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FUJI WATER DISPATCHING CONTROL SYSTEM

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I. INTRODUCTION

The FUJI's Dispatching Center Control System is composed of (1) Centralized supervisory control system (2) water operating control system (3) Information processing system and (4) Waterworks simulation.

The comprehensive waterworks facilities are being promoted at present for the purpose of coping with the difficulty of securing water sources and reinforcing the waterworks enterprise foundation.

On the other hand, the energy-saving measures must be established as a world-wide problem

In order to solve these problems, the civil engineering equipment, machinery equipment, electrical equipment, and instrumentation equipment sections composing the waterworks facilities plus the waterworks management section must develop and optimum technique to solve them. Since the instrumentation equipment organically connects these waterworks facilities, it plays a very important role, in particular.

FUJI's dispatching center control system is designed as a control system to allow these comprehensive waterworks facilities to function smoothly based on the understanding of the role of the instrumentation equipment. The problems on the instrumentation techniques related to the comprehensive waterworks control are as described below.

1) Since the controlled system is water in a strange water pipe network and it features the close relation to the public welfare, it cannot be experimented easily at site (because no failure is permissible).

2) "What is an optimum value?" cannot always apply to all waterworks enterprises indiscriminately. In other words, an optimum value as viewed from the water source security, energy-saving, and waterworks management differs depending upon waterworks enterprises.

3) In order to solve these problems, various simulation techniques related to the water supply system play a very important role for keeping track of the movement of water in the water supply system and determining the system and control system. It is no exaggeration to say that whether the comprehensive waterworks control system is succeeded or not depends entirely upon these simulation techniques.

4) In order to function the water supply system operation caused by serious shortage of water (interlinking operation of water sources, interlinking operation of water purification plant, operation of distributing reservoir, terminal pressure control, and uniform water supply limitation control), as expected, the software is very important as the water supply operation control system.

5) The information transfer system is a large-scale. Accordingly, the reduction of cost, expansibility, and reliability in the information transfer system are strongly demanded.

6) Since local meters, telemeter slave stations, and motor valves are mounted in manholes and on roads very often, the transmitters, telemeter slave stations and motor valves must be a submergible structure type to cope with the inundation when manholes overflow.

7) The water operating control and information processing (operating information, waterworks management information, and civilian service information) system must be harmonized with each other.

The FUJI's dispatching control system is assembled by taking the above problems into the consideration.

II. CENTRALIZED SUPERVISORY CONTROL SYSTEM

The centralized supervisory control system serves as the hardware composing the FUJI's dispatching center control system, and it consists of (1) host computer system, (2) TM/TC system, and (3) terminal equipment. It employs the digital information processing and control systems. Since recent tendencies of the digital information processing and control systems are closely related to this our system, they will be described below.

In the initial stage of introducing the computer system, the information processing, control functions, etc. were processed by a single computer only to economize the system by centralizing jobs. An increase of the processing quantity due to the centralization has caused the system to be on a large scale as a matter of course, and various disadvantages came to the front as problems to be solved, regarding the operation ease, maintenance ease, reliability, expansibility of the system.

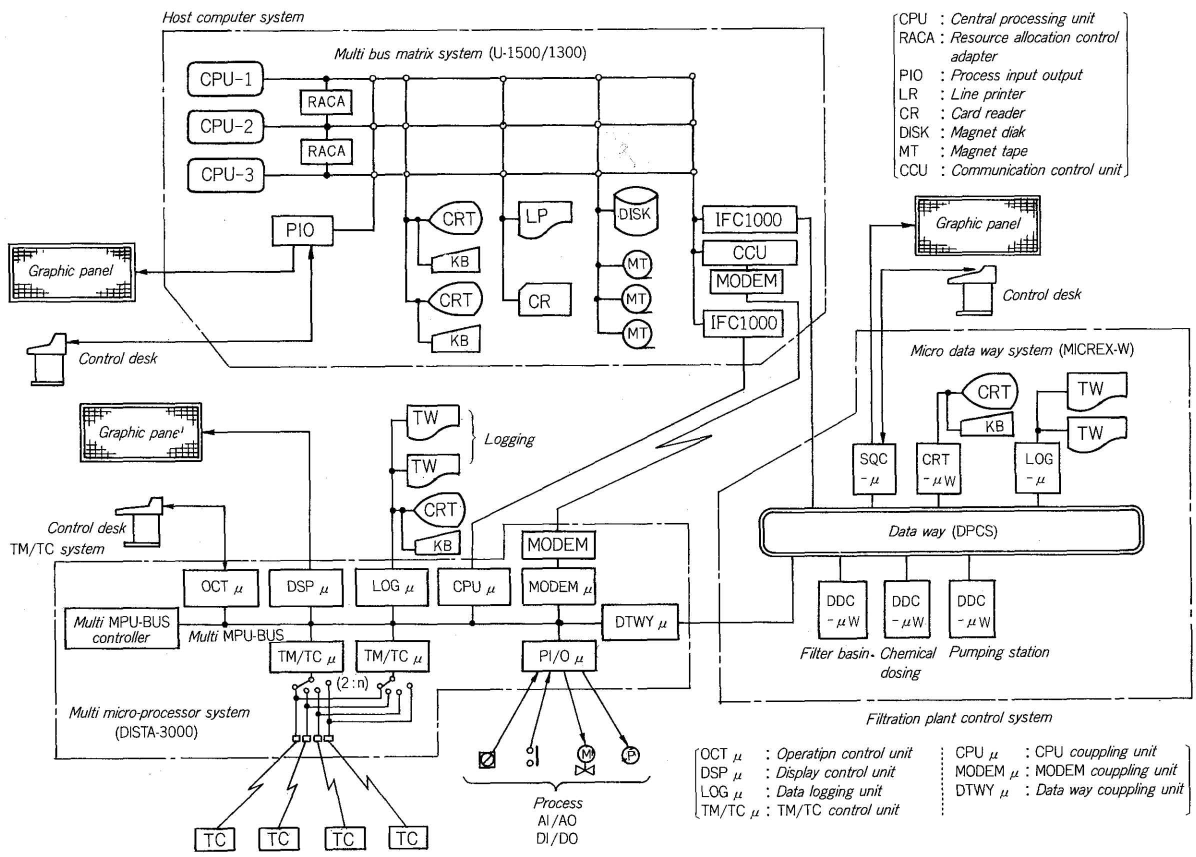


Fig. 1 Outline of dispatching control system

Fortunately, we have encoutered with such an era that we can effectively utilize technical environments called the development of transfer techniques plus semiconductor technique renovation, or, the appearance of microprocessors, in particular. Thus, such decentralized systems that are closely related with each other while attempting economical balance, have been developed to find the first step of solving these problems.

Now, "Supervisory jobs are centralized and control jobs are decentralized" have been popularized as a general concept.

