Prediction of Debris Flow Occurrence in Mizunashi River with 1-3 Hour Rainfall Amount Forecast

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Abstract

The prediction expreiments of debris flow occurrence with flooding in Mizunashi river are made using the rain score predicted by the 1-3 hour rainfall forecasting method. The results show the usefulness of rain score P information for the precaution activity of inhabitants against the damage. They have sufficient time of 20-30 minutes for escaping from debris flow hazard in all cases tested, if the precaution activity is started at the time when the predicted P is crossing the criterion $P \geqq -5$ with 62.5% probability of debris flow occurrence or $P \geqq 0$ with 75% probability.

1. Introduction

The prediction method of 1-3 hour rainfall amount using 10 minute rainfall data only was introduced by Shiotuki[1]. The rain score P as a new index of rain strength was proposed by the authors[2]. It was found the 100% probability level of debris flow occurrence in Mizunavshi river, Shimabara, Ngasaki Prefecture is the rain score P= 5. The rain score is calculated by the rain parameter a, b[2] that is determined by 10 minute rainfall data. The rainfall prediction method is also based on the behavior of parameter a, b. The prediction of rain score can be made with the rainfall prediction method. This paper describes the results of experiments applying the rain score prediction method to the debris flow occurrence prediction in Mizunashi river.

2. Prediction method of 10 minute rainfall change in 1-3 coming bours

The prediction method of rain score P in near future is based on the 10 minute change of parameter (a, b) set calculated from the estimated 10 minute rainfall amounts in 1-3 coming hours by the prediction method [1]. The method of predicting future rainfall is chracterized in using 10 minute rainfall data only. The personal and original forecast of local 1-3 hour rainfall is possible with the voluntary observation of 10 minute rainfall. The brief description of method predicting future rainfall is as follows.

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(1) Hyetograph

When the parameter (a, b) set of maximum rainfall intensity equation $R_T = a/(T+b)$ (R_T equation, explained in our previous paper [2]) is known with the time location of rainfall peak, the time change of rainfall amount (r mm/hr) in a rainfall is reformed by the following equations[3] and drawn as shown in Fig. 1.

$$r(tp-tb) = a \times b/((tb/m)+b)^2 \qquad (1) \text{ ; before peak}$$
$$r(tp+ta) = a \times b/(ta/(1-m)+b)^2 \qquad (2) \text{ ; after peak}$$

Here,

t0 ; the beginning time of a rainfall
te ; the end time of a rainfall
tp ; the occurrence time of rain intensity peak in a rainfall
tb ; the arbitrary time before peak
ta ; the arbitrary time after peak
$m = (tp-t0)/(te-t0)$; expressing the relative location of peak

If we have informations about the parmeter set (a, b) and the peak time (tp) of an overall rainfall from tbe rainfall data r observed during last minutes from t0 to the present time ti, the hyetograph of the present overall rainfall can be drawn by adding the future part of estimated hyetograph after ti. The future 1 hour or 3 hour rainfall amounts is estimated by the time integration of future r from ti to ti+60 min, or from ti to ti+180 min. as shown in Fig. 2.

(2) Prediction procedures

The 10 minute rainfall amount is adopted as r for prediction procedures.

Step 1; Input the 10 minute rainfall data (r10, mm) ovserved from t0 to ti.
Step 2; Determine the parameter set (a, b) of present rainfall by the six r10 data

