**Disaster Report**

**Landslide Hazards Induced by Heavy Rainfall in August 2021 in the Northern Part of the Aomori Prefecture, Japan**

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On August 10, 2021, a total of 454 landslides and debris flows in the northern part of the Shimokita Peninsula, Aomori, Japan, resulted in one of the major natural disasters in the region in recent years. Large amounts of rainfall of 385 mm fell on 9 and 10 August, due to low atmospheric pressure and the consequent Typhoon Lupit (No. 9) passing over the Sea of Japan. The event resulted in landslides, flooding, and damage to houses, roads, bridges, and carried large wood and debris into the rivers, which caused blockages at dam locations. Landslides occurred mainly in the fluvial dissected Koakakawa and Ohakakawa River Basins and on the steep slopes of costal terrace scarps nearby Yakeyamasaki. Landslides were primarily associated with weathered tuffaceous mudstone and weathered andesitic green-colored tuff in the Koakakawa and Ohakakawa Basins and weathered pyroclastic flow, colluvium, and gravel layers nearby the Yakeyamasaki. Pipping holes were observed within or at the bottom of weathered tuffaceous mudstone, weathered pyroclastic flow, and colluvium, suggesting the landslide occurrence may have been caused by the amount of groundwater present.

**Key words**: rainfall, landslide, large wood, Aomori

1. **INTRODUCTION**

Cyclones and typhoons in the area in and surrounding Japan can cause extremely devastating damage to infrastructure, agriculture, and even lives lost. In August 2021, due to the changing effects in extratropical cyclones and fronts caused by Typhoon Lupit (No. 9), the Aomori Prefecture, located in northern Japan, experienced an unusually large rainfall event with extremely heavy localized rainfall in the Shimokita and Kamikita Districts [Aomori Local Meteorological Observatory, 2021]. The rainfall began on the evening of August 9, 2021 and lasted until the morning of 10.

This event resulted in major disasters, mainly in Mutsu City, Kazamaura Village, and Shichinohe Town in the Shimokita District. In particular, there were many shallow landslides and coherent landslides...
occurring on the north-northeast slope of the Mt. Mutsu-Hiuchidake volcano, which resulted in a large amount of debris and large wood in the downstream rivers. No loss of life was confirmed, but the landslides caused severe damage to houses. Additionally, some villages were isolated due to the extensive road and bridge damage. There was also fishing and agricultural damage, and negative effects on tourism.

The Disaster Relief Act was applied to the affected areas in response to this disaster [Aomori Prefecture Disaster Countermeasures Headquarters, 2021]. The Japan Society of Erosion Control Engineering Tohoku Chapter organized the “Emergency investigation team for the August 2021 landslide hazards in the northern part of the Shimokita Peninsula, Aomori” together with the Japan Landslide Society Tohoku Chapter and conducted on-site surveys on September 19-20 and November 6-7, 2021.

This paper summarizes the damage in the Koakakawa and Ohakakawa River Basins, and the marine terraces facing the Tsugaru Strait (near Yakeyamasaki), where the landslides were concentrated. It presents a summary of the full survey results documented by the “Emergency investigation team for the August 2021 landslide hazards in the northern part of the Shimokita Peninsula.” The paper also reviews the geological and topographical features of the landslide disaster sites and the characteristics of the large wood that were generated in the disaster, and its consequences. Lastly, recommendations regarding the prevention of secondary disasters are made, as well as landslide-related countermeasures.

2. OVERVIEW OF GEOLOGY AND TOPOGRAPHY

Mt. Mutsu-Hiuchidake is a Quaternary period stratovolcano that has exhibited eruption activity since the Middle Pleistocene. This volcano is divided into the Older and Younger Hiuchidake, and formation activity of each is thought to be years ago, respectively [Umeda, 1992]. The Older Hiuchidake mainly formed the north-northeast slope of the volcano. A horseshoe-shaped caldera is located on the northeastern slope, which has been deeply carved by the Ohakakawa and Koakakawa Rivers and has subsequently created a highly eroded topography [Uemura and Saito, 1957] (Fig. 1(a)). There are also marine terraces on the Older Hiuchidake near the coastline [Umeda, 1992]. Koike and Machida (2001) indicated that although they are divided by several rivers, they were distributed almost continuously from Kinoppu to Ohmasaki.

