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THE UNCERTAINTY OF ROUGHNESS AND ITS INFLUENCE ON DYNAMIC RESPONSE AND PERFORMANCE OF CANAL SYSTEM

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ABSTRACT

In this paper, the influencing factors and the uncertainty of roughness coefficient are analyzed, an operating simulation mode for multireach serial canal system under gate regulating is established. The discharge feed-forward plus water lever feedback PID controller is adopted. Influence on dynamic response process and dynamic performance of canal system is studied according to the variation of roughness coefficient, combined with the canal operation methods. The results show: the larger roughness coefficient is, the better transient response and steady-state response of canal system are for the constant volume operation method of canal, moreover, the response of canal system to discharge variation is faster; along with the increase of roughness coefficient, the canal system has better transient response and worse steady-state response for constant downstream depth operation method, and the response of canal system to discharge variation is slower , moreover, the stable processes of gate discharge and gate opening become worse; the stable storage volume increases approximately linearly as the roughness coefficient becomes larger.

Keywords: canal operation, roughness coefficient, uncertainty, PID controller, performance indicator, dynamic response

1. INTRODUCTION

The roughness is one of essential technical parameters in channel designs. The rationality and reliability of roughness coefficient value has extremely important significance to project. Especially regarding large-scale long distance water transfer project, the determination of roughness coefficient along the channel route is an important question in the analysis of canal system operation control. Many scholars have done large numbers of researches on influence factors and computational methods of roughness coefficient as well as the influence of different roughness coefficient on channel water power designs (Ramesh et al., 2000; Ding et al., 2004; Wang et al., 2006), it is obvious that numerous factors have influence on channel roughness coefficient, and the selection of its value has prodigious uncertainty. In research of long distance canal automation operation, many people consider the head lost caused by canal curving, form and acreage variation of cross sections and bridges et al in the roughness coefficient along the canal route, moreover, the roughness coefficient generally adopts a given value in different areas and operation periods, and very little influence of roughness coefficient variation on canal dynamic response and dynamic performance is considered. Accordingly, a study on how the variation of roughness coefficient affects the dynamic response and dynamic performance of canal system is necessary, combined with the control and operation methods of canal.

2. THE UNCERTAINTY OF ROUGHNESS COEFFICIENT

According to existing studies, the roughness coefficient value changes approximately between 0.011 and 0.018 in actual concrete channels. For long distance water delivery channel, the correct determination of roughness coefficient value has major influence on the water delivery of main channel. The roughness coefficient is not only related to the surface roughness, but also is influenced by other factors. Therefore, the variation of roughness along the channel route will influence the response characteristics of channel system.

There are many formulas to calculate channel roughness coefficient at present, and following several kinds are famous.

(1) The formula proposed by the U. S. Bureau of Reclamation for long distance water transfer channel is as follows (U. S. Bureau of Reclamation, 1964):

$$n = \frac{0.0565R^{1/6}}{\lg(9711R)} \tag{1}$$

Whrere n is the roughness coefficient ; R is the hydraulic radius.

The formula (1) is fit for channels when the water depth and hydraulic radius are correspondingly larger, and generally the applicable condition of formula is that R is larger than 1.2m, and the formula is suitable for the hydraulic rough area.

(2) Open Channel Hydraulics formula (Sturn, 2002):

$$\frac{n}{K_s^{1/6}} = \frac{\dfrac{K_n}{(8g)^{1/2}\left(\dfrac{R}{K_s}\right)^{1/6}}}{2.0\lg\left(12\dfrac{R}{K_s}\right)} \tag{2}$$

Whrere K_s is the absolute roughness; K_n is the formula coefficient.

This formula is derived from the relation between the Manning formula and the Darcy-Weisbach coefficient, so it is suitable for the rough area.

From formulas (1) and (2) we can see that they have no relation to the Reynolds number, and all of them are suitable for the rough area.

(3) The formula of the Middle Route of the South-to-North Water Transfer Project of China (Ma and Shi, 2007):

$$n = SR^{1/6}\left(\frac{68}{Re} + \frac{K_s}{R}\right)^{0.125} \tag{3}$$

Where S is the correction coeffieient; R is the hydraulic radius; Re is the Reynolds number; K_s is the absolute roughness.