The dispatching center control system must provide very versatile functions from control functions to management functions, and the contents of these functions change from year to year.

Accordingly, the FUJI's dispatching center control system adopts the "Supervisory jobs are centralized and control jobs are decentralized" concept to a large extent for the purpose of realizing a system featuring expansibility of functions, reliability, operation ease, and maintenance ease.

1) Host computer system

Four CPU max. are connectable to one system. Each system executes its exclusive jobs, and if a CPU becomes faulty, the other CPU transfers the jobs of the faulty CPU. In case of figure 1, for example, CPU-1 executes the water operating control, CPU-2 executes man-machine interface control such as CRT, control desk, etc., while CPU-3 executes information processing.

2) TM/TC system (Telemeter Telecontroller system)

The master station of the TM/TC system employs a multi-microprocessor system (DISTA-3000) as shown in *Fig. 1*. This system decentralizes functional units with built-in microcomputer, and these units are connected with each other via a high-speed multi-MPU bus.

Accordingly, the master station of TM/TC allows the 2 : n transfer with the duplicated transmission unit functions.

Fifteen units are connectable to one system.

3) Terminal equipment

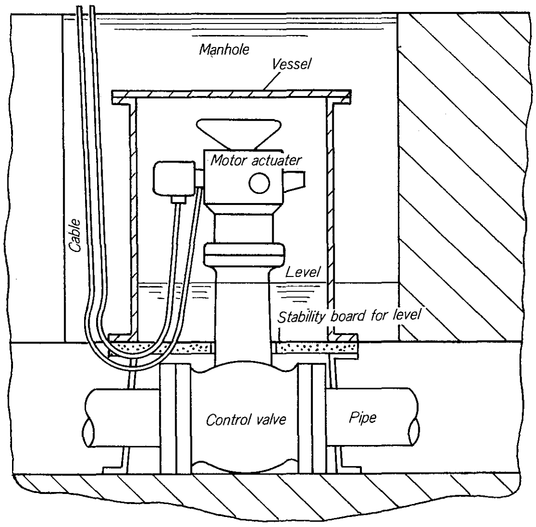
Since the pressure/flow transmitters and motor valves are mounted in manholes in the distributing pipe networks in cities, they must have a submergible structure.

Fig. 2 indicates a submergible motor valve (patent pending) (copper motor valve), featuring a low price and a simple structure.

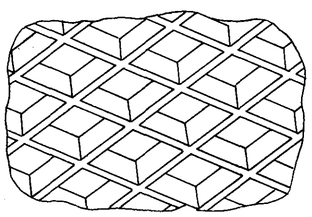
Since the telemeter slave stations are mounted on roads on poles, or in manholes, they must be compact and rigid.

The dimensions of this telemeter (DISTA-200W) slave station are 1050 mm high x 350 mm deep x 490 mm wide.

Fig. 3 indicates its internal composition.



(a) Outside view of copper motor valve



(b) Structure of stability board for level

Fig. 2 Copper motor valve

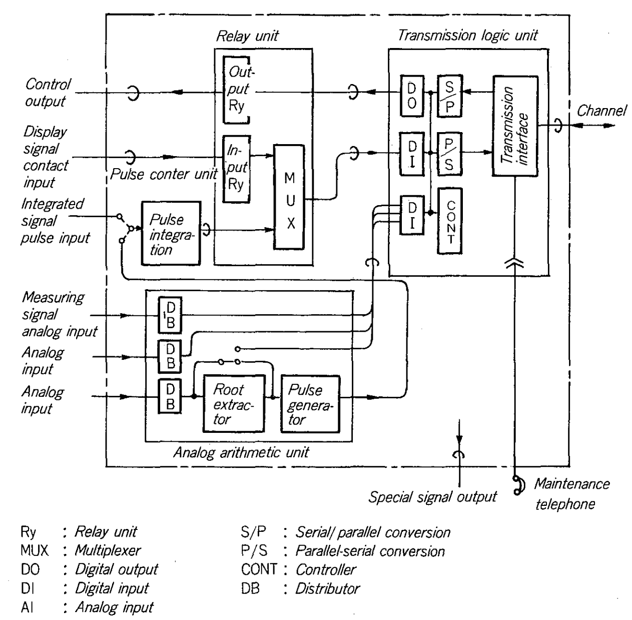


Fig. 3 System configuration in DISTA-200W slave station

III. WATER OPERATING CONTROL SYSTEM

The water operating control system serves as the software to reasonably and effectively utilize water by using all the water intake equipment, water conveyance equipment, water purification equipment, water supply equipment, and water distributing system in the dispatching center control system.

The water shortage is a serious problem. The shortage of (1,500,000,000) ~ (3,200,000,000 m^3) is estimated for water resources of (25,800,000,000 m^3) required in 1985. Under these circumstances, this software (Pipe network pressure control and water quantity dispatching control) contributes to solve this problem by reduction of leak water quantity, prevention of breakage of pipes, uniform water supply control in the dry season, mutual adaptability of water sources and water distributing areas.

On the other hand, the software contributes to solve this problem stabilization of the water receiving plan, energy-saving, reduction of chemicals quantity employed, reduction of fault ratio of equipment by means of distributing reservoir operation control and smoothness of water treatment quantity.

This software comprises the following 6 kinds.

(1) Water source operation method
(2) Water quantity distributing method
(3) Demand forecasting control
(4) Distributing reservoir operation
(5) Piping network state presumption method
(6) Piping network pressure control method

Fig. 4 indicates the mutual relations of the above software.

1. Water source operation method

The purposes of the water source operation lie in executing the effective utilization of water resources by reducing ineffective outflow and also executing programmed water intake so as not to cause the water shortage, even if the rainfall is small.

The water source operation is also executed to enhance these effects by mutual adaptability among plural water sources.

Regarding the dam type water source, the operating method of limiting the water intake will be shown in a small inflow period.

The inflow quantity to a dam and the water intake demand quantity based on demands are previously predicted.

Assume that the dam becomes empty, if water intake is made as demanded in the operation period. Let equation (1) be the object function of the intake limitation.

$$J = \sum_{k=1}^{N} \left\{ Q_D(k) - Q_t(k) \right\}^2 \quad \cdots\cdots\cdots\cdots (1)$$

where, $Q_D(k)$ and $Q_t(k)$: Intake demand quantity and programmed intake quantity of the k-th day.