Figure 1(b) shows a geological map around the survey site. Uemura and Saito (1957) indicated that the geology of the Koakakawa-Shimofuro region includes the Miocene Yagen Formation and the higher Pliocene Ohata Formation. The Yagen Formation is mainly composed of andesitic green-colored tuff and altered volcanic rock, and intercalated with sedimentary rocks such as sandstone, shale, and conglomerates. The Ohata Formation is mainly composed of pumiceous tuff and intercalated with tuff-breccia, sandstone, and conglomerates. The conglomerate is also distributed near the base, and there is a gravel layer (approximately 4 m deep) that consists of circular and subcircular rock fragments. These rock fragments had diameters ranging between 1 cm and 150 cm. Late Pliocene dacite is located at the top of the Ohata Formation, and volcanic ejecta of the Older Hiuchidake is distributed around Yakeyamasaki-Kuwahata [Umeda, 1992]. According to Uemura and Saito (1957), its composition is Suganoshiri tuff-
breccia, Okawajiri lava, and Lower Hiuchidake lava.

3. OVERVIEW OF RAINFALL AND SEDIMENT MOVEMENT

3.1 Rainfall conditions

Figure 2 shows the observed rainfall values at the Shimofuro rainfall gauge (Aomori Prefecture) in the area affected by the landslide. The event had a cumulative total rainfall of 385 mm, while the average rainfall for Shimofuro in August was 148 mm. Therefore, the rainfall was approximately 2.6 times the August average [Japanese Meteorological Agency, 2021]. The maximum hourly rainfall was 59 mm at 6:00 on 10 August, and the maximum 24-h rainfall was 369 mm. This was the highest observed maximum 24-h rainfall in the Aomori Prefecture since the start of rainfall measurements in 2001.

Figure 3 shows the relationship between the distribution of rainfall and landslides. Eight rainfall gauges were used to measure the rainfall for 9-10 August in the areas affected by the landslides. The Oma raingauge data was sourced from the Japanese Meteorological Agency AMeDAS, and seven rainfall gauges of Usoriyamako, Shimofuro, Ikokuma, Kinoppu, Ohata, Ohatachuryu, and Ohatajouryuy gauges were sourced from Aomori Prefecture. A comparison of the cumulative rainfall (Fig. 3(a)) and maximum hourly rainfall (Fig. 3(b)) (320-380 mm and over 45 mm/h, respectively) with the sediment movement range, showed that the sediment movement range in the Koakakawa and Ohakakawa Basins, and eastern side of Yakeyamasaki-Shinyukawa, coincided with the rainfall distribution. No landslide occurred on the south-west slope of Mt. Mutsu-Hiuchidake, which had less cumulative rainfall (280-300 mm) and a lower maximum hourly rainfall (40-45 mm/h). However, landslides were occurred in the western part of Yakeyamasaki-Kuwahata, despite having a similar, smaller scale of rainfall.

3.2 Sediment movement

The sediment movement range was extracted by interpreting images before and after the disaster. A Google Earth satellite image was used for the image before the disaster (July 19, 2021), while an optical satellite (a Pleiades image, with a spatial resolution of 0.7 m) was used for the image after the disaster (August 20, 2021). The landslides were also shown in photographs taken on August 11, 2021, which were released by Asia Air Survey Co. Ltd. (2021) and the Aero Asahi Corporation (2021). The Aomori Prefecture provided a video from a disaster prevention
A helicopter (nicknamed “Shirakami”) which was shot on 12 and 19 August. Field surveys were also carried out. The 454 extracted slope movement locations were concentrated in the terrace cliffs facing the Tsugaru Strait, on the edges of the terraces around Yakeyamasaki-Kuwahata, as well as in the Koakakawa, Ohakakawa, Shinyukawa, and Yakeyamazawa Basins (Fig. 1).

