Application of HEC-RAS for flood forecasting in perched river–A case study of hilly region, China

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Abstract. Flooding in small and medium rivers are seriously threatening the safety of human beings' life and property. The simulation forecasting of the river flood and bank risk in hilly region has gradually become a hotspot. At present, there are few studies on the simulation of hilly perched river, especially in the case of lacking section flow data. And the method of how to determine the position of the levee breach along the river bank is not much enough. Based on the characteristics of the sections in hilly perched river, an attempt is applied in this paper which establishes the correlation between the flow profile computed by HEC-RAS model and the river bank. A hilly perched river in Lingshi County, Shanxi Province of China, is taken as the study object, the levee breach positions along the bank are simulated under four different design storm. The results show that the flood control standard of upper reach is high, which can withstand the design storm of 100 years. The current standard of lower reach is low, which is the flooding channel with high frequency. As the standard of current channel between the 2rd and the 11th section is low, levee along that channel of the river bank is considered to be heighten and reinforced. The study results can provide some technical support for flood proofing in hilly region and some reference for the reinforcement of river bank.

1. Introduction
In recent years, frequent flood disasters caused a great threat to people's life and property in China, the situation affected by this is the most particularly serious especially in 2010, the death toll caused by the flood disaster as high as 2824[1]. In the condition of strong rainfall, the water level of the river and creek in hilly region rises rapidly, which leads to the levee breach easily. A large collection of storm water and flood in the upstream of the high incidence area of mountain torrents, often make the downstream river facing the serious problem of the levee breach, especially the river or reach relied on the dike to constraint the flow[2]. Such as the perched river, whose river bed or levee above the bank ground, once the river burst its banks will form the new waterlogging area, and then lead to the tragedy of river diversion, flood land, highway interrupted and real pour news. So that the perched river has greatly increased the danger of mountain flood disaster on both sides of the river valley[3]. In view of the above problems and challenges, the river flood simulation and risk prediction in hilly and mountainous regions have gradually become a research hotspot. The ascertain of flow profile is the basis of the analysis of flood routing, and the research on the application of HEC-RAS (Hydrologic Engineering Center - River Analysis System) model to simulate the water surface is very extensive both at home and abroad. Mohsin Jamil et al. constructed the HEC-RAS model in the northern mountain area of Pakistan, and analyzed the dam break risk based on the predicted flow profile[4]; Good results were obtained from the application process of this model in the natural river flow profile calculation both in plain terrain and
hilly region\textsuperscript{[5][6]}, Liu Yang compared the HEC-RAS and SOBEK-RURAL model results of water level and velocity in Beijing Huairou District Park River flow, and verified the reliability and rationality of the HEC-RAS application in the natural river flow profile\textsuperscript{[7][8]}; Dai Wenhong compared the simulation results from the HEC-RAS and MIKE11 which about the variation in water level of the Gan River Delta to Nanchang section, and presented a parameter calibration method to improve the simulation precision of the model\textsuperscript{[9]}. But the present research shows that the simulation for flood process in hilly perched river based on the HEC-RAS model is relatively less, and the experience and method for the simulation of flood level along the coastline is insufficient. Based on the section characteristics of the hilly perched river, this paper tries to establish the relation between the river shoreline and the flow profile ascertained by the HEC-RAS, and a torrent ditch in Lingshi County of Shanxi Province is taken as a research object, and the levee breach positions along the perched river is analysed under the different scenarios of design storm. The result is expected to provide technical support for flood control and early warning, and provide a reference for the reinforcement of shoreline.

2. Study Reach
The Jiaozhong Ditch is located in the territory of Lingshi County of Shanxi Province, southern Jinping basin, originated from Zhongshu of Jing Sheng Town in Lingshi County, the three tributaries of the upper reaches flow through the willow village, the Songjiashan village and other places, and eventually flow into the Jingsheng river in Suxi village. The length of the Jiaozhong Ditch is 7.7km, the drainage basin area is 20.5km\textsuperscript{2} and the slope of the ditch is 19.4‰. In the ground covered with loess, due to frequent flood season rainstorm, strong erosion, there are serious soil erosion, high mountains and steep slopes. Suxi is located in the right of the Jiaozhong Ditch downstream, with the accumulation of long-term sediment and dike reinforcement, the majority residential elevations in Suxi are significantly lower than that of the right bank of the ditch, and formed a huge steep slope. So it is a typical perched river in hilly region, the typical cross section form shown in Figure 1. Affected by the monsoon climate, the region often have "high intensity and large amount" rainstorm occured from July to August\textsuperscript{[10]}. According to the survey, in 1981 the flood caused by the heavy rain broke out of the embankment, submerged most of the Suxi area, the maximum water depth was more than 1m, so that the village residents suffered a huge loss of property. Therefore in order to carry out the corresponding measures for river regulation, it is necessary to understand the flood control capacity and determine the levee breach positions.

