PRELIMINARY ANALYSIS OF EFFECTS OF COMPREHENSIVE DEVELOPMENT OF CASCADE HYDROPOWER PROJECT ON RIVER COURSE

Gong Ping¹, Wan Jian-rong²
1, Changjiang River Scientific Research Institute, gongp163@163.com
2, Changjiang River Scientific Research Institute, jss9871@vip.163l.com

Abstract: At present of China, the mode of hydroelectric development on the one of basin is cascade development. IN schematic designs phase, aim at one of the water control project or several water control projects, the computation about reservoir region’s sediment accumulation or the effect about dam’s downstream is finished usually. In fact, build cascade development and other river project at the same time. In this paper, the author take the case of Hanjiang river, build 1D water and sediment mathematical model about middle and downstream river of Hanjiang river, conceptual calculate and analysis the cascade development and other works effect on river bed. Example build some water control project such as Danjiangkou and Wngfuzhou and Cuijiaying and Xinglong etc. And other work such as heighten of Danjiangkou dam and helping Hanjiang river by Yangtze river and waterway regulation works in Hanjiang river. The author analysis the series of effect by cascade development and other works about flood control and navigation and water supply and wastewater.

Key words: cascade hydroelectric development, integrated analysis of effect middle-downstream of Hanjiang river, mathematical model.

1Preface

The cascade hydropower development is a main method of hydropower development in river basin, and at the same time, the navigation, irrigation and other projects concerned are also considered, so as to a to achieve integrated utilization of water resources. Taking Hanjiang River as an example in this paper, the sediment deposition rules of Danjiangkou reservoir after the heightening of Danjiangkou dam and the operation of stage I works of the middle route for south-to-north water diversion project are analyzed, as well as the influences arisen from cascade hydro project in the middle and lower reaches on river regime, flood control, navigation, and water utilization, etc.

2General

The Hanjiang River with the total length of 1577km (main stem) is an important tributary in the middle of Changjiang River, and is divided into upper, middle and lower reaches by Danjiangkou and Huangzhuang separately. The upper of Danjiangkou is the upstream with the average gradient
ratio of about 0.2‰; the lower of Danjiangkou is the middle and lower reaches with the average gradient ratio of 0.1‰ and the length of 603km. For the river course of middle and lower reaches, see Fig. 1.

![Fig. 1 River course of middle and lower reaches](image)

At present, the stage I works of south-to-north water diversion project has been implemented, the construction scheme involves followings: the annual average transferable water of 95×10^8 m³, the heightening of Danjiangkou dam, and four regulation works such as the construction of Xinglong hydro project in the middle and lower reaches of Hanjiang River, the rebuilding and enlarging of partial water gate, the regulation of partial navigation channel and the water transfer project from Changjiang River to Hanjiang River.

For the planning of middle and lower reaches of Hanjiang River (1993), the scheme of 9-level cascade hydropower development is considered, the existing Wangfuzhou project, Cuijiaying project and Xinglong project are taken into account in calculation.

Along the stem stream of Hanjiang River, there are 248 small-scale pump stations for irrigation and waterlog drainage, 130 culvert gates and 4 power plant intakes. And three irrigation areas are divided as follows: the upstream of Huangzhuang is upper area, a pumping irrigation area; the middle area is a gravity irrigation area from Huangzhuang to Zekou; and the lower area involves part of Xiaogan and Wuhan.

The construction scale of partial channel regulation works in the middle and lower reaches of Hanjiang belongs to IV (2) so as to maintain the original channel standard of 500t.

The designed discharge of diversion water for the water transfer project from Changjiang River to Hanjiang River is 350m³/s, and the maximum discharge is 500m³/s. The designed compensation discharge from Dongjing River is 100m³/s, and the increased compensation discharge is 110m³/s.

The initial construction of Danjiangkou hydro project commenced on Sept. 1, 1958, the closure was carried out in Dec. 1959, the formal impoundment began in Nov. 1967 after flood detention for many years, and impoundment operation began after 1968. For the later scale of Danjiangkou hydro project, the normal storage level is 170 m, the total reservoir capacity is 290.5×10^8 m³. Danjiangkou reservoir is comprised of Hanjiang and Danjiang reservoir areas, the flow and sediment of reservoir come from Hanjiang River, Danjiang River, Baishi River, Tianhe River, Duhe River and Xishui River, with the annual average runoff of 360×10^8 m³, the total incoming sediment of 8310×10^4 t per year. The incoming flow and sediment concentrate in flood season from July to October, accounting for 60% of the total quantities in a year.
The Hanjiang cascade hydro project mentioned in this paper includes the existing and ongoing hydraulic projects in the stem stream of Hanjiang River Basin, such as Huanglongtan project, Ankang project and Danjiangkou project in the upper reach, and Wanfuzhou project, Cuijiaying project and Xinglong project in the middle and lower reaches.

A one-dimensional unbalanced sediment transportation mathematical model is used for calculation, after a long-time calibration and verification for the upper reservoir and the middle and lower river courses, preferable results have been obtained, and the calculation for application have been completed.

