COMPREHENSIVE IMPROVEMENT COUNTERMEASURES OF FLOATING DEBRIS FOR CASCADE RESERVOIRS OF THREE GORGES

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Abstract: Floating debris from upstream always concentrate on the two dam sites of cascade reservoirs of Three Gorges, endangering hydraulic head of power plants, ecology environment, water quality and navigation. In this article, by analyzing the sources of floating debris and its distribution, summarizing hydraulic model test result, investigating movement mechanism and treatment effect of floating debris at present, some key problems are disclosed for urgent solutions. According to new characteristics after Three Gorges cascade reservoirs putting into operation, considering the two sides of single reservoir or the whole system, comprehensive improvement countermeasures are discussed to find out possible methods for improving floating debris treatment effect. For the sake of improving ecology environment of cascade reservoirs, ensuring operation and increasing electric power production rate, it is suggested that regarding cleaning source as a main method for floating debris treatment, making floating debris concentrating on some areas in the reservoirs by guiding and intercepting facilities, cleaning them away in time.

Key words: planar source pollution, Yangtze River, cascade reservoirs of Three Gorges, floating debris movement pattern, current situation of treatment, treatment effect evaluation, ecology environment, water head of power plant, cleaning source and stopping transferring.

1. Introduction

The watershed area upstream from Three Gorges cascade reservoirs is 1×10^6 km^2 which is about 56% of overall Yangtze River watershed area. The watershed area between Yibing city and Yichang city is about 5×10^5 km^2. The water course of Yangtze River is wriggly and flexuous, through hilly lands, plains and gorges. On its way, the topographical feature is cliffy and rainstorm weather is frequent. The dam sites of Three Gorges cascade reservoirs become concentration zone of upstream floating debris consequently.

The source of floating debris is from rainstorm area of eastern SiChuan province and Three Gorges, surface runoff cover land by rainstorm, upstream riverside garbage dumps and navigation ships' trash.

The composition of floating debris is complicated and multifarious. According to investigation data of Gezhouba hydro project, incoming floating debris can be classified as three kinds, including the first kind of crop straw, rootstalk and hill vegetation (about 70%~80%), the second kind of home scrap such as foam plastic, knitted bags, plastic bags etc (about 10%~20%), the third kind of tree trunks and timbers which have big bulk. Sometimes wreckages from accidents such as wood rafts, bamboo rafts and stake boats also become one part of floating debris (about 10%).

The quantity of floating debris is related with rainfall intensity and flood discharge. When flood discharge is less than 25000m^3/s, a few floating debris is brought into the reservoirs, mostly classified as the second kind. When flood discharge is less than 30000m^3/s and greater than 25000m^3/s, there are many floating debris in the reservoirs, mostly classified as the second kind in early flood season and as the first kind in main flood period. When flood discharge is greater than 30000m^3/s, especially occurring heavy rainstorm or mountain torrents breaking out, the quantity of floating debris increases abruptly and the third kind of big floating debris appears. In flood period, the normal incoming volume of floating debris is 3000～4000m^3 during once flood, maximum value of 7000～10000m^3. The total volume of floating debris in Three Gorges cascade reservoirs is estimated to be 150×10^3～200×10^{3}m^3 each year. Besides, during the water storage process of Three Gorges Project, floatable objects in submerged area become floating debris with water level rising gradually. When upstream water level of Three Gorges Project reaches 135m in 2003, the gross volume is estimated to be more than 400×10^{3}m^3 at the end of the year.

In the past, owing to lack of scientific understanding about movement pattern of floating debris, especially part submerged debris, and about complex flow pattern upstream from dam site under disadvantageous conditions, some facilities used for guiding and discharging floating debris have lost effectiveness. During 20 years of operation, floating debris in front of Erjiang power station is a prominent problem, resulting in bad effect for productive head, environment, water quality and navigation etc[1] .Along with increasing global environment protection consciousness day by day, the problem of floating debris in Gezhouba hydro project, or even of cascade reservoirs in Three Georges Project, need to be solved over all.

