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OHNO DAM'S OPERATION RESULTS FOR REDUSING INNUNDATION DAMAGE IN EXCESS INFLOW SITUATION (*)

Josuke KASHIWAI
Director, Engineering Department 1, Japan Dam Engineering Center

Tadanori KUBOZONO
Supervisor, Kyoto Prefectural Ohno Dam Integration Control Office

Tohru TAKADA
Director, Kyoto Prefectural Ohno Dam Integration Control Office

JAPAN

1. INTRODUCTION

More than 500 multi purpose dams, including flood control purpose, are under operation in Japan. Both of gated and gateless spillways are installed for them. Gateless spillways have been mainly employed at dams of small catchment areas, where run-off is too rapidly for appropriate gate operation. Also, gateless spillways are employed by reason of easier and economical management recently. The number of gateless flood control dam is increasing nowadays.

However, there are many gated flood control dams in Japan. Floods are controlled more effectively by gates. Gated facilities still keep the meaning of their existence. Actually, the situation is more than that: expectations of gate operation from downstream areas are gradually growing. Residents in downstream areas, often threatened by flooding, are getting to request more effective operation than the planned flood control method.

(*) *Résultats des opérations effectuées au barrage d'Ono pour réduire les dégâts dus aux inondations en cas de débit entrant trop important.*

According to a flood control operation rule, outflow is usually related with inflow of a reservoir in Japan. The control method of a rule is same as the method for reservoir planning. Flood control capacity, maximum outflow, minimum outflow etc. are decided by the control method and hydrographs, which obtained from past floods adjusted to planning return period. Although flood magnitude can be statistically evaluated as the return period, evaluation of hydrograph is difficult. Various hydrograph can occur after planning or dam construction. Requests from downstream areas insist on reducing outflow than the ruled method considering the flooding risk or flooding situation at that point.

Flexible operation, considering the situation of downstream areas, is desirable. The question of flexible operation, especially in the case of reducing outflow operation, is the mode change timing from flood control to prevent overtopping. If flood control operation will be continued in an excess flood inflow situation, water level possibly overtop a dam. Gate operation should be changed to prevent overtopping mode in such situation. Outflow should be increased to catch up inflow before water level reaches to the design water level. Judgment of changing mode requires future inflow conditions. This causes the difficulty of judgment especially in Japan's dam site where run-off time is generally short. Of course, these are the questions also in case of ruled operation. Flexible operation, however, brings greater difficulty of the mode change judgement and increasing operation of outflow. Discharge difference between inflow and outflow increases by reducing outflow operation and longer time is required to catch up inflow. This means longer time prediction of inflow is necessary for flexible operation.

There is an operation rule for overtopping prevention of a dam as well as flood control. The rule provides the relationship between reservoir water level and gate openings. Lager gate openings are required in higher water level, and design flood discharge or more can be released at design water level of a dam. The lowest water level for the operation is set below highest water level of flood control for effective use of a reservoir (refer to Fig.1). Because of this, dam control office manager is forced to judge whether to continue flood control operation or to change into overtopping prevention mode when water level reaches the lowest level. If the manager judge to change mode, he should decide the way to provided gate openings from flood control openings at that point, which depends on the flood hydrograph. Incidentally, the outflow of overtopping prevention rule at the lowest level is maximum outflow of flood control planning.

Office manager may feel strong stress at that situation, and flexible flood control may strengthen the stress. Based on the recognition of above problems, Kyoto prefectural government tried to find the way to improve the rule for overtopping prevention for Ohno dam. The government picked up the method presented by The Public Works Research Institute Japan and prepared prototype rule for Ohno dam in 2012. After this, the government tried to examine the practical use of the new rule, and met the typhoon that caused excess flood in Sep. 2013 on the way of examination. Prepared rule was referred at the operation and brought good results.

This paper will introduce the idea of new rule and operation results of Ohno dam at 2013's typhoon. The new rule connects gate operation of flood control includes flexible control and overtopping prevention.

2. OUTLINE OF OHNO DAM

Ohno dam is a gravity concrete dam constructed in the upstream area of Yura River system, Kyoto prefecture. Area of Yura river basin is 1882 km^2, about 40% of Kyoto prefecture, and catchment area of Ohno dam is 354 km^2. Purposes of the dam are flood control and power generation. Fig.1 shows facilities for releasing floods and related water level with flood discharging, both of flood control and overtopping prevention. Height of the dam is 61.4 m, total storage capacity is 28.55 million m^3 and flood control capacity is 21.32 million m^3.

