A REPORT ON THE FOLLOW-UP SURVEY OF RAINFALL INFILTRATION FACILITIES AT AKISHIMA TUTSUJIGAOKA HEIGHTS HOUSING COMPLEX

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Abstract

In Japan, the expansion of impermeable areas due to rapid urbanization has distorted the water cycle drastically by hindering normal rainfall infiltration into the ground. It has also caused an increase in runoff resulting in frequent floods in the urban lowland. In an attempt to restore a sound water cycle to the urban area, some measures to increase the underground water supply have been put into practice since the early 1980s. One of these is a new drainage system, Rainfall Infiltration System, which was designed to make rainfall infiltrate into unsaturated subsurface to promote recharging of the underground water. Although infiltration systems are now being widely adopted, mainly in the Tokyo Metropolitan Area, and their effectiveness for runoff control have begun to be recognized by many people, little information has yet been accumulated about the durability and maintenance of this system.

The Urban Renaissance Agency (UR), formerly the Housing and Urban Development Corporation, an independent administrative agency in charge of urban and housing development and restructuring, adopted the rainfall infiltration system at Akishima Tutsujigaoka Heights Housing Complex to mitigate the impact of increasing runoff on downstream areas caused by urban development. As this was the first case of full-scale rainfall infiltration system in this country, UR has started monitoring the system to examine its durability and effectiveness in 1981 and continued over a period of twenty years.

This report, after summarizing the results of hydrological observations and the field surveys over twenty years first, describes the evaluation and review of the design and arrangement of the infiltration facilities, which have several devices for deposit prevention, and make some suggestions for the planning, designing and maintenance of the system to retain its function longer.

KEYWORDS: *rainfall infiltration system, runoff control, infiltration trench, infiltration inlet*

1. Introduction

As a consequence of Japan's explosive economic growth after World War II, the rapid concentration of the population in big cities brought about many problems, one of which has been the frequent flooding in lower-lying urban areas. River improvement became quite difficult and time-consuming because of the problems, which included land-acquisition. UR, as a housing and new-town developer, was obliged to take effective measures to cope with increasing floods in the downstream areas of its development sites. In the

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1970s, regulating ponds, which store discharge from the development site tentatively to decrease peak-time flow, were widely constructed to decrease peak-discharge to the pre-developed level, or to an allowable level considering the flowing-capacity downstream. But the expanding urbanized area made river improvement more and more difficult and UR and other developers were required to construct larger regulating ponds, which put a heavy strain on the budget, as well as the need for further land to be used exclusively for the ponds. To cope with these situations, UR began research into the possibility of a rainfall infiltration system, which can be made by converting the ordinary drainage system into infiltration facilities and needs no specific land for building the system. Preliminary research started in 1978 at UR's Hatiouji laboratory and Akishima Tutsujigaoka, in cooperation with the former Ministry of Construction. In this research, a series of on-site permeation tests using infiltration inlets were carried out to verify the infiltration capacity of the upper part of the loamy layer, which widely covers the Kanto Plain to which Tokyo Metropolis belongs. The following suggestions were obtained to make this system practical.

(1) Kanto loamy soil, classified as a volcanic cohesive soil, has fairly high permeability when it is undisturbed because of its porous structure.
(2) On average, the final infiltration capacity of one infiltration inlet is 1.0 L/min, although the values vary with soil differences, conditions and remolding during excavation.
(3) New methods of design and arrangement of infiltration facilities are necessary.
(4) Maintenance measures to deal with deposits and prevent clogging are necessary to improve the functional durability of infiltration facilities

In 1981, the first full-scale rainfall infiltration system was planned and installed at Akishima Tutsujigaoka Heights Housing Complex in Akishima city as a temporary drainage system serving only until the completion of main public drain pipes downstream. Four types of infiltration facilities, infiltration trench, infiltration inlet, infiltration gutter and permeable pavement, were newly designed and built in the compound of the housing complex.

Following the completion of the infiltration facilities, a follow-up survey has started to monitor the actual condition of infiltration and collect technical data for design and maintenance. This survey has two aims. One is to verify effectiveness for run-off control and durability by observing hydrological changes in the survey area. The other object is to survey the actual condition of infiltration facilities by observation of deposit conditions and an on-site permeation test.

A sequence of surveys was implemented by the Urban and Housing Technology and Research Institute under the advice of the committees, which consist of academic experts of the national and local governments and public offices, chaired by Katsumi Mushiake PhD, emeritus professor at Tokyo University. Some results of these surveys were already reported (Haneda and Kagawa, 1996; Urban Infrastructure Development Corporation, 2002; Housing and Urban Development Corporation, 1982, 1987, 1993, 1997).

Several reports based on these surveys have already been presented. Ishizaki et al. (1993) reported the results of hydrological observation and of the infiltration capacity tests conducted over ten years from 1981.

Imbe et al. (2002), on the basis of the surveys of over twenty years, evaluated the effectiveness of the system on the runoff control and ground water recharge by utilizing a simulation model, SHER (Similar Hydrological Element Response) Model).

No particular maintenance work for the infiltration facilities have been implemented in Akishima Tutsujigaoka Heights so far. But the latest survey in 2000 revealed that these facilities began to deteriorate due to the accumulation of deposits which indicated the necessity of cleaning the facilities. UR conducted a thorough cleaning of infiltration facilities in Akishima-Tutsujigaoka Heights including the removal of deposits and washing of crushed stone in 2006, the result of which will be reported if we have another opportunity.

