Research on emergency control mode of sluice gates in water delivery canal

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ABSTRACT: The regulation of sluice gates (control gates, dividing gates and exit sluices) in water delivery canal is very important and complicated especially in emergency conditions. Most of existing achievements are about canal control theory or based on normal operation condition, lack of researches about emergency joint dispatch under accident conditions and its internal mechanism. In this paper, a mathematical model for emergency dispatch of a long water delivery canal was established to study gate control modes. Some typical operating conditions were selected as study cases and some indicators which could affect safety and economical efficiency of project operation like water level, return water, gate action times were selected as measuring indices. The simulation calculations about different gate control modes of control gates and exit sluices (control speed, open and close time, action frequency, etc) were carried out, through changing gate group control modes to simulate disturbances in emergency regulating process, then track the unsteady flow hydraulic response of channel, analyze the variation of hydraulic parameter, ascertain the relationship between disturbances and channel hydraulic response, summarize the induction mechanism at last. The results can enrich canal gate emergency control theory and improve operation safety and economical efficiency. They can also provide scientific guidances for operation of water diversion projects to enhance emergency disposal ability, and it has strong academic and practical value.

1 Introduction

In order to solve regional water shortage caused by uneven spatio-temporal distribution of water resources, many water diversion projects (large flow discharge, large-scale structures, long line, etc.) have been built at home and abroad. Open canal is a commonly used structure, through setting online control gates (adjust water level at the upstream of control gates and control flow discharge) to achieve piecewise regulation for long canal, some dividing gates are opened along the line to supply water requiring areas, and some exit sluices (generally located at the end of a canal pool or at the upstream of some important canal buildings, and its design discharge is generally half of canal's design discharge) are arranged at the positions where "waste water" can be drained out. The open channel structure is a series connection system composed of gate partitions, the biggest feature of its operation is the coupling of canal pools and the coupling reaction is hysteretic. Single control gate's disturbance wave will spread upstream and downstream respectively, if it

superposed with exit sluices' and dividing gates' disturbances, the water flow in canal pool may present a complex and disordered flow regime, thus there must be a better channel control mode to maintain normal and stable operation state. In the event of emergency, timeliness and economical efficiency should be considered simultaneously, it's a big challenge for canal control system. There are many types of emergency events may occur during operation in diversion projects, if the accident is very serious, such as highly toxic pollutants entering into canal water or dike burst, many types of interrelated gates in accident segments must be adjusted to deal with the situation in time. However, when the gates should be opened and closed respectively, at what rate and whether they need to be adjusted again during its process, these factors will affect the final result of emergency control directly. Generally, dividing gates should be closed as soon as possible to stop water supply to reduce the impact to water requiring area, because its water discharge is much smaller than that of the trunk canal, so the degree of influence of dividing gates' adjustments to whole emergency dispatch is also smaller. But, control gates

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and exit sluices are different, as functional gates for controlling and releasing canal water, their regulating actions will bring great disturbance to canal water especially in serious accidents, they need short-term gate adjustments to achieve the goal of flow reduction ,or even cutting off the water transportation, faster gate regulation will inevitably lead to dramatic changes of flow discharge and severe fluctuations and oscillations of water level. Therefore, the focus of this paper is how to select appropriate control modes to control accidents timely and avoid the occurrences of secondary disasters, and make sure the loss is reduced to the minimum at the same time.

Domestic and international researches on canal operation control began very early, from the three point channel controller (Wu Baosheng et al, 2008) to PID (proportional-integral-derivative) controller which accompanied by microprocessor's appearance, and then other continuous attempts like fuzzy-PID control (Fan Jie et al, 2003), neural network (BP) (Wang Tao et al. 2004), the combination of dynamic matrix control (Wang Changde et al, 2005) and PID ,and then some new researches appeared recently like robust control and artificial intelligence control (Guan Guanghua et al, 2005; Shang Tao et al, 2005) etc. In a word ,current achievements on hydraulic control of water delivery canal are expected to control canal water as accurately as possible through establishing stable channel controller. Some related researches are in progress continuously. In addition, through taking hydraulic response as breakthrough point, many scholars have also explored the relationship between gate control disturbances and changes of hydraulic elements from dispatch angle. Zhang Cheng (Zhang Cheng et al, 2011) has studied the variation of hydraulic parameters like change range of water level fluctuation , influence distance, wave propagation time and falling rate of water level near gates under the function of gate disturbances, a preliminary relationship between gate actions and hydraulic responses has been established; Mu Xiangpeng (Mu Xiangpeng et al, 2010) has analyzed hydraulic response sensitivity to canal characteristic parameters when dividing gates were in working condition in Beijing-Shijiazhuang section of the South-to-North Water Diversion Project(SNWDP), a sensitivity index was proposed through analyzing simulation data; Fan Jie (Fan Jie et al, 2006) has discussed the relationship between water level decline rate, stability time and flow change time, operation mode, distance between the gates when water discharge changed, analyzed the influence of various factors on steady flow process; moreover, some scholars (Ding Zhiliang et al. , 2005; Wang Kai , 2009) applied characteristic method to establish one-dimension

