BEHAVIORS OF LARGE TURBID CURRENT AND COUNTERMEASURES FOR LONG TERM TURBIDITY PROBLEM IN THE STRATIFIED RESERVOIR

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Abstract: A series of numerical calculation results are shown on dynamic behaviors of turbid current in the reservoir. With a large volume of the current, it flows down along the bottom of the reservoir, and the return current after clashing the dam contributes much on mixing of the turbid water with surroundings, causing prolonged turbidity in the reservoir.

The mechanism implied possible treatments to reduce the volume of the turbid water. Numerical experiments indicate that successful purging the turbid water by a low layer outlet, such as a selective withdrawal device, reduces the period of turbid water by 88%. Then, some calculations are conducted to improve the condition of sediment flow in reservoirs. The results suggest that the behavior of sediment flow can be controlled if the stratification condition or the outlet elevation in reservoirs can be changed.

Kewords: Large turbid current, long term turbidity problem, reservoir, countermeasures, stratification, selective withdrawal

1. INTRODUCTION

The request to improve the long-term turbidity problem, for improving the scene and increasing the fisheries resource, are often from the water's user and the residents of the downstream reaches of the river. Especially since the new law of environment assessment has been in force in Japan, the attentions to the long-term turbidity problem in dam reservoir have also been raised further more. Therefore, the technology for evaluating this phenomenon is requested widely.

Generally, if the temperature stratification cannot be formed in the reservoir and the exchange speed of the water is comparatively fast, the phenomenon of long-term turbidity problem cannot be generated. On the other hand, the long-term turbidity problem is often appeared in the stratified reservoir, due to its long retention period for the flood currents and the intrusion of turbid current to the upper layer, which depends on the density flow.

The flowing velocity in the reservoir is usually much faster than the setting velocity of fine particles, which are induced by the flood. Beside of it, the mixture between the clean water and the turbidity water is produced due to the turbulent flow, which is generated by the flow and the wind. Therefore, the sedimentation of suspended sediment in the reservoir is obstructed, so that a long-term turbidity problem occurs.

Aki & Shirasuna (1975) found that the turbidity behavior depends on the scale of the flood as well as the situation of stratification and induced an index to present the turbidity behavior in the reservoir, named as the scale of the flood:

$\beta =$ The total volume of flood discharge/reservoir capacity

According to the analysis of Aki & Shirasuna, the flood scale can be classified into three levels: big scale flood for $\beta > 1$, mid scale flood for $1 > \beta > 1/2$, and the small scale flood for $\beta < 1/2$. The intrusion location of the flood depends on the scale of flood. The turbid current flows into the mid-layer of the reservoir for a small flood, and to the whole upper layer for a mid-scale flood. But for a big scale flood, the clean water in the reservoir can be exchanged for the turbid current. For this case, the heavy turbidity flow can overcome the density difference of water temperature between the two layers, being above and under the thermocline, where the water temperature slope is steep, and the stratification state can be reformed. As the result, the lower layer turbid currents are generated.

Fukuoka et.al (1980) studied phenomenon of long term turbidity problem in the stratified reservoir by experiment. They found that the turbid currents are divided into two currents, one flows along the thermocline with fine particles, the other flows down along the bottom of the reservoir with heavy particles. The period of turbid discharge outflow depends on the property of the two currents.

Yong and Lin (1991) constructed a vertical 2 dimensional model used the finite element method. Their model reproduced the turbid current in the stratified reservoir, as well as the variation of the water temperature.

However, this kind of studies is conducted only for middle and small scale of the flood. The turbid currents induced by a big scale of flood are rarely studied because the countermeasures are not considered to be effective.

Therefore, we construct a numerical simulation model first, which can express the diversity of the turbid inflow along the thermocline. Then, the flow activity of a big scale turbid current and the behaviors of long term turbidity problem are numerically analyzed. Finally, we provide a discussion on the method to treat the long-term turbidity problem.