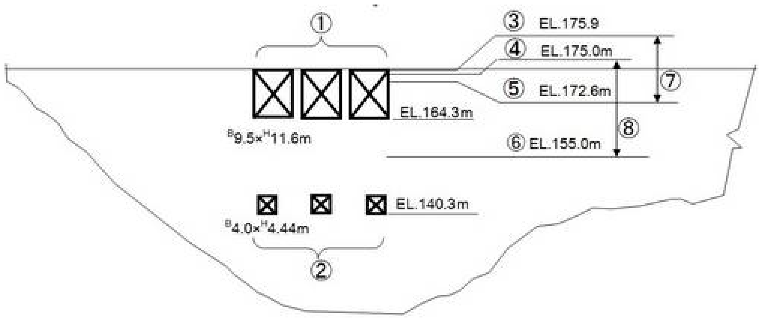

Fig.1
Arrangement of flood release facilities of Ohno dam
Aménagement des installations de rétention de crues du barrage d'Ono

(1) Crest gates
(2) Conduit gates
(3) Design water level
(4) Highest water level for flood control
(5) Lowest water level for overtopping prevention
(6) Start water level for flood control
(7) Range for overtopping prevention
(8) Range for flood control

(1) Vannes de surface
(2) Vannes conduit
(3) Niveau d'eau de référence
(4) Niveau d'eau maximal pour le contrôle des crues
(5) Niveau d'eau minimum pour la prévention d'un déversement en crête
(6) Niveau d'eau de départ pour le contrôle des crues
(7) À utiliser pour la prévention d'un déversement en crête
(8) À utiliser pour le contrôle des crues

Fig.1 shows facilities for releasing floods and related water level with flood discharging, both of flood control and overtopping prevention. Height of the dam is 61.4 m, total storage capacity is 28.55 million m^3 and flood control capacity is 21.32 million m^3.

There are three outlet conduits and crest gates. Both facilities are used for flood control and overtopping prevention. Conduit gates are firstly opened for flood releasing, crest gates are used in the condition that conduit gates are fully opened. As mentioned before, flood control operations are executed from starting to highest water level for flood control operation, that is El.155.0 m to EL.175.0 m, and overtopping prevention operations are from lowest water level to design water level, EL.172.6 m to EL.175.9 m. Both flood control operation and overtopping prevention are possibly operated at the water level between EL.172.6 m and EL.175.0 m.

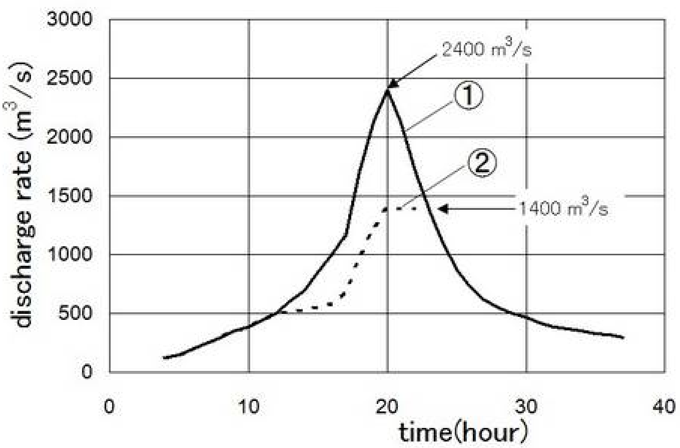

Fig.2
Inflow and outflow hydrographs of planning flood
Hydrogrammes des débits entrant et sortant de crue planifiée

(1) Inflow	*(1) Débit entrant*
(2) Outflow	*(2) Débit sortant*

Flood control method for Ohno dam is called constant ratio–constant discharge method. When inflow is less than 500 m^3/s, outflow is controlled equal to inflow to keep the water level of El.155.0 m. In the condition that inflow is greater than 500 m^3/s, gate openings of conduits are fixed at the openings which outflow 500 m^3/s at EL.155.0 m. If outflow from the fixed gate openings is greater than 58% of inflow, gate openings are controlled to keep outflow at 58% of inflow. This is the constant ratio method, and the constant discharge method is operated after the peak of a flood. Outflow is kept constant which is decided by constant ratio control method at the peak.

