UNDERGROUND INUNDATION BY SIMULTANEOUS PLUVIAL AND FLUVIAL FLOODING IN URBAN AREA

MITSUHIRO TERADA
Section Head of Engineering, Original Engineering Consultants, Osaka, Japan (Email: terada-a1314@oec-solution.co.jp)

TAISUKE ISHIGAKI
Faculty of Environmental and Urban Engineering, Kansai University, Suita, Japan (Email: ishigaki@kansai-u.ac.jp)

TAIRA OZAKI
Faculty of Environmental and Urban Engineering, Kansai University, Suita, Japan (Email: ozaki_t@kansai-u.ac.jp)

KEIICHI TODA
Graduated School of Engineering, Kyoto University, Kyoto, Japan (Email: toda.keiichi.4z@kyoto-u.ac.jp)

ABSTRACT

In Japan, flood disasters induce by typhoons and heavy rains are getting more serious. There are many underground spaces including the subway in Japanese urban cities such as Tokyo, and Osaka. In this paper, numerical simulations of inundation in Osaka, Japan, are conducted by using the general-purpose software Infoworks ICM. Study area Ebie and Ono treatment areas located on the both sides of Yodo River. In this paper, the impact of inundation on underground spaces is predicted when pluvial and fluvial flooding occur simultaneously. Numerical model includes a sewer system, an underground mall, and 15 subway lines. These underground spaces are prone to inundation by pluvial and fluvial flooding. The overtopping discharge by fluvial flood is calculated in the case of the maximum rainfall predicted by the Ministry of Land, Infrastructure, Transport and Tourism. Pluvial flooding is calculated by using extreme rainfall condition occurred in 2008 Okazaki flood. Almost all area on the ground is inundated, and there are some places where the flood depth is up to several meters. It is found that a large amount of flooded water flows into the underground spaces when pluvial and fluvial flooding occur simultaneously. The subway lines are also flooded and flood water spreads through tunnels to wide-ranging areas, and this brings catastrophic damage.

Keywords: subway, pluvial flood, fluvial flood, evacuation, simultaneous occurrence

1. INTRODUCTION

Disasters such as typhoons and heavy rainfalls are intensifying in Japan. There are many underground spaces including the subway in Japanese urban cities such as Tokyo, and Osaka. Therefore, it is increasing the risk of flood damage to subways. The flood condition of subway and the damage condition of underground space when fluvial flood and pluvial flood occur simultaneously. Takeda et al. constructed a numerical analysis of flow considering the cause of inundation. An urban inundation analysis was performed, taking into account the simultaneous occurrence of inland floods caused by heavy rain and external floods caused by the breakthrough. Sekine et al. performed a numerical analysis using the developed flood analysis method. The process and scale of pluvial and fluvial flooding during heavy rain were examined by them. The same model is applied to fluvial flooding in this study.

2. STUDY AREA AND SUBWAY LINES

The target area is Yodo River in the center of Osaka City. In addition, it is target that the sewerage areas of the Ebie treatment area and the Ono treatment area which are located on both banks of the Yodo River. The Ebie treatment area is 6 km east-west and 4 km north-south. The Ono treatment area is 8.5 km east-west and 5 km north-south. The area of the Ebie treatment area is 12.15km^2. The area of the Ono treatment area is 18.59km^2. There are main stations of JR, private railway lines and subways are located in this area. There are the largest underground space in Japan, which extends for about 1km square, is spreading in the basement of the Umeda area in the target area. There are one sewage treatment plant and three pumping stations in the Ebie treatment area. There are one sewage treatment plant and five pumping stations in the Ono treatment area. These facilities have a rainwater drainage capacity of 60mm / hr. Area less than 0m extend from the west to the center in the Ebie treatment area. On the other hand, the ground height is higher from the center to the east side. Area less

than 0m extend from the whole area in the Ono treatment area. Altitude of study area is indicated in Figure 1. Study areas and subway lines are indicated in Figure 2.

