Summary of Research on Evaluation of Local Scour around Bridge Pier

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Abstract. In recent years, bridge disasters caused by scour have occurred frequently; hence, scour has become one of the most important factors that threatens the safety of wading bridges. Although the research on the local scour around bridge pier has been carried out for many years, there are few research results on the evaluation of scour hazard of built bridge piers and that of unbuilt bridge piers. On the basis of previous research results at home and abroad, this paper systematically analyzes the research results related to the evaluation of local scour of bridge piers in recent decades, including the prediction of scour pit depth, the risk assessment of local scour failure and the prediction of scour depth based on risk theory. In this paper, the trend of local scour evaluation of bridge piers is also discussed.

Keywords: local scour; depth of scour pit; evaluation; prediction.

1. Introduction

Bridge is an important infrastructure and plays an important role in transportation and national economy. However, as an important transportation hub, bridges are also faced with various complex and harsh environments. Natural disasters, such as scour, flood, mudslide and earthquake, unreasonable design of construction, vehicle overload and ship impact, will cause damage to the bridge foundation. Domestic and foreign scholars have found that scour is one of the most important factors [1, 2] in bridge accidents.

When a bridge is built in a river, the foundation of the bridge, such as column and pier, will change the flow condition of the river and the natural flow condition of the river. When the flow is blocked by the pier structure of the bridge, the flow structure around the pier will change, forming vortices and undercutting currents, which will eventually form scour on the riverbed. The formation of scour pit will reduce the depth of bridge foundation and reduce the bearing capacity of bridge foundation.

At present, the research on scour around bridge pier mainly focuses on scour factors, scour mechanism, scour test and numerical simulation. Some achievements have been made and some problems have been solved. In fact, the construction of river related bridges requires a reasonable pre-judgment before construction, and a safety assessment during operation for the built river related bridges,
which involves the assessment of scour around bridge pier. However, there are few research results on the scour risk assessment of existing bridge foundation and unbuilt bridge foundation. The risk assessment of local scour can provide great support for the site selection, survey, design, construction and operation management of river related bridges. Therefore, it is of great significance to study the classification and evaluation of local scour around bridge pier.

According to the literature, the existing research on risk assessment of local scour mainly includes: prediction of scour pit depth caused by scour, risk assessment of local erosion damage and prediction of scour pit depth based on risk. This paper summarizes the related research on the evaluation of local scour, and discusses the possible trend of the development.

2. Study on Depth Prediction of Scour Pit

2.1. Influencing factors of local scour around bridge pier
There are many factors that affect the local scour around bridge pier. At present, the research on the influencing factors can be divided into three categories: flow factor, sediment factor and pier factor.

2.1.1. Flow Factor. Flow factors generally include approaching velocity, approaching water depth and water impact angle. In view of the influence of approaching velocity on local scour around bridge pier, many experimental studies have been carried out.

Dongol [3] considered that in the moving bed scouring stage, due to the supply of sand from upstream, the scour depth decreases with the increase of the approaching velocity, and increases to another peak value again when it is reduced to the minimum value. Wang Shunyi [4] studied the influence of different approaching velocities on the depth and range of scour pits under moving bed conditions through model tests. The results show that the maximum depth and range of scour pits increase with the increase of velocity.

Experimental studies by Wang Shunyi [4] and Raudkiv [5] show that the maximum depth of local scour increases with the increase of approaching water depth. According to Dey [6], when the near water depth is small, the maximum depth of local scour increases significantly with the increase of the approaching water depth, but when the approaching water depth increases to a certain large value, the maximum depth has nothing to do with the approaching depth.

Tian Yong [7] and Zhang Xinyan [8] and other scholars have also carried out local scour tests under different water impact angles, and obtained some conclusions.

2.1.2. Sediment Factor. Some scholars such as Santos [9] believe that the size of sediment particles has no effect on the maximum depth of local scour around pier, while Gill [10] and other scholars believe that the maximum scour depth of pier is related to the particle size.

Since the sediment in the natural river is generally non-uniform, it is necessary to study the influence of sediment heterogeneity on the local scour around bridge pier.

Chiew [11] and Zhao Kai [12] carried out model tests on the influence of bed sediment heterogeneity on local scour, and found that the depth, scope and volume of local scour pit decreased with the increase of bed sediment heterogeneity.

2.1.3. Pier Factor. The compression effect of pier on flow is the direct cause of local scour around pier. Therefore, the data of pier such as pier length and pier width are important factors in the study of local scour around bridge pier.

Han min [13] carried out model tests of cylindrical piers with different diameters, and the results show that the larger the diameter is, the larger the scope of scour pit is.

