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Effects of the underground discharge channel/reservoir for small urban rivers in the Tokyo area

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Abstract.

In the midst of global climate change, a large typhoon has hit Japan and unprecedented heavy rainfall is occurring. In large cities in Japan, underground discharge channels and underground regulating reservoirs are being developed to improve the flood control safety.

In this paper, we confirm the flood reduction effect of these underground facilities against the rainfall generated by Typhoon Hagibis in the Tokyo area in 2019.

In addition, the advantages of underground regulating reservoirs in the metropolitan area are discussed from two aspects: cost and land acquisition. It is confirmed that the underground reservoir type has remarkable advantages in both aspects.

1. Objective of this paper

In recent years, global warming has resulted in climate change worldwide. According to the observations conducted by the Japan Meteorological Agency, the average temperature in Japan has risen by 1.21 °C in the past 100 years[1]. In comparison with the situation 30 years ago, the number of short-term heavy rainfalls with an hourly precipitation of 50 mm or more has increased by 1.4 times. Besides, the number of rainfalls with an hourly precipitation of 100 mm or more has increased by 1.7 times. In addition, since 2013, the records for hourly precipitation has been broken at approximately 30 % of the rainfall observation points[2]. It is expected that the number of heavy rains will double that at the present time, the precipitation will increase, and the frequency of severe typhoons will increase also in the south sea of Japan. Such climate change has brought heavier rainfall than any we have ever experienced, and serious floods and landslide disasters have occurred in recent years. Moreover, the risk of water disasters will increase in the future.

The main measures for flood control can be classified into two categories. The first comprises measures for peak cutting by means of regulating reservoirs or discharge channels, and the second aims at increasing the river flow capacity by expanding the cross section of the river channel. In large cities where land use is dense, such as Tokyo, it is difficult to install regulating reservoirs or widen rivers on the ground because of the large number of land acquisitions that would be required. Therefore, in recent years large scale facilities for flood control such as regulating reservoirs are increasingly begin installed underground in the Tokyo area.



Many studies about the safety level of flood control in the Tokyo metropolitan area have been performed. For example, Sekine et al.[3] researched on inundation damage prediction in the Kanda river basin by numerical simulation, and Ishimori et al.[4] studied the flood control effect of an underground reservoir. However, limited research has been performed concerning the flood control against the recent heavy rainfall. In addition, few studies have attempted to discuss the advantages of reservoirs under the ground compared with those on the ground.

In this paper, the effects of underground discharge channels and regulating reservoirs against the heavy rainfall caused by Typhoon Hagibis, which hit Tokyo in 2019, will be reviewed, and the superiority of the underground system for the reservoirs being developed in the Tokyo metropolitan area, where the land use is dense, will be discussed.

2. Underground discharge channels and reservoirs in the Tokyo area

2.1. Abstract of the metropolitan area outer underground discharge channel

In the Nakagawa and Ayase river basins located in the northern part of Tokyo, small- and medium-sized rivers are prevented from an overflow by draining the flood of those rivers through the discharge channels and pumping it out into the Edo river, which is the major river next to them. There are two major discharge channels. One is the Misato discharge channel and the other is the metro metropolitan area outer underground discharge channel (MAODC). Each of them has drainage pumps that can pump flood waters out at 200 m³ per second.

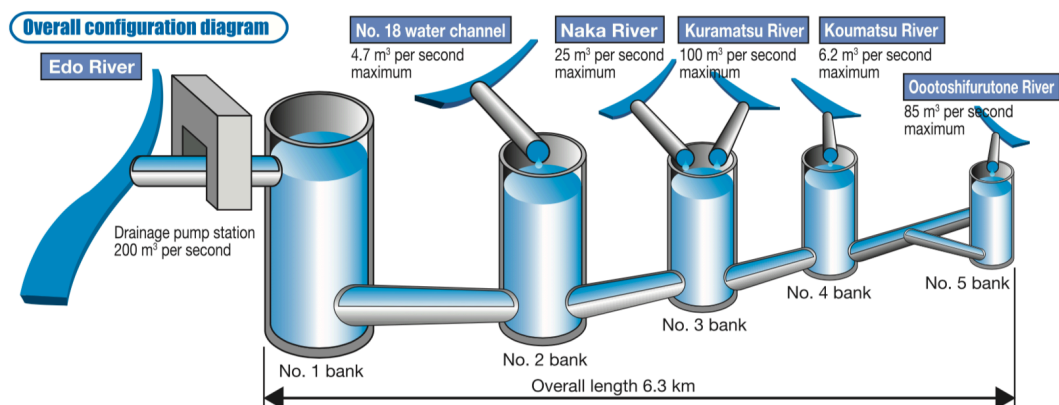


Figure 1. Overall configuration diagram of the metropolitan area outer underground discharge channel (MAODC)[5]