unsteady flow mathematical model, the influences of different regulation speed of gates to changes of water-surface profile have been given; Fang SG (Fang Shenguang et al., 2008) suggested that the amplitude of water level at the upstream of control gates should be limited to $\pm 0.15\text{m}$; Zhang Jianyun (Zhang Jianyun. 1995) has proposed a mathematic model which was suitable for operation of large-scale interbasin water diversion project and combined with simulation model and optimization technology.

In the aspect of emergency dispatch, Zhang Cheng (Zhang Cheng, 2007) has selected some typical sections of the middle route of the SNWDP in China as research object, simulated hydraulic response characteristics of canal under abnormal conditions and the function of exit sluices, the results showed that use of exit sluices can reduce the magnitude of water level rise preferably and reduce the risk of water overflow effectively. Yang Min (Yang Min, 2010) has done some researches about synchronization control method and sequence control method in gates joint control, some comparison and analysis about hydraulic characteristics(water level, hydraulic transition time, etc) under different control methods were developed too. Shu Jin (Shu Jin et al. 2012) has simulated hydraulic response process of canal under accident condition, and has gotten conclusion that the control water level before control gates has direct impact on total amount of return water and the rise range of water level, the higher control water level is, the higher the rise of water level is. A fast and effective feedforward algorithm for closing gates of diversion channel has been developed by Soler and Joan (SolerJoan, 2013) , this method can calculate the trajectory of gates quickly which was based on sequential quadratic programming(SQP), it can also complete gate adjustments from initial opening to final opening smoothly by keeping water depth of the checkpoint unchanged; Wang Hao (Wang Hao et al, 2017) has selected the SNWDP as example, proposed main technical and scientific problems existing in the project, summarized existing research results from five aspects: forecasting, dispatch, simulation, control and evaluation, the key technologies of urgent need were elaborated, and some scientific problems that need to be solved urgently have been discussed.

Generally speaking, there are abundant research achievements in the field of dispatch and canal controlling theories, scholars (Filiz, et al, 2009, G, et al, 2005, Jay, 2002, Renault, 1999) in different countries have also conducted a lot of exploratory researches on engineering management, risk assessment, water use efficiency and so on. However, there are few researches on emergency control mode of canal gates under condition of accidents. This paper hopes to simulate the

quick response disturbance of control gates and exit sluices under emergency condition, and take hydraulic response of water flow in canal pool as research breakpoint, compare and analyze calculation results of different gate control mode cases and summarize the regularity.

2 Mathematical model

A one dimension mathematical model of a long distance diversion canal was built to study emergency operation problems, there are several different types of gates in the model.

2.1 Governing equation

The Saint-Venant equations which was commonly used in describing channel unsteady flow was selected as the basic equation, the control gate flow equation was added in as coupling condition. Through using the Henry formula, the continuity of flow calculation can be guaranteed basically, for some discontinuous phenomena existing in special cases, it can be solved by dividing flow coefficients into more piecewise functions.

(1) Saint—Venant equations

Fig 1 Schematic model

The discretization of one dimension Saint Venant equations was finished by using the Preissmann implicit difference method which had advantage of fast convergence and good stability. As mentioned above, the gate flow equation was added as coupling condition and double iteration method was used in solution procedure so that the accuracy of model can meet the requirement.