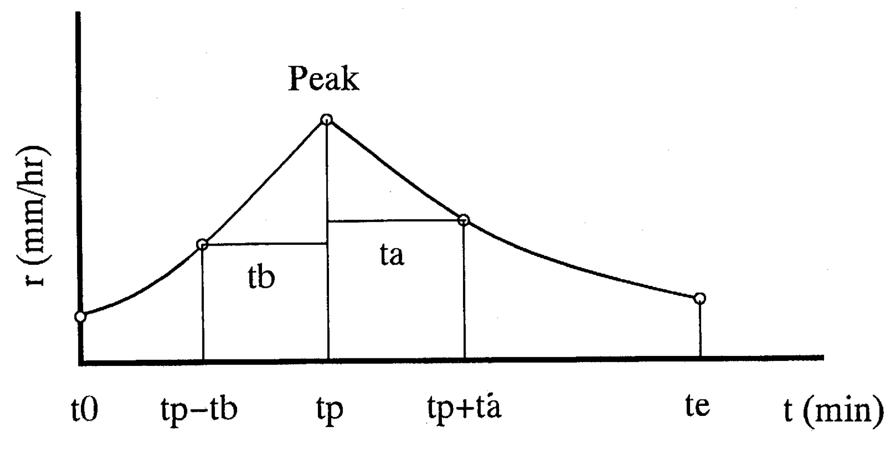

Fig. 1 Hyetograph

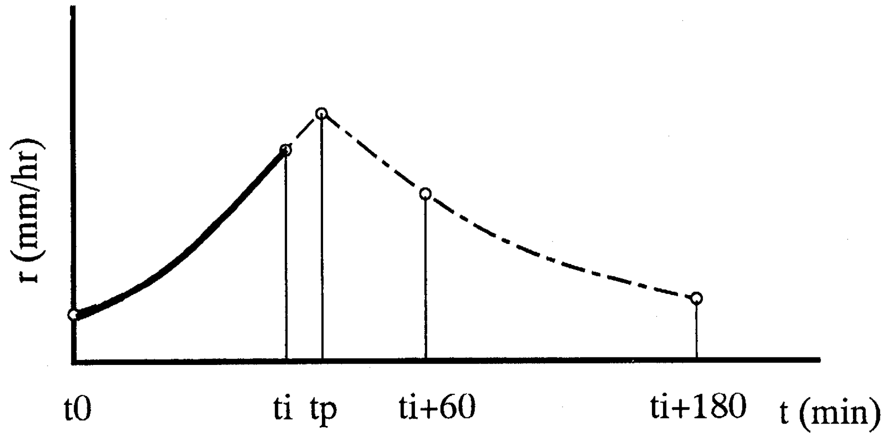

Fig. 2 Hyetograph estimted at ti.

during a last hour. If the rainfall time duration from t0 to ti is longer than 1 hour, all r10 data from t0 to ti are used for calculating the another parameter set of (aT, bT).

Step 3 ; Compute the space liquid water content within rainclouds, M10 (g/m^3), bringing the maximum 10 minute rainfall (R10, mm, calculated from Talbot equation, [2)]), by (a, b) and M10T by (aT, bT), respectively. The larger one of M10 and M10T, is adopted as M10.

Step 4 ; Compute the overall rainfall duration time DR (min.) from t0 to te, estimated by the following equation. The te is assumed here the time T when the R_T is smaller than 10 mm/hr in R_T equation.

$$DR = \sqrt{a \times b/10} - b, \text{ min.}$$

The larger one of DRs by (a, b) and (aT, bT) is adopted as DR.

Step 5 ; Estimate tha parameter b of predicted hyetograph, as follows.

$$b = (692 - 8 \times M10^{1.040}) / (M10^{1.040} - 3.846), \text{ when } M10 \geqq 6g/m^3$$

$$b = (DR - 4 \times C + \sqrt{(4 \times C - DR)^2 + 4 \times (C-1) \times DR^2}) / (C-1), \text{ when } M10 < 6g/m^3$$

here, $C = 2.600 \times M10^{1.040}$

Step 6 ; Estimate the prameter a by giving b to R_T equation.

Step 7 ; Estimate the maximum 10 minute rainfall amount, MAXR10, mm (peak rainfall), by giving the parameter set (a, b) and T=10 min. to R_T equation.

Step 8 ; Estimate the rain peak location tp. DR=te-t0 in Fig. 1 makes tp=m× DR. Changing m from 0.05 to 0.95 in the following Step. 9 , the tp of best adequate one of estimated hyetographs is looked out.

Step 9 ; Determine the best adequate hyetograph in which the summation of squared error between the actual 10 minute rainfall (r10) and the estimated 10 minute rainfall (r10E) of various hyetographs is least.

