Physical Model Results on Intrusion Between Channel and Tributary in Xiaolangdi Reservoir

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ABSTRACT

Interaction between reservoir sedimentation topography and water and sediment transportation characteristic is deeply affected the reservoir storage capacity. From the surveyed data of reservoir built many years ago, it shows that when there is a bar in tributary mouth, the tributary volume below the bar will become nullification during the period of flood control or water and sediment regulation of reservoir. There are more tributaries in Xiaolangdi reservoir than the others that it occupies 41.3% of the total initial volume of tributary volume. Obviously, the effective use of tributary volume has been important influenced by comprehensive utilization efficiency of reservoir scheduling, such as flood control, sedimentation reduction and comprehensive utilization. Results of Xiaolangdi Reservoir mobile-bed physical model experiments show that tributary is equivalent to lateral extension of river bed, the tributary intrusion deposition process have strongly relations with the factors, such as original topography, river bed deposition shape and its regime, process with input discharge and input sediment, and method of reservoir regulation. The variation trends of main river and tributary terrain forecasted by model test are basically in accordance with field surveyed data. Based on the physical graphics revealed by mobile-bed physical model experiments, a method of tributary diversion ratio is preliminarily generalized for calculation and is verified by field surveyed data. The results could be used for research, design, and forecasting of reservoirs in sediment-laden river.[1]

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INTRODUCTION

Tributary sandbar often occurs at the mouth of tributary which lie in a disadvantageous site[1-2]. With reservoir operation, if there are little possibility for tributary flood and poor water and sediment input match from main river[3-4], large scale sandbar forms at the mouth of tributary with interrupting the water and sediment exchange between main river and tributary and influencing the reservoir operation precision. For example, sandbar development in the mouth of Guishui river in Danjiang kou reservoir, stops the water supply from the reservoir. Sandbar development in the mouth of Wei river induced by the Yellow river, heavens the flood threat and water environment pollution in the Wei river valley[5-7]. Sandbar development in the mouth of Yuan river and Longmen river brings many problems. From the built reservoirs with long term practical operation, sandbar stops the water and sediment exchange between main river and tributary, and reservoir capacity of tributary cannot be used efficiency[8].Even the reservoir general utilization benefit would be heavily hindered. By now, water and sediment movement law have not been controlled and modeled. From the study on the physical model of Xiaolang di reservoir by Zhangjunhua[9-14], the deposition in tributary which is mainly induced by turbidity current had been found with further study on the backward flow between main river and tributary. With the help of field surveyed data from built reservoirs are analyzed in analogy, the research results of sandbar variation in long series model tests in the first stage of late retainning sediment period of xiaolangdi reservoir is condensed. The results could be technically referred by the sediment-laden river planed, designed and operated.

OVERVIEW OF XIAOLANGDI RESERVOIR AND ITS PHYSICAL MODEL

Initial Conditions

Xiaolangdi Reservoir belongs to canyon-Reservoir, and the upper reach is wider in than that in lower reach. According to the plane modality, the reservoir could be divided into two parts. The upper reach is from Station Sanmenxia to Section HH37 with the length 60.92km and bottom width of river valley about 200m to 400m. The lower reach is with the length 62.49km and bottom width of river valley about 800m to 1400m,especially bottom width of river valley about 300m between 27km and 31km to the dam. The normal water storage level is below 275m with the original volume 12.750 billion cubic metre and branch volume 5.263 billion cubic metre which occupies 41.3% ratio of the total volume. The quantity of branches which volume is bigger than 0.1 billion cubic metre is 11. These branches all distribute the lower reach of the reservoir. The main characteristics are listed in Tab.1.

Some sand and little stone will flow downstream when short period flood comes during the flood period. According with analying, the transporting quantity of bed material and suspend sand quantity per year is respectively 0.27 million tons and 2.97 million tons.it could be ignored with the input sediment quantity. Therefore, the branch sediment storage could meet the designed quantity or not, which is decided by the quantity of the incoming sediment from the main to the tributary. Morever, the sedimentation distribution of the branch mainly influence the effective storage capacity. When the sediment from the main stream comes into the branch, sand bar often occurs at the mouth of branch. The storage capacity of branch below the sand bar elevation is not be effective utilized. Even it would become invalid volume which neither intercept sediment nor participate in normal operation. According to the surveyed data before the flood period in 2015, the difference between sand bar and its river bed is beyond 10 meters in the biggest branch named River Zhenshui.

