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Research on Fairway Width Design in Curved Bridge Waters Channel

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Abstract: Bridge construction can promote economic development but if the bridge layout is unreasonable, it would hinder ship's safety navigation in the bridge area. There is little reference for fairway width design about curved bridge channel in ⟨⟨inland river navigation standards⟩⟩ of China. In this study, a fairway width design method in curved bridge channel was put forward by taking into account the scope of turbulent scope of pier, ship's track width, drifting distance due to wind, drifting distance due to current, the scope of ship's safety field and additional width in curved channel. The fairway width design concept for curved bridge channel presented in this studyit may provide reference for bridge design and other fairway layout.

Key words: Fairway width, design, turbulent scope, curved bridge channel, navigation safety

INTRODUCTION

With the sustainable development of China economy, the construction of bridge crossing over sea strait and river becomes more and more. Until 2010, there are more than 150 bridges crossing over sea strait and river (Chen and Wang, 2004), whose span exceed 200m. Because the appropriate sites for bridge construction become more and more finite, a number of bridges have to be constructed over curved channel. At present, fairway arrangement in bridge area in China is carried out by mainly referring to China's ⟨⟨inland river navigation standards⟩⟩. However there is no explicit standard about the fairway width in curved bridge channel in the ⟨⟨standards⟩⟩ and the fairway's dimension determination methods mentioned in ⟨⟨standards⟩⟩ are only related with ship's length and its width and are without considering ship's maneuvering characteristics and flows condition in curved bridge channel (Wu and Zhan, 1999). As a matter of fact, flows regime in curved bridge channel is very complex and fairway width is one of important factors giving rise to traffic accidence, such as Huangshi Yangtze River Bridge which constructed over curved channel and fairway dimension layout exists deficiency, collision accidences happened frequently in the past years. Many factors affect fairway's width design in curved bridge channel, such as wind and stream, pier turbulent scope, ship's special maneuvering capability in curved channel and so on. Ship's course-keeping characteristics and turning characteristics are poor in pier turbulent scope and the fairway should be designed outside the scope of pier turbulent scope. The wind and the current not only make ship deflect but also make ship adrift. Rudder must be used frequently to guarantee ship navigation in fairway in curved channel. Therefore if only considering ship's dimension and not thinking pier turbulent scope, ship's drift distance induced by wind and current, ship's safety field scope and ship's special maneuvering capability in curved channel, it is unreasonable to design the fairway width in curved bridge channel. The purposes of the present work, therefore, are to investigate the effects of fairway width on collision accident, the width in curved bridge channel and to put forward fairway width design mathematical model in curved bridge channel based on considering the effects of pier turbulent scope, ship's drift distance induced by wind and current, ship's safety field scope and ship's special maneuvering capability in curved channel on it.

RELATIONSHIPS BETWEEN TRAFIC ACCIDENT AND FAIRWAY WIDTH

A large number of statistical results show that traffic accidents are closely related with fairway width. Figure 1, in which K stands for traffic accident probability (Qi, 1991) and B stands for fairway width, demonstrates that traffic accidents reduce with the increasing of the channel width.

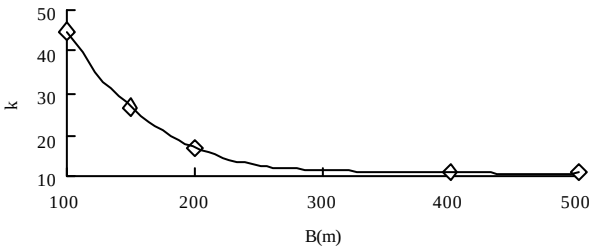

Fig. 1: Relationship between traffic accident and channel width

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But even so, fairway width cannot be too wide, because if it is too wide, channel resources will be wasted. It is very important to reasonably design channel width according to navigation requirements.

CONSIDERS ON FAIRWAY WIDTH IN CURVED BRIDGE CHANNEL

The factors effected fairway width in curved bridge channel include the following: ship's dimension, such as ship's length and ship's width, ship's drift distance induced by wind and current, pier turbulent scope, ship's safety field scope and width allowance induced by ship's special maneuvering capability in curved channel. The above factors must occupy the certain channel space. So, their effects on fairway width in curved bridge channel must be considered when designing channel layout.