From formulas above we can see that R, K_s and Re are the main factors to influence roughness coefficient value in theory. Regarding artificial channels, because their cross sections are quite regular, and are dissimilar with the natural river course, we can mainly consider the influence of above several factors on the n value. Even so, in allusion to an actual project, the computed result of n based on each formula is different, so the determination of roughness coefficient value still has prodigious uncertainty, and this will bring tremendous influence on the operation response process of channel system.

3. SIMULATION MODEL OF CANAL SYSTEM OPERATION

The discharge feed-forward plus water level feedback PID controller is proposed in simulation model, the frame of the control system is presented in Figure 1. The entire canal automation simulation system is composed by six modules: the steady flow calculation module, the gate opening inverse-solute module, the PID control module, the calculation module for gate opening, the calculation module for the discharge through the gate and the unsteady flow calculation module. Here the unsteady flow hydraulics model, the PID controller algorithm and the lockage discharge are introduced principally.

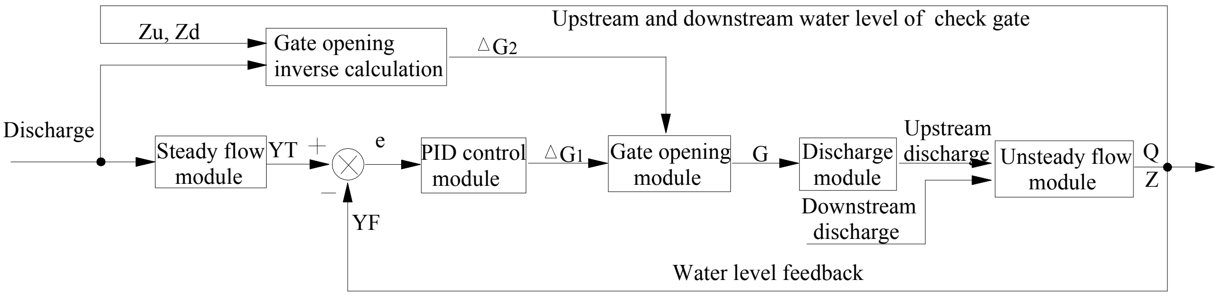

Figure 1 Canal automation control systems

3.1 Hydraulics model of canal system

Usually the main canal is divided into canal pools by check gates in series which contains some canalside turnouts. The check gates of upstream and downstream are boundaries of the conjoint pools.

The unsteady dynamic characteristic of channel can be described by Saint-Venant equations, which are composed by continuity equation and momentum equation:

$$B\frac{\partial Z}{\partial t}+\frac{\partial Q}{\partial s}=q \tag{4}$$

$$\frac{1}{gA}\frac{\partial Q}{\partial t}+\frac{2Q}{gA^2}\frac{\partial Q}{\partial s}+(1-\frac{BQ^2}{gA^3})\frac{\partial Z}{\partial s}=\frac{q}{gA}(v_{qs}-v)+\frac{BQ^2}{gA^3}(i+M)-\frac{Q^2}{A^2C^2R} \tag{5}$$

Where B is the width of canal water surface (m); Z is the water surface elevation (m); t is the time (s); Q is the discharge (m^3/s); C is the Chezy coefficient; s is the distance along the canal (m); g is the gravitational acceleration (m/s^2); A is the area of cross section (m^2); q is the inflow along the canalside (m^3/s/m); v is the flow velocity along canal axes (m/s); R is the hydraulics radius (m); v_{qs} is the average flow velocity along canal axes of the canalside inflow (m/s); i is the canal bottom slope; $M = \frac{1}{B}\frac{\partial A}{\partial s}\Big|_h$.

The preissmann implicit scheme is widely adopted as the numerical solution method of Saint-Venant equations for its fine characteristics such as high accuracy, unconditional convergence (Fubo et al., 1994).