Pen Peng [14] carried out a similar numerical simulation, and the results show that the depth of scour pit increases with the increase of diameter under the condition of moving bed.
2.2. Calculation formula for local scour depth of bridge pier

For a long time, due to the complexity of pier local scour mechanism and the diversity of influencing factors, there is no unified theoretical formula for the calculation of local scour depth. In recent years, there are two kinds of theoretical formulas and semi empirical formulas.

At present, the commonly used calculation formulas of local scour depth at home and abroad are as follows.

2.2.1. Standard Formula of JTG C30-2015 (in Chinese). Some Chinese engineers and experts summarized and analyzed the data and results of the local scour test of piers in China. Based on the data of 137 tests on the live-bed pier scour and 115 tests on clear water scour, the formulas of local scour depth prediction in non-viscous soil bed are established [15]. These are (64-1), (64-2), (65-1), (65-2) and revision (65-1). These formulas have been widely used in highway, railway and water conservancy projects in China.

For non-cohesive soil riverbed, formula (65-2) and revision (65-1) are based on the analysis of measured data and model test data of various river sections and bridges in China for many years, and have been widely used in the calculation of local scour around bridge pier. The formula (65-2) and revision (65-1) are as follows.

\[
h_b = \begin{cases} \frac{K_{\xi}K_{\eta}B_{1}^{0.6}h_{p}^{0.15}}{v_{0}}, & v \leq v_0 \\ \frac{K_{\xi}K_{\eta}B_{1}^{0.6}h_{p}^{0.15}}{v_{0}'}^{n_2}, & v > v_0 \end{cases}
\]

(1)

In the formula, \(K_{\eta_2} = \frac{0.0023}{d^2} + 0.375d^{0.24}, v_0 = 0.28(d + 0.7)^{0.5}, v_0' = 0.12(d + 0.5)^{0.55}, n_2 = \left(\frac{v_0}{v_0'}\right)^{0.23 + 0.19\log d}, \) \(\bar{d}\) is average size of sediment, \(h_b\) is local scour depth of pier; \(K_{\xi},K_{\eta_2}\) are pier shape coefficient and riverbed particle influence coefficient, \(B_1\) is calculation width of pier; \(v, v_0, v_0'\) are the approaching velocity before the pier after general scouring, the incipient velocity of riverbed sediment and the velocity of initial scour.

The formula revision (65-1) is:

\[
h_b = \begin{cases} \frac{K_{\xi}K_{\eta_1}B_{1}^{0.6}}{v_0}, & v \leq v_0 \\ \frac{K_{\xi}K_{\eta_1}B_{1}^{0.6}(v_0 - v_0')^{n_1}}{v_0 - v_0'}, & v > v_0 \end{cases}
\]

(2)

In the formula, \(v_0 = 0.0246\left(\frac{h_p}{d}\right)^{0.14} \sqrt{332\bar{d} + 10 + h_p}, K_{\eta_1} = 0.8\left(\frac{1}{d^{0.15}} + \frac{1}{d^{0.72}}\right), v_0' = 0.462\left(\frac{d}{B_1}\right)^{0.06}, n_1 = \left(\frac{v_0}{v_0'}\right)^{0.25d^{0.19}}, K_{\eta_1}\) is the Influence coefficient of riverbed particles, other parameters are the same as before.

2.2.2. HEC-18 formula (in USA). This formula was established by Richardson and Davis et al [16]. It is also recommended by FHWA of the United States Federal Highway Administration. The formula is:

\[
\frac{h_b}{h} = 2.0K_{f}K_{d}K_{b}K_{\eta_3}K_{w}\left(\frac{B_1}{h}\right)^{0.65}F_r^{0.43}
\]

(3)

In the formula, \(K_{f},K_{d},K_{\eta_3},K_{w}\) are the coefficients considering the impact angle of flow, bed condition, particle size distribution of bed sand and the influence of wide piers; \(F_r\) is Froude number; \(d_{x}\) is the bed sand particle size; \(V_{ld,c},V_{cd,x}\) are the velocity in front of the pier and the critical velocity respectively of diameter \(d_x\) particles.
2.2.3. Melville formula. Melville and Sutherland [17] established the calculation formula of local scour depth of envelope curve drawn based on experimental data. The formula is:

\[ h_s = K_s K_a K_l K_y K_\eta K \sigma \]  \hspace{1cm} (4)

In the formula, \( K_s, K_a, K_l, K_y, K_\eta, K_\sigma \) are pier shape coefficient, current impact angle coefficient, current intensity coefficient, water depth coefficient, sediment size coefficient and sediment gradation coefficient. Other parameters are the same as before.

