Research Paper

Calculation Methods of Design Flood and Comparisons in Small Watersheds

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Abstract: It is very important to design and apply the design flood in the design of the watercourse. The corresponding numerical values determined have a decisive influence on the design of the river way. The determination of the numerical value is related to the safety of bridges, railways and other facilities on the river and the cross-strait People's life. The calculation methods of design flood are different in different size basins. This paper will summarize the calculation methods of design floods and take the Laofenghe River Regulation Project as an example to analyze the calculation and application of design flood in small watershed.

Key words: Catchment; Design flood; Design storm

1 Design flood concept

The size of the flood and its timing are random, so flood control can only reach a certain limit, expecting safety under no more than a specific flood condition, and failing to guarantee safety under any extreme flood conditions. Flood control limits are generally relative to the frequency or recurrence of a flood, ie defensive floods of a specified frequency are called flood control standards. Due to the probabilistic significance of flooding, the flood control design of the project is precisely to reduce the risk of flood losses. Floods of different frequencies vary in size. Flood control measures should be compatible with flood control standards. Therefore, the primary issue in engineering measures and non-engineering measures is to estimate the flood rate at a specified frequency.

2 Design flood calculation

2.1 Calculation of the design flood area components are

The design flood area group[1] into the common calculation methods are the following

(1) Regional composition law

The regional composition method is a commonly used and convenient method of determining the design flood after the design section is affected by the regulation of upstream reservoirs or other projects. When designing natural flooding with design frequency in the section, by formulating a number of composition schemes mainly involving different areas of incoming water, the peak and the amount of flooding in the sections where the upstream works are located and without engineering control are calculated for each component scheme, Section of the same time period of the flood process line, the project section of the flood process line through the flood calculation of the discharge flood process line, and then with the interval flood process line combination (if necessary, flood calculation should be carried out), to determine the design section Flood process line, from which to select may occur to meet the design requirements of the results.

(2) Frequency combination method[2]

The frequency combination method takes the flood volume of each section above the design section as the combined variable. Through the frequency combination calculation and the flood regulation calculation of the upstream reservoir, the flood frequency curve and design value of the downstream design section affected by the upstream reservoir regulation and storage can be deduced directly.

(3) Random simulation method

Based on the observation data of the flood process, the random variation characteristics are analyzed, and then a stochastic model is established.

In addition to the above three methods, flood control embankments (walls) or flood control plans along river structures are required to design flood levels at specified locations or to design surface waterlines along rivers. For sections with sufficient water level data, under the condition of basically meeting the water level data, the design flood level meeting the specified frequency can be deduced through the way of frequency analysis of water level. Most embankment projects need to figure out the water surface curve in order to determine the embankment elevation along the river.

Under normal circumstances, the water surface curve used in the form of the basic equation[3],

$$Z_1 + \frac{\alpha_1 V_1^2}{2g} = Z_2 + \frac{\alpha_2 V_2^2}{2g} + h_f + h_j$$

Where, Z_1, Z_2 are upper and lower section of the water level (m);

V_1, V_2 is upper and lower section velocity (m/s);

a_1, a_2 is upstream and downstream section kinetic correction factor;

h_f is the head loss between the downstream section (m);

h_j is local head loss between upstream and downstream sections (m).

2.2Design flood peak, flood and flood process line calculation

Depending on the nature of the project and the hydrological data, different calculation methods are used. In general, take a variety of ways to calculate, comprehensive analysis and demonstration and rational use of the results. Common calculation methods.[3]

(1) Direct method

That is based on the flow data to infer the design flood. When there is a long flood flow observation data at or near the project site and there are several historical flood data, the maximum flood peak flow of the current year and the maximum flood flow of different periods (such as 1 day, 3 days and 7 days, etc.) Compose the maximum peak flow and the maximum flood volume at different time periods, and then perform frequency analysis to determine the design flood peak and flood time of floodwater corresponding to the design criteria. Finally, select the typical flood process line, according to the calculated design flood peak and the design floods of each period, amplify the typical flood process line at the same frequency or at same magnification as the design flood process line.

(2) Indirect method

The design flood is deduced from the rainfall data. When the series of flood discharge data at the project site and its vicinity are too short to analyze the frequency directly with the flood flow data but have a long series of rainfall data in the basin, the design torrential rain can be obtained first and then, through runoff and confluence calculation, Determine the design flood peak, flood volume and flood process line. The law assumes that heavy rains in a given recurrence period produce floods of the same recurrence period.

(3) District Comprehensive Law

If there is a shortage of flood flow and rainfall data in the project site, the flood flow, rainfall and historical flood data in the data basins can be analyzed and synthesized in the areas with similar natural and geographical conditions, and the flood peak flow in various recurring periods can be drawn, Rainfall, runoff and confluence parameters, or establish empirical relationships between these parameters and the natural geographical features of the basin (such as basin area and river ratio) and then calculate the design flood at the design site using these charts and empirical relationships.