3.2 PID controller algorithm

The incremental PID control algorithm can be described as follows (Liu, 2003):

$$\Delta G(k) = K_P \Delta e(k) + K_I e(k) + K_D[\Delta e(k) - \Delta e(k-1)] \tag{6}$$

Where $\Delta G(k)$ is the output of feedback control; K_P is the proportional coefficient; K_I is the integral coefficient; K_D is the differential coefficient ; e is the difference of water levels; Δe is described by $\Delta e(k) = e(k) - e(k-1)$; k is the sampling time.

3.3 Gate discharge calculation

We use the gate discharge formula including water velocity head to calculate the discharge through the gate:

$$Q = C_d ab\sqrt{2g\Delta H + (Q / A_u)^2} \tag{7}$$

Where Q is the discharge through the gate (m^3/s); C_d is the discharge coefficient; a is the gate opening (m); b is the gate width (m); ΔH is the difference between upstream and downstream water depths (m); A_u is the area of cross section before gate (m^2).

4. PERFORMANCE INDICATORS OF CANAL CONTROL

There are many performance indicators to weigh the control effects of canal, such as water level indicators, discharge and gate movement indicators et al. (Clemmens et al., 1998).

Maximum Absolute Error (*MAE*):

$$MAE = \frac{\max\left(\left|y_t - y_{target}\right|\right)}{y_{target}} \tag{8}$$

Where y_t is the observed water level at time; and y_{target} it the target water level.

Integral of Absolute Magnitude of Error (*IAE*):

$$IAE = \frac{\frac{\Delta t}{T}\sum_{t=0}^{T}\left|y_t - y_{target}\right|}{y_{target}} \tag{9}$$

Where Δt it the regulation time step; and T is the time period for test (12 or 24h).

Steady-state Error (*StE*):

The steady-state error is defined as the maximum of the average error over the last 2 h of each 12 h test. The assumption is that conditions will be stable during this time.

$$StE = \frac{\max\left(\left|\overline{y}_{10,12} - y_{t\arg et}\right|, \left|\overline{y}_{22,24} - y_{t\arg et}\right|\right)}{y_{t\arg et}} \tag{10}$$

Integrated Absolute Discharge Change (*IAQ*):

$$IAQ = \sum_{t=t_1}^{t_2}\left(\left|Q_t - Q_{t-1}\right|\right) - \left|Q_{t1} - Q_{t2}\right| \tag{11}$$

Where Q_t is the check gate discharge at time t. The second term is simply the difference between the initial and final flow rate.

Integrated absolute gate movement (*IAW*):

$$IAW = \sum_{t=t_1}^{t_2}\left(\left|W_t - W_{t-1}\right|\right) - \left|W_{t1} - W_{t2}\right| \tag{12}$$

Where W_t is the cheak gate position at time t.

The performance indicators should be computed for each pool for each 12h simulation period. For each indicator, the maximum and average values for all pools should be reported.

5. COMPUTATION EXAMPLE AND ANALYSIS

5.1 Model of simulation canal

According to the newest design data of the middle route water main of China South-to-North Water Transfers Project, the design discharge is 350m^3/s in canal head. The simplified canal model between the GuYun river check gate and the Tang river cheak gate is selected as the simulation canal, see Figure 2.