Figure 2. No.5 bank (state of inflow)[5]

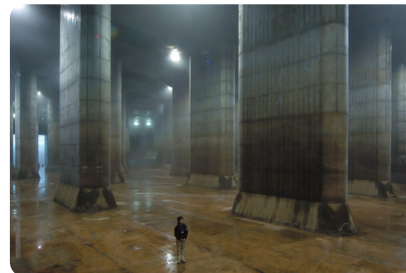


Figure 3. Pressure-adjusting water tank[5]

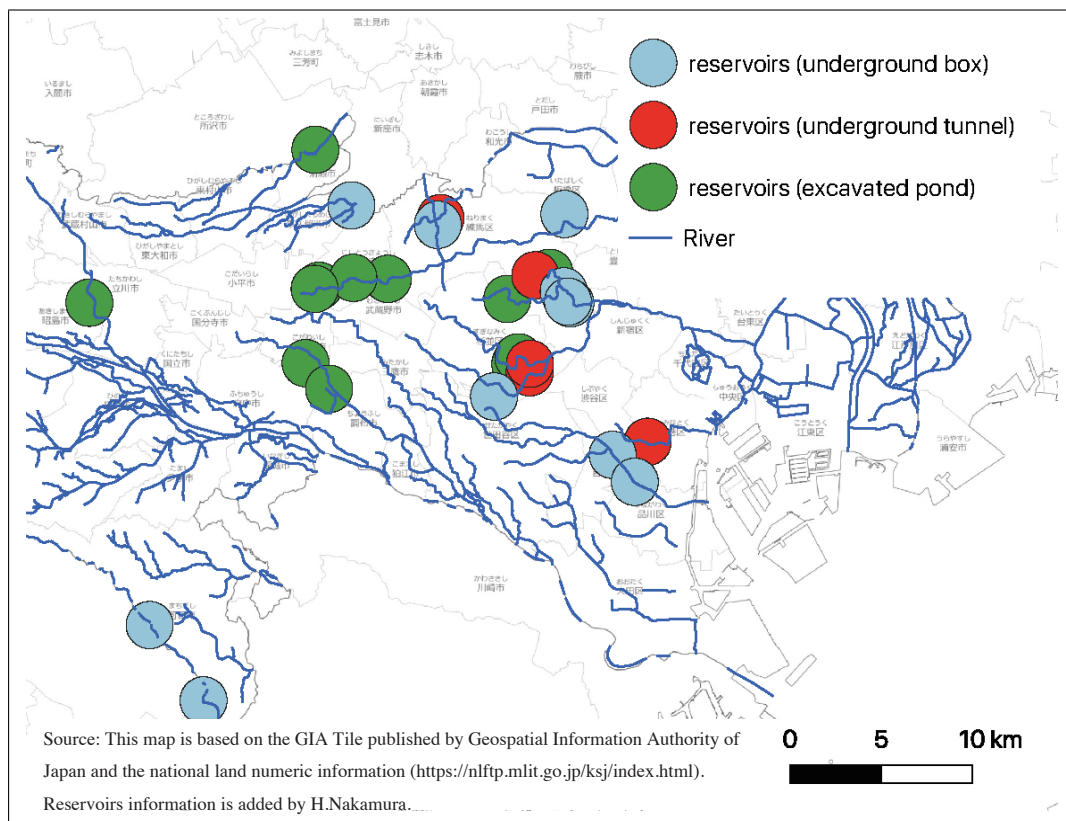


Figure 4. Location of the regulating reservoirs of Tokyo.

