Research on Reservoir Sedimentation of Baihetan Hydropower Station on Jinsha River

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Abstract：Baihetan hydropower station is one of the four cascade power stations on Jinsha river lower reach, which is the major project of China's implementation of "West-East Power Transmission Project"strategic plan,and the other three stations are Wudongde station,Xiluodu station and Xiangjiaba station.

In this paper,based on imbalance sediment transport theory,a 1-D full scale sedimentation mathematical model was established to analyze sedimentation of Baihetan reservoir,especially analyze the sedimentation amount,distribution,elevation at the dam site and released sediment load,etc..

Research results show that:(1) The sediment deposition amount in the reservoir would come to 3.717 billion m^3 after 100 years' operation,including suspended load 3.599 billion m^3,bed load 0.1182 billion m^3.After sedimentation,the remaining flood control storage would be 94.4%,and the regulating storage would be 90.4%.(2) After 100 years' operation,the sediment deposition in reservoir wouldn't have come to equilibrium state yet,the location of sedimentation is mainly located in middle reach of the reservoir,while less located in upstream reach and zone near the dam site. The deposition pattern in mainstream reservoir is delta deposit.(3) Because of the large storage capacity of reservoir(stilling storage below normal pool level is 18.532 billion m^3) and less sedimentation,the mean sedimentation elevation at dam site would be 674.7m(Huanghai Elevation System 1956,China) after 100 years' operation,which is lower than the elevation of water inlet of the power plant and therefore has less influnce on the plant;(4) During 100 years' operation,the reservoir would have retained most of the suspended load and total bed load,the discharged sediment into river reach below dam was greatly decreased,the ratio of sediment flushing would be 43.07%～44.80%,and the released suspended sediment concentration would be 0.162～0.220kg/m^3.

Key words：Jinsha river;Baihetan hydropower station;reservoir sedimentation; mathematical model

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1 Introduction

Jinsha river,which is the upper part of Changjiang river from Zhimenda of Yushu county of Qinghai province to Yibin city of Sichuan province,is 3464km long(Fig.1).Baihetan hydropower station is one of the four cascade stations on Jinsha river lower reach, which is the major project of China's implementation of "West-East Power Transmission Project"strategic plan,and the other three stations are Wudongde station,Xiluodu station and Xiangjiaba station.The main purpose of the project is power generating,as well as flood control,sediment retaining and navigation,etc..

