Optimal gate operation of main drainage canal in a flat low-lying area using tank model incorporated with genetic algorithm

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1. Introduction In flat low-lying areas, the appropriate operation of drainage structures during flood events are very important but have a great difficulty because each drainage structure should be operated not only by considering the flood condition near the structure but also by considering the present flood condition over the wide area in the basin including upstream and downstream. The local concentration of inundation should be avoided in the operation of flood drainage structures in flat low-lying areas. From this point of view, this paper presents a mathematical model of drainage system in Chiyoda basin for calculating the flood inundation and optimizing the operation of gates in a main drainage canal. The optimization of gate operation was carried out by Genetic algorithm (Coley, 2003). Chiyoda basin is located in Saga Prefecture in Kyushu Island, Japan. The total basin area is about 566 ha. The excess water during flood events is removed by the pumped drainage and the flap gate at the downstream end. However, it is assumed in this paper that the excess water is removed only by the flat gate as shown in **Fig.1**.

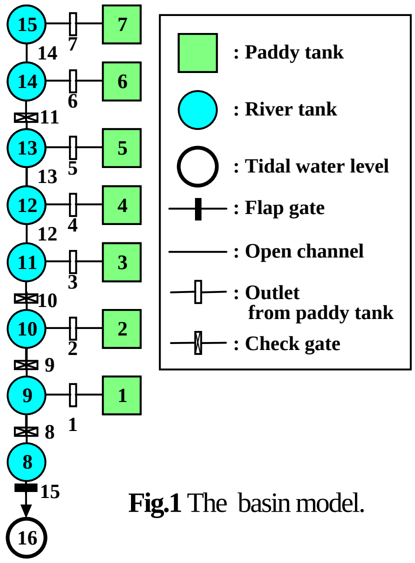

Fig.1 The basin model.

2. Methodologies In order to construct the tank model in Chiyoda basin, the data such as topographic map, existing condition of irrigation and drainage system, and rainfall time series were firstly collected. Secondly, the basin was analyzed, in which the paddy fields were divided into 7 tanks and the main drainage canal was also divided into 8 river tanks. Interfaces between paddy tanks and river tanks are drainage structures including 11 weirs, 4 gates, 3 open channels, and 1 flap gate at the downstream end. Equation (1) is the basis equation for calculating the flood inundation.

$$Z_{(i)} = \frac{1}{A_{(i)}}(Q_{\mathrm{in}(i)} - Q_{\mathrm{out}(i)}) + R \cdots\cdots (1) \qquad f_t = \frac{1}{|C_{v,p}| + |C_{v,c}| + \beta T} \cdots\cdots (2)$$

In equation (1), $Z_{(i)}$, $A_{(i)}$, $Q_{\mathrm{in}\,(i)}$, $Q_{\mathrm{out}\,(i)}$ and R are water level, surface water area, inflow, outflow of tank No. i, and rainfall intensity. This model is numerically solved to determine the water level in the paddy tanks and the river tanks, and the flow discharges at every connection. This computation was solved by using the Runge-Kutta-Gill method. Genetic algorithm was applied to optimize the operation of 4 gates in the main drainage canal including gates No.8 through gate No.11. By using Genetic algorithm, which is the process of decoding, calculation of fitness function, selection with elite preservation strategy, uniform crossover and mutation, the optimal heights of weirs were determined in the range from the minimum elevation (ordinary height – 1.5m) to the maximum elevation (ordinary height + 1.5m). The fitness function f_t, which is used in the genetic operation, is defined by equation (2). In this equation, $C_{v,p}$ is the coefficient of variance of excess water depth in paddy tanks; $C_{v,c}$ is the coefficient of variance of

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excess water depth in river tanks. T is the total time of inundation in paddy fields and β (=0.01) is a weight for the inundation time comparing with the coefficients of variance. In equation (2), the inundation concentration is evaluated by the coefficient of variance (relative standard deviation) C_v = (standard deviation)/(mean). This factor is affected by the operation of drainage structures in the drainage system. It should be minimized in order to make the inundation distribute more equally and otherwise some areas would be inundated very seriously.

3. Results and discussion The simulation process was carried out using the rainfall with a return period of 100 years. The total calculation time of simulation is 6 days, including 3 days with rainfall and the following 3 days without rainfall. The result of maximum water depth, the inundation time, the coefficient of variance in the paddy tanks and the maximum water depth, the coefficient of variance in the river tanks are presented in **Table 1**. The simulation results indicated that before the optimization of gate operation, the inundation concentrates at the paddy tanks No.5 and No.6 with the prolonged inundation time. As the result of that, the total inundation time increases up to 64 hours and the coefficient of variance stands at 0.252. The same situation occurred in river tanks and the coefficient of variance stands at 0.648. This local concentration of inundation, which affect to the crop yield especially in downstream areas, should be avoided by the optimization of operation of drainage system. In fact, four gates including gate No.8 through gate No.11 play an important role in the drainage system, therefore by optimizing the operation of these gates, the above issue can be solved. The result shows that the total inundation time in the paddy tanks will decrease down to 16.4 hours and the coefficients of variance of paddy tanks and river tanks also decrease down to 0.239 and 0.496 respectively, which means that the inundation distribute more equally. The optimal height of weirs are presented in **Table 2**.

4. Conclusion Tank model is a very useful tool to simulate the water flow in flat low-lying areas. In Chiyoda basin, it was applied to determine the water levels in the paddy field and in the main drainage canal. Moreover, the flow discharges at the main drainage canal and connection structures were computed at the following time step. Base on this model, the inundation concentration was quantified by the coefficients of variance. The most important point in here by optimizing the gate operation is that we can evaluate and minimize the inundation concentration in the whole drainage basin.

Table 1 Results of calculation using the rainfall with a return period of 100 years.

Paddy tank					**River tank**		
Tank No.	Without optimization		Optimization		Tank No.	Without optimization	Optimization
	Max. water depth (m)	Inundation time (hr)	Max. water depth (m)	Inundation time (hr)		Max water depth (m)	Max. Water depth (m)
1	0.360	8.839	0.386	3.961	1	-0.159	-0.119
2	0.240	0.000	0.228	0.000	2	-0.050	-0.024
3	0.228	0.000	0.228	0.000	3	-0.107	-0.221
4	0.289	0.000	0.228	0.000	4	-0.024	-0.124
5	0.439	36.684	0.341	3.728	5	-0.092	-0.190
6	0.376	19.031	0.367	8.721	6	-0.201	-0.299
7	0.228	0.000	0.228	0.000	7	-0.304	-0.314
Total		**64.555**		**16.409**	8	-.0304	-0.314
$\lvert C_v \rvert$	**0.252**		**0.239**		$\lvert C_v \rvert$	**0.648**	**0.496**

Table 2 The ordinary crest heights and the optimal operations of weirs.

Gate No.	8	9	10	11
Ordinary crest height (m)	1.420	1.750	2.110	2.110
Optimal operation (m)	-1.500	-1.500	-1.452	0.833

References: Coley, D. A. (2003): An introduction to Genetic Algorithms for Scientist and Engineers, World Scientific Publishing Co. Ltd., Singapore, pp. 1-34.