Study of debris-flow flooding area in a low-gradient zone

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INTRODUCTION

This study investigated the debris-flow flooding area in a low-gradient zone, using numerical simulations where the low-gradient zone was less than two degrees. Debris-flows do not usually flow and stop in a low-gradient zone. However, the debris-flows that occurred in Hofu city, Yamaguchi Prefecture, Japan, on 21 July 2009 flowed into the low-gradient zone and were deposited in the same areas. At that time, the Hofu rain gauge (Japan Meteorological Agency) recorded a maximum daily rainfall of 275 mm/day and maximum hourly rainfall of 72.5 mm/60 min. Subsequently, aerial photographs and a field survey identified that the debris-flows in these areas occurred from multiple tributaries. Furthermore, the low-gradient zone of these areas was damaged by the debris-flows. Therefore, in this study, we investigated the effects of multiple debris-flows occurring in tributaries on the main-stream and low-gradient zones using numerical simulations.

STUDY AREA

The study area was the Tsurugi River Basin (catchment area 4.24 km^2), in Hofu, Yamaguchi Prefecture, Japan. The Tsurugi River Basin is a tributary basin of the Saba River Basin.

METHODS

First, we collected published data on the rainfall characteristics, catchment area, length of the river channel, width of the river, and gradient of the river in the study area.

Second, we calculated the hydrological data for the Tsurugi River by rainfall-runoff analyses using the unit hydrograph for Nakayasu.

Finally, we conducted a two-dimensional numerical calculation in the target area using the hydrological data. Then, we used Brown's sediment discharge formula (Formula 1). Calculation conditions were two patterns. The first condition (CASE1) was that multiple debris-flows flowed in the upper area of the main stream (main stream angles exceeded 3.8 degrees). The second condition (CASE2) was that multiple debris-flows flowed in the lower area of the main stream (main stream angles were less than about 2.1 degrees).

$$\frac{q_B}{\sqrt{sgd^3}} = 10(\tau_{*e} - \tau_{*c})^{5/2}$$

$$s = \left(\frac{\sigma}{\rho} - 1\right)$$

$$\tau_{*e} = u_{*e}^{\ 2} / (sgd)$$

q_B :bedload discharge τ_{*c} :Dimensionless critical tractive force
σ :density of sediment ρ:density of water d :average grain diameter
τ_{*e} :effective tractive force u_{*e} :effective friction velocity

Formula 1. Brown's sediment discharge formula

RESULTS

The published information revealed that the gradient at which debris-flow stopped in the Tsurugi Basin was about 3.5 degrees, while the gradient for debris-flow sediment was only about 0.2 degrees. Therefore, we estimated that the debris-flows that occurred in the Tsurugi River Basin flowed downward, produced flooding, and then produced deposits in the downstream area (in the low-gradient zone) by sediment flow after the main debris-flow stopped. We found no correlations among the stop-gradient of debris-flow, catchment area, river density, and other parameters.

Results of the numerical calculations can be seen in Figure 1 and Figure 2. Figure 1 shows the results of CASE1. Figure 2 shows the result of CASE2. The numerical calculations revealed that when multiple debris- flows occur in tributaries joining the main stream in the upstream region (debris-flow section), there is little effect on the downstream region (low-gradient zone). However, if multiple debris-flows occur in tributaries joining the main stream in the downstream region (bedload section), it affects the downstream area and results in an

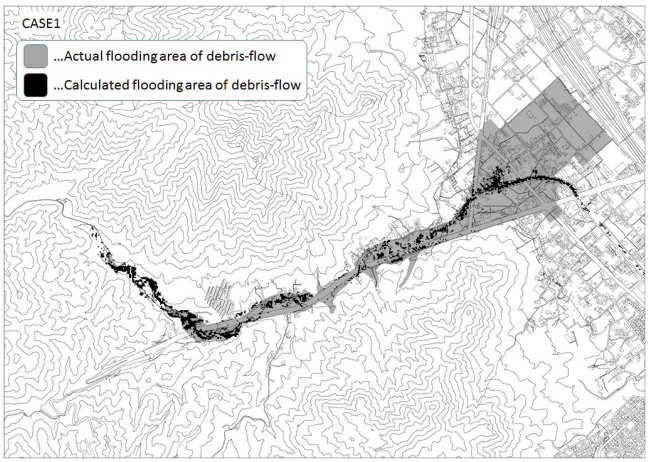

Figure 1. Comparison of the calculated hazard zone and the actual deposit at Tsurugi River Basin (CASE2)

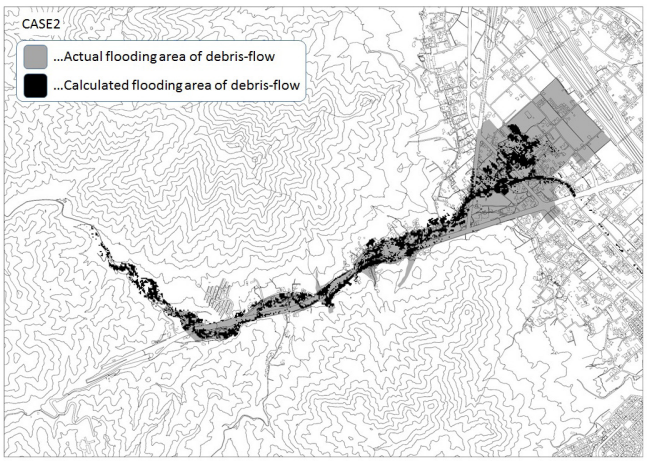

Figure 2. Comparison of the calculated hazard zone and the actual deposit at Tsurugi River Basin (CASE1)

expanded flooding area. This suggests that debris-flow occurring in tributaries in the downstream region can affect the low-gradient zone of the main stream.

CONCLUSIONS

The stop-gradient of debris-flow is usually about 2 degrees, but the gradient for debris-flow sediment in the downstream region is less than 2 degrees. If multiple debris-flows join the main stream in the debris-flow section, there is little effect in the low-gradient zone. However, if multiple debris-flows join the main stream in the bedload section, there is an effect in the low-gradient zone.

KEYWORDS

debris-flow; two-dimensional numerical simulations; flooding area; low-gradient zone

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