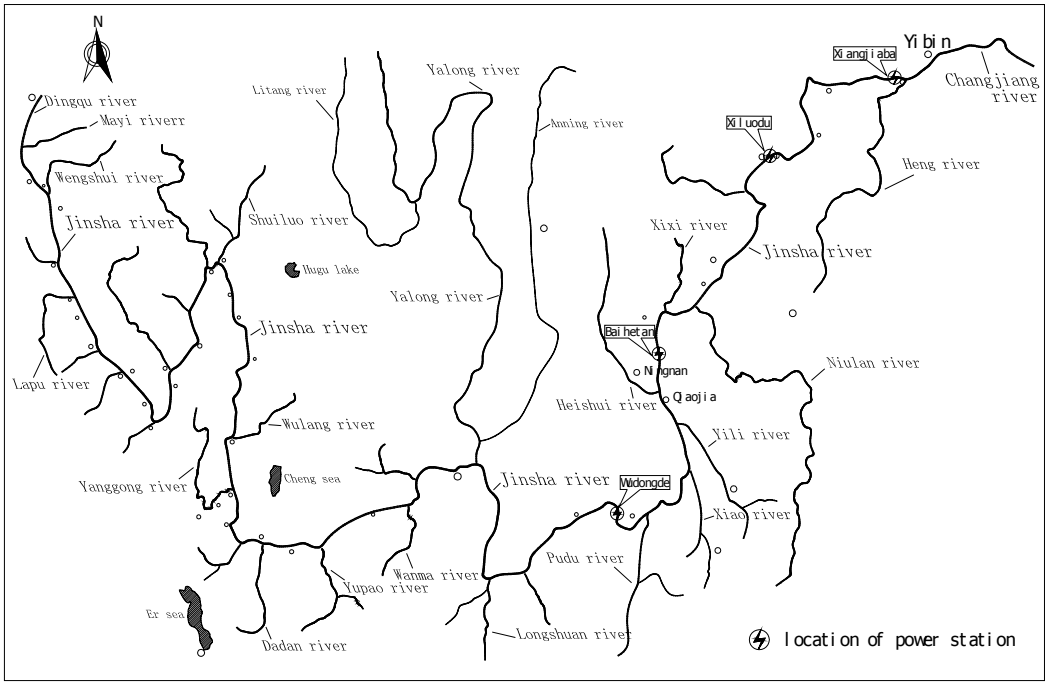

Fig.1 Sketch of water system of Jinsha middle and lower river reach

Baihetan station is located in Ningnan county of Sichuan province and Qiaojia county of Yunnan province.At the dam site section,the control catchment area is 43.03 $\times 10^4$ km^2 which is 91% of whole Jinsha river basin area,and the mean annual discharge is 4110m^3/s,and the mean annual runoff is 1297 $\times$ 10^8 m^3(1958 to 2000).Baihetan reservoir is stream type,and under normal pool level 825m(Huanghai Elevation System 1956,China,the same below),the length of the reservoir is about 190km,the width 200～400m,and the whole storage capacity 185.32$\times 10^8$ m^3.The main tributaries of the reservoir are Heishui river,Pudu river,Xiaojiang river and Yili river.

The mean annual sediment concentration of the river at the dam site is 1.46kg/m^3,the mean annual suspended load 1.853$\times 10^8$ t,the bed load 202$\times 10^4$ t,and the total sediment load is 75% of at Pingshan hydrological station,40.5% at Cuntan station,35.3% at Yichang station.The inflow runoff of Baihetan reservoir in flood season from June to September is 63.7% of the whole year,and the average sediment load in flood season is 89.17% of the whole year,and the mean monthly sediment concentration in flood season is 1.66～2.41kg/m^3.So in flood season,high discharge,high sediment concentration and high sediment load are main characteristics of water and sediment into the reservoir.

In this paper,based on imbalance sediment transport theory,a 1-D full scale sedimentation mathematical model was established to analyze sedimentation of Baihetan reservoir,especially analyze the amount,distribution,elevation at the dam site and released sediment load,etc..Since the reservoir is located in the main sediment yield area,the research work in this paper is of important significance for the reservoir's long-term use and related design works.

2 Mathematical model

Calculating software "HELIU-2" used in this paper,was developed by Changjiang River Scientific Research Institute(CRSRI) based on 1-D imbalance sediment transport theory. The following is the simplified basic equations used in "HELIU-2".

（1）water surface profile formula

$$Z = Z_0 + \frac{n^2 Q^2 \Delta x}{2}\left(\frac{B^{4/3}}{A^{10/3}} + \frac{B_0^{4/3}}{A_0^{10/3}}\right) + \frac{U_0^2 - U^2}{2g}$$

----------(1)

（2）suspended sediment concentration variety equation

$$S_i = S_{*i} + (S_{oi} - S_{*oi})e^{-Y} + (S_{*oi} - S_{*i})Y^{-1}(1 - e^{-Y}) \quad (i = 1,2,\Lambda\ ,8)$$

,----------(2)

where,

$$Y = \frac{\alpha\omega_i \Delta x}{q},\quad S_{*i} = K_i S_{*m},\quad S_{*m} = k\left(\frac{U^3}{gh\omega_m}\right)^m,$$

if $m = 0.92$, $k / g^m = 0.03$,then,

$$S_{*m} = 0.0175\frac{Q^{2.76} B^{0.92}}{A^{3.68}\omega_m{}^{0.92}},\quad \omega_m{}^{0.92} = \sum_{i=1}^{8} P_i \omega_i{}^{0.92}$$

, K_i ,grouped sediment-carrying capacity of flow(Douguoren formula,China)：

$$K_i = \frac{(P_i/\omega_i)^\beta}{\sum_{i=1}^{8}(P_i/\omega_i)^\beta},$$

K_i ,suspended load gradation,

$$P_i = \begin{cases} P_{oi} & balance \\ \dfrac{G_{soi} - \Delta G_{si}}{\sum(G_{soi} - \Delta G_{si})} & imbalance \end{cases}.$$

（3）river bed deformation caused by suspended load

$$\Delta Z_1 = \sum_{i=1}^{8} \frac{(Q_0 S_{0i} - Q S_i)\Delta t}{\gamma_{si}^{'} B \Delta x}\ .\text{----------（3）}$$

（4）bed load discharge

Bed load discharge was obtained based on empirical curve presented by CRSRI. The relationship of the empirical curve is

$$\frac{V_d}{\sqrt{gd}} \sim \frac{q_s}{d\sqrt{gd}}\ ,\text{----------（4）}$$

where, $V_d = \frac{m+1}{m}/\left(\frac{h}{d}\right)^{-\frac{1}{m}} U,\quad m = 4.7\left(\frac{h}{d_{50}}\right)^{0.06}.$