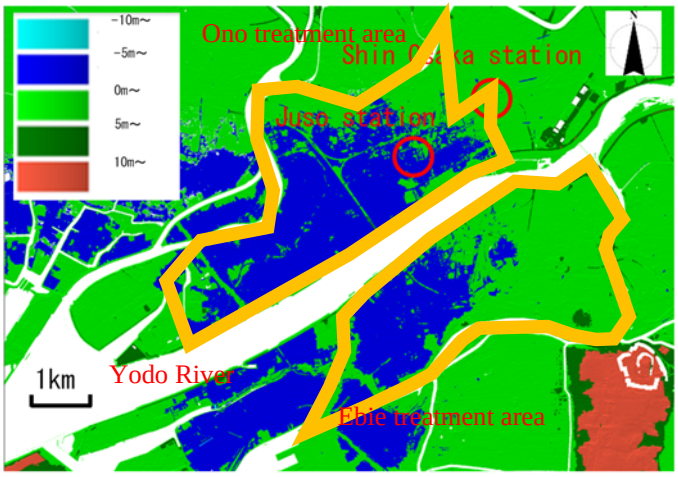


Figure 1. Altitude of study area

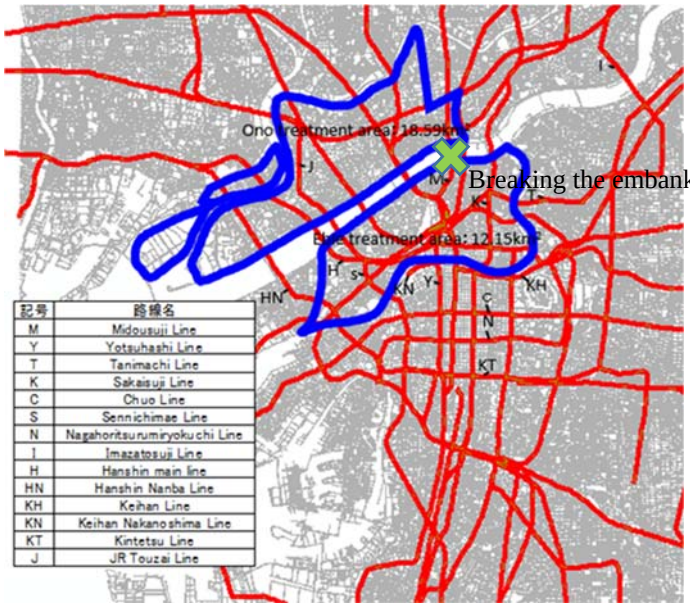


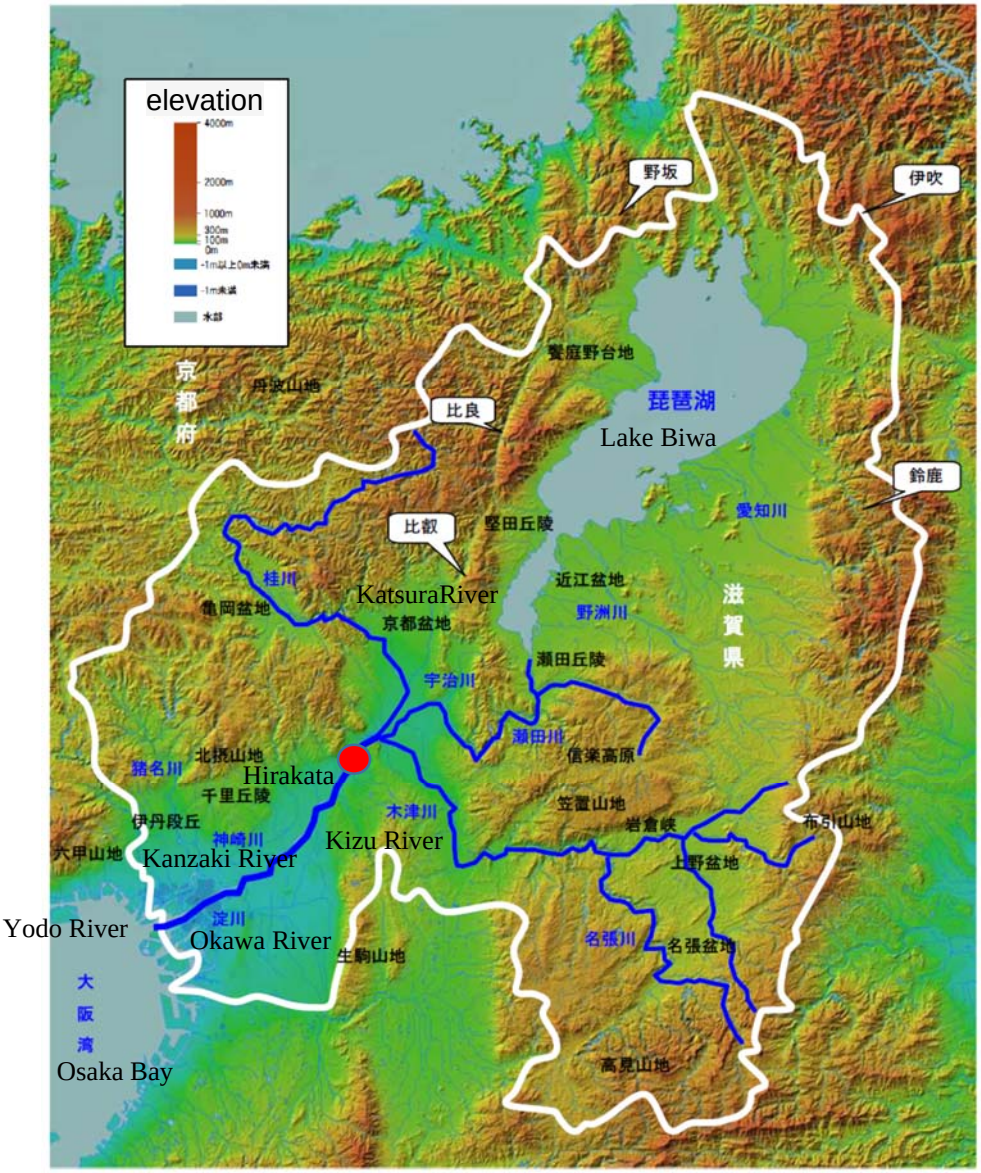
Figure 2. Study areas and subway lines

The target rainfall was midnight to 3:00 am on August 29, 2008, which was observed in Miai town, Okazaki city. This was the highest rainfall in August. Heavy rains were uniformly applied to the Ebie and Ono treatment areas at the end of August 2008.

The roughness coefficient of the subway was 0.025 in the range of 0.017 to 0.030 for mortar.

The Yodo River originates in the mountains of Shiga Prefecture, and its large and small tributaries flow into Lake Biwa. The water flowing out of Lake Biwa changes its name to Seta River and Uji River and flows. The river joins the Katsura River and Kizu River downstream, and becomes the Yodo River, which flows into Osaka Bay. On the way, it is Class A River that divides Kanzaki River and Okawa River and pours them into Osaka Bay. The length of the trunk river reaches 75 km and the basin area reaches 8,240 km^2. It spans six prefectures: Osaka, Hyogo, Kyoto, Shiga, Nara and Mie, and supports the social, economic and cultural infrastructure of the Kinki region. The Yodo River basin is mostly forested.

In analyzing the Yodo River, flood flow was given to the Hirakata observation point. The river section was modeled based on the survey data. The Watershed was modeled using Geospatial Information Authority of Japan 5m mesh data. The flood flow was analyzed by Yodogawa River Construction Office. In the analysis, the breaking the embankment was set. Figure 3 shows the Yodo River basin.



（Source：The 33rd Expert Meeting on Future Flood Control Measures）

Figure 3.Yodo River Basin

The maximum rainfall that can be expected in the Yodo River basin (294 mm at 8,122 km^2) is about 300 mm in 24 hours at 8,240 km^2 .The total rainfall in Kyoto from September 22 to 26, 1953 was 187.1 mm 200 mm). Therefore, the flow rate of the Yodo River is assumed to be 250 ÷ 200 mm ≒ 1.2 times the expected rainfall. Figure 4 shows the Yodo River Flow.