4. RESULTS

4.1 Damage to infrastructure

Evacuation orders were issued to 642 people in 339 households [Aomori Prefecture Countermeasures Headquarters, 2021], and no loss of life was reported. However, damage to houses was devastating. This included 14 houses which were completely destroyed and 498 partially destroyed [Aomori Prefecture Disaster Countermeasures Headquarters, 2021].

The damage to roads and bridges, which cut off links between regions, included the collapse of Koakakawa Bridge, which is a 10.4 km section of the National Route 279 from Kuwahata, Kazamaura Village to Akakawa Village, Ohata Town, Mutsu City. Forest roads were also damaged.

4.2 Koakakawa River Basin

In the Koakakawa River, a large amount of large wood flowed downstream to the estuary, but with no large sediment deposited. The accumulation of large wood debris was occurred at the Koakakawa Bridge. A sabo dam is located at the downstream end of the main river that accumulated various sizes of gravel, including rocks from the size of a fist to fine-grained sediment. It is assumed that large wood has a lighter density than gravel, and was carried over the dams with the heavy flows, travelling further downstream. Trapped woody debris caused inundation around the conservation target because the obstacle blocked the water flow in the river course.

Laser profiler (LP) data were acquired by the Aomori Prefecture in 2021, which showed imagery before and after the disaster, on 18 May and 29 August 2021, respectively. A differential analysis was performed using the LP data, which showed that there was a sedimentation build-up of approximately 2 m near the torrent control dam, which is located approximately 2 km upstream of the estuary. In this area, gravel build-up of approximately 1 m was mixed with fine sediment, and sedimentation occurred on the upstream side of the dam. In the main river channel, the accumulation of boulders, with a maximum diameter of approximately 2 m, was recorded at a point approximately 4 km upstream of the estuary. The gradient upstream of this area is approximately 8.0°, steeper than its downstream gradient of approximately 5.9°, where larger sediment was deposited. Therefore, it is possible that the debris flow accumulated up to this point and remained in this area.

Much of the landslides that occurred in the basin was shallow, with a depth ranging from 0.5 m to 3 m, and part of the argilized andesitic tuff became a slip surface (Fig. 4). Larger landslides were also observed at the upstream of the main river channel, of which with a maximum width and length of 23 m and 50 m, respectively (Fig. 4(a)).

Sections of the main and tributary riverbeds were exposed, and boulders exceeding 2 m appeared in the eroded and collapsed riverbanks, and were often near the centerline of the main river. This suggests that these boulders were deposited over time and were pre-existing accumulated debris, not a direct result of the landslide but rather a secondary effect of the heavy flows during the floods.

The peak volumetric flow rate was calculated by multiplying the flow velocity with the flow cross-sectional area. The flow velocity was estimated using the Manning formula, which uses water depth, average riverbed width, and average riverbed gradient. For this calculation, the water depth at the time of flooding was estimated based on the ground height from the LP data prior to the flood, and the roughness coefficient was set to n=0.10 (as it is assumed that the front of the debris flow contained boulders). From measurements taken prior to the flood using the LP data, the average riverbed width is between 8-17 m, and the valley riverbed gradient is between 3.0° and 7.5°. This calculation was done for three points in the river near the dam, located between 2.6-4.2 km from the estuary. The results showed peak flow of between 120-200 m³/s. Although the LP differential analysis in the tributary rivers showed a uniform erosion of approximately 2-5 m in the river channel (except for the collapsed upstream area), no local deposition of boulders were confirmed in the river channel.
4.3 Ohakakawa River Basin

4.3.1 Sediment and large wood flow

Sediment and large wood flowed downstream due to a total of 225 landslides in the upstream area of Ohakakawa. There are three sabo dams on the Ohakakawa River, and field survey results showed that sabo dam No. 3 (Fig. 1(a)) captured large amounts of sediment and large wood.

Sabo dam No. 3 is an open-type slit dam (concrete slit width of 1.8 m and height of 12 m) and is located approximately 1.7 km upstream of the estuary. Construction was completed in 2004, with a wall height and length of 14.5 m and 70 m, respectively. The riverbed gradient is approximately 3.8°. Subsequent to the flood, a visual inspection of the dam confirmed that the concrete slits were heavily blocked by sediment and large wood (Fig. 5).