Solution principle: as shown in figure 1, assuming that the canal has $M + 1$ control gates, the whole line is divided into M large sections, and each section is divided into L_k calculation sections by L_{k-1} inner sections (not the section of control gate). There are two unknown variables on each inner section, the control gate section has 4 unknown variables (water level at the upstream and downstream of the gate, flow discharge, gate opening), which have a total of $2\sum_{k=1}^M L_k + M + 4$ unknown variables. Each section can make two calculation equations, there is one flow equation in each control gate, and the water levels

$$\begin{cases} \frac{\partial Q}{\partial x} + \frac{\partial F}{\partial t} = 0 \\ -\frac{\partial Z}{\partial x} = \frac{u^2}{C^2 R} + \frac{u}{g} \frac{\partial u}{\partial x} + \frac{1}{g} \frac{\partial u}{\partial t} \end{cases} \quad (1-1)$$

Q —discharge; F —wetted cross-sectional area; u —velocity; Z —water level, $Z = Z(x, t)$;

C —Chezy coefficient, $C = \frac{1}{n} R^{1/6}$; R —wetted perimeter;

(2) Henry formula

$$Q = C_d a b \sqrt{2gh_0} \quad (1-2)$$

a —gate opening; b —gate width; g —gravitational acceleration; h_0 —upstream water level; C_d —discharge coefficient;

when $h_0 \geq 0.81h_2 \left(\frac{h_2}{a}\right)^{0.72}$, free outflow,

$$C_d = 0.611 \left(\frac{h_0 - a}{h_0 + 15a}\right)^{0.072};$$

when $h_0 < 0.81h_2 \left(\frac{h_2}{a}\right)^{0.72}$, submerged discharge,

$$C_d = \frac{0.611 \left(\frac{h_0 - a}{h_0 + 15a}\right)^{0.072} (h_0 - h_2)^{0.7}}{0.32 \left[0.81h_2 \left(\frac{h_2}{a}\right)^{0.72} - h_0 \right]^{0.7} + (h_0 - h_2)^{0.7}};$$

h_2 —downstream water level.

2.2 Model solution

before canal head and after last gate are known as boundary conditions, so total calculation equations are:

$2\sum_{k=1}^M L_k + M + 3$. The model degrees of freedom is $M+1$, and it still needs to add $M+1$ definite solution conditions to obtain numerical solution.

The hydraulic fluctuation process of the canal caused by emergency shutdown of gates is a unsteady flow transient process. In this process, the gate openings of $M+1$ control gates are closing processes which are designed by man based on the target value calculated by the constant flow model. With these conditions, the unsteady flow model becomes a definite solution model.

2.3 Initial and boundary conditions

The research object of this paper is the open channel under normal running condition. Therefore, the initial conditions of model should be water level and flow conditions of canal gates under normal operation state, namely steady flow state. The emergency dispatch needs an objective after accident, and the objective

should also be a stable state, the nature of emergency dispatch is unsteady flow process from one steady state to the other.

The selection of reasonable boundary conditions is the premise of mathematical model calculation, and it will affects the correctness of calculation results directly. The upstream source of this simulation model is a reservoir, when the canal system is operating normally, because the change velocity of reservoir water level is much slower than canal water, it can be ignored basically, so the upper boundary condition can be assumed as a constant value. If water level changes of canal head need to be considered in simulation, the change process at the front of canal head can be used as upstream boundary condition too. The downstream boundary condition can be water level known at the end of canal or a known flow process. In addition, since the water fluctuation in canal is mainly caused by changes of dividing gates flow which is generally planned by water demand downstream, the diversion discharge of canal head and control gates along the line can be adjusted according to water demand processes downstream, then, all the upstream and downstream boundary conditions of the simulation can be determined, it's a feedforward quantity.

In this model, the initial state is a diversion canal under normal operation, so the water levels and discharge are all determined as the values of design conditions.

2.4 Gate control rules

Firstly, some basic control strategies on kinds of sluice gates under accident condition are given out in the paper. Then, according to control ability of existing engineering equipments of gate control in current situation and considering requirements of project safety and simplifying gates operation in emergency dispatch, the simulation sets that emergency gate adjustment will carry out one time in every 5 minutes, and the gate will

operate adjusting instruction to a specified opening in 5 minutes, then wait for next instruction. There are different control modes depending on types of gates:

(1) Control gate

The two control gates at the upstream and downstream of accident section will be closed as soon as possible; The head gate of canal will be closed to target opening quickly, other gates (except head gate) upstream will conduct synchronous opening adjustments to the set target in certain step length and the gates downstream will gradually reduce their openings to the closed state.