Table 1. Main characteristic of branches in Xiao lang di Reservoir.

river name	Length between mouth and the dam/km	Original volume/billion m^3
Dayu	3.9	0.5797
Zhenshui	18	1.7672
Shijing	22.1	0.4804
Dongyang	31	0.3111
Xiyang	41.3	0.2353
Yanxi	54	0.4071
Boqing	57.6	0.1389

The physical model of Xiaolangdi Reservoir covers about 124km from Station Sanmenxia to the dam, which has the total main river volume and 90% of branch volume. It had been designed by use of similar condition on the sediment-laden reservoir movable bed model and river bed boundary feature. the main scale is listed in the Tab.2, which is decided by the validated experiments with the field data from Xiaolangdi reservoir. The model is designed by the vertical scale 100 and horizontal scale 60. The Zhengzhou thermal power plant fly ash is chose as model sand.

Table 2. Main scale table.

Horizontal	vertical	Velocity	roughness
300	60	7.75	0.88
settling velocity	Sediment concentration	time	
1.34	1.50	44.9	

Model Experiment Condition

Based on the surveyed surface topography of Xiaolangdi Reservoir on October, 2007, with 17 a water-sediment series from 1960 to 1976 designed the 2020 level, experiment on operation mode of Xiaolangdi Reservoir in its second stage of sediment retaining had been carried in use of operation mode which can achieve sediment pluriennial regulation and scour due to dropping pond water level occasionally.

The operation mode of Xiaolangdi Reservoir mainly reflects in scouring due to dropping pond water level occasionally with large discharge and operating on combination with gradually hightening pond water level for flushing fine sediment and retaining coarse sediment and water and sediment regulation. Selection of opportunity for scour due to dropping pond water level occasionally decided on the period, when reservoir sedimentation comes 4.2 billion cube metre, the max regulating discharge is 3700m3/s and the min regulating discharge is 400m3/s. Then flood process is made with the minimal water storage meets 1.3 billion cube metre. When the input discharge prediction ahead 2 days is not less than 2600 m3/s, reservoir door is opened for scoured or flood process is made by water supplement with storage. When the sum discharge of the input and Station Heishi and Station Wuzhi downstream is more than 4000m3/s, the reservoir is shifted into the anti-flood operation state.
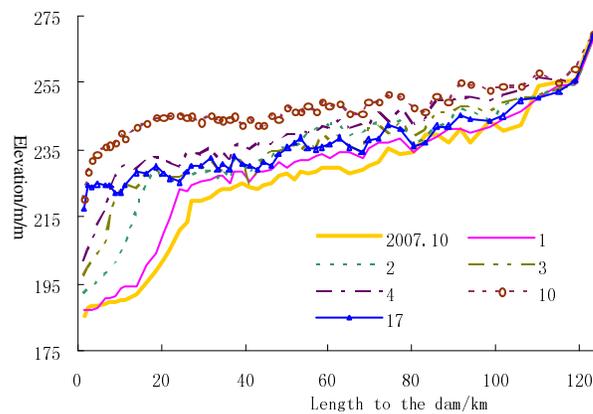

Figure 1. Chart of process on main channel talweg.

LANDFORM VARIATION PROCESS IN TRIBUTARY

Characteristic of Tributary Deposition

The input sediment of tributary in Xiaolangdi Reservoir could be ignored. The deposition mainly origins from the main river flow backward. The original slope of main tributary in the reservoir is normally about 1%. the original slope of the largest original volume of tributary is about 0.56%. The backward deposition after reservoir regulation changes the tributary landform and river bed composition. Vertical adjustment of the general trend of slope gradually reduce to horizontal, and inverted slope at last. The tributary mostly shows inverted slope at the experiment ends.

