Qualitative analysis by local ground water level observations and seepage analysis of underseepage during flood at the Kita river

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ABSTRACT: At the Kita River, which flows through Kyushu, Japan, there have been three major floods between 2016 and 2018 that significantly exceeded the height of the ground level. Each time, large-scale sand boils due to underseepage have been confirmed at around 13.0 km on the left bank. The base ground has a very thick permeable layer of gravel. Also, a sand layer (thickness of about 2m) has been distributed near the surface of the ground. Given this, the following mechanism may be in operation. While river water has penetrated into the permeable layer, it has been pressurized by the presence of the sand layer near the surface. It is assumed that the pressurized water has broken up the sand layer locally, causing an outflow at high velocity, which has ejected a large amount of sand. After the 2016 flood, an impervious sheet pile wall had been installed. While the effectiveness of the wall was confirmed in some places. But in other hands, there were some places where seepage and boils still occurred at floods after installing the wall. Ground water level observations were commenced around such sand boil locations and their surrounds. Until this, water had been observed to slightly exceed the ground level height twice. According to these results, it is considered that observation points near sand boil saw ground water levels superior to other observation points and even exceeding the river water level. It was assumed that ground water was supplied from not only the river side but also from the land side, towards the observation points. Thus, a 2D unsteady seepage analysis was conducted in a simulation of the area to qualitatively clarify the supply of ground water from the land side and etc.

Keywords: ground water observation; sand boiling; seepage analysis; water supply from landside

1. Introduction

There have not been many cases of breach due to base water seepage, underseepage in floods in Japan. There have been no breaches due to underseepage in government managed rivers since the case of the Yabe river in 2012. On the other hand, there have been many cases of seepage or sand boil that did not lead to breach. Locations of such seepage or sand boil are considered to be at a higher risk of failure compared to locations where there has been no seepage or sand boil. Therefore, a detailed investigation has been carried out in some of these locations to estimate the mechanisms of seepage and sand boiling and measures are being implemented.

One of these locations is at around the 13 km mark on the left bank of the Kita river which flows through Kyushu island in Japan. In the Kita river, there were three big floods between 2016 and 2018 which exceeded the height of ground level. On each occasion, large-scale sand bois due to base water leakage were confirmed.

First, we will introduce the seepage and sand boiling mechanism estimated from the flood and seepage conditions at this location and the structure of the embankments and base ground. On top of this, the records will be shown of observations of the ground water level observation holes installed in February 2019 after the floods. A seepage analysis was also performed based on these results.

2. Seepage conditions, embankment and base ground structure

2.1. Topography of seepage location

Fig. 1. shows the location of the Kita river. When typhoons pass nearby, wet air from the southeast hits the Kyushu Mountains causing a lot of rain to fall in the

Figure 1. Location of the Kita River

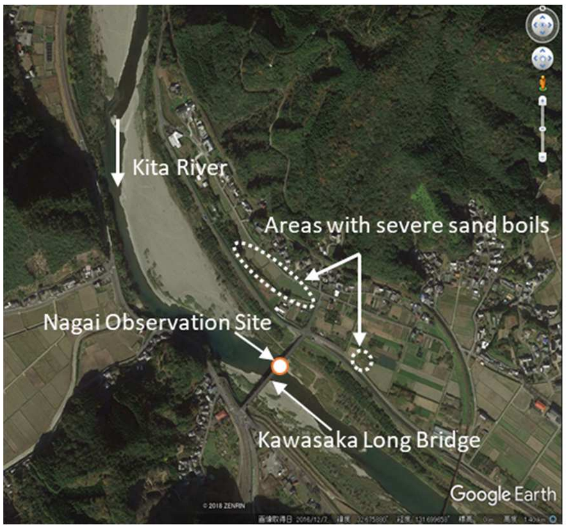

Figure 2. Location of seepage and surrounding terrain

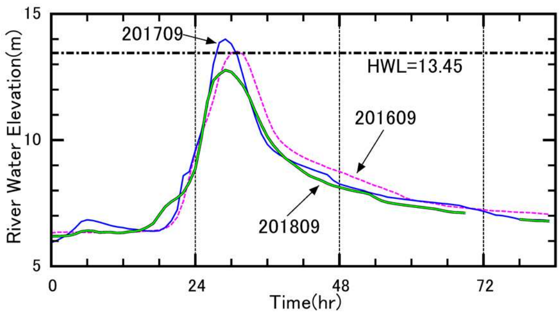

Figure 3. Time history of river water level during floods

Kita river basin. So, the rise in the water levels occurs mostly when typhoons pass.

