Experimental study on scour characteristics of the sheet-pile groin

Yuanping Yang 1,2, Zhiyong Zhang1,2, Kun He1,2, Gang Chen1,2

1Zhejiang Institute of Hydraulics & Estuary, Hangzhou, Zhejiang, 310020, China
2Key Laboratory of Estuary and Coastal of Zhejiang Province, Hangzhou, Zhejiang, 310020, China

*Corresponding author’s e-mail: yangyp@zjwater.gov.cn

Abstract: Spur dike is widely used to protect river bank in hydraulic engineering. However, the scour around spur dike caused by narrowing flow is often too deep to induce the failure of dike. In this paper, a new type of spur dike: sheet-pile groin is developed and the scour characteristics around it are studied based on experiment. The experiment results show that, compared with the solid spur dike of the same size, the maximum scour depth near the head of the sheet-pile groin reduces by averagely 30% under the same flow conditions. The sheet-pile groin makes the water flow away from itself and the shoreline. When there is an over-dam flow on the top of the spur dike, the sheet-pile groin has a stronger protective effect on the beach behind it than the solid spur dike does. The scouring and silting features of the local riverbed around the sheet-pile groin benefit the stability of the spur dike and the protection of the coastal beaches.

1. Introduction
As an engineering measure of beach protection and main channel control, spur dike is widely used in river course, channel regulation, and coastal protection \cite{1}. Due to the blocking effect of the spur dike, the water flow passes by the spur dike head, which forms high-velocity flow and complex flow states such as whirlpool and dive flow near the spur dike head. The flow results in severe local scour of the river bed around the spur dike head, and the deep scour pit poses a threat to the safety of the spur dike head \cite{2, 3}. At present, research methods including field measurements \cite{4, 5}, physical modeling \cite{6, 7}, and numerical modeling \cite{8-10} are widely used to study the scour and sedimentation of the riverbed around the spur dike. However, most research focuses on traditional solid spur dike, which has great block effect due to impermeable ability. In this paper, a new type of permeable spur dike: sheet-pile groin, was designed and the scour characteristics around the sheet-pile groin were studied. The difference of scour characteristics between solid spur dike and sheet-pile groin was discussed.

2. Experiment setup

2.1. Experiment flume and measuring equipment
The flume is 50m long and 4.0m wide. The movable bed section is 10m long and the sanding depth is 0.30m. The experiment model sand uses natural quartz sand with an average particle size of 0.32mm, which is non-cohesive and has a density of 2.65g/cm³. The experiment uses a variable frequency timing control system of pumps. During the experiment, the boundary water level is measured and compared with the predetermined water level. The bus industrial computer uses the PID algorithm of integral
separation, and according to the difference between the boundary water level and the predetermined water level, the boundary water level is corrected by adjusting the inverter output frequency and the system forms a closed-loop control loop. The field photos of the experiment flume and the model sand particle gradation are shown in Figure 1.

The washed terrain is measured using the three-dimensional laser topographic measurement system independently developed by Zhejiang Institute of Hydraulics & Estuary. After draining the riverbed surface water, the system can quickly realize topographic measurement and output high-density 3D point cloud data. The contour map drawn by the point cloud data can truly reflects the details of the riverbed topography. The three-dimensional topographic measurement system and contour map are shown in Figure 2.

2.2 Experiment Scheme

2.2.1. Experiment spur dike. The sheet-pile groin and the solid spur dike are selected for experimental study. The length of the sheet-pile groin and the solid spur dike are 67cm, and the spur dike crest is higher than the bed surface in two cases, 5cm and 10cm respectively. The solid spur dike used in the experiment is made of lightweight bricks. The sheet-pile groin is made of PVC pipe and plexiglass materials. The sheet-pile groin is composed of three parts, head, body, and root. The head part is 15cm
long, the dispersed pile foundation is adopted and the pile gap ratio is 3:2. The body part is 42cm long, and its upstream surface is continuous sheet piles. The root part is in solid form with a length of 10cm. The models of the spur dikes are shown in Figure 3.

2.2.2. Flow conditions. The scour depth and scour pattern of the spur dike are mainly related to the approach velocity (V), water depth (H) near the head of the spur dike, and the height (H0) and length (L0) of the spur dike structure. The experiment water depth adopts two typical water depths of 10cm and 20cm, and the velocity ranges from 15cm/s to 50cm/s.

3. Result Analysis

3.1. Maximum scour depth

3.1.1. Maximum scour depth of solid spur dike. Figure 4 shows the maximum scour depth of the solid spur dike under different water depths and different flow rates. It can be seen from the figure, under the same water depth, the scour depth increases with the increase of flow velocity. For example, under the condition of the same water depth of 20cm, the scour depth of the solid spur dike is basically linearly correlated with the flow velocity. With the increase of the flow velocity, the scour depth increases linearly. There is a similar rule under the condition of a water depth of 10cm. Under the same flow velocity, the scour depth decreases with the increase of water depth. Generally speaking, with the increase of the flow rate, the scour depth of the solid spur dike head under the condition of 10cm water depth and high flow velocity is greater than that of the corresponding 20cm water depth and flow.
velocity condition. This is because the water blocking rate under the condition of 20cm water depth is less than the water blocking rate under the condition of 10cm water depth, and the larger water blocking rate results in a deeper scour depth.

