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Operation Support System of Diversion Valves for Irrigation Pipelines

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Abstract

Pipelines are widely used for the irrigation channels in Japan. The maintenance of the pipeline system is considerd to be easy because the daily water management is simple and the trash does not go into the pipeline. On the other hand, it is difficult to operate the pipeline system: the operator must perform laborious tasks in setting the amount of discharge, since the operation of one valve affects the discharge at the other valves. In this paper, the problems associated with water management will be outlined and the operation support system for the diversion valve by which the operator can determine the optimum value of valve opening will be introduced. The support system which was applied to the irrigation pipeline system in the N-district for the diversion valve operation was found to be useful for systematic valve operation.

Discipline: Irrigation, drainage and reclamation
Additional key words: water management, valve opening

Introduction

Recently, many irrigation channels in Japan have been installed with pipelines, to facilitate the maintenance (since they cannot become clogged with garbage) as well as for daily water management. However, as all the discharge of diversion works is controlled by the operation of only one diversion valve, the operation of the diversion valves in the respective districts is difficult and requires technological development to facilitate the water management of the pipelines. Therefore, the objectives of water management were defined through hydraulic experiments of the pipelines. We developed an operational support system of diversion valves based on a method which enables to calculate the percentage of valve opening for diversion discharge using a personal computer, and which facilitates the water management of the pipelines. In this report, we introduce the results of our studies and the operational support system of diversion valves[1–4)].

In this system, as shown in Plate 1, the operator can perform hydraulic analysis of the pipelines using a personal computer in a dialogue-type format. By calculating both the percentage of valve opening for the diversion discharge and vice versa, the percentage of valve opening can be determined easily. Since

Plate 1. Use of the calculation system

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this system allows the operator to select the valves for opening and closing operations and to make only one operation, the diversion discharge can be determined within 1 h in the morning in districts where it once required up to a whole day to conduct such diversion operations.

In this report, we will introduce the operational support system for diversion valves, and give an