The cross section landform often rises parallel with the main river bed deposition. When the reservoir operate in scour due to drop the pond water level and main river bed sharply drops, deposition face close to the mouth of tributary drops either and the obvious channel forms. The tributary of river Dayu, which is about 4km away from the dam, has a parallel deposition before No.10 in the experiment process. After No.17 with scour due to drop the pond water level, the first section appears obvious beach and channel. The altitude difference of both is same to that at the mouth.

Rationality Analysis of Experiment Results

Guanting Reservoir，which lies in the Yong ding river, was built as first large-scale key project in 1950s in the sediment-laden river. The water storage formally operates in October,1955. The designed total volume of the reservoir is 2.27 billion cubic metre, volume of tributary Guishui river 1.29 billion cubic meter which occupies 57% ratio of the total volume. The longitudinal deposition landform of Yongding River, which is main river of Guanting Reservoir, is delta which gradually advances to the dam. After 1980, the sediment input decreases suddenly and the talweg of main river changes little. While sand bar at the mouth of Guishui River increases, the altitude difference between the sand bar and the inner Guishui river bed also increases, with adverse slope increasing to 8.0% in 1997.

In the experiments, the deposition in Zhenshui river mostly forms by backward flow which belongs to open channel flow regime. While deposition before 1980 was due to density current flow regime and after 1980 due to open channel flow regime in Guishui river. the field data show that backward flow in open channel flow regime takes a more prominent role in sandbar formation. For an example, main river and tributary backward flow each other by density current flow regime in Guanting reservoir from 1955 to 1980.Section Gui1000 near the Guishui river mouth rised about 10 metres, while the inner Section Gui1009 was about 6 metres. Main river and tributary backward flow each other by open channel flow regime in Guanting reservoir from 1981 to 1998. Section Gui1000

near the Guishui river mouth raised about 6 metres, while the inner Section Gui1009 raised only about16 metres. The ratio of the two periods and two parts respectively is 10:6 and 6:1.in the series experiment on the provised program on reservoir operation in the second sediment retaining period in physical model of Xiaolangdi reservoir, the backward flow belongs to open channel flow regime in all years except the first year with density current flow regime. If the landform after the flood period is looked as the demarcation point for mainly backward flow which belongs to open channel flow regime.

ANALYSIS ON THE FACTORS ON TRIBUTARY SANDBAR

Tributary amounts to the horizontal extend of the main river bed. The backward flow process on the tributary bed including deposition quantity and formation is closely related to the factors including the tributary natural landform conditions, main river deposition landform, main river regime, water and sediment input process and reservoir operation etc.

(1) Tributary natural landform conditions. The reservoir volume of tributary is big and wide in plane form. But the reservoir sediment retaining volume of tributary deposits slowly, sandbar problem is prominent with longitudinal height difference large. When the water and sediment from the main river goes through the convergence, the tributary is backward flowed laterally.in general, it is not better for sediment being backward flowing with larger tributary reservoir volume, narrower mouth and longer backwater.

(2)main river deposition landform in the period of reservoir sediment retaining main river deposition process is usually same as the process of the sedimentation delta moving downstream. When the peak of main river deposition delta lies in front of the convergence of the tributary, turbidity current occurs below the delta peak with the water and sediment input in the normal circumstance. So when the current goes through the tributary mouth, turbidity current backward flow into the tributary. The deposition of tributary bed is plane with turbidity current backward flow. the slope occurs due to the sediment deposited along the river. When the delta peak is proposed ahead and stride the tributary mouth, sandbar is obviously formed with the deposition face rising suddenly in the main river bed and tributary mouth. Above the main river deposition delta, the obvious beach and channel is modeled. The tributary mouth, which amounts to the main river beach, flood discharge in main river can laterally flow into tributary only when it is larger than the channel conveyance capacity.

(3)water and sediment input process. Whether backward flowing in turbidity current regime or open channel regime. Tributary deposition due to backward flow is heavier with that The flood period lasted longer, the order larger and sediment concentration higher. If turbidity current occurs in both main river and tributary with long flood period, this makes not only tributary reservoir volume full of deposition, but also suspend sediment depositing from the backward flow

and water separated out back to the main river. So the turbid water from main river and tributary water continuously changes. If the backward flow belongs to the open channel regime, only can long period and large flood overbank and flow into the tributary. If the water level in tributary is low, the water level difference makes the backward flow velocity larger, and even sours and lowers the sandbar. This would accelerate the backward flow process.

