DAMAGE TO BRIDGES DUE TO MEDIUM SCALE FLOODING: A CASE STUDY OF THE IWANE OHASHI BRIDGE

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ABSTRACT

In July of 2018, a flood with return period of 1/15 years attacked the Yubetsu River basin in Hokkaido. The Iwane Ohashi Bridge located in the Engaru Town over the Yubetsu River suffered great damage. This flood resulted in a subsidence of abridge pier, causing a great deformation of the bridge girder, even though this bridge was designed based on the flood with return period of 1/100 years, which is quite larger than the flood scale targeted here. The detailed understanding of the reason of the damage will provide a useful insight into future management of the river and bridge. In this study, we investigate the main cause of this disaster in detail by using numerical model of flow and bed evolution, iRIC-Nays2DH.

As the results of numerical calculation of two-dimensional bed variation, bars are not able to form during the high discharge condition. In the calculation which the bridge pier is modelled as an obstacle, the presence of the bridge pier greatly affects to the flow and bed evolution around the bridge pier, resulting in a deep scouring around the pier. This scouring might be the main factor causing the damage of the bridge.

Keywords: bed scouring, bridge failure, bridge pier, river disaster

1. INTRODUCTION

In recent years, flood disasters have occurred frequently due to heavy rainfall caused by typhoons and low pressure, causing serious damages of river structures. It is therefore necessary to accurately understand the damage situation for mitigating subsequent risk and proposing necessary countermeasure to prevent such damages.

From July 1st to 5th of 2018, a heavy rainfall occurred due to the tropical depression that changed from Typhoon 7 in the Hokkaido region, causing a medium flood (return period of 1/15 years) in the Yubetsu River. The Iwane Ohashi Bridge (bridge length is 336.6m, roadway width is 6.75m completed 1980) (Kokozo Shuppan, 2019) located in the Engaru Town over Yubetsu River suffered a heavy damage. This flood resulted in a subsidence of abridge pier, causing a great deformation of the bridge girder as shown in Fig.1 This bridge was designed based on the flood with return period of 1/100 years, which is quite larger than the flood scale targeted here, so that the detailed understanding of the reason of the damage will provide a useful insight into future management of the river and bridge. In this study, we investigate the main cause of this disaster in detail by using numerical model of flow and bed evolution, iRIC-Nays2DH.

2. OUTLINE OF THE FLOOD AND BRIDGE DAMAGE

Figure 2 shows the spatial distribution of the total amount of precipitation from July 1st to 5th of 2018(Sapporo Regional Headquarters Japan Meteorological Agency, n.d.). It can be seen that more

Figure 1. Damage of the Iwane Ohashi Bridge (photo taken from the right bank at July 4th 2018)

than 200mm of precipitation was observed in wide area at central Hokkaido, including the upstream of the Yubetsu River. More than 20 sites of Automated Meteorological Data Acquisition System (AMeDAS), which is a high-resolution observation network developed by the Japan Meteorological Agency, recorded the highest monthly rainfall in July this year (Sapporo Regional Headquarters Japan Meteorological Agency, n.d.). Mizuho Observatory in Asahikawa city recorded, the maximum value of 247.5mm in precipitation during this period. This heavy rainfall resulted in a flood in the Yubetsu River basin, causing a serious damage of the Iwane Ohashi Bridge located in Engaru town over the river. As shown in the Figure.1, a bridge pier (referred as P7) located in the main channel was tilted to the upstream and sink, and the bridge girders were greatly bent. Fig.3 shows the water discharge and water surface elevation observed from 0:00 on July 1st to 24:00 on July 10th, 2018 at Engaru Observatory Station located about 1.5 km upstream from The Iwane Ohashi Bridge. The water surface elevation at the peak discharge (i.e., 12:00 on July 4th) at the observatory station exceeded the height of the high-water channel (Kawajiri et al., 2019). It means that the water surface elevation close to the bridge should be also very high at the peak discharge. Fig. 4 shows the cross-sectional bed geometry at the bridge section before and after the flooding. The figure indicates that because of this flood the bed elevation at the left of the pier degraded approximately 1m.

