Peak Discharge Change by Different Design Rainfall on Small Watershed

Jun, Byong Ho*/Jang, Suk Hwan**

ABSTRACT / To design the minor structures in the small watersheds, it is required to calculate the peak discharge. For these calculations the simple peak flow prediction equations, the unit hydrograph method, the syntheic unit hydrograph methods or the runoff simulation models are adopted. To use these methods it is generally requried to know the amount and the distributions of the design rainfall; which are the uniform distribution, the trangular distribution, the trapezoidal distribution, or the Huff type distribution. In this study, the peak discharges are calculated by the different rainfall distributions and the results are compared.

1. Introduction

It is required to determine the peak discharge in designing hydraulic struture on small watershed. Peak discharge can be computed mathematically from surface runoff or channel runoff calculation by differenciating Saint Venent equation. But the full computation is so complicated that the simplified methods for examining rainfall – runoff relation are often recommended.

The rational method or simulation models based upon the Saint Venent equation is used practically to predict the peak discharge in many fields. Determing the design rainfall is an essential prerequisite for the predicton of the peak discharge. Design rainfall not only changes in accordance with the design period of the hydraulic structure but also varies in different location, which influences the peak discharge.

From this point of view, the objective of this study is to investigate how much the peak discharge is affected by the different design rainfall on small watershed. Through analyzing and checking the consequences by the different design rainfall distributions, it will be proved that other distributions as well as uniform distribution should be considered when desi-

* Professor, Dept. of Civil Eng., Korea Military Academy

** Research Assistant, Dept. of Civil Eng., Seoul City Univ.

gning the hydraulic structure on small watershed.

2. Several Distribution Types of Design Rainfall

Design return period, duration and rainfall distribution types are required to determine the peak discharge of some watershed. Because the rainfall is random event in fact, the design rainfall is decided from the long period of rainfall by using the probability concepts. The design return period is classified by the hydraulic structure type. At first using the rainfall duration decided from the watershed characteristic, the runoff hydrograph is simulated. After then several runoff hydrographs are also simulated by the slightly different durations. Among the peak discharges of these hydrographs the largest value is selected as the peak discharge of the watershed. Of course, the duration changes is available in simulation model but it is not available in the simple peak discharge prediction method such as the rational formula. Therefore in the rational method the first calculated duration is used to predict the peak discharge.

Random rainfall is generally assumed a few simplified types : uniform distribution, triangular distribution, trapezoidal distribution, Huff distribution and the specific distribution rainfall etc. These distributions are figured out in Fig.1[5] where i_o is the rainfall intensity of