2. Current situation of floating debris control in Gezhouba hydro project

2.1 Floating debris movement pattern upstream the dam site

Gezhouba hydro project is located at the middle of counter “S” riverway at Xiling gorge exit. With river water surface between Nanjingguan and the dam site broadening from 300m to 2200m abruptly, flow velocity decreasing, incoming floating debris do not move to discharging sluices along main riverway according to the deflecting flow pattern, but move along Sanjiang siltation prevention embankment. When floating debris moves near intake channel of Erjiang power station, it is guided to upstream Erjiang power station by flow intake division effect for power generation. Flow intake for power station and sand guiding sill make water flow rotating, turn into turbulence in every direction, with air bubble eddy forming. The flow turbulence intensity increases with increasing flow discharg from left area of Erjiang discharging sluices and the flow pattern is very complex[2].

Floating debris reaching upstream water inlet of Dajiang power station mainly belongs to the second category, which presses and twines on the trash rack’s grate bars. Floating debris reaching upstream Erjiang power station includes all three categories, mingled with others of big size. Since there is more floating debris upstream Erjiang power station than that of Dajiang power station, it becomes a key zone of floating debris control.

Before water storage begins in Three Gorges Project, The quantity of floating debris upstream Gezhouba hydro project is mainly affected by rainfall intensity of upstream area, decreasing after flood peak, with the specific character of high peak value and short cycle, due to run-of-river power station of non-storage. Floating debris upstream Dajiang power station blocks up the trash rack of 8# power generator, then moves rightwards gradually. Floating debris upstream Erjiang power station blocks up the trash rack of 1# and 2# power generators, then moves rightwards to the others trash racks gradually.

After water storage begins in Three Gorges Project, due to its periodical and concentrated way of floating debris discharging, incoming floating debris in Gezhouba hydro project has still a prominent feature of high peak value. In order to rise productive head for power generators in Three Gorges Project, upstream water level in Gezhouba hydro project needs to be lowered from 66.5m to 64.0m, resulting in limited cleaning range of the former debris cleaners and decreased cleaning efficiency, which make floating debris gather round trash racks for a long time and block them out eventually. However, the movement pattern of floating debris upstream Erjiang power station changes remarkably. When incoming flow discharge is less than 20000m^3/s, floating debris blocks out the trash rack of 3# power generator first of all, then blocks out the trash racks of 4#, 2# and 1# power generators gradually. When incoming flow discharge is more than 20000m^3/s, floating debris moves to the trash rack of 6# power generator, then rotates back around the trash racks of 2# and 1# power generators gradually. Floating debris blocks out the water surface part of the trash racks, then moves downwards to block out the second and third nodes, resulting in pressure head difference on trash racks. The site investigation shows that furious turbulent flow entangles floating debris of half floating and half submerge into deep layer water, pressure head difference on the trash racks of 1# and 2# power generators increases from 0.5m to 4.0m in a short time, resulting in power generation output decreased remarkably.

2.2 Current situation of floating debris control

2.2.1 Floating debris discharging facilities design and their application

Floating debris discharging facilities in Gezhouba hydro project are shown in Fig 1.

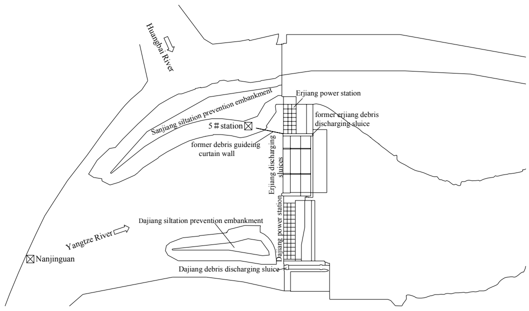

Fig 1 Floating debris discharging facilities in Gezhouba hydro project

(1)Floating debris discharging facilities: There are totally three floating debris discharging outlets on right side of Erjiang and Dajiang power station. Due to its flow discharge far less than flow intake discharge for power generation, with guiding curtain wall of floating debris dismantled completely, side direction flow upstream 9# power generator moves from right side to left side, brings floating debris into concentration at the left side of upstream Erjiang power station, so the outlet of Erjiang power station is useless for floating debris discharging and is rebuilt to self-provided power station. When the floating debris discharging outlets and the lower sand discharging outlets are used fully, flow discharge can reach 1000～1200m^3/s. Due to ring-shaped flow pattern upstream Dajiang power station, side direction flow at the right side of upstream 9# power generator can bring floating debris into the right discharging outlets, obtaining good floating debris discharging effect. The discharging outlet of floating debris has been used until today.

