Study on the Riverbed Evolution under the Condition of Clear Water Flushing

Cheng Xiaobing 1*

1Tianjin Research Institute for Water Transport Engineering, Key Laboratory of Engineering Sediment, Ministry of Transport, Tianjin 300456, China

*Corresponding author’s e-mail: tkscxb@126.com

Abstract: Water flow downstream of the hub is clear, and the riverbed scouring is large, which affects the navigation depth of the channel. In this paper, the flume experiment is carried out to study the degree of undercut of the riverbed under the action of clear water scouring, the change of the particle size of the bed load, the decrease of the water level and the change of the sediment transport rate along the channel. The results show that the initial channel of the lower reaches of the hub is eroded. With the deepening of the riverbed, the bed material is coarsened and the erosion is gradually weakened, and the later flushing rate is gradually constant. The inlet water level in the sanding section first drops steadily and then gradually stabilizes. The water transport rate along the channel is a power function relationship with time. In the power function relationship, there is a balanced sediment transport period.

1. Introduction

After the water control project is built in the plain area river, the riverbed of downstream dam is inevitable scoured, and the water level drop after the normal operation of the water control project is a very important issue in the design of each water control project. The water level drop may result in the water depth of the lower gate of the ship lock not meeting the design requirements, which will increase the construction and operation costs of the hub. Due to the lack of sufficient scientific argument for the determination of the water level drop value, the serious consequences of shipping are often caused by insufficient consideration. Flushing the riverbed often leads to roughening of the riverbed and lowering of the water level. Qin [1] believes that bed sand coarsening can be divided into cobble sand coarsening and sandy river bed coarsening. After the pebble sand bed is washed by flood, a stable anti-shrinking protective layer will be formed. If there are not more larger flow velocity, it will remain stable. While the sandy riverbed is highly mobile, it can also be moved when the flow velocity is less than the design value. It can’t form a protective layer with zero sediment transport rate, whose balance is marked by the formation of a relatively stable sand wave movement. Leng [2] proposed that the roughening of bed is the product of the scouring of the non-uniform sand bed, and the formation of the armoring layer can greatly reduce the scouring depth of the riverbed. The process of sediment incipience and transportation leads to the coarsening the bed sand. The incipience conditions of non-uniform sand particles are not only determined by the flow velocity, but also related to the sediment gradation and the environment in which the sand is located. The same size particles have different incipience conditions in different bed sand environments [3]. Hu [4] believes that the riverbed coarsening is related to the characteristics of the bed surface. The sandy riverbed coarsening is due to the separation of the current and the unequal exchange of the movement sediment. The roughening of
the bed is the result of the fine particles being carried away and the coarse particles staying. River bed coarsening has a significant increase in riverbed roughness [5]. The wide-graded riverbed is washed by long-term clean water, and the coarse-grained covering does not require a complete layer, and the roughening process can be completed [6]. The results of the Yongding River survey indicate that the area covered by the coarsened particles is approximately 50% to 85% [7].

In addition to the scouring depth and the gradation of the coarsening layer, the water level drop is also related to the scouring range, riverbed resistance and balance ratio drop [8-10]. The mechanism is very complicated.

In order to better predict the scouring problem downstream of the hub, and further reveal the hub of clean water scouring, and to find a method for estimating the scouring depth, a series of flume experiments were carried out. Through the flume experiments, the river bed adjustment process is summarized, the variation law of the bed load transport rate is analyzed, and the influence of the runoff process on the ultimate erosion of the riverbed is discussed.

2. Method

The experiment flume is 38m long, 0.5m wide and 0.6m high. It is a variable slope flume. The flume controls the flow discharge with an electromagnetic flowmeter, and the return water system is a pressurized pipeline. The test section is located in the middle of the flume. The natural river sand is used as the experiment sand in the flume. The sand is 30cm thick, and the gradation is matched according to the design requirements. The sanding section is connected with the bottom of the flume with a 30° slope. Table 1 is the test conditions, l is the sanding length; Δ is the sanding thickness; H is the initial average water depth of the sanding section; V is the initial water flow rate; dm is the average particle diameter; T is the water discharge duration, σg is the bed sand geometry standard deviation.

| l (m) | Δ (cm) | Q (l/s) | H (cm) | V (m/s) | Initial bed sand particle size (mm) | T(h) |
|-------|--------|---------|--------|---------|------------------------------------|------|
| 8     | 30     | 48      | 15     | 0.8     | dmax: 3, d50: 1.2, d10: 0.41, dm: 0.58, σg: 2.41 | 34   |

3. Experiment results and analysis

3.1 Variation of river bed elevation and longitudinal profile

During the experiment, the automatic topographer is used to measure the bed elevation every half hour. The measurement position is in the middle of the horizontal direction of the flume, and along the direction of the flume the points are measured every 10 cm. After the experiment is ended, the riverbed is subjected to an encryption measurement of 5 cm.
3.1.1 Variations in riverbed elevation at different times
Fig. 2 shows the changes of river bed elevation along different times. It can be seen from the figure that the inlet section is washed more and there is a reverse slope. The river bed is scoured more in the early stage, especially upstream. In the early stage, due to the high intensity of water flow, the strength of sediment transport is also large, and the initial flow flushing rate is very large. The whole river bed is almost simultaneously cut down. As the riverbed deepened, the bed sand is coarsened. Then the erosion is weakened, and the late flow flushing rate is significantly reduced, with only slight changes.