2.3Deduced from storm data

According to the situation of Laofeng River, in the project of river course control, the calculation method of design flood in small watershed is adopted (design flood is deduced from rainstorm data[3-5].

2.3.1 Rainstorm data to design floods

2.3.1.1Design storm

In general, the design storm should be replaced by the average surface storm above the river basin. If the area of the catchment above the project is small, heavy rain at the center can be used instead of heavy rainfall in the river basin.

1) Direct design surface rainstorm

Directly select the maximum surface area monthly rainfall for the specified statistical period and calculate the frequency of the surface storm. Steps are:

(1) According to the data for a fixed period of time, the maximum annual rainfall:

(2) The handling of extra-heavy floods with heavy rain:

(3) Using P-Ⅲ type curve fitting line, find the optimal statistical parameters.

2) Design point storm

When the river basin data is not enough to directly calculate the point rainstorm, it is necessary to deduce the rainfall at the center of the river basin. If there is rainfall at or near the center of the basin. The series of observation data are longer and can be directly calculated by using the frequency calculation method. In fact, rarely in this case, the general is to find the design of the station storm points, draw the design point storm contour map. Interpolation out of the design center of the basin heavy rain. When there is a shortage of storm data in the river basin. According to the reference hydrological handbook or storm water design handbook in the regional comprehensive statistical parameters. The frequency of heavy rain is calculated the same as before.

3) The use of point rain storm surface storm

There are two kinds of relations between point rain and surface rain:

fixed-point fixed-face relationship

$$\alpha_0 = \chi_f / \chi_0$$

Select a number of heavy rain, find the fixed point and the fixed surface heavy rainfall, find a number of values, the average as the point reduction coefficient.

(2) Moving point dynamic relationship

The relation between fixed point and fixed point is replaced by the relationship of heavy rain center and surface area. Movable points around the dynamic relationship between the use of methods and instructions can refer to the local hydrological manual or storm design manual.

2.3.1.2 Rainfall runoff calculation

(1) Rainfall Runoff Correlation Law (including correlation curves)

$R = f(P, P_a, T)$

Where, R - Runoff depth (mm);

P is rainfall (mm);

P_a is pre-impact rainfall (mm);

T is rainfall duration (h)

(2) Net surface rain method

The surface runoff process can be distinguished by the method of subtracting the distribution of underground runoff from the runoff process. The distribution of underground runoff time distribution can be used in the form of the average distribution.

2.3.1.3 Rainfall convergence calculation

(1) Experience unit line

The independent flood peak data with uniform rainfall, short duration and strong rainfall are selected. The unit runoff is derived from the ground runoff process after the removal of underground runoff and the corresponding net rain process. Unit line period should adopt the rise of the unit line or peak hysteresis of about 1/3. Due to the analysis of the unit line often with the spatial and temporal distribution of rain there is a considerable difference. So use should pay attention to choose to meet the design of rain-type unit line.

(2) Instantaneous unit line

$$U(0, t) = \frac{1}{k\Gamma(n)}(t/k)^{n-1}e^{-t/k}$$

Where, U (0,t) - Instantaneous unit line (m^3/s);

Γ is the gamma function;

n, k are parameters.

In the application, the need to establish nk or $m_1(nk)$ strong relationship with the rain.

(3) Reasoning formula method

$$Q_m = 0.278\psi iF = 0.278\psi \frac{s}{T^n} F$$

Where, Q is the maximum flow (m^3/s);

T is the convergence time (h);

n is the rainstorm index;

s is the rainstorm force (mm/h);

F is the catchment area (km^2);

ψ is the peak runoff coefficient;

i is the maximum average storm intensity (mm/h).

Hydrologic drill is not available in the vast majority of small watersheds. There is a lack of hydrological data and no rainfall data. Therefore, the calculation of design flood in small watershed is usually calculated without information. Small watersheds with small catchment areas tend to have a single physical and geographical condition. Proper simplification is permitted when calculating methods. A small number of small watershed, widely distributed. Therefore, when the calculation method is formulated, the accuracy can be guaranteed while simplifying. When designing small-scale water conservancy and power engineering, the capacity of flood control is small, and the general project scale is mainly controlled by the flood peak flow. Therefore, the accuracy of designing the flood peak is higher than that of the flood course[6].