（5）sediment pick-up velocity formula （Zhangruijin formula,China）

$$U_c = \left(\frac{h}{d}\right)^{0.14}\sqrt{17.6\frac{\rho_s - \rho}{\rho}d + 0.000000605\frac{10+h}{d^{0.72}}}$$

.----------（5）

（6）river-bed variation caused by bed load

$$\Delta Z_2 = \sum_{i=9}^{16} \frac{(G_{boi} - G_{bi})\Delta t}{\gamma_{si}^{'} B \Delta x}\ \text{----------（6）}$$

where, Δt ,time interval; Δx ,distance between two cross sections; S_i , S_{*i} ,,grouped sediment concentration and sediment-carrying capacity of flow; S_{*m} ,total sediment-carrying capacity at a cross-section; q ,discharge per unit width; ω_m ,average settling velocity of heterogeneous sediment; k , m ,coefficient and exponent of sediment-carrying capacity

formula; β ,exponent (1/6); U_d ,flow velocity near bed; U_c ,pick-up velocity of bed material; d ,grain diameter; H ,water depth; q_b ,sediment discharge of bed load per unit width; G_b ,total sediment discharge of bed load; G_s ,suspended sediment discharge at a cross section;subscript "0", known cross sections.

The above software "HELIU-2" has been well calibrated and validated before many times,and was used successfully to calculate reservoir sedimentation of Three Gorges Project , Danjiangkou reservoir,etc..and the calculating results were all accepted by experts.

3 Calculation conditions and schemes

3.1 Typical hydrological series

The upstream nearest hydrological station from Baihetan dam site on Jinsha river is Qiaojia station,which has control catchment area 429500 km^2,and was selected as representative station for analysing incoming water and sediment characteristics of the reservoir.

To select typical hydrological series,the basic principle is that the mean annual runoff and sediment load of the typical hydrological series are almost equal to that of long-term series.So from long-term hydrological series 1958 to 2000 of Qiaojia station,10 years typical series 1961 to 1970 was selected.The mean annual discharge of the typical series is 4180 m^3/s,the mean annual sediment concentration 1.3kg/m^3,and the suspended load 1.75×10^8 t.The whole calculating period is 100 years.

3.2 Reservoir regulation scheme and programme

In this paper,the reservoir regulation scheme would be 825m-795m-765m(normal pool level-flood control level-lever before flood).The regulation programme would be as follows.From June of flood season,the power station works under guaranteed output,and the water lever of reservoir will rise gradually to flood control level.From Sep.,the reservoir begin to retain water,and the water level will rise to nomal pool level gradually.In Dec. or Jan. of next year,the reservoir begin to supply water,and until May of next year the water level will drop to level before flood.

3.3 Water and sediment calculating conditions

In this calculation,the incoming water and sediment load of the reservoir is from the main stream and two tributaries(Heishui river,Xiaojiang river) which have relatively more sediment yield.For the main stream,the retaining action of reservoirs upstream,such as Jin'anqiao,Guanyinyan,Wudongde and Ertan(on tributary),was considered.

4 Calculation results analysis

4.1 Sediment deposition amount in reservoir

Because of the upstream reservoirs' sediment detention activities, the input sediment load with finer grain size into Baihetan reservoir is decreased during 100 years' operation.After 10 years' operation,the total incoming suspended load would be 6.9804×10^8 t,which is 39.9% of natural.

(1) suspended load deposition

The calculated results are shown in Table 1.The sediment deposition amount in the reservoir would come to 37.17×10^8 m^3 after 100 years' operation,including suspended load 35.99×10^8 m^3,bed load 1.182×10^8 m^3. After sedimentation,the remaining flood control storage would be 94.4%,and the regulating storage would be 90.4%.Therefore,the storage loss due to sedimentation would be less,and the reservoir would still be in initial operation stage within 100 years.

