Overbank Floods of Lower Yellow River Based on Two-dimensional Numerical Simulation and Analysis

Ma Liangchao¹,², Jiang Caodong¹,², Li Dongfeng²,⁴, Zhang Hongwu¹,⁵, Li Zihao²

¹Zhejiang Ocean University, School of Naval Architecture and Maritime, China
²Key Laboratory for Technology in Rural Water Management of Zhejiang Province, Zhejiang University of Water Resources and Electric Power, China
³Laboratory of Hydrosience and Engineering, Tsinghua University, Beijing 100084, China
⁴Corresponding authors: lidf@zjweu.edu.cn
⁵Corresponding authors: zhhw@mail.tsinghua.edu.cn

Abstract. When the flow of the Yellow River is large, a large range of floodplains will be formed around the main channel, and the crisis will greatly improve safety. Analysis of the changes of flood peak shape, flood peak propagation speed and flood level at large flow rate plays an important role in the protection and flood prevention of the Yellow River levee. Based on the established two-dimensional mathematical model of Luokou to the Yellow River estuary, the data of peak flow, velocity and water level are obtained by simulation calculation. By drawing the flood peak evolution process map from Luokou to Yellow River estuary, the change of flood peak type and flood peak propagation speed are analyzed to provide technical support for flood defense.

1. Introduction

The Yellow River is famous for its mud and sand. The continuous deposition of the Yellow River Delta and the upstream rivers leads to the decrease of the flood discharge capacity of the river channel, followed by frequent flood disasters, which has been an important issue for the survival and development of the Yellow River Basin. Flood propagation speed, flood water level and peak clipping rate are the main factors of flood propagation. Flood factors are analyzed, and the influencing factors of flood propagation time include flood magnitude, resistance condition of main channel riverbed and condition after flood. It is of great significance to analyze flood propagation law, improve flood forecasting accuracy and provide technical support for flood and drought disaster prevention.

There are many studies on the Yellow River flood using models. The characteristics of flood routing in Huayuankou-Sunkou reach were analyzed by Li Yuanfa et al [1]. The results showed that the velocity of flood spreading downstream gradually decreased, and the peak shape of flood peak changed little. Li et al. used Mike11 to establish a one-dimensional model of the narrow reach of the lower Yellow River [2], and simulated the flood process of Aishan-Luokou narrow reach. The results showed that the Xiaolangdi water and sediment regulation project could enhance the flow capacity of the reach and shorten the flood propagation time. According to the flood data of Longmen station from 1960 to 2015, Li et al. analyzed the flood evolution law of Xiaobei main stream of the Yellow River [3], and the results showed that the continuous scour of the river could shorten the flood propagation time. Based on the
analysis of the current channel scouring and silting changes and river section morphology, combined with the entity model test [4], Wanqiang discussed the characteristics of flood evolution in the lower reaches of the Yellow River. The results showed that the water and sediment regulation increased the overall flow capacity of the lower reaches of the Yellow River.

Studying the propagation law of the Yellow River flood movement is conducive to the prediction of flood disasters and the formulation of reasonable disaster prevention plans. This paper establishes a two-dimensional mathematical model for the lower reaches of the Yellow River and most parts of the Bohai Bay, and calculates and analyzes the movement forms and laws of the Yellow River flood propagation.

2. Numerical simulation basic theory methodology
The basic theory, boundary conditions and verification process involved in the model are presented in the literature [5]-[8].

3. Calculation results and analysis
The upper part of the model is Luokou Hydrological Station in Jinan, Shandong Province. The river channel topography is obtained by cross-sectional terrain interpolation. The lower part is the sea boundary, and the sea area topography is from the electronic topographic map. The two-dimensional mathematical model of the lower Yellow River and the large part of the Bohai Bay is established. The flood discharges of 3000 m$^3$/s, 3500 m$^3$/s, 4000 m$^3$/s, 4500 m$^3$/s and 5000 m$^3$/s are selected for calculation, and the initial conditions are calculated by 500 m$^3$/s typical flow. The scope and boundary of the model are shown in Fig. 1.

