Research on Round-pier Turbulent Scope in Straight Channel

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Abstract: It is very important for ship's navigation to layout the fairway in bridge area reasonably. The turbulent scope of pier, relating directly to traffic accident in bridge area, is an important index to take into account for bridge area's fairway layout. In the present paper, the turbulent scope of round-pier in straight channel and relative parameters, such as round-pier's diameter, flow's velocity and so on, were analyzed by theoretical considerations. It could be concluded that the maximum turbulent scope of round-pier in straight channel was mainly dominated by round-pier's diameter and flow's velocity in water surface. The larger the round-pier’s diameter and flow’s velocity in water surface are, the larger is the maximum turbulent scope of round-pier in straight channel. An empirical expression was presented to calculate the maximum turbulent scope of round-pier in straight channel.

Key words: Round-pier, turbulent scope, fairway layout, ship navigation, empirical expression

INTRODUCTION

The development of bridge construction in China is very rapid since the 1980s. Bridge construction in China greatly improves traffic condition; it also pours vigor into China's economic development (Chen and Wang, 2004). If the location of bridge area is inappropriate or bridge channel layout is unreasonable, bridge might become the bottleneck to shipping development. In recent years, due to channel layout defects of bridge area, accident of ship collision bridge occurs frequently (Wu and Zhan, 1999). It is very important to consider pier turbulent flow scope and bridge channel buoy is layout outside the scope of pier turbulent. The fairway layout in bridge waters is shown in Fig. 1. This is because that both ship's rudder effect and course stability are poorer when ship is sailing in turbulent flow area. At present, the reference to layout of fairway in bridge area in China is mainly implemented by China's inland river navigation standards, however definite define of turbulent flow scope around round-pier is not explicit in the standard, it is necessary to research on turbulent flow range to provide reference to fairway layout in bridge area.

About the turbulent scope of pier, some people, such as Hu et al. (2002, 2004), think that the bridge pier scope is mainly related with pier size, the Froude number closely. They think when the Froude number changes from 0.14 to 0.4, the pier turbulent scope also varies from 0.5D to 2.6D (D is diameter of round-pier) in straight channel. In winding channels round-pier bridge waters, when the Froude number changes from 0.10 to 0.18, round-pier turbulent scope varies from 0.5D to 2.6D (Shen et al., 2004). Although the conclusion about pier turbulent scope has some reference value to bridge area channel layout, it does not draw experience formula and it is much inconvenient to apply to practical engineering. Zhuang (2007) of Wuhan university of science and technology conducts model experiment to different kind of pier turbulent flow scope and obtains related experience expression, but because experimental data were insufficient, the accuracy of his experience expression about pier turbulent scope need to be improved. Foreign Olsen and Melaaen (1993) and Raudkivi (1986) also researched qualitatively on bridge turbulent flow scope, he considered that bridge area turbulent scope increased with flow velocity's increasing and water depth's

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increasing. His conclusions have guiding significance on bridge area channel layout, but quantitative research on bridge area turbulent scope need to be research further.

So it is necessary to research bridge area turbulent scope further. The purposes of the present work, therefore, are to investigate the effects of the relevant factors on round-pier turbulent scope in straight channel, i.e., the round-pier’s diameter and flow’s velocity and so on; to present an empirical expression of round-pier turbulent scope in straight channel by means of the numerical simulations; and to verify the rationality of the above empirical expression by using model experiment data.

THEORETICAL ANALYSES

There exist flows’ sub-velocity vectors which follow the fairway’s axis line direction (be defined \( U_i \) in his paper) and also there exist flows’ sub-velocity vectors which are vertical with the fairway’s axis line direction (be defined \( U_j \) in this paper) around round-pier in straight fairway.

Because round-pier is strictly ax symmetric, \( U_j \) can result in interaction between ship and pier and \( U_i \) has the most effect on ships navigation safety. The round-pier turbulent scope is defined as the biggest vertical distance between the point where \( U_i \) disappears (\( U_j = 0 \)) and round-pier’s horizontal axis line in this paper. The round-pier turbulent scope is expressed as \( L \) in this paper.

There are many parameters which affect the round-pier turbulent scope \( L \) and the relevant parameters of dimensional analysis come from the following groups:

- Fluid Properties. These consist of: the density of water \( \rho \) (kg m\(^{-3}\)), the dynamic viscosity of water \( \mu \) (N s m\(^{-2}\)) and the acceleration of gravity \( g \) (m s\(^{-2}\))
- Round-pier’s geometry, it is its diameter \( D \) (m)
- Flow Properties. These consist of: the flow velocity \( \mu \) (m s\(^{-1}\)), the water’s depth around round-pier (be defined \( h \) in this paper)

Each of these design parameters is a function of the initial independent parameters:

\[
1 - f(\rho, \mu, g, D, u, h)
\]