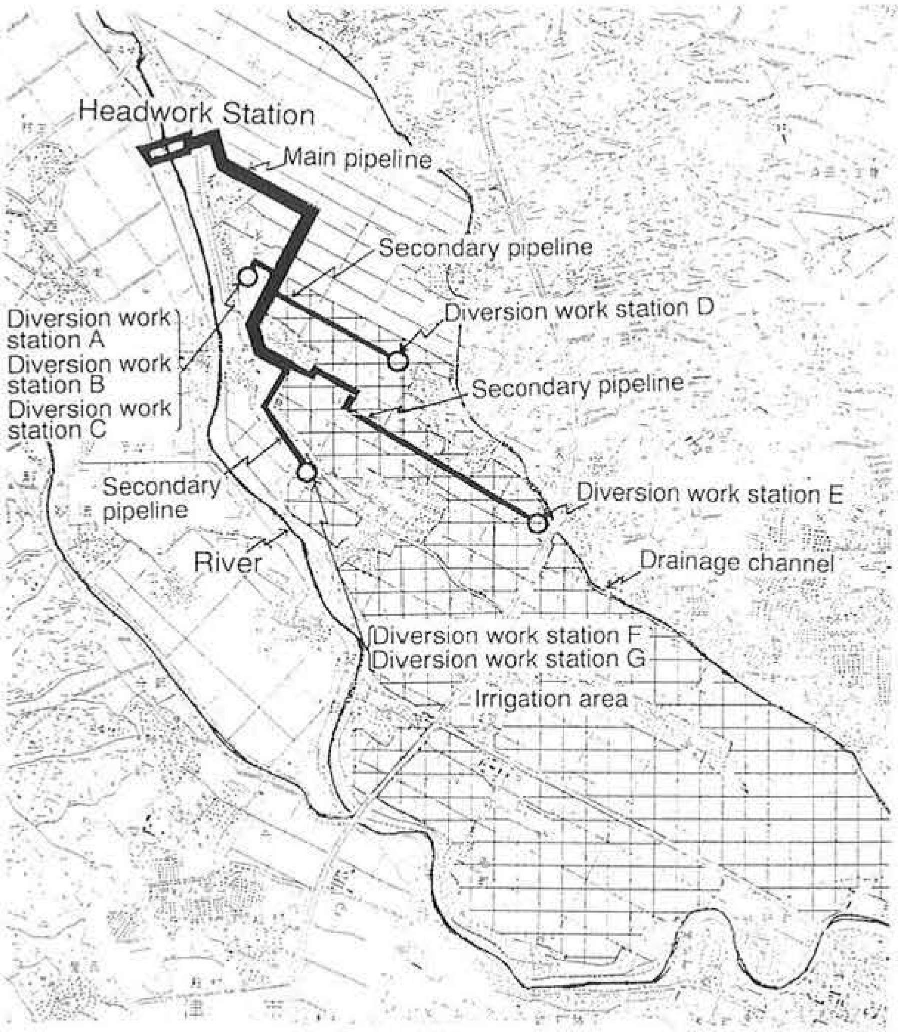

Fig. 1. Outline of irrigation system in N-district

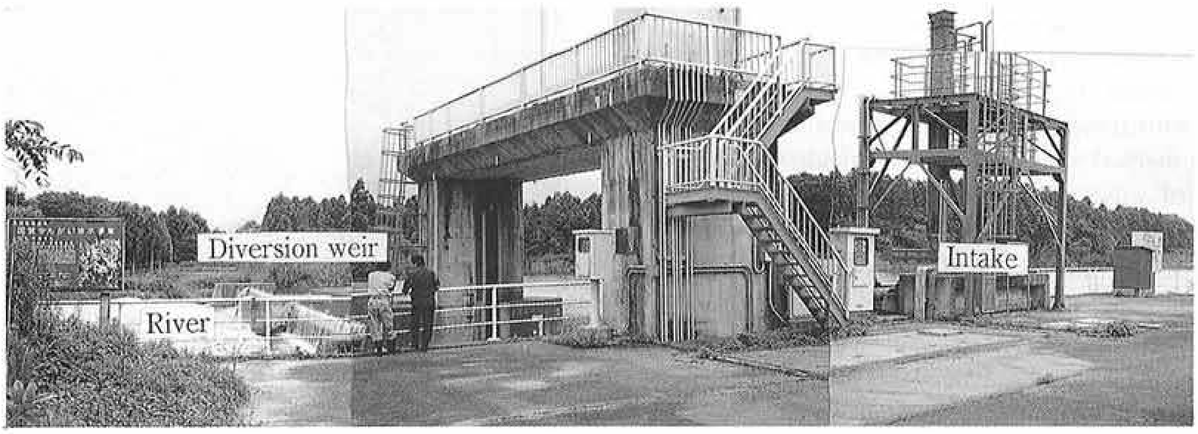

Plate 2. Headworks in N-district

example of practical use in the N-district.

We used steady flow analysis for hydraulic analysis in this system.

Irrigation pipeline system for paddy fields

1) Irrigation facilities in the N-district

In the N-district, as shown in Fig. 1, the water is taken from a headwork station and irrigation is carried out by the pipeline. The headwork station, as shown in Plate 2, controls the water level by a weir set on the river. The diversion system consists of 7 diversion valves which discharge the water into open channels, as shown in Plates 3 and 4. The area of this district covers 280.0 ha and the maximum irrigation discharge is 1.397 m^3/s.

In the pipeline for paddy field irrigation, the operation of each valve for diversion works changes the discharge at each station. For example, in the pipeline of N-district, D diversion work station receives more water while A, B and C stations receive less water than the required demand of water when all

