8 - 2 Tokyo Effective Drainage Plan Including Stormwater Reservoir and Connecting Pipe

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Abstract

The construction of storm sewers requires long period and vast investment for implementation, and sometimes faces difficulties because of shortage of flow capacity of receiving water bodies and insufficient workspace. Therefore, stormwater drainage plan has to be prepared taking into consideration on construction easiness and effectiveness.

This paper presents a case study in which existing drainage a new plan of economical and effective drainage plan of two river basins is prepared on the above concept.

The study area is neighboring two river basins; approximately 900ha of Kurome and Ochiai rivers located in northern part of Tokyo. Storm sewers were planed at Kurome and Ochiai river basins respectively. Kurome regional storm sewer was already constructed. However, Ochiai storm sewer faces difficulties of shortage of flow capacity of the Ochiai river and insufficient workspace for construction. In order to conduct flood mitigation project at Ochiai river basin, drainage plans of the two river basins are revised and a practical plan including staged construction program is newly prepared.

Since stormwater outlet structure of Ochiai storm sewer is supposed not to be executed in early stage because of workspace shortage, a connecting pipe for two basins and a regulating reservoir are added to the new plan. Unsteady flow analysis is introduced to evaluate an effect of each construction stage and to revise drainage diameter for economical facilities distribution.

As the results, staged program can be prepared in which drainage capacities of the area could be gradually improved from rainfall depth of 20mm/hr to 40mm/hr and to 50mm/hr and construction work can be started immediately. Moreover, construction cost is reduced because of revised smaller diameter of storm sewer estimated by unsteady flow analysis.

It is confirmed that even smaller diameter can cope with 50mm/hr of rainfall depth in standard design criteria at final stage of construction when the stormwater outlet of Ochiai River is constructed. The connecting pipe is also useful for exceeding rainfall occurred at either basin in the future.

Introduction

Storm sewer construction progresses lately compared with sanitary sewer construction at separate sewer service area in Tama region in Tokyo Metropolis. Stormwater drainage served ratio is only 24% at the end of March 2001. Since green zone has decreased rapidly by residential land development in recent years, water retention capacity of land has declined and flood damage has occurred frequently.

There are cities, where is no river as receiving water body for stormwater drainage. Tokyo Metropolitan Government (TMG) considered those cities as objective areas to undertake comprehensive drainage works and decided to construct regional storm sewers as urban infrastructure.

TMG is carrying out construction of such regional storm sewers at upstream of Tama River and Kurome River basins where flood occur frequently. This paper presents an efficient drainage facilities distribution plan at Kurome River basin.

Outline of Works

Service area of Kurome River regional storm sewer covers Higashimurayama, Higashikurume and Kodaira cities located at northern-central part of Tokyo Metropolis that have suffered frequently flood damages caused by rapid progress of urbanization. In order to eliminate the situation immediately, TMG decided to introduce 4 regional storm sewers named Kurome, Demizu, Ochiai and Kodaira. City-planning decision was made in 1993 so that whole area can cope with 50mm/hr of rainfall intensity. At present, Kurome and Demizu storm sewers are under construction to be completed by the end of March 2002.

Although Ochiai and Kodaira storm sewers are scheduled to be implemented following on the above two storm sewers, out-fall structures of Ochiai and Kodaira storm sewers are supposed difficult to install because of delay on improvement work in Ochiai river as receiving water body. Implementation of river improvement project is predicted for a long time. Moreover, narrow road width and congested underground utilities cause difficulty of immediate implementation of flood control measure because great expenses for replacement of the underground utilities are required for construction of the storm sewers as originally planned. Then, in order to produce work effect at an early stage and to mitigate flood damage efficiently under recent strict financial situation, original distribution plan of drainage facilities was revised by introduction of "storage and network" technique.

Storage and network system is a way to utilize capacity of drainage facilities for the maximum by "storage" and "network". Storage of storm water in pipe and regulating reservoir enables to reduce peak flow. Network of pipe lines connected mutually enables to level hydraulic gradient and to exchange storm water across drainage basins, resulting fully utilization of pipe inner space for efficient storage. The conceptual figures are shown in Figure 1 and Figure 2.



Contents of Revised Plan

Summary of the original and revised plans of Ochiai and Kodaira storm sewers are shown in Figure 3 and Table 1.

Pipe diameters were determined by rational method based on gravity flow in the original plan. And storage-flow typed pipe was introduced, in which pipe diameters were increased to store storm water, as permissible discharge rate was limited by shortage of river flow capacity. Adjusting to river improvement work progress for coping with 50mm/hr of rainfall intensity, storm sewer is scheduled to construct. However, construction of out-fall structure of storm sewer is difficult because of delay of river improvement work.

Since flood damage occurs every year constantly and residents of the area strongly call for flood mitigation works as soon as possible, upper portion of Ochiai storm sewer was decided to construct in advance.

