CHAPTER 81

THE OBITSUI RIVER WATER SCHEME AND IT'S SALINITY PROBLEMS

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ABSTRACT

In this paper, the authors describe the salinity problems and their solutions which were encountered in the Obitsui River Water Scheme. The salinity problems in this water scheme are caused by differnt origins; The one is seepage of the sea water through the earth embankment, and the other is the diffusion of the saline water from the reservoir bed.

Laboratory experiments and field observations were performed to confirm the detailed design of the reservoir.

It was found that the salinity concentration of the reservoir water could be controlled less than 500ppm in weight, when the earth embankment of 1,000m width was released.

The another way of salinity control studied by the authors was the recharging channel. At the present stage of studies, the recharging channel is considered to be favourable.

Finally, the wind effect on the interfacial mixing of the salt and fresh water in a reservoir was studied. An approximate theory to calculate the mixing rate of the salt water was derived from the field observations.

GENERAL SCOPE OF THE OBITSU RIVER WATER SCHEME

In the year 1964 industrial water amounting to 38,600 million tons was used in Japan. According to the statistical estimation made by the government, the total demand for industrial water in 1968 will increase to 53,400 million tons.

Development of new plans to utilize the river water more effectively is requested by the rapidly increasing demands for industrial water. In this country, it is unlikely to increase the use of ground water because of the land subsidence due to soil consolidation. A plan of constructing reservoir on the seashore near a river mouth would be one of the favorable ways of the solution, since it has few troubles with the existing water rights for agricultural use, in addition to other advantages.

The authors have been engaged in the planning of the Obitsu River Water Scheme in Chiba Pref. since 1963. The Obitsu River runs through the Chiba Pref. and pours into Tokyo Bay. The length and catchment area are 76km and 280km², respectively. The reservoir under planning which supplies 400 thousand tons of fresh water per day has the storage capacity of 26 million tons, and the area and the water depth of the pond are about 3 km^2 and 8 m below M.W.L., respectively. The total length of the embankment to be constructed in the sea area is about 4 km. The schematic plan of the reservoir is shown in Fig. 1a. And a typical example of the soil profiles at the dam site obtained from exploratory borings is shown in Fig. 1b. As shown in Fig. 1b the surface layer at the dam site, which is about 15m thick, is composed of permeable sand.

In confirming details of the plan the authors have encountered various technical problems. In the present paper the authors describe the salinity problems and their solutions in the Obitsu River Water Scheme.

ALLOWABLE SALINITY CONTENTS FOR THE RESERVOIR WATER

The allowable salinity contents of the reservoir water for the present water scheme is 500 ppm in weight. The inflow of the salinity into the reservoir will be occured through the following four ways:

- 1) Overtopping of waves and sprays during heavy storms.
- 2) Intrusion of sea water through gates.
- 3) Seepage of sea water through the enclosing embankment.
- 4) Salinity diffusion from the bottom sand.

The salinity inflow by overtopping waves and sprays and the intrusion of sea water through gates will easily be diminished to a negligible small amount by proper design of structures. And many data would be available for these purposes.

ALLOWABLE SEEPAGE RATE OF SEA WATER THROUGH THE EMBANKMENT

The maximum salinity contents of the reservoir water at the end of the drought season were calculated for several values of seepage rate of sea water through the embankment.

The relation between the volumes of water in the reservoir at time t and t + Δ t is given by (1). $\bigcirc = \bigcirc + \odot A t + \top A t = \bigcirc A t = \frown A t$ (1)

- q : Seepage rate of the sea water through the embankment
- I : Inflow rate from the river

COASTAL ENGINEERING

- 0 : Discharge rate for industrial water
- E : Evaporation rate from the water Surface of the reservoir
- t : Time
- P : Density of the reservoir water
- $S_{\rm S}$: Density of the sea water
- g : Gravitational acceleration

During Δt , the salinity changes from No to Ni. The relation between Ni and No is given by (2).

$$N_{t} = N_{b} + S_{b} S_{s} S_{s} S_{s} \Delta t \times 10^{-6} - \frac{N_{b} + S_{b} S_{s} S_{s} \Delta \Delta t \times 10^{-6}}{S_{s} S_{s} S_{s} \Delta t}$$
(2)
where No : Salinity (weight) at time, t
N1 : Salinity (weight) at time, t + Δ t

So : Salinity concentration of sea water. In the present calculation it is assumed to be 34,400ppm.

Therefore, the salinity concentration of the reservoir water S at time t $\pm \Delta$ t is given by (3)

$$S = (N_i / Q_i sg) \times 10^6$$
⁽³⁾

When Qo and No are given, the variation in the salinity concentration of the reservoir water from the above equations can be obtained from the eq-(2). The calculations were performed for various values of q. The result of calculations are shown in Fig-2.

