A BRIEFLY INTRODUCTION ON FORECAST METHOD OF ICE SLUSH AT THE HEILONG AND SONGHUA RIVERS

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ABSTRACT
In this paper briefly introduces the forecast of ice slush at Heilong and Songhua rivers, the estimate on thickness of ice and ice cover strength, the forecast of freeze up and break up in the river, and the ice dam flood prediction are described also. In the ice slush character date forecasting process, critical index critical date being used, so that the date of which represent the temperature rising or dropping stably on the point of zero degree can be defined. For ice flood forecasting, rainfall runoff in thaw and snow melted phase calculating theory and method are used. In the method all frozen earth hydrology factors are fully considered. For ice dam among those high fall rate mountainous rivers, the paper gives new concept and integrated calculating method to explain the forming mechanism of the ice dams. All those get satisfied result in the ice dam flood analysis for Heilong and Songhua Rivers. In the calculating for the ice thickness and ice cover strength the lasting period factor method being introduced, this improve the forecasting of long term and make it possible to forecast for those data lacking areas.

KEY WORDS: Ice flush, Freeze up, Break up, Ice dam.

1. INTRODUCTION
Heilongjiang River and Songhua River (ALL name the Heilong River) are located in a cold-temperature zone of the northern part of China. The mean annual air temperature in this area is between 2-5°C. For more than five months the daily air temperature is below zero. The extreme low air temperature in China, -52.3°C, has happed in the Mohe City. Due to it is very cold and long lasting, all rivers, lakes and reservoirs are frozen. In the upper reach, the average date of freeze-up is November 11; the average annual period of freeze-up is 172 days. The mean value of maximum ice thickness is 1.08m, and the maximum ice thickness is 1.2-1.5m. The winter in this area is very cold and long lasting. The rivers have obviously ice slush, freeze up and break up in autumn and spring, and there are ice dams sometimes. The probability of ice dam in
upper reaches of Heilongjiang River is over 30%. In some section of the river ice dam and ice slush happened almost every year. The most water head is in 5-9 meters high, the maximum height can reach 13.50 meters. The exist time of the ice dam usually last 1-2 days, or 3-4days, in some section could even last 15 days. There are seldom hydraulic projects, which could control river flow in upper reach of Heilongjiang River, so ice dam and ice slush became one of the threats to the life and material of local people.

In this paper authors focus on the forecasting of autumn ice flush and freeze up, ice thickness and ice cover strength, break up, ice dam and ice slush. In the ice slush character date forecasting process, critical index date being used ,so that the date of which represent the temperature rising or dropping stably on the point of zero degree can be defined.

For ice flood forecasting, rainfall runoff in thaw and snow melted phase calculating theory and method are used. In the method all frozen earth hydrology factors are fully considered. For ice dam among those high fall rate mountainous rivers, the paper gives new concept and integrated calculating method to explain the forming mechanism of the ice dams. All those get satisfied result in the ice dam flood analysis for Heilong River and Nenjiang River. In the calculating for the ice thickness and ice cover strength the lasting period factor method being introduced, this improve the forecasting of long term and make it possible to forecast for those data lacking areas.

2. ICE THICKNESS AND ICE COVER STRENGTH PREDICTION
2.1 ICE THICKNESS ESTIMATING

During freeze up period, the increase of ice cover thickness is dominated by the heat exchange between water and air. The heat exchange depends on the air temperature, as well as the ice cover thickness and snow thickness over the ice cover. So the ice cover thickness is closely related to the local air temperature and the function of the accumulated value of daily air temperature blow zero. It is also affected by flow discharge, average flow depth and other factors. In the upper reaches of Heilongjiang River, the mean value of maximum ice thickness is 1.08m, and the maximum ice cover thickness is 1.3m. In the some reach even the ice thickness is 1.5m. In past years, the experimental expression which related to the accumulated negative warm was used in China widely, the expression as following:

\[
h = a\sum T^n
\]

(2.1)

Here: h-ice thickness, T-negative accumulated temperature, a , n are coefficient and index. In China, the coefficient value of ice thickness is 1.9-3.1. When consider the effect of initial stage ice thickness, lasted time of freeze up and snow, we can use the forecast curve of the relationship between ice thickness, the lasted time of initial freeze up and the snow depth on the ice cover. It is as following Fig.1. The value of these indexes is related to individual rivers, so they cannot be applicable universally.
Recently, to considering the consistent property of ice thickness increment with accumulated negative warm and last period rising, the lasting period factor method is applied to forecast ice thickness in recent years. As using last period to substitute negative warm (temperature) in the derivate relationship, the ice thickness is as follows:

\[ h = A t^a \]  

(2.2)

Here: \( h \) - ice thickness (m); \( t \) - lasted time since the freeze up date; \( a \) is an Index, its value is 0.60; \( A \) is coefficient. \( A \) varies with ice thickness and it related to the ice thickness of 10 days after freeze up date.