3.1. Flood propagation velocity
The model is used to calculate the propagation time of flood in each section of the river under each flow, and the calculation results are shown in Table 1.
Table 1. Flood propagation speed in different sections of the lower Yellow River.

| Reach                      | Flow/ (m³/s) | 3000 | 3500 | 4000 | 4500 | 5000 |
|----------------------------|--------------|------|------|------|------|------|
| Transmission speed/ (m/s)  |              |      |      |      |      |      |
| Luokou—Qinghezhen          | 0.93         | 0.96 | 0.99 | 1.03 | 1.03 |      |
| Qinghezhen—Lijin           | 0.60         | 0.63 | 0.65 | 0.67 | 0.69 |      |
| Lijin—Xihekou              | 0.57         | 0.60 | 0.63 | 0.63 | 0.69 |      |

| Reach                      | Flow/ (m³/s) | 3000 | 3500 | 4000 | 4500 | 5000 |
|----------------------------|--------------|------|------|------|------|------|
| Spread time/ (h)           |              |      |      |      |      |      |
| Luokou—Qinghezhen          | 30           | 29   | 28   | 27   | 27   |      |
| Qinghezhen—Lijin           | 35           | 33   | 32   | 31   | 30   |      |
| Lijin—Xihekou              | 22           | 21   | 20   | 20   | 18   |      |

The analysis of flood propagation velocity in table 1 shows that the flood propagation velocity increases with the increase of flow rate under the condition of 3000-5000 m³/s flow rate of Luokou section. By comparing the propagation velocity under different flow conditions, it can be seen that when the flow rate increases from 4500 m³/s to 5000 m³/s, the flood propagation velocity of Luokou—Qinghezhen reaches does not change much. This is because in this flow interval, the flood spreads over the beach in this reach, and the beach resistance delays the flood propagation time. Similarly, under the conditions of 4000 m³/s and 4500 m³/s, the flood propagation velocity of Lijin-Xihekou section has little change.

3.2. Upstream flood discharge and downstream water level.

The model calculates the maximum flood water level of each section in the downstream under different flood discharges in the upstream, which can roughly determine the water level of each section in the downstream when Luokou passes all levels of floods, so as to prevent flood disasters before the arrival of floods. See table 2.

Table 2. The water level of each section corresponding to the flow.

| Section name | flow (m³/s) | 3000 | 3500 | 4000 | 4500 | 5000 |
|--------------|-------------|------|------|------|------|------|
| Huojialiu     | 29.72       | 30.06| 30.38| 30.67| 30.95|      |
| Lijiaoyuan    | 27.06       | 27.28| 27.47| 27.66| 27.85|      |
| Dongjia       | 24.32       | 24.61| 24.88| 25.14| 25.38|      |
| Qinghezhen    | 21.86       | 22.14| 22.41| 22.65| 22.89|      |
| Zhangxiaotang | 20.01       | 20.28| 20.52| 20.76| 21.00|      |
| Daoxu         | 17.31       | 17.69| 18.05| 18.38| 18.70|      |
| Mawan         | 16.80       | 17.19| 17.56| 17.89| 18.21|      |
| Lijin         | 15.77       | 16.11| 16.43| 16.73| 17.02|      |
| Yihaoaba      | 11.78       | 11.97| 12.15| 12.32| 12.47|      |
| Qianzuo       | 10.57       | 10.72| 10.85| 10.97| 11.09|      |
| Xihekou       | 8.22        | 8.42 | 8.59 | 8.75 | 8.89 |      |
| Shibagongli   | 7.15        | 7.24 | 7.32 | 7.39 | 7.46 |      |
| Qingsi        | 5.86        | 5.95 | 6.04 | 6.13 | 6.20 |      |
| Qingqi        | 5.21        | 5.28 | 5.33 | 5.39 | 5.43 |      |
| Chayi         | 5.09        | 5.15 | 5.20 | 5.26 | 5.29 |      |
| Chasan        | 4.48        | 4.49 | 4.51 | 4.52 | 4.53 |      |
Fig. 2 shows the water surface profile along the route from Luokou to the estuary of the Yellow River under various flood discharges. The water level varies greatly under different flood discharges in the river section 137 – 180 km away from Luokou, which may be due to the narrow river section and weak flood discharge capacity. The flood has already been on the beach, and the water level is greatly affected by the upstream flood discharge. However, in the section 232 km from Luokou to Haikou, the water level is not greatly affected by the change of upstream flood flow, because the section is relatively wide, and the cross-section area is large. A large area of beach makes the river flow capacity greatly enhanced.

