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AN OUTLINE OF HEAVY RAINFALL DISASTERS IN HIDAKA REGION, HOKKAIDO CAUSED BY TYPHOON NO. 10 IN 2003

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SYNOPSIS

Typhoon No. 10 hit the Pacific coast of Hokkaido on August 9 in 2003. Ten people were killed, 3 people were injured, and one person went missing who still has not been found. The typhoon resulted in the greatest damage caused by flooding in Hokkaido in the last twenty years. In the Saru River basin and the Appetsu River basin in Hidaka region, the typhoon caused serious damage, including flooding of houses and the destruction of houses and bridges. Farmland and flood plains were covered with large amounts of sediment.

In this paper, we report an outline of heavy rainfall damage in the Hidaka region in Hokkaido caused by Typhoon No. 10. The results of this investigation should help to clarify the mechanisms of heavy rainfall disasters using hydrologic and hydraulic knowledge.

INTRODUCTION

Typhoon No. 10 and a front caused heavy rainfall in Hokkaido from August 7 to 10 in 2003 with a record rainfall in Hidaka region, in the southern part of Hokkaido. The rainfall caused serious damage estimated at about 821 hundred million yen in Hidaka and Tokachi regions in the southern part of Hokkaido. Ten people died and one person was reported missing. The Hokkaido Regional Development Bureau of the Ministry of Land, Infrastructure and Transport asked the Japan Society of Civil Engineers to carry out an investigation of the damage caused by the heavy rain.

This paper presents a summary of findings in a report on the causes of damage in the Saru River basin and the Appetsu River basin (see Fig. 1) by the "Typhoon No. 10

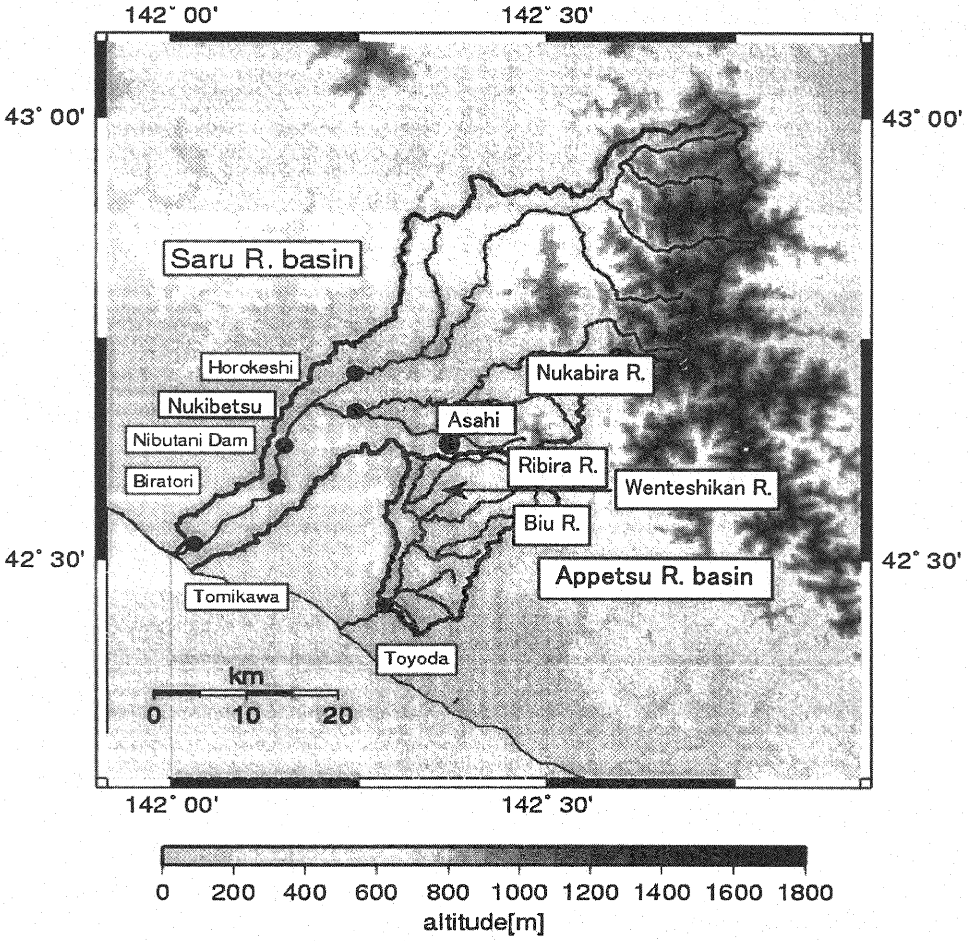

Fig 1. Overview map of the Saru River basin and the Appetsu River basin

Hokkaido Heavy Rain Disaster Investigation Team 2003" organized by the Committee on Hydraulics (Japan Society of Civil Engineers)(1). Translation to English was carried out by G. Tanaka.