Table 1 Calculating results of Baihetan reservoir's sedimentation

Years of operation	Sedimentation ($\times 10^8$ m^3)		Sediment flushing ratio (%)	Released sediment concentration (kg/m^3)	Median diameter of flushed sediment d_{50}(mm)	Remaining storage(%)		Sedimentation elevation (m)
	suspended	bed load				Flood control	Regulating	
10	3.19	0.118	43.07	0.162	0.0050	99.6	99.1	591.86
20	6.42	0.236	43.55	0.171	0.0051	99.1	98.3	606.51
30	9.74	0.355	44.07	0.183	0.0051	98.6	97.3	621.16
40	13.12	0.473	44.40	0.189	0.0051	98.1	96.6	632.27
50	16.57	0.591	44.62	0.193	0.0052	97.6	95.7	641.96
60	20.10	0.709	44.76	0.198	0.0052	97.0	94.8	649.50
70	23.95	0.828	44.82	0.204	0.0053	96.5	93.9	656.32
80	27.57	0.946	44.83	0.209	0.0054	95.8	92.8	662.68
90	31.58	1.064	44.83	0.214	0.0055	95.2	91.7	668.85
100	35.99	1.182	44.84	0.220	0.0056	94.4	90.4	674.73

(2) bed load deposition

The annual bed load discharge into Baihetan reservoir is about 202×10^4 t.During 100 years' operation,no any bed load would be released out of the reservoir.

4.2 Sediment deposition distribution in reservoir

Sediment deposition is mainly located in the middle part of the reservoir,but less located near the dam site and the end of the reservoir.After 100 years' operation,the sediment deposition in reservoir wouldn't have come to equilibrium state yet.The deposition pattern in mainstream reservoir is delta deposit(Fig.2).In Heishui tributary part of the reservoir, the sediment deposition amount would come to 1.27×10^8 m^3 after 100 years' operation. In Xiaojiang tributary reservoir,due to the steep slope of the river bed and rapid flow,there are scouring and silting actions in a hydrological year,so there is no cummulative sedimentation during 100 years.

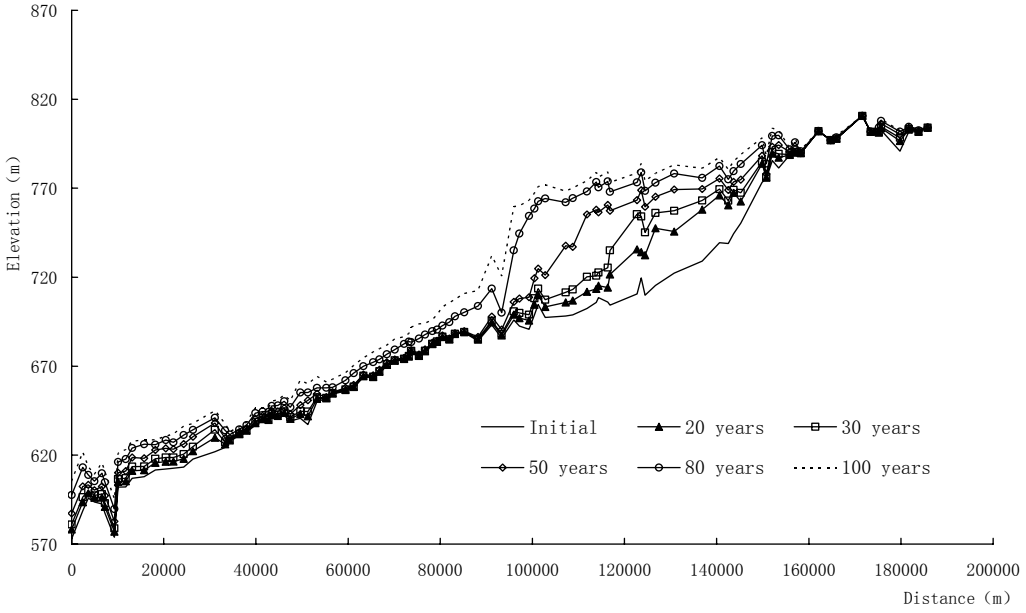

Fig.2 The longitudinal profile of Baihetan mainstream reservoir of different times within 100 years

4.3 Sediment flushing ratio and median diameter of flushed sediment d_{50}

Due to the finer sediment inflow and lower water level in flood season,the sediment flushing ratio is about 43.07%～44.84% within 100 years.Calculation results show that, the median diameter of flushed sediment changed not so much and d_{50} had a range of 0.0050mm～0.0056mm during 100 years(Table 1).

4.4 Sedimentation elevation at dam site

According to calculation results of 1-D mathematical model,the average sedimentation elevation at dam site would be 674.73m after 100 years' operation,which is lower than the elevation of water inlet of the power plant and therefore has less influnce on the plant.

4.5 Released suspended sediment concentration

During 100 years' operation,the reservoir would have retained most of the suspended load and total bed load.The discharged sediment into Xiluodu reservoir downstream was greatly decreased,and thus extended it's life to equilibium state.The released suspended sediment concentration would be 0.162 ～ 0.220kg/m^3.In the end of 100 years,the released sediment load is about 20 % of natural(Fig.3).