2. Outline of the infiltration system

2.1 Outline of the site the infiltration system was employed

The Akishima-Tutsujigaoka Heights Housing Complex is situated in Akishima City, in the western part of the Tokyo Metropolitan Area. Construction of high-rise apartment buildings containing 2673 flats (859 for rent and 1814 for sale) on a 27.8 ha of the whole site started in 1977 and was completed in 1981. (Figure1)

Photograph 1 Part of the housing complex area where the infiltration system was employed

Topographically, the housing complex lies on the Tachikawa terrace at an elevation of approximately 105 m above sea level, gently sloping down to the southeast. The land had been used for a golf course before the development. The geological formation consists of *kuroboku* topsoil from the surface to several dozen centimeters deep, with the Tachikawa loamy layer of soil under the topsoil down to three or four meters, below which is the thick Tachikawa conglomerate layer. The groundwater level is approximately 10 m deep from the surface in the Tachikawa layer. Rainfall infiltration facilities were designed to be placed mainly in the Tachikawa loamy layer and partly on reclaimed soil. The coefficient of permeability of the disturbed loam sample, tested in the laboratory, was in the range of 1.5×10^{-4} - 4.8×10^{-7} cm/sec, which is rather small by the effect of sensitivity.

The area of the rental housing block in Akishima-Tutsujigaoka Heights is approximately 3.1 ha containing 859 units of houses for rent. The area infiltration system was adopted (hereinafter referred to as the infiltration system area) in the northern part of the block, encircled by red line in Figure 1. The area is approximately 1.3 ha. Photograph 1 shows the area. In the southern part of the rental housing block (hereinafter referred to as the conventional system area), the area of which is approximately 1.8 ha, the conventional rainfall drainage system was used.

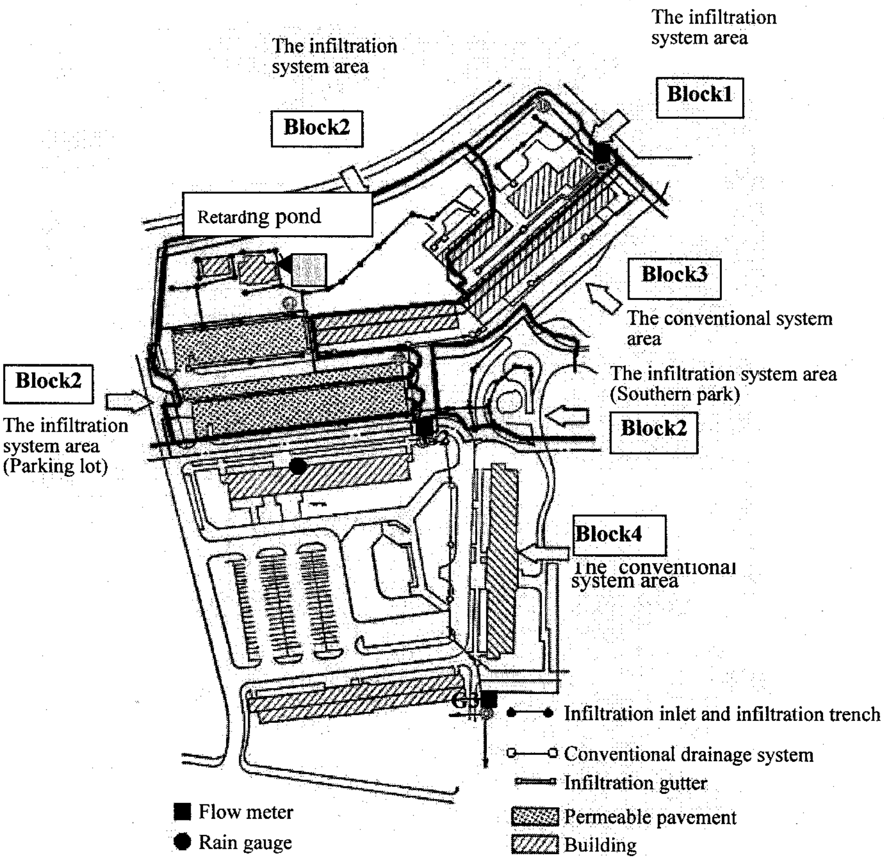


Figure 1 Arrangement of facilities and monitoring instruments in the two areas (modifild from Imbe et al., 2002)

Table 1 Installed facilities in each block

Block	Land-use in the block	Drainage facilities installed
1	Building, parking lots etc	Infiltration inlet・infiltration trench・infiltration gutter
2	Building park, parking lots, parks etc	Infiltration inlet・infiltration trench・infiltration gutter・permeable pavement・retarding basin
3	Building access road	Conventional drain pipe and inlets
4	Building, access road, parking lot etc	Conventional drain pipe and inlets

* Retarding basin ($80m^3$) was build in the northern park to store water surpass the infiltration capacity

2.2 Composition of the Rainfall Infiltration System

The rainfall infiltration system (hereinafter referred to as infiltration system) installed here is composed of four types of facilities, that is, infiltration inlet, infiltration gutter, infiltration trench and permeable pavement. Figure 2 shows the cross-sectional image of these facilities and their arrangement is shown in Figure 1 and Table 1. The infiltration inlet and infiltration gutter have a layer of crushed stone at the bottom instead of concrete to help rainwater permeate into the soil easily. The infiltration trench has a rectangular trench set in the round, filled with crushed stone and perforated pipe, the diameter being 15-20 cm. The rainwater in the pipe flows into the voids of crushed stones through the holes, then infiltrate into the surrounding ground. Generally, the infiltration inlets and infiltration trenches were used in combination as shown in figure 2. The perforated pipe was laid with a slight grade downstream to prevent retention of deposits in the pipes. On top of the crushed stone, permeable sheet was laid to prevent soil entering. The downstream-side pipe was connected at a higher point than upstream-side pipe to secure high infiltration pressure and to prevent deposits entering the perforated pipe. The permeable pavement was open graded asphalt with 4 cm thickness and its void ratio was about 12 % with a layer of sand under the crushed stone.

The quantity of infiltration facilities installed and their design factors are shown in Table 2. The infiltration capacity of each facility was determined in consideration of the ultimate infiltration capacity obtained by the preliminary on-site test.

