Gate Operation Support Table of Ohno Flood Control Dam against Excess Flood Inflow

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ABSTRACT:
Flood control operation requires smaller discharge than inflow. This operation raises water level of a reservoir, and cannot be continued until reservoir water level reaches to the dam design flood stage. Flood control operation mode should be changed into overtopping prevention mode in an appropriate way at a certain inflow and water level condition during excess flood inflow. Mode changing timing and the gate operation ways for increasing discharge to prevent overtopping are one of the most serious matters for operation managers.
In above situation, MOPO (minimum outflow to prevent overtopping) table, which was developed by Public Works Research Institute Japan, was employed by Ohno dam for supporting the operation judgment. MOPO is obtained through the gate operation simulation in the large inflow condition which reaches to the design inflow. If the outflow at the time in the pair of inflow and water level condition is greater than MOPO, future water level must be controlled under the dam design flood stage without extreme outflow increase. This paper will show the simulation conditions for the Ohno dam's MOPO table. They consist of the inflow condition, gate movement restrictions and outflow increase limitations.

Keywords: gate operation, excess flood, over topping, risk management

1. INTRODUCTION

Gate operations for flood control and preventing overtopping are completely opposite. The former operation releases much smaller discharge than the inflow of a dam, but the latter operation increases the outflow to reach to the inflow.

There are many multi-purpose dams, including flood control purpose, in Japan. They have, of course, rules of flood control operation and preventing overtopping operation. For the effective use of a reservoir capacity, water level regions for flood control and preventing overtopping operation are usually overlapped at 20% of a flood control capacity (Fig. 1).

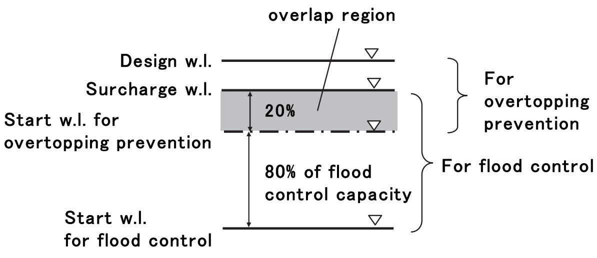

Figure 1. Overlap water level region of flood control and overtopping prevention

In the overlapping water level, flood control operation should be done if a flood is smaller than the flood control planning. On the other hand, overtopping prevention should be done in an excess flood condition. Therefore, if a water level is in the overlapping region and gate operation is in a flood control mode, flood magnitude should be predicted and the judgment of changing a operation mode from flood control to overtopping prevention should be done.

There are some responsible persons for the decision making of the judgment. Most influential and respectable judgment is given by a director of a dam management office. He is the best person to understand the situations of a dam, a reservoir, surrounding area of a dam and a reservoir, related facilities for a dam's management includes operation systems of gates, and so on.

Since the methods for flood dimension prediction and changing operation mode judgment have not been established, the decision of a director should be made using supports of his office staffs and his empirical knowledge. In this situation, a director may feel serious stress for the decision making of the judgment.

In the above situation, the method using the table of minimum outflow to prevent overtopping (MOPO) was proposed by Public Works Research Institute Japan and its prototype was employed by Ohno dam as a support method. Fundamental idea of MOPO and outline of the operation simulation were introduced together with the actual application of the prototype table at the excess flood in 2013 (Kashiwai et. al. 2015).

This paper will show the more details of the meaning of MOPO table and the simulation conditions for obtaining table based on the Ohno dam's revised one. They consist of the inflow condition, relationship between water level and reservoir storage capacity, gate movement restrictions and outflow increase limitations.

2. Outline of MOPO

Putting Qit is the inflow, Qot is the outflow and Wlt is the water level at the mode change time from flood control to overtopping prevention. From the operation conditions, Wlt is in an overlap region and Qot is smaller than Qit. If gates can immediately move to the target openings, which release the inflow at a time, the outflow will increase very rapidly and reach to the inflow in a moment. The water level will be kept near Wlt in this case and overtopping can be easily prevented. Rapid outflow increase, however, may increase the evacuation risk of residents and visiting people in a river and inundation areas. Also, that may cause damages to river structures such as intake structures including weirs, banks and flood storage facilities and so on. An outflow increase should be somewhat restricted.