Ship's track width: Ship's track width is determined by ship's length and its width. Figure 2, where L is ship's length, b is ship's width and $\alpha(^\circ)$ is ship's leeway angle, illuminates ship's track width. From Fig. 2, ship must occupy certain track width Bts as the following:

$$B_{ts} = |L\times\sin\alpha|+|b\cos\alpha| \quad (1)$$

Ship's safety field scope: As early as 1960s, according to the ship-to-ship effects and ship-shore effects, Japanese scholar put forward the ship field theory, the theory says that in order to safe navigate, ship need a certain field conditions, the field generally can be oval-shaped, the size of the field is concerned with scales of the ship, speed and environmental condition. When the ship is sailing at normal speed, its field is generally preferable to 6 times of the ship length along ship's length direction and 1.6 times of the ship's length along ship's width direction (Dai *et al*., 2009; Liu *et al*., 2006). So, the transverse distance of ship's safety field scope Bs can be regarded as:

$$B_s = 1.6L \quad (2)$$

where, L is navigation ship's length.

Ship's drift distance induced by wind and current: Ship's movement in current can be described as Fig. 3, where Y is the direction of fairway axis line and X is the direction which is vertical with Y and $\alpha(^\circ)$ is ship's leeway angle, $\beta(^\circ)$ is the angle between current direction and Y axis, O is ship's gravity center, S is ship navigation distance in bridge waters, U_c is current's velocity, U_s is ship's velocity. By decomposing ship's velocity alongside X axis and Y axis, U_X which is ship's sub-velocity alongside X axis and U_Y which is ship's sub-velocity alongside Y axis can be obtained. From Fig. 3, the following two equations can be gained:

$$U_X = U_c\times\sin\beta+U_s\times\sin\alpha \quad (3)$$

$$U_Y = U_c\times\cos\beta+U_s\times\cos\alpha \quad (4)$$

So, current-induced ship-adrift ΔB_1 can be expressed as the following when ship passes the bridge area:

$$\Delta B_1 = U_X\times S/U_Y \quad (5)$$

The calculation method of wind-induced ship-drift is similar with current-induced ship-adrift calculation approach. According to the calculation principle of current-induced ship-adrift, wind-induced ship-adrift might be expressed as the following (Yang and Ai, 2007):

$$\Delta B_2 = K.\left(\frac{B_a}{B_w}\right)^{\frac{1}{2}}.e^{-0.14V_s}.V_a.S.\frac{\text{Sin }\alpha_f}{|\text{VCos }\alpha+\text{UCos }\beta|} \quad (6)$$

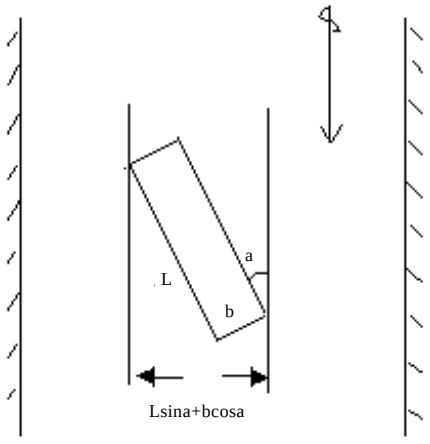

Fig 2: Ship's track width

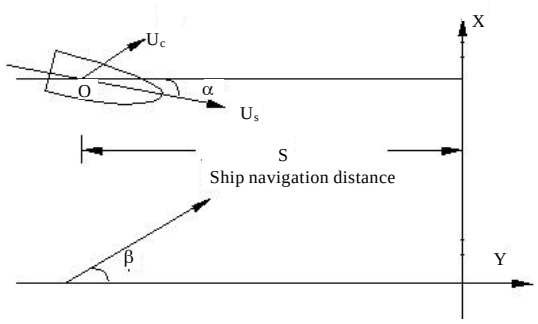

Fig. 3: Current-induced ship-drift

where, K is a coefficient and K = 0.038~0.041, B_a is ship hull's side area which suffers from the effect of wind above waterline (m^2); B_w is ship hull's side area below waterline (m^2), $B_w = L \times d$, L is ship's length and d is ship's draught; V_s is ship's velocity in wind (kn), Va is relatively wind velocity (m sec^{-1}); $a_f(°)$ is the angle between wind direction and fairway axis direction.