3. Rainfall amount forecast experiments

The future rain prediction method was experimented in the Nagasaki heavy rainfall event as reported in the previous paper[1]. The prediction of 1-3 hour rainfall is well performed in many cases when the prediction time ti is toward the actual occurrence time of rainfall peak. Fig.3a and 3b are the representatives of forecast experiments. Fig. 3 a is the result at 1830, July 23, 1982, Kohbutsu school in Nishi-sonoki peninsula, Nagasaki Pref. The ti is shown by the broken double line. The black squares are the observed 10 minute rainfall. The stars are every 10 minute rainfall of the best adequate hyetograph estimated. The forecast 1 hour (R1E=145 mm) and 3 hour (R3 E=236 mm) future rainfall after 1830 are very near to the actual 1 hour (R1=144 mm) and 3 hour (R3=239 mm) future rainfall after 1830, respectively. Fig.3b is for the case of Ohmura air port, Nagasaki Pref. at ti=2030 on the same date as Fig.3a. The forecast R1E=96 mm and R3E=111 mm are a little different from the actual R1=60 mm and R3=131 mm, respectively. It is interesting the predicted rainfall peak is seen at 2100, 30 minute later after the actual peak at 2030.

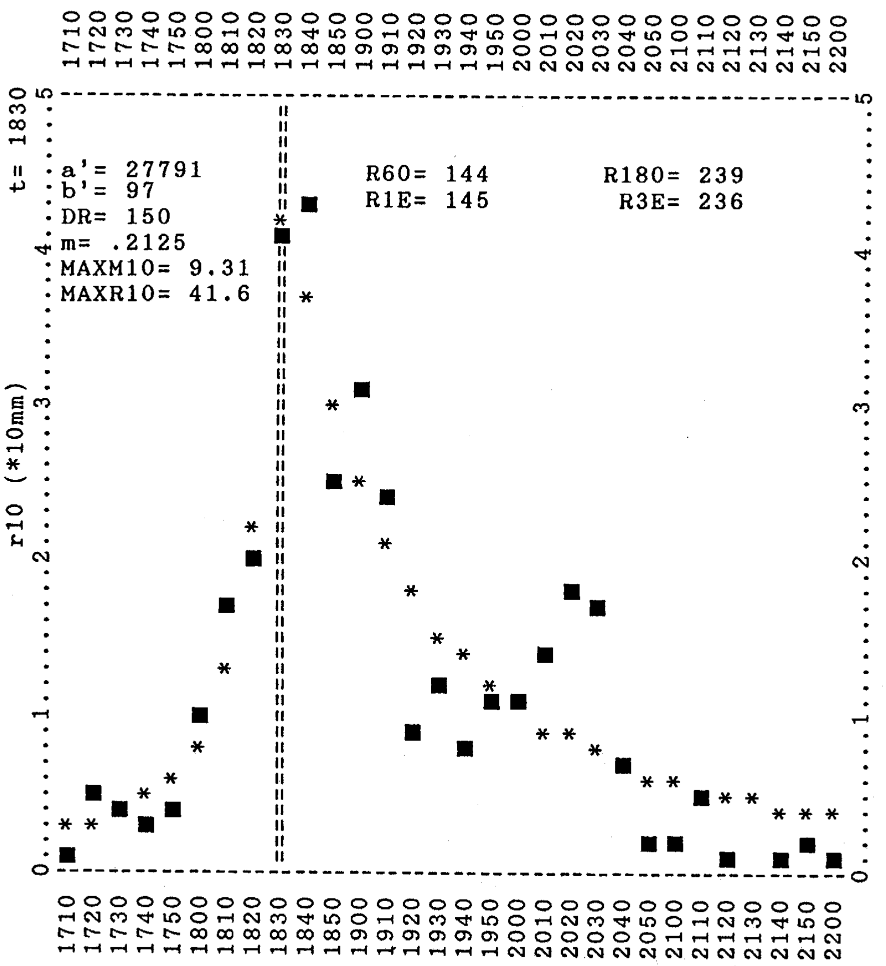

Fig. 3 a Rainfall prediction of 1830 at Kobutsu school in case of Nagasaki event.