This relationship could be rewritten in terms of dimensionless parameters:

\[
1/D = f\left(\frac{u}{\sqrt{g h}}, \frac{u D}{\mu/\rho}\right)
\]

where, above formula implies that the round-pier turbulent scope \( L \) is the function of Froude number and Reynolds number. Because density of water \( \rho \) (kg m\(^{-3}\)), the dynamic viscosity of water \( \mu \) (N s m\(^{-2}\)) and the acceleration of gravity \( g \) (m s\(^{-2}\)) have little variation in normal temperature, the effect to \( L \) of density of water \( \rho \), the dynamic viscosity of water \( \mu \) and the acceleration of gravity \( g \) can be omitted. Meanwhile, Zhuang (2007) regarded that pier turbulent scope \( L \) increases with water’s depth increasing. Eq. 2 shows that pier turbulent scope \( L \) increases with flow’s velocity increasing, the maximum water’s depth and flow’s velocity are on water surface, the maximum round-pier turbulent scope appears on water surface also. So it is safety for ship’s navigation to take account of round-pier turbulent scope on water surface. If only considering the maximum round-pier turbulent scope on water surface, Eq. 2 can be simplified as:

\[
L = \tilde{f}(D, U)
\]

where, \( L \) is the maximum round-pier turbulent scope; \( U \) is flow’s velocity on water surface. The above equation shows that the maximum round-pier turbulent scope has closely relationship with flow’s velocity on water surface \( U \) and round-pier’s diameter \( D \). So two-dimension simulation method can be used to research round-pier maximum turbulent scope.

METHODOLOGY AND PHASES

Numerical simulations model: The RNG \( k-\epsilon \) model was used to calculate the hydraulic parameters of the flow through the orifice plate, due to its suitability for simulating the flow inside large change boundary forms as well as its high precision and calculation stability. For the steady and incompressible flows, the governing equations of this model can be written as (Yang and Zhao, 1992).

Continuity Equation:

\[
\frac{\partial u_i}{\partial x_i} = 0 \quad i = 1, 2
\]

Momentum equation:

\[
u \frac{\partial u_i}{\partial x_i} = \frac{1}{\rho} \frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j} \left[ (u_j + \nu_i) \left( \frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right) \right] \quad i = 1, 2
\]

\( k \)-equation:

\[
u_k \frac{\partial k}{\partial x_i} = \frac{\partial}{\partial x_j} \left[ \gamma_k (u_j + \nu_i) \frac{\partial k}{\partial x_j} \right] + \frac{1}{\rho} \frac{\partial}{\partial x_i} \left( \rho \gamma_k - \tau_{ij} \right) - \epsilon_i \quad i = 1, 2
\]
\[ \rho \frac{\partial \mathbf{u}}{\partial t} = -\nabla p + \mu \nabla^2 \mathbf{u} - \rho \mathbf{f} \]

where \( \mathbf{u} \) is the velocity vector, \( \rho \) is the density of fluid, \( p \) is the pressure, \( \mu \) is the viscosity, and \( \mathbf{f} \) is the external force vector.

\section*{DISCUSSIONS}

Figure 2 and 3 is the streamline when pier's diameter is 1m, flow's velocity is 5 and 7 cm s\(^{-1}\), respectively. The two figure show that there are turbulence areas around pier. The simulation results is shown in Table 1, in which the round-pier's diameter \( D \) varies from 0.5 to 3.0 m and the fairways surface flow velocity \( U \) varies from 18 to 50 cm s\(^{-1}\). Figure 4 can be given according to the data in Table 1. It can be learned from figure 4 that \( L \) increases logarithmically with \( U \) when \( D \) is fixed.

Figure 5 is drawn by using the data in Table 1 when \( U \) is 18 cm s\(^{-1}\). Figure 5 shows that \( L \) increases linearly with \( D \) when \( U \) does not vary. This relationship between \( L \) and \( D \) is also demonstrated by Fig. 4. By fitting the curves in Fig. 4, the following empirical formula relating to round-pier turbulent scope can be obtained:

\[ L/D = 1.8 LD(U)^{4.7} \]
Fig. 3: Streamline around pier (U = 7 cm s\(^{-1}\))

Fig. 4: L when U varies and D varies

Fig. 5: Relationship between L and D when U fixed

Table 1: L when U varies and D varies

<table>
<thead>
<tr>
<th>U (cm/s)</th>
<th>18</th>
<th>22</th>
<th>29</th>
<th>35</th>
<th>50</th>
</tr>
</thead>
<tbody>
<tr>
<td>D = 0.5 m</td>
<td>0.27</td>
<td>0.56</td>
<td>0.65</td>
<td>0.88</td>
<td>1.22</td>
</tr>
<tr>
<td>D = 1.0 m</td>
<td>0.53</td>
<td>1.01</td>
<td>1.28</td>
<td>1.75</td>
<td>2.42</td>
</tr>
<tr>
<td>D = 1.5 m</td>
<td>0.81</td>
<td>1.52</td>
<td>1.94</td>
<td>2.64</td>
<td>3.66</td>
</tr>
<tr>
<td>D = 2.0 m</td>
<td>1.06</td>
<td>2.03</td>
<td>2.57</td>
<td>3.51</td>
<td>4.85</td>
</tr>
<tr>
<td>D = 2.5 m</td>
<td>1.33</td>
<td>2.54</td>
<td>3.25</td>
<td>4.39</td>
<td>6.12</td>
</tr>
<tr>
<td>D = 3.0 m</td>
<td>1.61</td>
<td>3.11</td>
<td>3.85</td>
<td>5.27</td>
<td>7.32</td>
</tr>
</tbody>
</table>

CONCLUSIONS

The relationships among the maximum turbulent scope L of round-pier, round-pier’s diameter D and the fairways surface flow velocity U were researched in this paper. By using theoretical analysis and simulation method, it is found that L increases logarithmically with U when D is fixed and L increases linearly with D when U does not vary. Empirical formula relating to round-pier maximum turbulent scope is obtained in this paper.

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REFERENCES