Plate 3. D diversion works A in N-district

Plate 4. D diversion works E in N-district

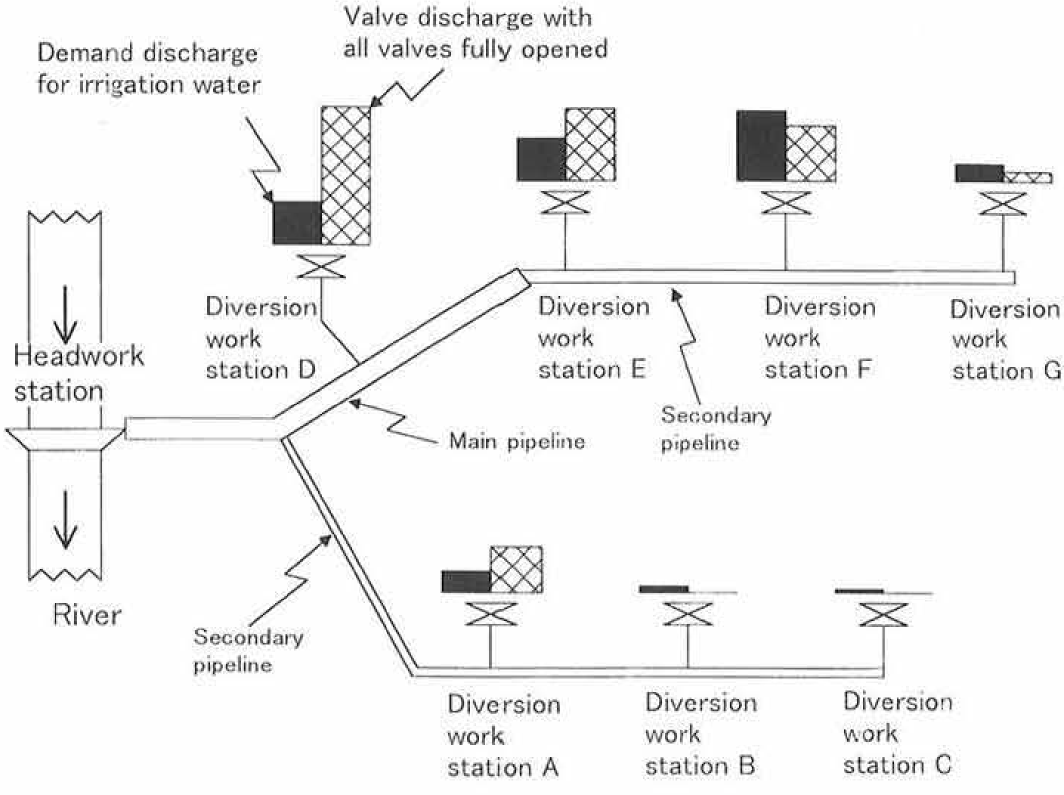

Fig. 2. Demand discharge and diversion discharge when the valve is fully opened

the valves are fully open. The total discharge is larger than the maximum discharge as shown in Fig. 2. Therefore, it is important to develop a method of operation of valve opening.

Operational support system for diversion valves

1) Analysis of steady flow of pipelines

(1) Friction loss of pipe flow (Hazenn-Williams' formula)

Takakuwa's method was used for flow regime analysis of a pipeline. Basic equations of pipe flow consist of successive equations for nodal points and an equation of loss head for the water discharge between the arbitrary nodal points a and b. The water discharge is represented as follows using Hazen-Williams' formula (H-W formula in the following) for the mean velocity in a pipe.

$$Q_{ab} = 0.27853 \cdot C_{ab} \cdot D_{ab}{}^{2.63} \cdot \Delta H_{cab}{}^{0.54} \cdot L_{ab}{}^{-0.54} = K_{ab}(E_a - E_b)^{0.54} \quad \text{......................... (1)}$$

where, Q_{ab} is the discharge (m^3/s), C_{ab} is the coefficient c of flow velocity in the H-W formula, D_{ab} is the pipe diameter (m), L_{ab} is the length of pipe (m). $H_{cab} = E_a - E_b$, in which E_a and E_b are energy levels at the nodal points a and b (m), respectively, $K_{ab} = 0.27853 \cdot C_{ab} \cdot D_{ab}{}^{2.63} \cdot \Delta H_{cab}{}^{0.54} \cdot L_{ab}{}^{-0.54}$

