Discussion on Some Problems of Local Scouring of Bridge Foundation

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Abstract. Local scouring is one of the main factors leading to bridge foundation damage. There are many aspects involved in the study of local scouring of bridge foundation. In this paper, the research progress of flow structure, sediment movement characteristics and evolution characteristics of scour pits in pier local scouring are summarized. The influencing factors of pier local scouring are concluded. Finally, the existing problems and future research trends are discussed.

Introduction

With the rapid development of social economy, bridges of high-speed railways, expressways and other projects have become one of the important symbols to measure the economic strength and modernization level of a country or region. It is an important part of transportation lines, and plays a very important role in developing national economy, promoting cultural exchanges and consolidating national defense. It has great social and economic benefits.

Due to various reasons, such as incomplete design considerations, river evolution, poor protection of bridge foundation, most of the bridge foundations are damaged, and some of the bridge bearing capacity declines until the bridge instability and other disasters.

New York State Transportation Administration and Texas A&M University counted 1,502 bridge damage cases in the United States between 1966 and 2005. Of these cases, 58% of bridge damage was caused by water erosion \cite{1}.

Yi Renyan analyzed 179 bridge collapse accidents from 2000 to 2014, and found that 32% of them were caused by flood scouring \cite{2}. It can be seen that pier scouring, as the main culprit of bridge water damage, is one of the most critical factors causing bridge damage.

At present, domestic and overseas scholars mainly divide pier scour into three parts: natural scour, general scour and local scour. Many years of practice has proved that local scour is the most important part of pier scour and the direct cause of bridge erosion. Therefore, it is of great significance to study the local scouring mechanism of piers.

In this paper, the research progress of local scour of bridge pier is summarized from three aspects: flow structure, sediment movement characteristics and evolution characteristics of scour pit. The influencing factors of local scour of bridge pier are concluded. Finally, the existing problems and future research trends are discussed.

Study on Flow Structure around Piers

Flow structure refers to the spatial and temporal distribution of movement characteristics and elements in flow, which is one of the main research contents of river dynamics. The construction of bridges hinders the flow under bridges by piers, changes the flow structure around piers, and produces strong eddy current, which causes local scour. At present, scholars at home and abroad generally agree that the flow structure around piers mainly includes downward flow, surge wave and eddy system of flow around piers\cite{3}. As a complex flow structure, the whirlpool system mainly consists of...
horseshoe-shaped whirlpool around the edge of scouring pit in front of pier and wake whirlpool caused by the separation of flow on both sides of pier[4].

By means of field investigation, experiment and numerical simulation, the researchers summarized the causes of local scour of piers into three viewpoints: (1) the impact of downward flow in front of piers, (2) the whirlpool system around piers, (3) and the compression effect of piers on water flow.

Unger [5] studied the flow field around the local scour pier through model tests. It was considered that the local scour was caused by the horseshoe vortex and downfall. Pournazeri found that the downward flow and vortices in front of piers are the main causes of local scouring through the scouring test of non-uniform sediment [6]. Through experimental observation, Zhang-Xianhui considered that the water-blocking effect of pier formed the downward flow in front of pier and the accelerating area of flow at the side of pier, and the combined action of the two resulted in the formation of horseshoe-shaped eddy [7].

In the study of local scouring flow structure of piers, Melville measured the complex flow field in the scouring pit of piers on the basis of quantitative measurement combined with bubble technology [8]. Dargahi analyzed the flow field of horseshoe-shaped vortices by hydrogen bubble flow visualization technology [9]. Ling Jianming used FLUENT to simulate the three-dimensional flow field near the cylindrical pier [10].

Study on Characteristics of Sediment Movement
The water-blocking effect of piers results in the increase of flow intensity around piers and the formation of vortices, thus causing sediment movement. Sediment movement mainly includes erosion, transport and deposition.

When the flow velocity around the pier is greater than the starting velocity of the bed sand, the bed sand starts and is carried downstream by the flow. Scouring phenomenon first appears on both sides of the pier. With the scouring process, the formation of vorticity structure increases the shear stress of the flow on the river bed, and scours through the pier leading edge to form scouring pits.

It is difficult to observe sediment movement in pier scouring experiment. So scholars mostly use numerical simulation to study sediment erosion, transport and deposition characteristics.

Considering only the transport of suspended load, Olsen carried out three-dimensional numerical simulation of local scour of cylindrical pier, which simulated the development process of scour pit and calculated the maximum local scour depth [11].

Considering only bed load transport, JIA proposed a numerical method using a three-dimensional free surface RANS turbulence model [12]. The non-equilibrium sediment transport method was used to simulate sediment erosion, transport and deposition.

Considering the transport of total sediment (suspended load and bed load), Mohammad used CFD model to simulate and calculate the scouring sediment movement characteristics of piers under constant flow conditions [13].

In natural rivers, river sediment is often heterogeneous. Fine sediment is easier to start and wash downstream than coarse sediment. Coarse sediment is left behind. With the scouring process, a coarsening layer is gradually formed on the surface of the river bed. Coarsening layer can protect the fine sediment in the lower layer from being washed away.

SUN have studied the local scouring limit depth and the gradation of coarsening layer after the formation of coarsening layer [14]. Zhang Tuoming have observed the formation and evolution of non-uniform sediment coarsening layer in local scouring process with fixed-point camera [15].

Study on Evolution Characteristics of Scour Pits
The construction of piers reduces the area under the bridge, and the increase of water flow around the piers causes the erosion, transportation and deposition of sediment around the piers, and finally forms
scouring pits around the piers. The depth and scope of scour pits will seriously affect the stability of piers, so it is of great significance to study the evolution characteristics of scour pits.