2. MODEL FORMULATION

This model deals with two-dimension vertical flow and suspended sediment in reservoirs. The governing equations are based on the uncompressible concept. It consists of the continuity equation and the momentum equations, which read as:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \tag{1}$$

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = -\frac{1}{\rho}\frac{\partial p}{\partial x} + \frac{\partial}{\partial x}(A_x \frac{\partial u}{\partial x}) + \frac{\partial}{\partial y}(A_y \frac{\partial u}{\partial y}) \tag{2}$$

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} = -g - \frac{1}{\rho}\frac{\partial p}{\partial x} + \frac{\partial}{\partial x}(A_x \frac{\partial v}{\partial x}) + \frac{\partial}{\partial y}(A_y \frac{\partial v}{\partial y}) \tag{3}$$

The water quality model consists of the state equation of temperature (T) and suspended sediments (C).

$$\frac{\partial T}{\partial t} + u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \frac{\partial}{\partial x}(D_x \frac{\partial T}{\partial x}) + \frac{\partial}{\partial y}(D_y \frac{\partial T}{\partial y}) + \frac{H}{\rho C_w} \tag{4}$$

$$\frac{\partial C}{\partial t}+u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}=\frac{\partial}{\partial x}(D_x\frac{\partial C}{\partial x})+\frac{\partial}{\partial y}(D_y\frac{\partial C}{\partial y})+S \quad (5)$$

where H and S are the source terms.

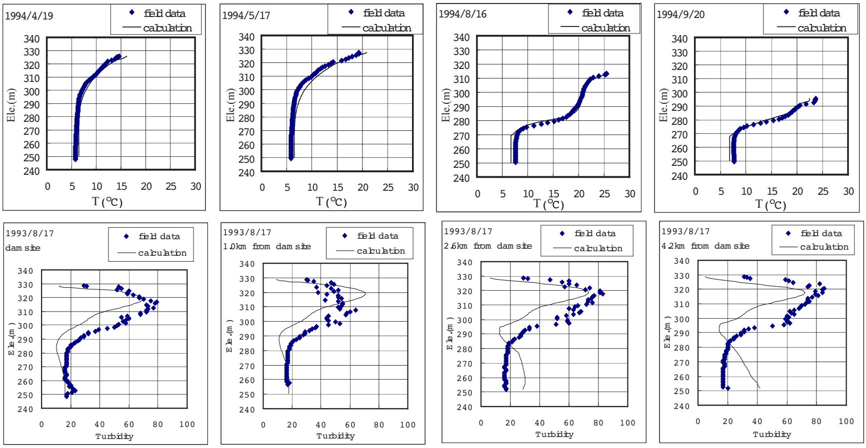

Fig. 1 Comparison of the calculation results with the field data

This model has been successfully applied to more than 50 dam-reservoirs in Japan to simulate long term turbidity problems (Chen et. al, 2000). Nearly all applications reproduce the temperature and turbidity very satisfactorily. Fig. 1 gives an example of simulation result for temperature and turbidity, in which the simulated results are compared with the field data. Because the sunlight is changed periodically, the water temperature near the surface varies periodically as well. Rayner (1980) has shown that the water in reservoirs is stratified and the typical diurnal and seasonal thermoclines are usually formed. Fig.1 suggests that a thermocline is formed from the beginning of April to the end of September for Dam A in Sikoku region, Japan. The elevation of thermocline and the temperature difference between the upper and the lower layers of the thermocline are varied during a year. The temperature difference depends mainly on the variation of the intensity of sunlight. The elevation of the thermoclines is usually influenced by the inflow, outflow, wind-stress, sunlight, etc. On the other hand, the profiles of turbidity show that the turbid current flows along thethermocline because of the withdrawal from surface water.

Then, the division of turbidity current at the thermocline, as an important phenomenon of inflow turbidity in the stratified reservoir, must be reproduced well to present a big scale of flood. Because the long term turbidity problem is depended on the inflow location of the turbidity currents. Fig. 2 gives an example of turbidity division flow Dam B. The figure suggests that this model can reproduce well this phenomenon.

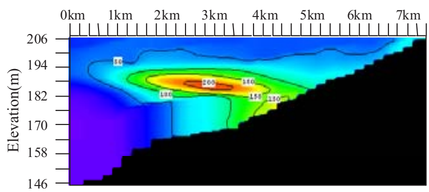

Fig. 2 The division flow at the thermocline

3. BEHAVIOR OF LARGE TURBID CURRENT

When the upper layer (eplimnion) over the thermocline is shallow, the flood can easily destroyed the thermocline and a lower layer turbid current can be generated.

Up to now, this kind of turbid current is treated as a big scale flood current, and the countermeasures to prevent the long term turbidity problem is considered to be almost ineffective. For example, the turbid current of Dam C shown in Fig. 3 generates a long term turbidity problem from the flood period to the next March (over 200 days). Here the prolonged turbidity problem is defined as the period of the outflow turbidity is over 10 degree according to the inflow suspended sediment concentration.