The Kita river basin has very few flatlands. The scale of each flatland is small, and there are many areas where the river is close to the mountains. As shown in Fig. 2., the locations of large-scale seepage and sand boils are confirmed in the narrow flatlands between mountains and the river.

2.2. 2016-2018 flood and seepage Conditions

There were three floods exceeding the ground level during the three years from 2016 to 2018, and in all of these cases significant water leakage was confirmed. Fig. 3. shows the water level waveform at the time of flooding as observed at the Nagai observatory. These are arranged to exceed the typical ground level of 10 m at around 24 hours. The highest water levels were in the order of 2017(highest water level of 14.2 m), 2016 (highest water level of 13.8 m) and 2018. Those in 2016 and 2017 exceeded the high water level (HWL) of 13.45 m.

Fig. 4. shows the transition in seepage and sand boiling locations due to these floods. Compared to 2016, the number of leakage points from the 2017 and 2018 floods increased to around 400-600 side lines[1].

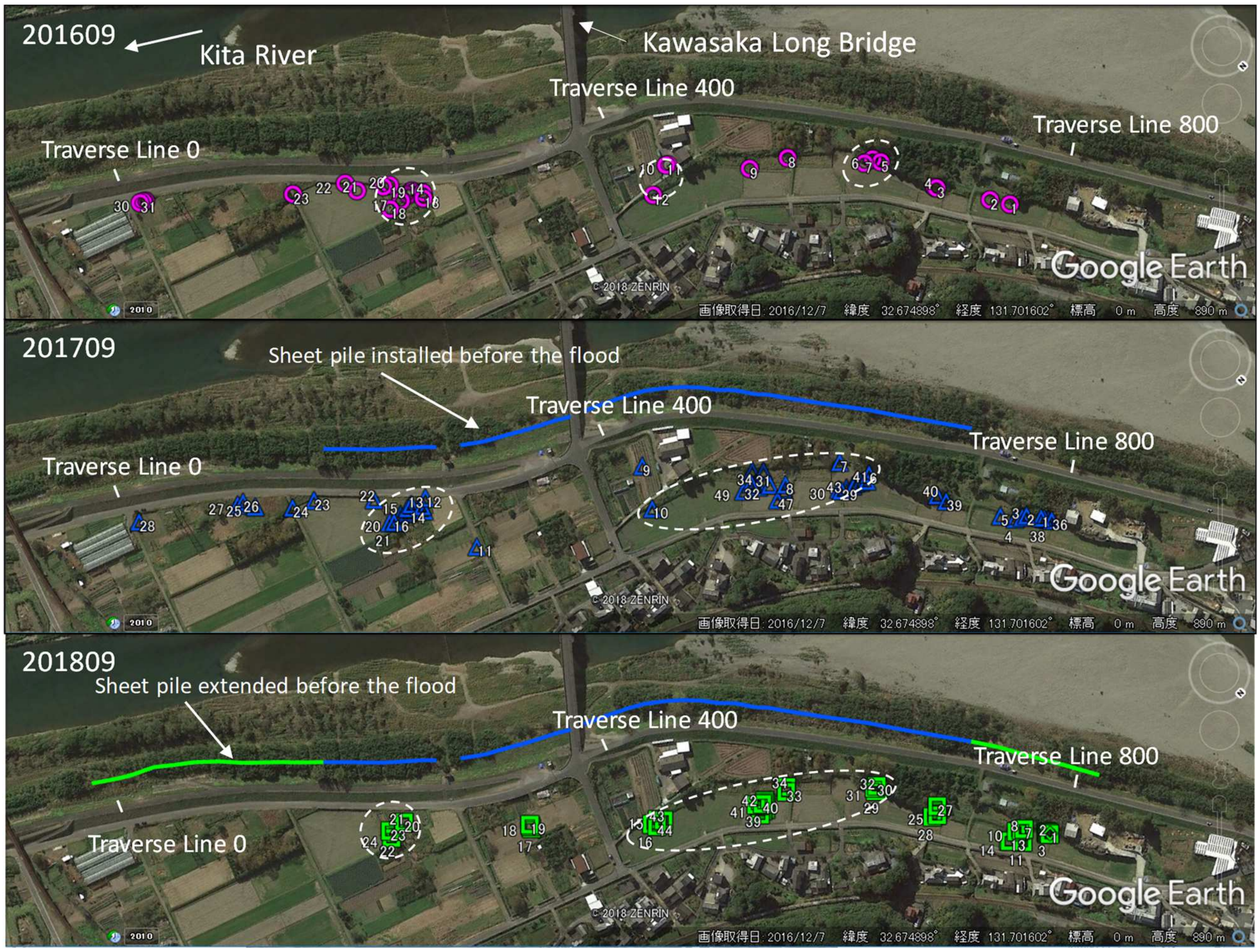

Figure 4. Changes in Water Leakage and Sand Boiling Locations (Area enclosed by broken lines includes major sand boiling and subsidence, with minor water leakage and sand boiling in other areas) from 2016 to 2018 and Range of Measures using Steel Sheet Piles[1]

