A STUDY ON ICE FLOOD AT THE SONGHUAJIANG RIVER

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ABSTRACT: The characteristics of Songhuajiang River watercourse, hydrological and metrological characteristics, and the disaster of ice dam flood in history were introduced in this paper. Based on the analysis of the cause of formation of ice dam and the change of the water thermodynamic factor, the cause of formation and the forecast method of ice dam were studied. This paper focused on the analysis and calculation of the water quantity that forms ice dam, so the formation of ice dam got the base of water quantity balance, and the accuracy rate of ice dam forecast increased consequently.

KEY WORDS: Ice flood, Ice dam, Melted snow, Rainfall

1. INTRODUCTION
The Songhua River, totaling 939 km passes from the source to the estuary). The difference of latitude between the source (41°40′) and the estuary (51°30′), is 9°50′; the difference of annual average temperature between the upper reach and the lower reach is 4.1°C. In the first ten-days of April, e.g. the break up period of river, the air temperature is 6.8 to 5.4°C and the difference of air temperature at the same period between upper reaches and lower reaches is 1.4°C. Due to the deference of the latitude between upper and lower reaches, each year the upper reaches is firstly heated and breaks up, forming an obvious reverse breakup in the whole river and providing a precondition for the formation of ice dam flood. Besides, the characteristic of Songhua River drainage and watercourse of Songhua River are important reasons for ice dam. The main branch of Songhua Rivers, Nenjiang River, The second Songhua River, Hulan River, Tangwang River and Mudan River, all originate from the Da Xinganling, Xiao Xinganling, Chuangbai Mountain, Zhangguangcai Area and Laoyeling Area. They have sufficient rainfall, good condition for conflux and located in low latitude areas. Each year when heated, snow and ice melted and form a peak in the upper reaches and move to the lower reaches. At the same time, when the weather is warm and snow cover melted, the air humidity increases and there will be a rainfall afterwards. The runoff of the rainfall and the runoff of melted snow coming together increase the ice dam
flood and promote the formation of ice dam. The middle reaches of Songhua River run through the plain area, receiving the flood of most branches. After entering Tonghe River, the water runs through Hills Mountain. The watercourse, more than 300 km, is narrow with high mountains at the two banks, and the heated and melted time of ice is obviously delayed. Each year the ice flood accumulated from the upper reaches is almost all blocked here and form obvious ice dam. When the situation is serious, the ice dam forms in the blocked watercourse and became a disaster. In this part of river ice dam occurs frequently. The occurrence rates in Yilan Station is about 30% and 67.2% of the occurrence of annual maximum water level are in the spring flood period.

In the recent one hundred years with record, there were several tens times of ice dams occurred in the Songhua River, among which there were more than ten times of big scale ice dams. And there are 5 times super big scale disastrous ice dams. When ice dam flood occurs, the change of water level is usually 3-5 m, and 6-8 m for big scale and super big scale ice dam. Water level with ice dam of the Yilan Station was more than 10 m in 1923 and 1960. The lasted time of ice dam usually is 1 to 2 days, and the longest is 11 days. Due to the random city of the formation of ice dam, each year it occurs in different river part. During the ice dam flood, the flood surged, ice gathered, and the water level increased greatly.

2. ANALYSIS OF THE CAUSE OF FORMATION OF ICE DAM

The ice dam of Songhua River mostly belongs to the stream channel block type. That is, during the breakup period, the ice sheet floating from the upper reaches gathered at the edge of the frozen ice cover causes section block; the water cannot run through so the water level increases. The conditions of the formation of ice dam are narrow water course, shadows, erosion ditches, branch streams, obvious change of the shape of water course and the obvious change of running speed of water, the capability of water running through sections \( \left( \frac{Q_m}{Q_{out}} \right) > 1 \); Obvious reverse breakup, ice sheet and water current moving from the upper reaches to the lower reaches and forming conflux of superposition and combination type. The stable conditions of ice dam are: low air temperature and water temperature, solid and thick ice cover, strong running through capability of ice dam, stable sequence water sources, \( \left( \frac{Q_m}{Q_{out}} \right) \approx 1.0 \) after the formation of ice dam.

In China, the analysis of the cause of formation of ice dam mostly begins from the watercourses characteristics, hydraulic characteristics and thermodynamic factor. Geographical conditions of river, such as running directions, conflux conditions and watercourse characteristics, are the preconditions that decide the uneven heating of ice cover, the reverse breakup of river and the accumulation of ice. The thermodynamic factor reflects the melting speed of snow and ice and the ice cover strength.