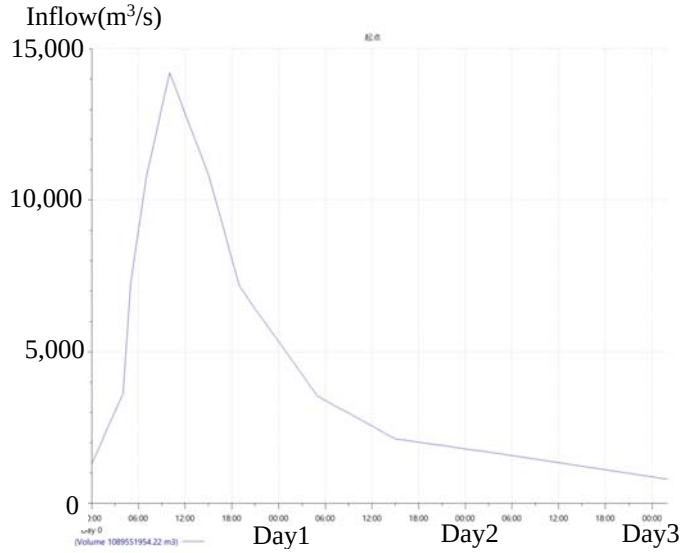


Figure 4.Yodo River Flow

3. Results and Discussions

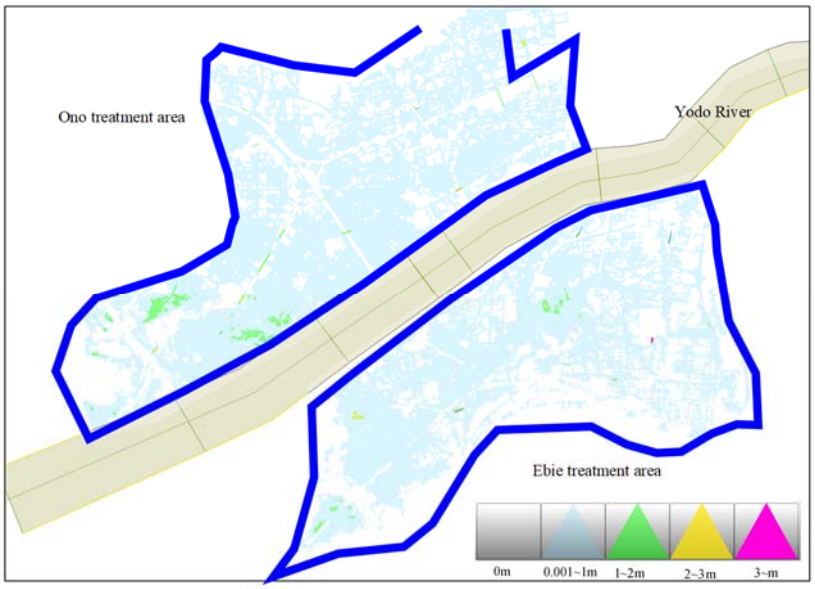


Figure 5. Calculation result plan view（pluvial flood）(Maximum)