A gate movement speed is also limited by some reasons such as operation error prevention matters, mechanical matters including power supply conditions. An outflow increase cannot be so immediate, so the storage capacity is necessary for getting the inflow (Fig 2). In the same Qit and Wlt condition, smaller Qot requires larger capacity and MOPO is defined as the minimum Qot that can reach to the inflow before the water level ups to a design water level in the Qit and Wlt condition.

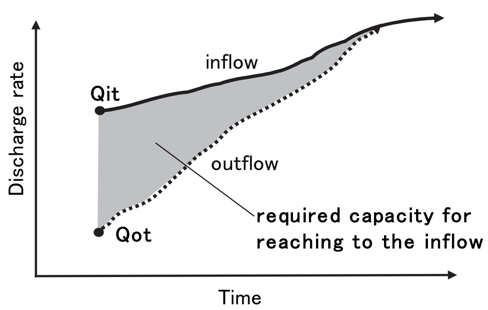

Figure 2. Required capacity for reaching to the inflow

From the above definition, it is clear that if Qot is greater than MOPO in the same Qit and Wlt condition, the outflow can reach to the inflow under the design water level. Gate operation has some options such as constant opening operation, constant discharge operation or reducing outflow operation to MOPO. On the other hand, if Qot is less than MOPO, outflow should be increased to MOPO. Images of time series of the outflow in the inflow increase condition are shown in Fig. 3,

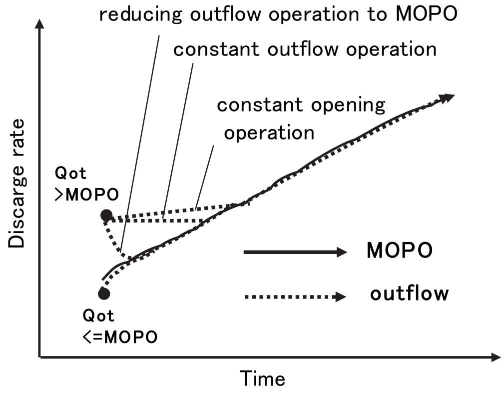

Figure 3. Images of time history of outflow based on MOPO information

MOPO is obtained by a gate operation simulation including a reservoir storage calculation for each pair of Qit and Wlt. Conditions for the simulation are an inflow increase from Qit, relationship between storage capacity and water level and outflow increase restrictions. Setting methods of these conditions were executed through the MOPO table application for Ohno dam. So the methods introduced bellows strongly reflect the characteristics of Ohno dam's specific conditions.

3. CONDITION SETTING FOR MOPO SIMULATION THROUGH OHNO DAM CASE

3.1 Outline of Ohno dam

Ohno dam is a gravity concrete dam completed in 1957. Location of the dam is in the upstream are of Yura River system, Kyoto prefecture. Area of Yura River basin is 1882 km^2 and catchment area of the dam is 354 km^2.

The dam height is 61.4 m, and the flood control capacity is 21.32 million m^3. The flood control method of Ohno dam is constant ratio-constant discharge method. If the inflow will increase and beyond the start discharge of flood control, 500 m^3/s, flood control operation will start, where constant ratio of 58% of inflow will be released to the downstream area till inflow peak. After the inflow peak, outflow at the inflow peak will be kept till the inflow will be equal to the keeping outflow. Fig. 4 shows the flood control operation at the flood control planning flood of Ohno dam. Maximum inflow is 2400 m^3/s and the outflow at the inflow peak is 1400 m^3/s.

Ohno dam has three conduit gates for flood control. These gates are also used for overtopping prevention with three crest gates. Conduit gates will be firstly fully opened, and then crest gates will start to open at the operation.

Table 1 shows Ohno dam's water levels shown in Fig. 1. The design discharge at the design water level is 3510 m^3/s, about 1000 m^3/s larger than the peak inflow of flood control planning flood. This value, however, is obtained by the current rule, which was established after the completion of Ohno dam, the outflow with all gates fully opened condition is about 300 m^3/s less than the design discharge. Considering the shortage of this outflow capacity, both conditions of reaching to the inflow and obtaining fully opened condition of the crest gates under design water level are employed as the satisfactory condition for overtopping prevention at MOPO simulation.