The constant ratio-constant discharge method is usually employed if planned improvements of levee of a river downstream seem to be required long time. Constant ratio operation can reduces flooding damages of not improved areas until the improvements. Fig.2 shows the inflow and outflow relationship at the planning flood of Ohno dam's flood control. Maximum inflow and maximum outflow of the planning flood is 2400 m^3/s, 1400 m^3/s respectively. The design discharge rate of Ohno dam is 2880 m^3/s. Total outflow capacity of the flood release facilities are designed to be able to release the design discharge rate of 2880 m^3/s at the design water level of EL.175.9 m

3. FLOOD CONTROL RESULTS BEFORE 2012

Ohno dam was completed in 1961 and has operation history of 53 years. 15 floods flowed into Ohno dam reservoir and controlled till 2012. Maximum peak discharge rate of these floods, which occurred in 1972, is 1989 m^3/s. The inflow reached 83% of the planning discharge rate. Total inflow volume greater than 500 m^3/s inflow was 24.1 million m^3, 58% of the planning flood.

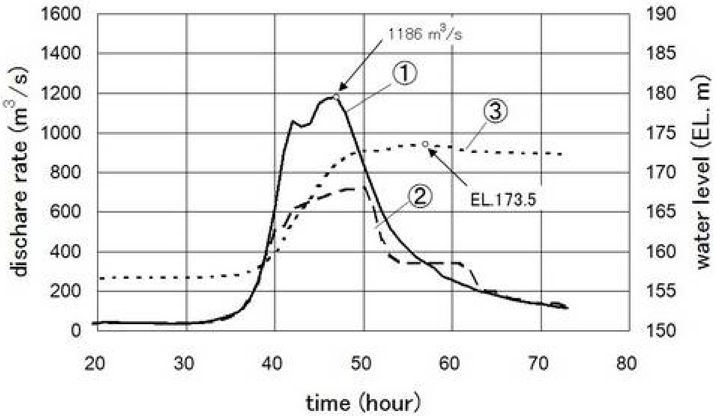

Fig. 3
Operation results at the flood in 2004 (within flood control magnitude)
Résultats des opérations effectuées lors de la crue de 2004 (y compris la magnitude de contrôle des crues)

(1) Inflow	*(1) Débit entrant*
(2) Outflow	*(2) Débit sortant*
(3) Water level	*(3) Niveau d'eau*

Ohno dam also had large flood in recent years. The flood brought by the typhoon in Oct. 2004. Peak inflow was 1186 m^3/s and total volume greater than 500 m^3/s inflow was 21.2 million m^3. Though the magnitude of the flood was a half of the planning flood, reservoir water level rose beyond lowest water level for overtopping prevention and reached EL.173.5 m, 1.5 m below from highest water level for flood control (Fig.3). One of the reasons of this is gradual hydrograph. There were two unclear peaks and judgement of decreasing situation of inflow was somewhat difficult. Gate openings were almost fixed after the first peak and flood control mode was continued with checking inflow, water level and information of flooding condition at areas downstream. During this operation, cities of the downstream area were flooded an inundated situation remained through the recession period of inflow. Outflow was fairly reduced till inflow reached about 300 m^3/s.

Above flexible operation was highly valued and supported by the residents and local governments of the areas downstream. However, operation of overtopping prevention would be required if the rainfall intensity was a little harder. Gate operation would be greatly harder in that situation. The typhoon flood in 2004 taught not only the importance of flexible operation considering flooding situation at downstream areas but the necessity of more practical rules against excess floods.

4. OPERATION RULES AGAINST EXCESS FLOODS

Kyoto prefectural government required more practical rules against excess flood inflows and tried to apply the idea presented by the Public Works Research Institute, Japan [1]. The idea is to prepare the relationship between water level and outflow discharge rate, same as the existing operation rule for overtopping prevention as it is. Differences are 1) Inflow at a point is introduced as a parameter to the relationship, 2) Minimum outflow to prevent overtopping (MOPO) is presented for the condition of inflow and water level at a point through the simulation of gate operations.