![Figure 1. Channel pattern of No.6 section in lower reach.](image-url)
3. Geometric and Hydrologic Data

With the assistance of the local water conservancy department, the digitization of the control sections is realized through the recent monitoring data of the river channel. Based on the 30×30m DEM (Digital Elevation Model) data in this study region, river network data is generated with ArcGIS 10.2, and the information such as river central line and catchment area are obtained. After comparing the measured data and the results calculated from ArcGIS 10.2, it shows that the actual river central line is basically consistent, which can be used as the main channel in this study. Combined with 1:20000 high-definition image and site investigation, the work on selection, complement, correction and testing of section control points is completed. The Jiaozhong Ditch flows from north to south. The upper and middle reaches of the selected ditch are in an arc shape, and the cross sections are wide and deep. However the channel in lower reach is straight, the river sections are narrow and shallow. The selected average distance is about 60m each section and 16 cross sections are finally determined. The distribution of river control sections is shown in Figure 2.

![Figure 2. Distribution of river control sections.](image)

Hydrological Handbook of Shanxi Province (hereinafter referred to as the Handbook) is regarded as a hydrologic instruction book based on local hydrogeological conditions, and the recommended methods from it have been validated with a certain authority\textsuperscript{[11]}\textsuperscript{[12]}. Therefore, the design storm is calculated with the Rainstorm Atlas Method. The design storm duration is selected as 10min, 60min, 6h, 24h and 3D (72h), and the return period is 5 years, 10 years, 20 years, 50 years and 100 years. The mean value, the coefficient of variation (Cv), the ratio of the coefficient of skewness and the coefficient of variation (Cs/Cv), the modulus coefficient (Kp) and the point-surface reduction coefficient (η) of the fixed-point torrential rain in the study area are determined by the isoline map of rainstorm statistical parameters, and then the results of design storm and its time distribution could be obtained, as shown in Table 1. According to the watershed model method recommended by the handbook, by means of the runoff generation calculation about the net rainfall depth and process, and the flow concentration calculation using the integrated instantaneous unit hydrograph method, the design flood at the same frequency is...
finally obtained, the flood factors are shown in Table 2. By comparison, the results are basically consistent with the results of the analysis and evaluation of local flood disaster, the peak flow derived by this method can be used as the input data of HEC-RAS model.

| Duration | Mean value (mm) | $C_v$ | $C_v/C_v$ | Precipitation (mm) |
|----------|----------------|-------|-----------|-------------------|
|          |                |       |           | 100 years (H%)    | 50 years (H%) | 20 years (H%) | 10 years (H%) | 5 years (H%) |
| 10min    | 12.0           | 0.55  | 3.5       | 31.2              | 27.3         | 22.2         | 18.3         | 14.3         |
| 60min    | 30.0           | 0.49  | 3.5       | 65.4              | 57.9         | 47.9         | 40.3         | 32.4         |
| 6h       | 44.0           | 0.46  | 3.5       | 111.6             | 99.6         | 83.4         | 70.9         | 58.0         |
| 24h      | 61.0           | 0.45  | 3.5       | 143.0             | 127.8        | 107.3        | 91.4         | 74.9         |
| 3d       | 77.0           | 0.39  | 3.5       | 169.8             | 153.7        | 131.8        | 114.6        | 96.4         |

**Table 1. Results of design storm.**

| Flood element | Return period | 100 years | 50 years | 20 years | 10 years | 5 years |
|---------------|---------------|-----------|----------|----------|----------|---------|
| Peak discharge (m³/s) |               | 159       | 132      | 96.4     | 70.2     | 48.1    |
| Flood volume (m³)    |               | 142       | 117      | 86       | 63       | 44      |
| Flood duration (h)   |               | 15        | 15       | 15.5     | 15.5     | 15.5    |
| Peak stage (m)       |               | 824.16    | 823.98   | 823.70   | 823.46   | 823.20  |

**Table 2. Results of design flood.**

4. Calibration of HEC-RAS Model
Due to the left bank of the perched river is higher than the right bank about 4m, the right bank residents are frequently affected severely in the historical torrential flood disaster. The main difficulty in the process of calibration is the lack of historical monitoring data in perched river, such as the river flow profile in middle and small floods in recent years. In view of the challenge for ungauged condition, considering the fact that the natural river can be generalized into open channel to simulate the flood process in SWMM (Storm Water Management Model), a method is attempted to apply in this paper that SWMM and HEC-RAS models are be used to determine the levee breach positions and simulate the maximum water depth in a precipitation condition of 5 years return period. Combined with the investigations of the history about torrential flood disaster, site surveys, visiting the nearby villagers and some other ways, the main parameters calibration for HEC-RAS are completed[13][14]. The perched river drop is finally determined as 13 ‰, and the manning coefficient is determined as 0.03. Simulation results from SWMM and HEC-RAS are shown in Table 2. For the 5 years return period flood, the positions near the 4th and 5th section are both determined to be the levee breach. Basically same results are computed from the two models except a few of cross sections. It can be considered that the model has a certain degree of simulation accuracy and the credibility of flow profile calculation. There are 81.3% of the cross-sectional simulation results with a relative error of less than 10%. In addition, 68.8% simulation results from HEC-RAS are slightly larger than that from SWMM in the maximum water depth of each section, which has a positive effect on river flood warning and levee reinforcement.
In the left banks, the levee near the 3rd section should be increased by 1.5m, and the length of the levee is increased below the right bank of the ditch, so the levee breach possibility is very less.