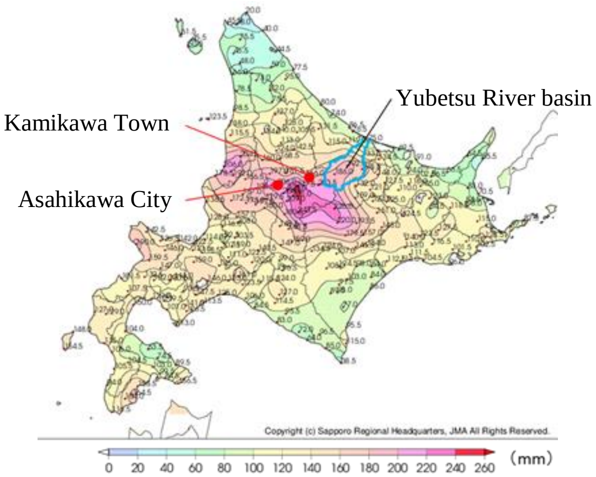

Figure 2. The spatial distribution of the total amount of precipitation from July 1st to 5th of 2018
(Sapporo Regional Headquarters Japan Meteorological Agency, n.d.)
(Edited image of Sapporo Regional Headquarters Japan Meteorological Agency)

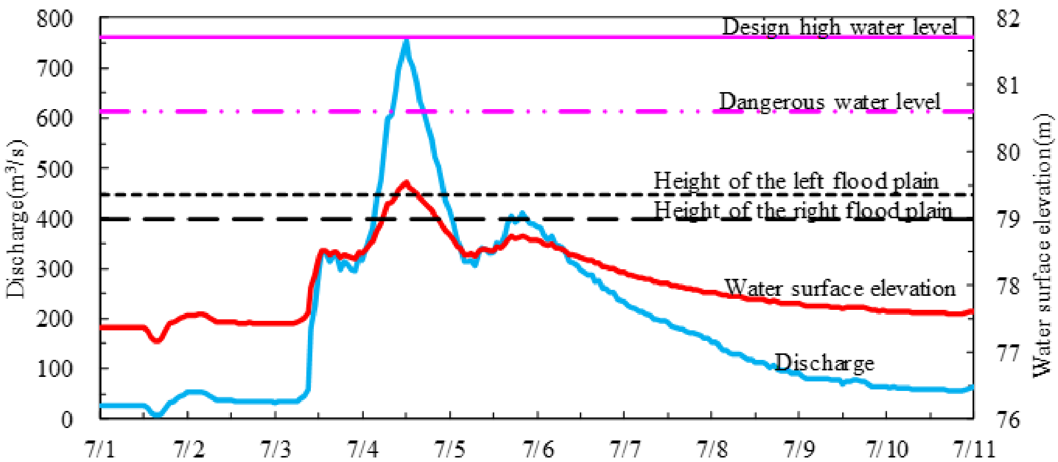

Figure 3. Discharge and water surface elevation observed from Engaru Observatory Station

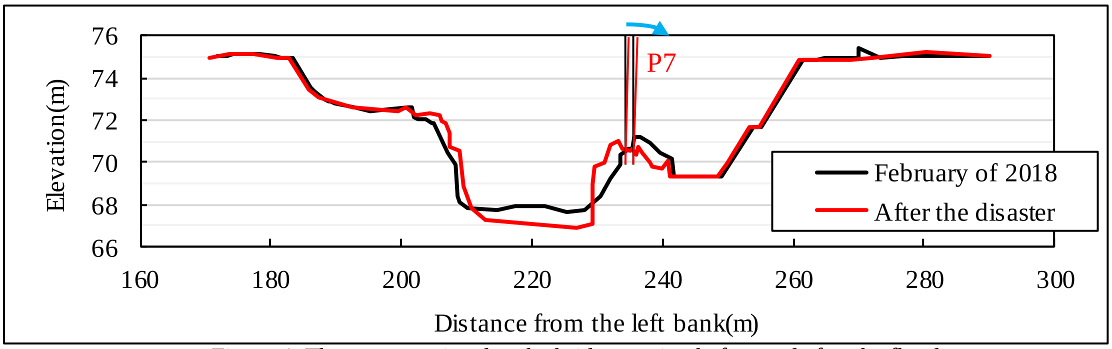

Figure 4. The cross-sectional at the bridge section before and after the flood

3. NUMERICAL SIMULATION OF BED EVOLUTION OF THE YUBETSU RIVER CAUSED BY 2018 FLOOD

3.1 Calculation condition

Numerical calculation of two-dimensional bed variation was conducted to clarify the causes of the subsidence of a bridge pier during the 2018 flood. For this, we perform two computational cases here, namely, 1) to understand effect of small (e.g., dunes) and medium (e.g., bars) scale bedforms on the damage of the bridge and 2) role of bridge pier itself in the bed evolution around the pier. In this section, the former calculation is presented, and next section describes the later effect.

