Explore on the Dynamic Cause of Local Scouring

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Abstract: Based on the physical model test method, the dynamic cause of local scouring is explored. Result shows that uneven distribution of vertical turbulence intensity of near-bottom flow is the main driving force for local scouring. Distribution characteristics of vertical turbulence intensity of the near-bottom flow determine the spatial shape of the local scouring, that is, the range and the extreme-deep point of the local scouring correspond to the position of the strong turbulent zone and maximum value respectively. When the effect of the near-bottom strong turbulence zone on the riverbed is completely isolated, local scouring disappears, otherwise it will occur in the uninsulated part.

1. Introduction

The cause of the local scouring in the vicinity of the project has always been a difficult problem for researchers who still have different opinions on this. Among these opinions, there is one that is attracting more attention, which believes that the characteristics of vertical turbulence near the river bottom (or pulsating pressure on the bed surface) have an important effect on the formation of partial scouring on the bed surface. Studies [1-3] have measured the pulsating pressure distribution on the bed surface of the head area of groyne, indicating that the area with the largest pulsation pressure on the bed surface basically suffers the most severe scouring. This paper further explores the relationship between local scouring and characteristics of vertical turbulence of the near-bottom flow by studying the Baimaosha waterway project of the first phase of the 12.5-meter deep-water channel downstream from Nanjing.

The Baimaosha waterway project of the first phase of the 12.5-meter deep-water channel downstream from Nanjing is mainly to build the submerged border dike at the edge of the high beach of the Baimaosha, and to build the submerged leading dike at the head of the Baimaosha and the upstream extension (See Figure 1) to protect the beach. The spur dikes are built on the south side of the submerged leading dike and the submerged border dike so as to adjust the flow.

2. Data and methods

2.1. Local scouring simulation

The simulation method of local scouring in this paper is elaborated in the literature [4-5]. There are three major points: (1) the model is normal, ensuring the similarity of three-dimensional flow; (2) the basic motion characteristics of sediment are similar; (3) reasonable simulation of regulating structure.
2.2. **Flow turbulence intensity**

The flow velocity is measured by ADV (Vectrino plus) flow meter (see Photo 1); the data acquisition frequency is 200HZ; the average distance between adjacent measuring points is about 60 m (converted to prototype, the same below).

\[
\bar{u}_z = u_z + u'_z
\]

\( u_z \) is the vertical average flow velocity; \( u'_z \) is the vertical pulsation flow velocity, which changes with time.

The standard deviation of the vertical pulsating flow velocity of each measuring point is used to represent its turbulence intensity, namely:

\[
\sigma_u = \sqrt{\frac{\sum_{i=1}^{n} (u'_z)^2}{n-1}}
\]

In the test, the flow velocity measurement was carried out on the fixed bed model, and the local scouring simulation was carried out on the movable bed model. The hydraulic conditions used in the fixed bed and movable bed model tests were exactly the same, which is corresponding to the maximum ebb flow velocity when spring tide and flood prevention design flood occur at the same time [2].

2.3. **Test area**

In the experiment, two representative zones were selected for the research, one was the submerged leading dike head zone and the other was the S1 spur dike zone (Figure 2). The area of the submerged leading dike head zone was about 0.95 km² with a total of 300 measuring points. The area of the S1 spur dike zone was about 1.76 km² with a total of 528 measuring points. The terrain change monitoring range is beyond the above two areas.

Due to the large number of measuring points (828 in total) and large terrain fluctuations, measuring points of the ADV probes in the test are fixed at about 5.0 m below the water surface in order to
facilitate measurement. Later studies have shown that this measurement method has certain defects. It can better reflect the vertical turbulence characteristics of the near-bottom flow only in shallow zones (such as the submerged leading dike head zone and the vicinity of S1 spur dike body), but not in the deep water zone (such as the vicinity of S1 spur dike head). It is because the vertical distribution of flow turbulence intensity varies greatly in this zone and the water depth of the probe is relatively shallow, the vertical turbulence characteristics of the near-bottom flow are not well reflected. This is a place for further improvement in future research. This paper focuses on the zone other than the vicinity of the spur dike head when analyzing the vertical turbulence characteristics of the near-bottom flow in the S1 spur dike zone.