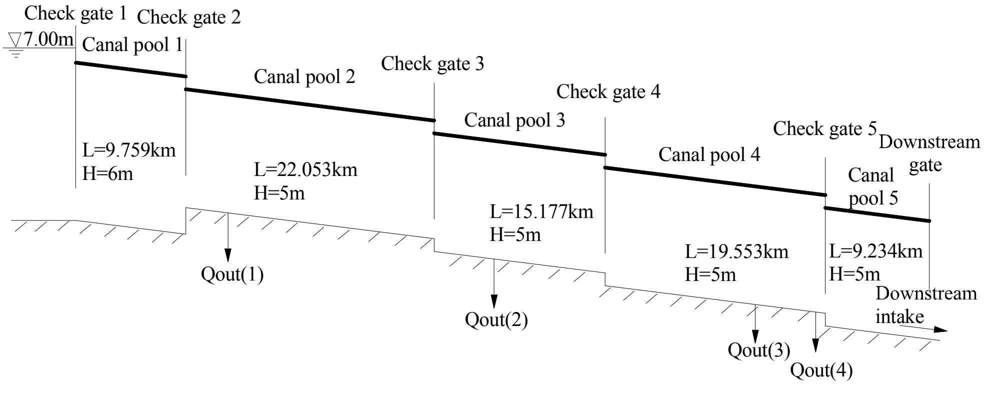

Figure 2 Sketch map of simulation canal

The parameters of each canal pool see Table 1. The variation range of roughness coefficient value in main canal of the south-to-north water transfers project is from 0.012 to 0.018, along with the roughness coefficient variation, the water surface profile also has corresponding variation along the canal route in main canal. The design water depth of canal for each roughness coefficient see Table 2. Because lacks the discharge data of canalside turnouts, according to discharge conservation principle, the maximal turnout discharge in canalside turnouts of each canal pool can be determined.

Table 1 Characteristic table of canal parameters

Canal pool No.	Bottom slope	Bottom width (m)	Side slop	Lengh (m)	Discharge (m^3/s)		Bottom altitude (m)	
					Design	Increase	Upstream	Downstream
1	1/20000	11.0	2.5	9759	170	200	2.729	2.241
2	1/25000	21.0	3	22053	170	200	3.091	2.209
3	1/25000	20.0	3	15177	165	190	2.059	1.451
4	1/25000	20.0	2.5	19553	155	180	1.301	0.519
5	1/25000	16.5	2.5	9234	135	160	0.369	0.000

Table 2 Design water depths of canal under different roughness coefficient

Canal pool No.	n=0.012	n=0.013	n=0.014	n=0.015	n=0.016	n=0.017	n=0.018
1	5.358	5.566	5.764	5.954	6.137	6.314	6.484
2	4.428	4.615	4.794	4.966	5.132	5.292	5.447
3	4.441	4.627	4.806	4.977	5.142	5.302	5.456
4	4.422	4.612	4.794	4.970	5.139	5.303	5.461
5	4.435	4.621	4.799	4.971	5.136	5.295	5.450

5.2 Canal constant volume operation

Canal dynamic response and dynamic performance are closely linked with canal operation methods. In terms of different locations of the canal pool water surface pivot point, there are constant downstream depth, constant upstream depth, constant volume and controlled volume operation methods.

When constant volume method of operation is proposed, the steady flow water surface profile must be calculated firstly under design discharge for each canal pool, and then calculates water body volume under this water surface profile of each pool. According to the volume of each canal pool and initial discharge conditions, the initial water surface profile is calculated inversely.

Both discharge increase and decrease operation conditions about scheduled flow change are simulated in the paper without considering unscheduled change in flow: (1) the discharge at the canal downstream end and each canalside turnout increases linearly from 50% design values to 80% design values at initial 2h; (2) the discharge at the canal downstream end and each canalside turnout decreases linearly from 80% design values to 50% design values at initial 2h.

For scheduled flow change in canal, the control performance indicators of canal are computed for 12h simulation period, see Table 3 and Table 4. The response time varies along with the roughness coefficient as shown on Figure 3 and Figure 4. The variation of stable canal storage volume along with the roughness coefficient is shown on Figure 7.

Table 3 Performance indicators when discharge increases for constant volume operation

n	*MAE* (%) 0-12h Period		*IAE* (%) 0-12h Period		*StE* (%) 0-12h Period		*IAQ* (m^3/s) 0-12h Period		*IAW* (m) 0-12h Period	
	Maximum	Average	Maximum	Average	Maximum	Average	Maximum	Average	Maximum	Average
0.012	0.209	0.151	0.036	0.025	0.0041	0.0015	9.31	5.88	0.432	0.283
0.013	0.177	0.129	0.031	0.022	0.0038	0.0014	7.74	4.87	0.339	0.240
0.014	0.151	0.111	0.027	0.020	0.0035	0.0013	6.52	4.11	0.279	0.207
0.015	0.139	0.097	0.026	0.018	0.0032	0.0013	5.56	3.51	0.242	0.181
0.016	0.131	0.087	0.025	0.016	0.0029	0.0012	4.76	3.03	0.212	0.162
0.017	0.124	0.078	0.024	0.015	0.0027	0.0012	4.15	2.64	0.187	0.147
0.018	0.118	0.070	0.023	0.014	0.0025	0.0011	3.70	2.35	0.165	0.136

