Disaster Report

Sediment-related disasters induced by the Noto Peninsula Earthquake in January 2024

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On January 1, 2024, a large-scale earthquake with a magnitude of 7.6 struck the Noto region, Ishikawa Prefecture, Japan. The earthquake and resulting tsunami together with crustal movement caused extensive damage across the region. The 420 cases of sediment movement (389 in Ishikawa Prefecture, 18 in Niigata Prefecture, and 13 in Toyama Prefecture) resulted in numerous casualties as well as damage to homes (57 completely destroyed, 33 partially destroyed, and 17 partially damaged) and infrastructure. River blockages occurred at 14 locations in six rivers. The Japan Society of Erosion Control Engineering immediately established a committee to investigate the sediment-related disasters, dispatching an urgent investigation team to the disaster area in collaboration with the Japan Landslide Society. On February 11 and 12, 2024, the team visited eight locations on the Noto Peninsula, investigating four landslide sites and four landslide with river blockage sites. Large-scale landslides along the coast on the northern side of the peninsula and a concentrated area of shallow landslides with associated continuous river blockages in the inland area were documented. The team concluded that the risk of the landslide dam body could burst and cause a debris flow at many river blockages is low. However, future disaster planning should include countermeasures aimed at the elimination of multiple large-scale river blockages formed in succession upstream and downstream.

Key words : 2024 Noto Peninsula earthquake, sediment-related disaster, landslides, river brockages

1. INTRODUCTION

On January 1, 2024, a large-scale earthquake with a magnitude of 7.6 struck the Noto region, Ishikawa Prefecture. The earthquake and subsequent tsunami together with crustal movement caused extensive damage across the region. The many landslides and river blockages resulted in numerous casualties as well as damage to homes and infrastructure. The Japan Society of Erosion Control Engineering immediately established a committee tasked with investigating the sediment-related disasters, and an investigative team, working in collaboration with the Japan Landslide society, was quickly dispatched to the disaster area. The team visited eight locations on the Noto Peninsula : Ichinose, Kumano, Inafune, Suzuya River and Kanakura River in Wajima City, Shimizu, and Nie in Suzu City, and Kawashima in Anamizu Town (Fig. 1), conducting their investigations on February 11 and 12, 2024. The objectives were to determine the overall scope of the sediment-related disasters and identify specific target areas for inclusion in more detailed investigations to be carried out during follow-up assessments. This disaster report provides a preliminary summary of information on the earthquake-triggered sediment movement and the resulting damage as determined by the urgent investigation team.