It was concluded from the calculations that the seepage rate of sea water through the embankment should be controlled less than 800 cc/m-min to keep the salinity concentration of the reservoir water under 500 ppm. However, the above value of seepage rate must be reduced to some extent when the salinity diffusion from the bottom sands in the reservoir is taken into account. The rate of salinity diffusion from the bottom was estimated at about 400 cc/m-min in the sea water seepage equivalent. Therefore, the control of the seepage rate of the sea water through the embankment to be less than 400 cc/m-min was the first problem subjected to the authors.

SEEPAGE OF THE SEA WATER THROUGH THE ENCLOSING EMBANKMENT

MEASUREMENTS OF THE COEFFICIENT OF PERMEABILITY IN SITE

The coefficient of permeability is the essential factor in the calculation of seepage rate. The authors presented a theory for the unsteady pumping test in unconfined aquifer. The theory of Theis-Nomitsu (1935), which is commonly used in practice, is a linearized approximate theory based on the assumption that the depression of the water surface from the initial water table is small enough in comparison with the initial water depth of the aquifer. The authors presented a non-linear solution, which is given by eq.(4) (Miyake, Kishi and Ikeda (1964)) where

$$\begin{aligned} \xi &= \delta \xi, \ + \frac{1}{2} (\delta \xi)^2 + \frac{1}{2} (\delta \xi)^3 \\ \xi_{,} &= \int_{0}^{\infty} (e^{-\xi^2} / \xi) d\xi \end{aligned} \tag{4} \\ \delta &= \frac{1}{2} / 2\pi \xi H^2 \\ \xi_{,} &= 5 / H \\ \xi_{,} &= 5 / H \\ \xi_{,} &= 5 / H \\ \delta_{,} &= \xi H / \lambda \\ S_{,} &$$

The theory of Theis - Nomitsu is the approximation neglecting the second and third terms on the right side of (4). Therefore, it is easily found that the theory of Theis - Nomitsu gives smaller values of coefficient of permeability than the authors' theory. A comparison of the linear theory with the non-linear's one is given in Fig-3.

The values of the coefficient of permeability and the effective porosity obtained from the field tests are 4.0 x 10^{-3} cm/s and 0.04, respectively.

SEEPAGE THROUGH THE EMBANKMENT

Hele-shaw model tests were performed for sand embankments without any artificial barrier ---- clay core, sheet pile, etc. ---- in it. Model embankments of various sections were set in the Hele-shaw model, which consists of two parallel acrilite plates of lcm thickness being set in 0.297cm spacing. In the model 95% glycerin solution was used to simulate the fresh water. For the sea water colored glycerin solution of which the density was adjusted by adding some amounts of sugar was used. Water levels in the sea and reservoir were controlled to simulate the design conditions which were determined from the hydrological data of the year 1942. The schematic arrangement of the Hele-Shaw model is shown in Fig.-4.

It was concluded from the experiments that the embankment of 1,000m width can prevent the intrusion of sea water completely, if the recharging effect of the rainfall is considered. In the present project, a large quantity of sand is dredged from the bottom of the reservoir, so that an enclosing embankment of 1,000m width is not wholly fantastic. However, it is more profitable to reclaim factorial lots from the sea by the dredged sands, if any artificial barrier with reliable water-proofing effect could be found.

WATER PROOFING EFFECT OF THE SHEET PILES

Prevention of the intrusion of the sea water by sheet pile was studied. Laboratory and field experiments were performed. For the laboratory experiments a conc-rete tank of 3m length, 1m width, and 1m depth was used. Several types of sheet pile being common-ly used in this country were set in the tank and two kinds of sand with different values of permeability coefficient were packed on both sides of the sheet pile to obtain the empirical relation between the discharge and the head loss for various sheet piles. For the field tests of the sheet piles several wells framed with sheet pile were dug near the mouth of the Obitsu River. To simulate the conditions of execution, sheet piles were first hammered to make the well frames. The relation between the discharge and the head loss for various sheet pile was investigated.

The fact that the water-proofing effect of sheet piles depends on the permeability and grain size of the surrounding sand as well as the conditions of sheet pile --- shape or type of joint, compactness of joint, etc. was noted.

Results of the laboratory and field tests for the water-proofing effect of sheet piles led the authors to the conclusion that sheet piles tested in the present experiments reduced the seepage rate only by 5 - 25% in comparison with the sand embankment without any artificial barrier and they were not suitable for the present purpose, when the cost is consider. Development of the new types of the sheet pile will be necessary to use the sheet pile as a reliable barrier, the authors guess.

