A debris flow broke out at 16:40 on Aug. 18, 2004 in the Kitamatasawa, one of the right-bank tributaries of the Namekawa River in the Kiso River system. The flow volume (around 50,000 m³) was safely captured by the Namekawa No. 1 Sabo Dam, located at the downstream end of the tributary. Damage was successfully prevented, proving the dam’s effectiveness. A set of monitoring cameras installed around the site of the Namekawa No. 1 Sabo Dam and at various upstream points captured images of the debris flow. Here, we discuss the features of the debris flow based on analysis of these images.

1. INTRODUCTION

The Kitamatasawa is one of the right-bank tributaries of the Namekawa River, which joins the Kiso River (one of the largest river systems in Japan). The flow in the Kitamatasawa is characterized by a high average bed slope of 1/3.2 (17.4 degrees) and a relatively short length of water course, as shown in Table 1. The catchment area of the Kitamatazawa tributary is smaller than that of the main Namekawa River, which suggests a higher velocity of flows in the tributary.

<table>
<thead>
<tr>
<th>Description of the Namekawa River</th>
<th>Catchment area (km²)</th>
<th>Length of water course (km)</th>
<th>Average bed slope</th>
</tr>
</thead>
<tbody>
<tr>
<td>Namekawa</td>
<td>26.2</td>
<td>12.0</td>
<td>1/5.4 (10.5 degrees)</td>
</tr>
<tr>
<td>Kitamatazawa</td>
<td>6.2</td>
<td>5.2</td>
<td>1/3.2 (17.4 degrees)</td>
</tr>
</tbody>
</table>

Fig. 1 Plane View of the Namekawa River
The Namekawa River is one of most polluted rivers in Japan, with the heaviest sediment run-off in the Kiso River system. The Kitamatasawa is one of the streams from Mt. Komagatake in the Chuo Alps. The main soil textures in the river are of weathered granite origin, and collapsed geography is often seen in the upper catchment. The geography is as shown in Fig. 1.

The frequent debris flows of the Kitamatasawa are deposited and covered by many large stones. The deposition is as shown in Photos 1 and 2.

2. METEOROLOGY

Before the Kitamatasawa debris flow at 16:40 on Aug. 18, 2004, the active meteorology was driven by a stationary front in Honshu, which was shed by typhoon No. 14 offshore Kyushu. Many rain clouds flew in from the Shikoku and Kinki Regions, bringing heavy thundershowers.

The rainfall started on Aug. 17, with a short interruption, and amounted to 227 mm in total. An intensive 40 mm/hr was observed during 16:00 – 17:00 on August 18, 2004. The meteorology at the time of the debris flow is described in Figs. 2 and 3.

3. FLOW CAPTURE

The Namekawa No. 1 Sabo Dam had a milder bed slope after it was filled with deposit. The flow energy was thereby dissipated, and around 50,000 m$^3$ of debris was captured, as expected (see Photo 3). As a result, there was no damage downstream.

A description of the Namekawa No. 1 Sabo Dam is as follows.

**STRUCTURE:** Gravity-type Concrete Dam
- Height: 22 m
- Length: 300 m

**PROJECT PLAN:**
- Checking Volume: 134,100 m$^3$
- Sand Storage Volume: 309,000 m$^3$
- Dam Effective Volume: 227,000 m$^3$
Namekawa No. 1 Sabo Dam captured a large debris flow (around 200,000 m³) on July 9, 1989, three months after its construction was finished (March 1989). The history of recent debris flows captured by the dam is shown in Table 2. During the 29-year period from 1976 to 2004, a total of 13 debris flows occurred in the Kitamatasawa, with a mean frequency of one debris flow every 2 to 3 years. However, three debris flows occurred in 1999, as a result of a landslide dam that blocked the torrent near 1800 m elevation in 1998. The sediment volume of the debris flows was 20 to 200 thousand m³.

Table 2 Recent debris flow history in the Kitamatasawa

<table>
<thead>
<tr>
<th>Year</th>
<th>Month</th>
<th>Date</th>
<th>Sediment Volume (m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1976</td>
<td>9</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>1978</td>
<td>9</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>1983</td>
<td>6</td>
<td>21</td>
<td></td>
</tr>
<tr>
<td>1985</td>
<td>7</td>
<td>17</td>
<td>20,000</td>
</tr>
<tr>
<td>1986</td>
<td>8</td>
<td>6</td>
<td>28,000</td>
</tr>
<tr>
<td>1989</td>
<td>7</td>
<td>9</td>
<td>200,000</td>
</tr>
<tr>
<td>1993</td>
<td>7</td>
<td>14</td>
<td>60,000</td>
</tr>
<tr>
<td>1995</td>
<td>7</td>
<td>3</td>
<td>20,000</td>
</tr>
<tr>
<td>1999</td>
<td>6</td>
<td>27</td>
<td>50,000</td>
</tr>
<tr>
<td>1999</td>
<td>9</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>2004</td>
<td>8</td>
<td>18</td>
<td>50,000</td>
</tr>
<tr>
<td>2004</td>
<td>8</td>
<td>18</td>
<td>100,000</td>
</tr>
</tbody>
</table>
Fig. 4 Plane view of the monitoring system