Figure 5. Traces of seepage and sand boiling 1

Figure 6. Traces of seepage and sand boiling 2

Two factors can be considered for such a change. One is the difference in the highest flood water levels. It is possible that the leakage locations around 400-600 side lines occur due to higher water levels. The second factor is the effect of impervious sheet piles. After the 2016 flood, the installation of impervious sheet piles commences as a means of mitigating the impact on embankments of seepage and sand boiling. Residents near the leakage points have suggested that the reduced water leakage is a testament to the installation of the impervious sheet piles. This can also be considered the case due to the fact that traces of water leakage were only found near the borders of the range where impervious sheet pile was laid and where the July 2018 flooding has slightly exceeded the ground level, which was thought to be the effect of installing the impervious sheet piles.

Large-scale traces of water leakage and sand boiling are shown in Fig. 5. and 6. Seepage and sand boiling locations were confirmed in several places where the accumulated sand spanned several meters in diameter. There were also many places where sand boiling was adjacent to subsidence. In the nearest cases, this type of seepage and sand boiling occurred in locations 10-20 m from the slope foot of the embankment.

2.3. Embankment and base ground structure

The embankments in this area had reinforcements for overtopping, like pavement at the top and impervious sheet at landside slope which are unusual in Japan. As mentioned above, impervious sheet piles have been installed and extended in this area since 2016. The result has been the embankment structure shown in Fig. 7.

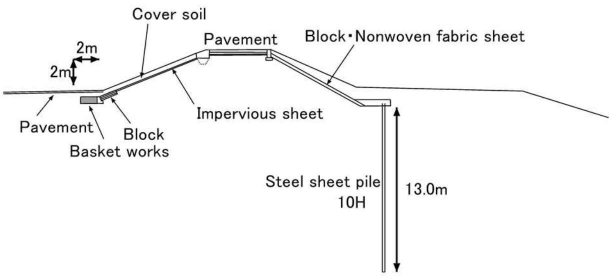

Figure 7. Embankment structure

Fig. 8. shows the geological profile of the base ground structure. A thick gravel layer is distributed on the base ground widely. At its deepest points this gravel layer extends to about 50 m, and so the above-mentioned impervious sheet piles cannot completely cover the gravel layer. This is the reason why there have still be seepage and sand boils in spite of the laying of impervious sheet piles. It has been a feature of ranges of intense water leakage and sand boiling that there has been a 2-3m layer of sand distributed near the surface of the levees. According to an