PREVENTION OF THE INTRUSION OF THE SEA WATER BY A RECHARGING CHANNEL

This is a kind of the pressure ridge methods. An open channel is constructed on the top of the embankment and the fresh water infiltrated from the channel creates a water table ridge to repel the sea water. The authors called this as the water curtain method.

Hele-Shaw model test were carried for an embankment 300m wide. Nine kinds of infiltration channel of about 5m width and various depths were tested. Water levels in the sea and reservoir were +2.00 A.P. and -6.00m A.P., respectively.

The following conclusions were obtained.

- When the water surface level is higher than +2.40m A.P. ----O.4m higher than the sea water level, the sea water is repeled from the reservoir.
- 2) The discharge of the fresh water being wasted to the sea is $4,700^{m3}/d$ and this is only 1.2% of the design water supply of $400,000^{m3}/d$.
- 3) It is not necessary to construct an infiltration channel of so large sectional area. An experiment for the infiltoration channel 5m wide and 1.5m deep shows that the repulsion of the

sea water is completed within one year. Another advantage of the water curtain method is that it has little troubles with the earthquake.

DIFFUSION OF SALINITY FROM THE BOTTOM SAND

The results of investigations on the diffusion rate of salinity from the reservoir bottom were reported by Elhott, and others (1965) in connection with the Plover Cove Water Scheme, Hong Kong.

In addition, the results of field and laboratory measurements of 0kuda (1962) and Yamaguchi (1965-6)are available in Japan.

The authors carried out laboratory experiments for the Obitsu River sand under the condition of running water. A sand layer of 15cm depth consisted of the Obitsu river sand of 0.2mm effective grain size was set on the bottom of the experimental flume.

The sand layer was first saturated with the salt water. Then, the fresh water flowing over the sand layer with the velocity of 2 cm/s and the depth of 12cm was supplied to measure the salinity entrainment from the bottom.

The salinity entrainment will be expressed by ~(5)

$$\frac{\partial S}{\partial t} = D_{\chi} \frac{\partial^2 S}{\partial \chi^2} + D_{\chi} \frac{\partial^2 S}{\partial y^2}$$
(5)

where:

s: concentration of salt water

Dx, Dy: Coefficient of diffusion

- t : Time
- x : Horizontal distance
- y : Vertical distance measured downward from the sand surface

According to the laboratory measurements salinity change in x direction was neglible small in comparison with that in y direction. Thus, (5) is simplied to become -(6).

 $\widehat{g_t} = 0, \widehat{g_y}^{25}$ The values of the diffusion coefficient for the present experiments were calculated from -(6). Solution of eq (6) under the following conditions is given (7)

 $y = 0, \quad S = 0$ $y = h, \quad 35/3y = 0$ where h is sand layer $S = \frac{450}{\pi} \int_{2\pi+1}^{2\pi+1} e^{-(\frac{2\pi}{2\pi})^2} gt, \quad S = S_{*}$ The value of the diffusion coefficient Dy which showed the best

The value of the diffusion coefficient Dy which showed the best fit with the measurement was 1×10^{-3} (cm2/s). When the value of Dy is given, the diffusion rate of the salinity from the bottom sand at any time is obtained from (7). In the present design, the value of diffusion rate at the end of the second year was taken as the design value, since at least two years will be necessary to complete the reservoir construction. The design value of the salinity diffusion thus obtained is $1.6^{m3}/min$. The numerical value of $1.6^{m3}/min$. is converted to $400 \ ^{cc}/m-min$. in terms of the seepage from the embankment. The variations of the salinity diffusion with time calculated for the reservoir under planning are shown in Fig. 6 and 7.

WIND EFFECTS ON THE MIXING OF SALT AND FRESH WATER OBSERVED IN THE TEST BASIN

A circular test basin of 63 m dia and 10 m depth has been constructed near the mouth of the Obitsu River. In April, 1965 the fresh water was poured on the surface and the salt water was sucked out of the bottom to create the fresh water layer of 3.5m depth on the salt water layer below. Then, the mixing of the stratified fluids had been continuously observed till November. From the field measurements the authors analyzed the mixing process of the salt and fresh water observed in the test bain.

EMPIRICAL RELATIONSHIP BETWEEN THE DEPTH OF THE SURFACE LAYER AND WIND VELOCITY

During the observations remarkable changes in the elevations of the salinicline and the thermocline were observed, as shown in figures 8 and 9 after gales. From the measurements togetherwith the other available data, the authors obtained the relationship between the depth of the surface layer and the wind velocity as shown in Fig. 10 (Kishi, Miyake, Takahashi and Ikeda (1966)).

