INFILTRATION TRENCHES FOR HIGHWAY DRAINAGE

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ABSTRACT

Flood control facilities such as permeable pavements and infiltration trenches must be installed in Japan as stipulated by law when a new road over 1000 m^2 is developed in designated urban river basins. To find out the basic flood control performance of infiltration trenches, and to investigate the influence area of seepage water, infiltration tests for a real-size trench, and runoff calculations under normal trench condition were carried out. From the experimental results, it was confirmed that the capacity of infiltration trenches were evaluated accurately by the formula developed by the Association of Rainwater Storage and Infiltration Technology (1995), and that the saturation region from the trench was almost the same regardless of the soil type. From the runoff calculation results, the relationship between soil permeability and runoff control performance was confirmed.

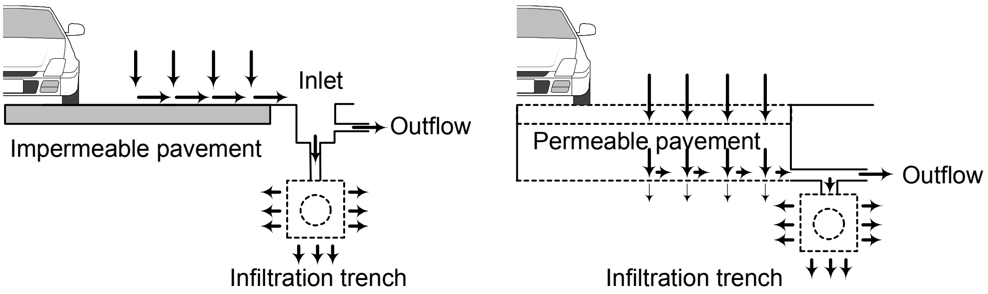
I. Introduction

Devastation from floods in urban river basins is a big issue in Japan. Especially in recent years, urban-specific damage such as loss of lives by underground inundation, lifeline paralysis, and shut down of computer systems is increasing. One reason is that extremely urbanized river basins are losing their natural water-retaining and retarding functions. Second reason is that local torrential rains occur frequently these days due to abnormal climate conditions. On the other hand, it is difficult to construct conventional flood control measures such as river channel improvement and flood control dams due to the difficulty of securing land in urban areas.

In order to prevent floods in urban areas, a law that regulates development in urban river basins was established in 2003. This law requires installation of storage and infiltration facilities when a new road over 1000 m^2 is developed in designated urban river basins.

Permeable pavements and infiltration trenches are expected to be effective countermeasures to control runoff from roads (**Figure 1**). There are, however, few studies and examples of these facilities, because road construction engineers have believed that rainwater from roads should be drained to rivers as soon as possible from the viewpoint of driving safety and stability of earth structures. For application of the facilities to roads, therefore, there are many problems such as long-term runoff controlling performance of these facilities, the effect of rainwater seepage on the durability of pavements, the stability of earth structures, and the effect of road drainage seepage on the quality of groundwater.

This study focuses on infiltration trenches as runoff control facilities for roads. In order to clarify the basic runoff control performance, laboratory tests and runoff calculations were carried out.