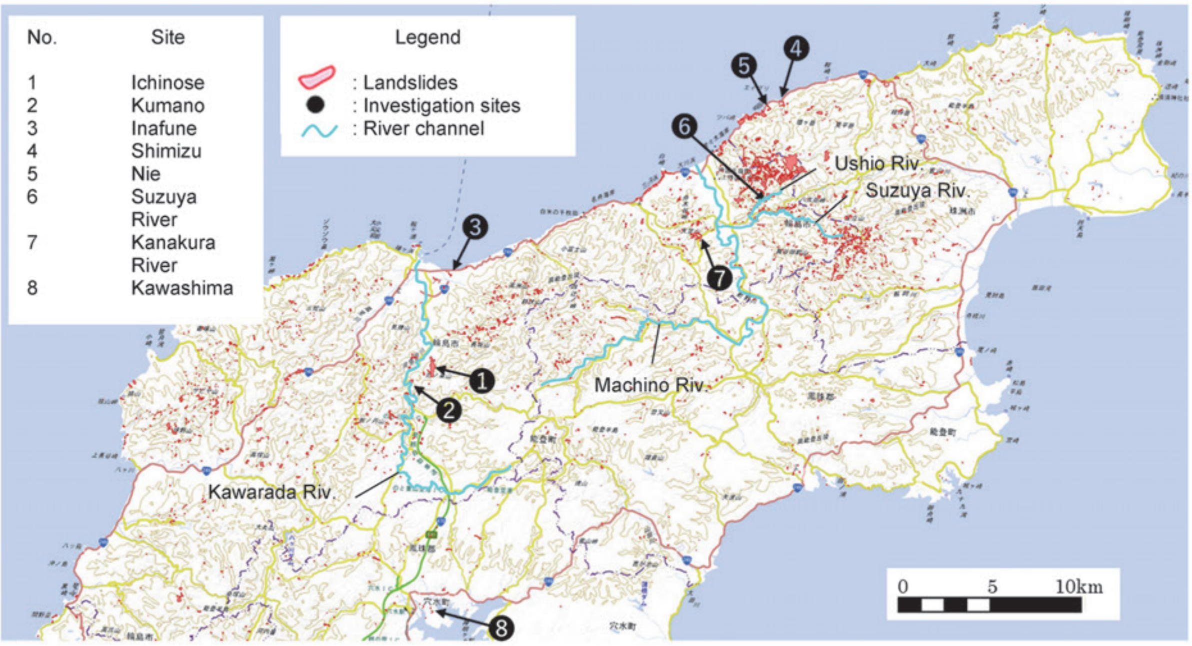

Fig.1 Map showing locations of the investigation sites (landslide location are shown on the map by the Geospatial Information Authority of Japan).

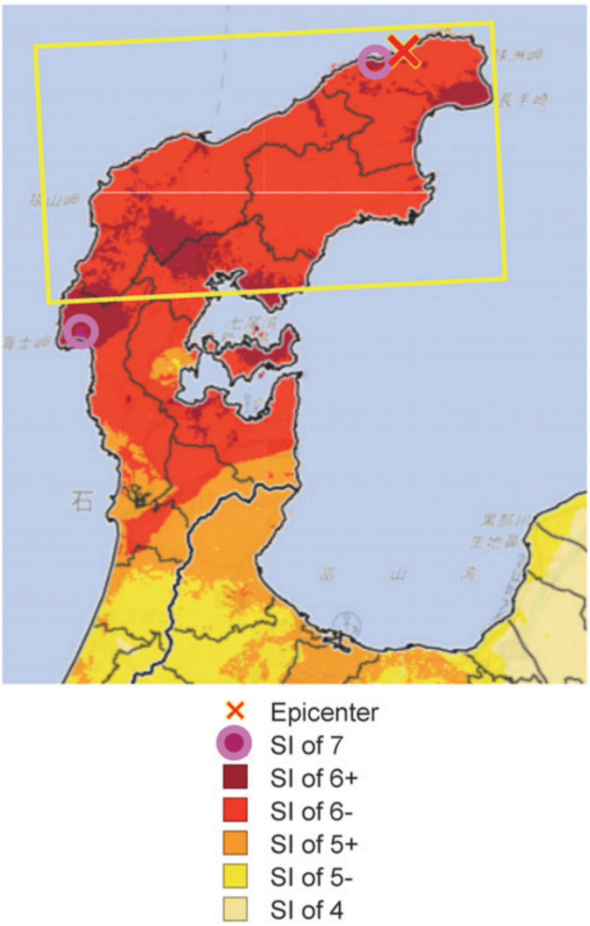

Fig.2 Distribution of estimated seismic intensity (Japan Meteorological Agency, 2024). The yellow rectangle represents the area in Fig. 1

