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A Study of Site Planning Integrated with Sustainable Stormwater Management in the Scale of Building -Comparative Analysis Utilizing 3D Measurement Technology Part2-

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ABSTRACT

This paper is the continuation of the previous paper, and thus the background of the study is shared. Reflecting the recent social needs, site planning integrated with sustainable stormwater management in the scale of building and district will become increasingly important. In this study, we focused on the scale of building. We conducted surveys using 3D measurement technology, targeting two types in the scale of building: a case where sustainable stormwater management has been prepared, Miyoshi Civic Hall Kiriri, and a case where the sustainable stormwater management was not sufficiently prepared, the Kawasaki City Museum. By analyzing and comparing the 3D data obtained from the surveys in the two cases, we aimed to examine relatively the effectiveness of stormwater management and damage by identifying the relationship between topographical features and the risks caused by them. First, for the Damaged case, we produced a 3D section of the damaged area and verified the relationship between the damage and the topography. Next, we verified the effectiveness of sustainable stormwater management for the Prepared case by following the same procedure. Then, we compared the two cases and examined how site planning integrated with sustainable stormwater management can be effective in the scale of building. Furthermore, we discussed the benefits and advantages in the two scales and examined the role of site planning integrated with sustainable stormwater management.

1. Introduction

In recent years, the global climate has been changing due to global warming. In Japan, the frequency of water-related disasters increased in recent years due to short-duration heavy rainfall and stronger typhoons. These data indicate that the amount of rainfall exceeds the city's drainage capacity, resulting in an increasing number of cases of inland flood.

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Particularly in areas where urbanization has progressed, and the permeability of the ground surface is low, stormwater is difficult to infiltrate into the ground and flows into sewerage systems and rivers quickly. As a result, a large amount of stormwater exceeding the capacity flows into the sewerage system and rivers in a short duration and overflows, resulting in inland flood. In such areas, it is necessary to control the occurrence of inland flood and mitigate the damage by managing stormwater flows adequately and preventing the concentration of stormwater in specific locations.

There are few studies on stormwater management in the scale of building. Most of the research on stormwater management is in the fields of hydraulic engineering, civil engineering, and urban engineering, and there are few studies on a small scale. The few studies that were conducted were on stormwater infiltration facilities in private residences. For example, the development of an analytical model of a stormwater infiltration facility by Hanaki et al. [1] and the evaluation of a stormwater infiltration facility installed in a private residence by Imbe et al. [2] Itsukushima et al. studied the effect of individual house storage on runoff control [3], and Yokota et al. developed a citizen-participatory survey tool for thin environments [4]. In addition, Kiuchi et al. studied the evaluation of the cost-effectiveness of floodproofing plans [5]. Silva et al. [6] and Stefan et al. [7] classify flood countermeasures including building size, although their target disasters are river flooding and sea level rise. Thus, although there are a few studies on stormwater management in the scale of building, few of them examine the topographical features in detail. For this reason, we focused on the scale of building in this study. As mentioned in the previous paper, we have other references [8-15].

In this study, we targeted two types in the scale of district: a case where sustainable stormwater management was prepared, and a case where the sustainable stormwater management was not sufficiently prepared. Firstly, data on topography, buildings, and trees in the target area are obtained using 3D measurement technology. Secondly, for the damaged cases, we produced axonometric drawings that show the cross-section of topography and buildings, hereafter called “3D section” of the affected area. For the prepared cases, we produced 3D sections, including the area around the stormwater management system. Thirdly, the relationship between topographic features and the resulting risks were clarified, and then the effectiveness of stormwater management and its relationship to damage were clarified. Then, we verified the relative effectiveness and damage of stormwater management. Finally, we compared the previous and this study to discuss relatively the difference in scales. The flow of this research is shown in Figure. 1.