(a) Infiltration trench (b) Permeable pavement + Infiltration trench

Figure1: Stormwater storage and infiltration facilities for road drainage

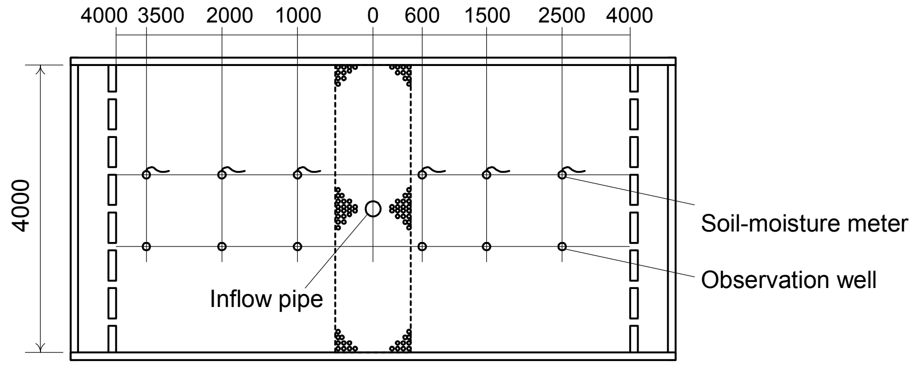
II. Laboratory Test

A. Outline

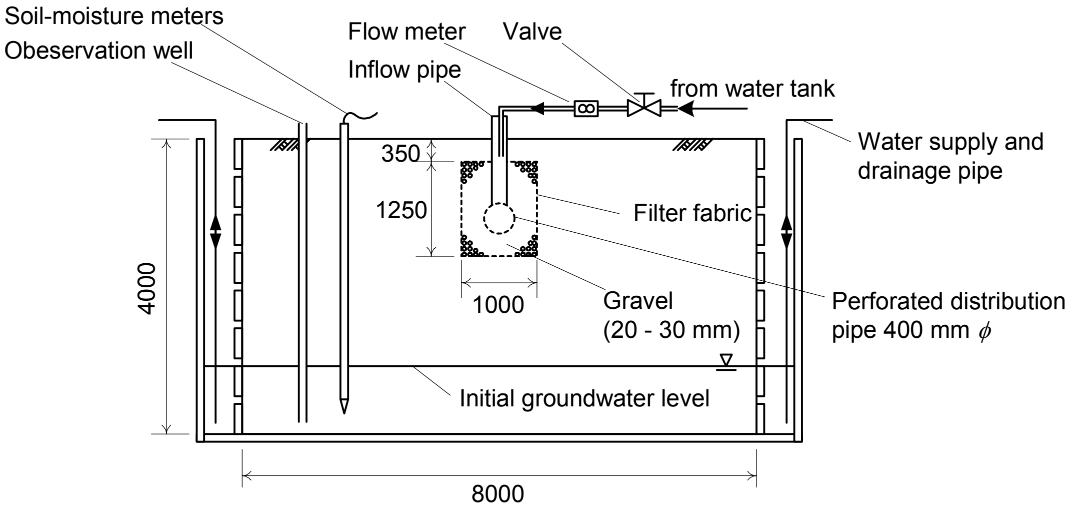
Capacity of infiltration trenches largely depends on the permeability of the ground and the groundwater level. In order to grasp the effect of these two factors, a real-size infiltration trench was constructed in a laboratory, and infiltration tests were carried out. Experimental infiltration capacity was compared with calculations from the formula developed by the Association of Rainwater Storage and Infiltration Technology (ARSIT, 1995), and applicability of the formula was verified. The influence area of seepage water was investigated using soil moisture meters set in the model ground.

B. Test condition

Figure 2 is the illustration of the model ground and the trench. The model ground was constructed in a concrete pit, which had drainage tanks on both sidewalls. The groundwater level was controlled using the drainage tanks. The remaining two walls were under an undrained condition. Therefore, this was a two-dimensional seepage model. The infiltration trench was 1.0 m wide, 1.25 m deep, and 4.0 m long, with a perforated distribution pipe of ϕ400 mm inside. The trench was filled with gravel with a grain size of 20-30mm and was wrapped with filter fabric to prevent clogging. Measurements were inflow q_{in}, water depth in the trench h, distribution of soil-moisture content by soil-moisture meters, and groundwater level distribution by observation wells.



(a) Plan view



(b) Elevation view

Figure 2: Configuration of the model test on infiltration trench (Unit: mm)

Experimental parameters were permeability of soil and initial groundwater level. Three kinds of sand, Sand A, B, and C, were used as ground material in this experiment. Coefficients of permeability of them are shown in **Table 1**. They were obtained from permeability tests in the laboratory. For initial groundwater level, deep level (G.L. -4.0m), and shallow level (G.L. -2.1 m) were tested. Test cases are shown in **Table 2**.

