TIME SEQUENCE ON THE DEBRIS FLOW DISASTER IN THE TSURUGI RIVER, HOFU CITY, IN JAPAN

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INTRODUCTION

Debris flows or flash floods occur in small torrents in granite mountainous regions at the time of the localized heavy rainstorms. In most of cases, the torrents had not been gauged so that it is often very difficult to obtain enough data or information on the phenomena especially on their time sequence. In this study, we tried to clarify the time sequence of the debris flow disaster through the post-event survey on high water mark and interviews.

A rainstorm that hit Hofu city in Yamaguchi Prefecture on July 21st, 2009 caused debris flows in many mountain streams around Hofu, claiming many lives and devastating downstream communities and roads. In particular, serious damage occurred on the small mountain stream, Tsurugi River (A=1.82 km^2, Fig.1); river flow was blocked at the Kamikatsusaka Bridge at the mouth of the river outlet, its floor deck was forced up, sediment overflow finally occurred, causing serious damage to the surrounding houses and the nearby national highway.

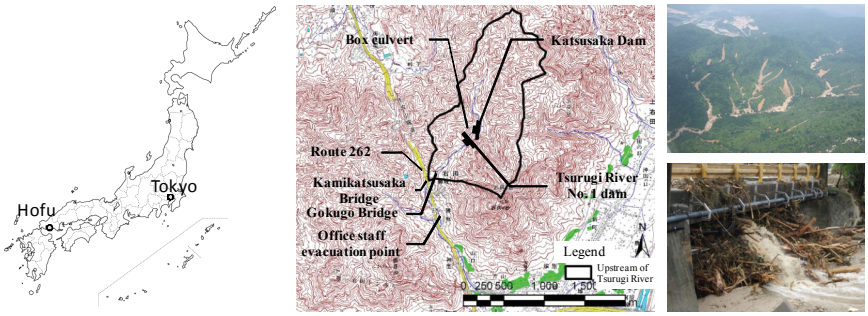

Fig. 1 Map and photos of the Tsurugi River basin, Hofu, Japan

SURVEY OF HIGH WATER LEVELS

We conducted post-event field survey to check the mud or water level marks left by the debris flow or flash flood, and the flow rate was estimated based on the sectional area, wetted perimeters, and the riverbed gradient upstream and downstream of the section.

Tab. 1 Estimation of peak discharge from the field survey

Name of Cross section	Distance from the Kamikatsusaka Br. (m)	Channel gradient	Drainage area (km^2)	Depth of flow (m)	Cross sectional area of flow (m^2)	Velocity of flow* (m/s)	Peak discharge (m^3/s)	Specific peak discharge (m^3/s/km^2)
Culvert	800	1/26.5	1.28	1.5-2.35	7.1-12.0	4.2-5.7	30-69	23-54
Cross section 1	547	1/10.5	1.47	1.62	13.2	7.1	151	103
Cross section 2	400	1/15.9	1.64	1.53	16	5.5	136	83
The Gokugo Br.	7	1/24.0	1.82	1.75-2.25	9.3-11.9	4.9-5.8	46-70	25-39

*Velocity of flow is calculated from the Manning's formula with using n = 0.06 m$^{-1/3}$ s, which was estimated by the results of the post-event hydraulic observation of the flow at the time of the other flood.

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Instead of the mud or water marks, the clearance of the Gokugo Bridge was also shown because it was the narrowest cross section of the river in the section upstream of the Kamikatsusaka Bridge.
The results are shown in Table 1. Comparing the estimated peak discharges in Table 1 with those computed from the Rational Method, the field estimation of the cross section “Culvert”, there is a good correspondence. On the other hand, the field estimation of the cross sections 1 and 2 are much larger than the computed ones.
The extent of influence of sediment movement at the cross sections 1 and 2 is much larger than that at the “Culvert”. This is considered to be the reason. At the same time, the inconsistency infers that the dominant phenomena which might have occurred around the cross sections 1 and 2 should not be flood but debris flow or hyper-concentrated flow. Actually, small debris flows were found to have occurred in the tributaries along the section near the cross sections 1 and 2(Fig. 1).

INTERVIEWS

We made interviews to the office staffs of the regional public works office who witnessed the development of the phenomena involved in the disaster and collected photographs taken of the damaged areas, mainly along Route 262 on the day of the rainstorm. Figure 3 shows pictures taken during the flood. It is estimated from the photographs and interview results that the phenomena involved in the rainstorm developed as follows:
The rain, which peaked once at around 9:00, peaked again around 12:00. However, they moved around in that area even after this time, which indicates that flow at the Kamikatsusaka Bridge was not blocked until around 12:00. They are sure that they crossed the bridge by car around 12:00. Although the bridge allowed traffic to cross until just before noon, The floor deck rose at 12:26 at the latest. The clogging of the bridge might have occurred at between 12:00 to 12:26 and caused the floor deck rift. Then they went along R262 around 550 m downstream of the bridge and, there, they could not move anymore because of debris flows began to occur from surrounding torrents along the road. According to photos taken in the field, they had already evacuated to the dividing strip of Route 262 (the location shown as the "Office staff evacuation point" in Fig. 1). At around 12:30, they said, the flow rate showed a sudden rise at that point. The flow of the increased discharge of muddy water had washed away the road maintenance car. At this moment, the bridge might have been completely blocked by woody debris or sediment.

CONCLUSIONS

We investigated high water marks of the flash flood or debris flow after the rainstorm and interviewed the eyewitnesses that were present during the disaster in order to determine the time sequence of the debris flow phenomenon in the Tsurugi River, Hofu, Japan. The results of the survey conducted so far suggest the following.

1. The peak discharge estimated from the high water marks was around 30 to 69 m^3/s at the investigated cross section. It was consistent with a peak discharge value obtained by simple runoff analysis. On the other hand, the peak discharge estimated for the downstream sections was much larger than that obtained through the runoff analysis. This is probably because of the influence of the debris flow or hyper-concentrated flow from the tributaries.
2. The flood discharge from the Tsurugi River to the national highway suddenly increased at around 12:30. At the same time, the ponding behind the Kamikatsusaka Bridge seemed to occur. Blocking of the river flow at the Kamikatsusaka Bridge had not occurred until around 12:00. However, it probably occurred at around 12:30 due to the occurrences of debris flows from the upstream.

These findings infer that the river channel of the Tsurugi River had succeeded in draining flood runoff until nearly the end of the rainstorm. At the last moment, however, occurrences of debris flows might result in the clogging of the bridge and the inundation.

Keywords: debris flow, post-event survey, interview, peak dischar