The Influence of Ice Apron Shape on the Collision Force of Drift Ice

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Using ANSYS / LS-DYNA display dynamic analysis software to establish drift ice and T-bridge structure model, through the deformation coordination and momentum equation to solve collision load, discuss the influence law of the collision force by the closed angle and the front vertical edges dip Angle of tip shape ice apron, the front vertical edges dip angle and the facing ice surface curvature of bow ice apron and present the design parameters advice. The results of the study show that: the front vertical edges dip Angle, the closed angle and bow before the ice surface curvature are the important factors of crash effect. When the closed angle increased from 45° to 130°, drift ice collision force and the closed angle are in a linear relationship; When increased from 130° to 150°, the collision force has a sharp increase; When more than 150°, the collision force is almost the same. The front vertical edges dip Angle affect the damage form of drift ice and make the ice show vertical fracture, transition state and bend destructive form; drift ice collision force decreases with the facing ice surface curvature of bow ice apron increase; when it is hemicycle, the drift ice force is the minimum; the crashworthiness effect of tip shape ice apron is far better than the effect of bow ice apron.
1. Introduction
The rivers in north of China's latitude 30° have widespread ice damage. In the years of serious ice damage, the spring drift ice shock to bridge piers and hydraulic structures can lead to different degree of damage. In order to reduce the spring drift ice impact force on the piers, this paper study influence of bridge pier ice apron shape on the drift ice impact force and provides the basis for the design to choose the appropriate ice apron shape. Taking Jiamusi Songhua River highway bridge pier to drift ice shock test as the foundation, using ANSYS/LS-DYNA simulation analysis to the drift ice impact force on the bridge pier, this paper discusses and compares the influence of the ice meet shape for the sharp edges and circular arc sharp on drift ice impact force.

2. Common Ice Apron Profile
To reduce the spring drift ice knock-on effect of the piers, in a strong drift ice river (ice thickness more than 0.5 m, ice flow speed is greater than 1 m/s), The bridge pier should be designed with vertical edges before (ice apron) of the bridge and the ice apron’s plane has two kinds: the tip-sharped form (Fig. 1) and circular arc form (Fig. 2). The vertical edges generally is 3:1~10:1, namely \( \beta \) Angle between 180°~160°, also have the vertical edges. Ice apron meeting ice with sharp edges, the Angle between the two sides in commonly 45°~120°.

The ice apron with circular arc form will made part of the circle to meet the bridge piers body, as described below convenient, the height of the bow with \( h \), the width of the pier with \( d \) said.

Its body can be made by high strength of the stone laying, also can use a higher grade reinforced concrete, also can be in concrete for external use in granite surface or outsourcing with steel plate.

Jiamusi Songhua River Highway Bridge, the main hole using prestressed concrete T-Frame, the side hole for fabricated prestressed concrete beam, span arrangement for 8×30+55+100+5×120 +100+55+8×30 m. Span 100 m and 120 m of the prestressed concrete T-Frame in 30 m across all with hung beam and concrete numbers as main girder C40. The main hole use open caisson basis and reinforced concrete hollow pier, the pier using C25 concrete. Main riverway pier set tip-shaped ice apron in his body, the ice apron with vertical edges for 0°, Angle is 127°, using C25 concrete, with the granite.

The main bridge to 10# pier and T structure design parameters as the basis, using the modeling method and drift ice material model noted (Yu et al., 2010), using ANSYS/LS-DYNA dynamic analysis software established the flow collision of the ice bridge piers simulation analysis model. In the modeling analysis, take hang beam and constant load as additional quality in bridge structure directly. To modeling drift ice and T-Frame respectively, and then through the deformation coordination and momentum equation to solve the impact load (Wu et al., 2008). The river drift ice and the contact area of the bridge by solid 164 unit, and the main girder and the contact area of the bridge beam 161 element, contact type using the contact type the ASTS automatic aspects contact, use symmetry penalty function contact method. In the pier and the open caisson use consolidation boundary conditions.
The drift ice size on April 12, 2009 of the actual measurement results, size for $80 \times 60$ m$^2$, ice thickness of 0.6 m, velocity of 1.42 m/s. The temperature measured 13°C, water temperature is 0.1°C, according to the literature (Yu et al., 2009), the method of drift ice determine physical and mechanical parameters of: bending modulus for 800 MPa, bending strength for 0.504 MPa, the river ice density of 916.8 kg/m$^3$, poisson's ratio of 0.33.

Figure 1. Elevation of ice apron in tool edge shape.

Figure 2. Plan of ice apron in bow shape.