(2)Guiding facilities for floating debris: as auxiliary facilities of floating debris discharging for the outlets and discharging sluices of Erjiang power station, guiding curtain wall made up of connected float bowls is installed between 5# hydrological station on Sanjiang siltation prevention embankment and the left side of Erjiang floating debris discharging outlets. During flood season in 1981~1983, it is hoped that the curtain wall can guide floating debris. However, impacted by strong lateral flow, some chain cables broke and float bowls were rushed away continually, resulting in large quantity of floating debris rushing to upstream Erjiang power station and trash racks blocked out badly. The guiding curtain wall was dismantled subsequently.

(3)Interception facilities: The vertical grate bars of 400mm×250mm were applied to trash racks for intercepting big size floating debris and passing through small debris which has little effect for power generator. This design can not bring good effectiveness during actual practice. Based on the extent of grate bars twined by trash and debris passing through them, considering the maximum open value of guide blades on power generators, the transversal grate bars of 1000mm×400mm were adopted for trash racks. After its application, floating life debris can pass through trash racks successfully, good interception effect obtained.

(4)Cleaning facilities for floating debris: The cleaning machines include mainly bucket cleaning bridges, portal cleaners and petal buckets etc. There are three bucket cleaning bridges, one installed at Dajiang power station and two installed at Erjiang power station. These bucket cleaning bridges make great contribution for floating debris cleaning. After reservoir water level is decrease to 64.0m, due to decreased underwater work depth, their cleaning effect is decreased. Only one bucket cleaning bridge is still used in Dajiang power station at present. The portal cleaners are installed in Erjiang power station. Due to ring-shape flow's side direction impact, their vertical-lift hydraumatic buckets have big range of oscillation. Their underwater work depth is 5m in flood season, 10m in non flood season. Working in with 25t rotation booms of portal cranes, petal buckets can be used for floating debris cleaning upstream the dam and trash racks, or in gate slots of power generator intakes.

2.2.2 Measures and application effectiveness of floating debris discharging and cleaning

(1)Regulating measures

(a)Using Dajiang scouring sluices: When flow discharge is more than 35000m^3/s, putting Dajiang scouring sluices in use can make upstream main flow line swing rightwards, floating debris strip moves rightwards correspondingly, the quantity of trash entering into upstream Erjiang power station can be decreased 5%～10%. But the quantity of trash entering into upstream Dajiang power station increases barely.

(b)Using the left side Openings of Erjiang discharging sluice: When flow discharge is more than 35000m^3/s, putting the left part of Erjiang discharging sluices in use and increasing flow discharge from this zone, can make its upstream water level lower than water level upstream Erjiang power station, forming transversal gradient, resulting in debris moving to upstream these discharging sluices. Good floating debris discharging effect is obtained in actual operation. When all power generators of Erjiang power station are out of operation, all floating debris upstream the station can be discharged to downstream riverway in 2～3 hours.

(c)Stopping power production to make floating debris running back: when electric power requirement of the whole power network is lower, shutting down all power generators can make floating debris running back, providing convenience for debris cleaning and decreasing pressure head on trash racks.

(d)Shutting up power generator by turns for guiding floating debris: When too much debris are conglutinated on trash racks, by shutting up power generators in left-to-right turn, floating debris can be guided to debris discharging sluices or discharging sluices gradually. In actual operation, power generators of left side are shut up first, followed by power generators shut up of right side. By putting every power generators out of operation for 0.5～2.0 hours, floating debris upstream the power station can be discharged through discharging sluices.

(2) Floating debris cleaning measures

(a) Raising up trash racks and discharging debris by power station: This method can obtain good cleaning effect, but threatening safety of power generators. Only when the cleaning machines are damaged, power generators can not be shut up, with too high pressure head on trash racks and no reports of big size debris from water surface surveillance, it is permitted to raise up trash racks and discharge debris in daylight after the director in charge has explored the site.

(b)New cleaning machine development: for new cleaning machine under development, the design demand is as below, cleaning bucket unaffected by flow pattern, capturing debris freely, adaptation for narrow area specifically, big bucket capacity, high cleaning efficiency, no touching transversal grate bars for bucket teeth, no damage for trash racks during operation, self moving and self discharging.

(c) Manual cleaning in non flood season: When power generators are scheduled to be serviced in winter, man power can be arranged for concentration cleaning of floating debris around intakes and trash racks, no interfering with normal operation of working gate and emergency gate.