(2) Exit sluice;

In order to reduce the maximum value of rise of water level caused by control gate's shutdown, the adjacent exit sluice(which is usually set in a certain range before downstream control gate)should be started up to adjust synchronously, when water level is lower than the closing level, exit sluices should be closed gradually, those exit sluices upstream should start to open when the water level of the canal pool where exit sluice was located rise to a certain level, and other ones downstream accident section will not be used.

(3)Dividing gates

Upstream dividing gates should keep working state, and the dividing gates in accident sections should be closed immediately, the other ones should be closed synchronously with these control gates in downstream canal sections.

3 Calculation and analysis

Simulation canal section: The open canal of a water diversion project is in normal water delivery state, the project adopts the mode of constant downstream depth operation (keep the water level before the downstream gate of a canal pool unchanged). Assuming water quality pollution accident occurs suddenly in the canal section (A-B) , the canal system will enter emergency state immediately, and control gates of accident section should be closed rapidly and cut off water supply. The parameters of related gates are shown in table 1 below, the schematic diagram of emergency control is shown in figure 2.

Table 1 Gates parameter table

Control gates	Lock chamber width (m)	Design water level (m)	Check water level (m)	Water discharge (m ³ /s)	Initial opening (m)	Gate pore (no)	Maximum mechanical speed (cm/min)	Minimum mechanical step size (cm)
A	25.00	134.60	135.36	290.0	3.56	2	40	2
B	38.62	133.06	133.84	286.0	3.35	4	40	2
Exit sluice	Design discharge (m ³ /s)	Gate pore (no)	Lock chamber width (m)	Maximum mechanical speed (cm/min)	Minimum mechanical step size (cm)			
C	160	1	5.5	40	2

Fig2 Sketch map of emergency control for water diversion open channel gate

3.1 Control gate research

3.1.1 Close rate

The closing action of canal gates directly affects the change of water level, large water level rise and falling in short time will be disadvantageous to canal lining, water diversion projects will generally give clear requirements about water level decline per unit time, such as the SNWD project, the water level decline must be controlled in 40cm/day and 20cm/h except in emergency condition, but faster gate open and close rate will usually be selected to achieve control goal as soon as possible when accidents happen, although it will bring some impact on canal lining. For control gates, complete closing target quickly is the key consideration under accident condition, based on this, three kinds of simulation conditions are set in this section, the closing rates of gate A are set 10cm/5min, 20cm/5min,40cm/5min respectively, for better comparison, other settings and gate control rules are same in different simulation programs. As shown in table 2:

No	Rate(A)	Control mode(emergency gate)	Gate operating frequency	Control rules(other gates)
1	10cm/5min	Close uniformly	5min/time	same
2	20cm/5min	Close uniformly	5min/time	same
3	40cm/5min	Close uniformly	5min/time	same

The gate opening and water discharge changes under different conditions are showed in figure 3 and 4 respectively, figure 5 is the process of dynamic change of water level at the upstream of gate, it can be seen that: the water levels in three simulations all showed the same process that rose first ,then fell down, then fluctuated repeatedly until reached a state of equilibrium finally, the different points are the ranges of water rose and the water level value after fluctuations have stopped. The faster the closing rate was, the higher the water level rose, the peak reached 135.21m,and the water level rising slope was steeper too. In addition, the faster gates closed, the faster water level value reached its maximum. Such as the program of 40cm/5min, water level reached the peak at about 30min, contrary to rise speed, the canal water level after stabilization showed opposite trend, the faster gates closed ,the lower stable water level was. It may be related to canal return water volume, the exit sluices keep open for longer time in the program that water level rose faster (see below).

Table 2 Simulation programs of gate closing rates

Fig.3Contrast diagram of gate opening change process

Fig.4 Comparison of flow discharge change

Fig.5 Change processes of water level at the upstream of gate A

Figure 6 shows return water volume in different closing rate programs. It can be seen that the return water volume is proportional to closing rate. The slower the closing rate was,the less the return water was.For water level, if gate closed slower, the water level would rise slower, and the speed and time of exit sluice also decreased correspondingly, so the total return water volume was less. The return water volume and the water level at the upstream of control gates are two important indexes to reflect economy and safety of canal emergency dispatch, the return water volume should be reduced as much as possible on the basis of ensuring safety of canal structures, this is the premise for selecting appropriate gates regulation rate.

Fig.6 Comparison of return water between different programs

3.1.2 Gate open and close mode

The open or close of gates under accident condition should follow the principle of direct and fast, this paper mainly studied the mode of quick closing, there are usually two kinds of gate control modes which can be selected: the constant speed and variable speed. The standard of choice is simplifying operation and saving time.