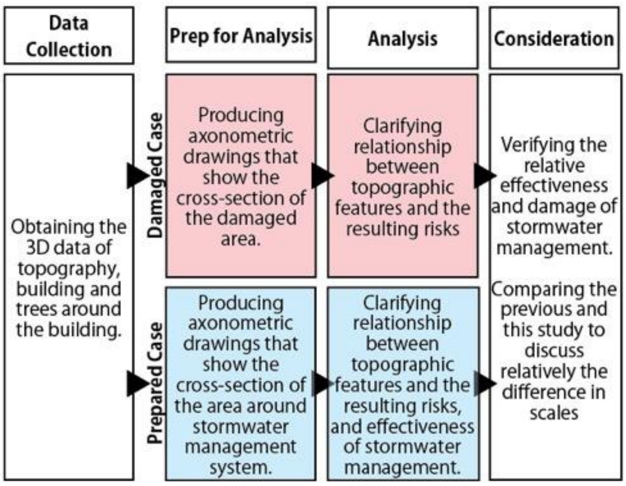

Fig. 1. Flow of research

2. Study area and survey

2.1 Study area

In this study, as a damaged case, we investigated buildings that were damaged in recent years by water-related disasters, especially inland flooding. Next, we attempted to find damaged buildings not in the suburbs and where there is no room for river expansion. As a result, the Kawasaki City Museum was selected as a damaged case. The Kawasaki City Museum was severely damaged by Typhoon No. 19 in 2019. It is located in the Todoroki Ryokuchi Park. Approximately 260,000 items submerged in the basement storage of the collection. Due to this damage, the museum has been closed since that time. The restoration of the damaged materials is still ongoing.

As a prepared case, we investigated buildings that introduced stormwater management. As a result, there were very few examples of stormwater management in the scale of building in Japan. Among them, Miyoshi Civic Hall Kiriri was selected as a prepared case study and it had already experienced a disaster. Miyoshi Civic Hall Kiriri was designed by Jun Aoki. The entire building was raised approximately 5 meters above the ground level. In addition, the site is lower than the surrounding area about 1 meter to store stormwater. The area experienced flood in 2018 and 2021. Basic information on both cases is shown in Figures 2 - 5.