3 Case Study of Laofeng River Small Watershed Design Flood Comparison

Laofeng River originates from Xinfeng Henan Dahongmen Gate and flows southeast through Qingyundian, Changziying, Caiyuzhen and other places. It flows out of the boundary of Beijing in Yingfengheying Village and enters the land of Hebei and Tianjin, Dianzhen office into the Beijing realm, and finally Yongle Economic Development Zone east out of Beijing. Laofeng River was originally a drainage channel that undertook Daxing Metro's stormwater drainage task. Later, due to the renovation of the new LaoFeng River and the diversion of rain and flood in a large new town, the LaoFeng River gradually became a regional flood control and drainage channel. The main flood control area was Qingyundian

Town, The eldest son of the town, Cai Yuzhen and other places, the status of the river width of about 10-61m, deep river about 2-1.5m. Along the river there are dry river, Chahe, Guogou, Bai Fenghe, fifteen branch canal ditches import, the total watershed about 310 km^2.

According to the Planning of River Management Project of Yongledian Economic and Technological Development Zone compiled by Beijing Urban Planning Design and Research Institute in 2011, the management standard of Laofeng River in Yongledian Economic and Technological Development Zone is designed to flood once in 20 years and to flood in 50 years Nuclear, 20-year flood level is basically not flooded Planning the main storm water pipeline exit top. Ordinary bridge beam elevation should be higher than 50 years once the planning flood level 0.5m above. Where the planned width of 64m river roughness rate of 0.025, river longitudinal slope of 0.00045, the slope coefficient of 4.0, the river depth of about 4.5m, the planned channel width of 100m. According to the related information, this section of river is medium and small river basin.

In this section of the river design flood calculation, the instantaneous unit line method, reasoning formula method, and empirical formula method.

3.1 Nash instantaneous unit line method basic principle

The vast majority of Nash's instantaneous unit-line method in small watersheds[6] is Nash's 1957 hypothesis that the basin's regulation of surface water purification can be modeled by the regulation of n linear reservoirs in series Derived out. Based on the empirical model of hydrological convergence based on the assumption of a series of linear reservoirs, the key to the application of this model is to determine n and K confluence parameters.

The instantaneous unit line mathematical equation is:

$$U(0,t)=\frac{1}{k\Gamma(n)}(t/k)^{n-1}e^{-t/k}$$

Where, U (0, t) is the instantaneous unit line;

t is the time;

n, k is the Nash model convergence parameter;

Γ (n) is a gamma function.

This time period unit process line is:

$$u(\Delta t, t) = S(t) - S(t - \Delta t)$$

$S(t)$ the curve is usually called the *S* curve, its mathematical form is:

$$S(t) = \int_0^t u(0,t)dt = \frac{1}{\Gamma(n)} \int_0^{\frac{t}{k}} (\frac{t}{k})^{n-1} e^{-\frac{t}{k}} d(\frac{t}{k})$$

note: In the actual work, the curve $S(t)$ can be obtained from the look-up table

Thus obtained by the instantaneous unit line conversion time unit line formula:

$$q(\Delta t, t) = \frac{10F}{\Delta t} u(\Delta t, t)$$

The confluence outlet section flow process is:

$$Q(n) = \sum_{i=0}^{M} \frac{h_i F}{\Delta t} q(\Delta t, M - i)$$

n is a parameter that comprehensively reflects the regulation and storage capacity of the river basin. The value of n in a river basin is relatively stable. Generally, *n* = 2 is taken in the Beijing Plain. *K* is the parameter reflecting the confluence time and is calculated by the formula *m = nK*. The value of *m* is determined by the catchment area and the impervious area ratio.

3.2 Reasoning formula method

Inferential formula method[7] is one of the methods used to infer the maximum flood of design flood indirectly according to storm data,

$$Q_m = 0.278\psi \frac{s}{T^n} F = 0.278(a - \mu)A$$

Where, *Q* is the peak flow (m^3/s);

T is convergence time (h);

n is rainstorm index;

s is storm rainfall mm/h;

F is catchment area km2;

ψ is the peak runoff coefficient;

A is the basin area km2;

a is the storm intensity mm/h;

μ is the loss strength mm/h;

When $t_c \ge T$, full confluence, $Q_m = 0.278(S_P / T - \mu)A$

When $t_c \le T$, part of the confluence, $Q_m = 0.278[(S_P t_C - \mu t_c)/T]A$

According to the average μ penetration rate; the design for 1h rainstorm; *n* is the rainstorm attenuation index; *m* is the empirical convergence coefficient. According to 24h runoff generated deep rainfall, using the formula:

$$\mu = (1-n)n^{\frac{n}{1-n}}\left(\frac{S_P}{h_{24}^n}\right)^{\frac{1}{1-n}}$$

Another type of reasoning formula method is to calculate the peak flow by combining the law of rainfall runoff in the region with the computational method of inference formula of Water Science Institute. This article is referred to as improved reasoning formula method. The principle is to get the net rain process according to the distribution of time history of rainfall and the law of rainfall loss, and to combine the net rain process with the convergence calculation method of Inland Waterway Reasoning Formula Method to get the design peak flow and confluence time.