2. OVERVIEW OF THE EARTHQUAKE

At 16 : 10 on January 1,2024, a magnitude 7.6 earthquake occurred at a depth of ～15 km in the Noto region of Ishikawa Prefecture. The earthquake induced a large acceleration with maximum of 16.32 m/s^2 (three-component composite), observed at the Wajima Observation Station of the Japan Meteorological Agency, and had a maximum seismic intensity (SI) of 7, recorded at Wajima City and Shika Town, Ishikawa Prefecture. An SI of 6 was registered across a wide area of the Noto region (Fig. 2). From 16 : 00 on January 1 to 8 : 00 on February 8, there were 1,608 earthquakes with a SI ≥ 1 (1 SI of 7, 2 SIs of 6−, 8 SIs of 5+, 7 SIs of 5−). The Japan Meteorological Agency has collectively referred to this series of seismic activities as the “2024 Noto Peninsula Earthquake” (Japan Meteorological Agency, 2024). The focal mechanism was a reverse fault type, with a pressure axis in the northwest-southeast direction, that occurred within a crust (Earthquake Research Promotion Headquarters, 2024). The area of subsequent seismic activity spread over an area of ～150 km, extending from southwest to northeast, across the Noto Peninsula and the sea area on its northeast side. In the northeastern part of the peninsula, seismic activity occurred at an even shallower depth than in the past.

3. OVERVIEW OF THE DISASTERS

In addition to the 8,754 completely destroyed, 18,974 partially destroyed, and 85,373 partially damaged residential buildings, there were 244 deaths, 320 serious injuries, and 980 light injuries (as of March 31, 2024; Fire and Disaster Management Agency Headquarters, 2024).

Tsunamis were observed over a wide area from Hokkaido to Kyushu region, mainly along the Sea of Japan coast, and the tsunamis with a height of 80 cm were observed in Kanazawa, in Ishikawa Prefecture and Sakata, in Yamagata Prefecture. A field survey showed traces of a tsunami with a run-up height of 5.8 m in Funami Park, Joetsu City, Niigata Prefecture (Earthquake Research Promotion Headquarters, 2024).

The damage to infrastructure and lifelines, including roads and water supplies, was catastrophic, and as of January 31 some 40,890 households in Ishikawa Prefecture still had water outages.

The earthquake caused 420 cases of sediment movement (389 in Ishikawa Prefecture, 18 in Niigata Prefecture, and 13 in Toyama Prefecture), resulting in numerous casualties and damage to both infrastructure and homes (57 completely destroyed, 33 partially destroyed, and 17 partially damaged).

4. OVERVIEW OF THE WEATHER

Figure 3 shows the precipitation and snow depth as determined at Wajima Observatory of the Japan Meteorological Agency. The total precipitation from December 15 to January 1,the day of the earthquake, was 342.5 mm, and the maximum precipitation intensity was 11.5 mm/h. From December 20 to 25, precipitation was mainly in the form of snow or sleet, with rain the rest of the time. On December 31, just before the earthquake, total precipitation, occurring as rain, was 29 mm, with a maximum rainfall intensity of 4.5 mm/h. Snowfall had occurred from December 21 to 22, with the snow depth reaching 60 cm. Rainfall and the relatively warm air temperatures beginning on December 23 caused active snowmelt, and the snow depth steadily decreased, reaching 0 cm on December 31. These precipitation conditions may have affected the occurrence of landslides and sediment transport mechanism, and this is an issue that should be investigated in detail.

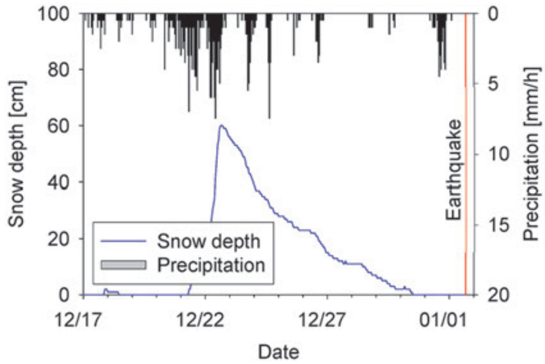

Fig.3 Changes in precipitation and snow depth at the Japan Meteorological Agency's Wajima Observatory.