Fig.5 shows the target river reach of the calculation (approximately 1.7 km long). The cross-sectional geometry measured in February of 2018 (spatial interval of the measurement is 200 m) was used for initial bed geometry of the computational grid. In this calculation, we neglect the presence of bridge pier, but the foot protection on the river bed around the pier and some revetments are considered as fixed bed. This is intended to focus on fundamental features of bed evolution in this reach during the targeted flood event. More specifically, we herein pursue whether or not the bedform could have significant impact on the observed damage of the bridge. The observed unsteady discharge at Engaru Observatory station from July 3rd to July

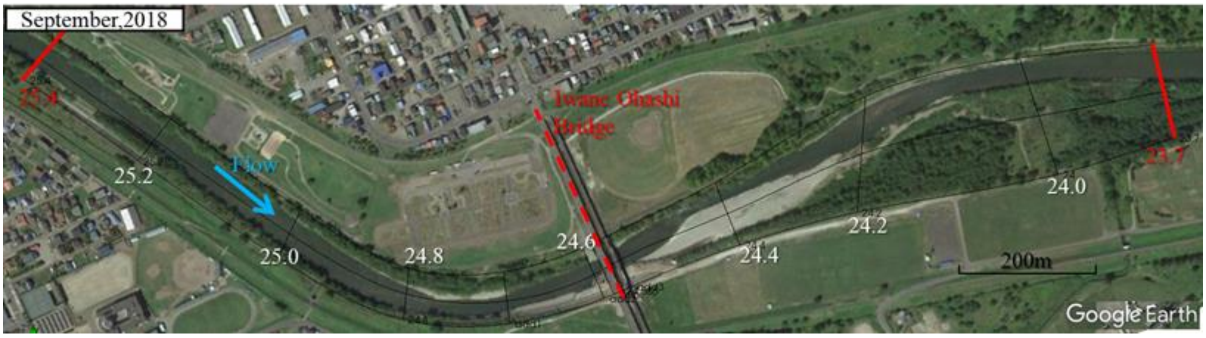

Figure 5. Objective reach of the calculation (Edited image of Google Earth)