Table 4 Performance indicators when discharge decreases for constant volume operation

n	*MAE* (%) 0-12h Period		*IAE* (%) 0-12h Period		*StE* (%) 0-12h Period		*IAQ* (m^3/s) 0-12h Period		*IAW* (m) 0-12h Period	
	Maximum	Average	Maximum	Average	Maximum	Average	Maximum	Average	Maximum	Average
0.012	0.250	0.179	0.032	0.022	0.0031	0.0010	7.61	5.21	0.172	0.133
0.013	0.212	0.154	0.027	0.019	0.0030	0.0010	6.35	4.33	0.141	0.115
0.014	0.182	0.134	0.024	0.017	0.0030	0.0010	5.51	3.70	0.120	0.102
0.015	0.157	0.118	0.025	0.016	0.0029	0.0010	4.82	3.20	0.106	0.091
0.016	0.137	0.105	0.024	0.015	0.0028	0.0010	4.27	2.81	0.094	0.083
0.017	0.120	0.095	0.023	0.014	0.0028	0.0010	3.81	2.50	0.088	0.078
0.018	0.112	0.085	0.022	0.013	0.0027	0.0010	3.40	2.24	0.099	0.074

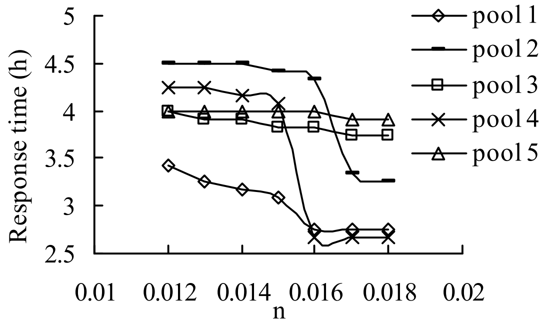

Figure 3 Canal response time when discharge increases

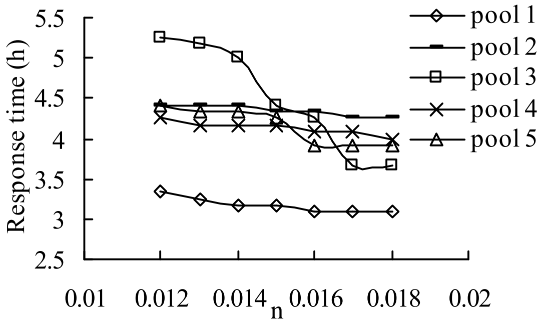

Figure 4. Canal response time when discharge decreases

The simulation results show:

(1) The discharge feed-forward plus water level feedback PID controller has good performance in control of canal water level.

(2) All control performance indicator values of canal operation decrease along with the increase of roughness coefficient, this indicates the larger roughness coefficient is, the better

transient response and steady-state response of canal system are for constant volume method of operation, which means the control performance of canal system is better, moreover, the stable processes of gate discharge and gate opening become better.

(3) Along with the increase of roughness coefficient, the stable time of canal system is shorter, which means the response of canal system to discharge variation is faster.

(4) The stable storage volume increases approximately linearly as the roughness coefficient becomes larger, which means the larger roughness coefficient is, the larger adjustable storage volume is available. The volume of water stored in canal is a function of the roughness coefficient *n*, and don't change along with the discharge of canal for this method. The variation of stable storage volume along with the roughness coefficient satisfies following correlativity in the calculated example: V=6.057*$10^8 n$+3.377*10^6 m^3 (R^2=0.999).

5.3 Canal constant downstream depth operation

The initial water depth at the downstream end of each canal pool is the design value in this method of operation. The same simulation conditions as the canal constant volume operation are adopted. The control performance indicators of canal are computed for 12h simulation period, see Table 5. The response time varies along with the roughness coefficient for each canal pool as shown on Figure 5 and Figure 6. The variation of stable canal storage volume along with the roughness coefficient is shown on Figure 7.