On April 12, 2009, the 10# pier ice impact force time process curve as Fig. 3, the calculation time process curve when made in figure together. The calculation of the ice impact force for 2477.36 kN, measured 2432.82 kN, both perfectly, prove model is effective. To compare the body shape on the ice in the collision, the effects of the ice related parameters of the body change of the simulation model respectively, to research and to reveal the ice form on the body the influence law of impact.

Figure 3. Ice impact force time process curve.
3. The Study on the Influence of Ice Apron Shape on the Collision Force of Drift Ice

3.1 The Influence of Tip-shaped Ice Edge Angle on the Impact Force

In order to analysis the influence of the ice apron edge angle $2\alpha$ on the impact force, in the finite element model, assuming that the vertical edge before the slope of $\beta = 0^\circ$, and only change the size of the ice apron body model $2\alpha$, respectively, will be set to $2\alpha$ as 45°, 60°, 70°, 75°, 85°, 95°, 105°, 127°, 140°, 150° and 180°. Drift ice impact force on pier calculation results in Fig. 4. Can be seen from Fig. 4, with $2\alpha$ angle increased from 45° to 130°, the drift ice impact force has linear relationship between the force and angle $2\alpha$, with the increase of angle $2\alpha$, the force increase. But the increase was not obvious; When $2\alpha$ angle from 130° to 150°, the impact force increases rapidly and reaches the maximum at 150°; When $2\alpha$ angle from 150° to 180°, the impact force is essentially the same. The above analysis shows the smaller $2\alpha$ angle of ice apron, the smaller harm caused by the impact force on the structure. Having regard to the actual situation, the general $2\alpha$ desirable 45°~130°, but not more than 130°.

3.2 The Influence of Front Edge Vertical Gradient of the Ice Apron with Tip-shaped on the Impact Force

Ice floe, pier, pier bottom boundary condition and the upper part of the structure parameters in the finite element model does not change, assume $2\alpha$ conditions of 127°, only to change the slope of the edge before the ice apron body vertical, the $\beta$ were taken 0° and 2°, 5°, 5.5°, 5.95°, 6°, 10°, 15°, 18°, 20°, 25°, 30°, 35°, 40°, 45°. Drift ice impact force calculation results shown in Fig. 5.

Can be seen from Fig. 5, when the ice apron body $\beta$ angle is less than 5°, the impact force changes little. At this time ice floe failure pattern is longitudinal splitting failure; When the ice-apron body $\beta$ angle between 5° and 6°, the impact force as the angle increases, a sharp decline in the ice failure pattern between split and bending. Failure modes of the ice destruction have a gradual transition from the longitudinal splitting to the bending failure; When the $\beta$ angle is greater than 6°, the impact force decreases with the increase of $\beta$ angle of the ice apron body. And when $\beta > 25^\circ$, with the increase of $\beta$, the impact force downward trend began to slow down. At this point, the drift ice failure mode is flexural failure.
In practical engineering applications, tip-shaped ice apron, the $\beta$ angle should be greater than 6°, bending failure was to make the drift ice the failure modes, to reduce the impact of drift ice on the pier; $\beta$ greater than 25°, ice-breaking effect crease is relatively slow, the actual project to save cost, the $\beta$ not greater than 25° is appropriate.

Figure 5. Impact force affected by changing the $\beta$ angle of the ice apron.

3.3 The Influence of Bow Ice Apron Curvature on the Impact Force
Ice floe, pier, pier bottom boundary condition and the upper part of the structure parameters in the finite element model does not change, assuming that the vertical edge before the slope $\beta$ is 0°, only to change the height of the ice apron body arched in order to analyze the curvature influence on the impact force. To this end, the height of the bow were taken as 0.2$r$, 0.4$r$, 0.6$r$, 0.8$r$, $r$ (r pier width 1/2), different bow height, the flow of ice impact force calculation results in Fig. 6 show. In essence, changing the height $h$ to ice apron body arched is to change the curvature of the ice apron body facing the ice surface in the plane, $h$ increasing process is known as ice apron body facing the ice surface curvature increases. Can be seen from Fig. 6, the drift ice impact force $h$ with ice apron body increases (facing to the ice surface curvature increases) decreases. When $h$ increases to $r$, that ice apron takes the shape of semi-circular, impact the smallest force.

Figure 6. Impact force affected by changing the $r$ length of the ice apron in bow shape.

Fig. 4 shows that the $\beta = 0°$ and $2\alpha = 130°$, the impact force of the tip-shaped ice apron is 2477.37 kN ($2\alpha$ proposed range of the largest impact force), far less than the impact of the arc-
shaped force 7520 kN (impact force of the arc-shaped ice apron body of the minimum), the tip shaped collision effects far superior to the arc-shaped ice apron body.