Table 2 Quantity of infiltration facilities installed

	Infiltration inlet	Infiltration trench	Infiltration gutter	Permeable pavement	Retarding basin	Total
Quantity	49	494	143	2,404	80	-
Unit	unit	m	m	m^2	m^3	-
Designed Infiltration capacity L per minute	1.0 L/min	1.0 L/min	1.0 L/min	7.0 L/hr	--	-
Total infiltration capacity (m^3/hr)	2.94	29.64	8.58	16.83	--	58.00
Storage capacity[a)] (L) per unit	202.86	138.02	144.13	33.01	--	-
Storage capacity[a)] (m^3) per facility	9.94	68.18	20.61	79.33	80.00	258.12

a) storage capacity means the volume of rainfall storable in the void of crushed stone (the designed void ratio is 30%).

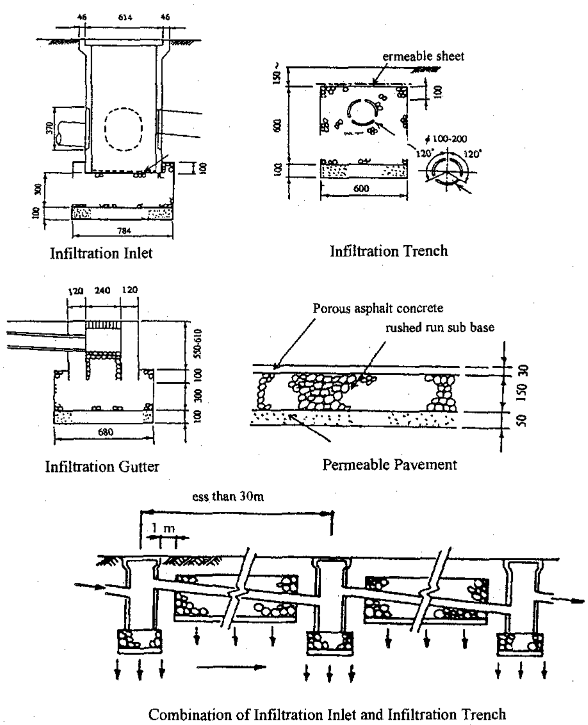


Figure 2 Cross-sectional Image of Infiltration Facilities (modifild from Imbe et al., 2002)

3. Hydrological observation

3,1 Method for evaluation of runoff control effects

In order to evaluate the infiltration system's effectiveness for runoff control, a comparison was conducted of the runoff ratios of the two systems. The average runoff coefficient of the two areas calculated in accordance with the land use of each area was about the same as shown in Table 3, which indicates that the values of specific discharge of both areas can be comparable.

The effectiveness of the infiltration system for runoff control can be evaluated by comparing the hydrological characteristics of the each area chronologically. To determine the hydrological characteristics of the two areas, one rainfall gauge and three flow meters were installed at the point shown in Figure 1 and monitoring was conducted continually from 1981. But some alterations of land use were made during the twenty years. For example, parts of green areas were converted into parking lots with permeable asphalt pavement. The green space in the block 2 was converted into parking lots, the increased area being 849 m^2 in 1989 and 327 m^2in 1997 in the infiltration system area. Part of the conventional pavement of parking lots with an area of 2589 m^2 was replaced by permeable pavement in 1997 in the conventional system area. These alterations should be taken into account in evaluating the changes of the run-off volume.

Table 3 Average runoff coefficient of the two areas

Land Use	Runoff Coefficient (C)	The Infiltration System Area		The Conventional System Area	
		Area (A1) m^2	A1 x C	Area (A2), m^2	A2 x C
Buildings	0.95	2438.8	2316.9	3461.1	3288.0
Roads	0.90	336.5	302.9	3528.4	3175.6
Parking Lots	0.90	3580.2	3222.2	2588.5	2329.7
Concrete Tiles	0.85	1611.8	1370.0	1638.8	1393.0
Pavement	0.70	1376.6	963.6	1552.0	1086.4
Green space	0.10	3744.9	374.5	5462.2	546.2
Open Space	0.20	32.2	6.4	328.2	65.6
Sand Boxes	0.10	76.7	7.7	0.0	0.0
Total		13197.7	8564.2	18559.2	11884.5
Average Runoff Coefficient		0.65		0.64	

3.2 Method employed for hydrological observation

Location of the instruments to measure amount of rainfall and runoff of the two areas is shown in Figure 1. Type of instruments and the data acquisition process are shown in Figure 3.

Rain gauge: Installed on the roof of No.7 building (Tipping bucket rain gauge)

Flow meter: G1, G2, G3 (Rectangular weir, refer to Figure 4)

Data input conditions: Measurement starts at the beginning of rainfall or at the time the water level exceeds the weir height (higher than 2-4 mm).

Data input interval: Every minute, which is totalized automatically at every 30 minutes

Rainfall to be analyzed: Total rainfall (over 30 mm per rainfall event or over 10 mm/30 minutes at peak time).

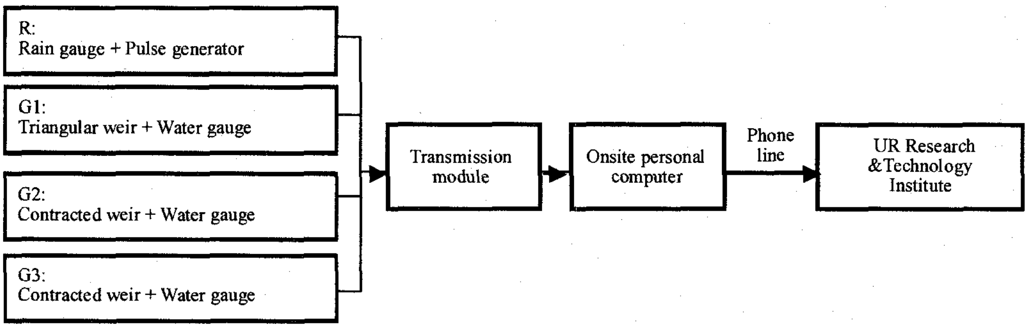


Figure 3 Flow of data acquisition

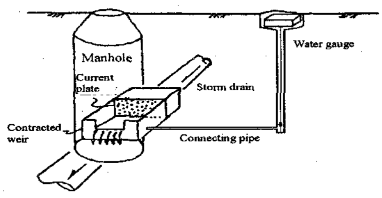


Figure 4 Schematic diagram of flow-meter.(rectangular weir)