Note: The above calculation methods such as heavy rainfall design can refer to "Beijing Hydrological Handbook - Heavy Rain Atlas"

According to the characteristics of storm flood peak in small watersheds, the maximum 24-hour rainfall should be calculated according to the corresponding design standards. In addition, according to the calculation method requirements for design floods, other diachronic design rainfall and storm time distribution should be investigated. , According to 24h design rainfall, first calculate the heavy rain index of decline *n*, according to the formula backdated short-duration design rainfall, and then calculate the flood peak flow formula.

This method is not recommended because the calculation steps in the original manual need look up chart calculation, tedious steps and low calculation efficiency.

3.3 Empirical formula method

The empirical formula method[8] directly establishes the empirical correlation equation between the main influencing factors and the peak flow based on the data of storm flood measured and surveyed in a small river basin in a region, namely, empirical formula of flood peak flow area. Applying it to a region with no data to deduce a design flood peak is the regional empirical formula approach. Empirical formula does not focus on the principle of catchment and production in the basin, but only makes statistical comparisons of the data in the area, so it is very regional. Generally speaking, the formula for which region data should be applied only applies to which region. If we borrow the empirical formula from other regions in the calculation of this basin, we must be cautious and must use certain data from Beijing Municipality to conduct the test.

Regional empirical formula is relatively simple, easy to use, if the formula can take into account the factors that affect the peak, and the formula developed using reliable and representative information, the calculated results can have a very good accuracy. Many provincial hydrological manuals contain their own formulas and how to use them.

(1)Regional empirical formula taking basin area as parameter

The simplest empirical formula holds that basin area is the major factor affecting peak flow, while other factors are expressed in terms of some comprehensive parameters in the form of,

$$Q_{mp} = C_p F^n$$

Where, Q_{mp} the design frequency for the peak *p* flow (m^3/s);

F is the catchment area (km[2]);

n, C_p are the empirical index and coefficient.

The above formula is easy to use. The conditions for producing the data required by this formula are higher, because only the partition is relatively small, and only take into account the fact that other factors besides F in the partition are more consistent. However, small zoning, it is difficult to ensure that there will be more long-range hydrological station data. So, when the data is not enough, we should consider the multi-parameter region empirical formula.

(2) Multi-parameter regional empirical formula containing rainfall factors

Multi-parameter empirical formula is based on the characteristics of the catchment and the design of rainstorm and other major influencing factors as parameters. It believes flood peak flow is mainly affected by factors such as catchment area, basin shape and design torrential rain, and other factors can be expressed by some comprehensive parameters. The common form of the formula is

$$Q_{mp} = CH_{24p}F^{n}$$
$$Q_{mp} = Ch_{24p}^{\alpha}J^{\beta}f^{\gamma}F^{n}$$

Where, $H_{24p}h_{24p}$ are the maximum annual 24 h rainfall and net rainfall (mm) at frequency *p* respectively;

J is the average slope of river mainstream;

f is the basin shape coefficient ($f = F / L^2$);

C is the empirical coefficient;

α, β, γ, n for the empirical index.

The instantaneous unit-line method is a method of calculation of river design flood without measured data recommended by "Beijing Hydrological Handbook". It is widely used in the calculation and analysis of flood-process flow and design flood peak without measured data, and is also used in calculation of river convergence in urban built-up area A commonly used method, and obtained the measured data to verify its rationality. Nash instantaneous unit line method considering urban area under the surface changes that the impervious area ratio changes and the level of urban development, rainfall-runoff relationship is more realistic and the calculation results are more accurate to overcome the drainage modulus method and the empirical formula method does not take into account the rain Type distribution and the determination of the empirical parameters of the proposed combination of the actual promotion of the use of various regions.

4 Summary

Design floods, including design floods under normal operation of hydraulic structures and floods under very operational conditions, are one of the most important design criteria for ensuring project safety.

Flood control standards in flood control design, is based on the size of the project, the consequences of the accident, the importance of the object of protection and social, economic and other integrated factors, formulated by the state unified norms. Many countries make comprehensive and economic comparisons through investment in engineering measures and flood control benefits, combined with risk analysis to select flood control standards. China promulgated in January 1995 the implementation of the national standard GB 50201-94 "flood control standards" for all sectors of national economy for different targets of protection for flood control made detailed provisions. Flood control targets for protection against floods or floods said the return period.

Design floods are the primary basis for estimating flood control capacity of hydraulic structures and flood control benefits of various engineering and non-engineering measures. They are determined according to flood control standards prescribed by the state and hydrological and meteorological data calculated and analyzed by analysis. The design flood calculation includes the eigenvalue of the largest flood of the year, the design flood process line, the design flood, the storage flood and the design flood area composition. According to the design requirements, one or all of them can be calculated. The design flood analysis and calculation method, according to the different data conditions, is divided into two categories based on the calculation of flow data and rainfall data. The design floods in some rivers are based on the floods that actually occurred in a particular year.

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