The strait line in Fig. 10 gives (8)

 $H = 5 \log_{10} V - 1.0$

(8)

where H : the depth of the surface layer (m) V : wind velocity (m/sec)

MIXING OF STRATIFIED FLUIDS BY WIND

Kishi (1966) presented a theory for the interfacial mixing of stratified fluid caused by wind. In this paper, he gave the relation between Ur/U* and U*H/ ν , which is shown Fig. 11, where Ur is the bottom velocity in the upper layer, U* is the shear velocity on the water surface caused by wind, H is the depth of the upper fluid and ν is Kinematic viscosity of the upper fluid. The curve in Fig. 11 was derived under the following assumptions.

1) The empirical relation $(\hat{\Theta})$ gives the depth at which the mixing by wind diminishes to negligible small amount.

2) The criterion for the inception of mixing between two layered flow is given by (9). for turbulent flow (Keulegan (1949)).

where

 U_r · fluid velocity of the upper layer

 ΔP : density difference between upper and lower fluids. P': density of the lower fluid.

3) For turbulent flow the relation between the shear velocity on the surface and the wind velocity is given by (10) Keulegan (1951).

$$\frac{U^{x}}{V} = 1.81 \times 10^{-3}$$
 (10)

An empirical relation(i) for the mixing rate of the two layered flow was given by Keulegan(1949).

$$Um = K (U_r - 1.15 U_c)$$
(11)
ere K : empirical constant (= 3.5 x 10⁻⁴)
U_c : value of U_r given by relation (9)
U_m : mixing velocity of lower fluid

Using the curve shown in Fig 11 and equation (10) one obtains Ur for given values of V and H. Then, substitution of U_T into (1) gives the value of U_m , which gives the salinity increase in the upper layer caused by the wind. Comparisons of the theory with measurements led the authors to the conclusion that equation (12) was more favorable than (11) as far as the present observations were concerned.

$$U_{\rm m} = K (U_{\rm r} - 0.8 U_{\rm c}) \tag{12}$$

Comparisons of the theoretical values of the salinity increase with the measurements are made in Table-la.

DIFFUSION OF SALINITY UNDER THE CALM WEATHER

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In the pieceding section relatively intense mixing of under the gale was considered. However, the inception of mixing given by (9) treats only the mechanical mixing, so that the theory described above could not apply to the salinity change recorded under the calm weather. It should be treated as a diffusion process. The authors are now, in detail, studying the diffusion process under the calm weather.

In the present paper, the authors show the observational results shown in table-lb, to give the rough estimation of the diffusion ratio.

This is found that the increase of the salinity under the calm condition is roughly one-several tenth of that under gale condition.

terms	period of calcu.	May 20-22 (2 days)	Sept. 17-18 (1 day)	Nov. 8-9 (1 day)
Cal- cula- tion	Max. Wind Velocity (m/s)	22.0	26.0	18.0
	Blowing time (hours)	29	6	2
	Mixing velocity (cm/s)	8.35×10^{-4}	6.05×10^{-4}	6.50×10^{-4}
	Total inc. of chlorinity (gr.)	2.64 x 10^6	7.85 x 10 ⁵	1.53 x 10 ⁵

Table-la The salinity increase under gale

Cal-	t			I
cula-	Chlorinity trans-	2	9	0
tion	portation (g/m ² /day)	2.15×10^{3}	6.30×10^{3}	3.84×10^{3}
0b-	Total inc. of chlo-		/	1
ser-	rinity (gr)	$3.30 \times 10^{\circ}$	$1.77 \times 10^{\circ}$	6.00×10^{-1}
va-	Chlorinity trans-	9	4	2
tion	portation (g/m ² /day)	2.70×10^{3}	1.41×10^4	1.50×10^{3}

Table-1b The salinity increase under calm weather

period of terms calcu.	July 7-13 (6 days)	July 14-17 (3 days)	July 17-24 (7 days)
Total inc. of chlorinity (gr)	7.04 x 10 ⁵	2.33 x 10 ⁵	1.50×10^6
Chlorinity trans- portation (g/m ² /day)	1.80×10^2	1.38×10^2	3.82×10^2

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Fig. 1-a. The schematic plan of the reservoir.



Fig. 1-b. The soil profile at the dam site.



2. The salinity concentration of reservoir water for variation value of the seepage rate. Fig.



Fig. 3. Comparison of the is-Nomitsu's theory with the authors' theory.



Fig. 4. Schematic arrangement of the Hele-Shaw model test.



Fig. 5. The movement of the salt water-freshwater interface after the operation of recharging.



Fig. 6. Distribution of salinity concentration in the bottom sand.



Fig. 7. Decrease of the salinity discharge rate with time.