Then, the restrictive conditions can be expressed by;

$$S(k) = S(k-1) + Q_i(k) - Q_t(k) \quad \cdots\cdots\cdots (2)$$

$$Q_t(k) \leqq Q_D(k) \quad \cdots\cdots\cdots\cdots\cdots\cdots (3)$$

$$S(k) \geqq S_0 \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots (4)$$

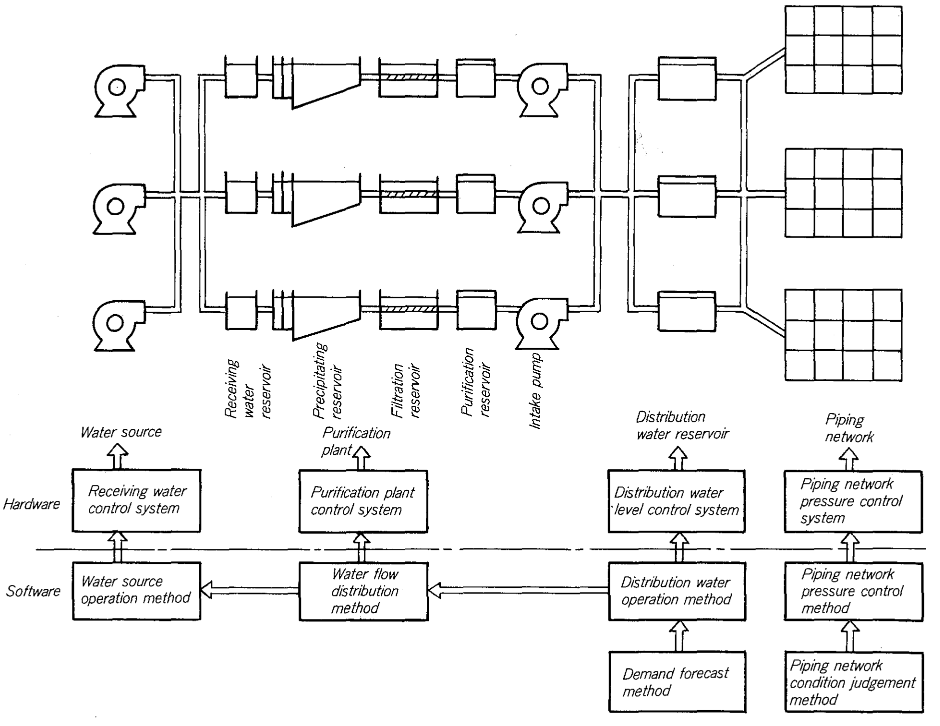


Fig. 4 Water distribution control system

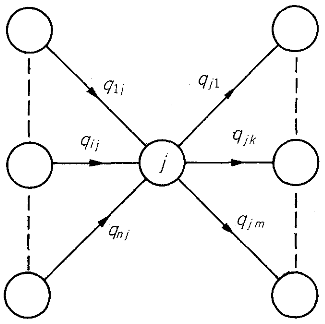


Fig. 5 Flow balance at node j

where, $S(k)$: Storage capacity

So : Lower-limit storage capacity

$Q_i(k)$: Inflow quantity

Thus, the intake quantity schedule with J minimized can be decided by the DP (dynamic programming) method, simply by specifying the storage capacity after N days.

2. Water quantity distributing method

The water quantity is distributed to minimize the required operation charges based on the predict demand quantity in each water distributing district. The restrictive conditions are the intake capacity, purification capacity and conveyance/distributing capacity of each plant.

The restrictive conditions are formularized by using the water intake plant, purification plant, distributing reservoir, pipe junction, etc. as nodes, and also using the channels connecting these nodes as branches. Each node can be expressed by the following equation about the j-th node, or, by the water quantity balance equation.

$$\sum_{i=1}^{n} q_{ij} = \sum_{k=1}^{m} q_{jk} \ (i \neq j, k \neq j) \quad \dots\dots\dots\dots (5)$$

The left side indicates the total of the flow to the j-th node, while the right side indicates the total of the outflow.

Regarding each branch, equation (6) is given for the l-th branch from the upper-limit and lower-limit flow restrictive conditions.

$$q_{l\min} \leqq q_l \leqq q_{l\max} \quad \dots\dots\dots\dots\dots (6)$$

where, $q_{l\min}$ and $q_{l\max}$ are the upper and lower limit quantities of respective q_l values.

Let's obtain q_l $(l = 1 \sim L)$ to minimize the following operation costs under the restrictive conditions of equations (5), (6).

$$J = \sum_{i=1}^{l} C_l \cdot q_l \quad \dots\dots\dots\dots\dots\dots\dots (7)$$

C_l is the intake costs, conveyance and distributing costs, labor costs, etc. per unit flow. This optimization problem can be solved by a linear programming method. The simplex method is its solution.

3. Demand forecasting method

The demand forecasting of the water consumption serves as an input factor for water operation control.

For the water source operation, the long-term (annual, monthly or weekly unit) forecasting is required.

For the water quantity distribution, the short-time forecasting in daily unit is required, while the short-time forecasting in the hourly unit is also required for the distributing reservoir operation. These forecasting methods are necessary for each distributing district.

This paper will describe the forecasting method of the daily water consumption employed for the Kalman filter.

Assume that the predictive equation format is the ARMA (Auto Regressive Moving Average) model calculated from the water consumption results of the past several days and the predictive maximum atmospheric temperature of the day; provided that a day of the week (including public holidays) as a cyclic fluctuating factor takes the form of the coefficient of a day of the week to eliminate possible effects. The coefficient of a day of the week, is obtained from past results, in advance.

$$\hat{X}_k = \sum_{i=1}^{m} a_i \cdot X_{k-i} + b \cdot \theta_k \quad \ldots\ldots\ldots\ldots (8)$$

$$X_{k-i} = Q_{k-i}/S_{k-i} \quad \ldots\ldots\ldots\ldots\ldots\ldots (9)$$

where, Q_{k-i}, S_{k-i} : Water consumption results and coefficient of a day of the week "i" days earlier as counted from the predictive day.

Q_k : Predictive maximum atmospheric temperature on the predictive day

a, b : Coefficients

m : Order number (about 3 ~ 7 usually)

$\hat{X}_k$: Predictive value (Value divided by the coefficient of a day of the week)

In the Kalman filter, a_i and b change from day to day according to a predictive error, and this correction is made according to the following equations.

$$H_k = H_{k\text{-}1} + \sigma^{-2} [X_k - M_k' H_{k\text{-}1}] \cdot P_k \cdot M_k \ldots (10)$$

$$P_k = P_{k\text{-}1} - (\sigma^2 + M_k' \cdot P_{k\text{-}1} \cdot M_k) \cdot P_{k\text{-}1} \cdot M_k \cdot M_k' \cdot P_{k\text{-}1} \quad \ldots\ldots\ldots\ldots (11)$$

where, $H_k' = [a_1, a_2, \ldots, a_m, b]_k \quad \ldots\ldots\ldots\ldots (12)$

$$M_k' = [X_{k\text{-}1}, X_{k\text{-}2}, \ldots, X_{k\text{-}m}, \theta_k] \quad \ldots\ldots\ldots (13)$$

where, σ^2 : Observation error variance of Q_k

P_k : Variance matrix of H_k

4. Distributing reservoir operation method

The water distribution quantity from the distributing reservoir largely fluctuates in a day as shown by an example in *Fig. 6*.