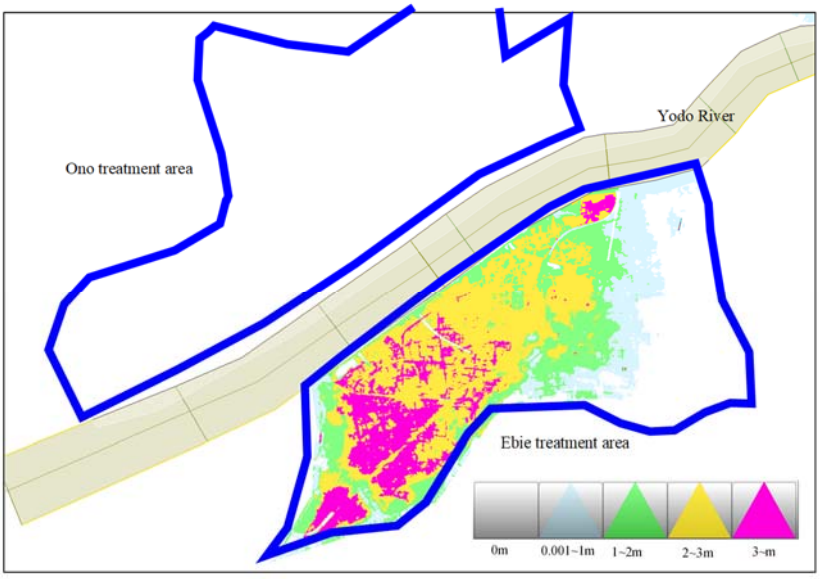


Figure 6. Calculation result plan view（fluvial flood）(Maximum)

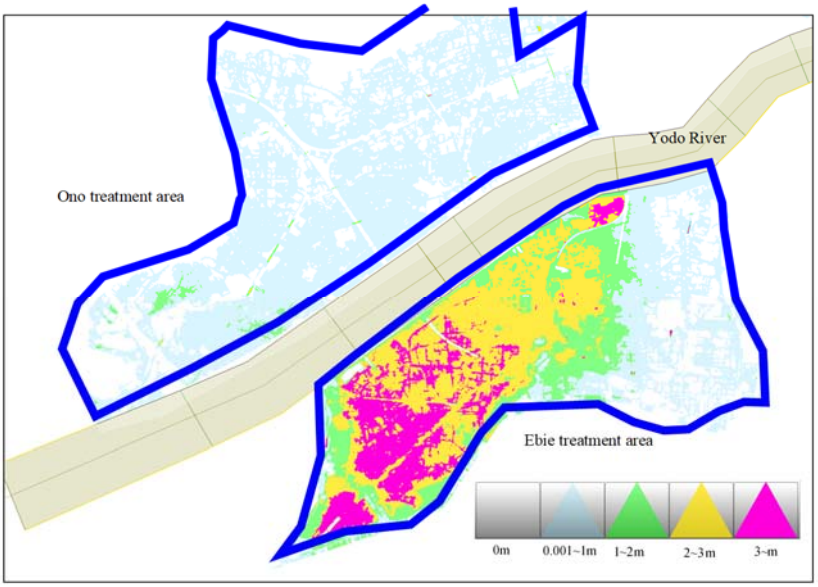


Figure 7. Calculation result plan view（fluvial flood and pluvial flood）(Maximum)

The inundation area is spread all over. There is not much difference in the magnitude of damage between the case of only fluvial flood and the case of simultaneous occurrence of fluvial flood and pluvial flood. The case of simultaneous occurrence of fluvial flood and pluvial flood Although the pluvial flooding has wider inundation area, the case of simultaneous occurrence of fluvial and pluvial flood has greater damage compared to the case of only pluvial flood.

Figure 5 shows Calculation result plan view（pluvial flood）(Maximum). Figure 6 shows Calculation result plan view（fluvial flood）(Maximum). Figure 7 shows Calculation result plan view（fluvial and pluvial flood）(Maximum).

It estimates the number of damages in underground space.

It is estimated that the number of flooded houses with underground space is 255. It is estimated that the number of flooded buildings with underground space is 2,672.

A comparison is made between simultaneous occurrence of fluvial and pluvial water floods and only fluvial water floods. The damage amount is approximately twice as large for fluvial flood and pluvial flood simultaneously than for fluvial flood alone.

In the case of simultaneous pluvial flood and fluvial flood, the damage amount is very large. Table 1 shows Prediction of damage amount for buildings in underground space.

When comparing the fluvial and the pluvial, the fluvial flood only, and the pluvial flood only in the analysis plan, the damage is greatly different between the fluvial flood and the pluvial flood.