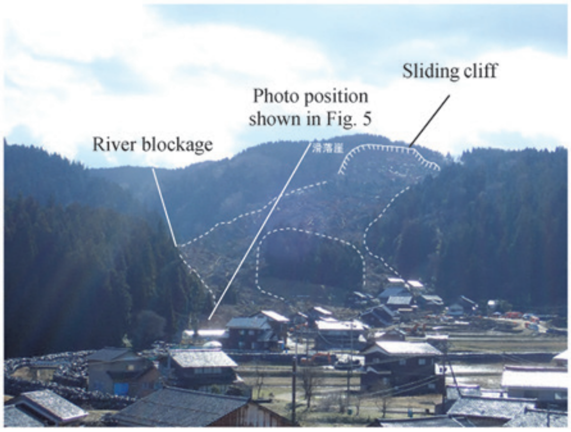

Fig.4 Landslide in Ichinose district.

Fig.5 Down most end of the landslide mass in the Ichinose district.

5. RESULTS OF THE SEDIMENT-RELATED DISASTER INVESTIGATION

5.1 Ichinose District

A landslide ～500 m long and ～150 m wide occurred on the left bank slope of the Momiji River (Sarutani), a tributary of the Kawarada River that flows north through the center of Wajima City. The landslide mass blocked the Momiji River, resulting in the formation of a dam lake (Fig. 4). Only visual observations from a distance were made during the February 11 investigation, but the landslide itself did not seem to be actively moving. The down-most part of the landslide mass was fluidized, consisting of fine particles and large amounts of water (Fig. 5).

The damage associated with the fluidized down-most part of the landslide mass is expanding. Whether this fluidization is due to the earthquake or to antecedent rainfall and snowmelt should be investigated. The movement range of the earthquake-induced landslides must also be assessed.

5.2 Kumano District

Landslides occurred at three locations on the slopes of the right and left banks of the Kawarada River, on the north side of the Kumano Tunnel on Prefectural Route 1 (Fig. 6). Landslide no. 1 (Fig. 6) was ～100 m long and ～250 m wide, and the landslide mass blocked the Kawarada River (Fig. 7). The survey on February 11 identified a flooded area upstream of the landslide dam. Because water was flowing through the dam and no seepage water was observed on the surface of the landslide dam body, there is little possibility that a burst of the landslide dam will cause damage downstream. The Kawarada River was temporarily blockaded due to landslides nos. 2 and 3 (Fig. 8), but the blockages had been disappeared at the time of the investigation.

Landslide no.1 on the right side of the bank involved the slope that collapsed due to the Noto Peninsula Earthquake in 2007 (Fig. 9), where a slope frame structure had subsequently been constructed. The development of effective countermeasures in the future will require studies of how the external forces exerted by the recent earthquake acted on slopes where countermeasures had previously been implemented.

5.3 Inafune District

A landslide occurred over an area ～200 m long and ～350 m wide on the slope south of National Route 249, which runs along the coast near the center of Wajima City. The landslide mass had not completely fallen, and many cracks and slope failures had developed in the surrounding area. Figure 10 shows the sliding cliff at the top (A), the collapse at the side (B), cracks in the pavement due to movement of the landslide mass (C), and collapse at the down-most end of the landslide mass (D). The top of the landslide appeared to be a sliding cliff located between the Wajima City Baseball Stadium (ocean side in the figure) and the Ishikawa Prefectural Wajima High School Baseball Stadium (inland side in the figure). This is because while cracks were found on the baseball field on the sea side (Fig. 11), none were found on the inland side. The eastern side of the landslide appeared to have extended to the area where the slope frame was damaged (Fig. 12). On the west side of the landslide, cracks extending through the baseball field and into the village were seen (Fig. 13), but beyond that cracks could not be confirmed. At the down-most end of the landslide, the landslide mass that had been pushed out from the slope facing National Route 249 collapsed (Fig. 14).