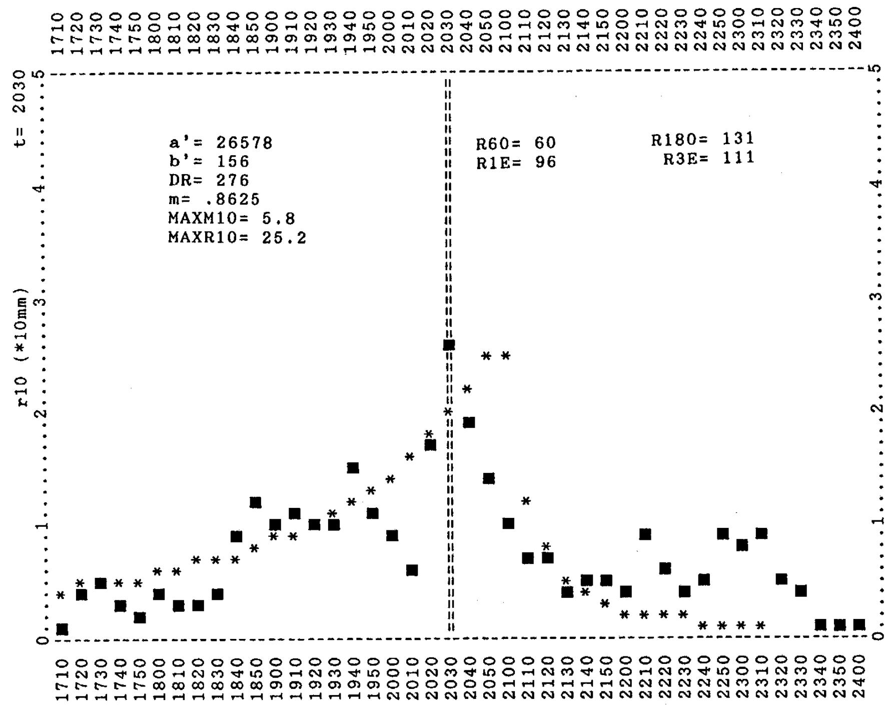

Fig. 3 b Rainfall prediction 2030 at Ohmura airport in case of Nagasaki event.

4. Prediction of future rain sore P and its application to debris flow occurrence in Mizunashi river, Shimabara

The future rain score at every 10 minute is calculated from the estimated (a, b) by the rain score equation proposed in our previous paper [2], using the predicted 10 minute rainfall amounts by the hyetograph. For instant, the rain score P of 20 minute later from now (=ti) is obtained from (a, b) determined by 6 data of last 4 observed ten minute rainfall amounts and 2 predicted ten minute rainfall amounts in future.

Prediction experiments of debris flow occurrence by rain score P in Mizunashi river, Shimabara are made as follows.

(1) Case 1; Flood debris flow on June 30, 1991.

The severe debris flow occurred at 1820 at Mizunashi river and flooded out to cause the heavy damages to the Route 251, Shimabara railroad line and many houses. Fig. 4 shows the prediction result of rain score P at 1800. The change of score P is shown by the square. The colums and black circles indicate the observed 10 minute rainfall amount, mm and the estimated 10 minute rainfall amount, mm, of the predicted hyetograph, respectively. The P prediction is shown within future 60 minutes. The explanation of signatures on the top of figure is as follows.

T ; present time, ti

RS ; accumulated rain from the biginning of rain t0 to ti, mm

a, b ; rain parameters at ti

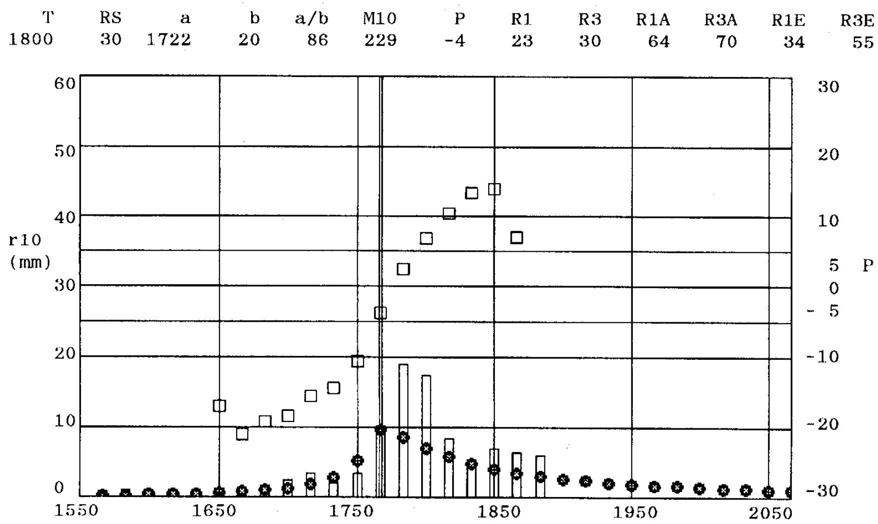

Fig. 4 Rainfall amount and score prediction for debris flow in Mizunashi river at 1800, June 30, 1991.

