t-Start}$	$V_{t-Start}$	M	$r_{t-End}$	$Q_{r-Out}$	$Q_{p-Out}$	$V_{t-End}$	$Q_{s-Out}$
Calc. method	Calc.-5	Calc.-6	Calc.-7	Calc.-8	Calc.-9	Calc.-10	Calc.-11	Calc.-12
Income	13.90	29.85	6.36					
Outgo				13.9	0.15	6.17	29.89	0.00
Cumulative	13.90	43.75	50.11 <sup>1)</sup>	36.21 <sup>2)</sup>	36.06 <sup>3)</sup>	29.89 <sup>4)</sup>	0.00 <sup>5)</sup>	0.00

Calc.-5: Water restraint amount at the start in analysis time section, shown in Table 4.

Calc.-6: Water storage amount at the start in analysis time section

Calc.-7:  $M=0.9 \times$  Rainwater obtained from Hyetograph

Calc.-8: Smaller one of 1) and Maximum water restraint amount in Table 4. [50.11>13.9: 13.9]

Calc.-9: Smaller one of 2) and subgrade percolation capacity  $Q_r$  shown in Table 6. [36.21>0.15: 0.15]

Calc.-10: Smaller one of 3) and drainpipe runoff capacity  $Q_p$ , shown in Table 6. [36.06>6.17: 6.17]

Calc.-11: Smaller one of 4) and Maximum water storage amount in Table 4. [29.89<43.71: 29.89]

Calc.-12: Value of 5). [0.00]

#### 4.4.3.3 Calculation of Water-level in Pavement

Table 8 shows the example of calculation for water-level in the pavement. This shows the process of calculation to derive the water-level in the pavement from the water storage amount at End obtained in Table 7. The detail of the calculation procedure is as shown below.

- 1) The numerical values in the relevant items in Table 4 are input into the columns in Table 8, “(h) Layer thickness”, “(i) Water restraint amount of each layer”, and “(j) Maximum water storage amount of each layer”.
- 2) “Water storage amount at End”, 29.89, obtained in Table 7 is input into the “(k) Water storage amount” of the sub-base course in Table 8.
- 3) The smaller one of “(j) Maximum water storage amount of each layer” and “(k) Water storage amount” of the sub-base course in Table 8 is input into “(l) Water storage in each layer” of the sub-base course shown in Table 8. This shows the water amount which would be stored in the sub-base course.
- 4) The difference of “(k) Water storage amount” and “(l) Water storage in each layer” is input into “(m) Water storage to upper layer” of the sub-base course. This shows the water amount which would be stored in the upper layer of the sub-base course.
- 5) “(n) Water level” shown in Table 8 shows the water level from the bottom of the sub-base course, which is calculated from the thickness and the water storage amount of each layer.

**Table 8.** Calculation example of water-level in pavement at end of analysis time (at 740 minute)

Item	Analysis time section: from 730 to 740 (minute)						
	(h)	(i)	(j)	(k)	(l)	(m)	(n)
	Layer thickness (mm)	Water restraint amount of each layer (mm.m <sup>2</sup> /m <sup>2</sup> )	Maximum water storage amount of each layer (mm.m <sup>2</sup> /m <sup>2</sup> )	Water storage amount (mm.m <sup>2</sup> /m <sup>2</sup> )	Water storage in each layer (mm.m <sup>2</sup> /m <sup>2</sup> )	Water storage to upper layer (mm.m <sup>2</sup> /m <sup>2</sup> )	Water-level (mm)
Calculation					Smaller one of (j) and (k)	(k)-(l)	(l)/(j)×(h)
Sub-base	410.00	10.66	18.45	29.89	18.45	11.44	410.00
Base course	105.00	1.66	12.94	11.44	11.44	0.00	92.83
Intermediate / Binder	50.00	0.79	6.16	0.00	0.00	0.00	0.00
Surface	50.00	0.79	6.16	0.00	0.00	0.00	0.00
Total		13.9	43.71				502.83