Under the same spur dike height condition, the maximum scour depth decrease with the water depth. When the spur dike height is determined, the greater the water depth, the smaller the relative water blocking surface area (water blocking rate) of the solid spur dike, and the weaker the water blocking effect of the spur dike. The maximum scour depth of the spur dike head with a large water depth under the same flow velocity is slightly smaller. There is no obvious difference in the depth of scour pits with different water depths with flow velocity less than 25cm/s. It can be seen from the figure that when the flow velocity is less than 25cm/s, the local maximum scour depth of the groin head is basically within 8cm, and the scour depths under different water depth conditions are relatively close.

3.1.2. Maximum scour depth of sheet-pile groin. The maximum scour depth of the sheet-pile groin under different water depths and different flow rates is shown in Figure 5. The maximum scour depth of the sheet-pile groin has the following: under the same water depth, the maximum scour depth increases with the flow velocity. Under the conditions of water depths of 10cm and 20cm, the rising trend of the scour depth within the experiment flow rate range is approximately linear. Under the same water depth, due to the influence of water blocking rate, the higher the sheet-pile groin height, the greater the scour depth. Under the same sheet-pile groin height condition, the smaller the water depth, the greater the water blocking rate of the sheet-pile groin, which increases the scour depth.
3.1.3. Comparison of spur dike scour depth. Figure 6 shows the comparison of the maximum scour depth between the solid spur dike and the sheet-pile groin. It can be seen that under the same spur dike height, water depth and flow rate, the maximum scour of the solid spur dike is generally greater than the sheet-pile groin. The flow velocity is greater, the difference in scour depth between the two is greater. The experiment data shows that the maximum local scour depth of the sheet-pile groin is 7% to 60% less than the solid spur dike, with an average reduction of 30%. The sheet-pile groin has obvious advantages in reducing the local scour depth near the sheet-pile groin head than the solid spur dike.
3.2. Comparison of scour patterns

3.2.1. Scour patterns of solid spur dike. From the experiment results, under the same water depth condition, as the flow rate increases, the maximum scour depth increases, and the range of the scour pit also increases. Under the same flow rate, the depth and range of the scour pit near the head of the solid spur dike decrease with increase of the water depth. From the perspective of the scour patterns, there are two types of erosion. One is caused by the flow around the spur dike head; the other is caused by the flow of water over the spur dike. The solid spur dike scour pit extends downstream at the spur dike head, and the direction is basically perpendicular to the spur dike, and it changes with the increase of the flow velocity. Under the condition of small water depth, an integrated scour pit is formed at the spur dike head; when the water depth increases, the over-dam flow of the spur dike will cause the downstream scour of the spur dike head. The spur dike head scour pit takes the form of double pits, and the main scour pit is still on the outside of the spur dike head. However, there are small scour pits on the downstream side of the head of the spur dike. The scour patterns under typical working conditions is shown in Fig. 7.
3.2.2. Scour patterns of sheet-pile groin. The deepest part of the scour pit appears on the side of the sheet-pile groin head, and the scour pit extends in the sheet-pile groin axis direction of the angle of 135°. With the increase of the experiment flow rate, the extent of the scour pit increases, and the length of the scour pit increases. The erosion on the downstream side of the groin head is not obvious. Under the condition of low flow velocity, there are some depositions, which indicates that the sheet-pile groin has better protection on its rear area than the solid spur dike.

![Figure 8. Scour patterns of sheet-pile groin](image)

3.2.3. Comparison of scour patterns. Under the condition of the same groin height, scour depth near the head of the sheet-pile groin is significantly smaller than that of the solid spur dike, and the range of scour pit is also smaller because the water body can pass through the sheet-pile groin body and the flow near the head is weakened. The scour pit near the head of the sheet-pile groin develops away from the spur dike. The sheet-pile groin has a better protective effect on its rear bed surface because the foundation has a decelerating effect on the passing water flow and the passing water flow is relatively stable. Overflow at the crest of a solid spur dike will easily cause erosion at the downstream side of the groin. Under the same conditions, the erosion of the downstream beach of the sheet-pile groin is weaker than that of the solid spur dike.

4. Conclusion
In this paper, a comprehensive experimental investigation on scour around sheet-pile groin was reported. The experimental research’s results show that under the condition of the same height and length of the sheet-pile groin and solid spur dike, the greater the flow velocity, the greater the scour depth. Under the same flow velocity, the water blocking rate increases with the decrease of water depth, and the maximum scour depth at the groin head also increases with the decrease of water depth. Under the same flow conditions and the same groin length and groin height, the maximum local scour depth of the sheet-pile groin is 7% to 60% less than the solid spur dike, with an average reduction of 30%. Overflow at the crest of a solid spur dike will easily cause erosion at the downstream side of the groin. Under the same conditions, the erosion of the downstream beach of the sheet-pile groin is weaker than the solid spur dike. Compared with the solid spur dike, the sheet-pile groin has obvious advantages in reducing the local scour depth of the groin head. The sheet-pile groin will make the water flow away from the spur dike and the shoreline, which is beneficial to the protection of the coastal beaches upstream and downstream of the groin.
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