a/b ; instantaneous rainfall intensity at ti, mm/hr
M10 ; space liquid water content calculated by (a, b), $\times 100 g/m^3$
R1, R3 ; maximum 1 hour and 3 hour rainfall amounts during t0-ti, mm
R1A, R3A ; actual 1 hour and 3 hour rainfall amounts after ti, mm
R1E, R3E ; predicted 1 hour and 3 hour rainfall amounts after ti, mm

The actual score P of 1800 is -4 more than $P=-5$ as shown in the figure. $P=-5$ means the rain causes the debris flow with 62.5% of occurrence probability[2)]. The predicted P of 1810 and 1820 are $P>0$ and $P>5$, respectively. According to the heavy debris flow occurrence criterion $P=5$[2)], we can predict the debris flow occurrence with flooding toward 1820 by 20 minutes before. The forecast 1 hour rainfall R1E=34 mm and 3 hour rainfall R3E=55 mm after 1800 were underestimated comparing to the actual R1A=64 mm and R3A=70 mm because of the intensified rainfall during 1810-1820.

(2) Case 2; Flood debris flow on March 1, 1992

The debris flow occurred and flooded at 0130. Fig.5a is the result of prediction at 0110. The predicted P of 0150 reaches -5. Fig.5b (0120 prediction) shows the predicted P of 0130 is more than 5. The rain will cause the heavy debris flow. The predicted rainfall amounts, R1E=42 mm, R3E=69 mm are about double of the actual R1A=18 mm, R3A=30 mm, respectively. Although the predicted rainfall amount is overestimated, the predicted rain score gives useful information for disaster precaution activity. The actual P at 0130 was 6 as predicted at 0120.

The precaution activity started at 0110 does not come in vain.

(3) Case 3; Flood debris flow on March 15, 1992

Fig.6a-c show the prediction results for the flooded debris flow caused at 0940. Fig.6 a is the prediction at 0910. The predicted P of 0950 is more than -5. The rain may

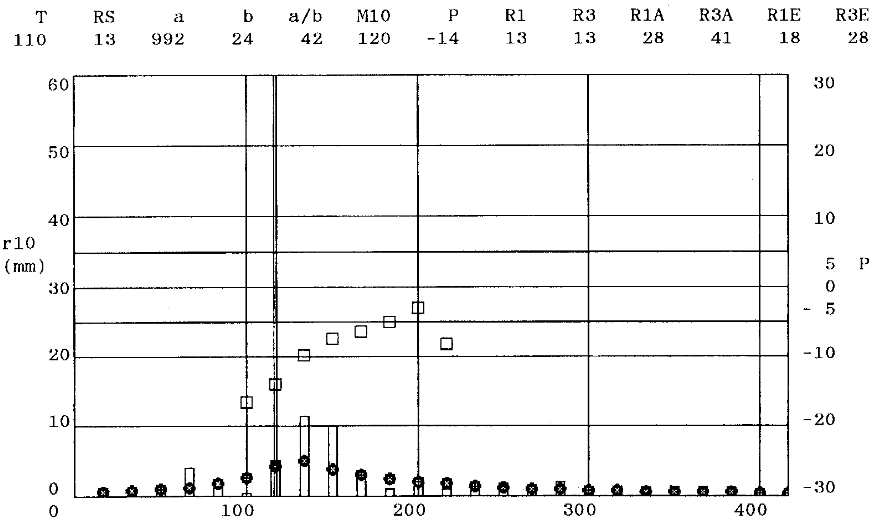

Fig. 5 a Prediction at 0110, March 1, 1992.