(4) reservoir operation. It is one of the most important factors for reservoir operation process that influence the reservoir deposition form and sediment transporting regime. It also decides the sediment transporting regime in the backward flow between main river and tributary and boundary conditions. The reservoir volume for regulating is larger, some medium and small flow without overbank in open channel flow regime will form turbidity current and be over the sandbar flowing into the tributary which adds the possibility for tributary backward flow. Therefore, during the random sediment flushing process, tributary sandbar scours correspondingly and river channel which runs through between main river and tributary forms. This is good for backward flow due to the subsequent flow and the tributary volume utilization.

(5) water and sediment exchange of backward flow between main river and tributary. the process on tributary longitudinal section variation showed that tributary deposition along the river is relatively uniform if backward flow occurred due to turbidity current. For example, tributary Dayuhe river, whose delta peak of main river lied on the mouth upstream with turbid water flowing into tributary as turbidity current regime and plane longitudinal section from 1st year to 4th year in series experiment. To the 5th year, when delta peak of main river came to the mouth downstream, sandbar suddenly formed and was prodimenent. The trend was accorded with the field data. For example, tributary Zhenshui river, longitudinal section slope ranged from the positive to the adverse which had an increasing trend .The max longitudinal height difference is about 1.7m after flood period in 2008, 3.18m before flood period in 2009, and 4.29m before flood period in 2010. In 2011, max longitudinal height difference is about 10.18m before flood period,where the elevation of the main river deposition face raised 12.79m to 213.24m near the Zhenshui river mouth. While the elevation of tributary deposition face of section ZS5 raised 6.9m to 203.56m, where is about 5km away from the Zhenshui river mouth upstream.

What needs to be pointed out is that in the sediment retaining phase of reservoir, the deposition face rised gradually. For the tributary Zhenshui river which has a larger volume, the height difference between main river and tributary deposition face increased little by little due to the range raised in tributary less than that in the main river. After the sediment retaining phase of reservoir is end, when river bed never continuously raised and lied in the state of dynamic balance, the tributary deposition face raised with main river flow overbank or backward flow through the linkage channel. This makes the height difference tending to decrease. The series experiment results shows that the comparison between the

15th year and 17th year is the mouth elevation changed little and the deposition elevation raised 4m where are 5km away from the mouth in tributary Zhenshui river.

CONCLUSION

Sandbar formation of reservoir tributary is decided by reservoir boundary conditions, water and sediment input conditions, reservoir operation process and combination among those conditions. Many influent factors and local sediment transporting regime make the tributary deposition landform and variation process random, diversity and complexity.

The model is designed by the vertical scale 100 and horizontal scale 60.The Zhengzhou thermal power plant fly ash is chose as model sand. It is accord with the movable bed model law in sediment-laden reservoir in Yellow river. Series model tests show that the main river talweg is delta deposition landform and whether the tributary sandbar forms is decided by the site where it lies. This can be known by the variation of vertical talweg process of Shijing river and Zhenshui river. the surveyed data show that the height difference is to 10.18m in Zhenshui river which is higher than that of 6m in Guishui river in Guanting reservoir.

From the formation of sandbar in Zhenshui river and Guishui river, the factors include many conditions like natural topography, deposition form of main river, water and sediment input, reservoir operation and water and sediment exchange of backward flow between main river and tributary.

It can provide technical support for controlling sediment deposit site and distribution in sediment retaining phase, being full use of tributary volume, and prolonging the life in reservoir sediment retaining to study the response mechanics between tributary deposition landform due to backward flow and influent factors in reservoir. At the same time, it also enriches the subject context in hydraulic, river sediment dynamics and river model technics. The next study should provide the compute mode of tributary backward flow which is based on theory of the river sediment dynamics to improve the level of understanding.

AKCNOWLEDGEMENT

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