Table1. Prediction of damage for buildings in underground space

Fluvial and pluvial flood	Number of houses (houses)	Number of buildings with underground space(houses)	Total number of buildings (house)	Percentage(%)	Number of houses damaged by flooding in underground space(houses)
Number of flooded houses	56,722	—	—	0.45%	255
Number of inundation offices	15,357	2,120	12,150	17.40%	2,672

Fluvial flood	Number of houses (houses)	Number of buildings with underground space(houses)	Total number of buildings (house)	Percentage(%)	Number of houses damaged by flooding in underground space(houses)
Number of flooded houses	24,576	—	—	0.45%	111
Number of inundation offices	6,972	2,120	12,150	17.40%	1,213

In the case of only pluvial flooding, the Yotsubashi Line will be flooded around Nishi Umeda. In the case of only fluvial flooding, all stations will be flooded on the Yotsubashi Line. Even the Sennichimae Line is flooded at all stations. A great deal of damage occurs even in the case of fluvial flooding alone. On the Sennichimae Line, it will be flooded at the west station. It was found that the inundation spread from the north at the Yotsubashi Line, and spread to the end of Suminoekoen Station. On the Sennichimae Line, all stations except Tanimachi9chome Station were found to be flooded. Figure 8 shows Inudation by Yotsubashi Line（Longitudinal section）（pluvial flood）(Maximum) .Figure 9 shows Inudation by Yotsubashi Line（Longitudinal section）（fluvial flood）(Maximum).Figure 10 shows Inudation by Yotsubashi Line（Longitudinal section）（Simultaneous pluvial flood and fluvial. Figure 11 shows Inudation by Sennichimae Line（Longitudinal section）（pluvial flood）(Maximum). Figure 12 shows Inudation by Sennichimae Line（Longitudinal section）（fluvial flood）(Maximum). Figure 13 shows Inudation by Sennichimae Line（Longitudinal section）（Simultaneous pluvial flood and fluvial）(Maximum).

4. CONCLUSIONS

The above results are summarized as follows.

1. If the river and sewer overflow at the same time, buildings with thousands of underground spaces flooded. The damage is great.
2. If the river and sewer overflow at the same time, all subways are flooded.
3. The damage from fluvial flood is large.
4. The risk of underground space is high even in the case of fluvial flood alone.

REFERENCES

Takeda,M. Murase,M. Mouri, R. Matsuo, N. (2018). NUMERICAL ANALYSIS ON WATER BEHAVIOUR IN URBAN AREA BY INUDATION DUE TO RIVER FLOOD AND HEAVY RAIN COSIDERING THE ORIGIN, The Journal of Japan Society of Civil Engineers, Ser. B1 Vol.74(2018) , No.5 (Annual Journal of Hydraulic Engineering), pp.I_1465-I_1470（in Japanese).

Sekine, M. Ikeda, R.(2014). NUMERICAL SIMULATION OF INUNDATION IN LOWLAND AREAS OF EAST TOKYO, The Journal of Japan Society of Civil Engineers, Ser. B1 Vol.70(2014) , No.4 (Annual Journal of Hydraulic Engineering), pp.I_1429-I_1434（in Japanese).

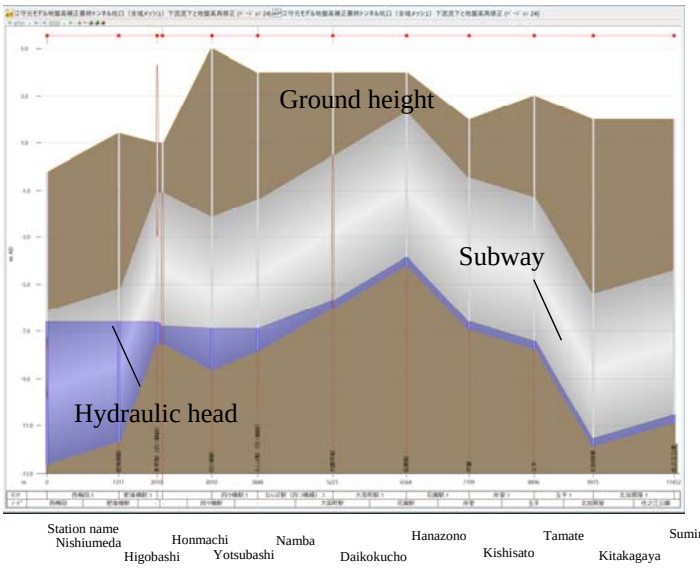


Figure 8. Inudation by Yotsubashi Line（Longitudinal section）（pluvial flood）(Maximum)