Fig. 2. Location of Kawasaki City Museum

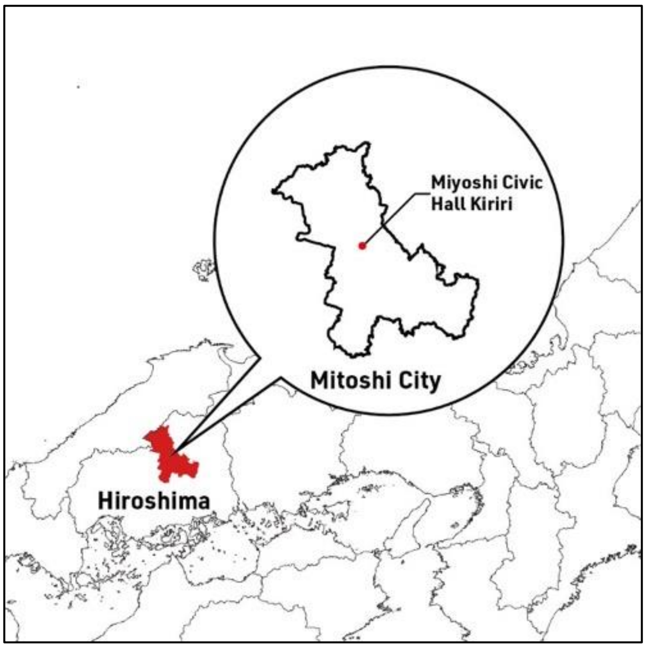

Fig. 3. Location of Miyoshi Civic Hall Kiriri

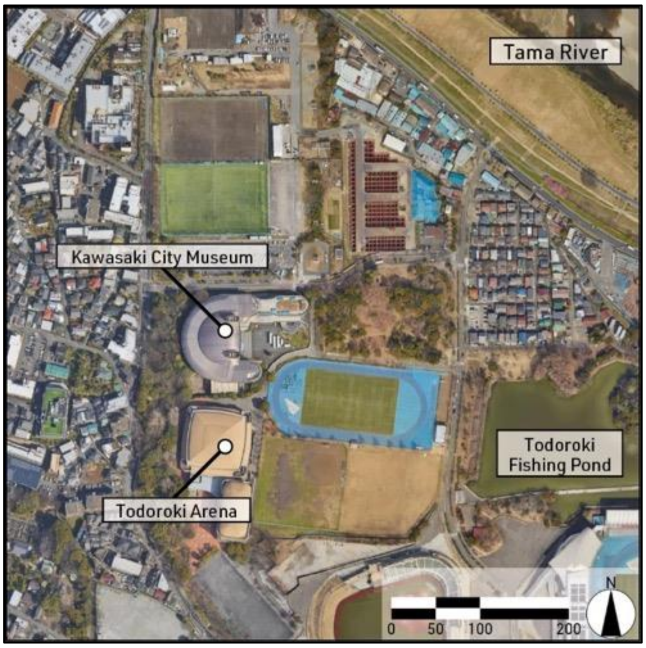

Fig. 4. Aerial photograph around Kawasaki City Museum

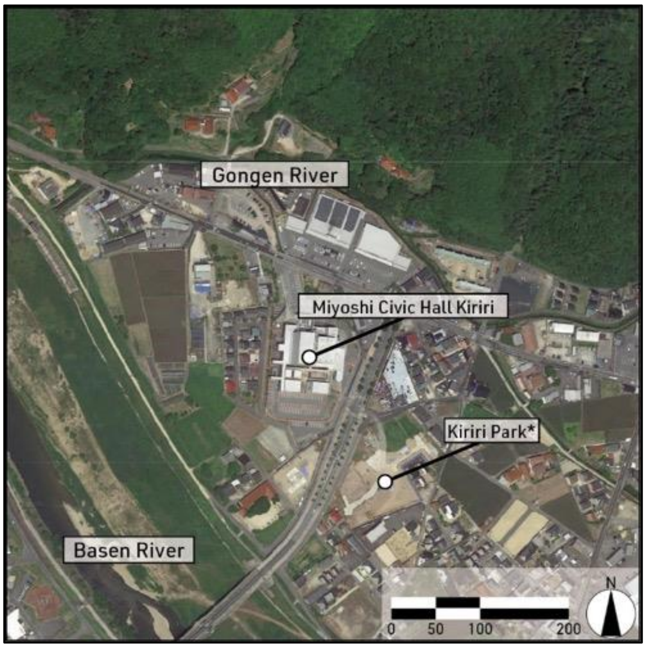

Fig. 5. Aerial photograph around Miyoshi Civic Hall Kiriri

2.2 Process of obtaining 3D data

The same reason that the lack of level of detail, we decided to obtain 3D data by ourselves. Furthermore, in order to obtain data of the target buildings sufficiently, we used a drone to obtain the data from the sky. The drone measurements used a technique called photogrammetry, which takes a large number of photographs and reconstructs the 3D data. The flight path, number of photos taken, and angle of photography were set in advance using flight control software. In addition, since it was considered insufficient to obtain information on the building only by a drone, a portable 3D scanner was used to obtain data on the building's lower part and parts of the interior.

2.3 Results of surveys

We obtained 3D data for almost the entire targeted area successfully through the survey process described above. The obtained data were processed using the manufacturer's software for each device. For the portable 3D scanner, the data obtained were processed using the software that are the manufacture of the scanner provided. Then, noises caused by people, vehicles, etc., were removed. The same process was applied to the data obtained by the drone, and then the data were integrated to produce a set of data for the entire area. The survey details are summarized in Table. 1. The results of the surveys are shown in Figure. 6.

Table. 1. Detail of survey

	Location	Tool	Date	Data size (GB)	Max height difference (m)	Measured area (m^2)
City Museum	Todoroki, Nakahara Ward, Kawasaki City, Kanagawa, Japan	Portable 3D Scanner	2023/6/9, 16	18.68	45.1	109514
		Drone + Photogrammetry	2023/6/13, 15, 19	10.47		
Civic Hall	Miyoshi-cho, Miyoshi City, Hiroshima Prefecture, Japan	Portable 3D Scanner	2023/10/31, 11/2	13.95	36.8	31537
		Drone + Photogrammetry	2023/11/1, 2	12.39		

