応答曲面による豪雨時にため池の破堤リスク評価

Risk evaluation for earth-fill dams due to heavy rains by response surface method

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1. Introduction

The breaching of the earth-fill dams due to natural disasters are frequently reported in recent years. After the disaster in July 2018, the Act on the Management and Conservation of Earth-fill dams was enacted in July 2019 by the Ministry of Agriculture, Forestry and Fisheries. It is necessary to select the earth-fill dams for disaster prevention and evaluate their failure risk. In this research, the probability of the levee breach is calculated using detailed analysis and response surface method for the selected 29 sites (Table.1), and finally evaluated the risk of the overflow failure.

2. Detail method to evaluate consequence

In order to calculate the risk of the earth-fill dam, the damage cost should be calculated using the detailed method. Using the flood analysis to show the flooded area about the earth-fill dam and its downstream area at first, collect the land use data and asset data in the same basin. Finally, calculating the estimated damage cost by superimposing the result of flood analysis and land use. Fig.1 shows the maximum inundation depth obtained from the flood simulation at a representative site.

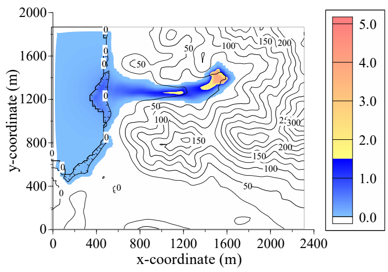
3. Response surface method to evaluate consequence

Since detailed analysis requires a lot of labor, this research propose a simple method to calculate the damage cost of the earth-fill dams. By determining the relationship between the response and 4 factors a, c, e, f, using cross validation to select the most appropriate one from all RS (shown as Table.2), and the one with the minimum error is shown as the Equation (1) from the variables requested by the regression methods of 29 ponds.

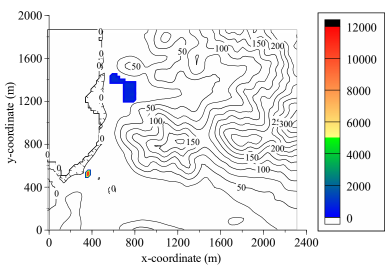
Table 1.10 examples of 29 sites.

Pond	Flooding ability (m^3/s)	Basin area A (km^2)	Water storage (km^3)
O-A	2.121	0.634	39,000
O-B	0.735	0.268	11,000
O-C	1.724	0.192	57,000
O-D	2.298	0.534	29,400
O-E	2.025	0.321	17,000
H-A	2.62	0.24	10,300
H-B	0.35	0.11	12,000
H-C	0.23	0.709	13,700
H-D	3.04	0.193	49,600
H-E	1.96	0.32	66,210

O-: Okayama, H-: Hiroshima



(a) Submergence depth (m)



(b) Damage cost (1,000JPY)

Fig.1.Result of Flood simulation.

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The cost of damage=

$$-1.04\times10^{6}lna-5.02\times10^{7}lnc+5.64\times 10^{6}lna\cdot lnc+1.67\times10^{3}e+1.07\times 10^{4}f \qquad (a<11000) \qquad (1)$$

$$-7.30\times10^{4}\,ln\,a-2.33\times10^{7}\,ln\,c+2.01\times 10^{6}\,ln\,a\cdot ln\,c-6.29\times10^{2}e+4.29\times$$

a : Effective water storage (km^3)

c : Median gradient of the main route of flood water (%)

e : the number of households in the available area per $1km^2$ of analytical area (households /km^2)

f : the number of employees in the available area per $1km^2$ of analytical area (person/km^2)

The comparison of damage cost by two methods is shown as Fig.2.

4. Probability of failure and risk assessment

As for the probability of breach breakage, the breach is assumed to be an overflow. The probability of levee breakage is generally expressed as the probability of overflow occurring multiplied by the cost of damage. To make the calculate of levee probability a high accuracy, the levee breakage probability is corrected by considering the storage function method and storage effect. The following formula is used to calculate the peak flood discharge

$$Q_p=\frac{Q_L\cdot A}{3.6} \qquad (2)$$

Q_p: peak flood flow (m^3 / s), A: catchment area (km^2), Q_L: outflow of earth-fill dams (m^3 / s),

The conditions of the limit that the reservoir overflows are as follows. Qd means design flood flow

$$P_f=\mathrm{Prob}[Q_d<Q_p] \qquad (3)$$

The calculated levee risk and ranking of 29 earth-fill dams in detailed approach and the response surface methods are shown in the Fig.3. According to the Figure, the risk of Okayama seems to be lower, but the risk ranking is scattered over a wide range.

5. Conclusions

In this research, the damage cost of 29 ponds is estimated using detailed analysis and response surface method. According to the risk evaluation, two methods could present similar order of the risk, and the response surface method is clarified to be possibly applied to determine the priority of the renovation works of the earth-fill dams.

Table 2. Error of damage cost

Response surface	Function type of response surface	Error of damage cos (1,000 JPY)
1	$x_a a+x_c c+x_e e+x_f f$	41,620,605
2	$x_a lna+x_c lnc+x_{ac} lna\cdot lnc+x_e e+x_f f$	40,805,706
3-a7000	$x_a a+x_c c+x_e e+x_f f$	46,797,710
3-a11000	$x_a a+x_c c+x_e e+x_f f$	40,700,785
4-a7000	$x_a lna+x_c lnc+x_{ac} lna\cdot lnc+x_e e+x_f f$	42,687,394
4-a11000	$x_a lna+x_c lnc+x_{ac} lna\cdot lnc+x_e e+x_f f$	33,549,979
5-1	$x_a a+x_c c+x_{ac} a\cdot c+x_e e+x_f f$	43,308,141
5-3-a-7000	$x_a a+x_c c+x_{ac} a\cdot c+x_e e+x_f f$	45,458,434
5-3-a11000	$x_a a+x_c c+x_{ac} a\cdot c+x_e e+x_f f$	37,686,107

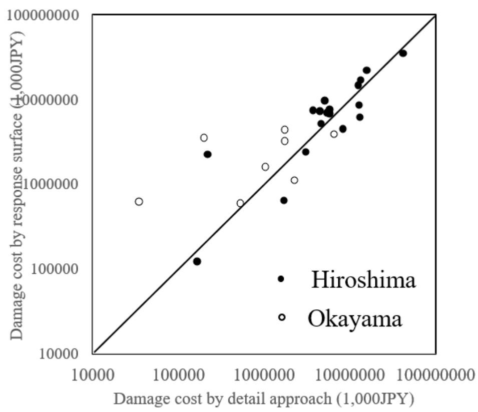

Fig.2. Comparison of damage cost by two methods

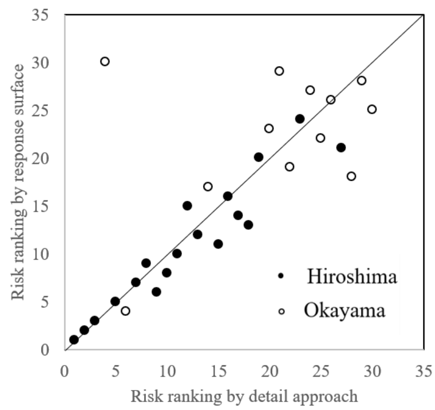

Fig.3. Risk ranking by two methods

REFRENCES : Mizuma, K., *et al.*. Simplified method for estimating risks due to earth-dam breaches using response surface method IRRIGATION, DRAINAGE AND RURAL ENGINEERING JOURNAL Volume.84 No.1 p. I_47-I_55, 2016