The main streams and branches of the upper reaches of the Songhua River originates and flows through low latitude hill areas, having big river slope and good conditions of conflux. In each year, the mainstream and branches of the upper reaches will be heated first and breakup. After the melted snow and ice and the rainfall runoff during the melting period joining in the mainstream, a heavy ice flood is formed and moves to the lower reaches.
the difference of the air temperature between the upper and lower reaches, the heating and breaking time of the ice cover of the watercourses of the lower reaches is delayed. The ice flood of the upper reaches accumulated in the curves of the watercourse or shallows or at the edge of the unmelted ice cover, blocked the watercourse and formed ice dam. The critical conditions of the ice dam of Songhua River are mainly that after the breakup, the superposition and combination mechanism of the ice flood of the upper reaches moving to the lower reaches. Due to the difference in watercourse characteristics, ice cover strength, breakup of ice cover, there are different types of accumulation of ice dam. For example Ice Cover Block Type mostly occur on the 50km part from the estuary of Mudanjiang River to Hongkeli; due to the obvious decreased river slope, the mountains along watercourse of the lower reaches, obviously delayed heating of ice cover and the big strength of ice cover, ice accumulated at the edge of the frozen ice cover. The Narrow River Block Type mainly occurred in the railway bridges of Jiamusi, Xinmin, Xinghuo part of Huachuan County and Tukesi part of Fujin County, the narrow coefficient mostly between 1.67 and 3.25. The Curve Block Type mostly occurs in the lower reaches (Jiaqi and Jianju), the watercourse is “S” curves or “L” right angle curves. The curve coefficient is between 1.40 and 1.68. The Bottom Block Type mostly occurs in Hafei Shallow of Yilan County. The height difference of hirst and stream channel is 2.8m. Hurst accounts for 5/6 of the width of the river and ice sheets are easily blocked when running through. The Branch Block Type is from Dawadan to Suibin part of the lower reaches, branches is in a crisscross pattern, like Wuguliu, Wudaogou and Wanlihe, the branch coefficient is between 2.43 and 3.58. since the direction of branches are greatly different, ice sheets crossed vertically and horizontally. From the analysis of the water quantity balance we can know that the cause of formation of ice dam mainly depends on water (ice) storage of the waterbed, melted snow and the rainfall runoff during the melting period. It can be showed with the water quantity balance formula:

\[ W_{ice} = \mu_{ice(water)} + \mu_{snow} + \mu_{rain} \]  \hspace{1cm} (1)

In the formula, \( W_{ice} \) — the total water quantity of ice dam flood, the unit is m³

\( \mu_{ice(water)} \) — the ice storage and water storage of the stream channel, the unit is m³

\( \mu_{snow} \) — the water quantity of the melted snow, m³

\( \mu_{rain} \) — rainfall runoff during the melting, m³

From the above analysis we can see that the ice dam flood of rivers in cold areas actually is under abnormal climate conditions, the combining course of melted snow, ice, and rainfall runoff in conflux. The melted snow and rainfall in the drainage area has crucial functions. The time and the strength of the increase of air temperature during the melting period influences the breakup sequence and the superposition and combination type of conflux; the ice cover strength influences the backwater height and lasted time of ice dam. In the course of ice flood, when the peak-quantity relationship is single; the height of the backwater of ice dam is as follows:
\[ H_m = H_0 + \Delta H \]

\[ H_0 = f(R_{\text{rain}} + R_{\text{snow}} + R_{\text{ice}}) \]

\[ \Delta H = f(\phi h) \]

Here, \( H_m \): the highest water level of ice dam, \( H_0 \): normal water level of the peak of melted ice, snow and rainfall runoff, \( \Delta H \): the backwater height affected by ice superposition and ice cover strength, \( \phi h \): the ice cover strength (kg/cm²).

### 3. THE CALCULATION OF ICE FLOOD

Due to the complexity and random city of the course of formation of ice dam, now there is no established calculation method for the calculation and forecast of ice dam home and abroad for reference. According to the above mechanism of the cause of the formation and the relationship showed in formula (1), taking the river reaches with frequent occurrence of ice dam (Yilan Station and Jiamusi Station) as examples, the main factors of calculation of several kinds of water quantity that affect the ice dam are as follows.