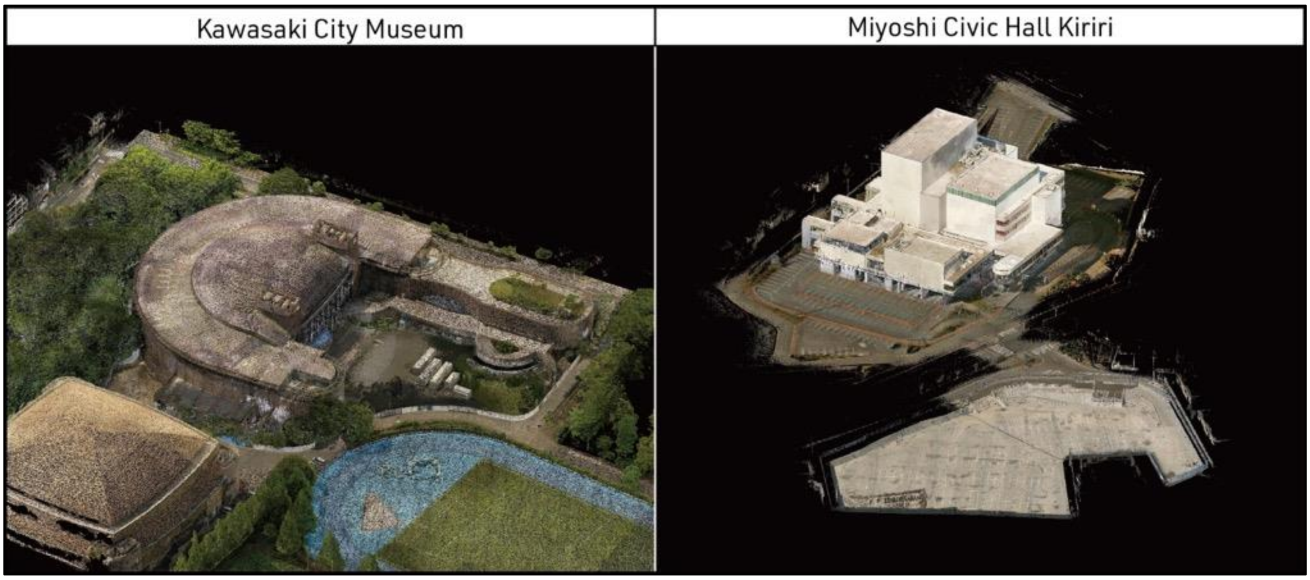

Fig. 6. Result of survey

3. Relationship among buildings, topography, and risks

3.1 Subject of this chapter

In this chapter, we use the obtained 3D data through the process described in the previous chapter to analyze the relationship between topographical features and caused risks. For the damaged case, first, we represent inundated areas during the recent disaster on a map. Then, we produce a 3D section by cropping the 3D data centered on the damaged area. We use the 3D sections to clarify the relationship between the topographical features and the damage. For the prepared case, first, we represent prepared stormwater management facilities. Then, we produce a 3D section by cropping the 3D data centered on the damaged area.

3.2 Damage of Typhoon No.19 in 2019 around The Kawasaki City Museum

The area around the Kawasaki City Museum was damaged by Typhoon No. 19 in 2019. In the accident, the stormwater overflowed from manholes nearby and flowed into the basement space of the Kawasaki City Museum. Typhoon No. 19 in 2019 has caused widespread damages, mainly in the Kanto region. The water level of the Tama River, which flows near the museum, almost reached the breaking point. This situation, constrained by the surrounding ground levels made it difficult to drain stormwater into the Tama River, and caused inland floods in many areas. The Kawasaki City Museum was one of those cases that were affected by the inland floods.