Because the sides of the landslide block (especially

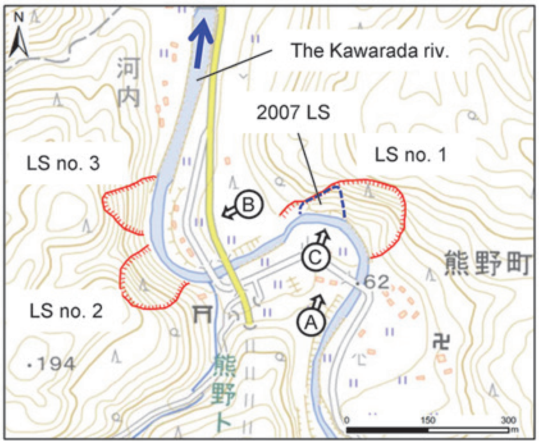

Fig.6 Landslide distribution in Kumano district (Added to the Geospatial Information Authority of Japan map).

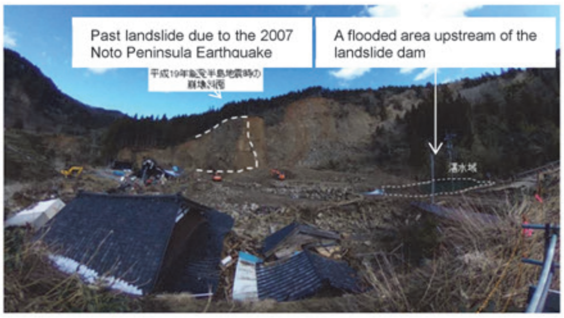

Fig.7 Landslide no. 1 and river blockage in Kumano district (A in Fig. 6).

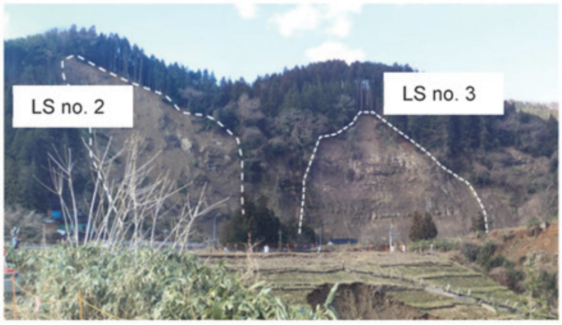

Fig.8 Landslide nos. 2 and 3 in Kumano district (B in Fig. 6).

Fig.9 Landslide by the 2007 Noto Peninsula earthquake (C in Fig. 6 ; Hayashi et al., 2007)

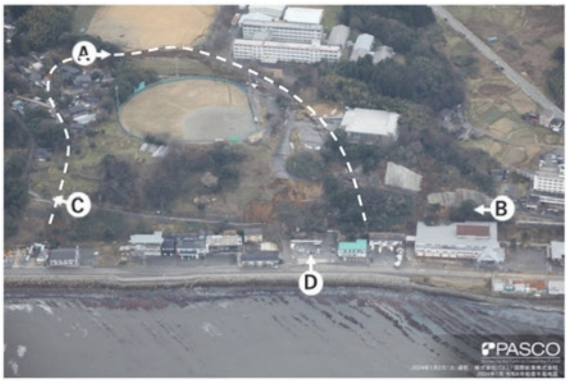

Fig.10 Oblique photo of the Inafune district taken from the north side on January 2, 2020 (provided by Pasco Co., Ltd. and Kokusai Kogyo Co., Ltd.).

Fig.11 Sliding cliff in the Inafune district (A in Fig. 10).

Fig.12 Collapse on the east side of the Inafune district (B in Fig. 10).

Fig.13 Collapse and road cracks on the west side of Inafune district (C in Fig. 10).

Fig.14 Collapse of the northern end of the Inafune district (D in Fig. 10).

the west side) could not be confirmed during the February investigation, the extent of the landslide block still needs to be determined. The top of the landslide block is a flat baseball field, and the topography before the construction of the baseball field must be investigated to identify the factors that caused the landslide. Cracks on the sliding cliff and sides of the landslide were clearly visible, and there is concern that the landslide will move again. Measures are thus required to prevent water from entering from the sliding cliffs and cracks.

