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Flash flood and debris flow in the Harihara River, Kyushu, Japan

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ABSTRACT

The flash flood and debris flow after a heavy rainfall wiped out a village of southern Japan on the tragic midnight of 10 July 1997, and a great loss of property and lives took place in this ill-fated incident. After the heavy rainfall, the debris flow induced by a sudden flash flood took 21 lives in Southern Kyushu. Detailed field investigation, in situ survey, electrical survey, and hydrogeological analyses were conducted to find out the triggering factors of the disaster.

The main factors of this disaster were a hidden fault and the perched groundwater. Moving soil mass downhill into the agricultural pond had triggered the flash flood. The details of sequential disaster events as perceived from the observation and analyses are presented in this paper.

INTRODUCTION

Disasters are frequently occurring all over the world. There are approximately 300,000 earthquakes in a year. The Pacific region alone suffers from about 25 typhoons per year, and there is a fire in every 9 minutes in Japan. Debris flows and landslides are natural disasters of geological origin. Debris flows are a mixture of the flowing earth, rock debris, and water that originate on a steep slope and may have devastating effect downstream. A sudden occurrence of debris flow without any pre-warning or awareness time makes it very dangerous. One such debris flow, which occurred just after a heavy rainfall, wiped out a village of southern Japan on the tragic midnight of 10 July 1997. The debris flow with a hydraulic jump had devastated the invaluable human lives, agricultural fields, and houses. The ill-fated event killed twenty one people on the spot. A big slope failure on the hillside and a large debris fan was observed on the morning of the next day.

The study area is on the southern foothills of Mt. Yahazu (687.5 m), and spreads around a fan-shaped circumference. The Harihara River originates from the springs of Mt. Yahazu and flows to the Ariake Sea. It forms fan deposits at the low-lying foothills near the Ariake Sea. The hydrogeological processes and analytical models were studied to determine the key mechanism of this disaster.

GEOMORPHOLOGY

The detailed survey and measurements were carried out in the landslide area. The positions of the river, fan, collapsed slope, agricultural pond, and check dam are shown in Fig. 1. The cross-sections of the collapsed hill and longitudinal section are shown in Fig. 2 and 3 respectively. A summary of the field measurements is given below:

Collapsed volume:	about 150,000 m^3
Thickness of collapsed slope:	maximum 40 m
Capacity of dammed water:	1,200 to 4,000 m^3
Distance from failed slope to pond:	160 m
Volume of earth at original riverbed:	30,000 m^3
Capacity of pond:	16,000 m^3 (depth 3 m), 20,000 m^3 (depth 4 m)
Capacity of debris barrier (check dam):	20,000 m^3
Watershed area:	0.69 km^2, and
Slope of fan:	about 3°

Slope failure and debris flow

Most of the documented debris flows in Japan have occurred in areas of relatively weak volcanic rocks that tend to trigger mass movements. Takahashi (1981) attributed debris flow initiation to landslide and subsurface flow during a heavy rainfall. Among the mass movements, most devastating ones are rock avalanche, mudflow, and rapid debris flow. Such mass movements are associated with flow-like phenomena. Terminal flow velocity, V_t, of a slide mass can be estimated as $V_t = \sqrt{2aL}$; where a is the acceleration and L is the travel distance of the mass movement. The flow can be laminar or turbulent depending upon the ratio of inertial forces to viscous forces termed as Reynolds number, R_e, defined as $R_e = \rho VR / \mu$; where ρ is the mass density of the flow, V is the flow velocity, R is the hydraulic radius of flow channel, and μ is the dynamic viscosity.

The momentum exchange (Henderson 1966) occurs on a microscopic scale in case of laminar flow. But the flow momentum exchange may be solely due to the shear resistance in case of turbulence.