In order to explain the mechanism of this phenomenon and find a method to solve the prolonged turbidity problem, the dynamic behaviors for the space-time variation of turbid currents are shown in Fig. 3.

As shown in the figure, the turbid current flows down along the bottom of reservoir before the flood peak (Aug. 10th, 12:00), so that some clean water are left near the surface layer. When turbid current comes to the dam-site, the flow is lifted due to outflows released from the surface layer and the mid-layer. As the result, the turbid water appears at the whole dam-site (Aug. 10th, 13:00-14:00).

During the decreasing period of the flood discharge, the suspended sediments in the surface layer begin to return to the lower layer due to the existence of gravity. Then a backward flow to the upstream appears due to the sedimentation of the turbidity material (Aug. 10th, 17:00). When the backward flow in the bottom meets the downstream flow induced by the inflow at the location near the thermocline, a part of the turbidity water in the backward flow is rolled into the upper layer and the relative clean water in the upper layer is mixed (Aug. 10th, 21:00). The left part of turbid current flows back to the dam site again because of the gravity (Aug. 10th, 23:00). After many times of flowing forward and backward before the lower layer flow is settle down, the suspended fine particles are spread to the whole region of the reservoir. Particularly, the fine particles in the upper layer will stay in this layer for a long period and induce the prolonged turbidity problem.

4. METHOD TO SOLVE THE PROLONGED TURBIDITY PROBLEM

4.1. DISCUSSION OF THE INFLOW LOCATION OF THE TURBID CURRENT AND THE STRATIFICATION

Now, we try to find a method to reduce the period of turbidity outflow induced by a big scale of flood based on the analysis in the above. First, we take a discussion on Dam C, which shows a prolonged turbidity problem in the above.

Since the outflow water is usually drained from the surface for Dam C, the thermocline is generated in the shallow layer for the actual case. In order to make the location of the thermocline to be formed in the mid-layer, we assume that the outflow water is not taken from the surface but from the middle stratum and predict the variation of turbid current. The results shown in Fig. 4 suggest that the thermocline is located near the flood conduit if the outflow is usually taken at this location. Then, the activities of the turbid currents for these two cases are compared in the followings.

As mentioned above, the stratification is destroyed by the large turbid current when the water is drained from the surface. On the other hand, the turbid current with fine particles flows downstream along the thermocline if the water is usually taken from the middle stratum. However, turbid current with heavy particles flows down along the riverbed still. In that case, turbidity and the temperature in the lower layer are increased after the flood, but there is a peak of suspended sediment in the middle stratum near the thermocline. It suggests that the change of

the thickness of eplimnion will affect the inflow situation of the turbid current.
The variation of the outflow turbidity in this situation is shown in Fig. 6. From the figure, you can read that on occasion of taking water from the mid-layer in general time, the outflow turbidity becomes high during the flood, but the period of high turbidity outflow becomes short after the flood. That is to say, since the location of the high turbidity appears at the mid-layer and much more suspended sediment load is released from this location during the flood in the early stage of flood. It is effective to shorten the period of high turbidity drainage.

4.2. A CASE STUDY TO TREAT THE LARGE TURBID CURRENT

In many cases, the storage capacity of the reservoirs in Japan is around 50 million m^3. In order to avoid the cold-water released from the reservoir, discharge is usually taken from the surface. For this case, a shallow upper layer with high temperature is formed so that the flood flow will destroy the thermocline easily and form an under layer flow. As the result, the flow and the stratification situation is brought into a dynamic state and the turbid materials are mixed in the whole reservoir. General, this kind of flood occurs once per two years, the volume of the flood is more than 50% of the capacity of reservoir. Beside of it, the flood is usually outlet from the crest near the surface, or the conduit at the middle layer, so that the under layer turbid current will clash the dam and a strong turbulent mixture is induced. As shown in Fig.6, the volume of turbidity water is increased to 45 million m^3 in the reservoir even if the inflow turbid current of the flood is just 30 million m^3. This can be considered as the main reason of prolonged turbidity problem

In order to improve the prolonged turbidity problem, two methods can be used. One is to reduce the mixture of the turbidity water and the clean water in reservoir; the other is to reduce the turbidity volume before the turbid current clashes the dam. For the after case, you can set a flood outlet, such as a withdrawal device or a conduit, at the lower layer of the dam so that a part of turbid current can be released from it. Fig. 7 shows the results of a case study on this case. We just suppose that the discharge released from the lower layer by a selective withdrawal device is $100m^3/s$, $200m^3/s$, or $300m^3/s$, the variations of the turbidity of outflow discharge are predicted and compared for the above 3 cases. The results suggest that the high turbid period of outflow is decreased from 76 days to 9 days (88% of the actual case can be improved) if a lower layer outlet is set. Of course, this is just a case study, but we can find the possibility of countermeasures to improve the prolonged turbidity problem.