SUMMARY OF HEAVY RAINFALL DISASTER

Ten people died, 3 people were injured and one person was reported missing after Typhoon No. 10 had passed over Hokkaido. Fig. 2 shows the flood in the upstream side of the Saru Rive. According to data collected by the Hokkaido Prefecture Government Office, 18 houses (18 households) were completely destroyed, 13 houses (13 households) were partially destroyed and 20 houses (20 households) were damaged, and flooding occurred above floor level in 129 houses (133 households) and below floor level in 438 houses (482 households). The total number of evacuees was 8,315. Most of the people who died had been traveling in cars when the typhoon passed over Hokkaido. A car fell into the Rubeshibe River in Kamishihoro Town because the road collapsed due to the progression of bank erosion to the backfill material of the abutment, and another car that had stopped near the Akamu Bridge across the Appetsu River was carried away by the flood. Residents of the area (7,304 persons, 3,058 households) were urged to evacuate,

Fig. 2 Flood in the upstream side of the Saru Rive (Kotan Bridge cross its tributary, the Nukibetsu River)

and 1,011 residents (266 households) evacuated. In Tomikawa district in Monbetsu Town, where the number of evacuees was largest (5,583 persons, 2,412 households), residents were urged to evacuate because of a warning water level for the Saru River. The latest estimates (September 25, 2003) of damage costs came to a total of 2.1 hundred million yen for housing, 177.3 hundred million yen for agriculture, 103.5 hundred million yen for forestry, 523.8 hundred million yen for civil engineering works, 5.4 hundred million yen for commerce and industry, 6.6 hundred million yen for water supplies, hospitals and waste treatment plants, and 1.8 hundred million yen for schools and educational facilities. In the agricultural sector, the greatest damage was to rice crops, and vegetables and grass were also severely damaged. Damage to barns and injuries to breeding horses were also significant (Fig. 3). Civil engineering works-related damages included damage at 690 sites of rivers (a total cost of 423.4 hundred million yen), 3 landslides (a total cost of 0.42 hundred million yen), damage at 389 sites of roads (a total cost of 81.1 hundred million yen), damage to 43 bridges (a total cost of 16.3 hundred million yen), damage at 3 parks (a total cost of 0.71 hundred million yen) and damage at 6 harbors and fishing ports (a total cost of 0.74 hundred million yen), and the total cost of damages as estimated on September 22, 2003 is 523.8 hundred million yen. Fig. 4 shows a collapsed road due to the progression of bank erosion to the backfill material of the abutment. Damages to railway lines included sediment inflow at 86 locations, collapse of embankments and banking at 19 locations, subbase course loss at 8 locations, and bridge pier loss at 1 location. As a result, Hokkaido Railway Company and Hokkaido Chihoku-Kougen Railway Company were forced to stop operations of 306 local trains. Thirty sections of 18 national roads and 60 sections of 50 prefectural roads were closed. Damage to lifeline services included power cuts to 1,419 households, suspension of telephone line transmission for 357 households, and suspension of water supply to 796

Fig. 3 Collapsed barn on the lower stream of the Appetsu River due to the flood

Fig. 4 Collapsed road due to progression of bank erosion to the backfill material of the abutment (Photograph offer: Hokkaido Prefecture Government Office)

households (2,162 persons). The suspension of water supply was mainly due to fractures of drainpipes, sediment inflow to intake facilities, pump trouble and disappearance of wells.