The four draining blocks (Blocks 1 to 4) in Figure 1 were determined in accordance with the drainage area of each flow meter. Amount of rainfall was measured by a rain gauge set on the roof of the N07 building shown in Figure 1. Runoff of Blocks 1, 2, and 3 is measured at G2 flow meter and Block 4 at G3 flow meter. Runoff of the Block 4 was measured by subtracting the runoff of the G2 meter from the G3. Runoff of the infiltration system area was obtained by subtracting the runoff of the Block 3(calculated by rational formula) from the runoff of G2 meter, because Block 3 has a conventional system. The runoff of the conventional system area is Block 4+Block 3.

3.3 Effectiveness of runoff control and its secular changes

During the monitoring period, 1981-2000, data of 109 rainfall events (total rainfall is over 30 mm per rainfall event or over 10mm/30 minutes at peak time) were acquired. To explain the rough trend of the runoff control effect with aging, the whole monitoring period was divided into four terms; each term being five years. The first term was 1981-1985, including14 rainfalls, the second term, 1986-1990, 15 rainfalls, the third term, 1991-1995,36 rainfalls, the fourth term 1996-2000, 44 rainfalls. Table 4 shows the characteristics of rainfall and runoff of the four terms.

Firstly, the average runoff ratio of the whole terms, the runoff ratio being defined as the ratio of depth of runoff to amount of rainfall of every rainfall event, was 0.11 in the infiltration system area and 0.55 in the conventional system area. Roughly, the difference between the two areas is considered as the ratio of infiltrated depth, in other words, the effectiveness of the infiltration system. Also, with respect to the peak-cut effect, comparison of the depth of peak runoff showed that the depth of peak runoff of the infiltration system area was 32.8 mm, while that of the conventional system area was 90.2 mm, which indicates peak-cut effects can also be expected when the amount of rain is in the range of the observed rain (min 12.5 mm, max 170 mm).

Secondly, to examine the changes in the runoff ratio of two areas with ages, the runoff ratios of two areas of the four terms is shown in Figure 5. The run-off ratios of the infiltration system area showed a near constant level of 0.11, which indicated no sign of deterioration, while runoff ratios of the conventional system area showed considerable fluctuation, reflecting the variation of the size of rainfall in every term and change of the land use of the area.

Table 4 Comparison of characteristics of the rainfall and runoff of the two areas in twenty years (modifild from Imbe et al., 2002)

Number of Rainfall Events		Duration of Rainfall (min.)	Total Amount of Rainfall (mm)	Peak Rainfall (mm/30min)	The Infiltration System Area			The Conventional System Area		
					Depth of runoff(mm)	Runoff ratio	Depth of peak runoff (mm/30min)	Depth of runoff(mm)	Runoff ratio	Depth of peak runoff (mm/30min)
Term I 1981 - 1985 (14 events)	Ave.	829	56.6	10.5	8.8	0.12	2.0	33.6	0.59	6.5
	Max.	2370	101.5	25.0	28.7	0.28	8.1	69.4	0.88	16.9
	Min.	120	19.0	3.0	0.2	0.01	0.1	11.9	0.38	1.4
Term II 1986- 1990 (15 events)	Ave.	574	62.6	10.9	7.6	0.08	1.6	35.5	0.52	5.8
	Max.	1199	154.5	19.5	46.3	0.30	5.1	110.0	0.71	9.8
	Min.	87	18.5	3.5	0.0	0.00	0.0	8.9	0.27	1.2
Term III 1991 - 1995 (36 events)	Ave.	670	57.4	11.9	7.7	0.12	2.7	38.2	0.63	9.6
	Max.	1724	170.0	56.0	44.7	0.38	32.8	140.9	1.19	90.2
	Min.	31	17.0	2.0	0.1	0.00	0.1	11.2	0.40	0.8
Term IV 1996- 2000 (44 events)	Ave.	557	49.5	9.7	7.9	0.10	2.7	26.4	0.49	6.1
	Max.	2930	143.5	35.0	61.5	0.43	20.4	123.6	0.87	28.0
	Min.	24	12.5	3.0	0.0	0.00	0.0	5.1	0.28	1.5
Whole term 1981-2000 (109 events)	Ave.	632	54.9	10.7	7.9	0.11	2.4	32.4	0.55	7.3
	Max.	2930	170.0	56.0	61.5	0.43	32.8	140.9	1.19	90.2
	Min.	24	12.5	2.0	0.0	0.00	0.0	5.1	0.27	0.8

Note: Analyzed rainfall events were total rainfall of over 30mm or over 10mm/30 minutes at peak time

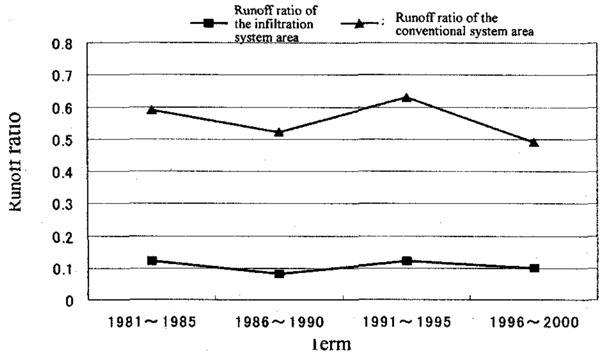


Figure 5 Change of the average runoff ratio in the four terms

Thirdly, as an explanation for the effectiveness for the runoff control with respect to the individual rain, Figure 6 and 7 show the examples of similar size and types of rainfall, center concentration type. One is a No9 rainfall in August 18.1982, with a total amount of rainfall of 76.5 mm. The other is No 96 rainfall in April 10, 1999, with a total amount of rainfall of 70.5 mm. Although the time interval between the two rains was 17years, the runoff ratios of the infiltration area showed almost the same value, while the conventional system area showed a 12 % increase.