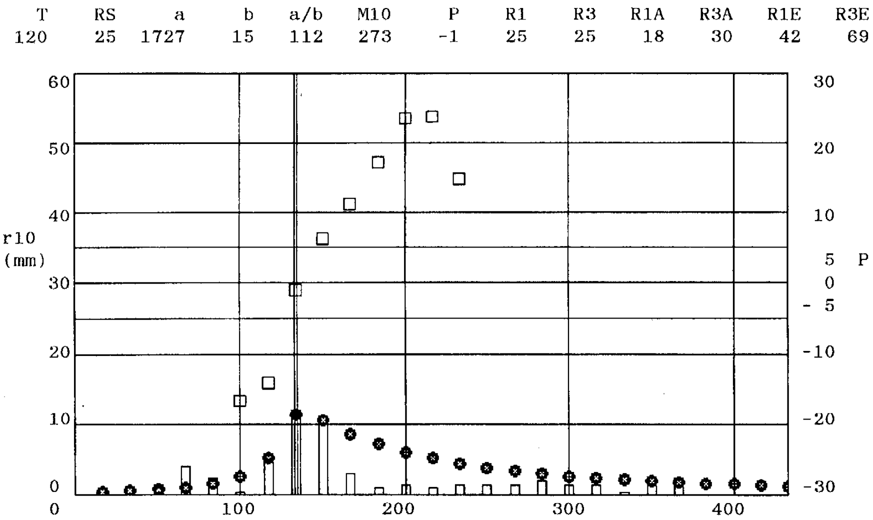

Fig. 5 b Prediction at 0120, March 1, 1992.

cause the debris flow. In Fig.6b of 0930 prediction work, the predicted P after 0950 comes near 0. The predicted R3E is 30 mm more than the maximum 3 hour rainfall amount R180=27 mm with the occurrence probability of debris flow 72.2%[2]. The actual R3A was 42 mm. In Fig.6c of 0940 prediction work, P is 1 and the prediction P after 0940 are far more than 5. The precaution activity begun at 0910 (30 minute earlier before 0940) does not come to nothing, while the forecast R1E, R3E at each prediction time were slightly different with the actual R1A, R3A.

(4) Case 4; Flood debris flow on August 8, 1992

The debris flow occurred at 0800 and flooded at 0900. Fig.7a of 0740 prediction shows the predicted P of 0750-0820 are more than P=0 with the occurrence probability 75%[2]. Fig.7b of 0810 prediction shows the predicted P of 0820-0840 are more than P=

T	RS	a	b	a/b	M10	P	R1	R3	R1A	R3A	R1E	R3E
910	12	1065	38	28	89	-15	11	12	26	51	15	23

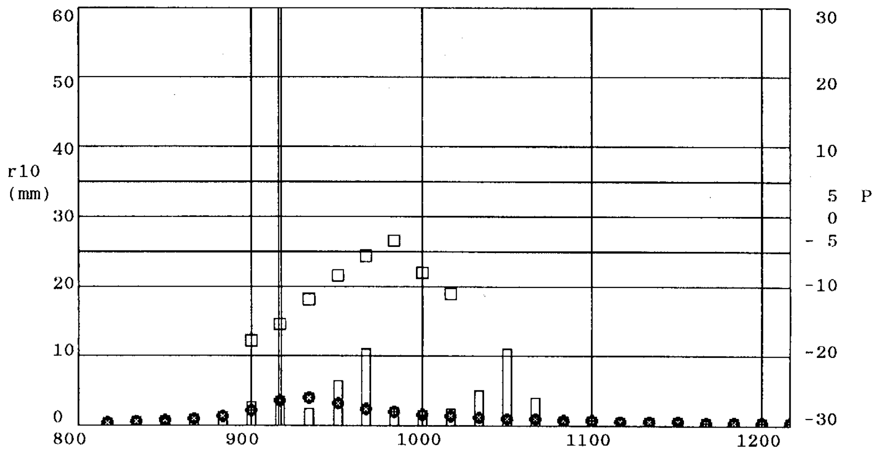

Fig. 6 a Prediction at 0910, March 15, 1992.