5. CONCLUSION

On the basis of the numerical stimulation, this paper treats the phenomenon of turbid current in the dam reservoir. According to the analysis, the following conclusions can be drawn.

1) In the dam which outflow discharge is often taken from the surface, the outflow location should be changed to the mid layer near the flood outlet (ex: conduit) if the outflow water temperature can be ensured. For that case, the turbid current will be induced to the mid layer so that the prolonged turbidity problem will be improved.
2) It is confirmed that the prolonged turbidity problem becomes a serious problem if a big scale flood current occurs. In this case, the stratification in the reservoir is reformed and a lower layer turbid current is generated. The turbid materials induced by the turbid current will be mixed with the water around it after the turbid current clashes the dam. The lower layer withdrawal equipment (such as outlet or a selective withdrawal device), as a countermeasure, is effective to release the turbid current and to improve the long-term turbidity problem

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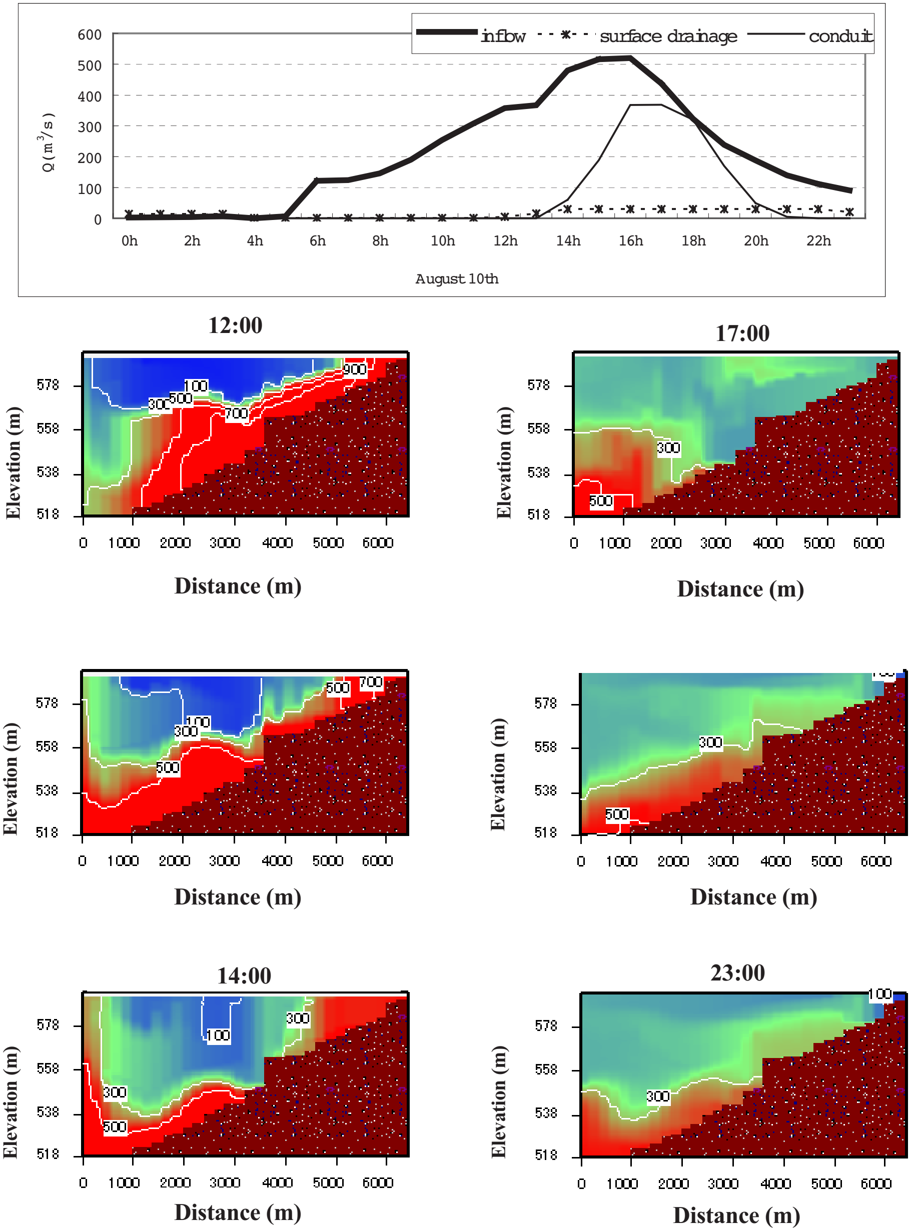