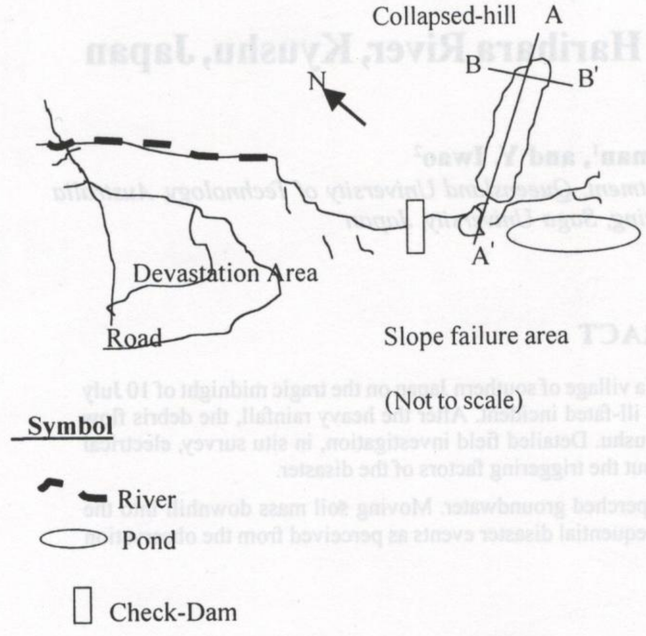

Fig. 1: General sketch of the landslide area

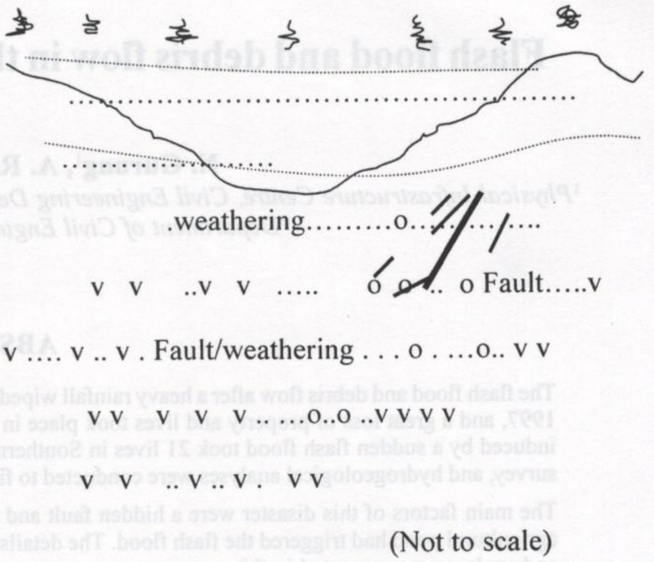

Fig. 2: Cross-section along BB'

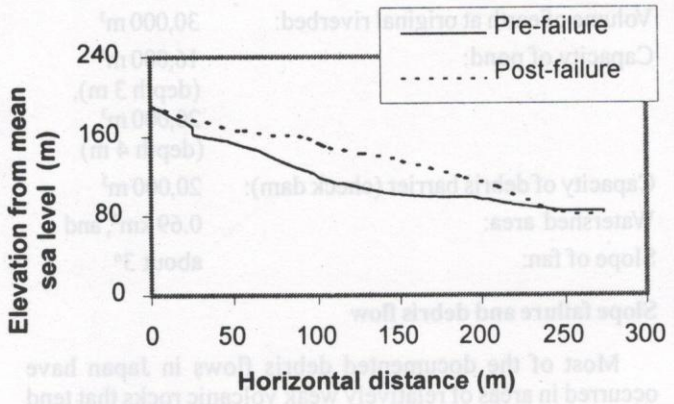

Fig. 3: Comparison of the pre- and post-failure longitudinal profiles along AA' (location is indicated in Fig. 1)

The dynamic viscosity (Johnson 1984) is defined as:

$$\mu = \tau_y [W / W_p - 1]^2 W_p / (4V_{\max})$$

The shear strength of the debris flow is described as:

$$\tau_y = t_d \gamma_d \sin\theta$$

where W is the channel width, W_p is the width of debris plug flow, $V_{\max}$ is the maximum flow velocity, t_d is the thickness of the equilibrium deposit, γ_d is the flow unit weight, and q is the slope of the channel. The shear strength of earth with roots may be estimated by $\tau = (c' + c_r) + (\sigma - u)\tan\phi'$; where τ is shear strength, c' is effective cohesion of earth, c_r is root cohesion, σ is total normal stress, u is pore pressure and ϕ' is effective angle of shearing resistance. Other dynamic models of landslide (e.g. O'Brien et al. 1993; Hungr 1995) were also examined in this study.

The foothill slope lying between 100 m and 190 m and having a width of 70–80 m had failed in a deep scoop shape. The failed slope was composed of highly fractured autobreccia of andesite, and its upper part was weathered strongly. Fig. 2 illustrates the lithology of the failure region. The soil surface was covered by vegetation (many trees were found buried in the debris). A fault zone with many slickensides was observed on the left flank of the failed convex valley. There was an aquifer of perched groundwater as indicated by the springs around the fault zone. The formation of a landslide dam in the river and development of a muddy water pool behind it were inferred on the basis of floodwater marks on the trees near the junction of the slope failure and on the left bank of the Harihara River. The landslide dam was partially filled up by the debris. The breaching of dam led to a hydraulic jump of the debris-laden water. The debris flow rolled down and abraded on the left bank of the Harihara River, and then buried an orange orchard. The head of the debris flow was tongue-shaped with big boulders in front of it. The riverbed of Harihara was filled up by the debris and was converted into an extensive fan containing big boulders underneath the red clayey soil. Some trees were standing intact on the fan.