RESULTS OF DISASTER INVESTIGATION

Rainfall Characteristics

Typhoon No. 10 and a stationary front, whose activities became active due to the typhoon, caused heavy rain in the southern and eastern parts of Hokkaido. The rain actually began to fall at 4 a.m. on August 9 and continued to fall for 24 hours until 4 a.m. on August 10. In particular, a heavy rain cloud covered the Hidaka region for 12 hours, from 2 p.m. on the 9th until 1 a.m. on the 10th. The amount of rainfall observed at the AMeDAS Asahi gauging station during this time was the highest in the whole observation period. The maximum daily precipitation and hourly precipitation reached 358mm and 76mm, respectively. The storm cluster, which occurred from dawn on August 9 to the morning of August 10, was comprised of three phases. Each phase had a local maximum intensity. The latest phase, which occurred from 8 p.m. on the 9th to 1 a.m. on the 10th, had the highest intensity in the storm cluster. The precipitation over the 3 days was more than 300mm. The majority of it fell in one day, on August 9. Moreover, about 50% of it fell within 5 to 6 hours during the night. This rainfall pattern was the most distinctive feature of the rainfall event. After examining the spatial distribution of hourly precipitation observed at each gauging station, it was observed that the highest hourly precipitation occurred near the Asahi district in the southwestern part of the Nukabira River basin, which was in contact with the Appetsu River basin. It rained locally and over a short term in this area. The area of heavy rainfall expanded just like a belt, moving towards the southwestern slopes of the Hidaka Mountains. It was presumed that the geographical features had an effect upon the development of the rain.

A stochastic evaluation of maximum 48-hour precipitations in one year was carried out from 1962 to 2003 including this rainfall event (42 samples) for the Saru River basin. It was estimated that the 100-year probability rainfall was 320mm to 350mm, and that the probability (return period) of rainfall of 300.6mm was 60 to 70 years. Significantly, the following data became clear after carrying out a stochastic evaluation of maximum 48-hour precipitations from 1962 to 1998 (37 samples): the 100-year probability rainfall was 250mm to 270mm, which was greatly surpassed by the amount of rainfall observed here, and the probability (return period) of rainfall was 210 to 320 years, which was well above the usual 100 years. In fact, rainfall events of over 150mm were recorded 6 times in the 37 years up to 1998. On the other hand, they also occurred 3 times in the 5 years after 1998. These findings indicated that the average maximum 48-hour rainfall for the previous 5 years had been increasing.

Runoff Characteristics

A feature of the runoff shown on a hydrograph was the very rapid increase of discharge, which reflected the features of this rainfall event. On a hydrograph estimated by using observation data from Horokeshi gauging station, the discharge curve began to rise at 3 p.m. on the 9th (at that time the discharge was about 200m^3/s) and peaked at 1:30 a.m. on the 10th (by that time the discharge was about 4000m^3/s). The difference between build-up time and peak time was about 10 hours, and the rate of increase of discharge reached 360m^3/s/h on average. The concentration time was very short, and the times of peak water stage observed at the gauging stations were almost the same. In the Saru Rive, the concentration time was estimated to be one hour. This was determined by evaluating the difference of the peak time of discharge observed at Biratori gauging station and Tomikawa gauging station, which was 13 kilometers away from Biratori gauging station, and by using the revised value at Biratori gauging station.

The coefficient of discharge estimated by using observation data from Toyoda gauging station on the Appetsu River was almost unity, even if missing values were estimated low. The coefficient of discharge was above unity in some floods with a large peak discharge in the whole observation periods. Such findings on runoff characteristics for the Appetsu River basin suggested that the runoff was similar to surface flow on ground with bad permeability. At the Toyoda gauging station point, a hydrograph was estimated by using the following calculation methods:

1) A calculation method using a lumped parameter model based on the flood data in the Appetsu River basin and the Nukabira River basin, which was in contact with it.
2) A calculation method using a Kinematic Wave model for the slope and the channel, simulated by using the Digital National Land Information.
3) A calculation method using a Kinematic Wave model for the slope and a Dynamic Wave model for the channel.

Each of the simulated peak discharges was 1) 2000m^3/s to 2200m^3/s, 2) around 2600m^3/s and 3) 2680m^3/s, respectively.

Slope Failure, Sediment Yield and Driftwood Occurrence

In the Nukabira River basin in the upper part of the main stream, the Saru River, the landslide area rate was below 0.4% from 1955 to 1993. However, the result of interpreting an air photograph taken after this heavy rainfall disaster showed that the rate increased rapidly to 1.5% (about 3.6 times normal). The following became apparent after carrying out field investigations on two tributaries of the Saru River: the small Rubesyubenai River tributary in the midstream and the Paradai River in the lower stream. A large amount of sediment was left on the stream bed; the estimated sediment in the Rubesyubenai River was up to 1.5 times of the level recorded after heavy rainfall in 1992, and the estimated sediment in the Paradai River was up to 1.8 times that recorded in the same rainfall event. In the Appetsu River, the landslide area rate reached 0.9%, which was an increase of about 3 times the rate estimated by interpreting an air photograph of Mt. Ga-hari taken in 1998.