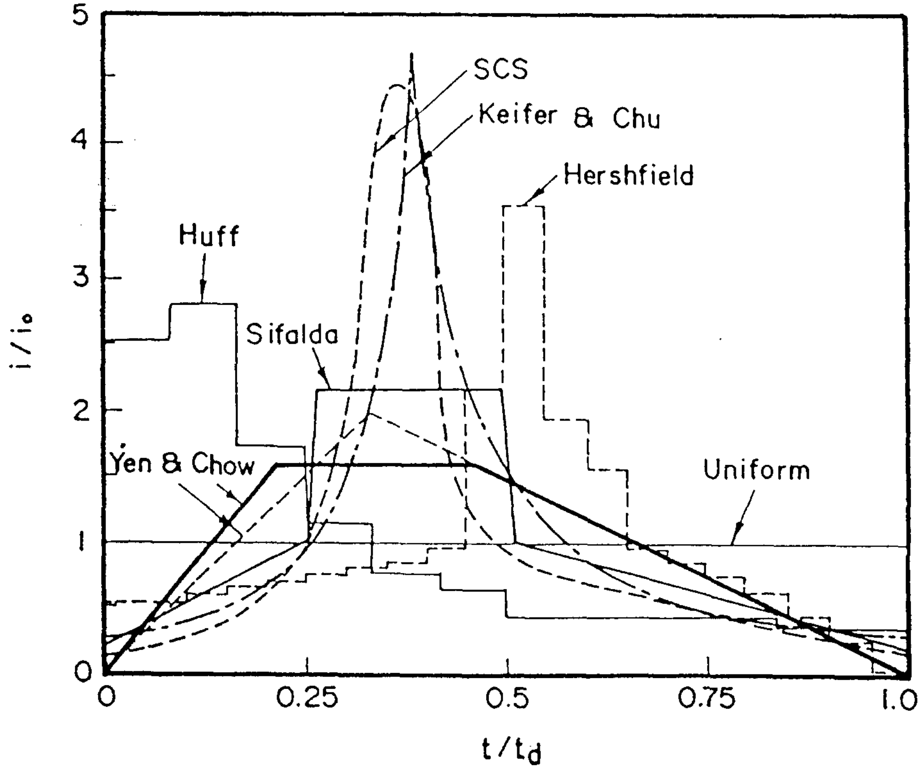

Fig. 1 Several Rainfall Distribution Types

the uniform rainfall distribution and td is the design rainfall duration.

Though the assumption on the uniform rainfall distribution is not realistic because the storm generally does not fall uniformly, the uniform rainfall distribution type is widely used because of its simplicity. The uniform rainfall distribution is tipically applied to the rational formula which is only intereted in the peak discharge and can controll the varying rainfall phenomenon with the runoff coefficient C. But the uniform distribution is not suitable for the watershed runoff simulation model. For this the similar rainfall distribution as the real case is considered.

The triangular or trapezoidal hyetograph method, which made by adopting the moment method to the long time storms occured in the watershed, is repeatedly used as the simplified types in the simulation models. In Korea, peak time ratio Ao of the triangular hyetograph is about 0.42 to 0.48 and a° of the trapezoidal hyetograph is about 0.17 to 0.23, bo is 0.25 to