For lower reach section, with the decrease of the designed storm frequency and the increase of the peak discharge, the positions of the levee breach gradually moves upwards for the design storm of 100 years, the sections with flooded risk near the 10th section increase as well as the 15th section. Obviously, the average elevation of the upper reach channel of the river is much higher than that of the lower reach. The maximum difference in levels between the 15th section and the 5th section is about 15.55m. On the whole, the maximum flood levels from design storm of 100 years in upper reach section are located below the right bank of the ditch, so the levee breach possibility is very less. For lower reach section, with the decrease of the designed storm frequency and the increase of the peak discharge, the positions of the levee breach gradually moves upwards, and the length of submerged channel increases as well as.

Specifically, as for the design storm of 10 years, the higher risk bank of flooding in current situation of the river is between the 3rd~8th section (the 8th section is the initial point); As for the design storm of 20 years, the sections with flooded risk spread to the position near the 3rd~9th section; As for the design storm of 50 years, the current high-risk river bank is continued to be lengthen, levee breach section in upper reach moves to near the 10th section, the lower reach high-risk section moves to near the 3rd section downward for 15m; As for the design storm of 100 years, the levee breach position moves up to about 30m above the 10th section in upper reach, the lower reach's moves downward 25m below the 3rd section.

5. Results Analysis

The peak discharges corresponding to the design rainstorm with the return period of 10 years, 20 years, 50 years and 100 years are taken as the precipitation input scenario of the HEC-RAS model, and then the simulation results of the maximum flood stage of each section can be obtained. The simulation results of 16 sections are connected by a smooth curve to establish the correlation between the right bank and the maximum flood level simulated by HEC-RAS, as shown in Fig.3.

The section number of the river section is decreasing from upper reach to lower reach. In this study, the 1st~8th sections are defined as the lower reach section, and the 9th~16th sections are defined as the upper reach section. Obviously, the average elevation of the upper reach channel of the river is much higher than that of the lower reach. The maximum difference in levels between the 15th section and the 5th section is about 15.55m. On the whole, the maximum flood levels from design storm of 100 years in upper reach section are located below the right bank of the ditch, so the levee breach possibility is very less. For lower reach section, with the decrease of the designed storm frequency and the increase of the peak discharge, the positions of the levee breach gradually moves upwards, and the length of submerged channel increases as well as.

### Table 3 Comparison of simulation results between SWMM and HEC-RAS.

| Section number | Levee height (m) | SWMM Computed depth (m) | HEC-RAS Computed depth (m) | Relative error (%) |
|----------------|------------------|-------------------------|---------------------------|-------------------|
| 1              | 3.59             | 1.28                    | 1.43                      | 11.9              |
| 2              | 3.55             | 1.67                    | 1.73                      | 3.5               |
| 3              | 2.29             | 2.15                    | 2.00                      | -6.8              |
| 4              | 1.79             | 1.97                    | 2.09                      | 5.9               |
| 5              | 1.11             | 1.93                    | 2.19                      | 13.3              |
| 6              | 1.83             | 1.86                    | 1.80                      | -3.2              |
| 7              | 2.25             | 2.13                    | 1.86                      | -12.5             |
| 8              | 2.26             | 2.14                    | 2.06                      | -3.8              |
| 9              | 2.46             | 1.63                    | 1.73                      | 6.4               |
| 10             | 3.03             | 2.07                    | 2.18                      | 5.3               |
| 11             | 3.97             | 1.88                    | 2.01                      | 7.0               |
| 12             | 3.81             | 1.28                    | 1.36                      | 5.9               |
| 13             | 5.72             | 1.75                    | 1.84                      | 5.1               |
| 14             | 8.39             | 1.78                    | 1.77                      | -0.6              |
| 15             | 9.07             | 1.29                    | 1.39                      | 7.7               |
| 16             | 4.90             | 1.56                    | 1.62                      | 3.8               |

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6. Conclusion
Parameters calibration for HEC-RAS is completed by comparing the simulation results from SWMM and HEC-RAS in this paper. The flow profiles of 16 sections in different design storm of 4 return periods (10 years, 20 years, 50 years and 100 years) are simulated with HEC-RAS model in perched river, which are established the relationships with the right shore line of the ditch. The distribution of the location of the levee breach positions along the river was presented. On the other hand, the levee breach positions computed from HEC-RAS model are basically the same as the investigation results of the historical floods in this perched river, therefore the simulation results are authentic and credible.

The simulation results show that the flood control standard of the upper reach is high, which can resist the design storm of 100 years. The standard of the lower reach is low, which is the flooding channel with high frequency. The current levee sections from 3rd to 8th are not enough to withstand the design storm of 10 years, the embankment between the 2nd and 11th sections is suggested to build and fill higher. This part of perched river should be focused on inspecting during flood season, which can prevent life and property safety of residents along the river from the flood caused by levee breach. The study results can provide the basis for the suspension of flood warning, the consolidation of river bank and the development of disaster evacuation plan.

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