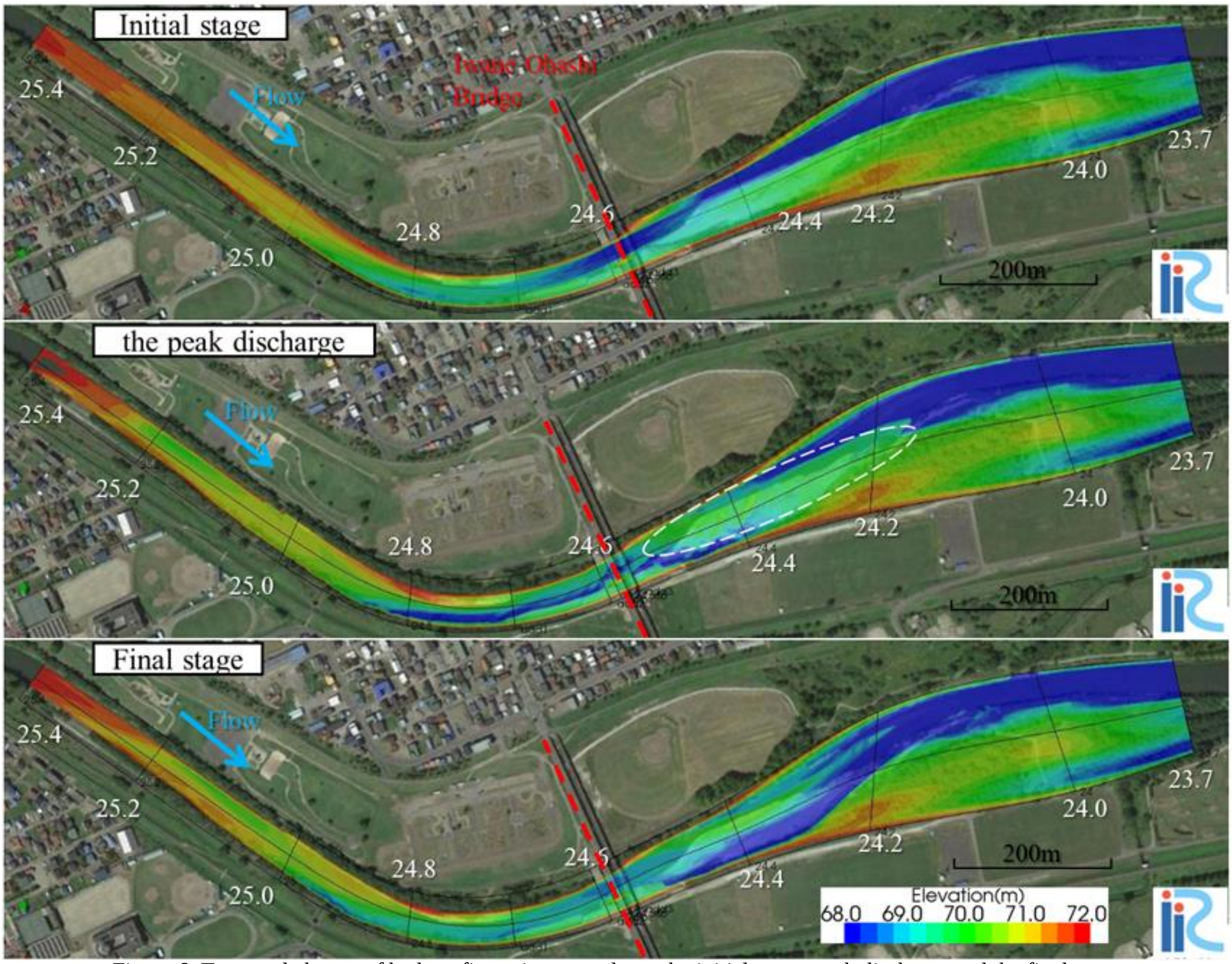

Figure 6. Temporal change of bed configuration, namely, at the initial stage, peak discharge and the final stage

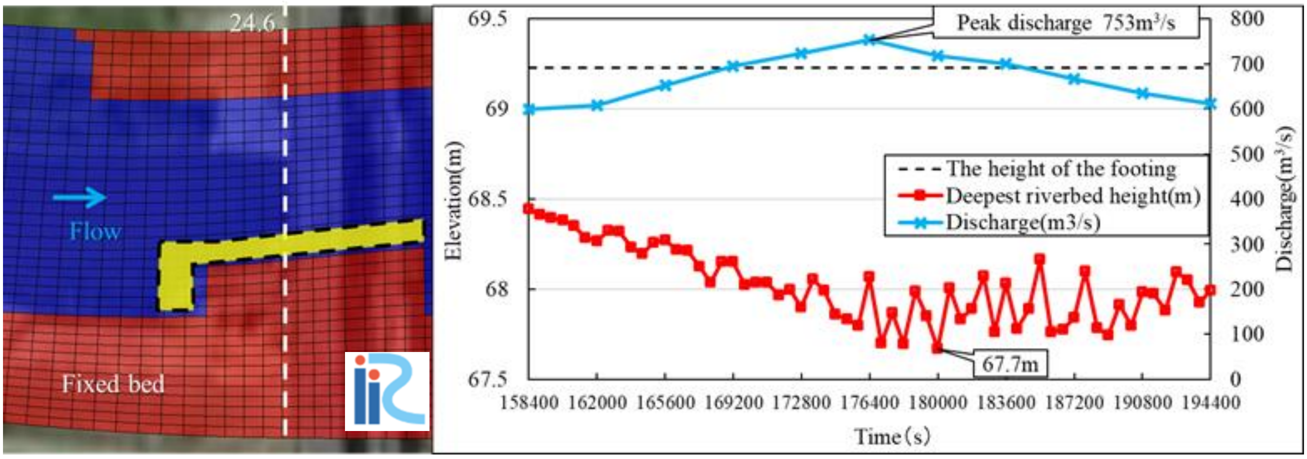

Figure 7. The temporal change of the deepest bed elevation around the foot protection (indicated as yellow area on the left figure)