In the simulation, inflow hydrograph starts from inflow at a point as the initial, and increases by probable maximum ratio towards the design flood discharge of a dam. Gate opening speeds, interval time of movement of gates, maximum movements for an operation step and other conditions of gate movements include data processing are introduced to the simulation. Maximum outflow increasing rates are also set to restrict outflow increase. Since evacuation performances require a certain time, restriction of outflow increase is important for the operation of overtopping prevention where downstream areas face the risk of inundation or already inundated.

It is not necessary to increase outflow if the outflow greater than MOPO at the inflow and water level condition, because overtopping can be prevented by gate opening operation after the point. Gate openings can be fixed or outflow can be reduced in the range to MOPO. On the other hand, if the outflow less than MOPO, outflow should be increased to MOPO to prevent overtopping. Fig.4 shows the prototype of MOPO presented to Ohno dam in 2013. Relationships between MOPO and reservoir water level are plotted at some representative inflows. Fundamentally, MOPO increases as water level rises. However, MOPO decreases in some water level and inflow areas. The reason of this is the discontinuity condition of the restriction of outflow increasing. It may be desirable to improve the condition setting of the restriction.

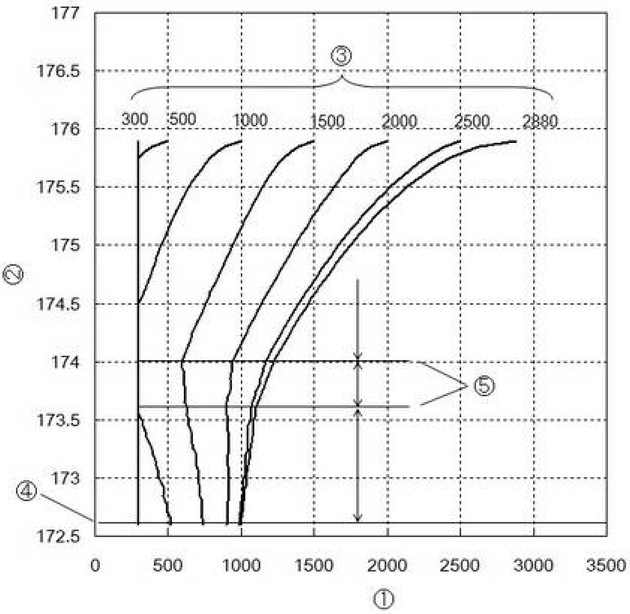

Fig. 4
Examples of variation of minimum outflow with water level for Ohno dam
Exemples de variation du débit sortant minimum avec le niveau d'eau pour le barrage d'Ono

(1) Minimum outflow for overtopping prevention (m^3/s)
(2) Water level (EL. m)
(3) Inflow
(4) Lowest water level for overtopping prevention
(5) Water levels of changing increasing rate condition of outflow

(1) Débit sortant minimum pour la prévention d'un déversement en crête (m^3/s)
(2) Niveau d'eau (EL. m)
(3) Débit entrant
(4) Niveau d'eau minimum pour la prévention d'un déversement en crête
(5) Niveaux d'eau du changement du taux de croissance du débit d'eau

Fig.5 shows the operation results against the magnitude changed hydrographs of the planning flood and the flood in 2004. Operations are calculated according to MOPO with keeping outflow operation in the case that outflow greater than MOPO. Fig.5 indicates operations of flood control and overtopping prevention are connected by using MOPO information. Changing mode to overtopping prevention requires no judgement of the operation manager. Also, flood control operation is continued over highest water level of flood control in smaller magnitude flood. This means reservoir capacity of upper side of flood control area is also effectively used for flood control by this method.

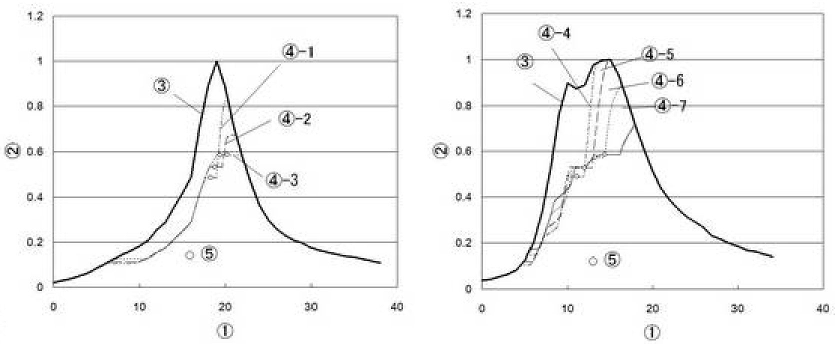

Fig.5
Operation according to minimum outflow information against excess floods of different magnitude
Opérations en fonction des informations sur le débit sortant minimum contre les crues excessives de différentes magnitudes