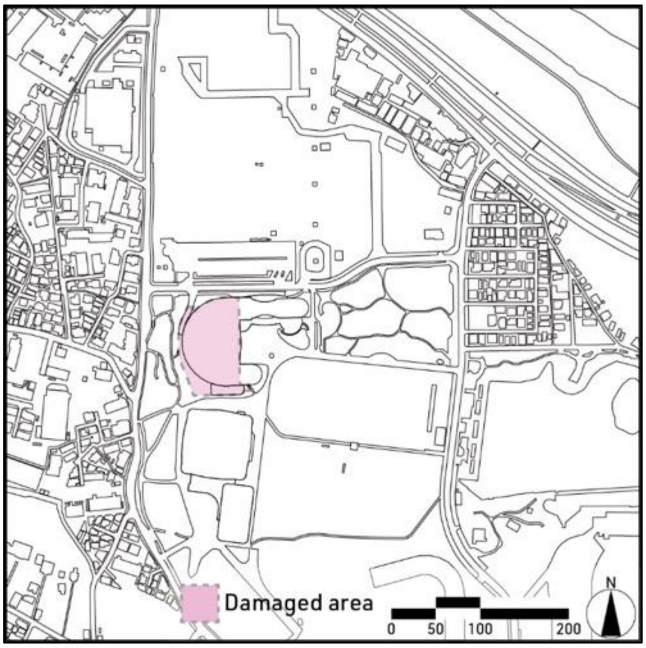

Fig. 7. Damaged area in 2019 with base map

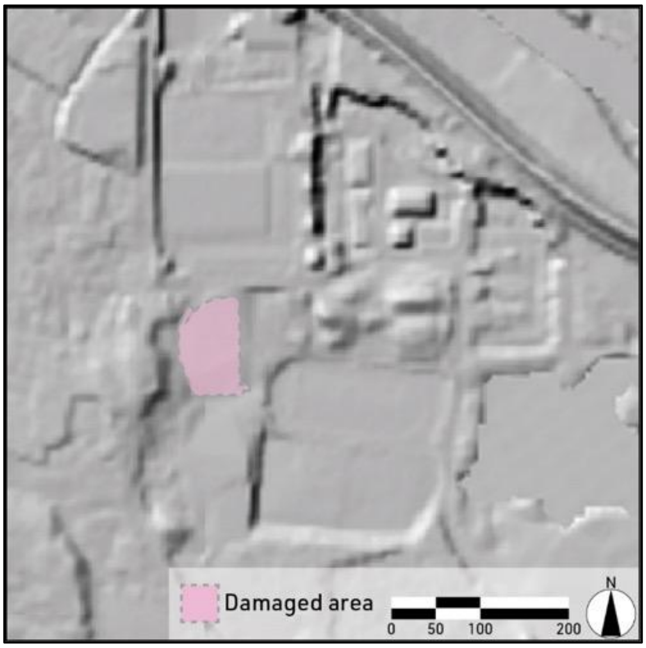

Fig. 8. Damaged area in 2019 with topographical map "Produced from 陰影起伏図 （国土地理院)."

A large amount of stormwater overflowed from manholes on the road on the west side of the museum and flowed through the trees into the passageway between the museum and the Todoroki Arena. The underground service yard and loading dock of the Kawasaki City Museum is located along the passageway. Thus, overflowed stormwater moved into the underground service yard, destroyed the steel shutter of the loading dock and flowed into the underground storage of the collection. Since the main collection of the Kawasaki City Museum includes comic books, magazines and movie films, the inundation caused severe damage to the collection.

3.3 Relationship among topography, and risks around City Museum

We focused on the areas where the damages occurred by inundation. Then, we produced 3d sections of the damaged area (Figures. 9 and 10).

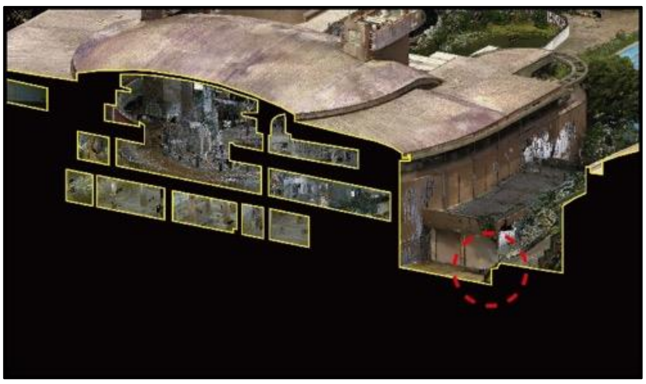

Fig. 9. 3D section of Kawasaki City Museum 1

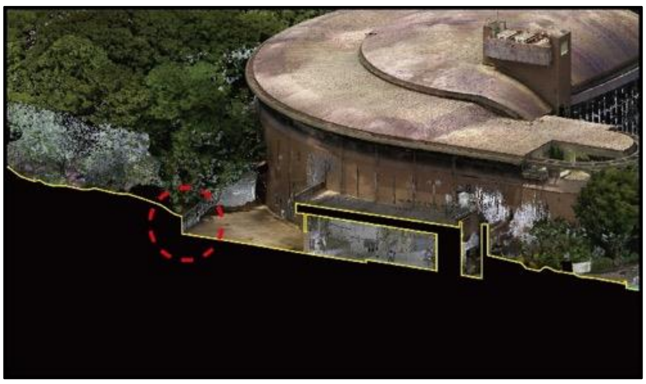

Fig. 10. 3D section of Kawasaki City Museum 2

The areas in the red dotted circle in both figures show the location of the service yard of the museum. As described in the previous section, this is the particular location where the stormwater entered the basement of the building. It is recognized that the ground level of the service yard is lower than the passageway between the museum and the adjacent building, as shown in Figure 9. It can also be seen that the underground storage is located on the basement level and shown from the left to the center of the figure. This underground storage encountered the most serious damage because its floor level is aligned to the one of the service yard. As shown in Figure 10, the ground level of the forest that appears on the left side of the figure is higher than the one of the service yard that appears in the middle of the figure.