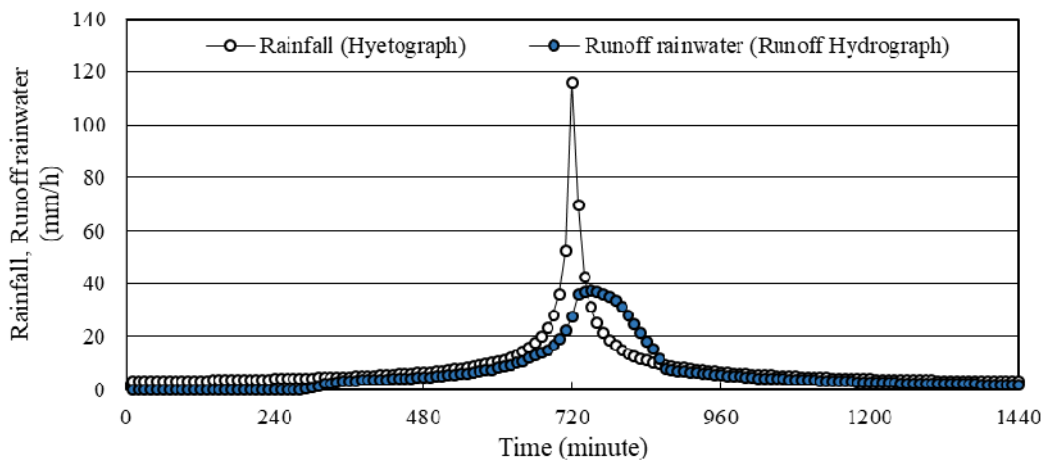
- 6) “(k)Water storage amount” in the base course layer shows the water storage amount, which cannot be stored in the sub-base course and shows the same meaning and the same value of “(m) Water storage to upper layer” in the sub-base course.
- 7) If repeating sequentially the same procedure as the same as above and totalizing them, the water level in the pavement can be derived.

#### 4.4.4 Making Runoff Hydrograph and Calculation of Maximum Runoff Rainwater Amount

Runoff rainwater amount is calculated by summarizing the drainpipe runoff amount and the surface runoff amount. And, the runoff hydrograph of the entire runoff rainwater amount in the evaluation target area is made and the maximum runoff amount rate is calculated by dividing the maximum runoff rainwater amount by the maximum rainfall. Table 9 and Fig. 5 demonstrate the calculation results of runoff and runoff amount rate derived in this example.

**Table 9.** Calculation results

Maximum runoff amount rate		Cumulative amount of rainfall and runoff amount for 24 hours	
Maximum rainfall (mm/h)	116.0	Total rainfall (mm)	1229.9
	(at 720 minute)	Runoff amount	Drainpipe runoff amount (mm) 911.6
Maximum runoff amount (mm/h)	37.1		Surface runoff amount (mm) 0
	(at 750 minute)	(mm)	Total runoff amount (mm) 911.6
Maximum runoff amount rate	0.32	Subgrade percolation amount (mm) 105.3	
		Total runoff amount rate (%) 74.1	



**Fig. 5.** Time change in rainfall (Hyetograph) and runoff amount (Runoff hydrograph)

As shown in Table 9, the maximum runoff amount rate (0.32) satisfies the maximum runoff amount rate targeted (0.41). In addition, if evaluating the results for 24 hours, the rainwater of 105.3 mm permeates into the subgrade and the rainwater corresponding to 911.6 mm is drained to the drainage facilities like a river. The rest amount from the total rainfall of 1229.9 mm is that restrained and stored in the pavement. The saturated permeability coefficient of the subgrade of this pavement is as small as  $1.879 \times 10^{-5}$  mm/s. However, a certain amount of rainfall can be permeated into the subgrade, it contributes to the reduction in the rainwater amount drained to a river.