On the other hand, the water supply quantity to the distributing reservoir is required to be as constant as possible.

Accordingly, the distributing reservoir is operated for the purpose of minimizing the adjustment times or smoothening of the inflow quantity under such a restrictive condition as to keep the water level of the distributing reservoir within the upper/lower-limit water level.

This paper will indicates an example of solving the operation method of minimizing the pump power consumption quantity by means of DP method when the distribution water quantity is controlled by the number of pumps.

The schedule of the number of operating pumps is decided by equally dividing the day into M every Δt time.

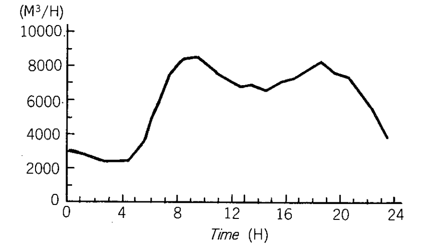


Fig. 6 Example of water distribution

Water level of distributing reservoir $H(k)$ of the k-th time is obtained by;

$$H(k) = H(0) + \Delta t \cdot Q_P/A \cdot \sum_{i=1}^{k} N(i) - \sum_{i=1}^{k} Q_D(i) \quad \ldots\ldots\ldots\ldots (14)$$

where, $H(0)$: Water level of distributing reservoir in the first time range of the day.

A : Distributing reservoir area.

Q : Flow per pump unit.

$N(i), Q_D(i)$: Number of pump units and predictive distribution water quantity of the "i"-th time, respectively.

Since N is an integer, the water level allowable within a range from LWL to HWL in each time range is expressed by finite pieces of points separated from each other every $\Delta t \cdot Q_P/A$.

Assuming that the daily working electric energy be the object function, give the final water level of the day, and the schedule of the number of pumps to minimize the working electric energy is decided according to the DP principle.

5. Piping network condition presumption method

The distributing piping network is connected to a number of general users from the distributing reservoir via large and small piping routes like a mesh.

Accordingly, it is impossible to know all conditions from the limited number of pressure and flow measuring values.

The piping network conditions to be desirably known on the water distributing side are the water supply pressure, water supply flow, leak water quantity, piping fissure, etc. at all positions. The following two items are important.

1) Method of selecting measuring points to estimate the conditions of the entire piping network with high accuracy from the minimized measuring points.
2) Method of estimating the water distributing conditions from the above measuring points.

Now, the method of (1) will be described. Model the distributing water piping network to a processable extent, first. Divide optional positions in the piping network into groups according to the correlational values of pressure fluctuations to the demand disturbances. Select such places that have many branches with considerable flow in each group as pressure measuring points. In order to obtain the correlation of pressure fluctuations, the piping network calculation is executed. The pressure distribution results in the piping network assuming the maximum demand time and minimum demand time, serves as the reference of the correlation of pressure fluctuations.

6. Piping network pressure control method

Now, the piping network pressure control method when the operating points (pump, pressure reducing valve) are mounted at one place only for controlling the pressure of the piping network. This method also applies to plural operating points in the same manner as for one operating point, if only the water distributing districts can be separated into districts corresponding to respective operating points. Find the place where pressure is the lowest by the piping network calculation, and execute the feedback control by measuring pressure, so that the pressure at this position meets the preset minimum guarantee pressure ($1.5 \sim 2\ kg/cm^2$ usually). If pressure at this place cannot be measured directly, execute this control with a pressure estimated from conditions. This is called presumption terminal pressure constant control. When the piping network is operated by plural operating points, the linearized piping network equation is expressed as follows.

$$A \cdot x = q + B \cdot u \quad \dots\dots\dots\dots\dots\dots \quad (15)$$

where, x, u, q : Dynamic water head at node, manipulated variable, and flow vector at demand point, respectively.

A, B : Coefficient matrix.

Determine set value x_s of x from the purposes of stable water supply and reduction of leak water quantity, and obtain the object function as follows.

$$J = (x - x_s)' \cdot w \cdot (x - x_s) \quad \dots\dots\dots\dots\dots \quad (16)$$

where, W : Weight

Since the piping route characteristic is non-linear, A and B become a function of x and u. Accordingly, x to