Almost all the landslides which occurred in this area were surface failures: forest soil of a thickness of 10 to 50cm slipped along over the bedrock of the steep (around 30 to 40 degrees) slope. However, it was found that a different type of landslide also occurred due to the respective differences of surface geology and rain conditions. In Nukabira River basin, the amount of hourly rainfall was one of the main causative factors of landslide. Geology, slope gradient and the total amount of rainfall were also significant factors.

When considering the landslide area with reference to a vegetation map, the respective rates of the area in the broad-leaved forest and the area in the conifer-hardwood mixed forest were found to be high. In the Nukabira River and the

Fig. 5 Landslide area in the Appetsu River basin

Appetsu River basins, about 75% of the landslide area was within the natural forest, but there was almost no damage due to landslide in artificial forest areas. The rate of the area in the natural forest and the rate of the area in the artificial forest for the landslide area in both basins also showed a similar tendency.

Collapsed sediment volume due to landslide, the volume of sediment which reached the river channel and sediment yield were estimated to be as follows: collapsed sediment volume in the Nukabira River basin due to landslide was about 8 million m^3 (including the void volume) and about 2.5 million m^3 of it reached the river channel. The sediment yield at the Nukibetsu site was estimated to be about 0.48 million m^3, excluding the void volume (the volume of soil particle), by measuring the SS (Suspended Solid) concentration of river water sampled from its surface. In the upper stream, from the confluence of the main stream of the Saru River and its tributary, the Nukabira River, investigations of collapsed sediment volume due to landslide and the volume of sediment which reached the river channel had not yet been carried out; however, the sediment yield at the Horokeshi site was estimated to be about 0.74 million m^3 (excluding the void volume) by using the similar way.

The sediment accumulated in the Nibutani Dam was estimated to be around 0.74 million m^3 (excluding the void volume) by examining the SS concentration and discharge observed at dam site and some points in its lower stream. The estimate was almost equal to the reading of sediment at the dam obtained by sounding, and was about 2 times that in an average year.

On the other hand, the areas which had largely collapsed due to landslide in the Appetsu River basin were located in the upstream basin of the main stream, the upstream basin of its tributary the Ribira River, the upstream basin of the Ribira River's tributary the Wenteshikan River, and the upstream basin of the Biu River. The total

Fig. 6 Flood in the lower stream of the Akamu Bridge cross the Appetsu River (Photograph offer: Hokkaido Prefecture Government Office)

Fig. 7 Flood levee failure in the upstream side of the Higashikawaoohashi Bridge (Photograph offer: Hokkaido Prefecture Government Office)

volume of collapsed sediment in the whole area due to landslide was estimated to be about 1.8 to 1.9 million m^3 (including the void volume) (Fig. 5). The total volume of sediment which flowed into the respective tributaries from the upstream basin of the main stream of the Ribira River, the upstream basin of the Biu River and the upstream basin of the Wenteshikan River was about 0.425 million m^3. The total volume of sediment which flowed into the tributary and the main stream from 10 river basins, excluding those just mentioned, was also estimated to be about 14 thousand m^3. The volume of wash load discharged from the whole of the Appetsu River basin was to about 0.36 to 0.72 million m^3.

The volume of driftwood which flowed out of the landslide area in the Nukabira River was estimated to be 81 thousand m^3, excluding the void volume. About 26 thousand m^3 of it reached a river channel. Moreover, about 20% of it drifted downstream and was deposited on banks and in reservoirs. The volumes of driftwood per unit area, which were produced in the basins of the Nukabira River and the Appetsu River, were almost equal (211 to 248m^3/km^2). The volume ratio of driftwood that reached a river channel outlet (the sea or a reservoir) to that produced in the river basin was estimated. That ratio for the Nukabira River in this rainfall event (about 10%) was roughly the same order as that ratio for the Saru River in 1992.

Flood Characteristics

At the gauging stations on the Saru River, the highest water level in the whole observation period was recorded: one observed at Biratori gauging station exceeded the designed high water level (27.55m) by 74cm, and one observed at Tomikawa gauging station exceeded the designed high water level (7.06m) by 60cm. Most of the estimated water levels on the lower stream of Nibutani Dam reached very high water levels, which were above the designed heights. From the results of investigation of flood marks observed on the Nukabira River on the upper stream of Nibutani Dam, it was found that high-water marks had reached the levee crown, and that the river had overflowed at 5 sites on left bank and 2 sites on right bank.