The ground levels of the forests on the left side appears at the same level as the one on the right side. The situation constrained by the surrounding ground levels makes it difficult to drain stormwater once it flows into the area. The ground level of the forest that appears on the right side of the figure is higher than the one of the loading dock that appears in the middle of the figure. Then, the level of the service yard is aligned to one of the loading dock, which is connected by the steel shutter. A large amount of stormwater flowed into the underground service yard and the loading dock came into the underground storage on the same level. In fact, after the disaster in 2019, it required four days to drain the water from the entire amount of stormwater from the inundation that occupied the loading dock and the underground storage.

As shown in Figure 8, the ground level of the Todoroki Ryokuchi Park, where the Kawasaki City Museum is located, is lower than the ground level of the surrounding districts. Furthermore, the ground level of the site of the museum is lower than that of the remaining area in the park. Therefore, it is probable that this situation caused considerable risk of flood to the site of the museum. In summary, the particular placement of the service yard, the loading dock, and the underground storage increased the risk in the particular situation. This spatial arrangement of the functions seems to be one of the reasons that caused the serious damages.

3.4 Stormwater management around Civic Hall Kiriri

The area around Miyoshi Civic Hall Kiriri experienced the damages caused by torrential rains in 2018 (Figure 11,12) and 2021. The torrential rainfall in July 2018 was especially severe. Miyoshi Civic Hall Kiriri was completed and opened to the public in 2015. This torrential rainfall in July 2018 was the first disaster that this building encountered after its completion. This area experienced a flood of the Basen and Gongen Rivers that flow near the site. The area surrounding Miyoshi Civic Hall Kiriri encountered the flood in large scale.