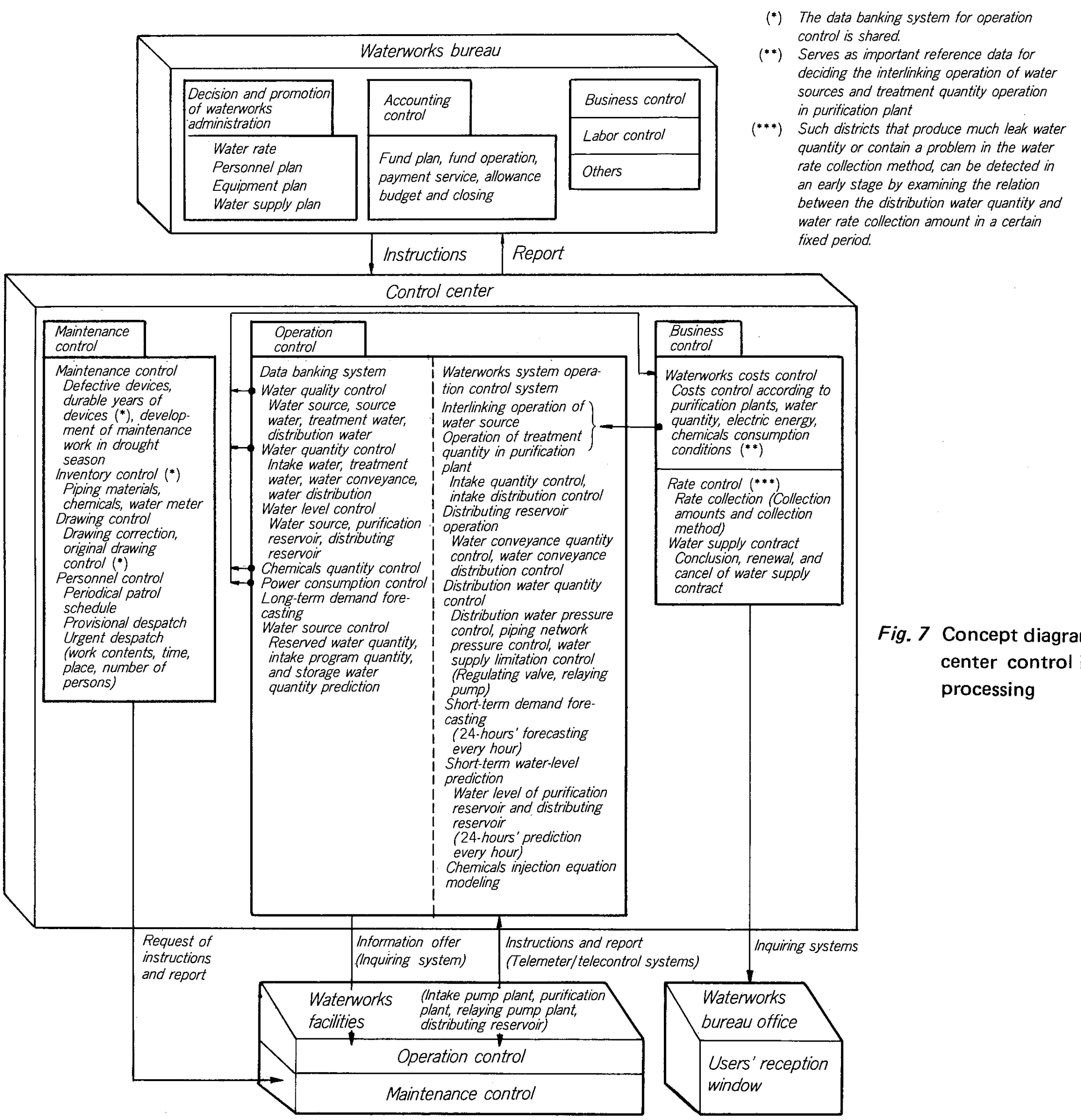


Fig. 7 **Concept diagram of dispatching center control information processing**

minimize J can be obtained by recurrent calculations.

IV. INFORMATION PROCESSING SYSTEM

The information processing system in the FUJI's dispatching center control system intends to contribute to the efficiency of the management in waterworks service by effectively utilizing various data on water operation being collected in the control center.

The information processing in conventional waterworks system was executed to offer data directly to those peoples who are engaged in the system. On the other hand, FUJI's information processing range is expanded to the maintenance control, business control, and management control, and its concept diagram is shown in *Fig. 7*.

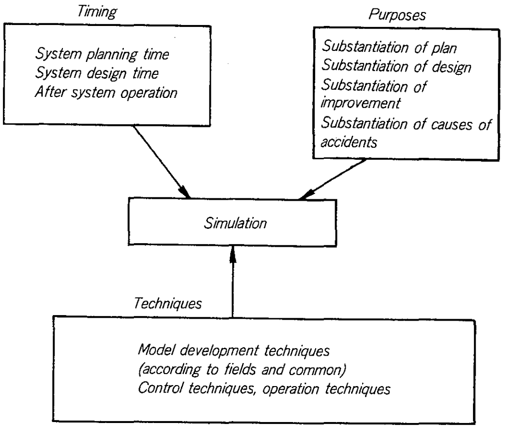


Fig. 8 Timing, purposs and techniques for simulation

V. WATERWORKS SIMULATION

The simulation is defined as a system for executing the optimum design of the equipment or system by creating its mathematical model and assembling this model into a computer to analyze the equipment or system while executing the same behaviour as that of the actual equipment or system in the computer.

The dispatching center control system treats such waterworks systems that are related to each other complicatedly in a wide area, as controlled systems.

Accordingly, this simulation is indispensable for determining the locations of the pressure detection points and pressure control points in the pressure control system design in the piping network. In the system design stage, detailed simulation is executed for the entire system to individual systems for the purpose of confirming the system performance previously, examining the design of the operation and control systems, establishing the early-stage starting of actual running of the system, and also improving the reliability of the entire system.

This simulation method can obtain a number of results in system troubleshooting, extension plan, modification plan, etc. even after system operation.

Accordingly, the model development technique, control technique, operation technique, and actual data analytical technique are accumulated as simulation techniques.

The model development technique comprises individual techniques according to the system and equipment fields (waterworks, sewerage, iron and steel manufacturing, electric power, etc.) and common techniques such as the utilization technique of physical community and similarity, numerical analysis technique, and computer utilization technique. As the control and operation techniques, the detailed simulation techniques of the control and operation systems of actual system are particularly useful. On the other hand, the organical utilization technique has been developed for putting the control theory and OR theory into practical use. In the simulation after system operation, analytical techniques based on actual data are unavoidably necessary. These techniques comprise the statistical processing technique, multi-variable analytical technique, identification technique, etc. See *Fig. 8*.

The dispatching center control system utilizes these simulation techniques for water intake and conveyance plan, water conveyance capacity of water conveyance channels, water level control, water pressure control of feed water pressure pipes, examination of water flow including the processing capacity from the purification plant to the distributing reservoir, predictive control of injection quantities of chemicals such as flocculent, chlorine, etc., flow distribution in distributing piping network, demand forecasting of water, distributing reservoir operation plan, and other optimum design in the operation and control of plants, starting with the design stage. The simulation techniques are also versatile, such as calculation of flow velocity distribution and diffusion by FEM based in the Navier-Stokes equation, characteristic equation technique, calculation of non-steady-state flow of piping channels and open channels by leapfrog technique, network techniques, calculation of piping network by LP, time series analysis, calculation of self-regression and multi-regression by multivariables analysis, and others. The packaged simulation software is variously available now.

VI. WATER CONVEYANCE AND DISTRIBUTION CONTROL IN KOBE, JAPAN

1. Introduction

Kobe is a long and slender city, fronting the Seto inland sea with the Rokko mountains at the back, and it features an abrupt topographic profile having a noticeable altitude difference.

The Kobe's waterworks system supplies water to general households and enterprises as distributing terminals via long and slender water conveyance tunnels and distributing reservoirs by mainly receiving the intake water from the Hanshin bulk water supply corporation and its self-water sources located at several places in the city.

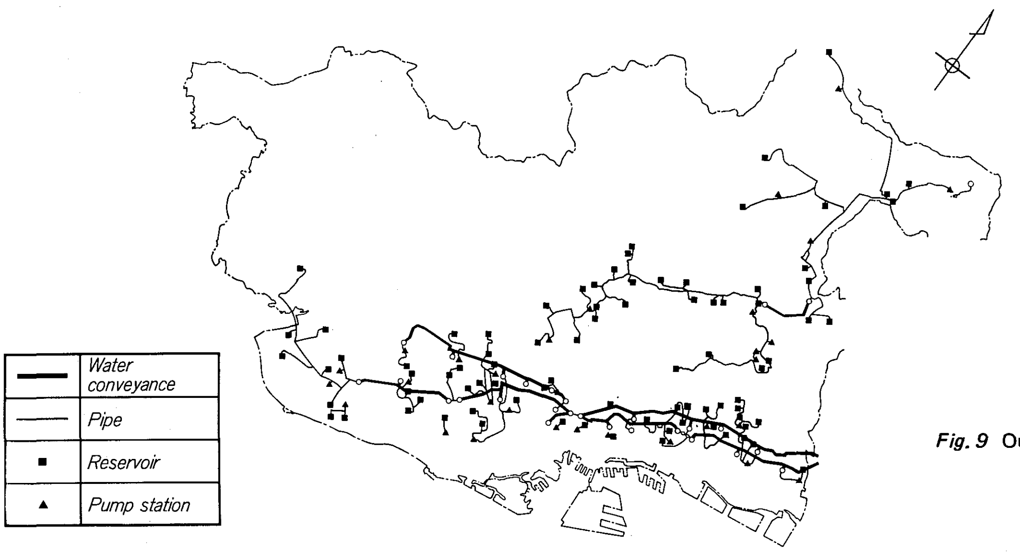


Fig. 9 Outline of process flow line

The inflow to each distributing reservoir and water conveyance tunnels, and also the receiving water from the Hanshin bulk water supply corporation are decided according to fluctuations of the water consumption.