Table 5 Comparison of similar type of Rainfall

Rainfall event No.	Amount of Rainfall	Amount of Rainfall at peak time	Runoff ratio	
	mm	mm／30min	Infiltration system area	Conventional system area
9	76.5	12.0	0.17	0.56
96	70.5	7.0	0.18	0.63

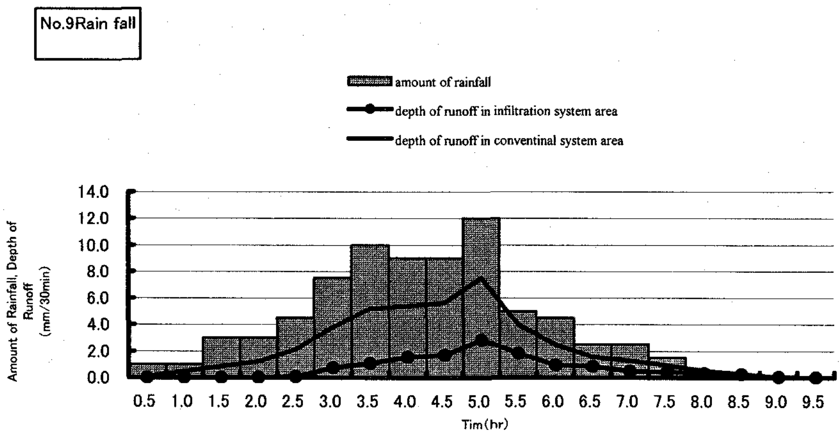


Figure 6 Rainfall and runoff (Aug. 18,1982, total amount of rainfall;76.5 mm)

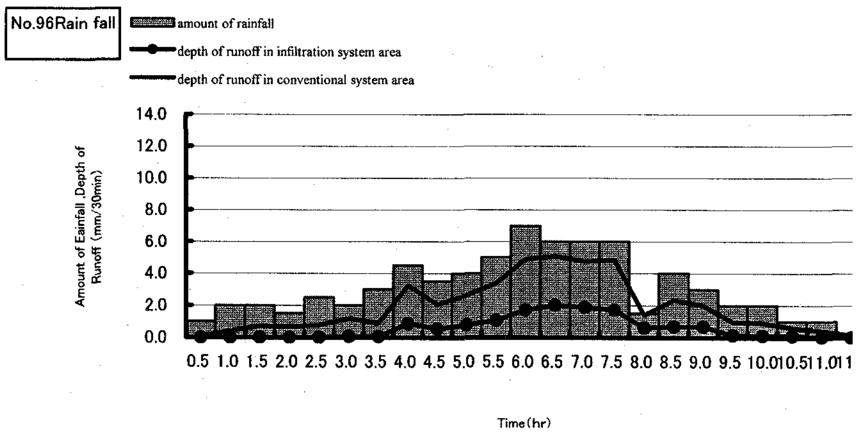


Figure 7 Rainfall and runoff (Apr. 10, 1999, total Amount of rainfall; 70.5 mm)

4. Survey on actual condition and secular changes of the infiltration facilities

The object of the survey is to acquire information about secular changes of the infiltration capacity and the condition of deposits within the infiltration facilities in order to establish maintenance guidelines for the system. From the completion of the facilities in 1981, ten actual condition surveys shown in Table 6 were conducted through on-site tests and observation over twenty years, at Akishima Tutsujigaoka Heights and other housing complexes, with the aim of understanding the trends of the increasing deposit and the declining rate of infiltration capacity due to clogging by crushed stone and soil.

Table 6 List of items surveyed for secular changes

Name of housing complex	Year of survey	Years after completion	Infiltration inlet		Infiltration trench			Permeable pavement	Survey on quality infiltration water etc.
			On-site permeation tests	Deposit survey	On-site permeation tests	Dig out survey	Survey on mouth of perforated pipe	On-site permeation tests	
Akishima-Tutsujigaoka Heights Housing Complex	S56(1981)	0	●		●			●	
	S57(1982)	1	●		●				
	S58(1983)	2	●	●	●	●		●	
	S61(1986)	5	●	●	●			●	
	H4(1992)	11	●	●	●	●			
	H5(1993)	12						●	●
	H6(1994)	13			●				
	H7(1996)	14	●		●				
	H8(1996)	15		●	●				●
	H12(2000)	19	●	●	●		●Videotape recording	●	
	H13(2001)	20			●				
	H14(2002)	21				●			

4.1 Survey on the deposit in the infiltration facilities

a) Infiltration inlets

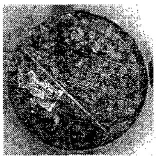
Deposit surveys in the infiltration inlets have been conducted five times so far. In order to evaluate deposit condition, criteria to classify the state of degradation of the facilities were proposed, shown in Table 7. The depth of deposit on the surface of crushed stone was measured with a steel measuring tape, and the deposit coverage area was roughly determined by eye observation. The result is shown in Table 8.

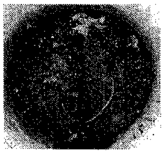
The average depth of deposit in 50 % of the inlets at the Akishima-Tutsujigaoka Heights Housing Complex was over 10 cm. Although the volume of deposit in each inlet showed substantial variation, the average volume of deposit per inlet reached 16-29 liters per unit, with a deposit depth of 7-15 cm.