As shown in Figure 1, the MAODC consists of the inflow facilities and banks (Figure 2) for taking water from the rivers, the tunnel of the underground water channel for directing the flood water downstream, the pressure-adjusting water tank (Figure 3) for reducing the water flow in the underground area and securing a smooth flow, and the draining pump station and drainage sluice-way for draining flooding from underground areas. The tunnel has an inner diameter of 10 m and a total length of 6.3 km. It is one of the world's largest underground discharge channels[5].

2.2. Underground reservoirs for small and medium-sized urban rivers in Tokyo

This paper focuses on the underground regulating reservoirs developed in small and medium-sized rivers in western Tokyo[6].

There are 28 regulating reservoirs with total storage capacity of 2,560,700 m³ in 12 rivers in this area (Figure 4). Reservoirs can be classified into three structure types, namely, excavated pond (57% of the total), underground box (32%), and underground tunnel (11%). Regarding the storage volume ratio, the underground box type accounts for 44% and the underground tunnel accounts for 35%. Figure 5 shows most of the facilities that have been installed underground since 2000.

In addition, new regulating reservoirs with a storage capacity of 1,246,500 m³ are being under construction, and 93% of these reservoirs are installed under the ground[6]. Thus the percentage of the underground type will reach 83% after their completion. It is obvious that the underground type has become the most common reservoir in western Tokyo.

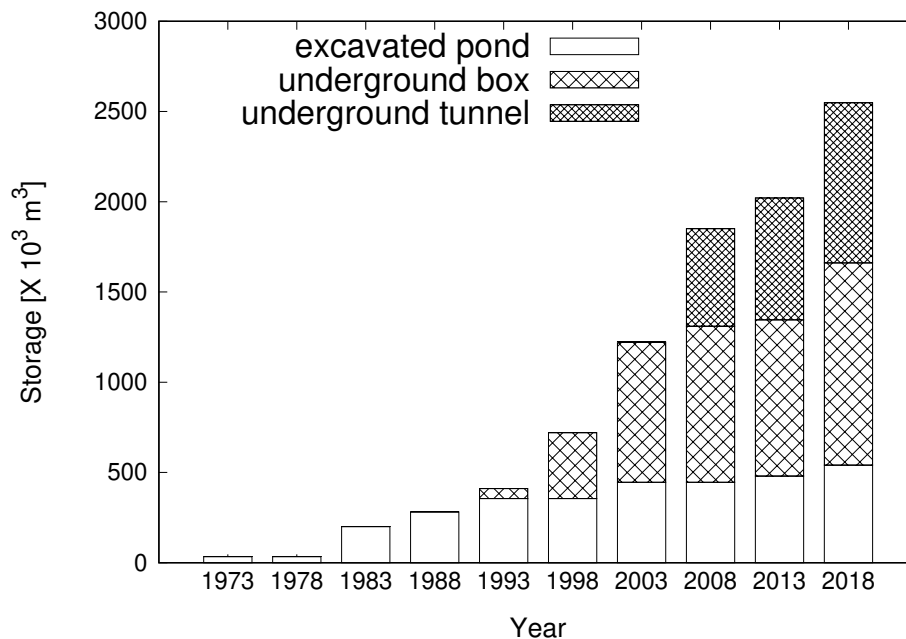


Figure 5. Changes in the development status of regulating reservoirs by type in western Tokyo.

3. Effect of underground facilities for flood control against Typhoon Hagibis

3.1. Summary of the rainfall and damage caused by Typhoon Hagibis

Typhoon Hagibis hit Japan in October 2019, and it brought great damage and a large amount of rain over all Japan. over one hundred persons were dead or missing, and more than 100,000 buildings were damaged[7].

The total rainfall reached approximately 300 mm in the west side of downtown Tokyo and approximately 600 mm in western Tokyo[8]. We had a record-setting rainfall in Tokyo. However, in the Nakagawa and Ayase river basin where the MAODC operated, and in western Tokyo where the regulating reservoirs operated, the damage was slight for the large amount of rainfall. In the following sections, the flood control effect of these underground facilities is reviewed.

3.2. Flood control effect of the MAODC

According to the Ministry of Land, Infrastructure, Transport and Tourism of Japan (MLIT), in the Nakagawa basin, 44.9 million m³, equivalent to approximately 30% of the 175.7 million m³ that fell in the basin, were drained outside the basin, and 27% of the water was drained by the MAODC[9].