Previous studies have shown that the evolution of scour pits can be roughly divided into three stages: (1) The acceleration of water flow on both sides of pier makes the bed sand shear stress greater than the bed sand initial shear stress, which leads to erosion; (2) the action of vortices on the bed sand leads to the penetration of scour pits on both sides of pier into pier front; (3) the scour pit is in a stable state after the end of scour.

At present, the study of scour pits is more about the depth and scope of scour equilibrium, and less about the evolution and development of scour pits.

Umesh studied the variation of scouring pit depth with time under uniform and non-uniform sand conditions [16]. The results showed that the scouring rate of pier in the initial stage of local scouring was very high, and the maximum scouring depth increased rapidly. After a period of time, the final scour pit tends to be stable.

Wang Fei used FLUENT software dynamic grid technology to simulate the erosion development process of Melville classical scour test [17]. The simulation results of the development process and shape of the scour pit are in good agreement with the test results, while the simulation depth of the scour pit is slightly smaller than the test results.

**Study on Influencing Factors of Partial Scour of Bridge Piers**

There are many studies on Influencing Factors of local scour of bridge foundation. At present, it is generally believed that the main influencing factors of local scour of piers can be classified into three categories: flow factor, bed sand factor and pier factor. Among them, flow factors include approach velocity \( v \), approach water depth \( h \), angle of water flow attack \( \theta \), and so on; bed sand factors include particle size, particle size distribution and non-uniformity; pier factors include shape, pier length, pier width, diameter and so on.

**Flow Factors**

Many scholars have carried out experimental studies on the effect of different approach velocity on local scour of piers. Chiew studied the change trend of scour pit depth by changing the approach velocity [18]. According to the test results, it was found that the maximum scour depth increased with the increase of current velocity in the clean water scouring stage, and decreased with the increase of approach velocity after entering the scouring stage of movable bed due to the recharge of upstream sediment. After reaching the minimum, the scouring depth increases again to another peak. Under the condition of clear water scouring, the scouring depth increases approximately linearly with the increase of the approach velocity. When the starting velocity of bed sand is reached, the scouring value reaches the maximum.

There is still some controversy about the influence of approaching water depth on local scour of piers. Raudkivi experimental results show that the maximum depth increases with the increase of the approach water depth [19]. Jiao Aiping believed that the relationship between the local maximum depth and the approaching water depth is a multi-value change [20]. Dey believes that the maximum equilibrium depth increases significantly with the increase of the approaching water depth when the approaching water depth is small, while when the approaching water depth is large, the maximum equilibrium depth has nothing to do with the approaching water depth, and there is a limit depth between the two [21].

Tian Yong carried out laboratory model tests on local scour of oblique rectangular circular piers at different angles of attack [22]. The results show that the scour pit range and depth increase with the increase of impact angle, and when the angle of water flow attack is greater than 15 degrees, conjugate scour pit will appear, and its depth and scope will also increase with the increase of the angle of attack.
Bed Sand Factors

There is a corresponding relationship between the size of bed sand particle and local scour depth, but there is no unified understanding. Santos believed that the size of bed sand had no effect on the maximum local scour depth of piers, while Gill believed that the maximum scour depth of piers was correlated with the size of piers [23,25].

Because the bed sediment is often uneven in the actual River channel, the study of the influence of the bed sediment non-uniformity on the local scour of piers has more practical significance. Chiew studied the local scouring depth of uniform sand and non-uniform sand under different flow intensities [18]. It was found that the more uneven the bed sand, the smaller the scouring depth. Zhao Kai studied the effect of non-uniformity of bed sand on the depth, scope and volume of scour pit through generalized physical model test [4]. The test results show that the depth, scope and volume of scour pit decrease with the increase of non-uniformity of bed sand, and the scour depth has a linear relationship with the logarithms of non-uniformity coefficient $C_u$ and geometric mean variance $\sigma_g$.

Pier Factors

Pier shape can directly affect the flow structure around pier, and it is very important to the local scour of pier. According to a large number of scouring tests on piers of different shapes, it is found that the relationship between local scouring depth is square pier > circular pier > triangular pier, and streamlined pier has the smallest scouring depth when it is arranged along the current [4]. Generally, the longer the pier is, the wider the pier is (or the diameter larger), the stronger the compression effect of the pier on the flow, and the more serious the local scour is.

In addition to the above factors affecting local scour of piers, there are also fluid density, fluid viscosity, sediment content, sediment bulk density and density, and the factors can interact with each other.

Question and Discussion

In view of the current research on local scour of bridge piers, the following problems and future research trends are put forward.

1) There are abundant research results on the local scour mechanism of Sandy and non-cohesive soil riverbed, but few studies on the mechanism of non-cohesive soil and rock riverbed. What is the difference between the local scouring mechanism of non-cohesive soil and rock riverbed and the influence of bed material characteristics on the local scouring? This will involve the related contents of geomechanics, and will be the focus of the future study on the local scouring mechanism of bridge piers.

2) At present, the study of scour pits focuses on the depth and scope of scour equilibrium, and the study of the evolution and development of scour pits is less. This is because of the limitations of measurement technology, it is difficult to achieve real-time dynamic measurement. Therefore, the breakthrough of measurement technology is imperative.

3) At present, the main research on influencing factors is the influence of a single factor on local scouring, while the influence of various factors on local scouring is less studied. Therefore, it is necessary to simulate the complex scouring process more accurately in the laboratory in order to further study the interaction of various factors.

4) In order to make the study of local scouring of piers more practical, the study can start with the analysis of the degree of damage caused by local scouring. How to classify the local scour of bridge foundation is also an important part of the future research on local scour.

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