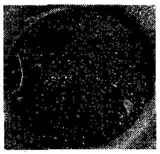
With respect to the secular trend, deposit has increased in all housing complexes observed, being especially remarkable over the last two years, in park areas. This is caused by the surface soils being washed away to the inlets from the bare ground where the groundcover of lawn and other plants had receded substantially; in several inlets, deposit reached the point of entering the perforated pipe of the inlet. Generally, the volume of deposit has varied remarkably depending on the land use around inlets, being smaller around buildings and parking lots and larger in areas with green spaces and parks.

Table 7 Criteria for evaluating the conditions of deposit on crushed stone surface of infiltration inlet

	Criteria	Contents
Degree of coverage	A	Little deposit can be seen on the surface of crushed stone (Photograph 2).
	B	Little deposit but part of the surface of the crushed stone can be seen (Photograph 3).
	C	Deposit covers whole surface of crushed stone (Photograph 4).
	D	Water fills the infiltration inlet (Photograph 5).
Depth of deposit	1	Average depth of deposit on surface of the crushed stone is less than 1cm.
	2	Average depth of deposit on surface of the crushed stone is 1-10cm.
	3	Average depth of deposit on surface of the crushed stone is over 10cm.


Photograph 2
Degree A of deposit coverage


Photograph 3
Degree B of deposit coverage


Photograph 4
Degree C of deposit coverage

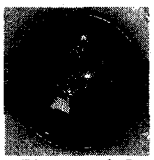

Photograph 5
Degree D of deposit coverage

Table 8 Conditions of deposits in the infiltration inlet in Akishima Tutsujigaoka Heights

		Number of inlets	Evaluation of degree of deposit coverage				Evaluation of volume of deposit			Average volume of deposit (liters per inlet),
			A	B	C	unidentified Infiltration inlet	1	2	3	
Central area	1983	9	3	6	0	0	-	-	-	-
	1986.12	9	0	4	5	0	4	4	1	8.3
	1992.3	5	0	1	4	0	3	2	0	3.3
	2000.1	9	0	2	6	1	1	2	5	28.7
Northern park area	1983	16	10	6	0	0	-	-	-	-
	1986.12	17	2	14	1	0	15	2	0	0
	1992.3	17	3	5	9	0	9	3	4	1.4
	2000.1	18	3	4	10	1	7	3	6	49.4
Parking lot area	1983	15	5)	9	0	0	-	-	-	-
	1986.12	14	0	12	2	0	9	5	0	1.8
	1992.3	13	1	3	9	0	9	3	1	3.1
	2000.1	13	0	3	9	1	2	6	4	15.8
Southern park area	1983	9	4	5	0	0	-	-	-	-
	1986.12	9	0	4	5	0	4	4	1	4.9
	1992.3	7	0	0	7	0	0	2	5	53.8
	2000.1	9	1	0	8	0	1	0	8	97.4
Total	1983	49	22(45)	27(55)	0(0)	0(0)	-	-	-	-
	1986.12	49	2(4)	34(69)	13(27)	0(0)	32(65)	15(31)	2(4)	3.2
	1992.3	42	4(10)	9(21)	29(69)	0(0)	21(51)	10(24)	10(24)	16.1
	2000.1	49	4(8)	9(18)	33(67)	3 (0)	11(25)	11(25)	22(50)	44.2

Remarks:

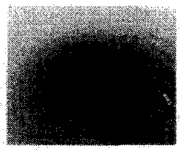
- A total of 49 inlets were surveyed. Forty-nine inlets were surveyed in 1983, 49 inlets in December 1986 and 41 inlets in March 1992
- Numbers in parentheses are the ratio (%) within each evaluation criteria
- No recording of deposit volume in 1983 (there was estimated to be almost no deposit)
- The average deposit volume was calculated by dividing the total deposit volume of inlets by the number of inlets.

b) Infiltration trench

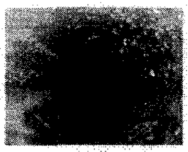
To evaluate the deposit in the trench, the deposit condition at the mouth of the perforated pipe was observed visually and classified in accordance with the evaluation criteria shown in Table 9. A noticeable amount of deposit in the perforated pipes of the infiltration trenches was found in 17.6 % of the downstream mouths of pipes and 14.3 % of the upstream of the mouths (figure8).

Table 9 Criteria for evaluating surveys of the mouths of pipes in the infiltration trenches

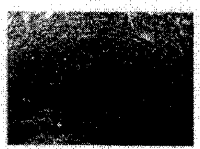
Criteria	Contents
A	Few Deposits were found in pipes
B	Deposits were found in pipes
C	Noticeable amount of deposits were found in pipes



Photograph 6



Photograph 7



Photograph 8

Criteria A Criteria B Criteria C

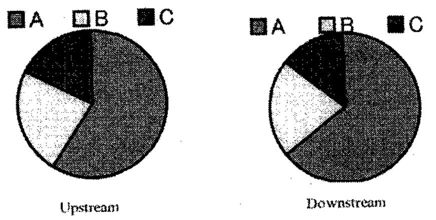
	Points	Criteria	Ratio (%)	
Deposit level at mousse of pipes	Upstream	A	58.8	
		B	23.5	
		C	17.6	
	Downstream	A	64.3	
		B	21.4	
		C	14.3	

Figure 8 Results of Survey on the Deposits in the mouths of pipes of the Infiltration Trenches

4.2 Secular changes in the capacity of the infiltration facilities

a) Infiltration inlets

The infiltration capacity of the infiltration inlets was evaluated by the ultimate infiltration capacity, which was decided by the on-site permeation test shown in Figure 9. While pouring water into the inlet, the volume of water and the water level were observed to measure the volume of infiltrated water. The volume of poured water is regulated to maintain the water head at a level of 600 mm from the bottom, until the infiltration volume shows a constant value. The constant volume per minute is referred to as the ultimate infiltration capacity.