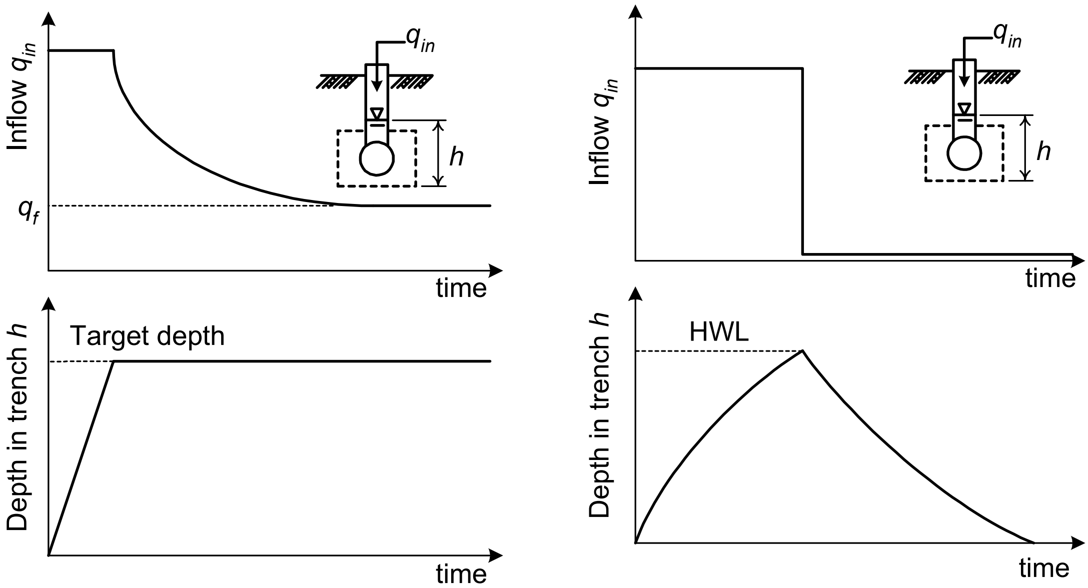
Two kinds of inflow methods, constant head test and falling head test, were used. Their process is explained in **Figure 3**. In the constant head test, inflow q_{in} is controlled holding the water depth of trench h constant. After reaching the targeted depth, the inflow q_{in} is equal to the infiltration flow. As shown in Figure 3(a), the inflow q_{in} decreases with time and converges to a constant value. The constant flow is called final infiltration flow q_f. On the other hand, in the falling head test, inflow q_{in} is stopped after the trench is full and the falling depth in the trench is measured, as shown in Figure 3 (b). In this experiment, falling head tests were repeated three times for each case.

Table 1: Material of model ground

	Soil type	Degree of compaction D_c [%]	Coefficient of permeability k [cm/sec]
Sand A	Sand (Kasumigaura)	89	4.9×10^{-3}
Sand B	Silty sand (Edosaki)	82	2.2×10^{-3}
Sand C	Decomposed granite soil (Kasama)	81	2.9×10^{-2}

Table 2: Test cases

Case No.	Ground material	Initial groundwater level
Case A0	Sand A	Deep (GL -4.0 m)
Case A1	Sand A	Shallow (GL -2.1m)
Case B0	Sand B	Deep (GL -4.0 m)
Case B1	Sand B	Shallow (GL -2.1m)
Case C0	Sand C	Deep (GL -4.0 m)
Case C1	Sand C	Shallow (GL -2.1m)



(a) Constant head test

(b) Falling head test

Figure 3: The change of inflow and depth in trench of constant head and falling head test.