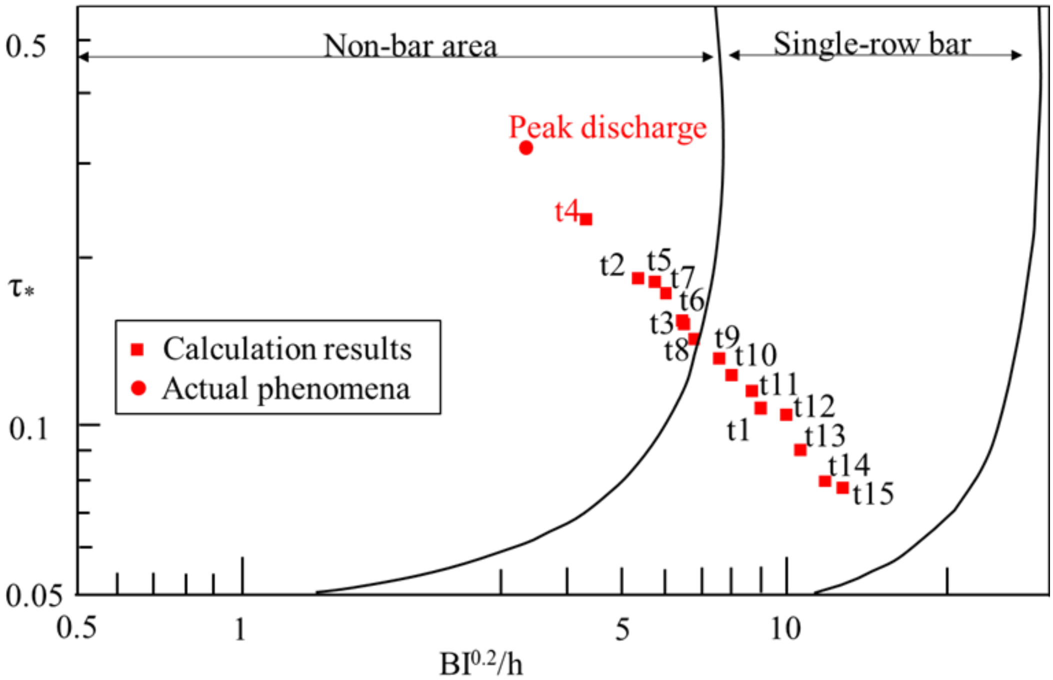

Figure 8. The bar regime change during the event on the diagram proposed by Kuroki and Kishi (1984)

10th (see Fig.3) is imposed at the upstream boundary. The computational grid sizes in streamwise and transverse directions are about 4m and 2m, respectively.

3.2 Calculation results

Figure 6 shows the temporal change of bed configuration in the calculation, namely, at the initial stage, at the peak discharge and at the final stage. The bridge pier is located at the outer bank of the river bend, so that generally the bed around the bridge pier are tend to be affected by the outer bank erosion. This can be seen in the bed configuration before the flood (see Fig.6) at KP25.0 to KP24.8, and at the downstream of this reach(KP24.8-24.6), the bed elevation of the left bank is lower than the one of right bank.

As shown in Fig.6, the flood event erodes the bed in outer bank, and the scouring position shifts to the downstream between KP24.6 and KP24.4. In addition, a deposition part appeared at the left bank between KP24.5 and KP24.2. In the cross section of the bridge, the left bank became higher than initial bed elevation in the calculation result. This calculated bed evolution is different from the observed pattern, namely, the bed of inner bend (i.e., left side of the bridge pier) is eroded as shown in Fig.4 In the calculation during the high discharge, dune-like bedforms moving to the downstream are simulated around the foot protection which was expressed as fixed bed in the calculation. However, there was very short time when the elevation of the low part of the shape was lower than the initial bed elevation, because the deposition part was developed as discharge decreased.

For reference, the relationship between the scour around the foot protection blocks and the cause of the damage is confirmed. Fig.7 shows the temporal change of the deepest riverbed elevation among the grid