(a) Hydrograph of planning flood
(b) Hydrograph of flood in 2004
(1) Time (hour)
(2) (Discharge rate)/(Inflow peak)
(3) (Inflow) / (Inflow peak)
(4) (Outflow) / (Inflow peak)
Extension ratio of the flood
-1) 1.43
-2) 1.31
-3) 1.2 and 1.08
-4) 2.22
-5) 1.91
-6) 1.57
-7) 1.34
(5) Start point of the operation using minimum outflow information

(a) Hydrogramme de crue planifiée
(b) Hydrogramme de la crue de 2004
(1) Temps (heure)
(2) (Taux de rejet)/ (Pointe de débit entrant)
(3) (Débit entrant)/ (Pointe du débit entrant)
(4) (Débit sortant)/ (Pointe du débit sortant)
Taux d'extension de la crue
-1) 1.43
-2) 1.31
-3) 1.2 et 1.08
-4) 2.22
-5) 1.91
-6) 1.57
-7) 1.34
(5) Point de départ de l'opération à partir d'informations sur le débit sortant minimum

5. OPERATION RESULTS OF THE FLOOD IN 2013

When Ohno dam office was examining employment of operation rule using MOPO to the management system, the typhoon brought the heaviest grade rainfall to the Yura river basin in Sep. 2013. The Peak inflow of Ohno dam was 1717 m^3/s, secondary discharge rate after completion, and the total inflow volume greater than 500 m^3/s inflow was 37.74 million m^3, the largest volume the dam had experienced. Hydrograph of this flood was gradual like the flood in 2004.

Fig.6 shows operation results of the flood. Since downstream areas had already flooded in the inflow increasing situation, gate openings were fixed when the outflow beyond around 850 m^3/s. After this, outflow was controlled below the flood control rule until the reservoir water level reached highest water level of flood control, EL.175.0 m. Opening operation of gates started in the condition that water level was beyond EL.175.0 m where inflow of the flood was judged in the recession mode and flooding situation at areas downstream seemed to go over the peak.

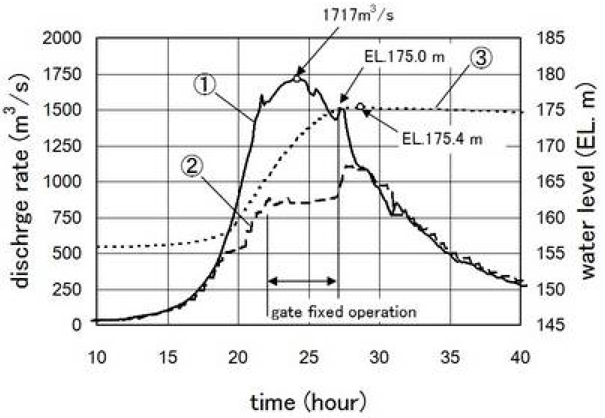

Fig. 6
Operation results at the flood in 2013 (excess flood beyond flood control planning)
Résultats des opérations lors de la crue de 2013 (crue excédant la planification de contrôle de crue)

(1) Inflow	*(1) Débit entrant*
(2) Outflow	*(2) Débit sortant*
(3) Water level	*(3) Niveau d'eau*

The operation against the flood is considered nearly the best use of the reservoir for reducing the disaster damages of areas downstream and preventing overtopping of the dam. Although the rule using MOPO was not included in the management system, Ohno dam stuffs prepared the table of MOPO printed on a sheet of paper. The above operation was carried out with referring to MOPO presented to the inflow and water level condition at each time. Good operation results were obtained with the confidence of the dam manager and stuffs, which was supported by the MOPO table.

6. CONCLUSION

If a gated dam has the purpose of flood control, operation mode should be changed from flood control to overtopping prevention mode in an excess flood inflow situation. The judgment of the changing mode and the decision of increasing way of outflow to connect both operations, mainly depend on a dam manager in Japan.