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3. Test Result

In the submerged leading dike head zone, the plane distribution of the vertical turbulent intensity near the bottom flow and the topographic changes after the same hydraulic conditions are shown in Figure 3 and Figure 4 respectively. In the S1 spur dike zone, the plane distribution of the vertical turbulent intensity near the bottom flow and the topographical changes in the same hydraulic conditions are shown in Figure 5 and Figure 6 respectively. Based on these test results, the following two salient features can be seen:

(1) When there is no obvious local strong turbulence zone near the project, there is no obvious local scouring phenomenon near the project. Take the submerged leading dike head zone as an example. Because the dike body in the submerged leading dike head zone is relatively low and the angle between the flow direction and the direction of dike body is relatively small, which does not cause significant increase of the vertical turbulence intensity of the bottom flow near the dike body, the vertical turbulence intensity distribution of the near-bottom flow in the whole study zone was relatively uniform. Correspondingly, there was no obvious local scouring near the submerged leading dike body in the whole study zone.
(2) When there is an obvious local strong turbulence zone near the project, obvious local scouring phenomenon also occurs near the project. Take the S1 spur dike zone as an example. Because the dike body in the S1 spur dike zone is relatively high and the angle between the flow direction and the direction of dike body is relatively large, that causes significant increase of the vertical turbulence intensity of the bottom flow in local zone near the lower reaches of the dike body. Correspondingly, there appeared obvious local scouring near the S1 spur dike body in the whole study zone. In addition, it can be seen from the distribution of the strong turbulent zone and the local scouring groove near the dike body that the positions of the two are substantially coincident on the plane, that is, the widths of the local scouring groove and the strong turbulent zone are substantially the same (about 120 m), and the thalweg of the local scouring groove also basically corresponds to the position of the maximum value of the vertical turbulence intensity of the near-bottom flow.

![Fig. 3](image1.png)  
**Fig. 3** Plane layout of the horizontal flow field and the vertical turbulent intensity in the submerged leading dike head zone

![Fig. 4](image2.png)  
**Fig. 4** The scouring situation in the submerged leading dike head zone

![Fig. 5](image3.png)  
**Fig. 5** Plane layout of the horizontal flow field and the vertical turbulent intensity in the S1 spur dike zone

![Fig. 6](image4.png)  
**Fig. 6** The scouring situation in the S1 spur dike zone
Limited by the measurement method of this test, the vertical turbulent intensity distribution of the near-bottom flow near the S1 spur dike head is not revealed, but its distribution law can be reflected from the existing research results. The literature [1] measured the pulsating pressure distribution on the bed surface near the dike head, indicating that the position with the largest pulsation pressure on the bed surface basically corresponds to the position of the most severe scouring. Because the variation of the bed pulsation pressure is consistent with the vertical turbulence of the near-bottom flow, the position with the largest pulsation pressure is the position with the maximum vertical turbulence intensity of the near-bottom flow. It can be inferred that the local scouring shape near the S1 spur dike head also corresponds to the vertical turbulent intensity distribution of the near-bottom flow.

4. Mechanism Analysis
Why the local scouring shape is closely related to the vertical turbulence intensity distribution of the near-bottom flow? In the following, two aspects are elaborated respectively from the change of force acting on sediment of the riverbed and the change of sediment carrying capacity of flow.

(1) The change of force acting on sediment of the riverbed. Under the turbulent load, the pore water pressure and seepage field inside the riverbed will change significantly, so that the fine sediment will move from the weak position of structural connection to the surface of the riverbed, and the loss of a large amount of fine sediment forms micropores inside the riverbed, which causes a significant decrease in the shear resistance of the riverbed, leading to softening or liquefaction [6]. Therefore, when the vertical turbulence intensity of the near-bottom flow in the local zone of the river bed is significantly enhanced, the force acting on sediment of the riverbed in this local zone is significantly decreased, and the riverbed sediment in this local zone is easier to move than in other zones. In addition, the particle size of the local scouring zone surface is generally coarser than that of the nearby riverbed surface, which is also in agreement with the above analysis.

(2) The change of sediment carrying capacity of flow. When the vertical turbulence intensity of the near-bottom flow in the local zone is significantly increased, the sediment carrying capacity of flow in this zone will also increase significantly. On the one hand, this change makes the riverbed sediment in this local zone easier to move than in other zones; on the other hand, it makes the sedimentation of this local zone more difficult than other zones, thereby causing an unbalanced sediment exchange between this local zone and other zones.

The above two points should be the intrinsic reasons for the occurrence of local scouring. Of course, there are also some scholars who believe that it is due to other reasons such as the special distribution of time-mean velocity, which the author has different views.

Figure 7 is the test result of the near-bottom hydrodynamic characteristics of a submerged dike under the condition of overflow at the top of dike. Among them, the turbulence intensity value is calculated according to the near-bottom vertical turbulent flow velocity. The flow velocity value is the time-averaged velocity in the horizontal direction (also vertical to the dike axis) near the bottom.