The Appetsu River flooded from the river mouth to the confluence with the Ribira River because the estimated flood discharge at the Akamu Bridge site was over 2000m^3/s-much higher than the river flowability at Akamu Bridge (about 1000m^3/s). In the downstream area where river improvements had already been carried out, the overtopping and the flooded water from the levee crevasses flowed on the protected lowland in the form of a river channel (Figs. 6, 7). In the upstream and midstream areas where river improvements had not yet been carried out, the entire area of even land in the valley became a flood plain when the river broke its banks. The confluence of the main stream of the Appetsu River and its tributary, the Biu River, flooded widely because a complicated flow occurred at the bend near the confluence of two rivers. The result of a numerical analysis based on a two-dimensional shallow water flow model showed that the flood plain played the role of an enormous double-row sand bar during the flood.

Characteristics of Sediment Transport and River Channel Process

In the Saru River basin, the sediment yields at the outlet of Nibutani Dam and the total sediment yields at the Sarugawa Bridge near the river mouth were 1.06 million m^3 and 1.01 million m^3, respectively. As a result, a sediment yield of 0.05 million m^3 was deposited at the lower stream of the Nibutani Dam. At many sites where bank erosion was investigated, and where marks had been laid underground before this rainfall event, it was found that the banks had at first been largely eroded. The eroded sites were subsequently refilled with discharged sediment from the upper stream. Because the concentration of suspended soil reached a high level due to bank erosion when the water level was rising, the eroded sites were refilled with this suspended soil when the water level subsequently decreased. At the erosion control dam in the upstream of the Syukusyubetsu River, a large amount of sediment was deposited in its lower stream after the flood. At the Nukabiragawa-3-gou Dam, the head decreased from about 5m before to 1.3m after the flood due to depositing of sediment.

In the Appetsu River basin, a large amount of sediment - about 1.8 million m^3 (including the void volume) - was produced due to landslide and a debris flow. The channel morphology changed largely; however, the respective rises in bed levels in the midstream and downstream basins of the tributary and the bed level in the main stream were several dozen centimeters on average. When a flood occurred in this area due to this rainfall event, the whole flood plain, whose shape was like lengthwise connected gourds, was covered with significantly deep flood water. The maximum water depth at the site was over 2m. The flood flow here had essentially the same properties as the flow on an enormous double-row sand bar. As a result, large-scale changes of the river channel such as the formation of new river channels along both sides of the valley, which corresponded to front sand bar-lines, occurred. Sediment including cohesive soil, silt and sand was deposited comparatively deeply on the central area of the flood plain. This corresponded to an antinode of a double-row sand bar. Damage, such as erosion of the low water channel and the levee, and flood levee failure, was concentrated at the node of a double-row river channel, where two flows met to start branching again (on the front edge of an enormous sand bar, at the point of divergence and convergence of an 8-shaped flow) (see Fig. 8). At the upstream side of the node, the flood flow over the flood plain corresponding to a double-row bar and two newly formed main streams, which occurred in the upper stream of this site, converged. As a result, levees and banks burst due to flow from the protected lowland side. On the other hand, at the downstream side of the site, failures of levees and banks occurred from the riverside land because the flood flow diverged and ran again over the flood plain. Such failures were widespread at this site, where the levee line intersected the axis of the valley at a large angle.

Driftwood Behavior and Its Effect

After making an extensive investigation into driftwood in the Saru River basin, it was found that mainly coniferous trees scores of years old, and willow trees at the age of around fifteen years were carried away from mountains and high-water channels, respectively, and that 280m^3 out of the total volume of those trees was drifting in the river. The following facts became clear: out of the driftwood not reaching the sea, about 24,000m^3 stayed in the Nibutani Dam; moreover about 8,600m^3 of driftwood was deposited in the river channel; the majority of the latter had been caught in the riparian forest. It was also clear that about 60% of the driftwood had been produced for the first time after this rainfall event. An observation of the process of the driftwood produced from the riparian forest in the river channel revealed that 3,400m^3 was deposited at the mouth up to the Nibutani Dam, and 8% of it (280m^3) was produced mainly from the