2.2.3 Floating debris control evaluation

In order to solve floating debris problem in Gezhouba hydro project, full designment about all kinds facilities including discharging, guiding, interception and cleaning, has carried out in combination with model tests. Due to complicated flow pattern upstream the dam and lack of scientific understanding about floating debris movement pattern, especially about part submerged debris, some facilities can not obtain anticipative effect. Based on full analysis about floating debris movement features and actual practice effect of debris discharging facilities, the reason that good floating debris control can not be achieved is summarized as below:

(1)The understanding about flow pattern and debris movement features upstream the dam is not completely scientific. During different operation period in Gezhouba hydro project, many disadvantageous operation conditions exist all the time, flow pattern and debris movement pattern upstream the dam would change accordingly. The superficial understanding about half floating and half submerge debris movement makes the related facilities design lack of scientific basis.

(2)No floating debris discharging openings is installed on the left side of Erjiang power station. There is one debris discharging opening installed on its right side, which can work effectively only when the curtain wall can intercept, guide debris. If the curtain wall is destroyed by water flow or fails, the debris sluices in Erjiang power station can not work properly, that is proved by actual practice. Even if the curtain wall works successfully and some debris are guided for discharge, a few debris of half floating and half submerge still pass through it and move into the area upstream Erjiang power station. Therefore, some debris discharging passages should be installed at the left side of Erjiang power station, which can discharge debris passing through the curtain wall and be used as backup facilities. For now, the function mentioned above has to be replaced by forced measure of raising trash racks up and debris discharging.

(3)The structure design strength of the debris guiding curtain wall is too low, resulting in its operation failure. In the time of big flood discharge and disadvantageous operation conditions, affected by sand guiding sill, water flow turns into violent turbulence around the entrance of intake channel. Due to periodical change of impact force in magnitude and direction, a angle of more than 45°existing between intake flow for power generators and axis line of the curtain wall, vertical velocity component of flow being greater than parallel velocity component, the floating pontoons of flexible connection turn into ogee formation, resulting in more trouble for its operation and its downwards movement. Since its structure strength can not meet the safety requirement, the curtain wall is damaged by water flow subsequently.

At the present, due to limited choice for floating debris control, much man power, supplies and money are spent on debris cleaning by the project administration every year. When floating debris covers huge water surface area and can not be cleaned away effectively in time depending on existing facilities, such measures as raising up trash racks or stopping power generators have been carried out according to the related rules and procedures, resulting in safety threat to power generators and decreased power production benefit. Therefore, since water storage process has been finished partially and the actual operation has begun in Three Gorges Project, it is very necessary to explore comprehensive measures for floating debris control from the big system view of cascade reservoirs of Three Gorges.

3. Current situation of floating debris control in Three Gorges Project

3.1 Floating debris movement pattern in the reservoir

According to operation regulation and normal incoming debris in Three Gorges Project, during flood season of four months, upstream water level of 145m and flood discharge of 35000m^3/s is the basic operation water level and the corresponding flow discharge of big debris quantity , which is also control operation condition for model test about debris movement pattern. The data[3] by model test shows, compared with debris distribution in upstream area of left power station, more floating debris is found in upstream area of right power station. There is 5% of total debris quantity located upstream left power station, 25%～50% located upstream right power station, the others distributed in backflow zones.

Floating debris movement pattern and debris distribution in Three Gorges Project dam site, are related with regime of flow, reservoir water level, flood discharge and operation regulation procedures, change accordingly when these parameters mentioned above change.

When reservoir water level rises from 145m to 167m, the debris quantity in front of left power station increases a little, but that of the right power station decreases a little, with no change from the overall distribution pattern mentioned above. When reservoir water level rises to 175m, incoming flow discharge decreases to less than 20000m^3/s, there is 36%,37% and 6% of total debris quantity located in upstream navigation channel entrance, upstream navigation channel and upstream area of left power station respectively. With about 70% of total debris quantity distributed in upstream left area, new debris distribution pattern appears.

When flow discharge increases further, the debris quantity of upstream left power station increases a little, debris distribution pattern of “more right and less left” is still maintained. When flow discharge begins to decrease, the debris quantity of upstream right power station tends to increase, but increase value is limited.