## 5. Case Study of the Permeability Pavement used for Field Trial

### 5.1 Outline of This Permeability Pavement and Input Data

The permeability pavement (Nakanishi, 2001) used for a case study has been constructed on the national road route-155 in August 2000 in Japan. The outline of this pavement was already introduced in the former journal of KAI, but here, further detail information is provided and required input data are arranged as shown in Fig. 6, Table 10 and Table 11.

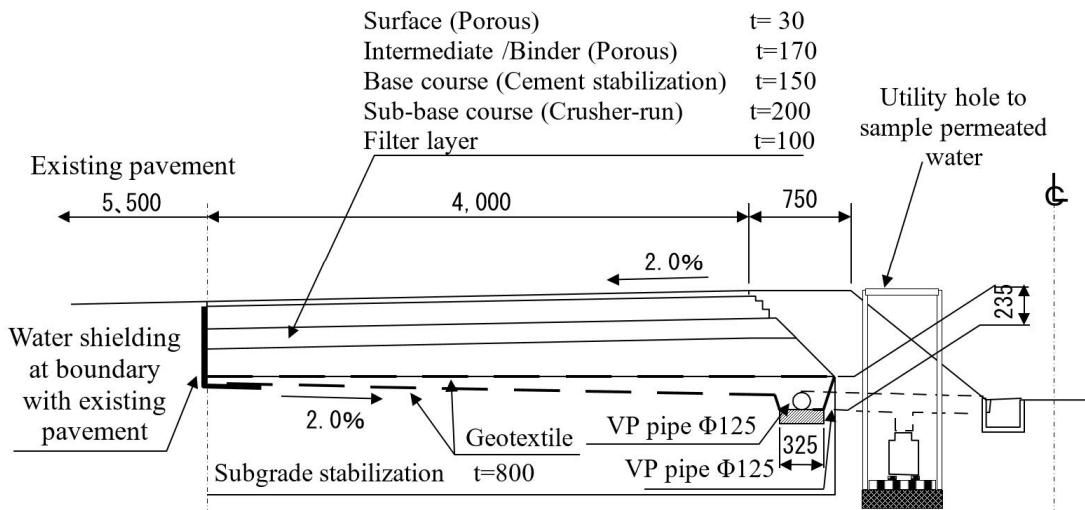


Fig. 6. Cross section of permeability pavement for case study

**Table 10.** Input data for case study

Layer	Material	Thickness	Air void	Permeability coefficient	Water restraint rate <sup>1)</sup>	Water storage rate <sup>2)</sup>
		(cm)	(%)	(cm/s)	(%)	(%)
Surface layer	Porous (13)	3	20.2	$1.50 \times 10^{-1}$	1.5	14.2
Intermediate/Binder	Porous (20)	17	20.3	$1.43 \times 10^{-1}$	1.5	14.3
Base course	Open graded cement stabilization (20)	15	11.27	$4.46 \times 10^{-3}$	1.5	5.27
Sub-base course	Crusher-run (40)	20	15.84	$5.63 \times 10^{-2}$	0.5	12.84
Filter layer <sup>3)</sup>	Sand	10	-	$1.00 \times 10^{-3}$	0.5	12.84

<sup>1)</sup> As shown in Table 3, Water restraint rate is set to be 1.5% for asphalt mixture and 0.5% for granular material.

<sup>2)</sup> As shown in Table 3, water storage rate is set to be air-void -6% for asphalt mixture and Air-void-3% for granular.

<sup>3)</sup> Filter layer shall be included into Sub-base course for calculation. As a result, the total thickness: 30 cm, Water restraint rate: 0.5%, And Water storage rate: 12.84%.