Fig. 5 Longitudinal section of the riverbed
4. MONITORING SYSTEM

The Tajimi Office has established a debris flow monitoring system and has observed debris flows since 1982. Debris flow observations started at the Namekawa No. 1 Sabo Dam and extended to a series of goundsel series located from 550 to 1300 m upstream of the dam.

The monitoring system was installed in areas where debris flows had occurred. A total of 22 wire sensors were installed in the goundsel series and in the river channel upstream from the observation area. These wires are cut by passing debris flows. When sensors detect the wire breakage, closed-circuit television (CCTV) cameras begin to operate automatically.

For the Kitamatasawa debris flow (see Photo 4, Figs. 4 and 5), there were four CCTV cameras. Camera 1 viewed the Kitamata 4 goundsel from the front, Camera 2 viewed the torrent bed directly from above at a point directly downstream from the same goundsel, Camera 3 viewed the river course between the Kitamata 1 and 2 goundsel series from the right bank, and Camera 4 viewed the sedimentation area at the Namekawa No. 1 Sabo Dam. These cameras were equipped with floodlights and lens wipers so they could record images at night and during rainfall. Rainfall gauges installed at two locations in the basin provided precipitation data that could be used to study the triggering rainfall conditions.

Camera 1 recorded images of the flow, flow cross-section, wave height, and diameter of the transported boulders. Cameras 2 and 3 recorded images of the flow velocity, wave height, and diameter of the transported boulders. The velocities of the debris flows were measured by (1) records of wire breakage, (2) differences between the arrival times at the cameras and (3) particle velocities in images from Cameras 2 and 3. Methods (1) and (2) were used to measure the fronts of the debris flow, while method (3) was used to measure the surface velocity of the debris flow. The mean velocity was calculated by multiplying the surface velocity by 0.6, based on the flow distribution formula of Takahashi (1977). Calculating the mean velocity was useful for comparison with observation results from other regions and allowed calculation of the debris flow discharge. The wave height of the debris flow was measured by Camera 1 at the spillway of the Kitamata No. 4 goundsel, and the discharge of each debris flow was calculated by multiplying the mean flow velocity by the flow cross-section at the spillway of the Kitamata No. 4 goundsel.

Photos 5 and 6 show debris flow images taken by Cameras 3 and 4 on August 18, 2004.

5. CONDITION OF THE DEBRIS FLOW ON AUGUST 18, 2004

5.1 Specifications of the debris flow

Table 3 gives the specifications of the debris flow that occurred on August 18, 2004.

5.2 Conditions of the debris flow

Aerial photographs, laser measurements, and images taken by the CCTV cameras were used for analysis of the debris flow, as described below (Fig. 6).

(1) Occurrence Section

Aerial photographs and laser measurements confirmed large-scale erosion (to a depth greater than 10 m) of the streambed in the upper reaches, especially between elevations of 2100 and 2200 m. The expansion of the collapsed area could be seen at elevations above 2400 m, but on a smaller scale than that of the streambed erosion.

(2) Flow / Development Section

Scouring of the streambed was frequently observed in this section at elevations between 1,450 m (upstream of the uppermost goundsel) and 2000 m. Deposition was observed in narrow regions of the stream and its surrounding area around falls 1 and 2.

A lesser degree of degradation was observed immediately upstream of the No. 1 fall and the goundsel series, apparently because of the suppression effect of the No. 1 fall and goundsel on the streambed erosion.

(3) Flow Section

No conspicuous riverbed erosion or deposition was observed. The goundsel series exerted their ability to suppress sediment yield.

(4) Deposition Section

Sediment deposition was frequently observed downstream of the goundsel series. The debris flow moved down the channel on the left bank in the goundsel series region. Sediment deposition created by the debris flow blocked the watercourse that existed before the debris flow.

Once the sediment had blocked the channel, the subsequent flow followed a different course, moving away from the blockage point. The subsequent sediment overflowed and was deposited in a lightly forested flat area on the left bank. This sediment deposit stopped at the 2/3 gradient of the old riverbed on the left of the sediment range.
Photo 5 Debris flow images from a diagonal angle (CCTV camera 3)
5.3 Debris flow form (Figure 7)

A hydrograph of the debris flow was obtained from the images taken by Camera 3 (at an elevation of approximately 1,400 m). Images of the debris flowing down the sediment range of the Namekawa No. 1 Sabo Dam were also obtained.