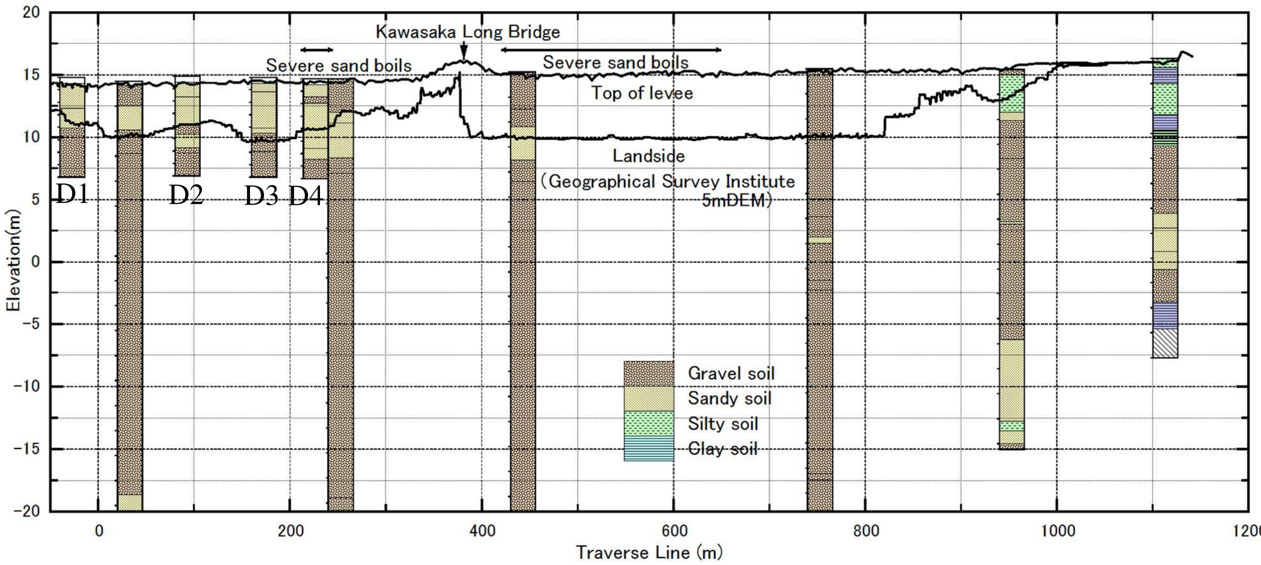

Figure 8. Geological profile

excavation survey of the location of sand boils shown in Fig. 9., because this sand layer included a lot of fine silt mixed in it is thought to have resulted in seepage as the water leaks from vein erosion. Sand that accumulates on the surface of the earth is assumed to be in the gravel layer, between the gravel.

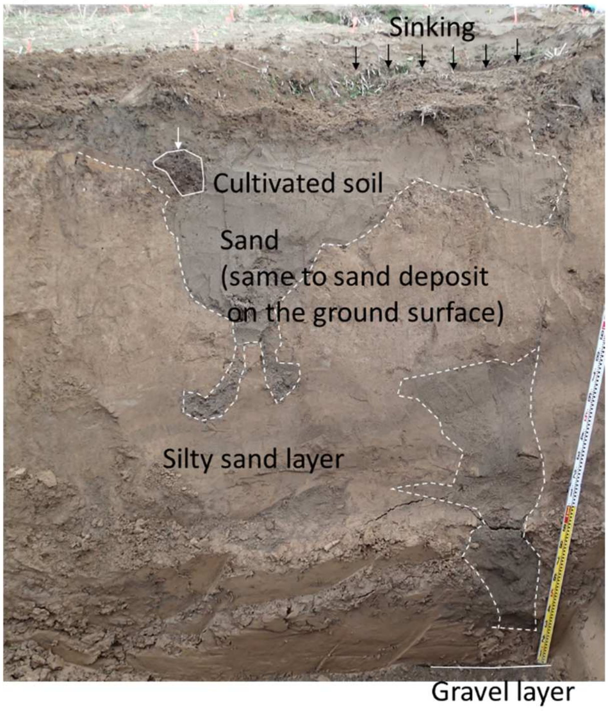

Figure 9. Base ground structure at sand boil observed in excavation survey

2.4. Seepage and sand boiling mechanisms

Seepage and sand boiling are thought to occur due to rising water pressure in base ground gravel layers from rising river water levels. However, where serious seepage and sand boiling have been confirmed, sand layers have been observed at a height near the surface of ground levels. This is assumed to make it more difficult for the water pressure within the gravel layer to dissipate to the ground surface because of the sand layer above the gravel layer, which is estimated to make the water pressure rise. Furthermore, the occurrence of seepage and sand boiling breaking through local sand layers, is considered to be the cause of large flow rates and the accumulation of large amounts of sand.

3. Ground water level observation

3.1. Observation positions and methods

Observation holes were installed in 4 locations as shown in Fig. 10. to measure the gravel layer pressure distribution directly under embankments at the locations of large-scale seepage and sand boiling and their surrounds.

The most downstream point, D1, was located outside of the impervious sheet pile installation range to verify the effect of the impervious sheet piles. However, it was clear from the boring work for the installation of the observation holes that unlike D2 to D4, the gravel layer at D1 is very dense. When setting the placement of the impervious sheet piles it was not known that there was a change in gravel layer properties between D1 and D2, but this change in gravel layer density happened to be in the location where the impervious sheet piles were laid. The most upstream point of D4 was the closest to the location of large-scale seepage and sand boiling.

Boring was carried out to the gravel layer to measure the gravel layer water pressure during floods, but boring was not done to the normal ground water depth. Fig. 8. shows the columnar section obtained from drilling. From the top, there is sandy soil filling material and naturally deposited sandy soil, but this is followed by a naturally deposited gravel layer, while at D1 and D2 there is no naturally deposited sandy soil layer, or only a very thin one. At D4, this sandy soil layer is extremely thick. As a result, the depth of the gravel layer is deeper the more upstream, and except for at D4 the appearance depth and ground level are in roughly the same position.