3 Effects of sediment deposition in Danjiangkou reservoir area

In the calculation, considering the function of sediment trapping and regulation & storage of the upper cascade reservoir, the hydrologic years of 1974~1983 are selected as typical serial years, and the survey map of the end of 1994 is selected, involving a river stretch of 203 km long in the upper of Danjiangkou dam site with 112 cross sections arranged at an average interval of 1.81 km, and supposing that the hydro project operates up to 2010 under current conditions, then operates until 2110 according to the dam heightening water transfer scheme (with water transfer amount of 95×10⁸ m³, and normal storage level of 170 m).

The calculation results show that, under normal storage level of 170 m, the accumulated deposition of the reservoir will be about 30×10⁸ m³ until 2110, and the reserved reservoir capacity for flood control will be 99.8% by the end of 2030; when the heightened dam operates to the end of the 100th year, the reserved reservoir capacity for flood control will be 93.7%, and the deposition of reservoir areas in tributaries will be 6.96×10⁸ t (including 1995~2010).

Due to the lowering of water level in flood season, it is easy for sediment to be carried to the front of dam, and a lot of coarse-grained sediment is trapped by Ankang power station in the upper of Hanjiang reservoir area and Huanglongtan power station in Duhe River, therefore, the incoming sediment of reservoir area in the stem stream of Hanjiang River reduces and the grain size becomes fine, and a large amount of sediment accumulates in the lower river stretch 80 km away from dam. As a result of the effect of sediment deposition in reservoir area, the water level of the river stretch from 132 km to 190 km away from dam will rise when encountering the flood of different frequencies in the end of the 20th year (see Fig.2).
Due to the regulation of Danjiangkou reservoir, the characteristics of hydrology and sediment of the middle and lower Hanjiang River change. Table 1 shows the flow and sediment characteristics at Huangjiagang hydrologic station 6.19 km down away from Danjiangkou dam. Before the construction of Danjiangkou reservoir, the annual flow distribution of Hanjiang River was extremely unbalanced, the flow mainly concentrate in July, August and September. After the operation of Danjiangkou reservoir, due to the function of regulation & storage and flood peak reduction of reservoir, the flood peak was reduced and leveled, and the annual flow distribution tends towards balance. And due to the function of reservoir regulation and storage, the flood peak discharge decreased obviously, the normal water level period prolonged and the lower water discharge increased.

Table 1 Statistics of long-term flow-sediment characteristics at Huangjiagang station

<table>
<thead>
<tr>
<th>Items</th>
<th>Before construction of reservoir</th>
<th>Flood detention period</th>
<th>Impoundment stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average water level (m)</td>
<td>90.1</td>
<td>89.19</td>
<td>88.73</td>
</tr>
<tr>
<td>Average discharge (m³/s)</td>
<td>1310</td>
<td>1310</td>
<td>1080</td>
</tr>
<tr>
<td>Average runoff (10^8 m³)</td>
<td>413</td>
<td>413</td>
<td>340</td>
</tr>
<tr>
<td>Average sediment concentration (km/m³)</td>
<td>3.24</td>
<td>1.76</td>
<td>0.03</td>
</tr>
<tr>
<td>Average sediment discharge (10^4 t)</td>
<td>12700</td>
<td>7260</td>
<td>102</td>
</tr>
</tbody>
</table>


The heightening of Danjiangkou dam and the operation of stage I works of the middle route project for south-to-north water diversion will make the flow and sediment conditions of the middle
and lower Hanjiang River change further, the runoff process alter obviously, the flow and flood peak discharge reduce evidently, as a result, the scour-silting conditions of the middle and lower reaches variate.

4 Variations and effects of scour and silting in the middle and lower Hanjiang river courses

Current situations: during the period of 1978 to 2005, the middle and lower riverbed was scoured or silted up now and then, but the scour predominated, with scouring capacity of about $3.4 \times 10^8$ m$^3$ in this 28 years, 19% for the riverbed between Danjiangkou dam site and Xiangfan, 61% for the riverbed between Xiangfan and Huangzhuang and 20% for the riverbed from Huangzhuang to Xiantao, while only little changes in scour and silting occurred for the riverbed from Xiantao to estuary.

For the calculation of riverbed scour and silting in the middle and lower Hanjiang River, the initial landforms is obtained by the use of landforms in 2005 calculated up to 2010 according to the current situation (the water transfer scheme of $15 \times 10^8$ m$^3$), and then the water transfer scheme of dam heightening is adopted.

After the implementation of the stage I works of south-to-north water diversion project in the level of year 2010, together with a serious of harnessing works in the middle and lower reaches, the middle and lower riverbed will be scoured or silted up now and then, but the scour tends to predominate, and the accumulated scouring capacity of the river stretch between Danjiangkou dam site and estuary will reach $1.10 \sim 1.16 \times 10^8$ m$^3$ from the year of 2010 to 2050.