3.3. Water level along the flood

It can be seen from Fig. 2 that under different flood discharge conditions, the water level along the river has three significant attenuations, which are in Qinghezhen section, Qianzuo section and shibagongli section, respectively. Combined with topographic map analysis, in the section of Qinghezhen, the significant attenuation of water level is due to the sharp bend of the river, and the flow velocity of the flood is reduced to produce backwater, resulting in the gentle water surface line in the upstream of the sharp bend. Turning to the sharp bend river channel is relatively straight, flood discharge leads to sharp decline in the sharp bend downstream water surface. As shown in Fig. 3.
In the front left section and the 18 km section, the reason for the sharp decrease of water level is the sharp widening of the river channel, which greatly increases the area of the river section and enhances the water conveyance capacity. As shown in Fig. 4 and Fig. 5.

4. Conclusion
Flood spreads downstream, the greater the flood magnitude, the faster it spreads downstream, at the same time affected by the beach on both sides, flood floodplain will slow down the speed of flood spreading downstream.

According to the magnitude of upstream flood, the corresponding water level of downstream section can be predicted, which provides reference for downstream disaster prevention. The flood water level is not only decayed along the river, but also affected by the river channel shape and section width.

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References
[1] Li Yuanfa, Chen Junjie, Ren Yanfen, Song Lixuan. Huayuankou-Sunkou flood evolution characteristics analysis [J]. People’ s Yellow River, 2011,33 (08): 23-24.
[2] Li Wenyi, Yang Jun, Meng Xianglei, He Binglin. Research on flood evolution characteristics of narrow reach in the lower Yellow River [J]. People’ s Yellow River, 2018,40 (01): 27-30 + 39.
[3] Li Baoguo, Cui Zhenhua. Analysis of flood evolution in the small north main stream of the Yellow River [J]. Renmin Yellow River, 2018, 40 (05): 12-16.

[4] Wan Qiang, Jiang Enhui, Zhang Linzhong. Flood evolution characteristics of the lower Yellow River since the operation of Xiaolangdi Reservoir [J]. People’s Yellow River, 2010, 32 (07): 23-24 + 144.

[5] Numerical analysis of the influence of sediment from north branch of Qingshuigou on Dongying Port [J]. Yellow Sea and Bohai Sea, 1998 (01): 2-7.

[6] Calculation and study on the influence of sediment from Diaokou River on Dongying Port [J]. People’s Yellow River, 1998 (03): 8-9.

[7] Li Dongfeng, Cheng Yiji, Zou Bing, Zhang Hongwu, Han Qiaolan. Two-dimensional tidal wave and sediment finite element mathematical model and its application (I) – model and verification [J] in the Yellow River estuary. Advances in marine science, 2004 (01): 21 – 28.

[8] Li Dongfeng, Zhang Xiuzhong, Han Qiaolan, Cheng Yiji, Chen Mei. Two-dimensional sediment finite element mathematical model and its application in the Yellow River estuary (II) - - tidal current and sediment transport and deposition process simulation analysis [J]. Marine science progress, 2004 (03): 284-291.