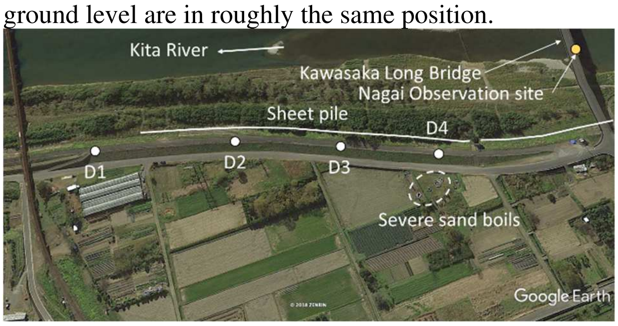

Figure 10. Ground water level observation sites (D1 to D4) and locations of seepage and sand boiling

3.2. Observation results

In July and August 2019 there were medium-scale floods slightly above the ground level. Fig. 11. and 12 .show the combined river water level and precipitation at the time as observed from the observation holes and at Nagai observatory.

In the July flood, the small peak was reached from the rain on the afternoon of the 18th. At this time, the water level in the borehole also peaked, with a time delay of 1 or 2 hours. The peak borehole water level was of an order that was close to the location of the large-scale seepage and sand boiling, but both were lower than the river water level, and it was assumed that the borehole water level changed due to pressure propagation due to river water levels. After this, the river water level rose significantly, peaking from the night of the 20th to the early morning of the 21st. At this time, D4 and the river water level rose about the same amount. While this is thought to be dominated by pressure propagation from the river, the rise to the same height as the river water level cannot be completely explained by pressure propagation from the river. Other factors could be thought to include ground water supply from the land sides. Prior to the rain on the 18th, there had been no rain for five days, so the ground water supply had been decreasing, suggesting that pressure propagation from the river had become dominant. Until the peak on the 20th, there was an increase in ground water supply due to rainfall on the 18th and 19th, and this may have led to the river water level being the same as the observation hole water level.

A similar waveform can be observed to the July 18 night peak in the August flood. There was no rain over