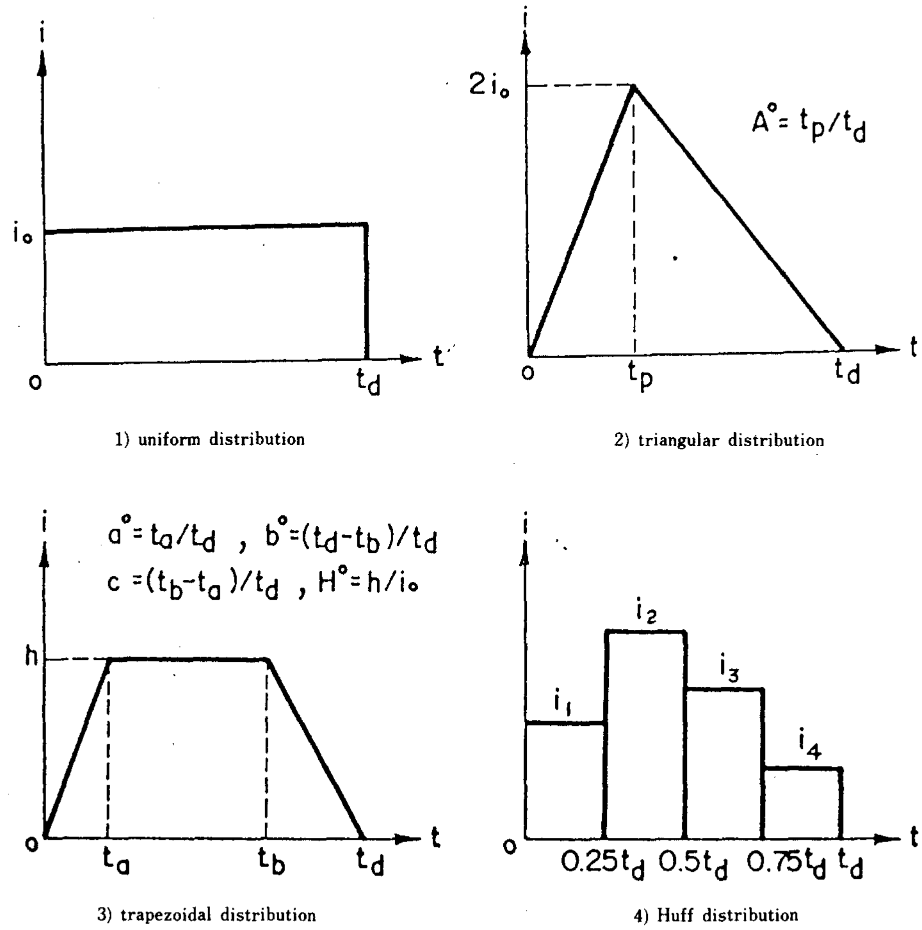

Fig.2 Simplified Design Rainfall Distribution Types

0.32, co is 0.49 to 0.57 and Ho is 1.31 to 1.41[4] (Fig. 2)

In Huff distribution hyetograph the rainfall duration is equally devided into 4 equal time bands (or quartiles) and the rainfall amount during each quartile is expressed with the percentage of the total rainfall which is calculated by the probability analysis. In Korea, heavy storm has 21.7% rainfall at 1st quartile, 38.1% at 2nd quartile, 27.5 at 3rd quartile and 12.7% at 4th quartile. Sometimes 10–band classification is adopted instead of 4–quartile classification.

Because the real storm events are random and complex, these simplified distribution types are generally used for the determination of the design peak discharge or the runoff analysis of any watershed.

3. Peak Discharge Change by Runoff Simulation Model

In this study, the peak discharge will be computed by the uniform rainfall distribution and the triangular rainfall distribution types and the difference between two distributions will be investigated and analyzed. The runoff data measured in fields are needed for more accu-

Table 1. Peak Discharge (m³/sec) computed by ILLUDAS Model

return period / distribution / watershed	5 yr		10 yr		20 yr	
	tri./uni.	ratio	tri./uni.	ratio	tri./uni.	ratio
W-1-1(16.7 ac, urbanization 70%)	2.59/2.53	1.16	3.17/2.72	1.17	3.71/3.19	1.16
W-1-2(16.7 ac, urbanization 50%)	1.98/1.71	1.16	2.43/2.10	1.16	2.85/2.48	1.15
W-1-3(16.7 ac, urbanization 30%)	1.29/1.10	1.17	1.58/1.36	1.16	1.87/1.61	1.16
Forth Street (31.5 ac)	4.38/3.55	1.23	5.38/4.37	1.23	6.33/5.17	1.22
Inchon Kieyang (9.13 ha)	1.22/1.05	1.16	1.55/1.36	1.14	1.84/1.63	1.13
Nonsan Donghung (44.6 ha)	6.39/5.66	1.13	7.59/6.72	1.13	10.19/8.93	1.14
Buchon Jakdong (59.1 ha)	6.97/5.64	1.24	9.01/7.53	1.20	10.81/9.21	1.17
Inchon Soongeui (124 ha)	29.23/23.57	1.24	35.13/28.59	1.23	40.85/33.62	1.22

* tri. : peak discharge by the triangular rainfall hyetograph.

* uni. : peak discharge by the uniform rainfall hyetograph.

rate and appropriate analysis but those data are not available yet in Korea. So, the values calculated by runoff simulation models are presented and compared in this chapter.

ILLUDAS (The Illinois Urban Drainage Area Simulator) model was selected to simulate the peak discharge and the watershed data in Jun's reports[1),2)] were selected.

In table 1, 70 percents urbanization at W−1 watershed means that about 70% is composed of impervious area. To test the effect of urbanization, the runoff hydrographs under 30% and 50% urbanization are also simulated. Table 1 shows that the peak discharge by the triangular rainfall distribution is 13% to 24% more than that of the uniform distribution.