The MLIT has provided the simulation results for the water level at Nakagawa (Yoshikawa water level observatory) in comparison with the case without discharge channels. According to this, the huge amount of drainage resulted in a reduction of the period in which the water level was above the alarming level that could trigger floods. It was 24 h shorter, decreasing from 28 to 4 h, whereas the maximum water fell 0.3 m, from 4.52 to 4.22 m. In addition, the effect of the reduction in inundation damage by the MAODC was estimated to be of 249 million dollars[10].

3.3. Flood control effect by regulating reservoirs in western Tokyo

According to the Tokyo Metropolitan Government[8], 21 of the 28 reservoirs in service took in flood water from the rivers, and were filled with water up to nearly half their storage capacity. The Kandagawa Ring Route 7 underground reservoir (KRUR), which is the largest underground

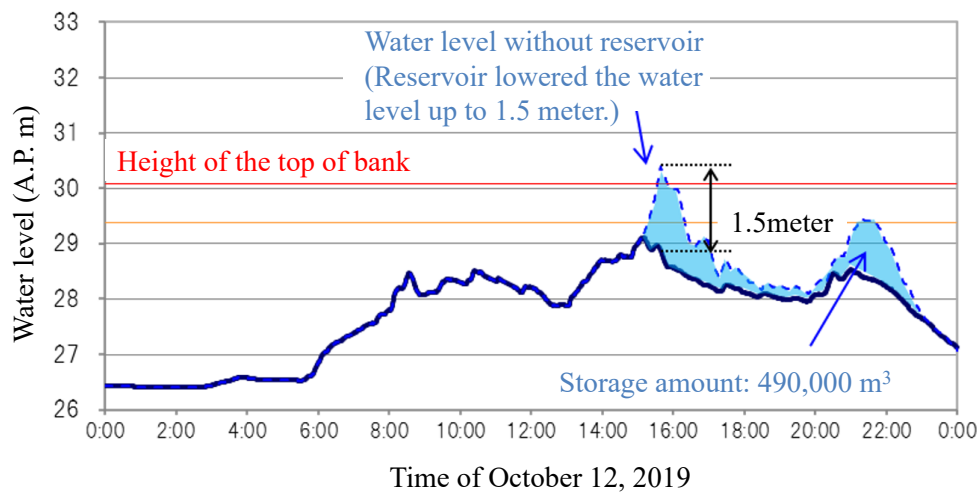


Figure 6. Changes of water level of Kanda river[8]

reservoir in western Tokyo, collected flood water from the Kanda and Zenpukuji rivers and stored approximately 490,000 m³, nearly 90% of the total storage. As it is pointed out by the estimate of the government of Tokyo the retention by the regulating reservoir resulted in a decrease of 1.5 m in the water level at the downstream point of the reservoir (Figure 6).

4. Advantage of underground reservoirs in the metropolitan area

4.1. Development cost advantage

In this subsection, the installation cost of a regulating reservoir whose storage is the same as that of the second stage of the KRUR is estimated to examine the economic advantage.

The installation cost consists of construction cost, land cost, and compensation cost. The site area and construction costs in the case of the excavated pond type presented in Table 1 were set based on the case of another excavated reservoir in Kanagawa prefecture. Using these values, the unit price per square meter of land is \$4,920, which is the land price at the location of the KRUR indicated in the published land prices of 2019. In addition, the compensation cost per building is \$189,000, and the number of buildings counted on the map is 495.

Table 1. Cost factors of Shimotuchidana Reservoir (Storage: 460,000 m³)

Factor	Value	Value per 1,000 m ³ of storage
Construction Cost (million \$)	142	0.309
Site Area (m ²)	14,000	30.4

Source: hearing to Kanagawa prefecture.

Table 2 reveals that the cost of a excavated pond is 1.4 times higher than that of an underground tunnel. Owing to the land acquisition cost, the cost of a excavated pond becomes excessively large. It has been confirmed that the use of underground structures that do not require land acquisition can reduce costs in large metropolitan areas such as Tokyo, where the land use is dense.

