# Design of Detention Pond and Critical Duration of Design Rainfall in Seoul

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ABSTRACT/This study is to determine the critical duration of design rainfall and to utilize it for the design of detention pond with pump station. To examine the effect of the duration and temporal distribution of the design rainfall, Huff's quartile method is used for the 9 cases of durations (ranges from 20 to 240 minutes) with ten years return period, and the ILLUDAS model is used for runoff analysis. The storage ratio, which is the ratio of maximum storage amounts to total runoff volume, is introduced to determine the critical duration of design rainfall. The duration which maximizes the storage ratio is adopted as the critical duration. This study is applied to 18 urban drainage watersheds with pump station in Seoul, of which the range of watershed area is 0.24～12.70㎢. The result of simulation shows that the duration which maximizes storage ratio is 30 and 60 minutes on the whole. It is also shown that the storage ratios of 2nd- and 3rd-quartile pattern are larger than those of 1st- and 4th-quartile pattern of temporal distribution. A simplified empirical formula for Seoul area is suggested by the regression analysis between the maximum storage ratio and the peak ratio. This formula can be utilized for the preliminary design and planning of detention pond with pump station.

## 1. Introduction

When the stormwater outflow exceeds the drainage capacity the urban area is inundated with interior waters. The increased volumes and peak runoff rates caused by urbanization result in increasing the damage of flood, unless it is dealt with properly. Rapid changes in the usage of land, especially in Seoul metropolitan area, have resulted in overstressing the drainage systems. The disposal of stormwater is one of the major problems in urban water management.

To reduce the flood damage due to inundation of low lands, drainage facilities such as sewer,

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drainage gate, detention pond, and drainage pump station ought to be constructed and the appropriate design criteria for those facilities are required. To decide the size of flood control facilities, the runoff analysis of the design rainfall is necessary and the selection criteria of appropriate design rainfall should be provided.

Interior drainage facilities have been constructed according to the design criteria of sewer system, and the design frequency has been determined based on the importance of drainage facilities(Ministry of Construction, 1980). In Seoul, the return periods of design rainfall is adopted 5～10 years for the case of the sewer system, and 5～20 years for the case of the detention pond and pumping station. But the design frequency of newly-established drainage facilities show a tendeney to take longer period due to the high-urbanization (Seoul, 1984, 1991). But the criteria of duration on the design rainfall in the design of sewer system are obscure and uncertain, and the rainfall duration for the design of detention pond with pump station is adopted to 120 minutes without appropriate analysis(Seoul, 1984, 1988).

Since the peak discharge and outflow hydrograph are varied due to rainfall duration, and the critical duration which produces maximum load to the drainage system should be determined.

The rational method is still widely used for the runoff estimation of urban sewer system. In this method, the critical duration is regarded as the time of concentration. Since the rational method was developed to estimate peak flows from small drainage areas, its application is usually restricted to drainage areas of less than 2.5㎢. Thus, when the interior drainage plan is considered by detention pond and drainage pump station, it is difficult to apply the rational method. Hence, the rational method is applied to sewer design and the Road Research Laboratory(RRL) method is applied to detention pond design. Therefore the results of runoff analysis at basin outlet(detention pond inlet) have differences between two methods.(Seoul, 1988).

To solve this problem, recently, the design of sewer or detention pond with pump station is performed by the ILLUDAS model(Terstriep and Stall, 1974) to unify the drainage system analysis.

Several studies regarding design of detention pond with pump station have been published by Curtis et al.(1977), Burton(1980), Boyd(1987), McCuen(1988), and Lee et al.(1991). The storage ratio (the maximum storage volume divided by the total runoff volume) is introduced to determine a critical duration of design rainfall. The duration is adopted as a critical duration which maximizes the storage ratio. 18 urban drainage watersheds among 63 watersheds in Seoul metropolitan area are selected for this study. The estimation method of the detention pond size and pump capacity is derived from the relationship between the storage ratio and peak in-out flow ratio. The purpose of this paper is to suggest a basic concept which are necessary to design the detention pond with pump station.