Though these ratio (tri./uni. in Table 1) may change by the geological characteristic or the location of peak point in triangular hyetograph, the peak discharge by triangular distribution is higher than by uniform, which is known by hydrological understanding as well as results from Table 1.

From the results, we see that it is more profitable to select the specified design storm distribution type than the uniform rainfall distribution when appling to runoff simulation models.

4. Peak Discharge Change by Formula.

Weighted storm discharge formula[6)] which can check peak discharge change by rainfall distribution is used in this study.

It is reported that peak discharge on small watershed in Korea is highly correlated to 1.5 power of rainfall.[3)] Weighted storm discharge formula used in IHP(International Hydrological Project, 1990) study is presented herein and compared.

4.1 Peak discharge computation suggested in IHP report[3)]

1) Determination of the time of concentration tc (hr)

If the channel slope is less than 1/200 (Sc > 1/200), use Rizha Equation.

$$tc = 0.833\ L\ /\ (\ 60 \times S^{0.6}\ ) \tag{1}$$

where L is the channel length in Km, and S is the channel slope in dimensionless.

If the channel slope is larger than 1/200 (Sc < 1/200), use Kraven Equation.

$$tc = 0.444\ L\ /\ (\ 60 \times S^{0.515}\ ) \tag{2}$$

2) Determination of the weighted rainfall P1.5

(a) Decide one value of the rainfall intensity i (mm/hr), the total rainfall depth D (mm), or one–day maximum rainfall R_{24} (mm) for the rainfall duration same as the time of concentration.

(b) If the total rainfall or one–day maximum rainfall is decided, calculate the rainfall intensity (mm/hr).

(c) $P_{1.5}$ is calculated as follows if design rainfall is general distribution type.

$$P_{1.5} = \int i\,(t)^{1.5}\,dt \tag{3}$$

(d) Simplified formula can be used if design rainfall is uniform distribution.

$$P_{1.5} = (i^{1.5}) \times tc \tag{4}$$

3) Determination of flood peak discharge Qp (m^3/sec)

$$Qp = 0.0453\ A^{0.996}\ P_{1.5}^{0.86}\ L^{0.04}\ S^{0.15} \times AF \times SF \tag{5}$$

where A is a basin area (km^2), AF is a Area Factor and SF is a Slope Factor. These factors are presented in Table and Table 3.

Table 2. Area Factor (AF)

range of area(km^2)	AF	range of area(km^2)	AF
$A \leq 3$	1.50	$10 < A \leq 30$	1.00
$3 < A \leq 5$	1.35	$30 < A \leq 55$	0.90
$5 < A \leq 10$	1.10	–	—

Table 3. Channel Slope Factor (SF)

range of channel slope	SF	range of channel slope	SF
$S \leq 0.005$	1.50	$0.05 < S$	1.50
$0.005 < S \leq 0.05$	1.20	–	—

4.2 Peak discharge change by design rainfall distribution.

When equation (5) is used for calculating the peak discharge, the channel length L, the channel slope S, the area factor AF, and the channel slope factor SF have same values for a watershed. So it is easily known that the peak discharge is changed by the equation for the weighted rainfall ($R = P_{1.5}^{0.86}$ in this case).

Let's see how the peak discharge is changed by the uiform, the triangular, the trapezoidal and Huff distribution.

1) Uniform distribution design rainfall

$$P_{1.5} = \int_0^{td} i(t)^{1.5}\, dt = i_o^{1.5}\, t_d \quad (6)$$

$$R_{uniform} = P_{1.5}^{0.86} = (ic^{1.5}\, t_d)^{0.86} \quad (7)$$

2) Triangular distribution design rainfall

$$P_{1.5} = \int_0^{tp} (2io\ t\ /\ tp\ )^{1.5}\, dt + \int_{tp}^{td} (2io\ (td - t)\ /\ (td - tp))^{1.5}\, dt$$