According to the calculated results, under the same flow conditions, the progressive water level in the middle and lower reaches will be lowered to different degrees after the implementation of the stage I works of middle route project for south-to-north water diversion, the change of water level in the middle reach is small, while the scouring scope of the riverbed from Huangzhuang to Xiantao is large relatively, the lowering range of water level is also larger than that of the middle reach, and it is more difficult to divert water than that before the construction under the condition of low water; under the conditions of normal and high water, the water level lowers, which is beneficial to water diversion of culvert gate. However, in the process of river regime regulation, the variations of flow returning to main channel, river width narrowing and main current shifting will occur inevitably, which will influence part of intakes probably.

After the heightening of Danjiangkou dam, the duration with the flow less than 300m$^3$/s will reduce from original 26.7% of the total duration to 0.1%; the duration with the flow of 1000 ~ 3000m$^3$/s will increase from original 5.6% of the total to 25.3%, the duration with the flow more than 3000m$^3$/s will increase from original 1.0% to 8.1%. It is shown that, the heightening of Danjiangkou dam will make the flow process of the middle and lower reaches change, the low water flow reduce greatly, the normal flow increase, which will be advantageous to the improvement of navigation conditions of the middle and lower Hanjiang River.

During 10 years from 2041 to 2050 after the implementation of the stage I works of south-to-north water diversion project, the navigable depth can meet the demand of navigation
except individual sections. From the angle of channel depth, the water diversion will not effect the navigation of the middle and lower Hanjiang River greatly. But on the other hand, the river regime of the middle and lower reaches will adjust itself with the change of flow after water diversion, the bed-forming discharge reduce, the river width becomes narrow relatively, which will influence the effect of existing channel regulation works, therefore, the regulation works shall be adjusted basing on the new river regime, and the river regime shall be controlled to a favorable conditions.

Danjiangkou reservoir is an important one in flood control system of the middle and lower Hanjiang River, after operation, due to the discharge of clear water, the scour happens widely in the lower riverbed. The scour occurs near the dam, and then develops from upstream to downstream. After bed scour, the discharge area increases. Compared the landforms of 1978 and 2005, the average discharge area of the river stretch from dam site to Miaogang increases by 772 m²; the average discharge area of the river stretch from Miaogang to Xiangfan increases by 3088 m²; 3241 m² increased from Xiangfan to Yicheng; 4781 m² increased from Yicheng to Huangzhuang; 788m² increased from Huangzhuang to Maliang; 942m² increased from Maliang to Xiantao; 16m² reduced from Xiantao to estuary. Compared the landforms of 1978 and 1988, the average discharge area of the river stretch from Xinglong to Zekou increases from 10800m² to 11900m², if encountering the flood of 20-year-frequency, the flow will increases by 1850m³/s approximately; the average discharge area of the river stretch from Zekou to Yuekou increases from 9600 m² to 10450m², if encountering the flood of 20-year-frequency, the flow will increases by 1230m³/s approximately. All of these indicate that the flood conveying capacity of river channel enhanced after scouring, which is beneficial to flood discharge.

After the implementation of the stage I works of middle route project for south-to-north water diversion, the scour or silting will occur in the middle and lower riverbed now and then, but the scour tends to predominate. If the average river width of Danjiangkou dam site to Xiangfan, Xiangfan to Huangzhuang, Huangzhuang to Xiantao and Xiantao to Hanjiang estuary is 1000m, 800m, 500m and 300m respectively, at the end of the 40th year (the end of 2050) after the implementation of the stage I works, the scour depth of above mentioned river stretch will be 0.17m, 0.26m, 0.54m and 0.51m respectively with the use of scheme of water transfer from Changjiang River to Hanjiang River. The above mentioned scour depth is the average one, the local scour depth can be 2~3 times of them. With the deep scour of riverbed, the discharge area will become large, and the water level will be lowered under the same flow, which is helpful to flood control. However, the flood control situation of the middle and lower Hanjiang River is not optimistic, the restriction of both embankments, the narrower river course near the lower reach, and additionally the retarding of flow from the stem stream of Changjiang River in flood season will be unfavorable for flood discharge when encountering catastrophic flood. Even the discharge area is widened it is still insufficient for discharging the flood from the upper reach in due course.

After the implementation of stage I works of the middle route project, the advantages will outweigh the disadvantages in flood control, navigation and water diversion and drainage of the middle and lower Hanjiang River, at the same time, the effects on local river regime produced by the variation of flow and sediment conditions cannot be ignored, the bank line with poor controlling conditions shall be monitored closely to prevent the adverse impacts effectively.
5 Conclusion

In this paper, taking the Hanjiang River as an example, one-dimensional flow sediment mathematical model with long river reach and long duration for the middle and lower reaches of Hanjiang River is used, and it is supposed that the hydro projects such as Danjiangkou project, Wangfuzhou project, Cuijiaying project and Xinglong project, the heightening works of Danjiangkou dam, the water transfer project from Changjiang River to Hanjiang River and the channel regulation works, etc. will produce effects on the scour-silting of river course, flood control, navigation, and water diversion and drainage. It is concluded through analysis that, after implementation of the project, the advantages will outweigh the disadvantages in flood control, navigation and water diversion and drainage of the middle and lower Hanjiang River, at the same time, the effects on local river regime produced by the variation of flow and sediment conditions cannot be ignored, the bank line with poor controlling conditions shall be monitored closely to prevent the adverse impacts effectively.

References