Four simulation conditions were set in this section. For better comparison, the regulating frequency of gates under different conditions were all set as 5min/time, the step length of gate opening is 20cm, and other settings and control rules were same, as shown in table 3.

Table 3 Simulation programs of sluice control mode

No	Program	Gate control mode (control gate)	Initial velocity	Gate regulating frequency	Control rules(oth er gates)
1	Mode 1	Close uniformly	20cm/5min	5min/time	same
2	Mode 2	Adjusting step reduces to 1/2 when gate opening is less than 1/2 of its initial value	20cm/5min	5min/time	same
3	Mode 3	Adjusting step reduces to 1/2 when gate opening is less than 1/2 of its initial value; adjusting step reduces to 1/3 when opening is less than 1/3 of its initial value	20cm/5min	5min/time	same
4	Mode4	Adjusting step reduces to 1/2 when gate opening is less than 1/2 of its initial value; reduces to 1/4 when opening is less than 1/4 of its initial value	20cm/5min	5min/time	same

The gate opening and discharge changes in different modes are showed in figure 6 and 7 respectively. It can be seen that, the flow discharge of control gate changed with opening adjustment. The variation trends in mode

3 and 4 were similar , because the initial values of gate opening in these two simulation conditions were relatively small , thus the numerical difference was small.

Fig.7 Contrast diagram of gate opening change

Fig.8 Comparison of of flow rate change

Table 4 Maximum water level at different control mode

No	Gate closing program	Highest Water level before the gate (m)	Time (min)	Gate action number
1	Mode 1	135.04	89	18
2	Mode 2	134.90	130	27
3	Mode 3	134.87	546	36
4	Mode 4	134.91	565	37

oscillation. In the first round of water level increase, the amplitude and slope of water level rise in mode 1 were all the largest, the maximum value of water level was 135.05m which appeared in 88th min; the program 4 was the slowest and the least, the peak of water level reached 134.79m in 128th min. The time of water level peaks' appearance delayed in turn, and the maximum value also decreased (see in table 4), in addition, the peak of water level rise in the first round were all lower than stable value after oscillation in the 3th and 4th simulation condition. The total action times that gates completed their closing process in different programs were listed in table 4, the least was 18 times in mode 1, the most was 37 times in program 4; besides, there weren't obvious differences on last stable water level in four control modes, it was decided by canal control mode (Constant downstream depth operation).

Fig.9 Water level change process before gate

The change processes of water level in different control modes are shown in figure 8. With the gates' close, the water level before gate rose sharply at first, then decreased gradually after reaching the peak in short time, then remained stable during a period of time, then began to rise gradually to a new water level and kept stable again after a period of fluctuation and

Figure 10 shows the changing processes of exit sluice in different control modes, the main difference is reflected in closing process. The exit sluice in mode1 started to close last (227 min), mode 2 took second place (217 min), mode 3 and 4 were same (207 min), and their opening and closing processes were exactly same too. The return water volume in four accident programs were shown in figure 10, it can be seen that the maximum was 273840m³(mode1), the minimum was 243360 m³(mode 3 and 4).

Fig.10 Flow chart of exit sluice

In summary, control mode has great influence on water level and return water, the method that reduced gate closing rate when gate opening got close to the target can reduce water level rise and the return water volume effectively. It was more favorable for the economy of emergency dispatch program and the safety of canal structures.

3.1.3 Gate regulating frequency

Generally speaking, the dispatch response of long distance diversion canal has characteristics of large time delay, the reason lies in long distance of single canal section, the transfer time of wave caused by gates adjustments is very long. For safety, the interval time of

Fig.11 Comparison of return water between different programs

gates control is generally set longer, and single adjustment should not be too large. In addition, the existing gate control system generally adopts hydraulic equipments to open and close, their mechanical properties directly limit the reaction time and movement frequency of gates. The mechanical properties of gate control system will not be considered temporarily in this paper, only select the gate open and close frequency as research objects to investigate its effect on canal hydraulic response.

Four conditions were given out, as shown in table 4, the opening and closing rate was set 20cm/step, the gate opening adjustment of initial step length was 20cm, and other settings and gate control rules were same.