$$= 1.131\ i_o^{1.5} t_d \quad (8)$$

$$Rtriangular = 1.112\ Runiform \quad (9)$$

3) Trapezoidal distribution design rainfall

$$P_{1.5} = \int_0^{ta} (4io\ t\ /\ 3ta)^{1.5}\, dt + \int_{ta}^{tb} (4io\ /\ 3)^{1.5}\, dt$$

$$+ \int_{tb}^{td} (4io\ (td - t\ )\ /\ 3(td - tb))^{1.5}\, dt$$

$$= (4io/3)^{1.5} (-3ta/5 + 3tb/5 + 2td/5) \quad (10)$$

Widely used in Korea, if a^o=0.2, b^o=0.3 and c^o=0.5 are substituted in equation (10).

$$P_{1.5} = 1.078\ i_o^{1.5}\ t_d \quad (11)$$

$$Rtrapezoidal = 1.067\ Runiform \quad (12)$$

d) Huff distribution design rainfall

$$P_{1.5} = \int_0^{0.25td} i_1^{1.5}\, dt + \int_{0.25td}^{0.5td} i_2^{1.5}\, dt$$

$$+ \int_{0.5td}^{0.75td} i_3^{1.5}\, dt + \int_{0.75td}^{td} i_4^{1.5}\, dt$$

$$= (i_1^{1.5} + i_2^{1.5} + i_3^{1.5} + i_4^{1.5})\ t_d\ /\ 4 \quad (13)$$

For typical heavy storm events in Korea, If i_1 = 21.7 % (i_1 / i_o =0.868), i_2 =38.1 % (i_2 / i_1 =1.524), i_3 = 27.5 % (i_3 /i_2 =1.10) and i_4 = 12.7 % (i_4 / i_3 = 0.508) are substituted,

$$P_{1.5} = 1.051\ i_o^{1.5}\ td \quad (14)$$

$$R_{Huff} = 1.044\ R_{uniform} \tag{15}$$

4.3 Analysis

In the previous section, the simplified peak discharge formula shows that the peak discharge by the traingular rainfall distribution is 11.2%, the trapezoidal rainfall distribution is 6.7% and Huff distribution is 4.4% higher than that by the uniform rainfall distribution.

5. Conclusion

The peak discharge change by different design rainfall distributions was examined through the runoff simulation model, ILLUDAS, and the simplified peak discharge formula. The design rainfall assumed as triangular, trapezoidal or Huff rainfall distribution – though they are also simplified – instead of the actual rainfall on watershed, is more reasonable than the uniform rainfall distribution and the peak discharge by other rainfall distributions was higher from 5% to 21% than that by the uniform rainfall distribution.

Though this difference is not always proper because the peak discharge may be influenced by the watershed geological characteristic or the rainfall duration, it is proven that the prudent selection of the rainfall distribution type should be required for the design of hydraulic structures.

References

1. Jun, Byong Ho (1988) Increasing Effect of Flood Damage by Urbanization and Flood Control Device, Korean Institute of Construction Technology.
2. Jun, Byong Ho (1989) Urban Runoff Analysis and Simulation Modeling, Korean Institute of Construction Technology.
3. Jun, Byong Ho (1990) Small Watershed Peak Flow Prediction, International Hydrological Program Final Report, Ministry of Construction, Korea.
4. Korean Institute of Construction Technology (1988) Analysis of Temporal Variations for Determining the Local Design Storms.
5. Akan, A.O. and Yen B. C. (1984) Effect of Time Distribution of Rain fall on Overland Ruoff, Analysis and Design of Stormwater Systems, Proc. of the Third IAHR /IAWPRC Conference on Urban Storm Drainage, PP. 193–202 Goteborg, Sweden.
6. Bren, L, J., Farrell, R. W., and Leitch, C. J. (1987) Use of Weighted Integral Variables to Determine the Relation between Rainfall Intensity and Storm Flow and Reak Flow Generation, Water Resources Research, Vol.23, NO.7. PP. 1320–1326.