3. Risk Assessment Study of Local Scour Failure

Local scour is an inevitable problem in the design and operation of bridges and an important aspect of safety evaluation. Therefore, it is necessary to study the risk-based analysis and evaluation method to determine the damage caused by the basic scour. Risk assessment of local scour around bridge pier is of great significance to judge the damage level of bridges that have occurred locally and to judge the potential damage risk of bridges to be built locally. At present, the common methods of risk assessment are accident tree method, fuzzy comprehensive evaluation method, analytic hierarchy process and inverse method. According to the actual situation and combined with these assessment methods, the risk assessment of local scour of bridges is beneficial.

On the basis of analyzing and summarizing the factors affecting the local scour around bridge pier, Wang Fei [18] selected the main damage factors as the evaluation index, quantified the four levels of the indicators, and established the model for evaluating the risk of local scour and blurring. This model was used to evaluate the hazard of Yangjiawan Bridge in Lanzhou capital of Gansu Province.

Based on the characteristics of hydrology and geology in the loess valley, Jiang Xu[19] studied and analyzed the damage types of bridges subjected to the scour action of water flow, and based on the actual investigation, established the damage index system of bridges affected by the scour in the loess valley environment.

On the basis of full analysis of factors affecting pier foundation safety of bridge across the Yellow River, the safety evaluation index system and safety evaluation model of bridge pier foundation under the Yellow River were established by Fuzzy Level Comprehensive Evaluation Method by Feng Zhongju [20]. This model was used to evaluate the safety of the Liujiang Yellow River Bridge in Zhengzhou.

Bryan [21] and others conducted risk assessments of eight road bridges in a certain area of Tanzania under scour conditions, established a functional relationship under scour conditions, calculated critical loads, and calculated the scour failure probability under critical loads using a pessimistic principle combined with statistics.

At present, some methods, such as damage model, damage effect analysis and risk priority, have been used to quantify the damage risk of local scour diseases of the bridges.

4. Study on Depth Prediction of Scour Pit Based on Risk Theory

The development of the local scour around bridge pier is influenced by the combination of many factors, and the uncertainties are quite great. These uncertainties are the risk sources, which lead to the inaccuracy of the traditional formula on the depth prediction of local scour pit. Therefore, how to predict the depth of the local scour pit around bridge pier more accurately is a difficult problem for all the researchers and engineers. With the application of risk assessment in the research of local scour around bridge pier, some scholars applied it to the research of depth prediction of scour pits.

Based on the Markovian model, taking into account the key time effect of the evolution of the scour during the accumulation and the randomness of future flood events, the uncertainty of flood flow and the development trend of flood line, Tubaldi [22] proposed a framework for assessing the probability of a local scour disaster under clear water conditions.

In NCHRP project " Risk-Based Approach for Bridge Scour Prediction " [23], Lagasse and others conducted a risk-based study of methods on local scour prediction, identified and assessed uncertainties related to the hydrological, hydraulic and prediction models associated with local scour prediction, and linked the most widely used hydraulic model to a framework on flood prediction, putting forward a
technique to predict the flood. Based on this project, in the report of the NCHRP 761 project, Lagasse and others developed a risk and reliability-based approach that links erosion estimates to statistical probability in order to more effectively predict the depth of local scour pit.

Due to the need for relatively more flood investigation, site investigation as the support and statistical basis for the uncertainty factors to carry out probability statistics, currently based on the risk assessment of the scour pit depth, the research direction is still in the development stage.

5. Discussion
This paper systematically summarizes the main research results of the hazard evaluation on the local scour around bridge pier, and makes a preliminary analysis, including the research results of prediction in scour pit depth, local scour damage risk assessment and risk theory evaluation.

At the same time, this paper considers that the following aspects should be studied in the harm assessment of the local scour around bridge pier.

(1) Refine the prediction formula of scour pit depth. Due to the differences in hydrology, geology, topography and buildings, it is difficult to put forward a formula suitable for different working conditions. At present, the method of soil property classification and other factors as influencing factors is slightly rough, and the calculation results often have much deviation, so it is recommended to refine the formula classification.

(2) Quantification of risk assessment factors for local scour of bridge piers. In the aspect of risk assessment of local scour, the methods based on fuzzy theory or analytic hierarchy process (AHP) depend on people to determine the index, which will cause subjective error. In the future research, it is necessary to deepen the research on the internal relationship of parameters to minimize the possible bias caused by human cognition.

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