## 2. Determination of the Critical Duration and Design of Detention Pond with Pump Station

### 2.1 Criteria to Determine the Critical Duration

Generally, the storage capacity of detention pond is inversely propotional to the pump capacity of the pond. With consideration of the safety, the large storage volume of the pond allows a small pump capacity, while the small one requires a large pump capacity.

If the outflow of pumping is constant with time, the total storage volume of detention pond increases with increasing the duration of design rainfall. Usually, the maximum storage volume is varied not only by the characteristics of a watershed area and a drainage network but also by the pump capacity. In general, it is difficult to determine a critical duration of detention pond due to the fact that the characteristics of the interrelated parameters are strongly nonlinear. To determine a critical duration of design rainfall, the ratio of the required storage volume to the total runoff volume due to design rainfall, Sr, can be expressed as shown in eq. (1).

$$S_r = \frac{V_r}{V_t} \tag{1}$$

where, $S_r$ : storage ratio

$V_r$ : required storage volume of detention pond ($m^3$)

$V_t$ : total runoff volume due to design rainfall ($m^3$)

If a detention pond has the maximum storage ratio, it has the maximum loading factor to the rainfall. In other words, it indicates high risk on a detention pond. The duration with maximum storage ratio is considered as a critical duration and it can be used as an important parameter to design a detention pond. It is assumed that the pump capacity in this paper is that of existing detention ponds, and the pumps are operated with their full capacities during the critical duration of the design rainfall.

### 2.2 Planning and Design of Detention Pond with Pump Station

In case of internal drainage system which contains detention pond and pump station, the required storage volume of detention pond and storage ratio are affected by pump capacity. The ratio of pump capacity to peak inflow of hydrograph(peak in–out flow ratio), $\alpha$, as shown in eq. (2), was used by Curtis(1977), Burton(1980), Boyd(1987), and McCuen(1988) to design a detention pond. Combining eqs. (1) and (2), the storage ratio can be expressed as a function of the peak in–out flow ratio, as presented in eq. (3). If this functional relationship is determined, the maximum storage ratio can be estimated, and a required detention volume also can be calculated. The storage volume of existing detention pond also can be evaluated by using eq. (3). Conversely, when the maximum storage ratio is determined, a proper pump capacity can be determined and a pump capacity of existing detention pond can be evaluated.

$$\alpha = \frac{Q_{pump}}{Q_{peak}} \tag{2}$$

$$S_r = \frac{V_r}{V_t} = \frac{V_t - V_p}{V_t} = 1 - \frac{V_p}{V_t} = f(\alpha) \tag{3}$$

where, $\alpha$ : peak in-out flow ratio

$Q_{pump}$ : maximum capacity of pump ($m^3$/sec)

$Q_{peak}$ : peak inflow of hydrograph ($m^3$/sec)

$S_r$ : storage ratio

$V_r$ : required storage volume of detention pond ($m^3$)

$V_t$ : total runoff volume of design rainfall($m^3$)

$V_p$ : volume of outflow by pump($m^3$)

Otherwise, a drainage pump capacity is determined first and a required storage volume can be calculated by eq. (3). The determination of a critical duration of design rainfall and the relationship f($\alpha$) between peak storage ratio and peak in-out flow ratio of the eq. (3) in Seoul is described in section 4.2.

## 3. Internal Drainage System

### 3.1 Detention Pond

At the present time of 1993, Seoul metropolitan has 63 drainage pump stations, and a number of watergates have been constructed at 193 stations. 47 stations among the 63 drainage pump stations have detention pond with storage function and the rest have no storage function but have simple collector wells.

In this study 18 drainage watersheds are selected to decide the critical duration of design rainfall. And a variety of the detention pond basins are selected by their characteristics to consider complex characteristics of runoff phenomena(Table 1).

The relationship between a drainage basin area and the Horton's shape factor for 57 detention ponds in Seoul is shown in Fig. 1. The range of watershed area of 18 detention ponds is 0.24~12.70 ㎢, and range of the Horton's shape factor is 0.10~0.76.