The portion is connected to Kurome storm sewer, which would be completed by the end of March 2002, to utilize existing stormwater out-fall. Early achievement of work effect is aimed by the above construction.

		Original plan		Revised plan		
		Diameter	Length	Diameter	Length	
Ochiai sewer	storm	4000	1,360m	2400	2,350m	
		4500	310m			
		4200 x 4200	460m	3800 x 3800	370m	
Kodaira storm sewer		3250	380m	2200	410m	
				2200 2200	410111	

Table 1 - Summary of original and revised plans

Unsteady and distributed model of XP-SWMM popular in the Western countries, was employed for runoff estimation and flow calculation instead of rational method and uniform flow for hydrologic calculation used in the original plan. Runoff and flow behavior could be expressed more closely to the practical phenomenon, as hydraulic analysis in pipe was carried out by unsteady state in place of uniform state.



Figure 3 - Summary of revised plan

Adjustment with River Plan

In order to perform effectively flood control measures for an extensive area, urban drainage and river control have to be cooperated. Since revised urban drainage plan includes change of receiving water body that affects river plan drastically, adjustment with river plan is required.

While urban drainage plan targets rainfall intensity of 50mm/hr with runoff coefficient of 0.6, river improvement plan is divided into three stages including present condition.

The river provisional plan targets rainfall intensity of 50mm/hr with 0.51 of urbanized ratio, permissible discharge volume of river is less than the designed discharge flow of urban drainage system. Therefore, regional storm sewers are planed as storage-flow type until river flow capacity become 65mm/hr of its future plan and will be perfect flow type when river flow capacity will accomplish 65mm/hr.

Since there is a period which river flow capacity falls below the flood control target of urban drainage plan in Kurome and Ochiai river basins, runoff control measures are required for the amount which exceeds the allowable discharge volume of the river. The concept of staged program is shown in Figure 4.



Drainage plan using the existing facilities

Kurome storm sewer, which is under construction and to drain stormwater to Kurome river, locates in Kurome drainage division neighboring Ochiai drainage division. Since the storm sewer is subject to discharge regulation of river, it must be enlarged to store excessive amount of permissible discharge and has some margin in its capacity. Paying attention to this situation, it was decided that Ochiai storm sewer was connected to Kurome storm sewer with connecting pipe, and that about half amount of runoff in Ochiai storm sewer was flowed into Kurome storm sewer.

Moreover, Hakusan regulating reservoir of stormwater with nominal capacity of 45,000m3 maintained by Higasikurume city links with Kurome storm sewer. The reservoir was also decided to use for runoff control.

As shown in Figure 5 and 6, runoff from Ochiai 1st and 2nd sub-divisions is made flow into Kurome storm sewer by connecting pipe, and excessive amount of Ochiai storm sewer capacity is stored in Hakusan regulating reservoir. By the above revised plan, cross-sectional reduction of Ochiai storm sewer could be attained, and the investment efficiency to drainage construction works could be raised.

The connecting pipe is installed without slope and an orifice is prepared at Ochiai storm sewer, as shown in Figure 7. Stormwater is guided to Ochiai storm sewer by hydraulic gradient raised by the orifice.

For preparing network, hydraulic and ground levels were checked repeatedly so that flood portions would not be moved to other areas.

A part of runoff in Ochiai drainage division is drained to Kurome storm sewer by network, and the runoff is stored in Kurome storm sewer up to 30mm of rainfall depth. Rainfall depth over 30mm is stored in the existing Hakusan regulating reservoir, and drained to Kurome River afterwards with shifting a peak. The estimated storage volume of Hakusan regulating reservoir is 22,000m3 and inflow is calculated to occur once a year according to actual rain records of the area.

Out line of Hakusan regulating reservoir is indicated in Figure 8 and 9.



Figure 5 - Network outline by connecting pipe



Figure 6 - Network plan



Figure 7 - Vertical section of network



Figure 8 - Hakusan regulating reservoir plan



water level and storage volume

Expectation of Cost Reduction

Pipe flow analysis methods were changed and runoff route in Ochiai division was modified to discharge into two directions of Ochiai and Kurome Rivers. The above revisions enable to reduce cross-sectional areas of storm sewers and contribute to construction cost reduction.

Cross sections of Ochiai storm sewers were changed to 2.4m from original ones of ranging from 4.0m to 4.5m in diameters and box culvert portion was reduced from original 4.2m x 4.2m to revised 3.8m x 3.8m. And Kodaira storm sewer was from 3.25m to 2.2m in diameters. Total cost reduction effect of the two storm sewers is about 20% of originally estimated value, as shown in Table 2. Moreover, the upper stream portion of storm sewer is decided to construct in advance for storage-flow pipe to achieve formation of work effects in early stage. As for lower stream portion, staged construction is proposed to coordinate with progress and change of circumstances of the area, such as river and city planning road.