Total outflow of the three conduits at the design water level is about 950 m^3/s, which is about a quarter of the design discharge.

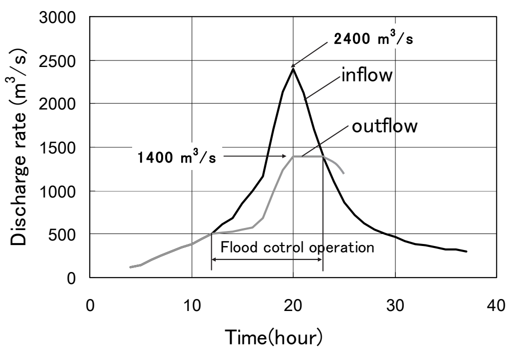

Figure 4. Flood control operation at planning flood

Table1. Ohno dam's water levels shown in Fig. 1

Design water level	EL. 175.9 m
Surcharge water level	EL. 175.0 m
Start water level for overtopping prevention	EL. 172.6 m
Start water level for flood control	EL. 155.0 m

3.2 Inflow condition

Inflow condition for MOPO simulation should be set as a probable maximum increase condition. The probable maximum increase of Ohno dam was obtained from hydrographs of all experienced floods. Peak discharges of floods were enlarged to the design discharge and the largest increase of all floods at each continuous time length was applied. It is important that the probable maximum increase is given as the function of continuous time length.

The probable maximum increase of shorter continuous time length was arranged from the start of the simulation, because this arrangement gave the largest MOPO. Inflow increase rate decreases along with the passage of time.

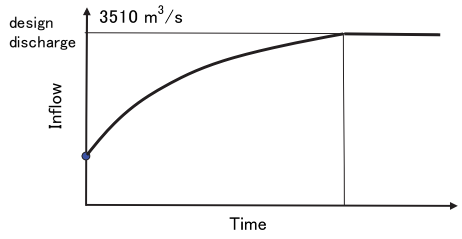

Figure 5. Ohno dam's inflow hydrograph for obtaining MOPO table

Fig. 5 shows Ohno dam's inflow hydrograph for obtaining the MOPO table. The design discharge is set as the maximum inflow. In Japan, a spillway is designed to outflow more than or equal to a design discharge at a design water level and it is considered at a spillway design that the outflow of a design discharge may continue some duration. Referring to above design idea, the inflow of the design discharge is set after reaching to that discharge.

3.3 Relationship between water level and storage capacity

A storage capacity of a reservoir is obtained by measurement, and future change of the capacity by sedimentation has to be considered for MOPO simulation. In order to keep the long term safety against overtopping, capacity reduction by sedimentation should be counted. Evaluation of future sedimentation in a region between start water level for overtopping prevention and design water level is required. This means, sediment distribution should be estimated as well as sedimentation volume. In the case of Ohno dam, measurement survey of the reservoir has been executed once in every year, and 100 years sedimentation or more was set based on the analyses of survey results.

3.4 Restrictions of outflow increase

3.4.1 Items to be set for operation error prevention and mechanical matters

As mentioned before, a gate movement is limited by operation error prevention matters and mechanical related matters. They may vary with dam and reservoir characteristics such as dam's purpose, reservoir dimension, principle of dam management and so on.

Table 2 shows actual setting items of Ohno dam's MOPO simulations. Since most of items have the both meaning of operation error prevention matters and mechanical related matters, they are not appropriate for classifying the actual items. In the table, data processing system related matters and gate control system related matters are applied for the classification from the other point of view.

Regarding a data processing system, a smoothing way of water level data should be set for MOPO simulations. A storage capacity change, which is used for estimating inflow, is obtained from a water level change in a decided time interval. Water level smoothing is necessary to obtain stable inflow outputs.