#### 3.1 CALCULATIONS OF MELTED SNOW AND RAINFALL RUNOFF

During the ice flood, melted snow and rainfall runoff are the major water source. Usually the breakup of the black river is in the first twenty days of April. The melted snow and rainfall runoff during the breakup period makes runoff course. The calculation method adopted the hydrological model of frozen soil in cold area studied by us:

\[ R = P - E - (\bar{W}_m - \bar{W}_0) \]  

Here, \( R \): the depth of the melted snow and the rainfall runoff in melting period e.g. \( R_{\text{rain}} + R_{\text{snow}} \) (mm); \( P \): the sum of the snow in winter and the rainfall quantity during melting period; \( E \): the corresponding vapor-transpiration, \( \bar{W}_m \): the maximum water storing capability in drainage area, \( \bar{W}_0 \): the original water storage. Calculated according to single layer evaporation model.

The runoff generation \( R \) is calculated as follows:

\[ R = f(P_e + \bar{W}_0) \]

\[ \bar{W}_{0,t+1} = K(P_t + \bar{W}_{0,t}) \]

\[ K = 1 - E_m / \bar{W}_m \]

Here, \( K \): coefficient of the water content decrease of soil \( E_m \): the maximum evaporation
ability.
In the formula, the parameter calculation is basically the same as the calculation method of summer flood. The differences is that because of the ability adjustment of water storing of freeze-up soil, $\overline{W}_0$ need to be calculated from the previous year flood. Since water content of the soil during freeze up period increases 20% to 40%, when $\overline{W}_0$ is calculated from the start day of the breakup, it should be multiplied with a coefficient between 1.2 and 1.4, to include the increased water storage during the soil water freeze up period. In addition, the evaporation of the soil water during freed up period is constrained, so the evaporation quantity should make an altitude conversion revision and a freeze up soil revision, referring to reference. When making a cross year calculation of $\overline{W}_0$, to simply the calculation, it can be calculated on month basis. From October to march is the stable freeze up period, the rainfall runoff can be incorporated into the same time period. $\overline{W}_0$ is calculated to April 1, as the original water storage of melted snow and rainfall. The precipitation of October to March in winter can be treated as snow cover. If there is no precipitation during the break up period, the runoff from April 1 to the break up of river is the runoff of the meted snow. If there is precipitation, the flood will be a mixed runoff. When calculating the runoff on month basis, the revised raining season evaporation of frozen soil should be deducted.

3.2 CALCULATION OF WATER STORAGE OF ICE (WATER)
In winter, the water storage of the stream channel is classified into two parts: ice storage and water storage. The ice storage of stream channel is:

$$\overline{W}_{\text{ice}} = \int_0^L h_m B dt$$

Here, $h_m$ : the maximum ice thickness, :B: width of the ice surface (m); L: the length of river part (m); t: the time. Branch part is calculated to the maximum ice thickness

$$\Delta \overline{W}_{\text{ice}} = h_m \frac{B + B_c}{2} \Delta L$$

$$\overline{W}_{\text{ice}} = \sum_1^n \Delta \overline{W}_{\text{ice}}$$

Here, B: average width m of the upper and lower section at the beginning of freeze up of river, $B_c$: average width of the upper and lower section when maximum ice thickness m, $h_m$: average maximum ice thickness m of neighboring sections of the upper and lower section, n: number of river reaches.

3.3 CALCULATION OF THE INCREASE OF WATER STORAGE OF STREAM CHANNEL
Stream channel water storage mainly reflects the quantity of frozen water as well as the water storing status of the drainage area during freeze up period and the influxes to runoff of rainfall and melted snow, usually is calculated from the flux of the time of freeze up, the flux of certain time period can be calculated through upper and lower sections flux, for example when the fluxes of the upper and lower reaches is the same

$$\bar{W}_{water} = \int_{0}^{T} (Q_{upper} - Q_{lower}) dt$$

(7)

Here, T is the total time; t is the time.

Calculation by time period

$$\bar{W}_{water} = \sum_{1}^{n} \Delta W \Delta t$$

(8)

This water quantity can influence the water level of ice dam flood, but is not a main factor, and can be ignored. The water quantity influence the ice dam flood most is the increase of the storage of stream channel of the upper and lower reaches during the break up period, e.g. the increase of water entering into stream channel after the break up of the upper reaches. This water quantity reflects the dynamic mechanical action of water current to ice cover, and is the main source of ice dam. It can be calculated by summing the difference between the original flux of the control station of the upper reaches and the flux of the section of the lower estuary, till the time when flux of the upper and lower reaches are the same. The increase of water storage of the overall river can be expressed as:

$$\bar{W}_{add} = \int_{0}^{T} (Q_{up} - Q_{down}) dt$$

(9)

Flux on daily basis:

$$\bar{W}_{add} = \sum_{1}^{n} (Q_{up} - Q_{down}) \Delta t$$

(10)

Here, n: number of the days from the start day to the break up day of the station, $\bar{Q}_{up}$ and $\bar{Q}_{down}$ are respectively the average flux of the stations of the upper and lower reaches, unit m$^3$/s.