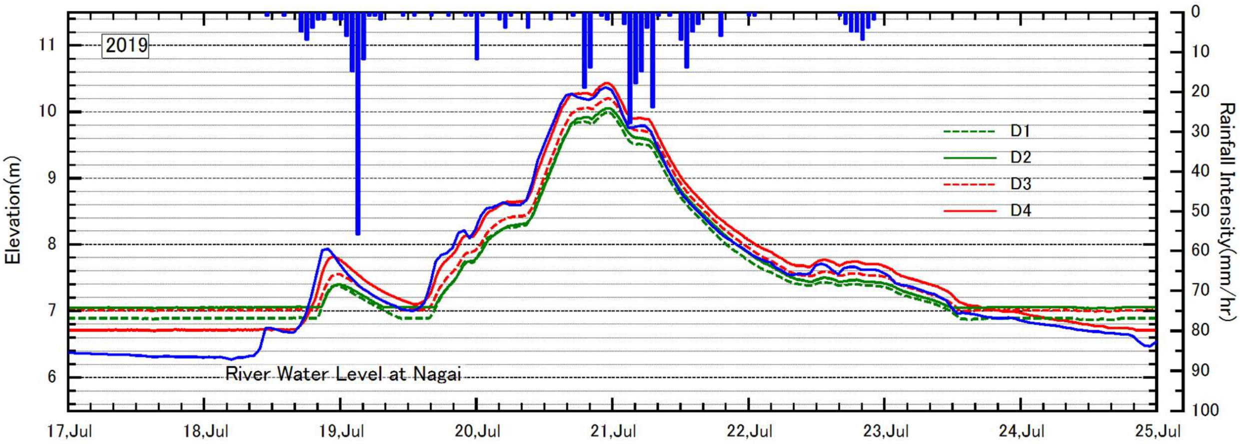

Figure 11. Observation results during July 2019 medium-scale flooding

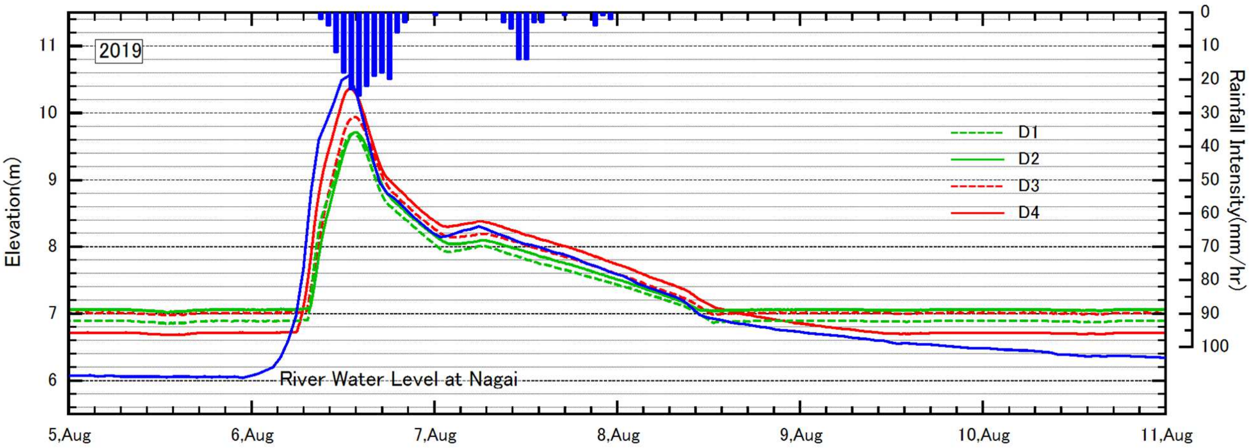

Figure 12. Observation results during August 2019 medium-scale flooding

the five days from August 1 through 5, and the ground water supply conditions are assumed to have been very similar to those of the night of July 18.

4. Analysis of ground water supply and impervious sheet pile based on seepage analysis

4.1. Common analysis conditions

A 2D unsteady saturated and unsaturated seepage analysis [2] was performed to qualitatively analyze the impact of ground water supply and the effect of the sheet piles.

Fig. 13. shows the geological cross-section from the results of a machine boring survey and auger boring survey in the location in which observation hole D4 was installed.

The 2D seepage analysis model was created as shown in Fig. 14. from the geological cross-section and slope of surrounding mountains. In the analysis model including the sheet pile, the impervious sheet pile was expressed as a double node and a completely impervious boundary.

Table 1. gives the constants for each soil layer used in the seepage analysis. The coefficient of permeability was estimated from the in-situ permeability test, indoor water-permeability test and particle size distribution, but was rounded for qualitative reasons. For the unsaturation characteristics, the relationship commonly used in the design of embankment strengthening measures in Japan was used.

First, we examined the conditions which explained the hole water level from the July and August 2019 floods.

Table 1. Caption to table

Soil layer	Permeability (m/sec)	Unsaturation characteristics
Embankment	1.0 E-06	FS
Sandy soil layer	1.0 E-05	SF
Silt layer	1.0 E-07	FS
Gravel layer	5.0 E-03	GS
Rock	Impervious to water	-

4.2. August 2019 flood

An analysis was performed simulating the August 2019 flood. An external force raised the river water level from 6 m to 10.5 m over 12 hours, and this was then lowered to 6 m over 12 hours. During this, 10 mm/hour of rainfall was applied.

Fig. 15. shows the application of multiplying the gravel layer with the permeability of 1.0E-03m/sec, 2.0E-03m/sec and 5.0E-03m/sec. The permeability of 1.0E-03m/sec was obtained from the in-situ permeability test. According to these results, the speed of water level reduction was slow compared to actual results for the values of 1.0E-03m/sec and 2.0E-03m/sec, while 5.0E-3m/sec result showed the closest to actual behavior. Thus, in the following calculations the figure of 5.0E-03 m/sec is used for the permeability of the gravel layer. This value

also obtained a maximum borehole water level closest to actual values.

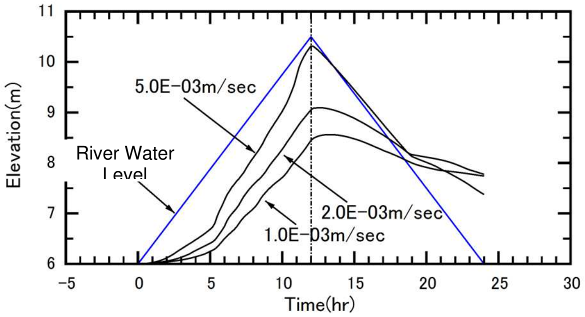

Figure 15. Changes in response due to differences in ground base coefficient of permeability

4.3. July 2019 Flood

An analysis was performed simulating the July 2019 flood (from the afternoon of the 19th to the 22nd). An external force raised the river water level from 6 m to 10.5 m over 36 hours, and this was then maintained for 12 hours at 10.5 m before being lowered to 6 m over 36 hours. During the raising of the water level 1 mm/hour of rainfall was applied, and after this 2 mm/hour of rainfall was applied.