5.4 Shimizu District

A landslide occurred on a slope of the south side of National Route 249 in Shimizu District, Suzu City, over an area ～250 m long and ～300 m wide (Fig. 15). A UAV survey revealed that the surface layer had collapsed over a wide area, with cracks apparently caused by the earthquake. The top of the landslide seemed to be a sliding cliff that occurred near the ridge, ～300 m south of National Route 249, with the movement of multiple blocks towards National Route 249 on the north side and towards the Sentani River flowing on the east side. The collapsed soil deposited along National Route 249 below the slope consisted of sandy soil, and saturated water flowed from the deposited soil (Fig. 16). The slope had been designated a landslide-warning area, and countermeasures such as slope protection, drainage borings, and channels had been implemented, but whether they suffered damage has not yet been evaluated (Fig. 17). The UAV survey revealed that sediment had accumulated in the

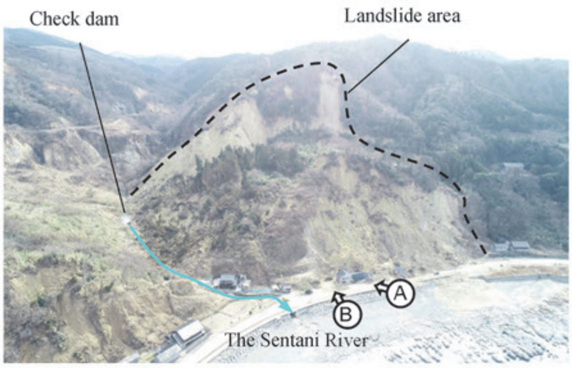

Fig.15 Landslide occurred in the Shimizu district (taken on February 11, 2024).

Fig.16 Damage at down most end of the landslide occurred in the Shimizu district (The photo was taken from position A in Fig. 15, National Route 249 : February 11, 2024).

Fig.17 Landslide slope with existing countermeasures in the Shimizu district (The photo was taken from position B in Fig. 15, National Route 249, February 11, 2024).

impermeable type check dam installed over the Sentani River on the east side of the slope, but it is unclear whether the sediment inflow had occurred before or after the earthquake.

During the February survey, the landslide area could

Fig.18 Landslide occurred in the Nie district (taken on January 2, 2024, provided by Asia Air Survey Co., Ltd. and Aero Asahi Co., Ltd.).

Fig.19 Landslide occurred in the Nie district (The photo was taken from position A in Fig. 18, National Route 249 on February 11, 2024).

be only visually confirmed from along National Route 249, using a UAV. A detailed investigation must be conducted to define the entire landslide area, by examining the sliding cliff at the top and sides of the landslide, and to elucidate the movement mechanism of the multiple individual landslide blocks. The landslide-warning areas and existing countermeasure facilities, such as the check dam, should also be assessed to confirm the damage and evaluate the efficacy of the countermeasure facilities during the earthquake.

5.5 Nie District

A shallow landslide occurred on a slope of the south side of National Route 249 in Nie District, Suzu City, over an area ～220 m long and ～100 m wide (Fig. 18). The slope topography is steep (～30°), and the top of the landslide was assumed to be near a ridge at an altitude of ～170 m. The condition of the landslide scar suggests that weathering had progressed deep into the bedrock. In addition, the discontinuous topography in the middle of the landslide scar (Fig. 19) suggested

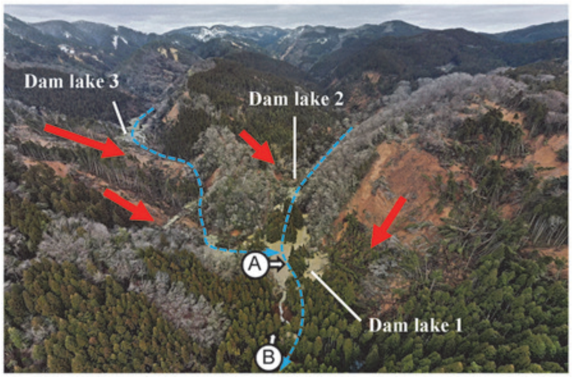

Fig.20 River blockages and their dam lakes formed in the Ushio River watershed (River channels are indicated by blue dotted lines and landslide directions are indicated by red allows).