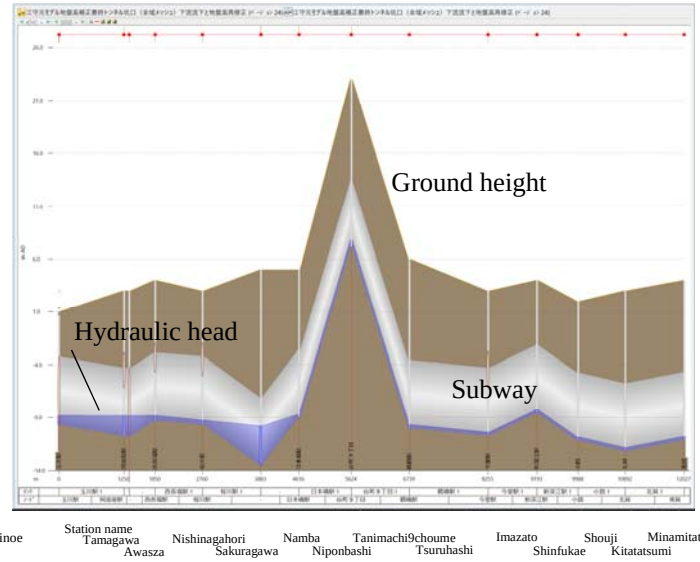


Figure 11. Inudation by Sennichimae Line（Longitudinal section）（pluvial flood）(Maximum)

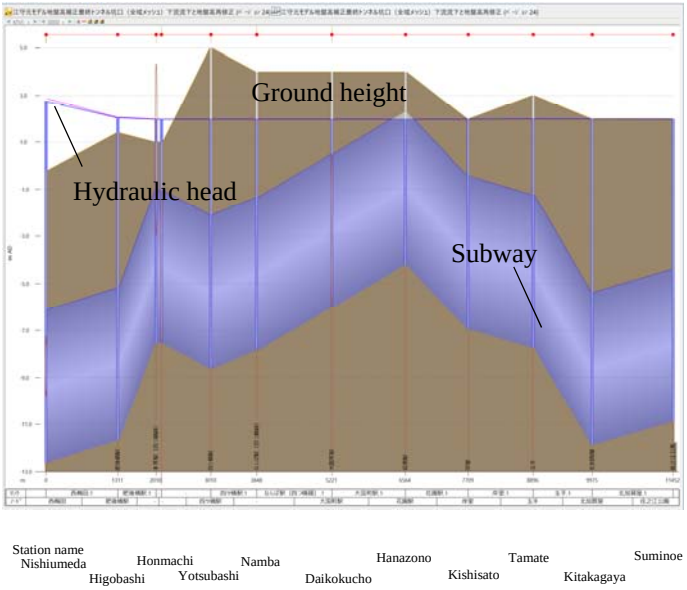


Figure 9. Inudation by Yotsubashi Line（Longitudinal section）（fluvial flood）(Maximum)