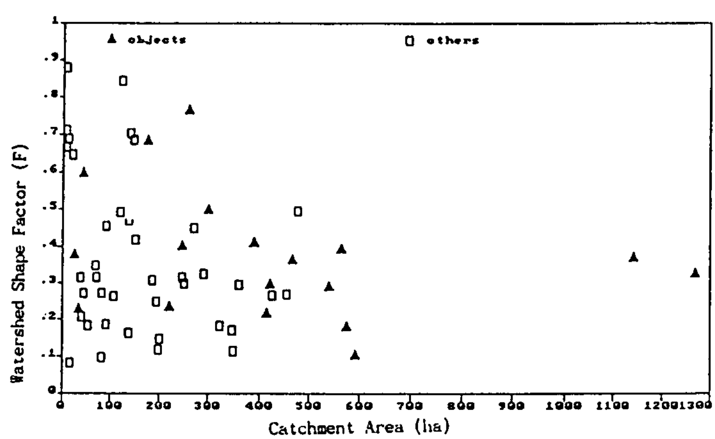


Fig.1 The Relationship between the Catchment Area and Horton's Shape Factor (Seoul)

Table 1. Detention Pond and Characteristics of Drainage Basin in This Study

| Detention Pond | Pump Drainage Capacity ($m^3$/min) | Basin Area (ha) | Pipe Length (km) | Shape Factor |
|---|---|---|---|---|
| Dduk Do | 1,197 | 465.0 | 3.60 | 0.36 |
| Ja Yang | 2,306 | 412.8 | 4.40 | 0.21 |
| Eung Bong | 140 | 42.2 | 0.84 | 0.59 |
| Keum Ho | 500 | 174.2 | 1.60 | 0.68 |
| Ma po | 670 | 299.6 | 2.46 | 0.50 |
| Hap Jeong | 188 | 24.0 | 0.80 | 0.38 |
| Sin Jeong1 | 5,340 | 1,269.5 | 6.30 | 0.32 |
| Sin Jeong2 | 1,750 | 592.3 | 7.70 | 0.10 |
| Gae Bong | 3,680 | 1,142.0 | 5.60 | 0.36 |
| Gu Ro3 | 525 | 32.2 | 1.20 | 0.22 |
| Jam Won | 2,375 | 247.3 | 2.50 | 0.40 |
| Yang Jae | 955 | 540.0 | 4.35 | 0.29 |
| Jam Sil1 | 1,283 | 562.2 | 3.80 | 0.39 |
| Jam Sil2 | 950 | 390.0 | 3.10 | 0.41 |
| Seong Nae1 | 975 | 220.0 | 3.10 | 0.23 |
| Seong Nae2 | 1,265 | 574.6 | 5.70 | 0.18 |
| Tan Cheon | 753 | 421.0 | 3.80 | 0.29 |
| Am Sa | 540 | 260.2 | 1.85 | 0.76 |

### 3.2 Design Rainfall

The probable rainfall intensity formulas in Seoul have been suggested by several investigators. The probable rainfall intensity formula developed by Lee(1967) had been used for the design of hydraulic structures till the year of 1987. After that, the probable rainfall intensity formula developed by Korea Institute of Construction Technology has been used temporarily(Seoul, 1988).

However, a new probable rainfall intensity formula is suggested at entitled 'Report on Investigative Study for the Safety Diagnosis and Management Measures of the River Shore Hydraulic Structures' including rainfall events induced two deluges in 1987 and 1990(seoul, 1991). The new formula is used to determine the design rainfall in this study.

Presently, a time of concentration for each drainage watershed to detention pond with pump station is 60 minutes or less on the whole. Inflow mass curve is made out on the basis of the 120 minutes empirically without hydrologic analysis on the rainfall duration. Generally, under the rainfall with same frequency, even though the absolute outflow volume of a short duration rainfall is smaller than that of longer one, outflow rate per unit time of a short duration is larger than that of long duration rainfall. In this case the short duration rainfall can be selected as design rainfall of sewer system. But, when the inundation control is mainly planned by the storage function of detention pond and drainage pump station, the long duration rainfall has a large possibility to determine the governing factor of facilities.