Table 2 -	Expectation	of cost	reduction
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	Original plan			Revised plan		
	Ochiai storm sewer			Ochiai storm sewer		
	4000 ~ 4500 L=1,670m		2400	L=2,3	50m	
Construction	4200×4200	L=	460m	3800 × 3800	L=	370m
contents						
	Kodaira storm sewer			Kodaira storm sewer		
	3250	L=	380m	2200	L=	410m
Construction Cost	\$65 million			\$48 million (\$17 million)		

(1\$=130yen)

Staged Construction Schedule and Effects Evaluation

First stage. Upper stream portion of storm sewer by 2.4m in diameter with length of 2,350m except for out-fall structure is constructed by shield tunneling method. The portion was decided to construct without intermediate shaft for cost reduction. Starting shaft for a shield machine was set at the down stream end.

At this stage, constructed drainage facility of Ochiai 3 section is used as storage pipe for runoff from Ochiai 3rd to 5th sub-drainage divisions, as no out-fall structure is constructed. The stored stormwater is drained to Ochiai river by drainage pumps through existing drain pipe in dry weather after rainfall events.

Since storm water in Ochiai 1 and 2 sections can be discharged to Kurome river by connection of Ochiai1 and 2 sections and Kurome storm sewer, the two sections are used as storage-flow typed pipes for Ochiai 1st and 2nd drainage sub-divisions.

Thereby, the flood control capacities of basins are 40mm/hr for Ochiai 1st and 2nd drainage sub-divisions, 20mm/hr for Ochiai 3rd to 5th sub-drainage divisions and 40mm/hr for Kurome division, when it corresponds only in regional storm sewers.

Although the flood control capacity of Ochiai 3rd to 5th sub-drainage divisions is relatively low compared with the other divisions, public storm sewers have a capacity of around 15mm/hr. Together with the capacity of public storm sewers, the total flood control capacity reaches 35mm/hr.



Figure 10 - First construction stage

Second stage. After the improvement work of Ochiai River will be carried out, out-fall structure of box culvert with cross section by 3.80m x 3.80m can be installed. By out-fall structure installation, Ochiai 3, Ochiai storm

sewer and Kodaira storm sewer can be used as storage-flow typed pipes. By this arrangement, even if a flow capacity of receiving water body of Kurome river is 30mm/hr, the whole Kurome river basin will have the capacity of 40mm/hr. In addition, when a flow capacity of receiving water body of the river become 50mm/hr, the whole Kurome river basin will have the capacity of 50mm/hr because of discharge deregulation.



Figure 11 - Second construction stage

Final stage. When the improvement work of Ochiai river will be completed with flow capacity by 65mm/hr, the design runoff can be drained to Ochiai river, since permissible discharge rate of 31m³/s exceeds the designed urban drainage runoff rate by 26m³/s.

For this reason, the connecting pipe between Kurome and Ochiai storm sewers will be blockaded and the network is canceled. As for the connecting pipe, it is used as storage-flow typed pipe, and storage function is given to exceeding the design runoff. Evaluation of each stage is shown in Table 3.



Figure 12 - Final construction stage

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Table 3 -	Staged	Construction	Schedule and	Effects Evaluation

Staged construction		Effect evaluation		
Construction plan	Sub-divis ion	Pipe type	Drainage capacity	
First stage	Ochiai 1st~2nd	Storage-flow typed pipe	40mm/hr	
(30mm/hr)	Ochiai 3rd~5th	Storage pipe	20mm/hr	
Second stage (30mm/hr) (50mm/hr)	Ochiai 1st~5th	Storage-flow typed pipe	40mm/hr (30mm/hr) 50mm/hr (50mm/hr)	
Final stage (65mm/hr)	Ochiai 1st~5th	Flow pipe	50mm/hr	

() Flow capacity of rivers

Conclusion

Flood control capacities are increased by making a network of regional storm sewers planed individually in the Ochiai and Kurome river basins with mitigating load to the rivers of which flow capacities are low because of late schedule of river improvement works. In the plan, a runoff control measure is introduced considering storage function of the existing regulating reservoir and storm sewers. Moreover, pipe flow behavior is expressed in more practical way by introducing unsteady flow analysis for economical facilities distribution, and effects of staged construction are estimated quantitatively.

As a results, staged program in which urban drainage capacities can be gradually improved by rainfall depth from 20mm/hr to 40mm/hr and to 50mm/hr.

Moreover, the diameters of storm sewers are reduced by unsteady flow analysis and stormwater is drained out under surcharged state by raised hydraulic gradient. This arrangement brings that construction cost can be reduced by 20% approximately and construction work becomes possible to start promptly under the strict financial situation.

Even if the flow capacities of rivers are not sufficient due to delay of river improvement works, flood control levels can be raised by introducing the new design technique of "storage and network" for storm sewer planning.

Thus, runoff control before flowing into drainage system, storage in drainage system and slow discharge from drainage system are efficient for flood mitigation measures of urbanized area, instead of conventional way of prompt discharge. Such kind of techniques should be introduced in planning and designing flood mitigation in the future.