C. Test results

(1) Results of constant head infiltration test

Figure 4 shows the change of inflow q_{in} with time in the constant head tests. As shown in this figure, infiltration flow decreases with time because of the growth of the saturation area in the ground. It is confirmed that the final infiltration flow q_f, depends on the soil type and the initial groundwater level. **Table 3** shows the final infiltration flow per one meter length of the trench q_f [m^3/hr/m] of all cases.

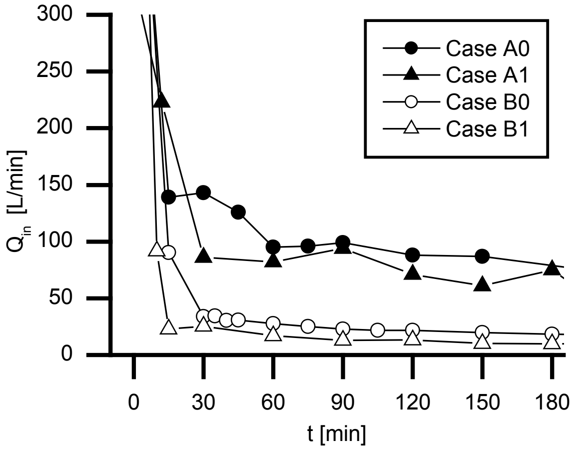


Figure 4: Time - infiltration flow curve

Table 3: Experimental results of final infiltration capacities

Soil	Initial groundwater level	Head h [m]	Final infiltration capacity q_f [m^3/hr/m]
Sand A	Deep (GL -4.0 m)	1.25 m	1.000
		0.75 m	0.613
		0.25 m	0.375
	Shallow (GL -2.1m)	1.25 m	0.763
		0.75 m	0.450
		0.25 m	0.220
Sand B	Deep (GL -4.0 m)	1.25 m	0.420
		0.75 m	0.296
		0.25 m	0.203
	Shallow (GL -2.1m)	1.25 m	0.291
		0.75 m	0.167
		0.25 m	0.068
Sand C	Deep (GL -4.0 m)	1.25 m	1.065
		0.75 m	0.615
		0.25 m	0.270
	Shallow (GL -2.1m)	1.25 m	0.885
		0.75 m	0.465
		0.25 m	0.150

(2) Applicability of ARSIT formula

According to the ARSIT manual (1995), the final infiltration flow of a trench can be calculated by the following formula.

$$q_f = k\,K \tag{1}$$

Where, q_f: final infiltration flow per one meter of trench [m^3/hr/m], k: coefficient of permeability of soil [m/hr], and K: specific infiltration flow [m^2]

Specific infiltration flow K is a coefficient that depends on the shape and the size of the infiltration facility and the water head in the facility. In the case of the infiltration trench, the following formula is given on K in the manual.

$$K = 3.093\,h + 1.34\,W + 0.677 \tag{2}$$

To evaluate the accuracy of the formula, K that is calculated from the equation (2) was compared with K' that is calculated from the following equation, using final infiltration flow q_f in Table 2 and the coefficient of permeability in Table 1.

$$K' = q_f/k \tag{3}$$

Figure 5 shows the comparison between *K* and *K'*. From this figure, it is confirmed that *K* is very close to *K'* for Sand A and Sand B. This confirms that the formula of the ARSIT manual estimates the experimental infiltration capacity with good accuracy. In regard to Sand C, however, the ARSIT formula overestimated *K* in about six cases. It is inferred that the in-situ permeability of Sand C was much less than the value in Table 1 that was obtained by the laboratory permeability test. Aoyama et al. (1978) reported that the permeability of Sand C varies with the change of the hydraulic gradient and that it dropped to less than 1/10 in some tests. In this experiment, falling head tests were carried out before the constant head tests, and it was repeated three times. The falling head test might decrease the permeability of Sand C.