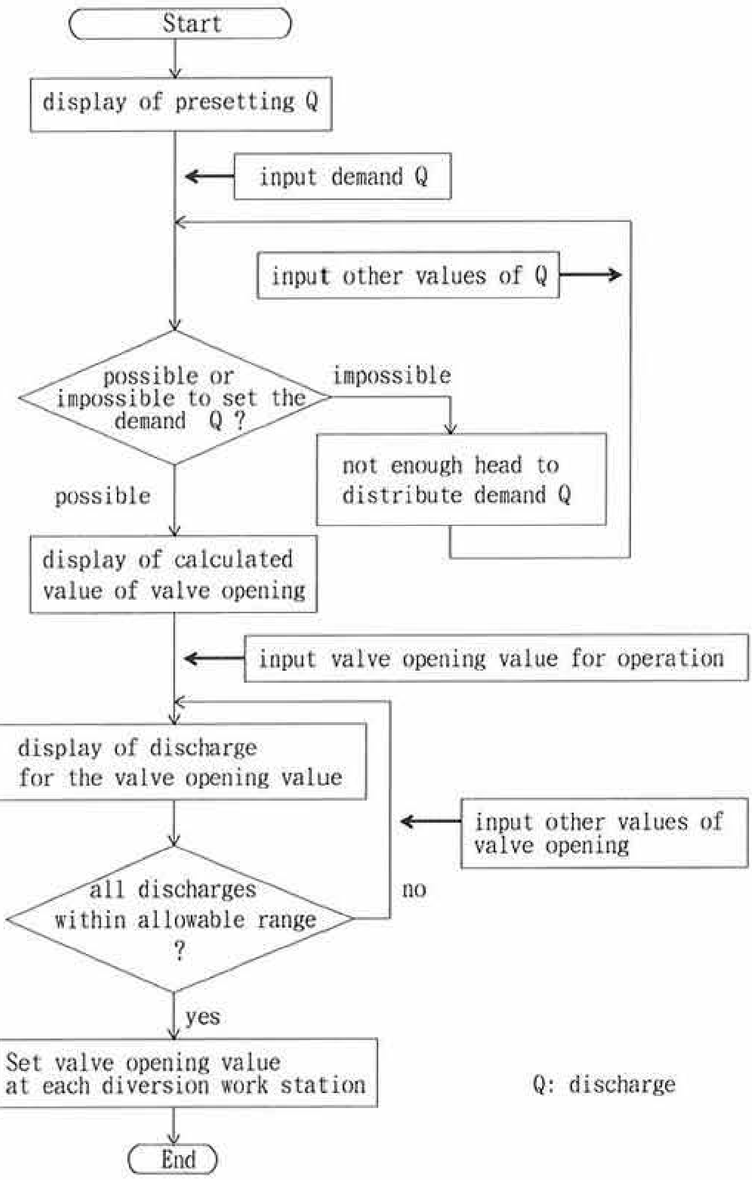

Fig. 3. Flow chart of selection of valve opening value at each diversion work station

and ab represents the distance between the nodal points a and b.

(2) Loss head of bends

As the loss head increases if there are bends between the nodal points a and b in a pipe, the loss head of bends will be calculated according to the following equation in addition to the loss head of the pipe flow.

$$\Delta H_{pab} = f_a \frac{v^2}{2g} \quad \cdots\cdots (2)$$

The relation between the discharge and the loss head of bends is as follows:

$$Q_{ab} = 3.4771 \cdot f_a^{-0.5} \cdot D_{ab}^{2} \cdot \Delta H_{pab}^{0.5} = M_{ab}(E_a - E_b)^{0.5} \quad \cdots\cdots (3)$$

where, f_a is the loss coefficient of bends, g is the acceleration of gravity ($=9.8\ m/s^2$), v is the mean velocity $(A_{ab}/(\pi D_{ab}^2/4))(m/s)$, π is the ratio of circumference, ΔH_{pab} is the loss head of bends $(=E_a - E_b)(m)$, and $M_{ab} = 3.4771 \cdot f_a^{-0.5} \cdot D_{ab}^2$. When there were many bends in a pipe, the value of the loss head including all bends was used.

(3) Loss head of valves

When there were valves between the nodal points a and b in a pipe, the loss head of valves was calculated according to the following equation:

$$\Delta H_{vab} = f_v \frac{v^2}{2g} \quad \cdots\cdots (4)$$

The relation between the discharge and valve loss head is as follows:

$$Q_{ab} = 3.4771 \cdot f_v^{-0.5} \cdot D_{ab}^{2} \cdot \Delta H_{vab}^{0.5} = N_{ab}(E_a - E_b)^{0.5} \quad \cdots\cdots (5)$$

where, f_v is the valve loss coefficient, ΔH_{vab} is the valve loss head $(=E_a - E_b)$, and $N_{ab} = 3.4771 \cdot f_v^{-0.5} D_{ab}^2$.

2) System composition

This system consists of the following 5 programs:

① Input program of diversion discharge (language used: N88BASIC) to input the demand diversion discharge at each diversion work station.