Table 5 Performance indicators when discharge decreases for this operation method

n	*MAE* (%) 0-12h Period		*IAE* (%) 0-12h Period		*StE* (%) 0-12h Period		*IAQ* (m^3/s) 0-12h Period		*IAW* (m) 0-12h Period	
	Maximum	Average	Maximum	Average	Maximum	Average	Maximum	Average	Maximum	Average
0.012	5.03	3.44	2.21	1.40	0.580	0.236	116.61	61.45	1.43	0.87
0.013	4.74	3.25	2.16	1.35	0.658	0.271	115.06	61.55	1.37	0.86
0.014	4.51	3.09	2.11	1.32	0.733	0.308	116.00	62.28	1.36	0.87
0.015	4.31	2.95	2.07	1.28	0.806	0.344	118.41	63.41	1.36	0.89
0.016	4.13	2.83	2.03	1.26	0.876	0.380	120.77	64.60	1.47	0.92
0.017	3.98	2.72	1.99	1.23	0.945	0.416	123.25	65.87	1.62	0.95
0.018	3.84	2.62	1.96	1.21	1.012	0.451	125.85	67.19	1.80	0.99

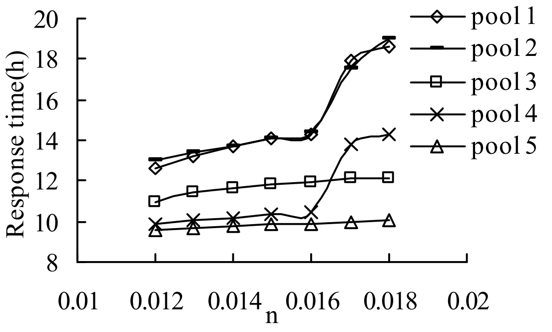

Figure 5 Canal response time when discharge increases

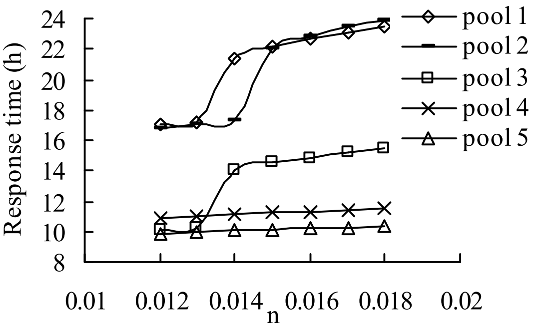

Figure 6 Canal response time when discharge decreases

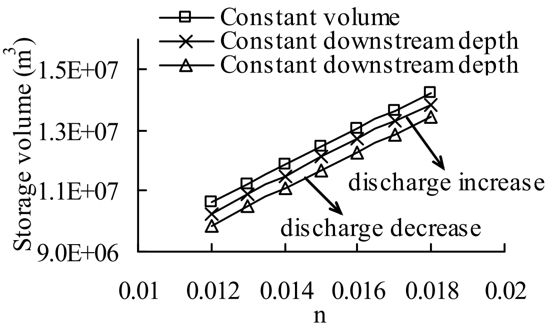

Figure 7 Variation curves of canal stable storage volume along with roughness

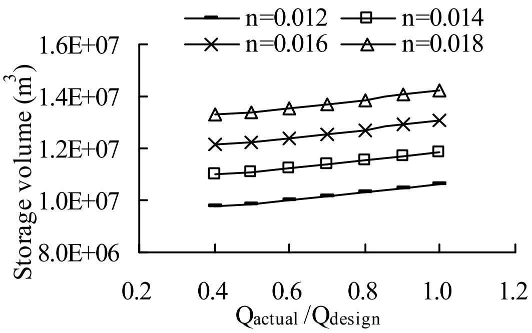

Figure 8 Storge volume for 5 pools as a function of discharge and flow resistance

The simulation results show:

(1) Under the same conditions, the constant volume method of operation is more suitable than the constant downstream depth method of operation for long distance water transfer projects, especially for which lacking on-line storage. Because in constant downstream depth control, the storage change of each pool should be supplied by the headwater (when flow rate increases) or consumed by the downstream pool (when flow rate decreases), the whole canal system can't get a quick response and the stable time turns to be long.