Changed operation regulating procedures results in oscillating movement of main flow reaches from Jiuling mountain to upstream the dam, the debris distribution changes accordingly. On the condition of unchangeable total flow discharge, the discharge value of left dam monolith increases, resulting in increased debris quantity, vice versa. The overall debris distribution pattern is maintained as “more for right and less for left”.

3.2 Current situation of floating debris control

3.2.1 Discharging facilities design of floating debris and model test result

Three debris discharging openings are installed on left guide wall, 1# right longitudinal dam monolith and 1# right non-flood-discharging monolith, with intake bottom elevation of 133m and orifice size of 10m×12m, which is used for low reservoir water level of 135m～150m. When reservoir water level is more than 158m, surface spillway openings are used for floating debris discharging. The model test result shows floating debris movement pattern is consistent with surface flow pattern[4][5]. Floating debris in the upstream of spillway dam monolith and left power station can be discharged into downstream riverway by surface spillway or debris discharging openings. Due to big clockwise backflow area in the upstream of right power station and slow movement of floating debris in this area, a little debris can move from backflow edge belt to surface spillway (high reservoir water level condition) or debris discharging sluices(low reservoir water level condition).On the condition of high reservoir water level, 80% of total debris quantity can be discharged by surface spillway. On the condition of low reservoir water level of 145m～150m, 90% of total debris quantity can be discharged by debris discharging openings. For efficiency comparison, 2# debris discharging opening has best efficiency, the next is 1# debris discharging opening, the last is 3# debris discharging opening. The debris discharging efficiency can be increased in combination with debris cleaning boats.

3.2.2 The actual practice and evaluation

When reservoir water level is 135m, only 1# debris discharging opening can be used. Due to water depth of only 2m on its intake bottom plate, the debris quantity discharged by 1# opening is 7%～15% of total debris quantity and its work efficiency is low. By putting more power generators into operation, raising upstream water level up and using left side deep outlets for dispatching on the condition of small flow discharge, the debris discharging rate can be increased to 30% at best for 1# opening. The overall improvement effect is remarkable after using cleaning boats to clean and push debris[6]. On the initial operation condition of 138m～156m reservoir water level, the debris discharging rate of all three openings is 45%～90%. When reservoir water level is more than 158m in later stage, by using surface spillways for debris discharging, the debris discharging rate can reach more than 80% and the debris cleaning effect is very good. For floating debris distributed in upstream navigation channel, permanent ship lock and backflow area, the only way of cleaning is by salvage.

At the present, adopting debris discharging as main way of floating debris treatment, in combination with cleaning facilities, the designment of debris discharge passages can meet operation demand of every period basically in Three Gorges Project. With the aid of cleaning boats, the overall effect of floating debris control is very good. However, by concentrated debris discharging into downstream riverway, floating debris treatment method of Three Gorges Project just transfers the trouble to downstream hydro project, resulting in a severe problem to solve for Gezhouba hydro project. The overall solution needs to find out from the big system view of cascade reservoirs of Three Gorges.

4. Comprehensive improvement counter measures of floating debris

4.1 Traditional measures evaluation and the related countermeasures

The traditional measures of floating debris control is adopting debris discharging as main way of floating debris control, in combination with cleaning facilities, which plays a important point on single hydro project and pays a little attention to bad effect on downstream environment. This kind of measures has been carried out in both hydro projects of Three

Gorges cascade reservoirs. In Three Gorges Project, floating debris is discharged into downstream riverway periodically, resulting in severe environment problem for Gezhouba hydro project. The related countermeasures are shown as below for further discussion.

(1)According to current situation of much floating debris concentrated in front of Erjiang power station with no discharge passages, in order to reduce bad effect on flood control, power generation and navigation etc, based on overall consideration of efficiency and economy, new debris discharging passages should be set up on suitable location recommended by model test.

(2)The reason of the curtain wall facility failure is due to lack of scientific understanding about flow pattern, debris movement pattern and disadvantageous operation condition, which results in low structure strength design. If new debris discharging passage is possible to be installed in left area of Erjiang discharging sluices, in order to increase debris discharge efficiency, based on the past experience, it is suggested that the curtain wall for guiding debris should be recovered by adopting new materials and suitable structure design.

(3)In floating debris concentrated area, work platforms or cleaning bridges are recommended to be set up for manual debris cleaning and mechanical debris cleaning.

(4)It is suggested that new type cleaning facilities are developed with the adaptation of regulation requirement in Three Gorges cascade reservoirs.