But, Kobe has more than 80 distributing reservoirs, and the time lag in water transportation through the water conveyance tunnels from the Hanshin bulk water supply corporation to terminal distributing reservoirs amounts more than 10 hours. Therefore, these problem are a very complicated control system.

FUJI Electric Co. recently delivered a water conveyance and distribution control system to Kobe city. This system models these comprehensive waterworks facilities to predict the water consumption of the next day, and plans the water distribution to distributing reservoirs and tunnels so as to decide the intake water quantity from the Hanshin bulk water supply corporation on the next day.

2. Outline of water conveyance and distribution control system

Fig. 9 indicates the water system diagram of this system.

The water conveyance systems comprise the Hokushin system to which water is sent from the Sengari purification plant, and the city system plus Seishin system to which water is sent from the Hanshin bulk water supply corporation via tunnels. The central control center is located in the Okuhirano purification plant and connected to each slave station by means of telemetering telecontroller to execute systematic control of the entire facilities of the waterworks system. The water conveyance control system is arithmetically operated by a large type computer in the control center to analyze instrumentation data sent from each slave station every hours so as to execute the demand forecasting and operating instructions of each plant.

The water distribution control system is a part of the systematic control system and classified as follows.

Systematic control system
- *Operating system*
- *Application system*
  - *Data transfer system*
  - *Graphic display processing system*
  - *Magnetic processing system*
  - *Various daily reports and slips creation system*
  - *Alarm processing system*
  - *Water conveyance and distribution control system*
    - *Monthly receiving water plan program*
    - *Annual receiving water adjusting program*
    - *Water conveyance control plan arithmetic program*
    - *Water conveyance control testing arithmetic program*
    - *Intake water quantity distribution arithmetic program*
    - *Plan change arithmetic program*

Fig. 10 Configuration of systematic control system

1) Monthly intake water planning program

This program predicts the monthly receiving water plan from the Hanshin bulk water supply corporation of the planning fiscal year and produces the operation plan of the self-water sources to satisfy the water distribution predictive quantity of the entire city.

2) Annual receiving water adjusting program

This program adjusts the water quantity from the Hanshin bulk water supply corporation several days earlier than the last day of the fiscal year to meet the annual receiving water quantity and contract receiving water quantity from the Hanshin bulk water supply corporation at the last day of the fiscal year (the end of February), and then decides the daily receiving water quantity from the Hanshin bulk water supply corporation.

3) Water conveyance control plan arithmetic program

This program starts arithmetic operation at P.M. 16 everyday to predict the daily water conveyance quantity and its hourly quantity in each water distribution area and the entire city, and creates an intake plan of each plant. It also decides the receiving water quantity from the Hanshin bulk water supply corporation based on the plan this produced.

4) Water conveyance control testing arithmetic program

This program starts arithmetic operation every hours to test planning arithmetic operation results based on results data inputted every hours, and corrects the intake plan, as required. It also corrects the demand forecasting at the planning time for an error, if any.

5) Receiving water quantity distribution arithmetic program

This program starts when the receiving water quantity from the Hanshin bulk water supply corporation or self-water source was limited due to a certain reason, and calculates the allowable quantity of each distributing reservoir and regulating reservoir according to the predetermined sequence to change the plan. It is used when a fault occurs or when the year-end adjustment is made.

6) Plan change arithmetic program

This program serves as an operator starting system using a graphic display as a main component. It provides the dialogic function of operator and control arithmetic operation for a plan change by the operator's decision or simulation.

3. Water demand forecasting technique

The demand forecasting is done for the distribution water quantity from each distributing reservoir and direct distributing water quantity from the tunnels, and the daily quantity is calculated by using a regression equation, while the hourly quantity is calculated by using the water distributing accumulation ratio.

1) Demand forecasting by regression equation

$$Q^* = (1 + \sum_i a_i x_i) \times (1 + \sum_j a_j x_j) \times Q \quad \ldots\ldots (17)$$

where Q^* : Predictive value

Q : Daily quantity on the day before the predictive day

x_i, x_j : Weather, temperature, holiday and other results data

a : Predictive coefficient

$i = 1, 2, \ldots 4, \; j = 5, \ldots 10$

2) Demand forecasting by water distribution accumulation ratio

$$SQ_i = r_i \times Q \quad i = 1, 2, \ldots, 24 \quad \ldots\ldots\ldots (18)$$

where, SQ_i : Sum of hourly quantity up to "i" hours

r_i : Water distribution accumulation ratio at i

Q : Daily water distributing quantity

Predictive coefficients and water distribution accumulation ratio were obtained by the regression analysis using past 3 years' results data.