![Fig.7 The near-bottom hydrodynamic distribution behind the dike caused by overflow at the top of dike](image-url)
It can be seen from the figure that the near-bottom horizontal velocity in the position of the maximum near-bottom vertical turbulent strength is zero, and the zone corresponding to the local strong turbulence is exactly the low-value zone of the time-averaged velocity distribution near the bottom. If only the effect of time-averaged velocity is considered, the sand in the low-value zone should be the most difficult to move and the most likely to fall, that is to say, the zone should not form “local scouring”, but should form “local siltation”. Obviously this is not consistent with engineering practice.

The analysis result shows that the local scouring is closely related to the vertical turbulence intensity distribution of the near-bottom flow, and the uneven distribution of the vertical turbulence intensity of the near-bottom flow is the main driving force for local scouring.

5. Mechanism Verification

It can be known from the previous understanding of the mechanism of local scouring that the vertical turbulence intensity distribution of the near-bottom flow determines the spatial shape of local scouring if other conditions remain unchanged. It can be further seen that if the action of the near-bottom strong turbulence zone on the riverbed is completely isolated, local scouring should not occur. Otherwise, local scouring will occur in the uninsulated part.

In order to verify the above speculation, the S1 spur dike is selected for test with four sets of different isolation positions, and the isolation method used is soft mattress. The 1st to 3rd groups of tests are integral tests of different isolation widths, and the specific isolation positions are shown in Figure 8 to Figure 10 respectively. The isolation width (distance from the dike axis) is 55 m, 90 m and 120 m, respectively, among them, the isolation width of the 3rd group basically covers the all range of the near-bottom strong turbulence zone. The 4th group is a local test with a loophole, which mainly simulates the unsatisfactory overlap of the soft mattress in engineering practice, leading to the existence of loopholes. For reference, see photo 2. The test results are shown in Table 1.

| Name | No isolation test | The 1st group | The 2nd group | The 3rd group | The 4th group |
|------|------------------|---------------|---------------|---------------|---------------|
| Test results | A scouring ditch is generated near the dike body, and the maximum scouring depth is about 10m, and the scouring width is about 120m. | The maximum scouring depth in front of the soft mattress is about 9.0m, and the scouring width is 50-70m. | The maximum scouring depth in front of the soft mattress is about 4.5 m and the scouring width is 20-40 m. | The local scouring phenomenon in front of the soft mattress disappears basically | Serious scouring occurs in the position of the loophole, and the soft mattress sinks near the loophole. |

![Fig.8 Isolation layout and scouring results in the 1st group test](image1)

![Fig.9 Isolation layout and scouring results in the 2nd group test](image2)
It can be seen that the test results are completely consistent with the previous understanding of the mechanism of local scouring. It is mainly manifest in the following two aspects:

1. Under the condition of completely isolating the action of the near-bottom strong turbulence zone on the riverbed (the 3rd group test), local scouring disappears.

2. Local scouring occurs in the uninsulated parts (the other three groups of tests). In particular, the 4th group test was the most convincing. If the problem is considered only on the basis of the time-averaged velocity, the sediment in the loophole of the soft mattress cannot be lost because the velocity of the water in it is close to zero. However, the turbulence intensity in it is actually large and the sand can’t be kept, which is the main reason for the serious loss of sediment and the sinking of the soft mattress.

6. Conclusion
This paper explores the dynamic cause of local scouring through physical model tests. New insights in the following four aspects are gained.

1. Uneven distribution of the vertical turbulence intensity of the near-bottom flow is the main driving force for the local scouring.

2. When there is a near-bottom strong turbulence in a local zone near the project, it will cause significant change of the force acting on sediment of the riverbed in this local zone, leading to softening or liquefaction, which makes the riverbed sediment in this local zone easier to move than other areas. On the other hand, it will lead to a significant increase of the sediment carrying capacity of flow in this zone conducive for the sediment in this local zone to move but not stay, causing an unbalanced sediment exchange between this local zone and other zones. And thereby, local scouring occurs.

3. The distribution characteristics of vertical turbulence intensity of the near-bottom flow determines the spatial shape of the local scouring, that is, the range and the extreme-deep point of local scouring correspond to the range of the near-bottom strong turbulence zone and its maximum value respectively.

4. When the action of the near-bottom strong turbulence zone on the riverbed is completely isolated, local scouring disappears, otherwise, the local scouring phenomenon will occur in the uninsulated parts.
Acknowledgments

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