Fig.21 A dam lake formed due to the river blockage by the landslide on left bank slope of the Ushio River (The photo was taken from position A in Fig. 20, flow direction and landslide direction are indicated by blue and red allows, respectively).

Fig.22 A dam lake with a small buoy installed for water level observation (red device in the center of the photograph), and its overflow part on existing forest road in the Ushio River watershed.

Fig.23 Overflow part seen from the downstream side of the river blockage on the Ushio River (The photo was taken from position B in Fig. 20).

the occurrence of multiple landslides in succession. As the slope had been designated a landslide-warning area, countermeasures, such as drainage borings, had been implemented, but damage to the respective facilities has not yet been evaluated.

Rescue operations were underway at the time of the investigation, such that the landslide area could be visually confirmed only from along National Route 249. The entire landslide area must be investigated in detail by assessing the sliding cliff at the top and sides of the landslide. The mechanism underlying the movement of the multiple landslide blocks remains to be elucidated. The landslide-warning areas must also be examined to determine both the damage and the effectiveness of the previously constructed countermeasure facilities during the earthquake.

5.6 Suzuya River Watershed

Numerous landslides occurred in the Suzuya River, a tributary that flows from the east to the Machino River in Wajima City. In the catchment of the Ushio River, which is the right tributary of the Suzuya River, a large-scale landslide developed on the slope along the river, with multiple river blockages confirmed near the confluence of the left and right tributaries in the middle reaches (Fig. 20). Near this confluence, a landslide over an area ～200 m long and ～100 m wide on the left bank slope of the meandering river channel (Fig. 21) resulted in the blockage of the river by the landslide mass, which included many large trees. The landslide dam was found to consist of silty sandstone gravel, and although water was not flowing down over it, seepage water was detected in the middle of the dam body. Water from the dam lake was flowing over the existing forest road, which had been constructed to create a shortcut through the meandering section (Fig. 22) and flowed down with a drop of ～15 m (Fig. 23). At the time of the investigation, the paving of the forest road and the exposed rocks underfoot were preventing erosion, and the point of overflow seemed to be relatively stable.

At the time of the investigation, there was no obvious evidence of erosion at the overflow point on the forest road. However, the bedrock beneath the collapsed forest road is easily weathered, such that continuous monitoring for signs of erosion is necessary. The spread of erosion and changes in topography around the seepage from the landslide dam body must also be monitored. Near the confluence, multiple large-scale river blockages and dam lakes formed in succession upstream and downstream. When the dam lake (no. 1 shown in Fig. 20) water is drained during a future measure, the expansion of the water head difference between dam lakes upstream (nos. 2 and 3 shown in Fig. 20) and downstream (no. 1) may affect the stability of the sediment dams and dam lakes (nos. 2 and 3). Careful monitoring of this area is therefore needed as well.

5.7 Kanakura River Waterched

Two landslides occurred on the left bank slope of the Kanakura River, a left tributary of the Machino River that flows through Machino-cho, Wajima City. The landslide on the northeast side (no. 1 in Fig. 24) was ～70 m wide and its path followed the valley's topography. The landslide on the southwest side (no. 2 in Fig. 24) was ～140 m wide with a cliff at the top, and the landslide mass had not completely collapsed but remained on the slope. The geology of the slopes is siliceous mudstone. Sediments produced by the landslides joined to reach the Kanakura River, resulting in its blockage (Fig. 24). However, the sediment that reached the Kanakura River appeared to have mainly come from the landslide on the southwest side. The landslide dam at the river blockage was only a few meters high, and water was already flowing over it (Fig. 25). Because the gradient of the Kanakura River is gentle, even if the dam bursts it is unlikely that the flooded sediment will travel far downstream. However, as there are houses downstream of the blockage, where the difference in relative height from the Kanakura River is small, whether re-evacuation will be necessary due to flooding should be evaluated.