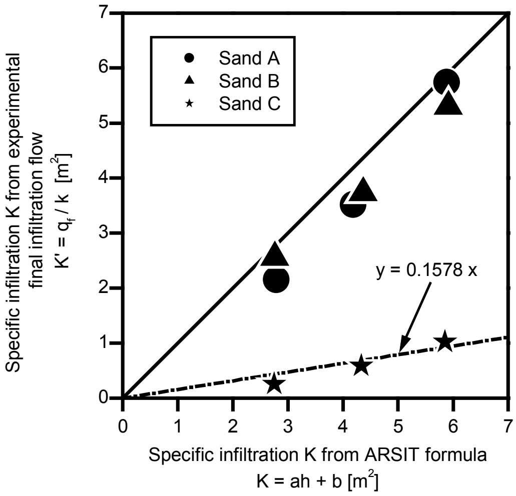


Figure 5: Comparison of K-value

(3) Effect of groundwater level

Figure 6 shows the comparison of q_f between deep groundwater level cases and shallow groundwater level cases. From this figure, the plots are in the same straight line regardless of the soil type. This confirms that infiltration capacity can be formulated in consideration of the effect of initial groundwater level, although the equation (1) and (2) do not contain groundwater level terms. This is an issue to be studied in the future.

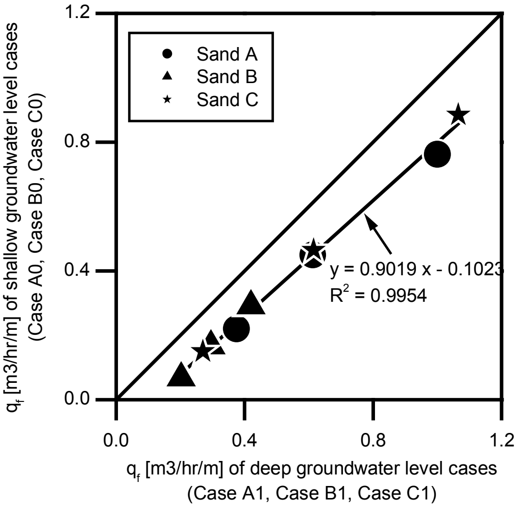


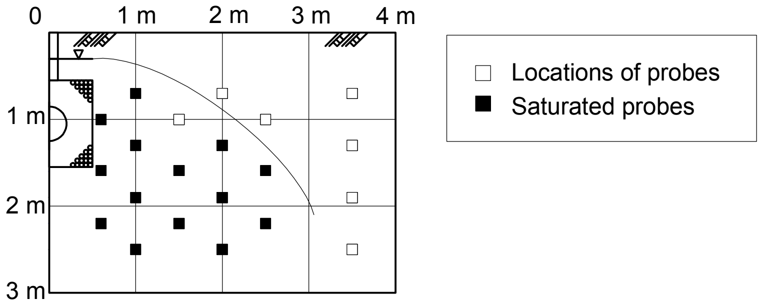
Figure 6: Comparison of infiltration flow q_f between deep groundwater level cases and shallow groundwater level cases.

(4) Influence area of seepage water

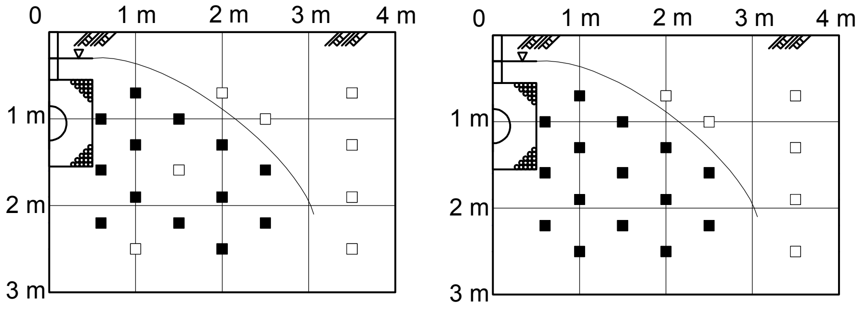
Figure 7 shows the distribution maps of soil saturation after 5 hours holding the water depth of

1.25 m. The square plots show the locations of the soil-moisture meters, and the black plots show saturated sensors. From the maps, it is confirmed that the saturation region after many hours is almost the same regardless of the soil type.