Table 5 Simulation programs of gates control frequency

No	Program	Gates control frequency (min/step)	Closing time (min)	Control mode	Control rules(other gates)
1	Model	2	100	Close uniformly	Same
2	Model2	5	100	Close uniformly	Same
3	Model3	10	100	Close uniformly	Same
4	Model4	20	100	Close uniformly	Same

Fig.12 Gate opening change diagram

Fig.13 Comparison of flow rate change

Fig.14 Water level change process before gate

Table 6 Maximum water level at different control frequency

No	Gate closing mode	Highest water level (m)	Time (min)	Gate action (no)
1	2min	134.97	91	46
2	5 min	135.00	91	19
3	10 min	135.02	91	10
4	20 min	134.99	91	6

The changing processes of gate opening and flow discharge in different conditions are shown in figure 12 and figure 13, figure 14 shows changing processes of water level at upstream of the control gates. It can be seen from the figures that water levels all kept rise when gates were in process of closing action, it climbed to the peak(135m) after gate closed(100min)completely, then declined rapidly, whereafter, entered a period of oscillation time which caused by transmission and superposition of water waves until reaching final stable state. Figure 14 shows that the first lifting process of water level at the upstream of control gates were basically similar, the maximum value was about 135m which appeared at 91th min. The differences mainly lied in the process of declining and stabilization, faster gate control actions (higher frequency) caused faster water level decline in the simulations(figure14, purple line) and the condition with higher frequency entered into oscillation period earlier, the others followed by time, the simulation condition with the smallest frequency (20min/ time, black lines)had the longest adjustment time.

Fig.15 Comparison of return water between different programs

The return water of the canal in different conditions is shown in figure 15, it can be seen that ,the lower the action frequency was ,the larger the return water was, the maximum value was 5795520m³, the minimum value was 1847040m³,as much as three times. Hence one can see that: the operating frequency of gate has large impact on emergency dispatch. In the premise of ensuring channel water doesn't exceed the safe water level, more frequent gate actions will bring burdens to gate control system to a certain extent, but it will also reduce economic loss caused by emergency response significantly. Thus, in terms of sudden accidents, considering the capacity of gate control system and structures' safety, taking a shorter time interval adjustment scheme will be more favorable for emergency controlling in time and reducing economic losses.

3.2 Exit sluice research

3.2.1 Without exit sluice

For comparative study, the control mode that gate A and B were closed rapidly and other gates didn't participate in was been simulated firstly, the simulation result showed that, the water level before gate A

continued to rise when the gate closed, it exceeded the top elevation 134.33m (check water level+0.5m) of gate A at about 35th min, then the canal water crossed the sluice and flowed downstream, it may induce secondary damage, the changing process of water level was shown in figure 16. Thus, it is very hard to finish rapid discharge reduction without causing other damages by using control gates only, there must be other gates or methods participating in and cooperating to control water level rising speed. The exit sluice is usually served as the role, opening exit sluices can reduce the diversion discharge directly and create a degressive water wave transmitting downstream, it will bring inhibitory effect on the rise trend of water level before the gate A.

Fig.16 Water level change before gate A without using exit sluice

3.2.2 Exit sluices engaging in dispatch

This section has simulated joint operation of control gates and exit sluices, it can be seen from figure 17 that when exit sluice C was opened up, the rise trend of water level has been diminished, because the degressive wave created by exit sluice C transmitted downstream and superposed with the rising wave caused by gate A.

Fig.17 The change processes of water level before gate A and the discharge of exit sluice C

In addition, it can also be found in the simulation that the opening time of exit sluice had greater impact on water rise and total amount of return water. In general, the earlier gate opens, the water rise will be smaller, but the return water volume will increase, there's a game relationship between them; similarly, the closing time has the same relationship. To this end, some studies aiming at the opening and closing of exit sluice have carried out in this paper.

(1) Open research

Simulation conditions: the design/check water levels of downstream adjacent control gate were taken as reference standard to set the open and close water level of exit sluice, when the water level before control gate rose or fell to the setting value, the exit sluice began to open or close. Three conditions about open water level were assumed respectively in this section: check water level, check water level -0.2m and check water level +0.2m. The close water level were all set as design level in three different conditions and the control modes of other types of gates were same too, as shown in table 7:

Table 7 Simulation programs of exit sluice on open and close levels

No	Accident canal section	Open water level	Closewater level	Control rules(other gates)
1	A~B	Check water level	Design water level	Same
2	A~B	Check water level -0.2m	Design water level	Same
3	A~B	Check water level +0.2m	Design water level	Same