② Calculation program of loss head (language used: FORTRAN) to calculate the loss head of a pipeline for the discharge.

③ Calculation program of valve opening (language used: N88BASIC) to calculate the percentage of valve opening for the diversion discharge.

④ Calculation program of diversion discharge (language used: FORTRAN) to calculate the diversion discharge for valve opening.

⑤ Printing program (language used: N88BASIC)

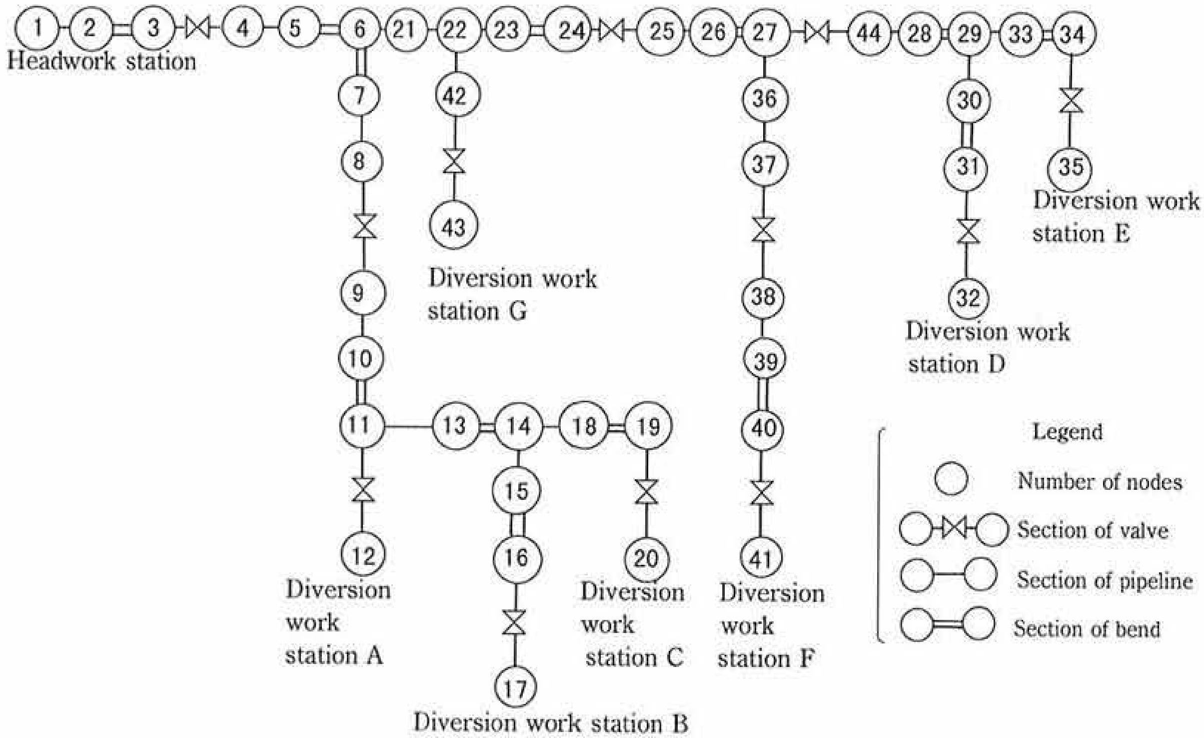

Fig. 4. Systematic diagram of pipeline system in N-district

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      NE*a      NB*b     MAX*c      MAXG*d           *a Total mode number
      44         3       1000       100              *b Pipe number at a node
EMIN                                                 *c Repetitive operations
 0.00001                                             *d Judgement on convergence
NO1*f  NO2*g  D(MM)*h    C*i        L m*j            *f *g Node number
 1      2     1200.    110.000    141.000            *h Diameter of pipe
 2      3     1200.    1.19         0.02             *i Coefficients related to roughness
 3      4     1200.    1.414        0.01             *j Length of pipeline
 4      5     1100.    110.000   1027.624               0.01 mean section of valve
 5      6     1100.    0.609        0.02                0.02 mean section of bend
 ...   ...     ...      ...         ...
 ...   ...     ...      ...         ...
 ...   ...     ...      ...         ...
39     40      600.    0.41660      0.02
40     41      600.    0.14199      0.01
42     43      600.    0.06788      0.01
 0      0       0.       0.         0.
(P(M), M=1, NE)         Discharge m3/s(These values are changed by inputting operation)
      0.0       0.0       0.0       0.0       0.0       0.0       0.0
      0.0       0.0       0.0       0.0     0.0994      0.0       0.0
      0.0       0.0     0.0255      0.0       0.0     0.0091      0.0
      0.0       0.0       0.0       0.0       0.0       0.0       0.0
      0.0       0.0       0.0     0.1628      0.0       0.0     0.0354
      0.0       0.0       0.0       0.0       0.0     0.2883      0.0
   0.1530       0.0
(EL(M), M=1, NE)        Initial values of energy head (m)
   17.800     17.77     17.75     17.04     16.71     16.69     16.68
    16.65     16.52     16.49    16.360     16.00     16.00     16.00
     16.0     16.00      16.0    16.000      16.0     16.00     16.00
     16.0      16.0      16.0      16.0      16.0      16.0      16.0
     16.0      16.0      16.0      16.0      16.0      16.0      16.0
     16.0      16.0      16.0      16.0      16.0      16.0      16.0
     16.0      16.0
(BL(M), M=1, N)         Height of outlet of pipe at diversion work stations (m)
   17.800       0.0       0.0       0.0       0.0       0.0       0.0