The dynamic and static pressure of the incoming debris-laden water in the pond overtopped and destroyed it. Any trace of the agricultural pond after the disaster could not be detected. Grasses and small shoots were mowed down towards the downstream on both sides of the debris barrier (check dam) without any visual debris traces. The highest level was about 8 m above the dam crest. Towards the downstream of the debris barrier, many houses and orange trees were destroyed and uprooted, respectively. There were vivid flood marks (red stains of muddy water) around some houses, and a few cars were toppled down to wreckage without any trace of debris.

Faults

A number of slip surfaces associated with the fault zone were detected at the failed concave valley. Its direction of strike is N50–70° E and dip is 55–70° due W. Details on the weathering state of soil, rock mass condition, groundwater, as well as the presence of joints, slickensides, and slips in that location confirmed the fault zone as the real source of disaster.

Soil consistency

The red soil from the debris flow deposits as well as the clay from the fault zone was tested for consistency. The test results of liquid limit and plasticity index are summarised in Table 1. The soil from the fault zone contained a higher amount of clay minerals and showed greater plasticity index as well as higher liquid limit than that from the debris flow deposits.

Outflow of Harihara River

The longitudinal section (Fig. 3) shows the slopes along AA' before and after the failure. From the hydro-meteorological records of that day, the outflow of the Harihara River was back analysed, and obtained normal flow and maximum flood level are shown in Fig. 4.

RECORDS OF THE INCIDENCE

The records of the disaster incidence presented here are based on the memory of the survivors of the disaster as well as the field observation after the event.

Pre-warning sound

Many people heard a loud sound from 11 to 12 p.m. The disaster hit the area about 50 minutes later all of a sudden. The reported sound was like that of huge rock collapse and smash, and it is inferred to be the sound of moving landslide mass. The sound had echoed not only once, but also repeatedly for several times before the catastrophe.

Table 1: Results of soil test

S. N.	W_L (%)	W_P (%)	I_P (%)
1	66.6	39.6	27.0
2	77.5	39.5	38.0
3	96.0	41.9	54.1

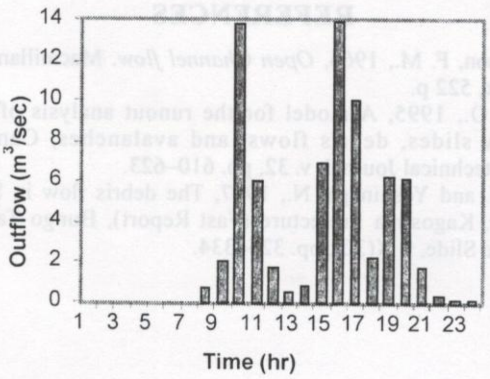

Fig. 4: Outflow hydrograph of the Harihara River

Flash water and debris flow

The survivors reported that they heard just before the disaster a loud repeated sound like "Ghoh … Ghoh….", as if giant pieces of rock were being ground, smashed, and rolled (Iwao and Yoshinaga 1997). It was nothing but the sound of moving debris flow. Hearing this sound, some alarmed people ran away from their homes. Many people lost consciousness during that sudden tragic moment. Only the lucky ones could come back to the sober world after a few moments later. The bodies of the unfortunate people were found buried under the debris deposits, between the damaged cars, refrigerators, and even under the beam wreckage.

Precipitation and river water level

At 4 p.m. on the previous day, the water level in the river had reached to its maximum. The water had overflowed the riverbanks and submerged the orange orchard and garden. The flood subsided to the normal condition only after 11: 00 p.m. Consequently, all the villagers went to bed. Only at midnight, the echoes of loud sounds had awakened them. But most of them could not figure out the reason and meaning of the sounds until it was too late for any safe runaway.

CONCLUSIONS

Detailed field investigations, laboratory tests, and hydrogeological studies were conducted to find out the main cause of this disaster. It seems that the presence of a fault zone along the foothills was one of the main factors of the disaster. A rise in pore pressure from subsurface flow in the fault zone started the initial slope failure, presumably between 11 and 12 p.m. The failed soil mass dammed the Harihara River, and large blocks of soil mass from the foothills began to slide. The soil chunks slid into the agricultural pond, and the liquefied soil mass due to mixing with pond water had attained hydraulic jumps and destructive speed. The resulting debris flows from the pond generated debris flow jumps that devastated the orange orchards, debris barriers, and houses.

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