In this study, when the detention pond is planned using the ILLUDAS, 9 durations with 20~240 minutes are selected to compare with the critical duration of design rainfall. Table 2 shows the probable rainfall of 10 years return period in Seoul area.

**Table 2.** Probable Rainfall of 10 Years Return Period in Seoul

| Duration(min) | 20 | 30 | 60 | 90 | 120 | 150 | 180 | 210 | 240 |
|---|---|---|---|---|---|---|---|---|---|
| Rainfall(mm) | 38.4 | 48.3 | 70.6 | 87.7 | 102.2 | 115.0 | 126.6 | 137.3 | 147.2 |

Temporal distribution type within design rainfall is determined from the result of the Huff's quartile method in Seoul area(Korea Institute of Construction Technology, 1989).

## 4. Results

### 4.1 Storage Ratio and Critical Duration of Design Rainfall

The design rainfall of 10 years return period with duration 20~240 minutes is distributed with the Huff's quartile method. The outflow hydrograph is obtained using the ILLUDAS which was developed by Terstriep and Stall(1974), and the total runoff volume is also estimated. The critical duration of rainfall when the storage ratio in eq.(1) becomes the largest, were calculated based upon data from the network system and pump capacity of 18 selected detention ponds and based upon various durations of design rainfall. The storage volume was estimated from the storage equation. Fig. 2a~2d show the relationship between the storage ratios and durations using the Huff's 4 quartiles. The case of the Guro 3 detention pond is excluded since the pumping plant capacity is larger than the peak discharge.

The results indicate that the maximum storage ratios are occurred about 30 and 60 miniutes. The values of storage ratio of the Huff's second and third quartile are larger than those of the Huff's first and fourth qurtile.

Based on the above results with the concepts of the maximum storage ratio, it seems that the critical duration of design rainfall for detention pond in Seoul area is about 30 or 60 minutes. But, when the design is fulfilled under the concept of the maximum of required storage volume($V_r$), various durations can be determined according to the drainage watershed. So it is difficult to present a formal duration at the present time. The decision of duration should be determined independently with the characteristics of drainage watershed and design condition.

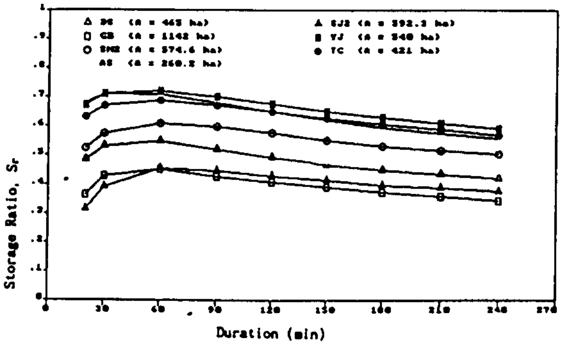


Fig. 2a-1 Relations between the Storage Ratios and the Durations using the Huff's First Quartile

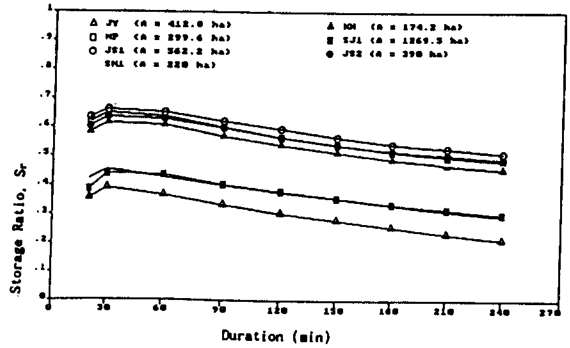


Fig. 2a-2 Relations between the Storage Ratios and the Durations using the Huff's First Quartile