      0.0       0.0       0.0       0.0    14.479       0.0       0.0
      0.0       0.0    14.926       0.0       0.0    14.941       0.0
      0.0       0.0       0.0       0.0       0.0       0.0       0.0
      0.0       0.0       0.0    13.300       0.0       0.0    13.300
      0.0       0.0       0.0       0.0       0.0     8.700       0.0
   14.420       0.0
(KYOU(M), M=1, NE)      Calculated condition of hydraulic analysis
        2         1         1         1         1         1         1
        1         1         1         1         1         1         1
        1         1         1         1         1         1         1
        1         1         1         1         1         1         1
        1         1         1         1         1         1         1
        1         1         1         1         1         1         1
        1         1
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Fig. 5. Numerical data of pipeline system in N-district

to output the valve opening percentage value and diversion discharge of diversion work stations.

Here, after the operator calls up a system on the personal computer, the diversion valves are opened according to the flow as shown in Fig. 3.

Input is usually performed as follows:

1. First, the water level at the headwork station is input and the demand diversion discharge (diversion discharge divided by the volume of water required by each farmer) is calculated for every diversion work station.

2. If in the diversion work stations the difference between the fixed percentage of valve opening (opening before operation) and the calculated percentage of opening for the demand diversion discharge is large, the operator inputs the opening value closest to the calculated opening value within the limits of the allowable opening and closing operations of valves. If the difference is small, the fixed valve opening value is not changed.

3. The diversion discharge for the valve opening input is calculated by the operator, who decides if the percentage of opening is within the allowable range of the demand diversion discharge. If in some

Headwork station	WEL= 17.8 m				Total Q= 0.910 m³/s				
	Node No.	Preset. Q	Outlet E. L. m	Energy Head m	Effect. Head m	Demand Q m³/s	Input open%	Pre. open%	Cal. open%
Div. work station A	(12):	0.150	14.48	16.46	1.98	0.100	20.00	30.00	20.05
Div. work station B	(17):	0.020	14.93	16.44	1.51	0.020	10.00	10.00	6.93
Div. work station C	(20):	0.010	14.94	16.44	1.50	0.010	10.00	10.00	8.00
Div. work station F	(32):	0.300	13.30	15.07	1.77	0.300	40.00	40.00	37.12
Div. work station G	(35):	0.080	13.30	14.95	1.65	0.080	40.00	40.00	39.41
Div. work station E	(41):	0.200	8.70	13.81	5.11	0.200	15.00	15.00	15.20
Div. work station D	(43):	0.200	14.42	16.50	2.08	0.200	25.00	25.00	24.71

Fig. 6. Calculated values of opening value (computer display)