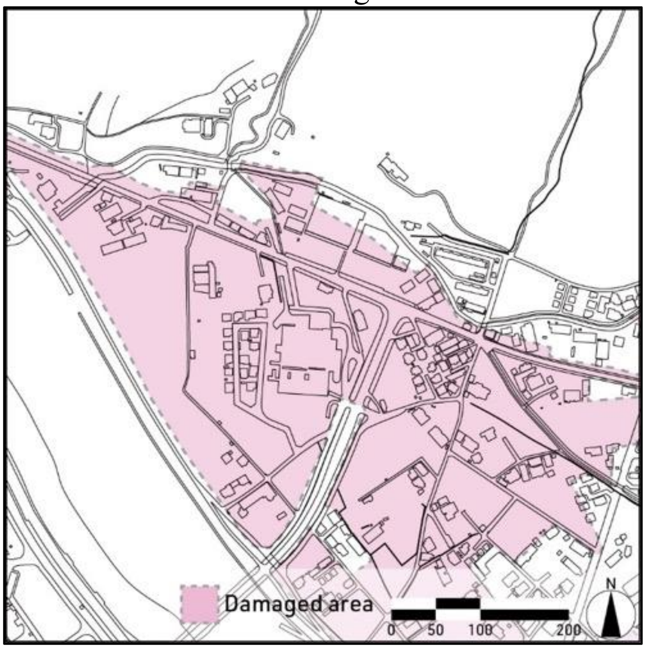

Fig. 11. Damaged area in 2018 with base map

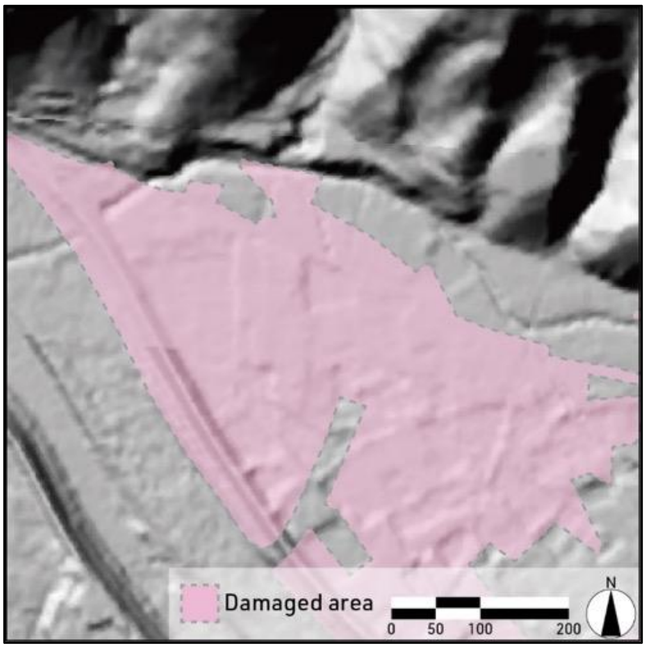

Fig. 12. Damaged area in 2018 with topographical map "Produced from 陰影起伏図 （国土地理院)."

Jun Aoki has won the open proposal to select the architect and designed the Miyoshi Civic Hall Kiriri. 35 applicants submitted their plans for the open proposal. Mr. Aoki was the only one who considered the risks of the site for water-related disasters and proposed a scheme that includes the countermeasure to the disaster. He designed the Miyoshi Civic Hall Kiriri in such a way that the entire building was elevated 5,000 mm from the ground level (Figure 13). His intention for this design was to avoid damages caused by the potential flood of maximum 5-meter heigh as shown in the hazard map. The detailed hazard map for flood was published by the local government and indicated the risk at the time of the proposal.

Fig. 13. Section of Miyoshi Civic Hall Kiriri

In addition, as shown in Figure 14, the parking lot on the ground level is placed 1100 mm lower than that of the surrounding area. This spatial arrangement allows to store approximately 630 m^3/7000 m^{3*1} of rainwater in the parking lot.

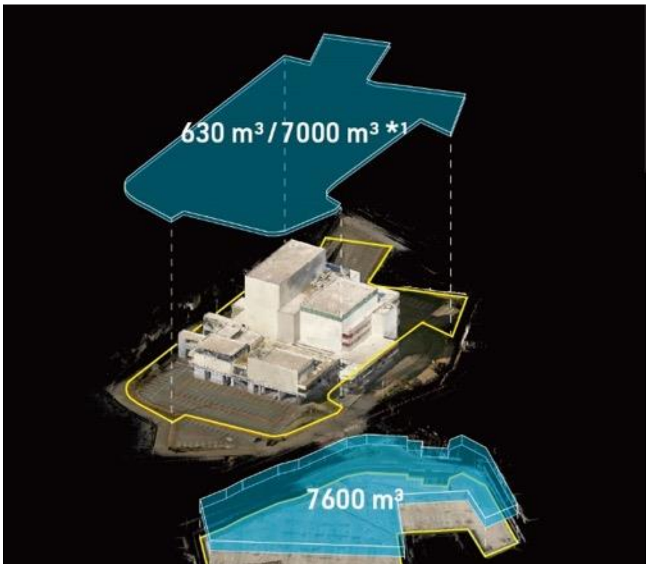

Fig. 14. Capacity of Miyoshi Civic Hall Kiriri and Kiriri Park

During the torrential rains in 2018, Miyoshi Civic Hall Kiriri was used as a shelter to evacuate for residence who live nearby. Fortunately, the elevated portion of the building was not damaged and could operate as a shelter. However, the elevators, fire extinguishing equipment, and machine rooms that were not prepared for the inundation, encountered damage. After the 2018 disaster, Miyoshi City worked with the national and prefectural governments to prepare additional countermeasures to control floods. Kiriri Park, a reservoir with a water storage capacity of 7,600 m3*[1], has been constructed on the adjacent site.