As a result, the borehole water level was considerably low with respect to the river water level and differed from observed results. Then, a source of current was applied to 5 nodes located at the border with the impermeable layer below the viscous soil on the land side. The amount of current from each node was of three types, 0.00001 m^3/sec, 0.00002 m^3/sec and 0.00004 m^3/sec. These results are shown in Fig. 16. By applying a current of 0.00004 m^3/sec, the borehole water level was confirmed to reach the same height as the river water level.

The ground water supply was thought to be derived from rainfall infiltration, but some of this was considered as rainfall applied to the ground surface with the seepage analysis. The ground water supply given from the current was thought to have appeared as ground water supply from rainfall over time in the surrounding area.

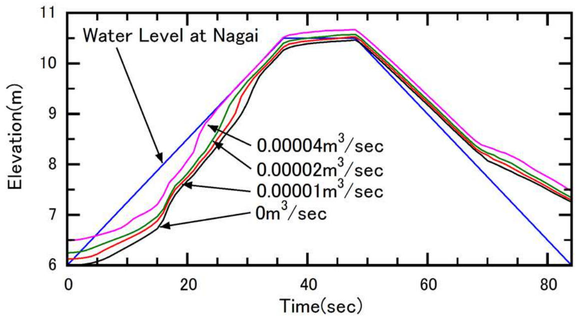

Figure 16. Changes in response due to differences in ground water supply

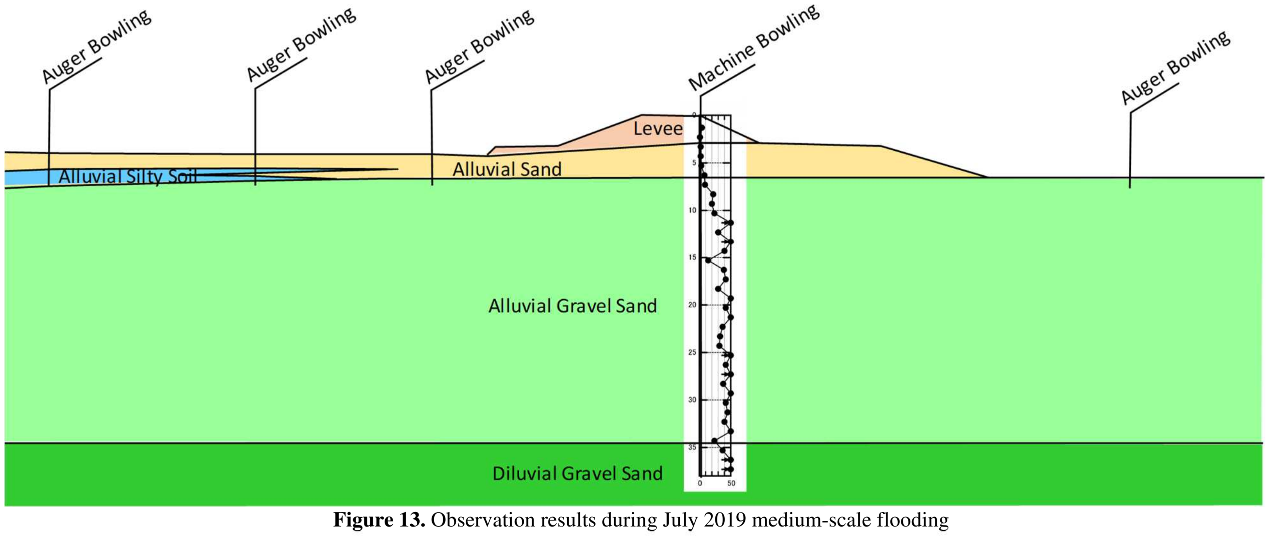

Figure 13. Observation results during July 2019 medium-scale flooding

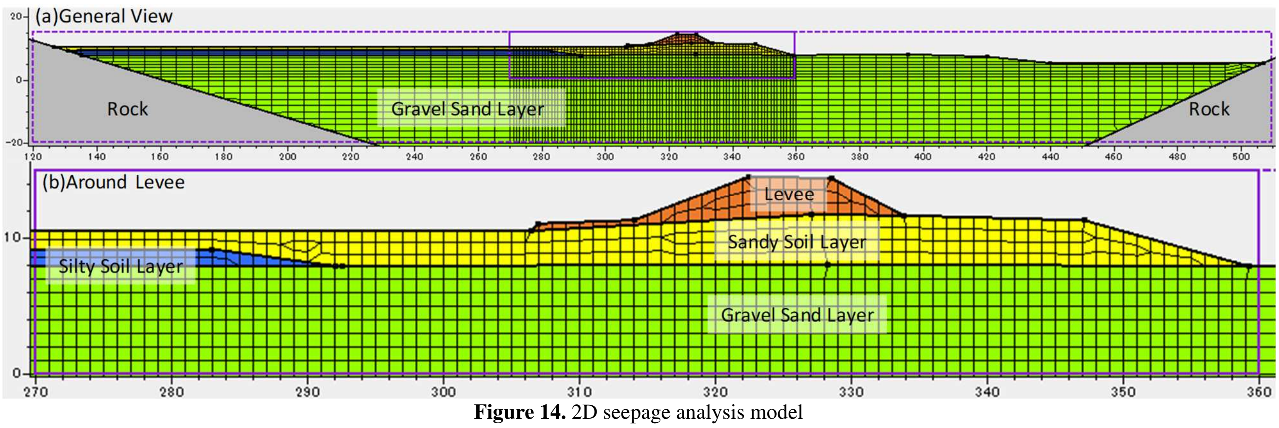

Figure 14. 2D seepage analysis model

4.4. Presence of ground water level supply and impervious sheet pile

A seepage analysis was performed on the presence or absence of the ground water level supply and impervious sheet pile.

The river water level was raised from 6 m to the high water level of 13.45 m over 12 hours, and this was then maintained at high water level for 1 hour, after which the water level was lowered to 6 m over 12 hours. Continuous rainfall of 10 mm/hour was applied.

In a flood that reaches the high water level, it is assumed that the ground water supply from the land side will also increase, but the analysis results from the July 2019 flood of 0.00004 m^3/sec was applied to 5 nodes.

Fig. 17. shows the nodal pressure head time series at the location of the border of the sand and gravel layers directly under the slope foot. It was found that the results changed a relatively large amount depending on the presence of ground water supply, regardless of the presence of impervious sheet piles. Viewed from the land side, impervious sheet piles appear to artificially create a dead end, but according to the results of