Through numerical simulation and data analysis, the statistical characteristics of results were shown in table 8:

Table 8 The water rise and return water

Category	Open water level	Check water level-0.2m	Check water level	Check water level +0.2m
The maximum water level before gate A(m)		0.87	0.88	0.96
Time(min)		258	239	145
Total return water of the whole canal(10 thousand cubic meters)		1087.7	1014.5	976.2
Return water of the canal section next gate A (10 thousand cubic meters)		427.6	432.5	606.5
Return water of other canal sections (10 thousand cubic meters)		660.1	581.9	369.8

It can be seen from table 8 that: when the open

water level of exit sluice increased gradually, the increase amplitude of water level before sluice A

increased gradually too, the maximum value was 0.96m in the simulation, and the time that the maximum value appeared also shifted to an earlier time; similarly. With the increase of open level, the total quantity of return water in whole canal decreased gradually, but the quantity of the canal section before sluice A increased, and the sum of which in other canal pools decreased. In general, if exit sluices start to open earlier, the rise of water level will be smaller, the project will be safer, but economic losses will be larger, because more water will be discarded. As shown in figure 18.

Fig.18. Comparison of the return water between different exit sluice opening programs

(2) Close research

The simulation conditions were: the open water level of exit sluices was set as check water level, and the close water level was set as design water level, design water level+0.2m, design water level+0.4m respectively, and the control modes of other types of gates were same too, as shown in table 9:

Table 4-9 Simulation programs of exit sluice close level

No	Accident section	Open water level	Close water level	Control rules(other gates)
1	A-B	Check water level	Design water level	Same
2	A-B	Check water level	Design water level +0.2m	Same
3	A-B	Check water level	Design water level +0.4m	Same

Through numerical simulation and data analysis, the

statistical characteristics of the results were shown in table 10:

Table 10 The water rise and return water

Category	close water level	Design water level(m)	Design water level +0.2m	Design water level +0.4m
The maximum water level of the sluice A(m)		0.88	0.88	0.88
Time(min)		261	261	261
Total return water of the whole canal(10 thousand cubic meters)		1107.4	1018.6	892.2
Return water of the canal section next sluice A (10 thousand cubic meters)		432.5	421.9	382.9
Return water of other canal sections (10 thousand cubic meters)		674.8	596.7	509.3

Fig.19. Comparison of the return water in different exit sluice closing programs

It can be seen from the table 8 that: with increasing of close water level, the total volume of return water in whole canal decreased gradually, the quantity of the single canal section before sluice A decreased, and the

sum of which in other canal pools decreased too; the maximum value of water rise amplitude was 0.88m in the simulation, the time of which appeared was at 261th min, three conditions are same. Thus, the close method of exit sluice had great influence on canal operation, but it did not affect the rise of water level before sluice A (fig19).

4 Conclusion

In this paper, a mathematical model has been established to simulate emergency open and close process of a open diversion canal, some researches and analyses on the control mode of control and exit sluices

have been carried out respectively, main conclusions are as follows:

(1) The faster the control sluices close, the higher the water levels rise, and the return water will be larger too, it's more favorable for controlling accidents if the control gates are closed as soon as possible; different control methods all have great influence on water level rise and return water volume of the whole canal(section 2.1), using a piecewise close mode (mode three or four) can effectively reduce them, the project will be safer and the operation will be more economic too. The action frequency of control gates have less influence on water level rise, but have significant influence on return water, so the emergency control program with shorter time intervals should be taken firstly if the gate control system hardware can bear it.

(2) The exit sluice plays a key role in the joint emergency control of the project, the open and close modes affect the return water and the maximum value of water level directly. When accidents occur, the earlier the exit sluices open, the larger the water will be discarded, and the water level rise at the upstream of control gates can be smaller. In addition, if the exit sluices close earlier, the return water will be less, the close time has no effect on the maximum value of water level basically. Some optimization choices could be proposed according to canal design data, the open and close water level of exit sluices can be increased properly in the premise of ensuring the elimination effect on water level rise.

The emergency control of gates in open diversion canal affects the safety of the project directly, especially control gates and exit sluices, economic loss is also an important factor to assess the emergency control scheme. After accidents happen, controlling the spread timely and ensuring the safety of project are primary tasks for emergency dispatch, on this basis, regulation schemes with less return water can be selected.

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