Table 2. Comparison of costs by type of structure (Storage: 300,000 m³)

Type	Item	Cost(\$ million)	Remarks
Underground tunnel	Construction cost	462	
	Total	462	
Excavated pond	Construction cost	92	300×0.309
	Land cost	449	$300 \times 30.4 \times 0.0492$
	Compensation cost	99	495×0.189
	Total	641	

*) In excavated pond estimation, construction cost and required area are set based on fig-1, land price is from published land prices of 2019, number of buildings is counted by us.

4.2. Advantage in land acquisition

Based on Japanese law, land ownership is considered to extend above and under the ground in most cases. The Law on Special Measures concerning Public Use of Deep Underground, which was enacted in 2000, enabled public use of deep underground space without purchase of land, but there are still few examples of application of this law. Whether the regulating reservoir is above ground or underground, it is usually necessary to acquire it with the consent of the land owner. Because there is an expropriation of land act in Japan, the agency for implementation of the public infrastructure is able to acquire land under the appropriate procedure and compensation. In reality, however, this system is rarely applied, and generally the land is acquired through voluntary negotiations with the understanding and cooperation of the land owner.

As stated above, it is necessary for implementation agencies to negotiate with a large number of land owners during the installation of facilities above the ground. The corresponding agency will be held responsible for not only a rise in costs but also for lengthening of the execution period and the lack of manpower. However, by utilizing underground space, it is possible to shorten the period required for land acquisition and achieve early completion of the project.

In addition, as presented in Figure 7 and Table 3, the underground space can effectively utilize the vertical space. Therefore, the storage capacity per unit area is approximately 6.6 times that of the surface type

Table 3. Site area and storage of reservoir in Tokyo

Type	Number	Site Area (m ²)(A)	Storage (m ³)(B)	average depth (m)(B/A)
excavated pond	16	318,200	552,700	1.7
underground box	9	100,400	1,121,000	11.2

5. Conclusion

In this paper, we analyzed the effects and advantages of underground discharge channels and regulating reservoirs in the Tokyo area.

Regarding the flood reduction effect against the rainfall generated by Typhoon Hagibis, not only the underground facilities but also the entire system produced such effect. However, the use

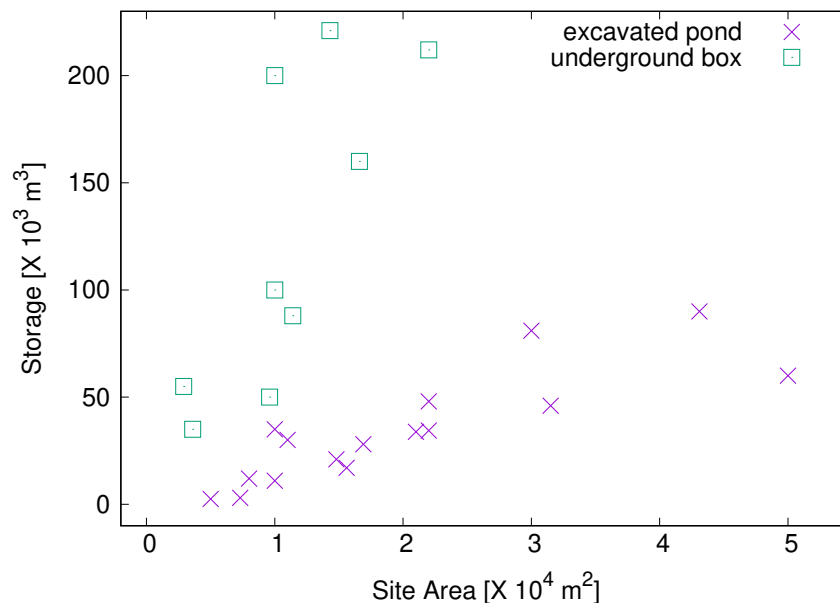


Figure 7. Storage per site area of reservoir in Tokyo

of underground space is one of the effective options to develop these facilities economically and in a short period of time considering the geographic features and land use of the area, especially in a metropolitan area such as Tokyo.

The superiority of the use of underground space in large cities was examined from the two aspects of cost and land acquisition. It was confirmed that the underground type of structure has significant advantages in both aspects.

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