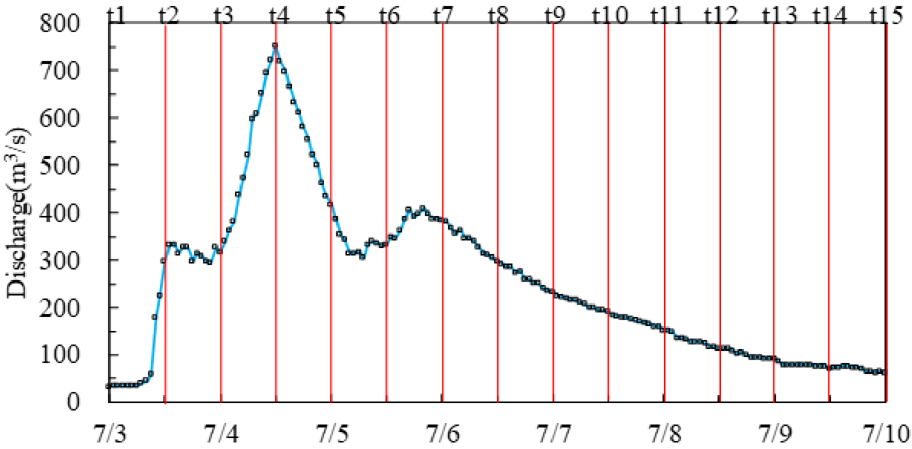

Figure 9. Observed discharge at the Engaru station. This is obtained as the upstream boundary condition. The indexes t1 to t15 are used to identify the bar and bedform regimes on Fig.8 and 10.

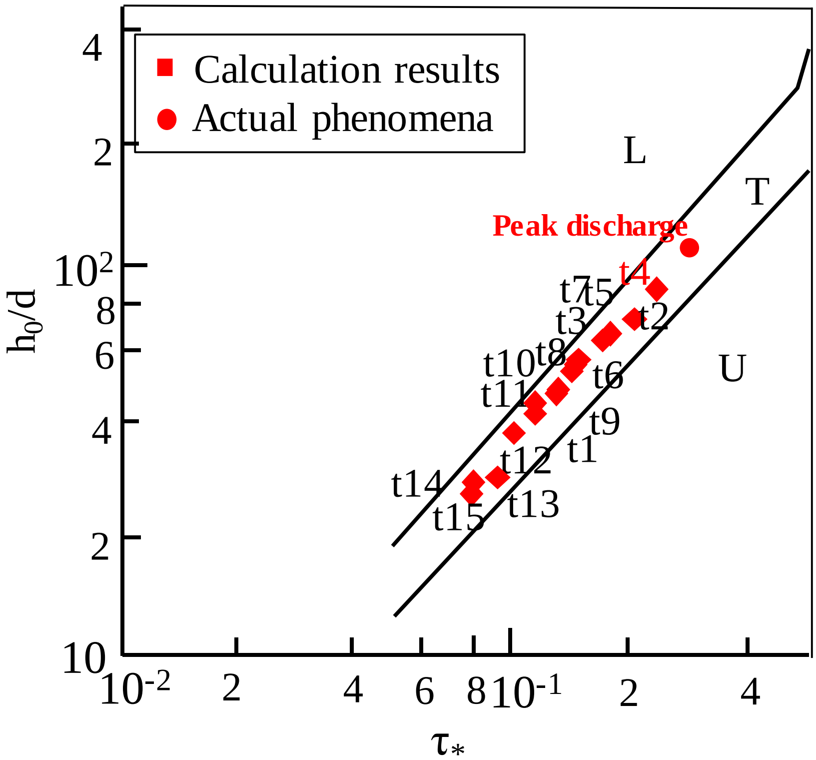

Figure 10. The bedform regime change in the targeted flood on the diagram proposed by Ashida and Michiue (1972)

points (indicated as yellow) around the foot protection. The elevation of the deepest point is 67.7m at 6 hours after the peak discharge. This is about 1.5m lower than the height of the bottom of the footing of the sinking P7 pier, it is presumed that the riverbed of the foot protection blocks and the pier was considerably lower than the footing height of the pier.

We next focus on the bedform and bar regime change during the flood event to understand the effect of such bedforms, which are oriented by a spontaneous (instability-related) response of the bed, on the damage of the bridge. Fig.8 shows the bar regime changes estimated for this flood event on the diagram proposed by Kuroki and Kishi (1984). In the figure, "Actual phenomena" is calculated using the actual observation data, "Calculation results" in the figure is calculated using the time series calculation results data (e.g., water surface elevation). As shown in Fig.9, several flood stages are represented as t1 to t15. Fig.8 indicates that during the high discharge, bars (i.e., alternate bars) is not able to form, on the other hand, the alternate bars may be developed on the low discharge condition (i.e., at very beginning of the flood (t1) and at the latter half of the flood (after t9)). In addition, Fig.10 shows bedform regime change during the flood on the diagram proposed by Ashida and Michiue (1972), suggesting transition regime for the entire flood period.

Both figures indicate that dominant bed feature during the high discharge condition is classified non-bar regime of medium scale bedform and transition regime of small scale bedform in this reach. In the calculation during the high discharge, dune-like bedforms moving are also confirmed, so these bedforms may have effects on the damage of the bridge. This is consistent with the fact that the damage of the bridge was observed just before the discharge peak, so that there might be another factor causing this damage.