Installation of infiltration facilities is restricted around natural slopes and earth fills because the water seepage raises the risk of slope failure. The range of no-filtration-facilities zone is within a distance of 2H around slopes in Japan, as shown in **Figure 8**. H is a height of slope here. This is called the 2H-rule. The saturation area of Figure 7 is also superimposed on Figure 8. From Figure 8 it is confirmed that if the trench is set 2H away from the slope, saturation regions do not reach the slope. This confirms that the 2H-rule is a reasonable rule from the viewpoint of slope stability. Seepage of natural slopes is, however, more complex, because their configuration is generally inhomogeneous and sometimes they have alternate layers and discontinuities, which is different from the model ground of this experiment.



(a) Case A0



(b) Case B0 (c) Case C0

Figure 7: Saturation region in the model ground observed by the soil moisture meters

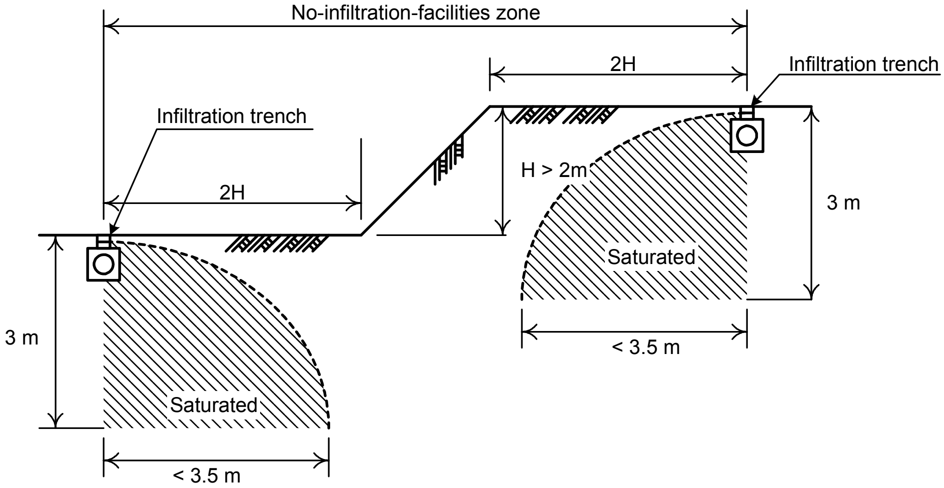


Figure 8: Installation of infiltration facilities is restricted around slope for slope stability by law. Hatched area is saturated region obtained by the model tests.

III. Runoff Calculation for Roads in Consideration of an Infiltration Trench

A. Outline

Flood control facilities are required by law to reduce the peak of runoff to the amount before the development. The required performance is illustrated in **Figure 9**. In order to investigate basic performance of infiltration trenches, a runoff calculation was carried out under general road conditions. The Calculation condition and model is shown in **Table 4** and **Figure 10**.

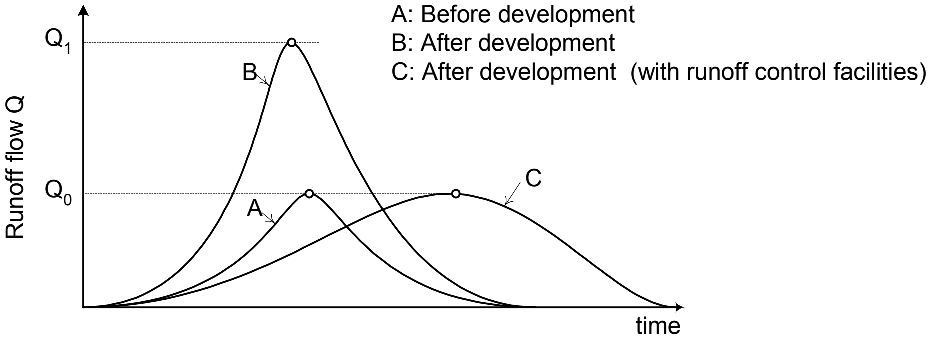


Figure 9: Required performance of runoff control facilities. Peak flow should be reduced to the level before development.