The February field survey was limited to visual inspection and observation of the slopes and river blockage from a distance, using a UAV. Therefore, a landslide survey should be conducted to determine whether countermeasures are necessary, particularly with respect to the landslide on the southwest side.

5.8 Kawashima District

A landslide ～30 m wide occurred on the west slope of the baseball field in Kawashima District, Anamizu Town (Fig. 26). The sliding mass destroyed the houses directly below it, and its tip stopped ～80 m from the top of the landslide. Because the relative height of the landslide from the foot to the top was ～20 m, the soil mass moved horizontally over a distance approximately four times its height, which is farther than the distance moved by a typical landslide. Furthermore, the sliding mass was not completely disturbed but moved with its original shape intact.

Due to snowfall in late December and rainfall on December 31, the moisture content of the soil layer on the landslide slope may have been high at the time of the earthquake. It is important to clarify the causes of the movement of the sliding mass over long distances to develop effective countermeasures. This will require

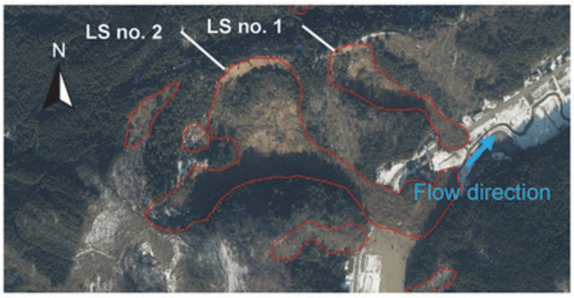

Fig.24 Landslides and a river blockage on the Kanakura River (added to orthogonal image by Geographical Information Authority of Japan).

Fig.25 Overflow part on the river blockage on the Ushio River (taken on February 12, 2024).

Fig.26 A landslide (shown by white dotted line and red allow) and damaged area at the Kawashima district (taken on February 12, 2024).

investigations of the factors that affect the moving distance of the sliding mass, including the level of moisture in the soil.

6. CONCLUSION

Taking into account the difficult situation in the disaster area, the urgent investigation team was made up of the minimum number of personnel necessary to carry out the investigation within a limited time in areas deemed to be highly urgent. Detailed investigations and research by the main investigation team are planned, but the issues revealed in the meantime by the urgent investigation team are as follows.

- Numerous sediment movement phenomena, such as shallow and deep-seated landslides as well as river channel blockages, were observed. To predict further damage, wide-area monitoring using satellites, helicopters, and drones should be conducted, with individual locations observed and monitored using extensometers and inclinometers.
- Although the urgent investigation did not reveal any areas with a high-urgency danger of a landslide dam burst, in some areas, such as the Ushio River, the multiple river blockages could affect each other. For this reason, both the water level and the movement of the surrounding soil in the landslide dam should be carefully monitored during countermeasure work.
- The damage caused by landslides on the north side of the peninsula, especially along National Route 249 facing the sea, was particularly severe. A large-scale landslide was also observed in areas such as Inafune District. Because there are areas where landslide prevention measures had already been implemented, whether the functionality of those measures has been lost should be determined before the next rainy season.
- While existing countermeasure structures were effective in some places, others were damaged such that their functionality and effectiveness may have been lost. The effectiveness of the countermeasures should thus be evaluated and additional measures taken as needed to prevent further damage from future earthquakes and rainfall.
- In some areas, such as the Ichinose District, the landslide mass fluidized and moved over a longer distance than generally expected. The moving distance of the landslide mass should be investigated along with the effects of the preceding rainfall and seismic motion.
- Whether it is possible to assess the risk of sediment-related disasters caused by earthquakes in advance, based on the characteristics of landslide slopes, should be determined. This is an issue that is closely related to the recovery and reconstruction of the disaster areas. It is also an important issue that must be addressed in Japan, as a country prone to earthquakes.

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NOTE: This disaster report is a partially edited version of the Japanese version of the report submitted to the Journal of the Japan Society of Erosion Control Engineering.

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