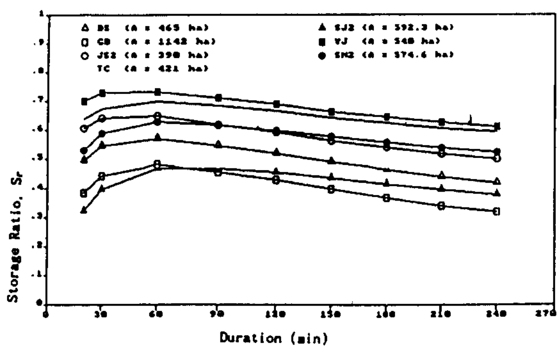


Fig. 2b-1 Relations between the Storage Ratios and the Durations using the Huff's Second Quartile

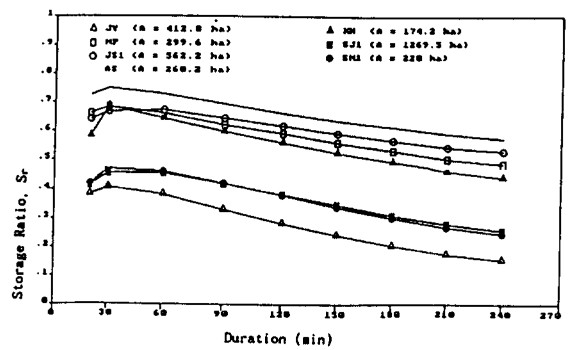


Fig. 2b-2 Relations between the Storage Ratios and the Durations using the Huff's Second Quartile

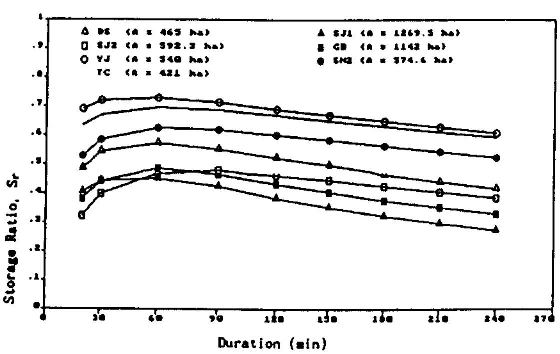


Fig. 2c-1 Relations between the Storage Ratios and the Durations using the Huff's Third Quartile

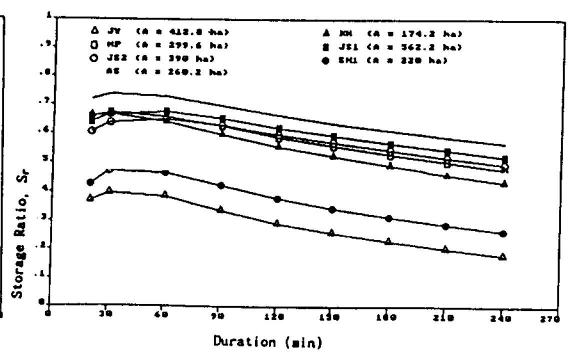


Fig. 2c-2 Relations between the Storage Ratios and the Durations using the Huff's Third Quartile

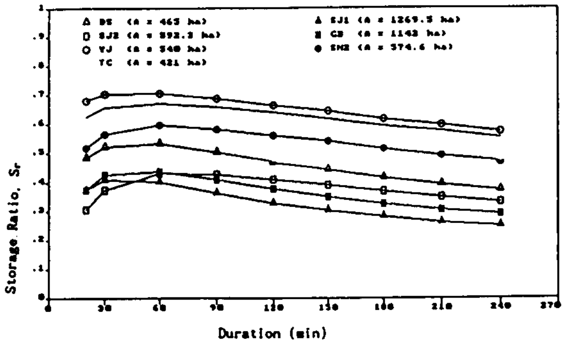


Fig. 2d-1 Relations between the Storage Ratios and the Durations using the Huff's Fourth Quartile

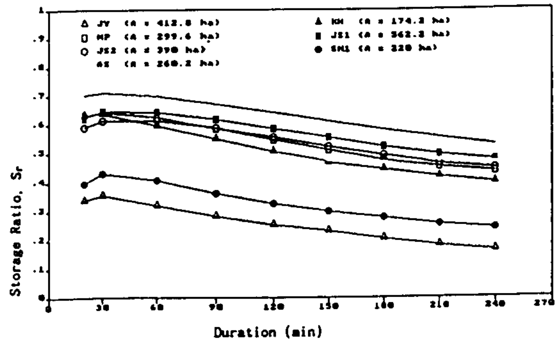


Fig. 2d-2 Relations between the Storage Ratios and the Durations using the Huff's Fourth Quartile