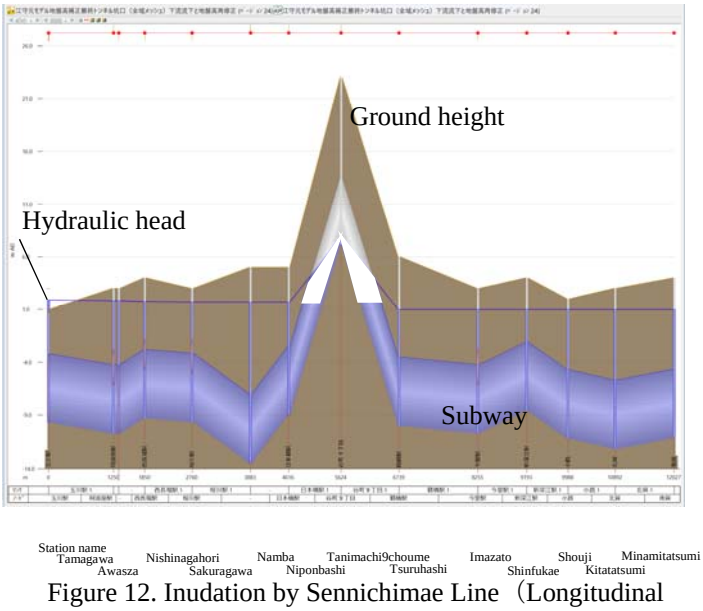


Figure 12. Inudation by Sennichimae Line（Longitudinal section）（fluvial flood）(Maximum)

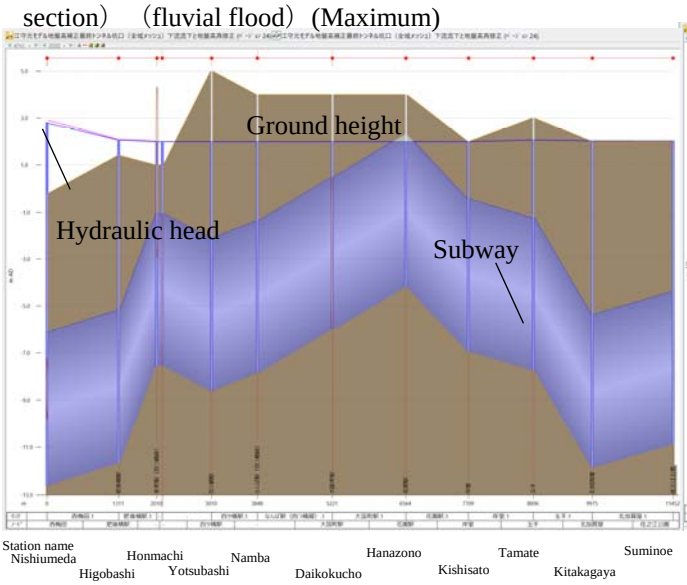


Figure 10.Inudation by Yotsubashi Line（Longitudinal section）（Simultaneous pluvial flood and fluvial flood）(Maximum)

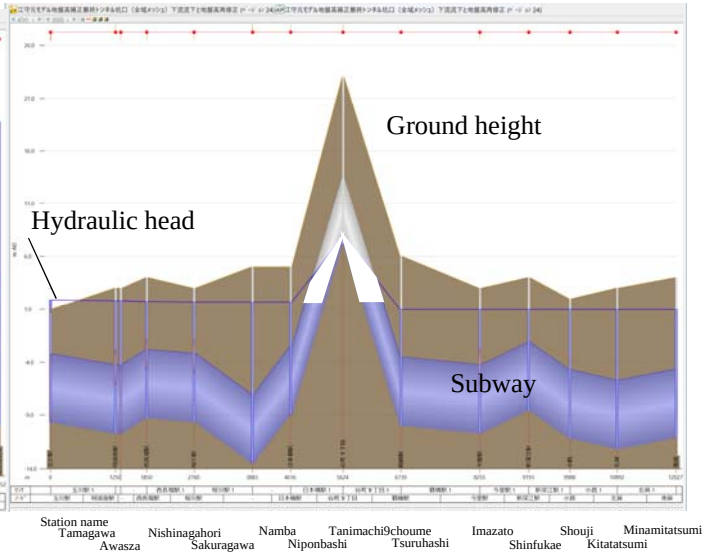


Figure 13. Inudation by Sennichimae Line（Longitudinal section）（Simultaneous pluvial flood and fluvial flood）(Maximum)flood）(Maximum)