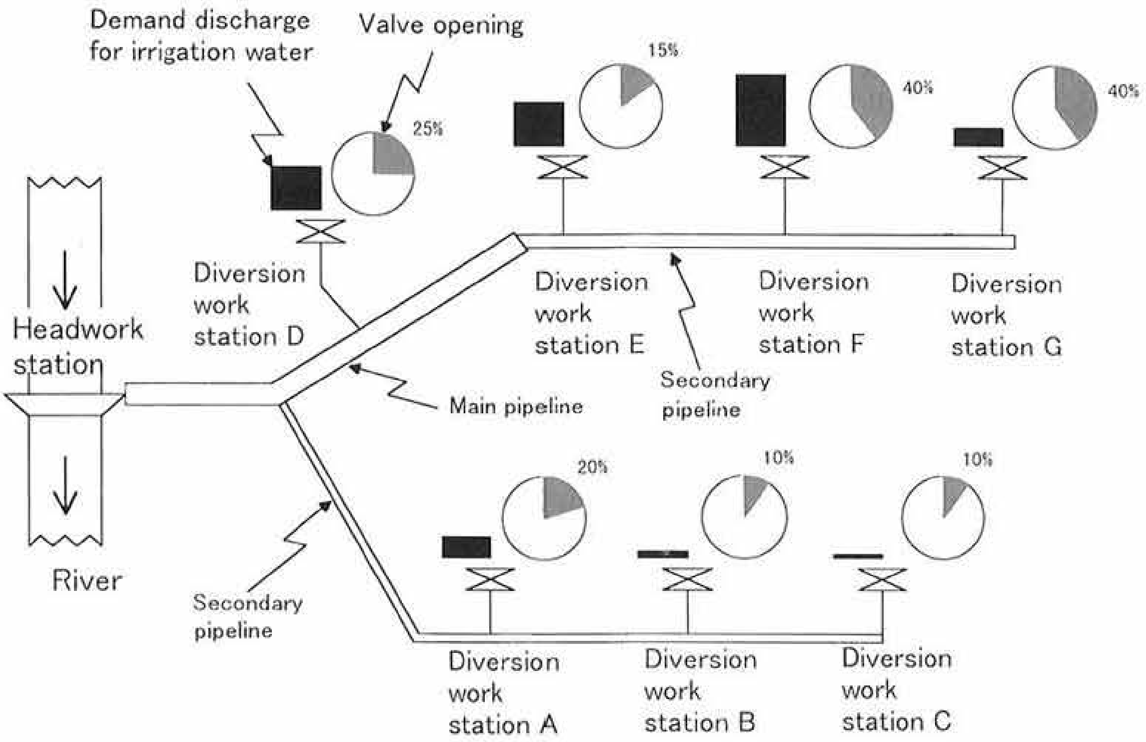

Fig. 7. Demand discharge and calculated value of valve opening

diversion work stations the demand exceeds the allowable value, the percentage of valve opening at such stations decreases by one rank, and then the valve opening value closest to the demand diversion discharge is redetermined.

3) Hydraulic analytical model of the pipeline in the N-district

As the numerical data of the pipeline must be prepared for the pipeline of the N-district to carry out the hydraulic analysis by this system, the systematic diagram shown in Fig. 4 was prepared to divide the pipeline into a pipe channel section, bending loss section, and a valve section. The numerical data were prepared, as shown in Fig. 5, according to the nodal point numbers in this systematic diagram.

4) Method for selecting valve opening value

In this system, when the calculated valve opening value corresponds to the input demand diversion discharge, the calculated results are displayed on the computer screen as shown in Fig. 6. Since the diversion valve should be opened at intervals of about 5%, when the diversion discharge is calculated by the input of the opening within the limits of that fixed, the calculated results will be displayed on the computer screen as shown in Fig. 6, which indicate a value of 15.0% for the calculated opening value of 15.2%. If the diversion discharge is within the allowable range, the valve opening value will be determined and printed. The operator then checks the printed results, selects the valve to change the opening, and performs the opening and closing operations. If at some diversion work station the diversion discharge is greater than the allowable value in the calculations shown in Fig. 7, the opening value of such diversion work stations decreases by one rank, the diversion discharge before and after the change is compared with the demand diversion discharge, the diversion discharge is set close to the demand diversion discharge, and the opening value of the diversion valve is determined.

By such hydraulic analysis of the pipeline, the optimum value of valve opening can be determined for the demand diversion discharge. Then the operator selects the valve and decides the value of valve opening at each diversion work station.