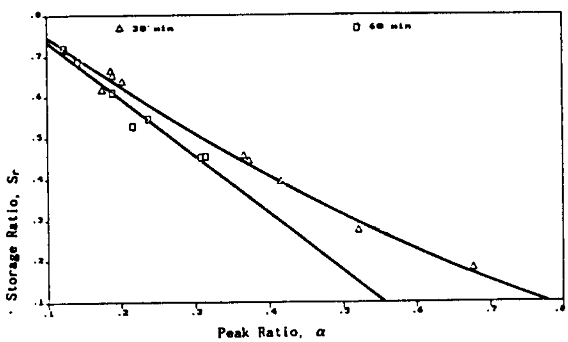


Fig. 3a Regression Line between the Peak In-out Flow Ratio and the Maximum Storage Ratio (Huff's First Quartile)

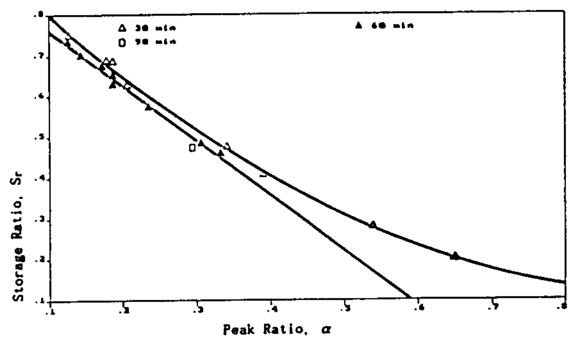


Fig. 3b Regression Line between the Peak In-out Flow Ratio and the Maximum Storage Ratio (Huff's Second Quartile)

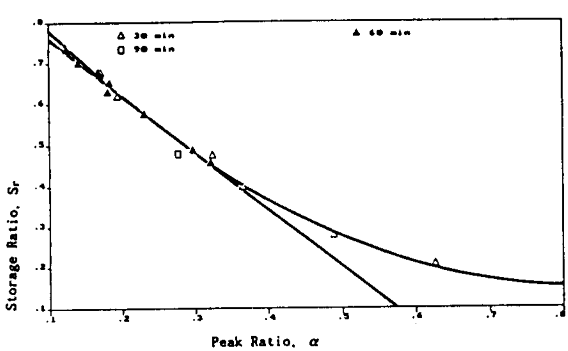


Fig. 3c Regression Line between the Peak In-out Flow Ratio and the Maximum Storage Ratio (Huff's Third Quartile)

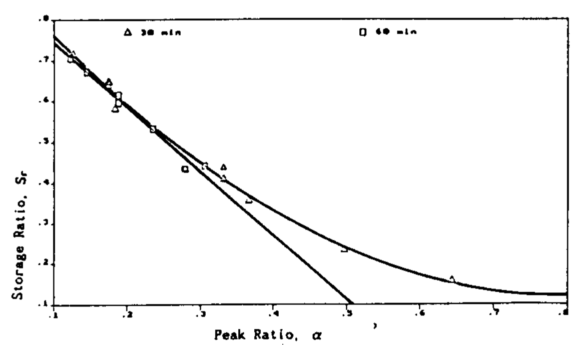


Fig. 3d Regression Line between the Peak In-out Flow Ratio and the Maximum Storage Ratio (Huff's Fourth Quartile)

### 4.2 Peak Storage Ratio and Peak In-out Flow Ratio

In order to design a detention pond with ease, the relationship between the maximum storage ratio, $S_r$, and the peak in-out flow ratio, $\alpha$, were analyzed. Fig. 3a~3d show the result of regression analysis between the peak in-out flow ratio and the maximum storage ratio using 18 watershed data based on the results in Fig. 2.