3.4 The Influence of Semicircular Ice Apron $\beta$ Angle on the Impact Force

Under 3.3 conclusion, the semicircular ice apron crash is better than the bow ice apron body, may study the semicircular ice apron crash of measures. Modeling parameters for the analysis has influence of semicircular ice apron body $\beta$ on the impact force. Under the premise of $h = r = d/2$, only to change $\beta$ angle of the ice apron body model, $\beta$ are taken as 0°, 5°, 6°, 8°, 10°, 15°, 18°, 20°, 25°, 30°, 35°, 40°, 45°, the different $\beta$ drift ice impact force calculation results in Fig. 7 shows.

![Figure 7](image)

**Figure 7.** Impact force affected by changing the $\beta$ angle of the ice apron in half round shape

Fig. 7 shows that the ice apron for the arc-shaped body, $\beta$ influence on ice impact force is similar with the tip broken ice apron: the curve of the impact force and $\beta$ is divided into three stages, when the ice apron body $\beta$ angle is less than 5°, impact force change little and the ice’s failure modes is longitudinal splitting failure; The failure modes of ice apron when $\beta$ between 5° to 10°, the impact force as the angle increases, a sharp decline, the ice failure pattern between cleavage fracture and flexural failure, the ice gradual transition from longitudinal splitting failure to bending failure; when the ice apron body $\beta$ angle greater than 10°, the impact force decreases with the increase of $\beta$ angle of the ice apron body. And when $\beta > 35°$, the impact force with the increase of $\beta$, the downward trend began to slow down. At this point, the ice failure mode is flexural failure.

In practical engineering applications, the arc-shaped ice apron body, the $\beta$ should be greater than 10°, so that the drift ice failure pattern was bending failure, reducing the impact of drift ice on the pier; $\beta$ greater than 35°, the increase of breaking effect is relatively slow, the actual project to save cost, the $\beta$ not greater than 35° is appropriate.

3.5 Comparative Analysis of the Crash Effects of the Semicircle and the Tip-shaped Ice Apron

Comparative semicircle with tip-shaped ice apron body collision effects, according to the conclusions of the study of 1, to take the shaped ice-breaking $2\alpha = 130°$ (the upper limit of recommended values, (tip-shaped ice apron impacts maximum); according to the findings of 3, take the bow height of minimum width $h$ for the pier 1/2 (in this case, bow-shaped ice apron body impacts minimum). Different $\beta$, the calculation of impact force results in Table 1.
Table 1 data show that the $\beta$ is same, the ratio of the impact force of the tip-shaped ice apron impact force and the arc-shaped ice apron, with the increase of $\beta$, the difference of the two collision effect decreases. When $\beta$ is less than 25°, tip-shaped ice apron crash effect is far superior to the arc-shaped ice apron body. To improve the crash effect of the arc-shaped ice apron, need to increase $\beta$. When $\beta$ take 35°, impact force of the arc-shaped ice apron is same to that of the tip-shaped ice apron which $\beta$ take 25°.

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4. Conclusions
Using LS-DYNA display dynamic analysis software, study the influence of ice apron shape on the collision force of drift ice and get the following conclusions:

(1) Sharp angle and vertical front edge is an important factor in tip-shaped ice apron body on collision effects. When sharp angle increased from 45° to 130°, the drift ice impact force and angle is a linear relationship. With the sharp angle increases, but the increase is not obvious; when sharp angle from 130° to 150°, the impact force increases rapidly and reaches the maximum at 150°; when $2\alpha$ is greater than 150°, the impact force is essentially the same; When the ice body vertical edge angle is less than 5°, impact force is big, drift ice was longitudinal splitting failure pattern; between 5° to 6°, the impact force as the angle increases, a sharp decline in the drift ice by the longitudinal splitting failure gradual transition to the bending failure; when the ice apron inclination greater than 6°, the impact force decreases as the ice apron body inclination increases and the ice failure mode is flexural failure. But when the inclination is greater than 25°, the impact force’s downward trend began to slow down. Vertical before tip-shaped ice apron edge inclination to take the 6° to 25°, sharp corners desirable 45°~130° is recommended.

(2) The arc-shaped ice apron curvature and the slope of vertical front edge are important factors on collision effects in tip-shaped ice apron body. The drift ice impact force decreases with the ice apron body curvature increases and the semicircular has the smallest impact force. Vertical edges of drift ice angle before the influence law of the collision with the sharp edges form similar. For circular arc form ice apron body, vertical edge is advised to take 10°~35°.

(3) The ratio of tip-shaped ice apron body impact force and arc-shaped ice apron body impact force decreases as the vertical edge inclination increase and the difference of the two collision
effect decreases. When angle is less than 25°, tip-shaped ice apron crash effect is far better than the arc-shaped ice apron body.

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References