**Table 11.** Input data for case study

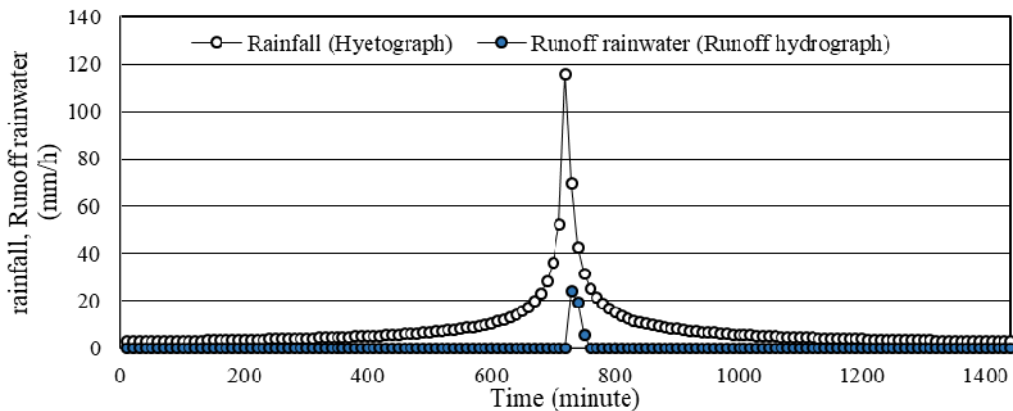
Item	Input value
Maximum runoff amount rate targeted	-
Probability rainfall intensity equation	$r_t = 1452 / (t^{0.7} + 7.5)$
Coefficient of Effective rainfall	0.9
Layer thickness of pavement	See Table 10
Water restraint rate & water storage rate in each layer	See Table 10
Type of Permeability pavement	Subgrade percolation + Runoff through drainpipe
Permeability coefficient of subgrade [ $k_0$ (cm/s)]	$2.34 \times 10^{-3}$ (Adoption)
	$9.98 \times 10^{-4}$ $9.98 \times 10^{-4}$
Specific percolation amount [ $K_f$ (m <sup>2</sup> /m <sup>2</sup> )]	$K_f = 0.014 \times H + 1.287$
Width of pavement	W=4 m
	Diameter: 12.5 cm
Drainpipe	Flow coefficient: C=0.6
	Interval of drainpipe: L=90 m

## 5.2 Simulation Results

In this case study, the saturated permeability coefficient of the subgrade is high and the air void and the expected permeability coefficients of each material are also high. Therefore, almost of rainfall permeates into the subgrade, the surface runoff does not take place, and the runoff amount to the drainage facilities like a river is very small as shown in Table 12 and Fig. 7.

**Table 12.** Simulation results

Maximum runoff amount rate		Cumulative amount of rainfall and runoff amount for 24 hours	
Maximum rainfall (mm/h)	116.0	Total rainfall (mm)	1229.9
	(at 720 minute)	Runoff amount (mm)	48.9
Maximum runoff amount (mm/h)	23.82	Drainpipe runoff amount (mm)	0
	(at 730 minute)	Surface runoff amount (mm)	48.9
Maximum runoff amount rate	(0.21)	Total runoff amount (mm)	48.9
		Subgrade percolation amount (mm)	1017.6
		Total runoff amount rate (%)	13.3

**Fig. 7.** Time change in rainfall (Hyetograph) and Runoff amount (Runoff hydrograph) of the case study

Actually, we have wasted a lot of time to determine the pavement structure and the materials used and we did not have enough time to simulate the runoff amount from the permeability pavement. If we have evaluated the drainage design along with the determination of the pavement structure and materials, a more effective and efficient design should have been carried out. This is a point we should reflect on and a meaningful finding.

## 6. Summary

The urban floods have taken place so far many times even in many urban area. If the runoff amount of the rainwater through the permeability pavement would be able to reduce, the problem with the urban flood should be significantly improved. In spite of the fact that the calculation method has been developed by PWRI in 2005, it looks like the calculation method has not yet been employed widely. As shown in this paper, this calculation method is very difficult and complicated but very meaningful and available to evaluate and estimate the damage by high-intensity rainfall.



And, the most important thing is that the runoff amount of rainwater can be easily simulated. Therefore, this method can be able to be employed when the effects on the urban flood are quantitated even in changing the conventional pavement into the permeability pavement.

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