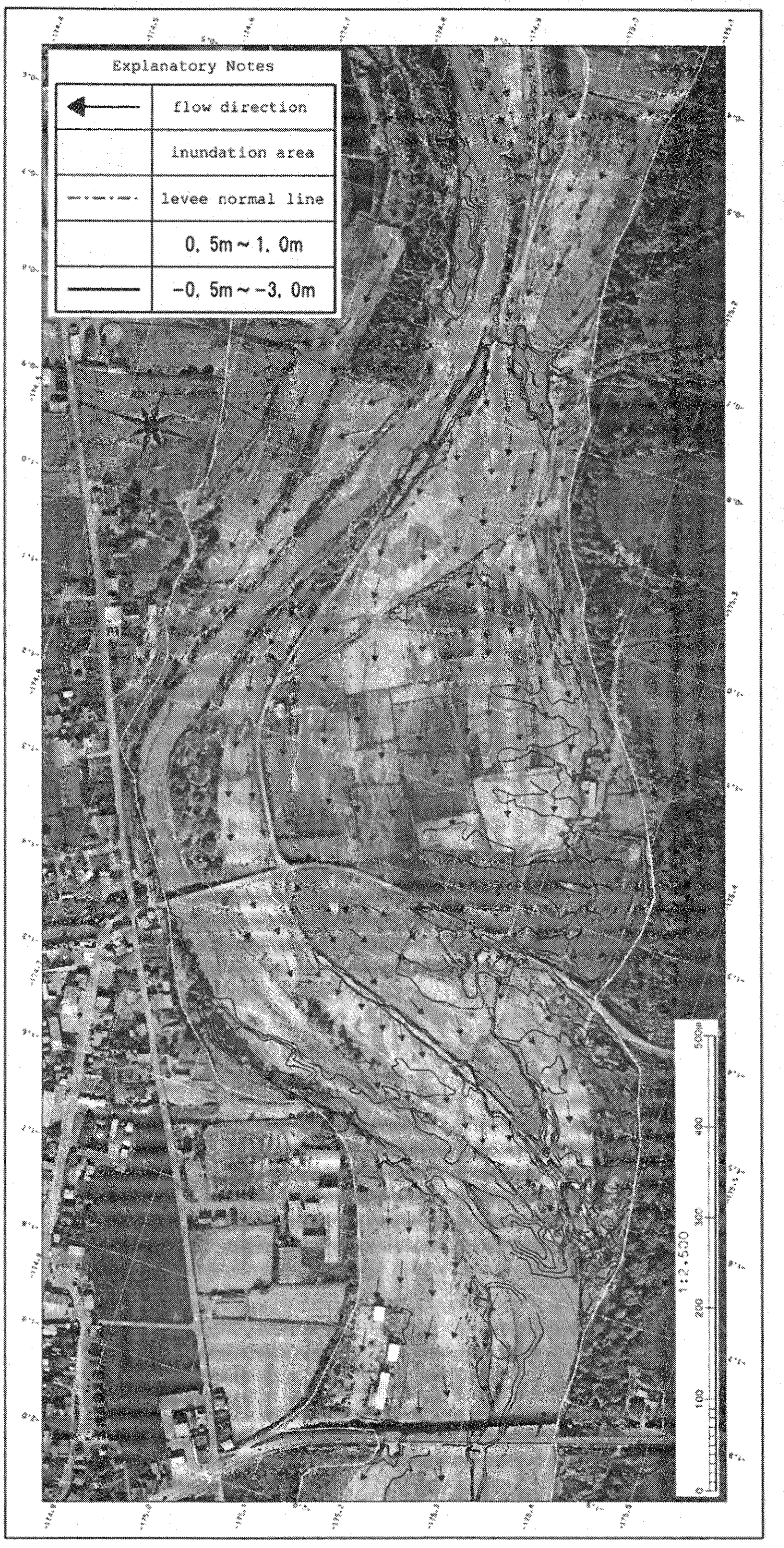

Fig. 8 Flood flow and sediment accumulated on the flood plain near the mouth of the Appetsu River (Photograph offer: Hokkaido Prefecture Government Office)