the seepage analysis there was no impact. However, when viewed from the opposite perspective, it can also be said that when there is a ground water supply the effect of the impervious sheet pile does not appear. The original effect of impervious sheet pile was not leakage control but the suppression of piping formed directly below the embankment. Therefore, it can be considered that the effect of the impervious sheet pile should not be evaluated based on a single point of pressure directly below the slope foot, but based on the pressure distribution directly under the embankment.

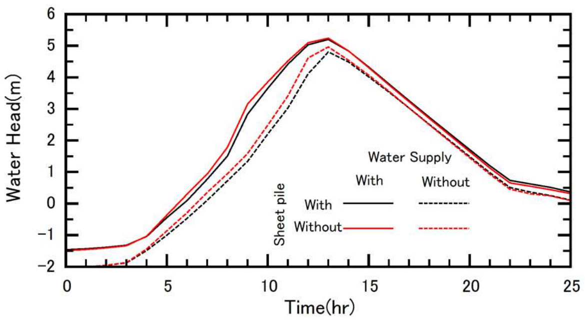

Figure 17. Slope foot base ground pressure head

5. Conclusions

Between 2016 and 2018, there have been three floods which significantly exceeded the ground levee height on the Kita River in Japan. In these cases, large-scale sand boiling was confirmed due to base water leakage at around 13.0 km on the left bank. Ground water level observations were commenced near and around the locations of large-scale water leakage and sand boiling. Two discharges which were slightly above the ground levee height were observed. According to these results, the observation points near the occurrence of water leakage can be considered to have a higher ground water level compared to other observation points, and also to exceed the river water level. It is assumed that the ground water level is supplied towards the observation point, not just from the river side but also from the ground levee side. Therefore, 2D unsteady seepage analysis was performed on a simulated area to clarify the ground water supply from the levee ground side and the effect of impervious sheet piles.

6. Ancknowledgements

Miyazaki prefecture has cooperated on our various survey including the excavation survey, making ground water lever observatories.

The excavation survey results shown herein are from participation in the excavation survey carried out mainly by the geological team of Mr. Shinagawa, and various advice was received on survey methods and interpreting excavation surfaces, and various discussions held on the mechanisms of water leakage.

We would hereby like to express our thanks to Miyazaki prefecture and Mr. Shinagawa.

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