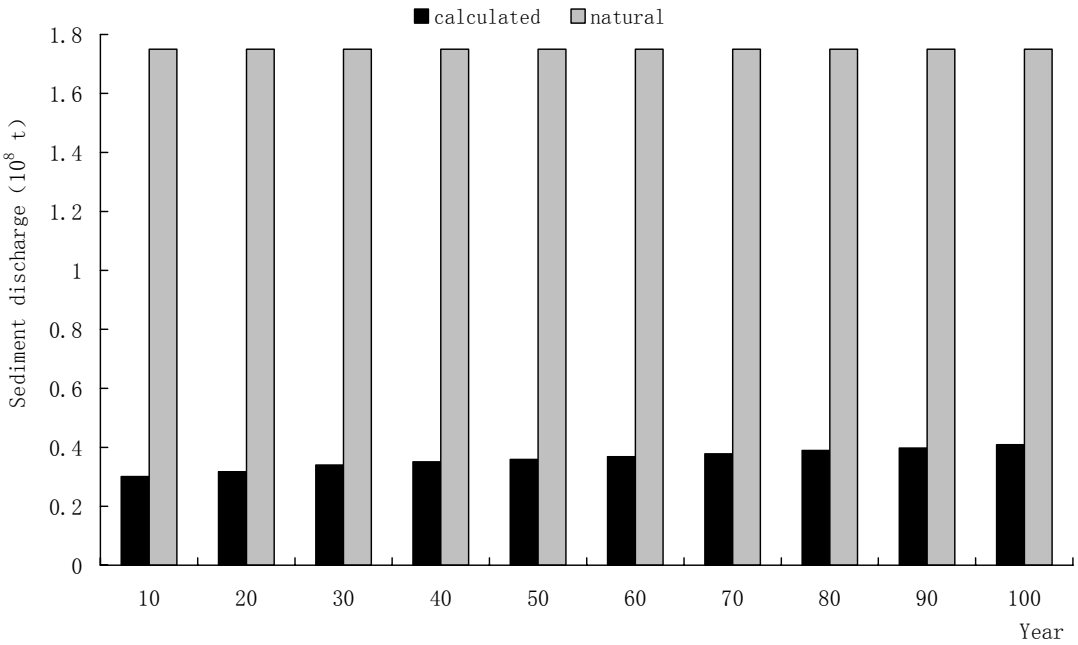

Fig.3 Comparision between released sediment load of reservoir and natural sediment load at dam site

5 Conclusions

(1) Baihetan hydropower station is one of the four cascade stations on Jinsha river lower reach,which is the major project of China's implementation of "West-East Power Transmission Project"strategic plan. In this paper, a 1-D full scale sedimentation mathematical model was established to analyze sedimentation of Baihetan reservoir.

(2) Under selected calculating conditions and schemes,because of the vast storage capacity of the reservoir,and the retaining action of upstream reservoirs built,under building or planned,the storage loss due to sedimentation would be less,and the reservoir would still be in initial operation stage within 100 years.

(3) Calculation results show that,the sediment deposition amount in the reservoir would come to 37.17×10^8 m^3 after 100 years' operation,including suspended load 35.99×10^8 m^3,bed load 1.182×10^8 m^3.After sedimentation,the remaining flood control storage would be 94.4%,and the regulating storage would be 90.4%.The sediment deposition in reservoir wouldn't have come to equilibrium state yet The deposition pattern in mainstream reservoir is delta deposit.The sedimentation in reservoir has less influnce on the power plant.The discharged sediment into Xiluodu reservoir downstream was greatly decreased.

References

[1] HAN Qi-wei and HUANG Yu-ling(1977). Calculating method of reservoir sedimentation and application of electronic computer. Selected papers on application of electronic computer in water conservancy and hydropower projects, *publishing house of water resources and electric power,Beijing city,China*.

[2] ZHANG Rui-jin,XIE Jian-heng and WANG Ming-fu(1988). River sediment hydrodynamics, *publishing house of water resources and electric power,Beijing city,China*.

[3] ZENG Zhao-fen,etc.(2005). Pre-feasibility report on Baihetan hydropower station on Jinsha river, *East China investigation & design institute,Hangzhou city,China*.

[4] WAN Jian-rong,GONG Ping and WANG Cheng(2008). Reservoir sendimentation research of Yinpan hydropower station on Wu river, *Yangtze river,vol.39,p. 94*.