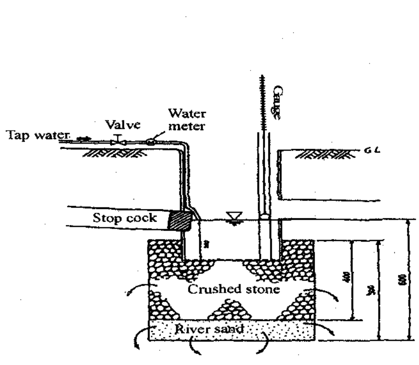


Figure 9 Measuring of the ultimate infiltration capacity of inlet

The result of on-site permeation tests is shown in Table 10. Secular changes of the infiltration capacity showed a different trend in each inlet. No 82 inlet maintained its initial infiltration capacity even after two decades, while the others' infiltration capacity declined substantially. Such variations of the infiltration capacity in each inlet may largely be associated with the surface coverage of the ground around the inlets, as the infiltration capacity tends to decline in proportion to the mass of deposit. No 82 inlet had mainly received water from a roof drain, which had brought comparably less deposit in the inlets. On the other hand, the other inlets, which had received water from green areas and parking lots, containing larger amounts of deposit, suffered a decline in infiltration capacity only after five years. The infiltration capacity of these inlets was restored by cleaning work in 1986, with the removal of deposit and washing of gravel, although they were found to have deteriorated again in 2000. Observation of dug-out crushed stones from the bottom of inlets showed that deposit was found to be retained only in the surface part of the crushed stone, not in the lower part, which shows that periodical washing of the surface gravel is considered an effective measure to restore infiltration capacity.

Table 10 Result of On-site Permeation Test of the Infiltration Inlets

No. of infiltration inlet	When commenced functioning S56 [1981]	One year from start S57 [1982]	2years from start S58 [1983]	5 years from start-1 S61 [1986]	5 years from start-2 S61 [1986]	11 years from start H4 [1992]	15 years from start H8 [1995]	twenty years from start H12 [2000]
53	12.1	13.4	12.1	10.0	–	11.2	2.6	6.3
57	11.0	10.6	7.0	0.3	15.8*	19.1	0.6	1.9
60	15.6	18.4	12.8	6.2	13.2*	1.9	0.9	1.8
64	18.2	21.8	6.4	7.4	25.4*	7.2	4.8	8.2
82	10.7	14.6	14	15.2	–	13.8	13.0	8.2

Remarks: Head of water: 600 mm, Unit: liters/min
* Deposit was removed and crushed stone were washed in 1986.

b) Secular changes in the infiltration capacity of the infiltration trenches

To evaluate the infiltration capacity of the infiltration trenches, an on-site permeation test was conducted at the trench near the No 82 inlet in the Block 2. The water head was kept at 700mm constantly. Water was poured continuously until the constant infiltration volume was confirmed, which value is defined as the ultimate infiltration capacity of the trench (Figure 10). The on-site permeation test has been conducted six times at this trench so far.

Table 11 shows the change of the ultimate infiltration capacity of the trench conducted in twenty years, which showed a gradual increase of the infiltration capacity.

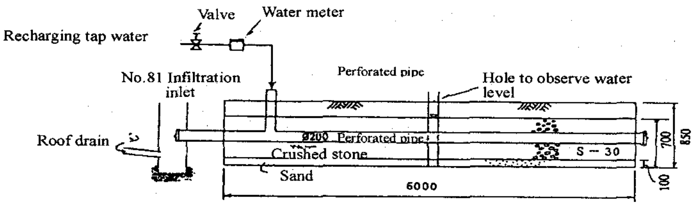


Figure 10 Measuring of the infiltration capacity of trench

Table 11 Change of infiltration capacity of infiltration trench

Date	1981. 8.11	1981. 12.9	1982. 4.9	1982. 7.8	1983. 9.14	1986. 10.21
Days from installation	174	294	415	505	938	2,071
Ultimate infiltration capacity (L/min/m)	5.2	5.1	4.3	4.7	4.7	6.1
Date	1992. 3.9	1992. 3.23	1994. 10.14	1994. 10.14	1995. 7.25	2000. 1.29
Days from installation	4,027	4,041	4,976	4,976	5,260	6,908
Ultimate infiltration capacity (L/min/m)	8.4	7.2	9.7[*1]	9.6[*2]	10.5[*3]	10.0[*4]
Water head (cm)	700	700	537	635	673	611

c) Secular change in the permeable pavement

In Akishima Tutsujigaoka Heights, considerable damage caused by vehicles at the permeable surface and clogging and deposit from the surrounding area were found on the permeable pavement in the Block 2. The initial permeability of the new permeable pavement is generally more than 400 ml/15sec, but the values measured by the on-site permeability test in parking lots of Block2 was as low as 1.12-41.1 ml/15sec. The coefficient of permeability of pavement samples was 1.5×10^{-4} cm/sec. Although this permeability has declined considerably, the permeable pavement still held the capacity to infiltrate rainfall of around 5 mm/hour, when the permeability was expressed as the amount of rainfall.

4.3 Design Evaluation and Improvement to Prevent Clogging

By reviewing the results of these surveys on the actual conditions of the infiltration facilities over the twenty years, some useful suggestions to preserve the infiltration capacity of the infiltration facilities can be pointed out, as shown in Table 11. It was confirmed that some devices designed at the introduction stage were found to be very effective for conserving the capacity of infiltration facilities. Above all, the combination of infiltration trench and inlet shown in Figure 2, together with the manner in which the perforated pipes and the inlet were connected, was a very effective measu because infiltration inlets have played an effective role in storing and preventing deposit from entering into the trenches, helping trenches continue to function well over the long term.