At this point in the river, the flow rate at the time of flooding was considerable, and the scale of the backwater effect was extensive. Therefore, the flow of sediment and large wood was blocked at the upstream end of the backwater. Once stationary, the accumulation of sediment (in the backwater area) and the floating large wood separated. The subsequent decrease in water level resulted in the large wood settling just upstream of the No. 3 dam, where it finally remained.

4.3.2 Geology and features of landslides

The geology of the landslides was composed of tuff that has undergone hydrothermal alteration, with continuing argilization. The tuff generally softened as the argilization progressed, and it collapsed easily upon impact, for example, with a hammer (Fig. 6(a)).

In the collapsed areas, the bedrock exhibited cracks in several directions. The crack surfaces often exhibited slickensides (Fig. 6(b)) and dip slope characteristics. Landslides of various sizes occurred along these cracks, varying between several hundred to several thousand square meters. The landslide depth was usually approximately 1-2 m; however, the opening of the cracks resulted in separation of rocks, up to a depth of approximately 10 m. The separated bedrock pieces were soft and easily crushed, which indicated high hydrothermal alterations. The landslide was in an arc shape in the bedrock, which reflected that the geology was comprised of argillized tuff. Piping holes, which serve as pathways for water, were also noted in the highly weathered layer of the basement rock above the colluvium slope.

4.4 Yakeyamasaki-Kuwahata Area

4.4.1 Shindoutairasawa-Yakeyamazawa Area

Instances of landslide in Shindoutairasawa-Yakeyamazawa were distributed along the steep slopes of terrace cliffs (Fig. 1(a)). This collapse occurred in the gully-like topography, which may be former collapse sites. The highly weathered areas of the Lower Hiuchidake lava were noted as the probable source of the landslide. The Ohata Formation is distributed below this; however, the surface layer did not collapse to the point that it was scraped. On the outcrops of the landslide, a thick layer of gravel (approximately 1-2 m), was found on the basement.
rock Ohata Formation (Fig. 7). The colluvium was a loose deposit, mainly composed of a gravel layer on the basement rock.

4.4.2 Yakeyamazawa Area

Landslides that occurred in the area approximately 670 m west of the Yakeyamazawa River estuary were mainly distributed on the steep slopes of terraced cliffs and the upper slopes. The landslides were concentrated along the slope break near an altitude of 30 m. Highly weathered Suganoshiri tuff-breccia was seen at the head of the landslide source along the slope break (Fig. 1(a) and Fig. 8), with the Ohata Formation exposed below it. Beneath the highly weathered Suganoshiri tuff-breccia, there was a clay layer and sand layer with gravel and cohesive soil below these layers (Fig. 8). The clay layer became extremely impervious, and piping holes formed at the boundary between the clay layer and the layers below it (Fig. 9). Despite the fact that approximately 1 m of its surface layer had been removed, the Ohata Formation had not collapsed significantly. Figure 10 shows a failure that occurred below the slope break on a steep slope of approximately 40°. The bedrock of the slope is Ohata Formation that overlain by colluvium about 1 m thick. The colluvium is assumed to have higher permeability rate than the impermeable bedrock.

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4.5 Features of large wood

4.5.1 Ohakakawa River

A visual inspection indicated that approximately 70% of the large wood species in the basin comprised of cypress. As per the Koakakawa River Basin, the other species included cedar/pine (~20%) and broad-leaved trees (such as beech) (~10%). The morphological characteristics of the large wood varied, each piece with various combinations of roots, leaves, branches, and stems. Sometimes only a tree stem would be present, or only a stem with roots, for example. There was a large amount of large wood without bark in the sedimentation banks of the dam, but there was a large amount of large wood with bark present in other sections of the river.

Large wood surveys were conducted at four points; Fig. 11 shows these locations and Fig. 12 shows the results of the surveys. Measurements of large wood showed that at the most upstream site (No. 4), the maximum and average lengths were 25 m and 19 m, respectively. At the most downstream site (No. 1), the maximum and average lengths were 14 m and 8.0 m, respectively. The average diameter was 47.7 cm at site No. 4 and 36.7 cm at site No. 1, and exceeded 50 cm at other points. The maximum diameter of large wood found was 90 cm (these large pieces of large wood were of cypress).