![Figure 2. The changes of river bed elevation along different times](image)

3.1.2 River bed elevation variation in the same point with time
The observed bed surface is at 3m from the upstream sanding point. The elevation changes with time as shown in Fig. 2. It can be seen from the figure that the general trend of riverbed elevation in the same position is decreasing, and the initial rate of reduction is large. From the same position, the bed surface elevation begins to decrease steadily because the starting flow rate is large, the bed surface is quickly washed away. In the late stage the bed surface erosion rate is reduced, and the bed surface elevation is high and low. One of the reasons is related to the sand wave movement. When the sand wave crest arrives, the bed elevation is high. When the sand wave trough arrives, the bed elevation is low. The second reason is the instability of the underflow. The paroxysmal violent scouring occurs before the arrival of the sand wave peak, and the riverbed has a large crater. When the deep pit is filled with upstream sand waves, a thick layer of coarsening appears here, and the rate of change becomes smaller thereafter.
3.2 Variation of bed-load gradation

The test samples the bed load at different times and draws the gradation curve as shown in Figure 4. It can be seen from the figure that the initial bed load of the experiment is larger and the late period is smaller. The main reason is that the initial water flow is the largest, and the bed surface is loose and uneven. The coarse sand is exposed to a large extent and is easy incipient.

3.3 Water level variation

The change of water level is related to the undercut of the riverbed, the change of the shape of the bed surface and the change of the downstream water level. The lowering of the riverbed reduces the water level. The sand wave on the bed surface, the back siltation of the river section and the rise of the downstream water level can raise the water level. The sediment from the sanding section is deposited at the exit to form a new sandy section, which is extended with the diachronic growth. The sand waves are also formed on the newly-formed bed surface, which increases the resistance of the original smooth flume. As a result, the water level downstream of the sanding section is continuously rising.

Figure 5 shows the process of water level change. The inlet water level of the sanding section first drops steadily and then gradually stabilizes. The water level in the middle part of the sanding section rises first and then decreases. Because the initial downstream water level is high and the water level rises. The scouring continues, the riverbed is scoured, and the water level is lowered. The water level in the outlet sanding section is fluctuating up and down, and the total variation is not large. The rise and fall of the water level along the course are not synchronized, so the water surface ratio is not consistent at each time. The main reason for this phenomenon is that the water surface ratio is greatly reduced at the initial stage, and then the water surface ratio is gradually reduced. Since the test uses a water self-circulating system, the tailgate has no adjustment, and the water surface ratio is naturally...
adjusted to lower the surface resistance. The outlet water level is basically unchanged, the inlet water level is gradually reduced, and the water surface ratio is gradually decreasing.

Figure 5. Water level variation with time

3.4 Characteristics of sediment transport rate

In the scouring process, although the flow rate is constant, due to the spatial imbalance of the sand waves, the inconsistency in time, and the instability of the bottom water flow, the instantaneous sediment transport rate of the bed is not constant, especially the pebble bedload sediment transport rate is more paroxysmal, and the size varies greatly. Figure 6 shows the change of sediment transport rate over time in the middle of sanding region. From the graph of the sediment transport rate process line, it is not difficult to see that there is a large rate of sediment transport in the initial stage of water release, and then gradually decrease. The sediment transport rate has a power function relationship with time. In the power function relationship, the sediment transport rate is constant for a certain period of time, or its mean value is constant. This is the duration of the equilibrium sediment transport rate.

Figure 6. Sediment transport rate variation with time

4.Conclusions

The clear water flushing experiment at the downstream of the hub shows that the initial riverbed erosion is large, the bed surface elevation begins to wash rapidly, and the bed surface reduction rate decreases at the later stage. With the development of the experiment, the riverbed erosion and deposition are very small. The water level in the sanding section first decreased steadily and then gradually stabilized. The water level in the middle part of the sanding section first increased and then decreased. The water level in the sanding outlet section is relatively stable. In the experiment, the rate
of sediment transport in the river is large in the initial stage, and then gradually decreases. The rate of sediment transport is a power function relationship with time.

References

[1] Qin Rongyu, Hu Chunhong. Investigation on armoring of sand bed material. Water resources and hydropower engineering, 1997(6): 8-13.
[2] Leng Kui, Wang Mingfu. Stochastic simulation on scouring and armoring for river bed. Advances in water science, 1994(2): 111-18.
[3] He Wenshe, Cao Shuyou. Method of grading calculation for armoring bed materials under clear water erosion. Journal of hydroelectric engineering, 2003(2).
[4] Hu Haiming, Li Yitian. Computation of river bed scouring and armoring. Journal of sediment research, 1996(4): 69-76.
[5] Ning Chien, Change of bed material composition in a degraded bed and its effect on the Stabilization of Stream Channel. Journal of sediment research, 1959(1): 1-9.
[6] Zhang Junyong, CHEN Li. Phenomena of replacement between spatial and temporal processes during the process of reformation downstream reservoirs: A case study of middle-lower Han river after the construction of Danjiangkou reservoir. Advances in water science, 2006(3):348-353.
[7] Xu Quanxi, Zhang Xiaofeng, and Tan Guangming. Multi-step prediction modeling on riverbeds scouring and armoring. Advances in water science, 1999(1):42-47.
[8] SUN Zhilin, SUN Zhifeng. Experiment and prediction of an armoring layer. Journal of hydroelectric engineering, 2000(4): 40-48.
[9] YUE Peijiu, Cheng Xiaobing. Method of estimating scour depth and fall of water level in scour holes below dams. Journal of sediment research, 2006(6): 16-25.
[10] Wang Rongxin, Zhang Houyu. Analysis of Z-Q relationship change in the downstream of Danjiangkou reservoir dam. Yangtze River, 2001(2): 25-27.