Table 4: Calculation condition

Rainfall Condition	Rainfall intensity data: Yokohama Return period: 10 years Rainfall pattern: Center-concentrated pattern Duration: 24 hours Concentration time: 10 min
Road Condition	Road Width: B = 10 m Asphalt pavement Runoff coefficient f = 1.0
Trench Condition	Trench size: W 1.0 m, H 1.0 m Void percentage of trench: n = 0.5 Permeability of soil: $k = 10^{-2}$ to 10^{-5} cm/sec Infiltration capacity: Calculation from ARSIT formula

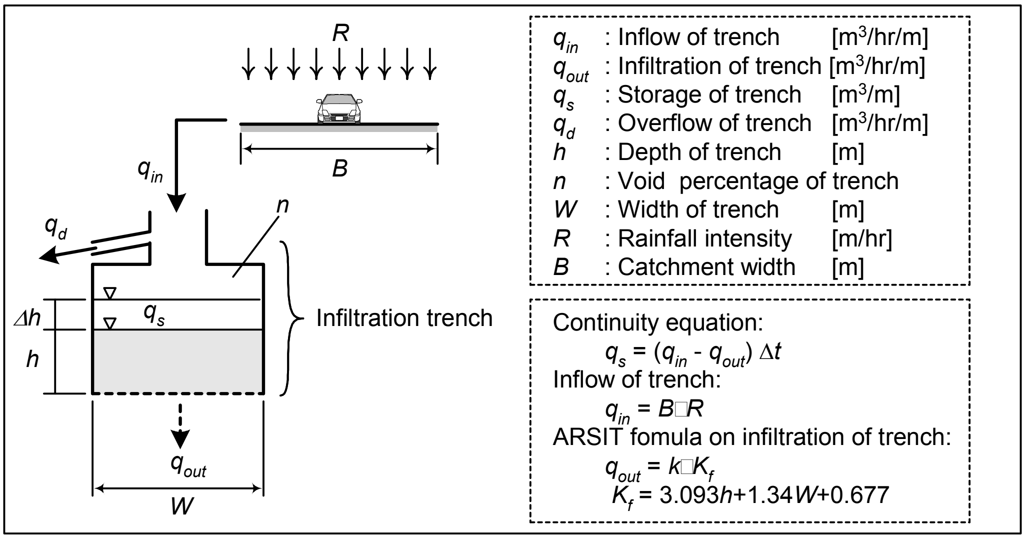


Figure 10: Runoff calculation model

B. Results of runoff calculation

Figure 11 shows calculation results for various ground permeabilities. The lines in the figure show overflow from the trench. From this figure, it is confirmed that the trench can control all of the rainfall when the ground permeability is $2.0\text{x}10^{-3}$ cm/sec. In the case of $k = 1.0\text{x}10^{-3}$ cm/sec, however, half of the rainwater overflows at peak. In the case of *k* is lower than 10^{-4} cm/sec, peak flow is not cut off, because the infiltration capacity is too low.

Figure 12 shows the calculation result of water depth in the trench with time, after the trench is full. From the figure, in the case of $k = 10^{-5}$ cm/sec, it takes more than two weeks for the trench to empty. This means that the trench cannot provide the required performance, if there is an antecedent precipitation. Therefore, in the case that the ground permeability is very low, like the example, a structural device is needed to prevent the inflow of normal rainfall, and to permit inflow only at peak periods.