3.4 ICE COVER STRENGTH CALCULATION

In melting period, when air temperature rises, ice thickness becomes thinner, ice cover strength also decreases. After analyzing the relationship of the change of ice thickness with air temperature and time, we adopt the relationship of accumulated temperature and the thinning of ice thickness, to calculate the ice thickness of melting period:

$$h_t = h_0 [1 - \left( \frac{t_n}{T} \right)^{1.5}]^2$$

(11)

Here, $h_t$, $h_0$ ice thickness and the original ice thickness (m) on $t_n$ day, $t_n$, $T$ is the time for calculation of $h_t$ and the total time of the melting of ice cover.
For the calculation of the ice cover strength coefficient, the disintegration course is as follows:

$$\varphi = \varphi_0 \left(1 - \sqrt{\frac{t}{T}}\right)^2$$

(12)

Here, $\varphi$ and $\varphi_0$: the ice cover strength and the original ice cover strength at time $t$ (Russi: $\varphi_0$ adopts 5.5 kg/cm²).

According to the above formula, the ice thickness and the ice cover strength is calculated to the critical date of predicted break up of river; $\varphi h$ is for the calculation of ice cover strength.

4. EXAMPLES OF ICE DAM FORECASTING

4.1 THE METHOD OF STREAM CHANNEL WATER STORAGE

This relationship (see Fig. 1), is the relationship of the water level of freeze up of Yilar Station and the water level of ice dam. The water level of freeze up is the water and ice storage of stream channel. This relationship can have good result in long term forecast.

![Fig.1 The relationship curve of the maximum water level and the ice cover level at the Yilar station](image)

4.2 THE METHOD OF WATER QUANTITY BALANCE

This method mainly considers the melted snow precipitation and stream channel water storage. The relationship formula is:

$$H_m = f (R_{rain} + R_{snow} + R_{ice} + R_{water})$$

(13)

The concept of the physical cause of the relationship is clear, and has certain accuracy, referring to Fig. 2. The causes that affects the accuracy of the relationship are mainly big drainage area, uneven heating during break up period, inconsistent conflux course and complex relationship of peak quantity.

4.3 FLUX RELATIONSHIP CONSIDERING THE CORRESPONDING WATER
LEVEL OF THE UPPER AND LOWER REACHES

In spring, the river is heated and breaks up, the upper reaches firstly form a peak and move to the lower reaches. The extension of the blocked ice dam relates to the quantity of incoming water, and the unmated ice cover strength of the lower reaches. Figure 4 shows the relationship of the upper and lower reaches using the ice cover strength as parameter. The parameters are the ice cover strength of the lower reach stations when the break up of the upper reaches. This relationship reflects the correspondence of the flux of the upper and lower water level. The ice cover strength reflects the height of the backwater; this relationship is reasonable and more accurate.

![Graph](image)

Fig. 2 The Relationship curve of $H_m = f(R_{\text{rain}} + R_{\text{snow}} + R_{\text{ice}})$

![Graph](image)

Fig. 3 The relationship curve of the maximum water level in the Harbin and Jiamusi

4.4 MULTIPLE FACTOR STATISTIC METHOD

Carry out the liner regression to the ice storage of the watercourse, average discharge at the Haerbin during the March, and the early stage rainfall at the Jiamusi station by section method. The forecast formula is as follows:

$$H_m = 0.00293x_1 + 0.00115x_2 + 0.0029x_3 + 74.8$$ (14)

Here, $x_1, x_2, x_3$ are distances between the sections.

This relationship reflects a comprehensive relationship of all factors, the accuracy of forecast is high, referring to Fig.4. To comparison the figure of the forecast and actual water level of ice dam of Jiamusi Station. The accuracy rate is 84%.
5. CONCLUSION

Since 1978, these are the deepest systemize analysis of ice dam. Based on the analysis to the characteristics of hydrology, geology, hydrology, metrology and watercourse of the Songhua River drainage, the process of ice dam in past decades and the formation mechanism of the ice dam were studied. Calculations were made to the factors that influence ice dam including, the quantity of water storage and ice storage, precipitation, runoff of snow melting and the strength of the ice cover. All kinds of relationship figures for forecast are formed. The method is based on the analysis of water balance, giving the result of a definite physical cause of formation. The accuracy of forecast is increased. Due to the time is limited and the problems are so complicated, further study and improvement need to be made for the course and calculation of the formation of ice dam.

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