From these images, the discharge of the debris flow was estimated at approximately 50,000 – 60,000 m³ (a total runoff of 81,000 m³). The peak discharge in the area of the groundels (at an elevation of approximately 1,400 m) was estimated at approximately 950 m³/s.

5.4 Sediment balance (Figure 8)

In the Occurrence Section, where the debris flow initiated, approximately 74,000 m³ of sediment derived mainly from the riverbed was transported downstream. We assumed that after having grown approximately 1.3 times in the Flow / Development Section, the debris flow stopped in the Deposition Section.

5.5 Sediment yield mechanism

(1) Medium- to long-term phenomena (indirect causes of the debris flow)

In the catchment area of the Namekawa River, 305 freeze–thaw days were observed during the period between 1999, when the second-latest debris flow took place, and August 2004. It is assumed that these freeze–thaw events advanced weathering and degradation of the granite, the bedrock of the area, and that unstable sediment had been deposited on the hillside and the streambed by the time the debris flow occurred in 2004. Conspicuous aggradation was noted in the previous year, 2003, at an elevation of approximately 2,050 m, where the debris flow was initiated.

(2) Short-term phenomena (direct causes of the debris flow)

When the debris flow occurred (in 2004), cumulative, hourly, and 10-minute precipitation values of 227 mm, 40 mm, and 10 mm, respectively, were observed. This rainfall pattern resembled the conditions before the initiation of previous debris flows. The slopes of the upper reaches and riverbed were supplied with enough water to trigger a debris flow. This caused a bed load transport debris flow.

5.6 Deposition mechanism

After the sediment of the debris flow was first deposited upstream of the Kitamata No. 11 groundsel (at an elevation of approximately 1,345 m), it created upstream sedimentation on the right bank of the sediment range of the Namekawa No. 1 Sabo Dam. It then shifted its course to the old channel on the left bank and approached the area immediately upstream of the dam.

Analysis of the particle sizes of the sediment from the three locations confirmed a gradual tendency of decreasing size. This change supports the hypothesized order of deposition for the debris. Moreover, we can assume that in the course of the deposition process, the main body of the debris flow deposited the sediment while its energy gradually dissipated.

Meanwhile, the upstream sedimentation that occurred in the sediment range of the Namekawa No. 1 Sabo Dam since 1995 was assumed to be a factor in the course shift back to the old channel on the left bank during the debris flow. After
The completion of the Namekawa No. 1 Sabo Dam in 1989, several debris flows were captured, resulting in topographic changes in the sediment range, which led to upstream sedimentation. The point where the slope of the old riverbed increased was a major boundary point of the area of upstream sedimentation. The old river course followed the left bank before the completion of the dam. These facts suggest that the old topography around the dam also affected the deposition of the subject debris flow.

### Table 3 Specifications of the debris flow

<table>
<thead>
<tr>
<th>Date of occurrence of debris flow</th>
<th>August 18, 2004</th>
<th>Time of occurrence</th>
<th>Around 16:40</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of debris flow</td>
<td>Bedload transport type (complex type)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overview of rainfall (at time of occurrence of debris flow)</td>
<td>Duration of rainfall: From 7:00, August 17 to 17:00, August 18</td>
<td>Rainfall pattern: Intense rainfall in the latter period</td>
<td></td>
</tr>
<tr>
<td>Observation station</td>
<td>Cumulative precipitation: 227mm (from 7:00 August 17 to 17:00 August 18)</td>
<td>Maximum daily precipitation: 163mm (from 15:00 August 17 to 15:00 August 18)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Maximum hourly precipitation: 40mm (from 16:00 to 17:00, August 18)</td>
<td>Maximum 10-minute precipitation: 10mm (16:20–16:30, August 18)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Maximum wave height: 6.0m</td>
<td>Maximum discharge: Approximately 950 m³/s</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total runoff: Approximately 81,000 m³</td>
<td>Sediment yield: Approximately 129,000 m³</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sediment deposits: Approximately 104,000 m³</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Fig. 6** Topographic changes before and after the debris flow in 2004
Fig. 7 Hydrograph of the debris flow in the Namekawa No. 1 Sabo Dam on August 18, 2004
6. POSTSCRIPT

The images of the debris flow presented in this paper provide important documentation of the views at a distant angle from the beginning till the end of the flow. It would be our pleasure if they could contribute to any further research on debris flows in the future.

REFERENCES

Received: 1 June, 2011
Accepted: 2 December, 2012