4.5.2 Koakakawa River

There were many large pieces of large wood in the river after the large rainfall event. The main tree species was cypress, with cedar/pine, and broad-leaved trees (such as beech) being the other most predominant species.

Large wood accumulated at the Chijiri Beach near the estuary of the Koakakawa River (which included large wood drifting in the sea and from outside Koakakawa) had a diameter of approximately 40 cm and length of approximately 9 m (Fig. 12). In the area that was surveyed in this study, partially-remaining large wood had been captured in the No. 2 slit sabo dam, the sloped sections, and nearby trees in the river channel. There was no large-scale logjam present. The large wood generated in the area where the large-scale landslide had occurred was swept further downstream with the high flows. The maximum diameter of the large wood, which remained in the basin, was approximately 60-80 cm, and many large trees were destroyed. Diameters of cypress large wood sometimes exceeded 70 cm, and destroyed some trees which were over 150 years old.

5. CONCLUSIONS

This paper presents a summary of the full survey results by the ‘Emergency investigation team for the August 2021 landslide hazards in the northern part of the Shimokita Peninsula.’ The following bullets highlight the main conclusions from this disaster. In addition, urgent recommendations are made regarding the prevention of secondary disasters from cyclones, and makes landslide-related countermeasures in the affected areas.

1) The rainfall event discussed in this report is the largest since the start of measurements at the Shimofuro rainfall gauge in 2001. Since the Aomori
Prefecture is a region with relatively little rain, there are many slopes that are not acclimatized to rainfall. This may therefore contribute to the tendency for landslides to occur during a heavy rainfall event.

2) In this event, 454 locations experienced slope collapses due to heavy rainfall and created a large amount of unstable debris (sediment, gravel, and damaged trees and vegetation), which remained in the mountain streams and on hillside slopes.

3) The capture of debris was observed at the sabo dams and torrent control dams in the Koakakawa, Ohakakawa, and Shinyukawa rivers, which contributed to the reduction of damage in downstream areas. However, large wood has a lighter density than gravel, and was carried over the dams with the heavy flows, travelling further downstream. In Koakakawa River, inundation damage was significant around the conservation target. In the future, it would be beneficial to not only remove the sediment and large wood but also consider the installation of an open-type sabo dam that has a higher debris flow and large wood capture function than a close-type sabo dam (e.g., steel slits).

4) The landslides near Yakeyamasaki occurred on the terraced cliffs with large slopes. The topographical distribution of the collapse sites showed that these occurred along previous collapsed locations and slope breaks which formed horseshoe-shaped cliffs. Furthermore, the colluvium slopes were overlaid with formations of differing characteristics. Piping holes formed in locations where water flow was poor, resulting in water rising to the surface, causing landslide. Previous landslides may have been subject to these same influencing factors. However, in addition to the above, the August 2021 landslide may have been subject to the additional influencing factor of underground erosion (prior to the collapse), further aggravating the circumstances and possibility of landslides.

5) Considering the greater area of similar conditions and, therefore, the high probability of another such disaster occurring, it is recommended that detailed surveys of the collapsed locations be carried out. The topographical and geological features need to be determined, and the landslide mechanisms should be studied and estimated. Subsequently, countermeasures can be developed and put into operation.

6) Effective disaster mitigation methods, specifically for large wood, may only be proposed by clarifying the mechanisms which generate large wood during such an event. It is important to note that the large wood in this study contains a large amount of high-grade, large-diameter cypress material. This is advantageous, as it is otherwise difficult to acquire an under normal circumstances.

7) Landslides have caused major damage and impacted the lives of people who live in the affected areas. However, there is an opportunity to conduct disaster prevention education and public awareness, within the affected region.

This paper provided a brief summary of the full findings of this event, published under the title “Landslide hazards induced by heavy rainfall on August 2021 in the northern part of the Shimokita Peninsula, Aomori Prefecture” and was published in the Journal of Japan Society of Erosion Control Engineering, 74(6), 41-51, in 2022.

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