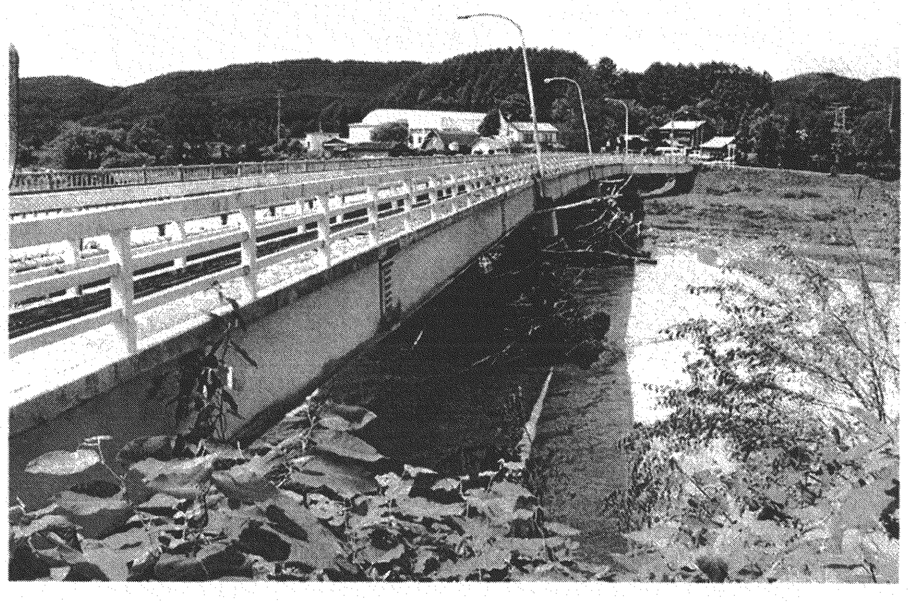

Fig. 9 Damage to the pedestrian bridge over the upstream side of the Nukibetsu Bridge due to driftwood caught in the bride pier

area in the riparian forest and was only 5% of the total volume of the riparian forest in this site. 85% of the driftwood deposited at the mouth up to the Nibutani Dam (about 2,900m^3) had been caught in the riparian forest.

The tree volume of the driftwood deposited in Appetsu River basin was estimated to be about 46,000m^3. About 70% of it was produced in the Ribira River basin and the upstream basin from the midstream of the main stream. Moreover, about 80% of it flowed from the mountainside. By classifying the driftwood by tree species, it was revealed that 90% of it was from broad-leaved forest, and that very little of the artificial forest (the coniferous forest) had been washed out of this area. On the other hand, the volume of the riparian forest carried away from this area was very large because the flood water had flowed over the whole area of the valley. The area of toppled riparian forest and the area washed away by the flood were estimated to be 66ha and 32ha, respectively. The tree volume of damaged forest reached about 7,800m^3. The volume of driftwood caught in the riparian forest was estimated to be about 11,100m^3.

The driftwood caused heavy damage, mainly to bridges. After investigating the Nukibetsu Bridge (Fig. 9) and the Abushitoenai Bridge (Fig. 10), the following became apparent. Because most of the driftwood was caught in the bridge pier and bridge girders, the pedestrian bridge over the upstream side of the Nukibetsu Bridge had become tilted on the downstream side and two bridge girders of the Abushitoenai Bridge, a 4-span continuous bridge, were washed away. Judging by the fact that mud had been deposited on both bridges, it was thought that flood water had flowed over the bridges. The high-water marks on the upstream and downstream sides of the Abushitoenai Bridge were significantly different in height. This finding indicated that the driftwood caught at the bridge pier and bridge girders had dammed up the river. Erosion damage caused

Fig. 10 Abushitoenai Bridge of 4-span continues bridge washed away due to driftwood caught in the bride pier and bridge girder

Fig. 11 Damage to the Eishin Bridge due to the flood (Photograph offer: Shin Engineering Consultants Company, Limited Company)

by the flood flow was inflicted at many sites. The road near the Eishin Bridge (Fig. 11) collapsed due to progression of bank erosion as far as the backfill material of the abutment. Similar damage, such as erosion of the embankment, frequently occurred even in the river basins, excluding the Saru River and Appetsu River basins.

Characteristics of Fine Sediment in the Estuary

From the investigation results of sediments deposited in the estuaries of the Saru River and the Mu River, it was found that sediment of 290 million t (109 million m^3 excluding the void volume) and sediment of 190 million t (72 million m^3 excluding the void volume), out of the discharged sediments from the respective rivers, had accumulated there. Sediment was found to have been deposited in the estuary of the Saru River over 10km away from its river mouth and where the water was over 30m in depth. The thickness of sediment deposited there after the flood was around 10 to 27cm. In the Mu River, sediment of around 10 to 20cm in depth was accumulated in the estuary over 3km away from its river mouth at a water depth of over 13m.

The results of the investigations carried out after 40 and 60 days respectively showed that the thickness of sediment deposited in the estuary of the Mu River had decreased. One of the conceivable causes was that the sediment was transported by waves and coastal flow. On the other hand, sediment in the Saru River had hardly decreased at all. The following were conceivable causes: a large amount of sediment was exchanged and transported in the surrounding sea area, including this area, and fine sediment had been discharged from the Saru River after the flood. The specific causes had not yet been discovered.

After analyzing core samples of the sediment collected from the sea bottom after the flood, the following became apparent: the sediment heaped up in this area due to the flood consisted of fine sand and pebbles as well as fine soil particles. In the estuaries of both rivers, there had been a considerably large amount of sediment, whose grain size had normally been coarser than that of fine sand, before the flood. However, it seemed that the grain size distribution heaped up in the bottom of the sea changed due to fine soil particles, such as wash load, flowing into this area as a result of the flood.