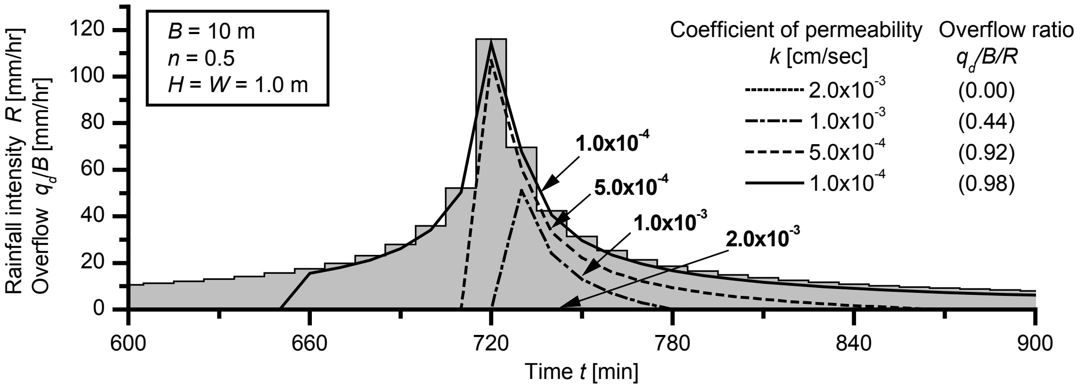


Figure 11: Stormwater calculation results for various *k*.

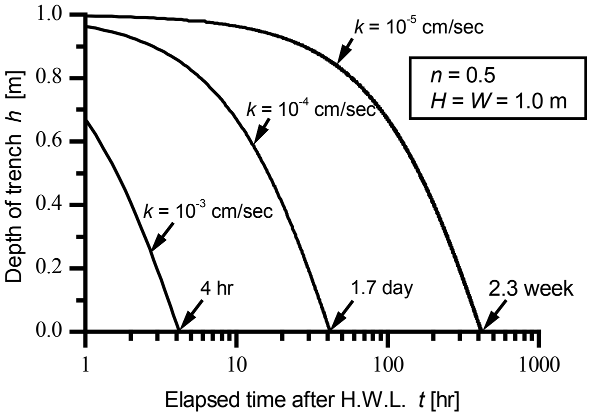


Figure 12: Calculation result of the depth of trench after H.W.L.

IV. Conclusion

From laboratory tests and runoff calculations on infiltration trenches, the following were determined;

1) The ARSIT formula estimated the experimental infiltration capacity of the trench accurately in the case of Sand A and B. The formula is applicable for the design of the infiltration trench.
2) In the case of Sand C, however, the formula overestimated by six times the experimental infiltration capacity. This is because the permeability of Sand C decreased due to the change of the hydraulic gradient caused by the ups and downs of the water depth in the trench during the test.
3) The result of Sand C implies a very important thing in the design of infiltration facilities. The permeability coefficient of the soil is one of the most important input datum, as can be seen in formula (1). In the case of particular kinds of soil like Sand C, however, if the facility is designed using a permeability coefficient from a constant head permeability test in a laboratory, the performance might be overestimated, because the permeability of the soil will decrease during in-service by the change of water depth in the facility. Therefore, in order to determine the lowest permeability of such soils, permeability tests in which the hydraulic gradient varies are needed.
4) From the experimental result of the distribution of soil-moisture content, it was confirmed that

the saturation region of seepage water from the trench is almost constant regardless of the soil type.

5) From the runoff calculation, the effect of soil permeability on the performance of an infiltration trench was confirmed. In the case k is higher than 10^{-3} cm/sec, the infiltration function can be expected during a storm. In the case k is in the order of 10^{-4} cm/sec, the infiltration function is hardly expected, and the storage function is only effective during a storm. The water stored during the rainfall should be infiltrated after a storm. In the case k is less than 10^{-5} cm/sec, infiltration cannot be expected at all. Therefore, the trench should be designed not as an infiltration trench, but as a storage trench. In this case, a structural device is needed not to allow the inflow of normal rainfall.

V. References

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VI. Biography of presenting authors

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