(2) Water level indicators *MAE* and *IAE* of canal operation decrease along with the increase of roughness coefficient, which indicates the larger roughness coefficient is, the better transient response of canal system is. But indicators *StE*, *IAQ* and *IAW* increase along with the increase of roughness coefficient, this indicates the larger roughness coefficient is, the worse steady-state response of canal system is in control of water level, also with the stable processes of gate discharge and gate opening becoming worse in system operation process

(3)Along with the increase of roughness coefficient, the stable time of canal system is longer, which means the response of canal system to discharge variation is slower.

(4) The stable storage volume increases approximately linearly as the roughness coefficient becomes larger. The volume of water stored in canal is a function of both the discharge and the resistance to flow for this method of operation, expressed in terms of roughness coefficient n, as illustrated in Figure 8. The variation of stable storage volume along with the roughness coefficient satisfies following correlativity in the calculated example: V=5.976*$10^8 n$+3.129*10^6 m^3 (R^2=0.999, discharge increase); V=5.893*$10^8 n$+2.834*10^6 m^3 (R^2=0.999, discharge decrease).

6. CONCLUSION

The roughness is one of essential technical parameters in channel designs.The rationality and reliability of roughness coefficient value has extremely important significance to project. Especially regarding China South-to-North Water Transfers Project, its long water delivery line and large discharge, passing through multitudinous buildings along the route and involving complex questions determine that numerous factors have influence on channel roughness coefficient, and the selection of its value has prodigious uncertainty, thus the adoption of roughness coefficient along the channel route is an important question in the analysis of canal system operation control. In this paper, the influencing factors and the uncertainty of roughness coefficient are analysed, an operating simulation mode for multireach serial canal system under gate regulating is established. The discharge feed-forward plus water lever feedback PID controller is adopted. And the performance indicators of canal control are introduced to evaluate the effects of canal operation control. In view of constant volume method of operation and constant downstream depth method of operation which are widely proposed in actual projects, influence on dynamic response process and dynamic performance of canal system is studied according to the variation of roughness coefficient. The results indicate different influence is generated on canal dynamic characteristic and steady-state characteristic as well as the dynamic performance when different canal operation methods are proposed.

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REFERENCES

Clemmens, A. J., Kacerek, T. F., Grawitz, B. and Schuurmans W. (1998), Test cases for canal control algorithms, *Journal of Irrigation and Drainage Engineering*, 124(1), pp.23-30.

Ding,Y., Jia, Y.F. and Sam S. Y. Wang. (2004), Identification of Manning's roughness coefficients in shallow water flows, *Journal of Hydraulic Engineering*, 130(6), pp.501-510.

Fubo Liu, Jan Feyen, and Jean Berlamont. (1994), Downstream control algorithm for irrigation canals, *Journal of Irrigation and Drainage Engineering*, 120(3), pp.468-483.

Liu, J.K. (2003), Advanced PID control and MATLAB simulation. *Publishing House of Electronics Industry*, Beijing.

Ma, J.M. and Shi, Z. (2007), Research on the absolute roughness of the typical channel of the south-to-north water diversion project, *Journal of Hydroelectric Engineering*, 26(5), pp.75-79.

Ramesh, R., Bithin Datta and Murty Bhallamudi, S. et al. (2000), Optimal estimation of roughness in open-channel flows, *Journal of Hydraulic Engineering*, 126(4), pp.299-303.

Sturn Terry W. (2002), Open channel hydraulics, Mac GrawHill.

U. S. Bureau of Reclamation. (1964), Analyses and descriptions of capacity tests in large concrete-lined canals, *Technical Memorandum 661*, Denver, Colo.

Wang, G.Q., Huang, Y.F., Wei, J.H. and Wu, B.S. (2006), Identification of roughness-coefficient value for the channel of the South-to-North Water Transfer (middle line) Project, *South-to-North Water Transfers and Water Science & Technology*, 4(1), pp.8~14.