Examination of Inflow to the Nibutani Dam

When evaluating the storage factor of the reservoir, it was necessary to estimate the inflow to the reservoir with a high accuracy. The Hokkaido Regional Development Bureau of the Ministry of Land, Infrastructure and Transport, Nibutani Dam Management Office estimated the inflow to the reservoir at a specific time by using the average water levels per one minute from water level data observed at 2-second intervals in the reservoir. After converting the basic water level data of the reservoir obtained at that time and 10 minutes before (the value set for this particular flood) into the respective storage values of the reservoir, the estimation was obtained by adding the outflow discharge from the dam site at that time to the difference of those storage values divided by 600 seconds. This method of estimating inflow was effective in cases where undulations, such as seiches, hardly occurred on the water surface of the reservoir. After analyzing the basic water level data, it was clear that an undulation with a short period occurred near the peak water level time. This finding indicated that the basic water level data might include a noise component. Thus, another method of estimating inflow by using the water level data, which was obtained by removing seiches of natural oscillations from the series of basic water level data, was also attempted. The estimated discharge around the peak time of discharge by the dam management office, and the discharge estimated by the latter method were about 6350m^3/s (with a difference of 850m^3/s between maximum inflow and maximum discharge) and about 6160m^3/s (with a difference of 680m^3/s between maximum inflow and maximum discharge), respectively. The maximum inflow and maximum discharge designed for the Nibutani Dam were 4100m^3/s and 3850m^3/s, respectively, meaning a difference of 250m^3/s. The Nibutani Dam gave satisfactory results for the flood control.

Disaster Attitude Survey

A committee on the ideal way of sharing disaster information organized after this heavy rainfall disaster obtained the following information through a questionnaire to residents of the area (622 answerers).

75 or 80% of all respondents obtained "weather information" such as a "Heavy Rain Warning", which gave some warning of landslide and flood in their cases. However, only 62% of all respondents were able to predict the occurrence of a disaster. The remaining people replied on the questionnaire that they had not considered the possibility of a disaster occurring nearby. The number of people who considered that 350mm of rainfall "would cause a disaster" did not even reach half of all respondents.

CONCLUSIONS AND OUTLOOK

This paper presents a summary of findings of the heavy rainfall disaster investigations carried out by the "Typhoon No. 10 Hokkaido Heavy Rain Disaster Investigation Team 2003". The main characteristics of this heavy rainfall disaster are summarized as follows:

1) After carrying out a stochastic evaluation of sample values (maximum 48-hour precipitations in one year) including those for these years for the Saru River basin, it was clear that the sample values in the population for these years were significantly higher than for other years. When discussing possible measures to prevent flood disaster, such changes have to be carefully examined.

2) Collapsed sediment volume in the Nukabira River basin due to landslide was about 8 million m^3 (including the void volume) and about 2.5 million m^3 of it reached the river channel. The sediment yield at the Nukibetsu site was about 0.48 million m^3, excluding the void volume (the volume of soil particles) and a part of it was deposited in the river. Sediment movement produced in the area has to be continuously and carefully observed.

3) At the gauging stations on the lower stream of the Nibutani Dam in the Saru River, most of the estimated water levels reached very high water levels, which were above the designed highs. However, great damage, such as flood levee failure, was not caused in the downstream area of the Nibutani Dam because the Nibutani Dam fulfilled its function, which exceeded the storage factor of its reservoir, at around the peak time of discharge.

4) Damage to the Appetsu River, such as erosion of the low water channel and the levee, and flood levee failure, was concentrated at the node of a double-row river channel, where two flows met to start branching again. Such failures were widespread at this

site, where the levee line intersected the axis of the valley at a large angle. Channel design has to be carried out taking special care of the relationship between the levee line and the axis of the valley.

5) Because the driftwood caught in the bridge pier and bridge girders dammed up the river, flood water flowed on the bridge and eroded the embankment and the backfill material of the abutment. As a result, many bridge girders were washed away. Some of the driftwood was carried away from the area in the riparian forest due to the flood. Moreover, some of it was caught in the riparian forest. From the point of view of preventing a river-related disaster, it is necessary to examine whether the riparian forest should be left as it is not cut down.

6) It seemed that the grain size distribution heaped up on the sea bottom changed because fine soil particles, such as wash load, flowed into the estuary due to the flood. This change exerts serious influence on the growth of the benthos.

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