Table. 3 Regression Equations for the Maximum Storage Ratio and the Peak In-out Flow Ratio for Various Rainfall Durations

a) 30 min. Critical Duration

| Rainfall Type | Optimum Regression Equations | Variance |
|---|---|---|
| Huff's 1 | $Sr=0.8781-1.375\alpha+0.426\alpha^2$ | 0.00030 |
| Huff's 2 | $Sr=0.9665-1.776\alpha+0.919\alpha^2$ | 0.00008 |
| Huff's 3 | $Sr=0.9672-1.976\alpha+1.195\alpha^2$ | 0.00012 |
| Huff's 4 | $Sr=0.9541-2.071\alpha+1.282\alpha^2$ | 0.00027 |

b) 60 min. Critical Duration

| Rainfall Type | Optimum Regression Equations | Variance |
|---|---|---|
| Huff's 1 | $Sr=0.8757-1.390\alpha$ | 0.00041 |
| Huff's 2 | $Sr=0.8950-1.354\alpha$ | 0.00007 |
| Huff's 3 | $Sr=0.8968-1.387\alpha$ | 0.00008 |
| Huff's 4 | $Sr=0.8990-1.571\alpha$ | 0.00021 |

c) 30 and 60 min. Critical Duration

| Rainfall Type | Optimum Regression Equations | Variance |
|---|---|---|
| Huff's 1 | $Sr=0.7426-0.935\alpha+0.372\alpha^2$ | 0.00065 |
| Huff's 2 | $Sr=0.7837-1.151\alpha+0.530\alpha^2$ | 0.00027 |
| Huff's 3 | $Sr=0.7766-1.220\alpha+0.603\alpha^2$ | 0.00015 |
| Huff's 4 | $Sr=0.7589-1.286\alpha+0.658\alpha^2$ | 0.00028 |

The relationship shows that the second order equations are derived for the critical duration of 30 minutes, and the first order equations are derived for the critical duration of 60 minutes regardless of the Huff's rainfall types.

The optimum regression equations for each rainfall types are presented in Table 3. These equations can be used to estimate a size of detention pond with pump station at the planning and design stage. But in this case, it is necessary to assume that each of the 18 detention ponds was properly designed. In order to improve the reliability of these regression equations, it is necessary to calibrate those equations with more reliable data.

Comparing the peak in-out flow ratio for the critical duration of 30 minutes and 60 minutes with the same peak storage ratio, the peak in-out flow ratio of 60 minutes is smaller than that of 30 minutes regardless of the Huff's rainfall types in Fig. 3. This indicates that the storage function of detention pond is more important than the pumping function with longer rainfall duration. Thus, for the design of a detention pond with pump station in Seoul area, it is recommended that the critical duration can be used 60 minutes for detention pond where the function of the storage capacity is more important than that of pump capacity, otherwise it can be used 30 minutes.

## 5. Conclusion

This study presents a concept of critical duration of design rainfall for the design of detention pond with pump station.

According to the results of ILLUDAS based on design rainfalls and basic data of 18 detention pond with pump station in Seoul, it is shown that the critical duration which maximizes storage ratio are 30 and 60 minutes. The storage ratios of the Huff's second and third quartile are larger than those of the Huff's first and fourth quartile. In comparison of peak storage ratio with peak in-out flow ratio, for the rainfall with critical duration of 30 and 60 minutes, the peak in-out flow ratio of 60 minutes to the same peak storage ratio is smaller than that of 30 minutes regardless of temporal distribution of rainfall. This indicates that the storage function of detention pond is more important than the pumping function with longer rainfall duration. Therefore, it is recommended that the critical duration can be used 60 minutes for a detention pond where the function of the storage capacity is more important than that of pump capacity, otherwise it can be used 30 minutes.

The results of regression analysis show that the regression equations for critical duration of 30 minutes are the second order polynomials and those for critical duration of 60 minutes are the linear equations regardless of the Huff's rainfall types. It is expected that these simple empirical equations can be utilized to design a detention pond with pump station.

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