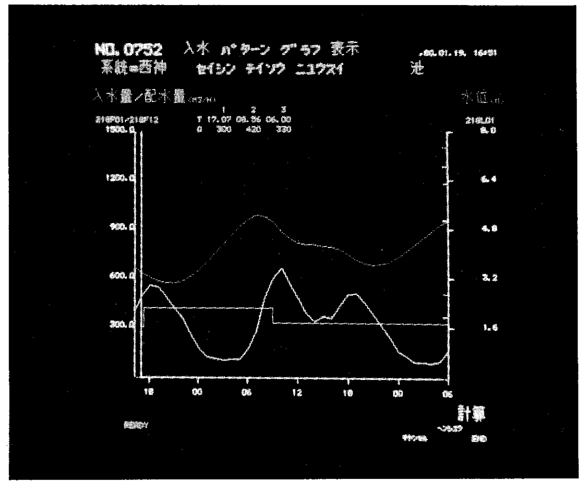


Fig. 11 CRT display of inlet schedule for reservoir

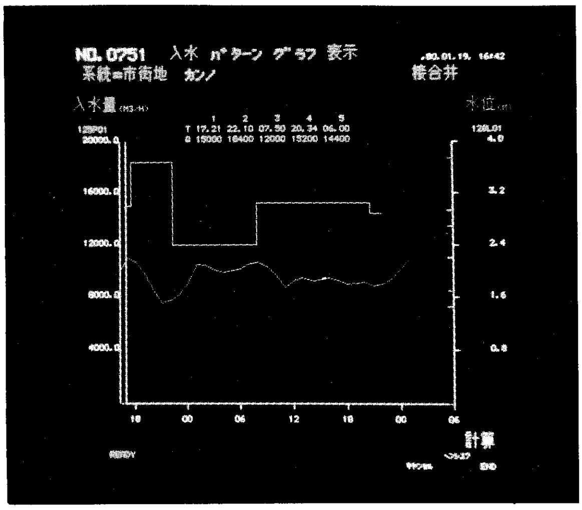


Fig. 12 CRT display of inlet schedule for conveyance tunnel

4. Intake plan of facilities

The intake plan starts with the distributing reservoir at the farest downstream, while taking the water flow and time delay into consideration, and advances toward the upstream facilities sequentially so as to finally decide the intake quantity from the Hanshin bulk water supply corporation. The controlled system facilities of the intake plan are as described below, and the flow is set.

1) Intake valve of distributing reservoir — 19 places
2) Intake water pump of distributing reservoir — 6 places
3) Water conveyance quantity of self-water source — 8 places
4) Connecting pipe valve of tunnel — 10 places
5) The receiving quantity from the Hanshin bulk water supply corporation — 1 place

In addition, local automatic pumps are mounted at 40 places in distributing reservoirs for simulation of the local automatic movement. The intake plan was designed based on the following basic principle.

The control results is reflected by CRT likely outputs of *Fig. 11* and *Fig. 12*.

1) The operating times of the intake valves are minimized, and the intake water should be kept constant as much as possible.
2) The control aimed water level is set in the distributing reservoir, and the distributing reservoir is adjusted to the preset water level at A.M. 6.
3) The water level prediction is done to adjust the water level with the range from the upper-limit to the lower-limit.
4) The surplus quantity is calculated to execute the limited distribution when a fault occurs, while taking the distribution balance with other distributing reservoirs.
5) In the tunnels, the water level is predicted by using the residual storage quantity calculated from the uniform-flow water depth and dynamic water head, and the intake plan is made with a time lag taken into account.

Fig. 11 indicates CRT display of inflow schedual for reservoir. These curves are water distributing quantity (lower curve), level (upper curve) and plan inflow. *Fig. 12* indicates CRT display of receiving quantity from Hanshin bulk water supply corporation.

5. Effect of water conveyance control system

The represented effect of water conveyance and distribution control indicates as described below. The water conveyance control system permits collectively monitoring the water distribution and conveyance conditions of the entire waterworks system.

The intake for more than 80 distributing reservoirs and 10 tunnels and the receiving water quantity from the Hanshin bulk water supply corporation are being planned for today and tomorrow.

In addition, an effect due to a change of the intake plan in respective distributing reservoirs is quickly noticeable.

VII. EXAMPLE OF DISTRIBUTING RESERVOIR OPERATION METHOD IN IZUMI-OHTSU CITY, JAPAN

1. Introduction

Izumi-ohtsu city having a population of about 70,000 is located in the suburbs of Ohsaka, and its maximum daily water consumption is 47,000 tons. Water is supplied from Ohsaka prefectural bulk water supply corporation by 57%, Senhoku bulk water sources (wells, Takatsu river) by 20%. This city cannot expect an increase of self-water sources in the future due to the difficulty of security of the land required, underground water control, and shortage of water in rivers in summer, etc.

Fortunately, since its piping network is wellarranged and its altitude difference is as small as 10 m to facilitate the water distributing pressure control, this city has coped with an increase of demands by effective utilization of existing small-capacity distributing reservoirs being scattered in the city and also aimed at the energy-saving, rationalization, and stabilization of receiving water.

2. Purpose and operation method

The following purposes were set to solve problems.

1) Since small distributing reservoirs are scattered at several places in the city, it is difficult to systematically control them by manpower. Accordingly, a computer-control system is introduced.

The effective capacity of these distributing reservoirs is attempted to increase by high-efficiency operation of each distributing reservoir (each distributing reservoir is operated to the maximum extent), so that these distributing reservoirs permit satisfying a demand increase to a certain extent, and also they have an allowance against an abrupt change of load under the present circumstances of the

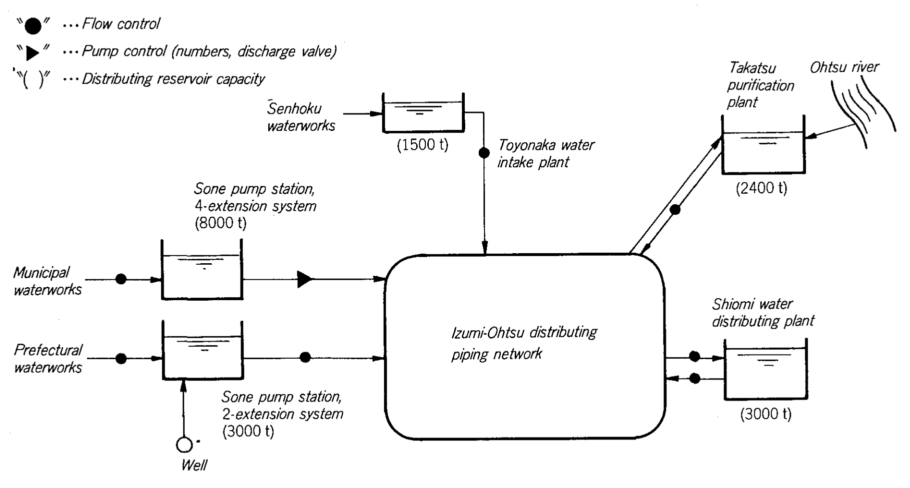
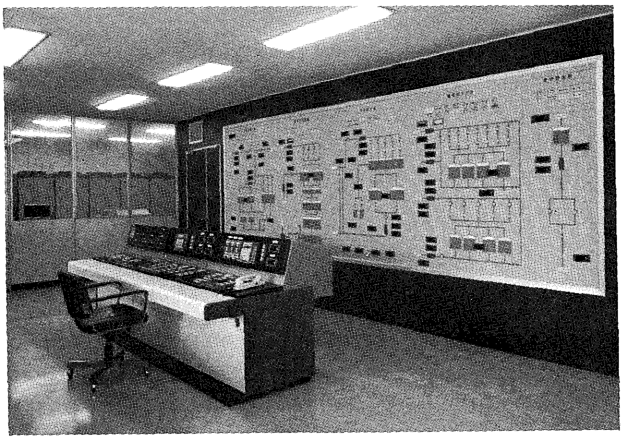


Fig. 13 Concept diagram of plant



equipment.