For the operation rule against excess floods, the Public Works Research Institute Japan presented the idea to prepare the minimum outflow, which can prevent overtopping, in the condition of inflow and water level at a point. The minimum outflow is obtained through the simulation of gate operation under the conditions related with hydrograph of inflow, gate movement, increasing rate of outflow and so on.

The effectiveness of the idea was confirmed by the actual operation of Ohno dam against the typhoon flood in Sep. 2013. The operation could appropriately reduce the disaster damages of areas downstream and prevent overtopping by referring to the minimum outflow table. Since the used minimum outflow table is a prototype one, presented rule has been examined for the improvement of setting more rational outflow increasing ratio connected with evacuation measures, making other tables for flood recession situation etc. for example.

REFERENCES

[1] KASHIWAI, J. Trial method for effective use of a reservoir against excess floods (in Japanese), *Engineering for dams*, 2013

SUMMARY

If a gated dam has the purpose of flood control, operation mode should be changed from flood control to overtopping prevention mode in an excess flood inflow situation. The judgment of the changing mode and the decision of increasing way of outflow to connect both operations, mainly depend on a dam manager in Japan.

Ohno dam had experienced many flood control operations till 2012 and contributed to reduce the disaster damages of flooding. At the flood in Oct. 2004, the water level went up to lowest water level for the operation of overtopping prevention. From the experience of the operation of the flood in 2004, Ohno dam learned not only the importance of flexible operation considering flooding situation at downstream areas but the necessity of more practical rules against excess floods.

For the operation rule against excess floods, Ohno dam picked up the idea presented by the Public Works Research Institute Japan and prepared prototype rule for Ohno dam in 2012. The idea is to present minimum outflow, which can prevent overtopping, in the condition of inflow and water level at a point. The minimum outflow is obtained through the simulation of gate operation under the conditions related with hydrograph of inflow, gate movement, increasing rate of outflow and so on.

After the preparation of the prototype rule, the Ohno dam tried to examine the practical use of the new rule, and met the typhoon that caused excess flood in Sep. 2013 under examination situation. The operation was carried out with referring to the minimum outflow table, which was printed out, and obtained good results. Effectiveness of the minimum outflow table was confirmed through the actual operation.

RÉSUMÉ

Si un barrage à vanne a pour objectif le contrôle des crues, dans une situation de débit entrant excessif, il faut passer d'un mode de fonctionnement de contrôle des crues à un mode de prévention d’un déversement en crête. L'appréciation concernant le changement de mode et la décision sur l'utilisation d'une méthode d'augmentation du débit sortant pour connecter les deux opérations dépendent, au Japon, principalement d'un responsable du barrage.

Le barrage d'Ono a expérimenté un grand nombre d'opérations de contrôle des crues jusqu'en 2012 et a contribué à réduire les dégâts provoqués par ces crues. Lors de l'inondation d'octobre 2004, le niveau d'eau a atteint son

niveau le plus bas pour les opérations de prévention d’un déversement en crête. Avec l'expérience des opérations effectuées lors de l'inondation de 2004, nous avons non seulement appris l'importance d’agir pour le barrage d'Ono de manière flexible lors des crues dans les zones en aval ainsi que la nécessité d'un plus grand nombre de règles pratiques contre les crues excessives.

En ce qui concerne la réglementation des opérations contre les crues excessives, le barrage d'Ono a adopté la proposition de l'Institut de recherche sur les travaux publics du Japon et a préparé un modèle de réglementation pour le barrage en 2012. L'idée est d’adopter un débit sortant minimum capable de prévenir un déversement en crête lorsque le débit entrant et le niveau d'eau ont atteint un certain point. Le débit sortant minimum est obtenu grâce à une simulation du fonctionnement des vannes dans des conditions liées à l'hydrogramme du débit entrant, le mouvement des vannes, le taux de croissance du débit sortant, etc.

Après la préparation d'un modèle de réglementation, le barrage d'Ono a tenté d'examiner l'utilisation pratique de la nouvelle réglementation et, pendant cet examen, a été touché par un typhon entraînant une crue exceptionnelle en septembre 2013. Les opérations ont été réalisées en prenant pour référence le tableau de débit sortant minimal imprimé et ont montré de bons résultats. L'efficacité du tableau de débit sortant minimum a été confirmée par les opérations effectives.