Fig.3 The prolonged turbidity problem induced by a lower layer turbid current

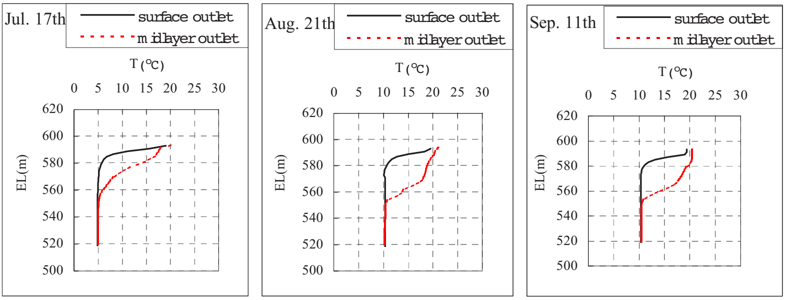
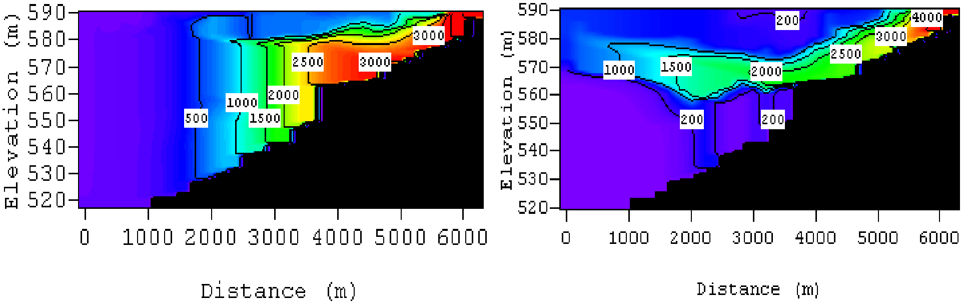


Fig.4 Variation of water temperature



(a) Surface drainage (b) Mid-layer drainage

Fig.5 The relation between turbid current and the outlet elevation

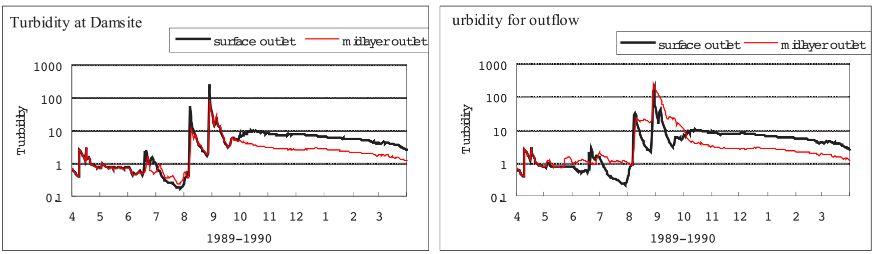


Fig.6 The improvement of the prolonged turbidity problem by a mid-layer outlet

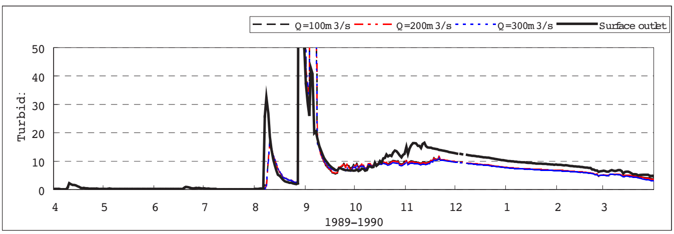


Fig.7 The improvement of the prolonged turbidity problem by a lower layer outlet