2) Electric energy is planned to be economized.

3) Water intake from the prefectural waterworks and Senshoku waterworks is placed to be close to a certain flow.

4) The distributing reservoirs are planned to be unattended with rationalized daily report service.

In order to accomplish the above purposes, the following techniques were employed. The water distributing pressure was controlled to keep constant in the Sone pump station and 4-extension system distributing reservoir, and other distributing reservoirs were flow-controlled for high-efficiency operation to meet respective circumstances of these distributing reservoirs. (The flow is controlled, irrespective of the water distributing pressure in the city, but it affects the 4-extension system through piping.)

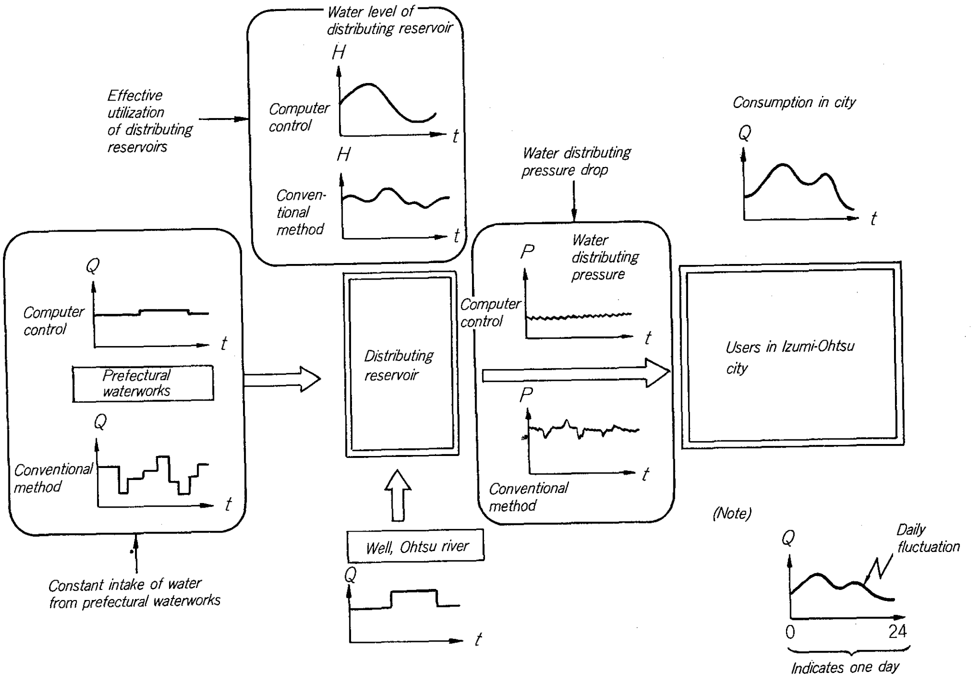


Fig. 15 **Concept diagram of water receiving and distributing network**

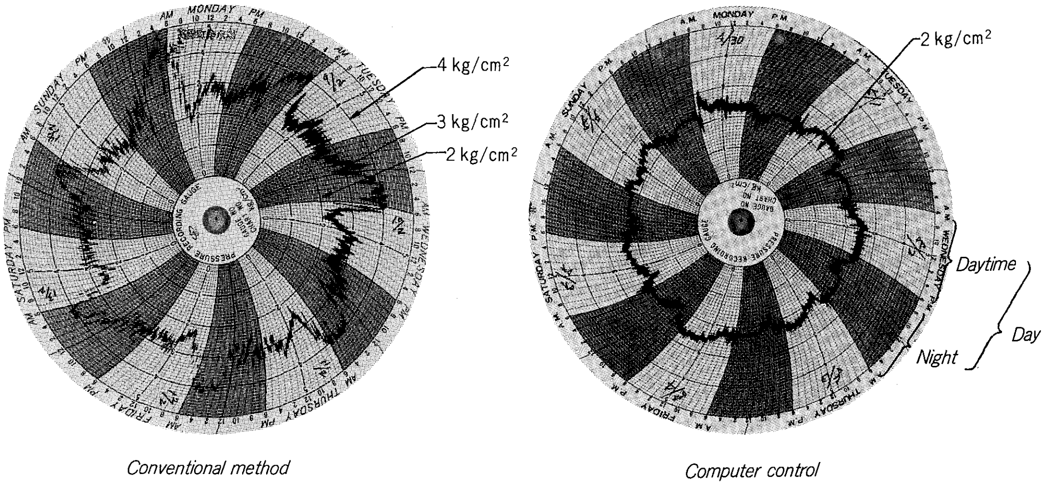


Fig. 16 **Comporison of distributing terminal pressure in city**

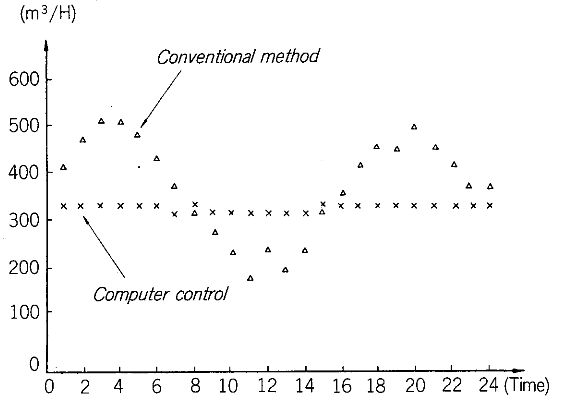


Fig. 17 **Prefectural waterworks intake pattern (4-extension system intake)**

The water level transfer to each distributing reservoir was made at the same time to economize electric power.

The Sone pump station and 4-extension system execute the water distributing pressure constant control with high accuracy by means of controlling the number of pump units as well as by control motor valves. (The control motor valves are employed with an average opening larger than that of conventional ones.)

3. Effect

The distributing reservoir operation by introducing the computer system has resulted as follows.

1) An effective capacity of about 2000 tons was increased by high-efficiency utilization of small distributing reservoirs. This may be considered to be equal to the extension of a distributing reservoir having equivalent capacity.

2) The power consumption was economized by about 30%. *Fig. 16* indicates a change of the water distributing pressure as a factor of the economization of power concumption.

As shown in this figure, the peak value lowers without a pressure difference between the daytime value and the night value. The distributing pressure is more or less contrary between the daytime and night, as compared with conventional circumstances. The average distributing pressure was reduced by 1 kg/cm^2.

3) The fluctuation of inflow from Ohsaka city waterworks is become constantly likely *Fig. 17.*

4) No person of operating reservoir (Shiome reservoir) is possible. Daily operation is become effectively by making a daily report by computer system.

Furthermore, it can be become to find the leak of pipe network by averaging of downstream pressure and to establish effective ratio at 90% or so.