4. CALCULATION FOCUSING ON THE EFFECTS OF STRUCTURES

4.1 Calculation condition

We next focus on the effects of structures such as piers and foot protection blocks, which are ignored in the calculation above. Numerical calculation of bed variation was conducted on the computational grid with grid sizes of 2m and 1m for streamwise and transverse directions, respectively. This means that the grid resolution of this case is double to the previous calculation. The previous calculation indicates that the large-scale bars may not be able to form, so that we shorten the targeted river reach as KP25.0 to KP24.2. This also contributes to reduce the computational time. As shown in Fig.11, the foot protection blocks around the pier and the revetment blocks were obtained as fixed bed, and the bridge pier is modelled as an obstacle in the calculation.

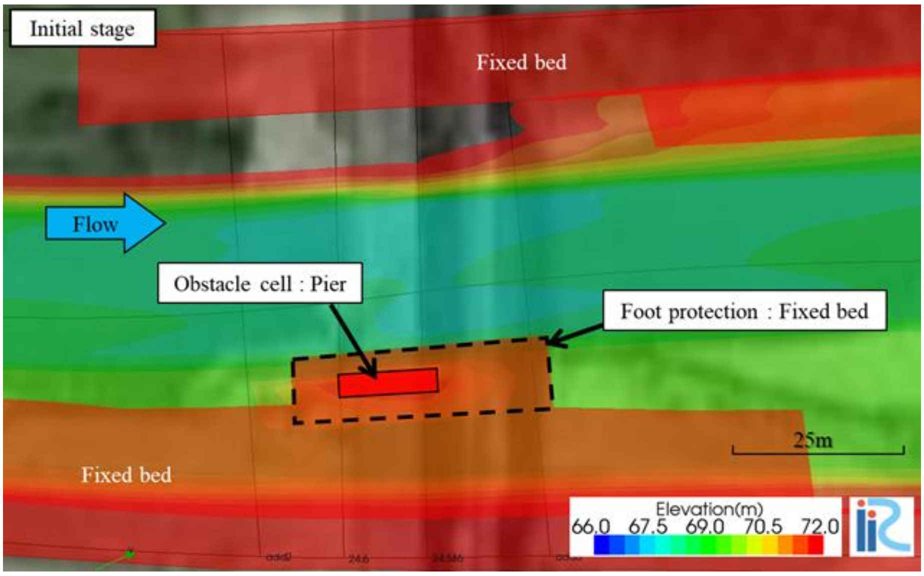

Figure 11. Settings of foot protection and bridge pier in the calculation

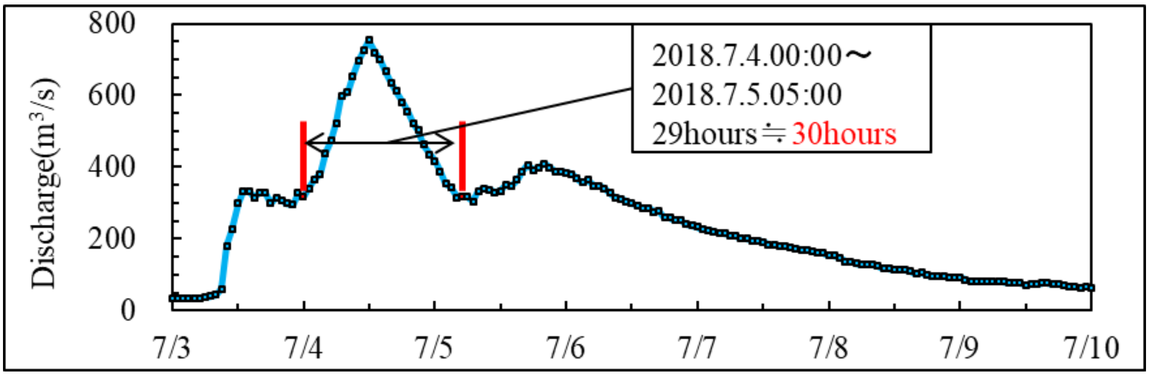

Figure 12. Settings of the flow time

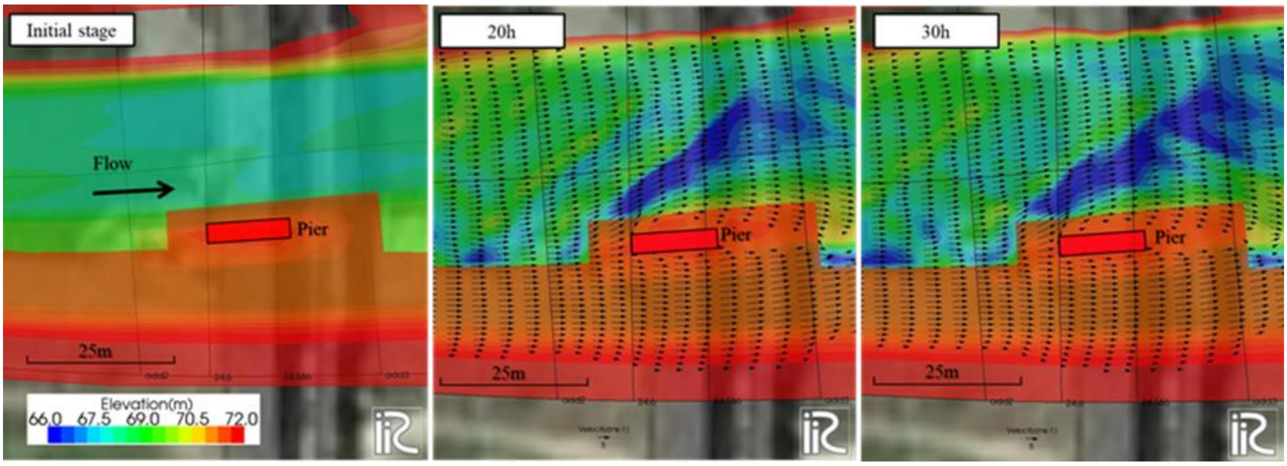

Figure 13. The temporal change of bed configuration and flow field at the initial stage, at 20 hours and at 30hours

Figure 14. Damage situation of the rooting blocks (Photo taken by Okhotsk General Subprefectural Bureau Abashiri Department of Public Works Management)
(Edited image of Okhotsk General Subprefectural Bureau Abashiri Department of Public Works Management)

We obtain a constant, steady water discharge of 753m^3/s for 30 hours at the upstream end. This discharge given in the calculation is the peak discharge of the flood, and the duration is modelled based on the high discharge condition of observed hydrograph as shown in Fig.12.

4.2 Calculation result and consideration of the cause of damage

Figure 13 shows the temporal change of simulated bed configuration and flow field at the initial stage, at 20 hours and at 30 hours. The figure shows the presence of the bridge pier splits the river flow into two directions, namely, left and right bank sides. It can be seen that the bed on the left side of the foot protection blocks is scoured. Dune-like shapes were generated in the river channel, resulting a large spatial bed variation. As a result, local scouring is persistently observed during the flood in front of the foot protection blocks, although because of the dune-like bedform the depth of the local scouring is highly fluctuated in time.