### 2.2 THE ICE COVER STRENGTH

The ice cover strength varies with several factors such as solar radiation, transmitting quantity of heat in advection, temperature, snow cover above the ice, heat radiation of riverbed etc.. But in practice heat balance method is rarely to apply for the strength of ice cover calculating. Usually experimental method is used both in the home and abroad, though the result is not to reflect the reality well. For example, in Russia Far East area such experimental relationship is recommended for the Wusulijiang River:

\[ \Phi = (1 - \sqrt{n/0.36h_0})^2 \]  

(2.3)

Here: \( \Phi \) - stress strength of ice; \( h_0 \) – initial ice thickness; \( n \) – calculated days for a critical strength of ice cover. Because of low temperature the ice cover in Heilong River melting and strength decreasing are slowly. After analyzing the relationship of positive accumulative warm with ice thickness decrement \( \Delta h \), the formula of ice thickness is given:

\[ h_t = h_0[1-(t_n/T)^{1.5}]^2 \]  

Here: \( h_t, h_0 \) are the ice thickness at date \( t \) and original ice thickness; \( t_n \) and \( T \) are the lasted time for \( h_t \) calculating and total last period of ice strength completely losing.

For coefficient of ice strength calculating, such formula being used for the attenuating process calculating:

\[ \Phi_t = \Phi_0 (1 - vt/T)^2 \]  

(2.5)
Here: \( \Phi_t, \Phi_o \) are the ice strength at time \( t \) and original; \( t_n \) and \( T \) as the same meaning as the formula (2.4).

In cold area the temperature of air and water is much low, even at the break up period the air temperature can be lower than 0°C, and this makes that ice cover melts slowly. In the middle of March as temperature rises, ice thickness is decreased, until middle and last ten-day of April the break up ends, after 30-40 days the ice thickness is decreased to about 0.3 meter. However the ice thickness at the day of break up is also about 1 meter, so it is suitable to apply above formula to calculating.

3. FORECAST OF THE ICE SLUSH DURING FREEZE UP IN THE RIVER

3.1 ICE SLUSH OF FREEZE UP

During the ice sluash period the temperature at water surface is close to 0°C. For calculate the date of ice sluash, that is to say calculates the lasted time during the water temperature is close to 0°C. On the basis of the conditions of local region area, we use the following formula:

\[
T = f\left(\frac{Q}{\theta}\right)
\]

(3.1)

Here: \( T \)- the lasted time of ice sluash, \( Q \)-Discharge, \( \theta \)-Water temperature.

The strength of dissipating heat is related with solar radiation, strength temperature, and heat change of water body and others. For easily to use, here make a relationship curve between \( T \) with \( \frac{Q}{\theta} \) (See Fig.2).

After format ice sluash in the river, the lowering of water level, the velocity reduces, freezing force increase, the river becomes freeze up. The air temperature reduced to -10°C. The critical velocity of freeze up is 0.5-0.7 m/s. Use some observation data, to set up a relationship curve of water level and critical date of freeze up time. Fig.3 is a forecast curve at one station of the Nenjiang River. This Fig.3 shows, the lasted time of the freeze up is changing related to water level of ice sluash.

![Fig.2 Relation curve between T & Q/θ](image1)

![Fig.3 Relationship curve between h-T at the Nenjiang River](image2)
In view of this concept, consider the water level or discharge in the other period also can get a good results. Such as Fig.4 is the relationship between the ice slush date and lasted time of freeze up at the Heilongjiang River.

![Fig.4 Relationship curve between h-t at the Heilongjiang River](image)

**3.2 FORECAST OF THE BREAK UP**

When spring comes, the rising air temperature and the increase in the intensity of solar radiation will bring about the melting of the ice cover. The strength of ice cover is usually weakened by short wave perpetration and heat condition. With an increase in runoff and the rise of water temperature, the ice cover breaks up. In the natural river, the first we have to calculate the heat force for break up and date of the break up of ice cover. Then to calculate the total heat quantity for heat change in the ice cover. And calculate the increase velocity of water level. Supposing it is consistent that is the process so heat energy for break up and the river discharge is increase. We have $H=at+bt+ct^2$. To differential above formula we got the equation as following:

$$\frac{d^2H}{dt^2}=2c$$  \hspace{1cm} (3.2)

Here: $H$-water level, $t$-date, $a$ $b$ $c$-constant. For forecast the break up to set up a relationship curve between $C$ and $D$(As the Fig.5). It shows the thickness of ice cover is larger; need quantity of heat is more. So the time of break up ice cover is late.