Table 2. Actual setting items of data processing system and gate control system related matters, considered in Ohno dam's MOPO simulations

1. Data processing system related matters.
(1) Water level smoothing a. Number of firstly averaging data (measuring original data) b. Number of secondary averaging data (firstly averaging data) (2) Calculation methods to obtain inflow from smoothing water level (3) Minimum time interval of the start of the same gate movement (4) Time interval of indication of target outflow
2. Gate control system related matters
(1) Fundamental course of gate movement a. Order of operation gate (classified by purpose) b. Gate opening combination of the same purpose gates for releasing target outflow (2) Gate movement a. Staggered start time in plural gate condition b. Opening/closing speed c. Maximum opening distance in continuous gate movement d. Minimum holding time to the next movement

Ohno dam's smoothing way is based on the past data averaging as shown in Table 2. Firstly, measuring data of every 2 seconds from the present to the past in decided time interval is averaged. Then secondary averaging is added using firstly averaged data. By this smoothing way, estimated inflow represents the averaged past inflow, so the gate operation based on this estimated inflow is always delayed compared with the operation based on the present inflow.

Target openings of gates are calculated and indicated by the system, which uses above estimated inflow, sum of released flow, flood control rule and overtopping prevention rule and so on. If the officer judges the indicated openings are appropriate, the officer orders the gates to move to target openings. If not, the officer can change the target. Final decision of the gate movement will be done by human beings.

The minimum time interval of the beginning of the same gate movement is also set. This time interval is required for the operational decision time including the handling time against unexpected incidents as well as the data processing. Ohno dam's gate control system has several rules for the gate movement. Since items of rules for the conduit and crest gates are almost same, Table 2 is applied to both gate types.

When gates are ordered to move to target openings, plural gates do not move at the same time to reduce power capacity of gate control facilities. Start time of each gate is staggered and each gate starts to move at the setting opening/closing speed. The gate speed should be fit with feelings of operators, ensuring braking accuracy and providing appropriate required power etc., and empirical value is commonly used.

The maximum opening distance in the continuous gate movement is set to prevent too much outflow increase. If the distance to the target opening is larger than the maximum distance, gate is once stopped in short duration to be checked to continue the gate movement. Gates will automatically restart to move if the target opening still lager than the maximum. Next movement to the target opening will be start after the all gates will have reached to the former target. In the case of Ohno dam, the same target openings are set for the three gates of conduit and crest. So, the three gate openings are always the same at the start of the gate movement.

Above items, which related with data processing system and gate control system, are organized in Table 2, and the actual values for each items should be decided for MOPO simulations.

3.4.2 Influences of outflow increase

Restrictions of outflow increase are ideally examined and decided by the influences on downstream areas. The examinations, however, may require analyses of various rainfall and run-off situations of floods at downstream area and a reservoir. Add to this, the evaluation of outflow increase should be discussed from the view point of disaster prevention plans, disaster reduction plans and damage reduction plans of downstream areas.

Recently, the importance of an operation considering the flood situation of downstream areas is getting recognized and examinations from some points of view have been executed. Areas and dams of the examinations, however, are limited and there are very few cases which try to exam the relation with overtopping prevention operation. It may be a long way to establish examination procedures and evaluation methods of decision making. Technical development of them should be expected, but more empirical or simple methods should be employed for the majority of flood control dams including Ohno dam.

For the simulation of Ohno's MOPO, the outflow restriction was decided referring to following three points of view.

(1) outflow increase that people in the river area can escape to the outside
(2) past records of inflow increase
(3) outflow increase based on the operation idea of overtopping prevention rule

The outflow increase restriction of (1) is already regulated in the operation rule by checking water level rise in the downstream area. This increase restriction is applied in the condition of inflow is 0 $m^{3/}s$ to the flood control start discharge $500m^3/s$.

Inflow increase records mean discharge increases at a dam site before a dam completion. The inflow condition of MOPO simulation is set as a probable maximum increase condition like Fig. 5, so the maximum increase during each flood, which was correlated with the maximum inflow increase, was picked up for Ohno dam. Fig. 6 shows the relationship between the maximum inflow increase and the inflow just before the maximum increase occurred. The linear approximate line and the envelope line are also shown in the figure. In order to use these relationships, 'inflow' should change 'outflow', of course.

Outflow increases of (1) and (2) are allowed without problems. Only these limitations, however, large amount of capacity for overtopping prevention will be required to cope with the probable maximum increase condition of the inflow. The restriction based on the idea of overtopping prevention rule ((3)) was introduced.

By an overtopping prevention rule, single relation between water level and gate opening is given to each gate. Fig. 7 shows the recommended relation for crest gate. The gate opening increase is zero at the start water level of overtopping prevention, and enlarged in the higher water level (parabola is usually employed). This relation may consider reducing the outflow increase near the start water level of overtopping prevention.