Fig.14 is a photograph of the damage situation of the foot protection blocks taken after the flooding. It is confirmed that foot protection blocks on the right bank of the pier was severely damaged. The reason that the pier was inclined to the right bank side is probably due to severe damage to the foot protection blocks. In addition, the foot protection blocks on the left bank side of the pier was also severely damaged, and the footing of the pier was exposed. The calculation results suggest that the riverbed on the front and side of the foot protection blocks was greatly scoured, which is consistent with the observation.

The numerical simulations presented herein suggest that alternate bar was not formed and that small-scale sand waves were generated during the flood. In the calculation which the bridge pier is modelled as an obstacle, the presence of the bridge pier greatly affects to the flow and bed evolution features around the pier, causing the persistent scouring of the front and side of the foot protection blocks around the pier. This might be a main factor of the damage and subsidence of the bridge pier.

5. CONCLUSIONS

In this study, we conducted numerical simulations of the bed evolution caused by 2018 flood event in Yubetsu River to understand main factor causing the damage of the Iwane Ohashi Bridge. The results suggested that dominant bed feature during the high discharge condition is classified non-bar regime of medium scale bedform and transition regime of small scale bedform. In the calculation which the bridge pier is modelled as an obstacle, the presence of the bridge pier greatly affects to the flow and bed evolution around the bridge pier, resulting in a deep scouring around the pier. This scouring might be the main factor causing the damage of the bridge.

In recent years, river structures have been frequently damaged by flooding. When examining damage factors and countermeasures, it is necessary to incorporate not only river engineering but also bridge engineering and geotechnical knowledge.

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