Width allowance in curved channel: In order to ensure ship navigates in curved fairway always, ship must alter course by using rudder frequently, so there exists kicks in the course of altering course, so there must set apart some space to meet kicks requirements. Figure 4 indicates the situation that the vessel is navigated into and out of the winding channel (Liu and Lv, 2006). Each parameter in Fig. 4 indicates the following meaning: a1 is the initial course angle when the vessel is navigated into the winding channel; a2 is the course angle when the vessel is navigated out of the winding channel; R is the radius of the curvature of the winding channel. According to Fig. 4, width allowance B_1 in curved channel can be expressed as following (Liu *et al*., 2006):

- When $a_1>0$ and $a_2 = 0$:

$$B_1 = \frac{1}{2}b(\cos\alpha_2 - \cos\alpha_1) + P(\sin\alpha_1 - \sin\alpha_2) + L\sin\alpha_2 + 2R\sin\frac{\alpha_1-\alpha_2}{2}\sin\frac{\alpha_1+\alpha_2}{2} \quad (7)$$

- When $a_1>0$ and $0 = a_2 = -a_1$:

$$B_1 = \frac{1}{2}b(\cos\alpha_2 - \cos\alpha_1) + P(\sin\alpha_1 - \sin\alpha_2) + 2R\sin\frac{\alpha_1-\alpha_2}{2}\sin\frac{\alpha_1+\alpha_2}{2} \quad (8)$$

In the above two formulas: b is ship's breadth; L is ship's length; P is the distance from the ship turning centre to the ship astern.

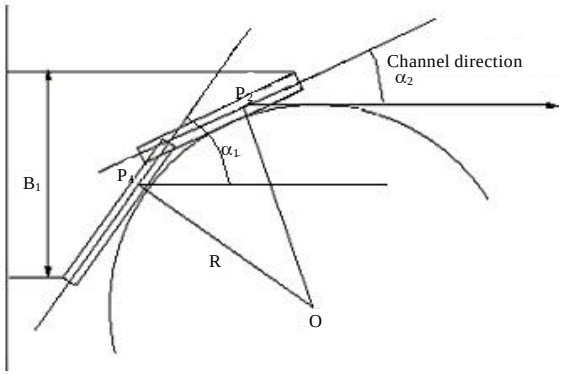

Fig 4: Ship's navigation in curved channel

Pier turbulent scope: Flow regimes are chaos and there are many vortexes in pier turbulent (Zhuang, 2007), ship is liable to collide bridge in this area. So fairway should be layout outside of this area (Hu *et al*., 2002). Pier turbulent maximum scope is mainly controlled by pier's dimension and flow's velocity (Shen *et al*., 2004; Raudkivi, 1986). The empirical formula is expressed as the following by Xu (Xu, 2007) based on model test data:

$$B_2/D = 0.0907\beta + 6.5835 \quad (9)$$

where, B_2 is pier turbulent scope width along channel width direction, D is pier's current wards width, β is the angle between flow's velocity and pier longitudinal axis direction.

DISCUSSION ON FAIRWAY WIDTH IN CURVED BRIDGE CHANNEL

In order to ensure ship navigation safety in curved bridge channel, it is essential to reasonably layout the fairway width and the following two principles must be observed: (1) Fairway must be layout outside of pier turbulence scope and (2) Ship's drift distance induced by wind and current, ship's track width, ship's safety field scope, width allowance in curved channel must be considered. Therefore, safety space L_1 of one-way navigation between two fairway side lines in curved channel can be expressed as following:

$$L_1 = \Delta B_1 + \Delta B_2 + B_{ts} + 2B_s + B_1 \quad (10)$$

For safety space L_2 of two-way navigation between two fairway side lines in curved channel, according the above analysis, can be described as the following:

$$L_2 = (\Delta B_1 + \Delta B_2 + B_{ts} + B_1)_u + (\Delta B_1 + \Delta B_2 + B_{ts} + B_1)_d + (B_s)_u + (B_s)_d \quad (11)$$

where, subscript u presents upstream ship, subscript d presents downstream ship.

CONCLUSION

The concerning factors which affect fairway width in curved bridge channel, are discussed in this study. And also, the fairway width principles and calculation method in curved bridge channel are based on analysis the above concerning factors.

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