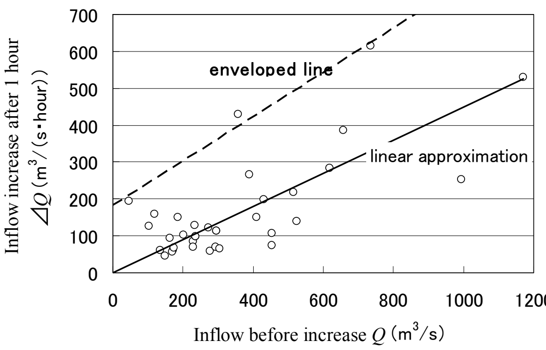

Figure 6. Relationship between inflow increase and inflow just before the increase

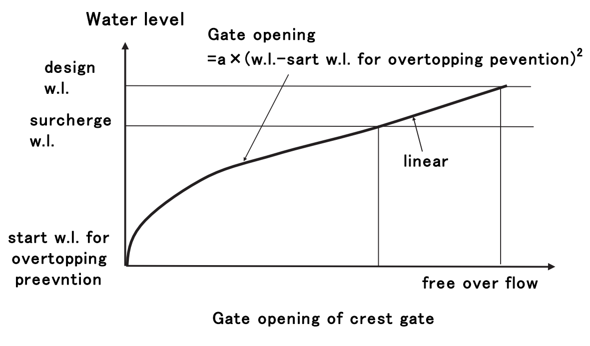

Figure 7. Recommended relation for overtopping prevention rule (crest gate)

Fig. 8 shows the example of the relationship between water level and outflow increase obtained by MOPO simulation, where the outflow increase restriction is based on the recommended relation and the increases of (1) and (2) conditions are allowed. The outflow increase relatively rapidly increases from the start water level of overtopping prevention, and has the peak. The greater initial inflow Qit condition brings the greater peak and the rapid increase.

Though variation characteristics shown in Fig.8 are fundamentally appreciable, there are following problems.

(a) outflow increase in the relatively larger initial inflow Qit condition is very large compared with inflow records (Fig. 6)

(b) in the probable maximum inflow condition, where inflow increases very rapidly and continue design discharge, it is more appropriate to enlarge the outflow increase in higher water level condition.

With regard to (a), the maximum outflow increase, an outflow increase cannot exceed that, was set for Ohno dam. From Wlt to the surcharge water level, that was set by substituting the design inflow for the linear approximation relation in Fig. 6 and the enveloped relation in Fig 6 was used at the design water level. The value of surcharge and design water level is connected by line. The maximum outflow increase mentioned above is also shown in Fig. 8. It is quite small in the relatively large initial inflow condition and greatly influence to MOPO.

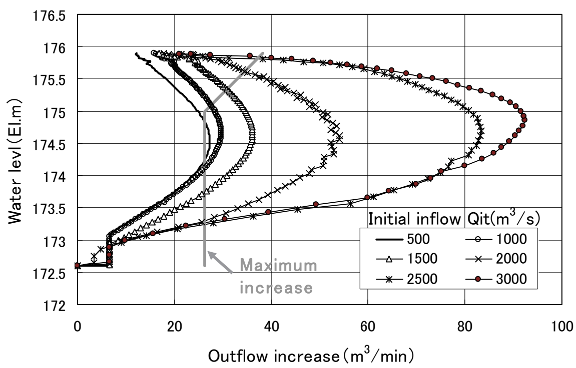

Figure 8. Example of relationship between outflow increase and water level at MOPO simulation (outflow increase restriction is based on the overtopping prevention rule)

For the problem (b), the simulation condition of 'if the outflow increase restriction obtained by the above explained way at the water level is smaller than that of the lower water level, the latter is employed' was introduced.

4. OHNO DAM'S MOPO TABLE AND EXAMPLE OF OPERATION SIMULATION BASED ON THE TABLE

Ohno dam's MOPO table obtained by above conditions is graphically shown in Fig. 9. Though, MOPO is given every $50m^3/s$ inflow for the table, the figure shows only every $250m^3/s$.