T	RS	a	b	a/b	M10	P	R1	R3	R1A	R3A	R1E	R3E
930	21	1614	33	48	148	-9	18	21	33	42	20	30

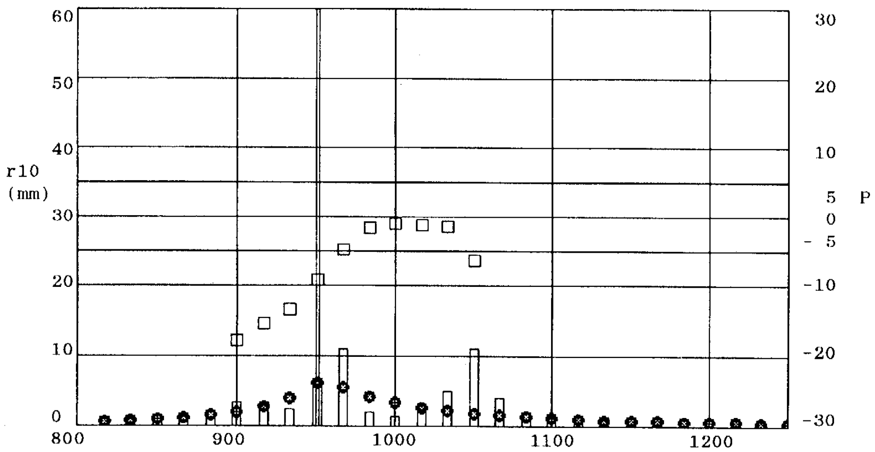

Fig. 6 b Prediction at 0930, March 15, 1992.

T	RS	a	b	a/b	M10	P	R1	R3	R1A	R3A	R1E	R3E
940	32	2302	25	92	259	1	28	32	26	31	37	59

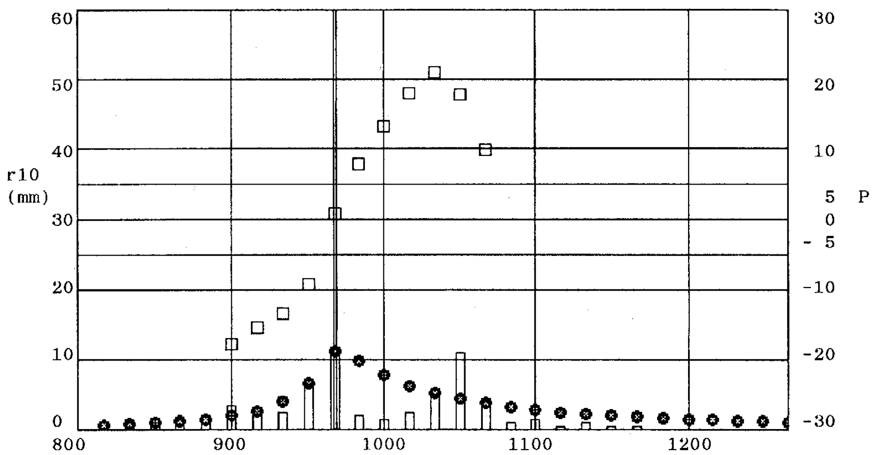

Fig. 6 c Prediction at 0940, March 15, 1992.

T	RS	a	b	a/b	M10	P	R1	R3	R1A	R3A	R1E	R3E
740	28	3174	118	27	97	-5	19	28	50	77	15	24

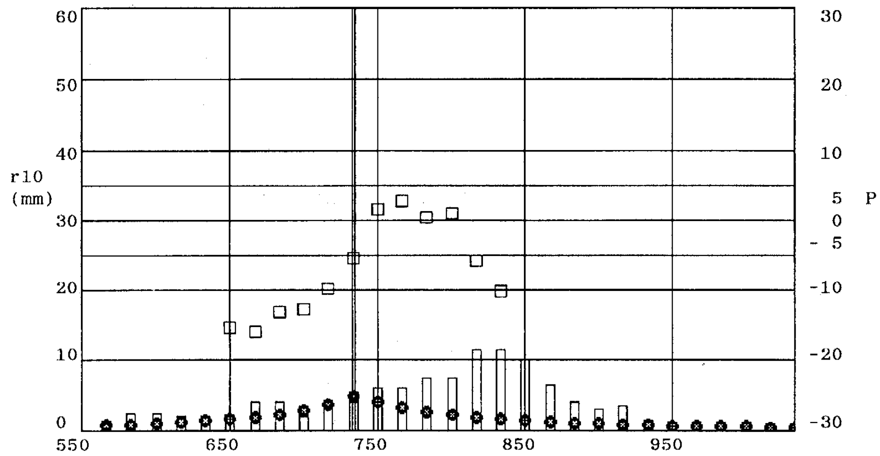

Fig. 7 a Prediction at 0740, August 8, 1992.