5) Diversion discharge for diversion valve opening value

(1) Determination of the opening value of diversion valves for the demand irrigation discharge

In the N-district, a member of the local water rights committee determines the water volume required by each farmer at each diversion work station every morning, and reports to the operator of each land improvement area. Then, the operator determines the diversion discharge from the water level of the understream of a diversion work station. He opens and closes the diversion valves, and determines the diversion discharge. Consequently, as the outlet discharge is affected by the operation of other diversion valves, the operator must confirm the outlet discharge and control the value of valve opening

Headwork station WEL= 17.8 m

Node No.	Diversion work station	Pre. Q m^3/s	Pre. open. %	Req. open. %	Operate open. %	Opera. Cal. Q m^3/s	Demand Q m^3/s	Rate
12	Div. work station A	0.146	30.0	20.1	20.0	0.097	0.100	0.975
17	Div. work station B	0.027	10.0	6.9	10.0	0.029	0.020	1.474
20	Div. work station C	0.014	10.0	8.0	10.0	0.015	0.010	1.462
32	Div. work station F	0.317	40.0	37.1	40.0	0.322	0.300	1.073
35	Div. work station G	0.077	40.0	39.4	40.0	0.078	0.080	0.974
41	Div. work station E	0.196	15.0	15.2	15.0	0.197	0.200	0.983
43	Div. work station D	0.194	25.0	24.7	25.0	0.198	0.200	0.992
	Total					0.936	0.910	1.029

Fig. 8. Calculated values of diversion discharge for input opening (computer display)

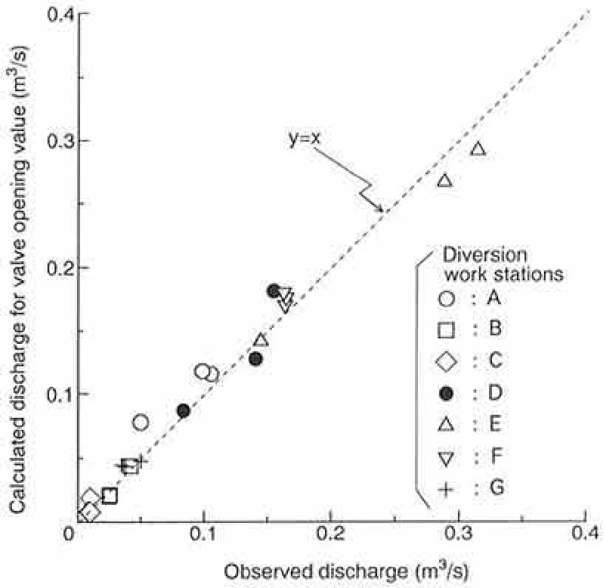

Fig. 9. Comparison of calculated and observed discharge

many times a day.

In the current system, the value of valve opening for the demand diversion discharge is calculated as shown in Fig. 6, and the modified diversion valve is selected according to the value of valve opening calculated on the previous day. The new value of valve opening is input within as many pitch intervals as possible, and the diversion discharge is calculated, as shown in Fig. 7. The computer output is shown in Fig. 8. If the calculated diversion discharge is within the allowable range of the demand diversion discharge, the opening value is derived, and only the valves at the diversion work station whose opening value needs to be changed from the value calculated on the previous day will be opened and/or closed, and the valve opening value will be determined. If the calculated diversion discharge is not within the allowable limit of the demand diversion discharge, it is recalculated by inputting the value of opening which was changed by only one rank of the opening pitch, and the optimum calculated diversion discharge for the demand diversion discharge is selected, to derive the proper opening value.

(2) Observation of diversion discharge

We operated the diversion valves, confirmed that the flow regime was stable for a sufficient time, measured the velocity of flow with an electromagnetic current meter, and then derived the diversion discharge.

When the diversion discharge for the value of valve opening calculated by this system (calculated diversion discharge) was compared with the observed discharge defined by the actual measurement of the flow velocity, it appeared that both were in good agreement, as shown in Fig. 9.

Conclusion

Although there are many irrigation pipelines in Japan, the operation of the diversion valves has been very difficult. Consequently, a system that enables to determine the valve opening value through hydraulic analysis was developed. As a result, the operation of diversion valves in both the experimental pipeline and N-district was facilitated, resulting in the reduction of labor for water management.

As this system can be easily used to simulate pipelines by the substitution of numerical data, it is considered to be suitable for diversion operations.

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