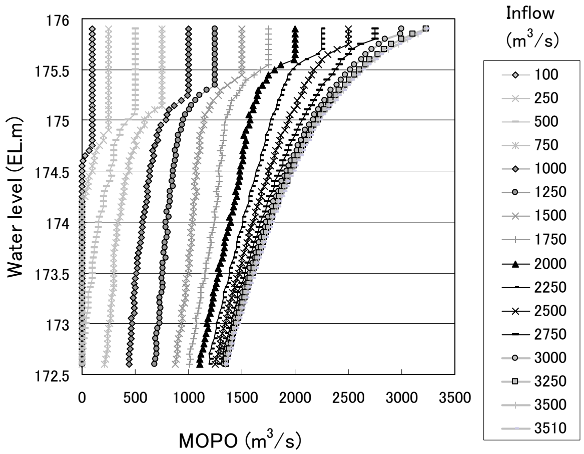

Figure 9. Graphic expression of Ohno dam's MOPO table

MOPO at the start water level of overtopping prevention is less than or equal to the outflow discharge of flood control operation, so the flood control operation is guaranteed at the start water level. Mode change from flood control to overtopping prevention operation will be introduced at higher than or equal to the start water level.

MOPO increases as the water level rises or the inflow increases. This character of discharge variation may follow the feeling of human being. Also, MOPO increasing rate increases at higher water level in the same inflow condition. Image of this is similar to the recommended curve of the gate opening and the water level relation shown in Fig. 7. Office staffs may easily get familiar with characteristics of MOPO variation.

Upper side of MOPO-water level curve in the same inflow condition has a vertical portion, where MOPO equals to the inflow. This means the outflow reaches to the inflow at a lower water level than the design water level in an actual operation. The lowest water level of the vertical portion is lower in the smaller inflow condition. One of the reasons of this may be the smaller allowable outflow increase in the smaller outflow situation.

Fig. 10 shows the example of operation simulation results using the MOPO table. The hydrograph of Ohno dam's flood control plan (Fig. 4) is used with changing peak discharge (maximum inflow peak is $3500m^3/s$). The flood control operation is executed till the water level reaches to the start water level of overtopping prevention, then operation based on MOPO is executed, with constant gate opening operation if the outflow is greater than MOPO.

As the maximum water levels of all peak ratios are higher than the start water level of overtopping prevention, it is ascertained that the mode change from flood control to overtopping prevention is executed by the MOPO table without officer's judgment. Also, as the inflow peak increases, the maximum outflow increases and the highest water level rise. This indicates the operation is appropriately executed along with the flood magnitude. The highest water levels of all cases are controlled under or equal to the design water level.

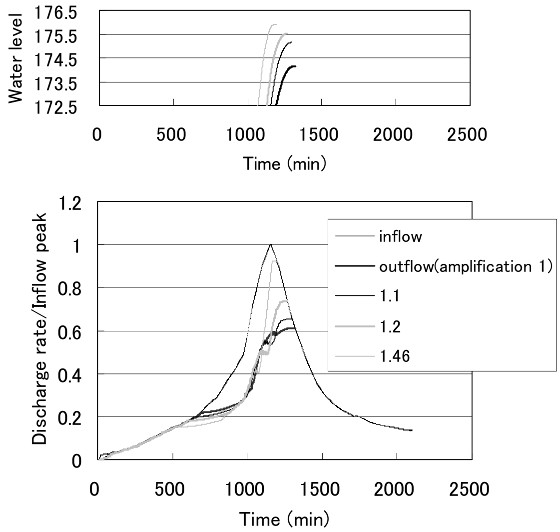

Figure 10. Examples of operation simulation results using the MOPO results (flood control planning flood)

5. CONCLUSIONS

MOPO (Minimum outflow to prevent overtopping) table was developed for supporting the mode change judgment from flood control to overtopping prevention and the decision making of the outflow increase way to get the inflow. This paper introduced the outline of MOPO and conditions for operation simulation to obtain MOPO table. Example of MOPO table and satisfactory gate operation results using the table were also shown.

Most of the introductions and explanations were done by Ohno dam's examination results. So the condition setting for MOPO simulations, especially outflow restrictions, were basically reflecting speciality of Ohno dam. Establishment of methods for the condition setting will be required for the future development of gate operation using MOPO table.

REFERENCES

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