T	RS	a	b	a/b	M10	P	R1	R3	R1A	R3A	R1E	R3E
810	47	4275	83	51	176	4	29	47	51	58	18	25

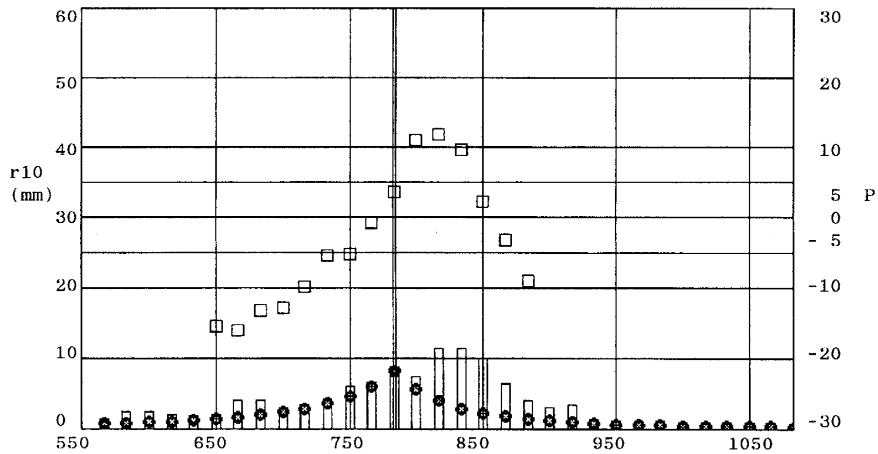

Fig. 7 b Prediction at 0810, August 8, 1992.

T	RS	a	b	a/b	M10	P	R1	R3	R1A	R3A	R1E	R3E
820	55	6926	137	51	180	14	35	55	47	50	18	25

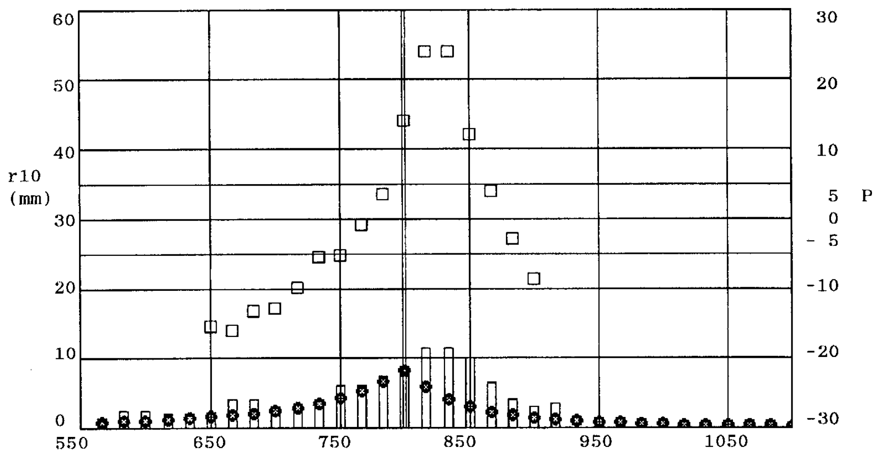

Fig. 7 c Prediction at 0820, August 8, 1992.

5 indicating the possibility of heavy debris flow with flooding. Fig.7c of 0820 prediction shows the 0820' P and the predicted P of 0830-0850 are more than 10. The precaution activity begun by rain score information at 0740 is well provided against the first debris flow occurrence (0800) and the danger of debris flow flooding (0900), although every forecast R1E, R3E were underestimated to the actual R1A, R3A.

5. Concluding Remarks

The results of prediction experiments for the significant debris flows with flooding in Mizunashi river show the usefulness of rain score P information for the precaution activity of inhabitants against the damage. They have sufficient time of 20-30 minutes for escaping from debris flow damages in all example cases, if the precaution activity is started at the time when the predicted P is crossing the criteria $P \geqq -5$ with 62.5% probability of debris flow occurrence or $P \geqq 0$ with 75% probability.

The usefulness of present method may be expected in many precaution and prevention activities for various rain-causing hazards, with knowing the peculiar rain score criterion of each hazard occurrence.

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