Table 12 Review of designs and structures of infiltration facilities focused on clog prevention

	Measures	Contents of design		Results of survey
		Design point	Intention of design	
Infiltration trench and infiltration inlet	Pipes connection at different levels	Downstream-side perforated pipe is connected at higher point than upstream-side pipe to inlet.	This design aims at increasing water depth to secure water pressure, thus accelerating infiltration and also prevent deposit and debris from entering into downstream pipes.	Although deposits in some infiltration trenches were found on the connection point of the infiltration trench with the infiltration inlet, it was not so serious as to block rainfall flow into the infiltration trench. Connecting the downstream-point at a higher point than the upstream was an effective way to both hinder deposit from entering into the trench and secure deposit storage in the inlet.
	Separation of inlet and trench	Separating infiltration inlet and infiltration trench		
Infiltration trench	Position of holes in perforated pipe	Holes of perforated pipe are set as shown in Figure 3 with no-holes range downside	To prevent muddy water of the initial rainfall from entering the infiltration trench and make it flow down to the downstream infiltration inlet	
	Laying permeable sheet	Laying permeable sheet only on the top surface of the infiltration trench	Infiltrating water from the top surface and preventing deposit from entering from the top surface	Dig out surveys confirmed that the permeable sheets laid on the trenches effectively protected trench from deposit intrusion, because only a tiny amount of deposit was found in all the sides of trenches.
Infiltration inlet	Laying permeable sheet	Laying permeable sheet on the top surface of crushed stones in the infiltration inlet	Preventing deposit from entering into the crushed stone voids	Deposit surveys confirmed that some of the infiltration inlets were clogged at the permeable sheet and water pool was formed in the inlets. It may be unnecessary to lay the permeable sheets on top of the crushed stones.
Void ratio of crushed stone in infiltration facilities		Using single granularity crushed stone (S-30), which have initial void-ratio of 40% on average, to obtain larger void ratio than crushed stone.		Dig out surveys at the infiltration trenches confirmed that the void ratio conserved its initial value of the approximately 40% even after twenty years.

5. Conclusions

Despite the general concern at the time of introduction of the infiltration system that clogging of infiltration facilities would occur in a short time and degrade the system, follow-up surveys conducted successively in Akishima Tutsujigaoka Housing Complex showed that the system has functioned invariably for twenty years.

The main reason of the conserved effectiveness of the infiltration system can be pointed out as follows.

(1) Comparison of runoff of the infiltration system area with that of the conventional system area showed that average runoff ratio of 109 rainfall events in twenty years of the infiltration system area was 0.11 and 0.55 in the conventional system area, the former being five times smaller than the latter. When compared at peak time, average peak runoff height in 30 min was 32.8mm/30min in the infiltration system area, while 90.2 mm /30 min in the conventional system. There are two explanations for the effectiveness, as follows.

The first reason is considered the unexpectedly high infiltration capacity of the ground in Akishima , as the Kanto Loamy Soil is generally known as volcanic cohesive soil (known as clay) with low permeability and high sensitive ratio, because its permeability is severely reduced when it is disturbed. The designed infiltration capacity of the infiltration inlet and the infiltration trench was 1.0 L/min per unit and 1.0 L/min for the 1 m of the trench, which was decided on the basis of the preliminary test. But the measured infiltration capacity of the infiltration inlets were 10.7 ~18.2 L/min per unit as shown in Table10 and the infiltration trench was 5.10 L /min for the 1 m of the trench as shown in Table11. This may be not only because the preliminary tests to identify the design value were conducted with inlets of smaller size than the types of facilities actually installed in Akishima Tutsujigaoka Heights but also because the permeability of undisturbed Kanto Loamy Soil was fairly higher than at the preliminary test. The coefficient of permeability of the natural soil surmised by the onsite permeability test was on an order of 10^{-3} cm /sec, while the disturbed sample was only 1.5×10^{-4}- 4.8×10^{-7} cm/sec.

The second reason is ascribed to the structure of the infiltration system, which is composed of infiltration trenches, infiltration gutters, infiltration inlets and permeable pavement. When rainfall reaches the ground surface, some of it goes into the subsoil through topsoil or permeable pavement or evaporates into the air; the rest enters the infiltration gutters or infiltration inlets and infiltrates into the ground or flows into the infiltration trenches. Minute materials which may cause the clogging of these facilities, before reaching the infiltration trenches, which have the largest infiltration capacity of the facilities, are considered to be eliminated by these preliminary deposit storages within the gutters and inlets, thus retarding the clogging of infiltration trenches. In consequence, the combined system of different types of infiltration facilities has worked well as a whole.

(2) With respect to the details of infiltration trench, the invention in which the downstream end of the pipe was set at a higher level than the upstream end was an effective measure to prevent deposit from entering the trench. At the same time, the position, in which the holes in the perforated pipes were arranged to avoid the very lower end, was also effective in preventing entrance of deposit.

(3) The declining run-off ratio of the conventional system area in the fourth term may be caused by the partial conversion of the ordinary pavement to a permeable surface. On the other hand, the runoff ratio in the infiltration area was not so affected by the alteration of land as that of the conventional system area.

(4) The reason of the improvement of infiltration capacity of the trench shown in Table 11 is not conclusively proven, and this trend can't be applicable to other trenches yet, as no monitoring of durability with age were implemented in other trenches.

One hypothetical explanation is that although the surface of excavated trench was considered to be disturbed by the excavation tools and its voids were partially destroyed or clogged, these parts gradually flaked off, thus restoring the infiltration capacity. The second explanation is that new water courses were made by roots, insects and worms, as these were observed visually, especially in the dug-up trench in the green space.

(5) In order to make the infiltration system work effectively for longer, the maintenance of infiltration facilities is indispensable. Despite no particular maintenance operations other than surface cleaning having been conducted in Akishima Tutsujigaoka Heights so far, the infiltration capacity of the system has been well maintained. But it seems certain that the system needs periodical maintenance work, such as the removal of deposit and the washing of crushed stones. In maintaining the infiltration facilities, the prevention of deposit is also an important measure to make the system work for longer. And the following measures were found to be effective in these surveys.

(a) Covering the bare ground with plants, such as lawn and groundcover

(b) Prevention of soil hardening by being stepped on.

(c) Raising the lid of inlets slightly higher than the ground level.

(d) Cleaning and removal of trash and fallen leaves.

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