4.2 Comprehensive countermeasures of big system for floating debris control

Regarding cascade reservoirs of Three Gorges and downstream riverway as a big system, decreasing upstream incoming floating debris, increasing debris interception quantity, just mean less working capacity for downstream hydro project. Therefore, comprehensive countermeasures of big system for floating debris control, viz. "cleaning source, stop transferring, comprehensive control " , as a good measure of multi-benefit, can increase the benefit of power generation and navigation, guarantee operation safety, improve water quality, protect water source and ecological environment. Its basic frame is shown as below.

(1) Cleaning source and stop transferring: In order to prevent trash accumulation on river bank and manual trash dump into river, strict regulation and the related law should be compiled and executed. Stopping tree cutting, breeding woods for soil and water conservation, can keep strict control on natural trash brought into river by surface runoff. According to natural water flow movement pattern, in combination with guiding and interception facilities, one or more floating debris concentration zone can be set up for cleaning incoming debris in time.

(2) Salvage treatment: a complete set machine including overwater push dozer, overturning skip with leather belt and cleaning boat, should be developed for floating debris cleaning in time. By building treatment factory, salvaged floating debris can be sorted for reprocessing or burying deeply, fire burning to avoid second pollution.

(3) Floating debris discharging: According to floating debris movement pattern upstream the dam, in combination with guiding, pushing and cleaning facilities, discharging passages are set up to discharge the rest debris into downstream riverway effectively, reducing bad effect on power generation, navigation, ecological environment and water quality as possible.

The artificial floating debris concentration zone is the most difficult part of the comprehensive countermeasures mentioned above. The model test result shows that the perfect riverway and topography are located in upstream Danzishi riverway. Big bay exists in the riverway between Tonghuigou and Quxi, where much floating debris can be concentrated. between Meirentuo riverway and Pianyanzi riverway in the upstream of the big bay, due to most floating debris moving to side bank, trajectory rows can be set up on projection mouth, interception rows can be set up in big bay. So floating debris moving along left bank can be pushed to right side of main river valley line and form concentration in the zone surrounded by interception rows. Many schemes are explored in model test. The recommended scheme is shown as Fig 2.

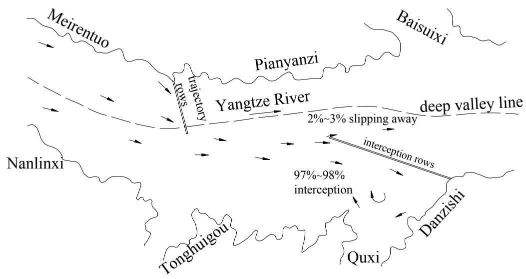

Fig 2 The facilities and flow pattern for debris trajectory and debris interception in Danzishi riverway

(H=145m,Q=19200m^3/s, 400m length of left bank trajectory row, 920m length of right interception row)

On the operation condition of 145m reservoir water level and 19200m^3/s flow discharge, more than 95% of floating debris from right trajectory rows is intercepted in big bay, except a little debris slipping away from left side. With increasing flow discharge, better effect of trajectory and interception can be obtained. The installation of trajectory rows and interception rows is involved with structure strength, navigation disturbance and adaptation for big water level change etc. Therefore, the scheme practicability need to be proved in many aspects.

5.Conclusion

At the present, the traditional floating debris control measure, viz. "floating debris discharging as main way in combination with cleaning facilities", is carried out in two hydro projects of Three Gorges cascade reservoirs. Since most floating debris upstream the dam can be discharged into downstream riverway, the debris discharging passages design can be thought to meet the operation demand of different reservoir water level. However, due to no discharge passages upstream Erjiang power station, floating debris control has been a severe problem in Gezhouba hydro project during 20 years operation. Therefore, the traditional measure can not solve floating debris problem of Three Gorges cascade reservoirs completely. Comprehensive countermeasures of large system for floating debris control, viz. "cleaning source, stop transferring, comprehensive control " , as a good measure of multi-benefit, can increase the benefit of power generation and navigation, guarantee operation safety, improve water quality, protect water source and ecological environment. For the traditional measures or comprehensive countermeasures of big system for floating debris control, the related research should be carried out as soon as possible. In order to find out the optimal scheme of feasibility and economy, it is necessary to extend research field and deepen research content.

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