![Fig.5 Relationship curve of c and D](image)

**4. THE ICE DAM FLOOD PREDICTION**

**4.1 REASONS OF ICE DAM FORMATION**

We know that the formation of ice dam is resulted in the somatically hydraulics, thermodynamics, flow discharge and boundary conditions. It needs large amount on with certain strength, specific geometric boundary condition that can stop the movement of the ice, such as continuous meander and braided channels, shoals, and
stable ice cover. In addition, it is necessary that a certain amount of water volume stored in the river channel. Generally, the reach of ice dam formation are by ice break up hydraulically mainly or both hydraulically and them dynamically. On the other hand, we have to say that the conditions of formation ice dam mainly are: During the break up of ice cover from downstream to upstream, the flowing discharge is more than the outflow discharge, there are some sinuous river reaches, the river is so narrow or shallow area at the river. Past precipitation and store water quantity in the river are sufficient, the water level is high, closely-packed snow in the winter is large, the air temperature is lower and the ice strength is large; during the period of break up of ice, The air temperature increase influenced on consists form of the break up order, strength of ice cover and ice flood repeat. The water level of the ice slush can calculate use following formula:
\[ H_{m} = H_{o} + \Delta H \]  
(4.1)
Here: \( H_{o} = f(R_{r} + R_{s} + R_{i}) \), \( \Delta H = f(\Phi_{h}) \); and \( H_{m} \)-maximum water level, \( H_{o} \)-function of the rain, snow and ice cover, \( \Delta H \)-function of the ice cover strength, \( \Phi_{h} \)-strength if ice cover. For thus, has been calculated by the hydrological method.

4.2 FORECAST OF ICE DAM FLOOD

For the Heilongjiang River, there are different from forecast methods for predicting ice flood. Most of them there are the experience formulas. The mathematical model of optimum factors also has been developed in China. But in the Heihe area they like to use the experience formulas because of the technical level in there is lower than in modern cities. But they have a large number observation data. Some coefficients and others can calculate by general hydrological method easily.

The contents of calculation ice dam flood mainly are of rainfall and snowfall and the depth of rain and snow runoff. Think over about the effects of frozen soil, the freeze up water quantity and the depth of the runoff is:
\[ V_{\text{freeze}} = \frac{1}{2} K_{c} Q_{o} T, \quad R_{\text{freeze}} = K_{c} Q_{o} T / 2F \]  
(4.2)
Here: \( V_{\text{freeze}} \)-water quantity of freeze up, \( R_{\text{freeze}} \)-ice quantity of freeze up, \( K_{c} = 1 - K \), \( T \)-lasted time of freeze up, \( Q_{o} \)=initial ice quantity; In the northern China, we take the \( K = 1.0 - 0 \), and the average value is 0.25-0.3.

4.3 CALCULATED EXAMPLE OF ICE DAM FLOOD

As above-mentioned, there are different from forecast methods for predicting ice flood. Here only to introduce two examples as following:
(1) The forecast method on thinks over the total rain and snow runoff. According to the formulas which has been mentioned above, to drawing a relationship curve between the rain and snow runoff and maximum water level during ice dam flood as Fig.6. This is the curve of the formula on \( H_{m} = f(R_{r} + R_{s} + R_{i}) \) at the Shihuiyao station of the Nenjiang River.
(2) The forecast on thinks over the ice cover strength. For the Heihe station at the Heilongjiang River, the relationship curve between $\Phi_h$ and $H_m$ has been set up in the Fig.7. From this Fig. We have get the maximum water level of the ice dam easily.

5. CONCLUSIONS
In the recent years, there are some progresses on the forecast method of ice dam flood in the Heilongjiang area. For the calculated method, that was considered about the ice thickness, the ice cover strength, the formation of ice dam, the freeze up, the break up and others. Especial the factors of water heat, the initial ice thickness, snow depth on the ice cover, and lasted time of break up have been leaded into the forecast method. For calculating water quantity of ice dam it thinks about the relationship between frozen soil impact on the rainfall and snowfall. According to the formation of ice dam the ice dam flood at the high cold mountain area had been given. But all of this method only is used in the Heilongjiang area of northern China. We have to say, that Because of the most methods have been sated up by observation data and the experimental formula.

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