3.5 Relationship among buildings, topography, and risks in Civic Hall Kiriri

We produced 3d sections focusing on the stormwater management facilities that are located in the area. (Figures 15, 16)

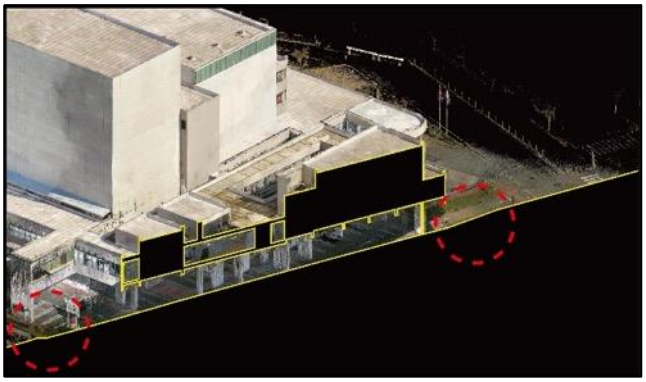

Fig. 15. 3D section of Miyoshi Civic Hall Kiriri 1

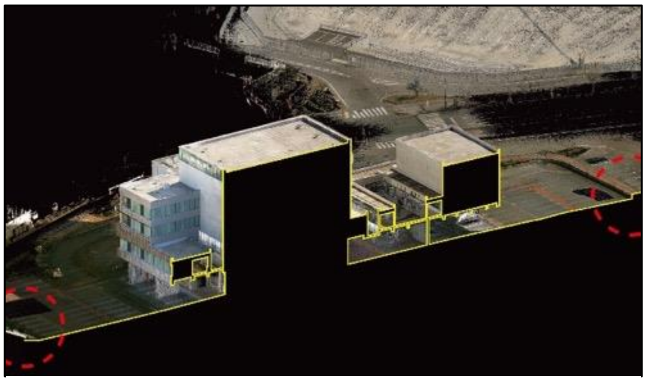

Fig. 16. 3D section of Miyoshi Civic Hall Kiriri 2

Figures 15 and 16 show the condition where the site of Miyoshi Civic Hall Kiriri is lower than the surrounding areas. The parking lot was intentionally designed in such arrangement to store stormwater and to control the amount of the surface water. Additionally, the main functions of the building were elevated to allow the building to escape from the damage of flood.

Figure 12 shows that the landform of the area along the river is very flat. Therefore, it is difficult to drain the stormwater once it flows into the area. Thus, it is reasonable to elevate the main functions of the building approximately 5 m above ground level and to effectively protect them from the flood. In particular, as a public facility, it is very important to make the building avoid damage from inundation and serve as a shelter in case of disasters.

On the other hand, the machine rooms and other facilities were placed on the ground level, as shown in the center of Figure 16. Thus, some equipments and facilities encountered damages during the torrential rainfalls in 2018. Although the Miyoshi Civic Hall Kiriri is recognized as a case where risks of flood were successfully controlled up to a certain extent by elevating the main functions of the building.

4. Comparison of two scales of studies and conclusion

4.1. Conclusion

Continuing on from the previous paper, this study addressed the importance of Site planning integrated with sustainable stormwater management. The study particularly focused on the scale of building and selected adequate cases that represent issues in the scale of building. The Kawasaki City Museum was selected as a damaged case with insufficient stormwater management, and Miyoshi Civic Hall Kiriri was selected as a case with the scale of building stormwater management. Firstly, we obtained 3D data by ourselves using our own 3D measurement technology. Secondly, using this 3D data, we prepared analytical outcomes and examined the relationship between topographical features and the caused risks. Thirdly, we clarified the relationship between topographical features and damages in the damaged case. Fourthly, we clarified the relationship between topographical features and the effects of stormwater management in the prepared case. Then, we examined the issues to be considered that were clarified in the cases in the scale of building.

Around Kawasaki City Museum, the damage caused by the inland flood was worsened by the particular layout of the service yard, the loading dock, and the storage of the collection on the basement floor in relation to the topographical features of the surrounding area that deploys site-specific risks. In the area around the Miyoshi Civic Hall Kiriri, in addition to storing stormwater, the damage caused by the overflow flood was controlled more successfully by elevating the main functions of the building. After reviewing the results in both cases, it is necessary to carefully examine the cases in the scale of building where the risks caused by topographical features can be mitigated, the damages can be controlled up to a certain extent, and thus the appropriate stormwater management was implemented successfully.

4.2. Comparison of two scales of studies

This study was conducted focusing on the cases in the scale of building, following the study focusing on the cases in the scale of district in the previous paper. In both studies, we examined how risks caused by topographical features can be controlled, if stormwater management is implemented adequately. After comparing the conclusions in the scale of district with the ones in the scale of building, we clarified to a certain extent that effective countermeasures are different depending on the size of the area where the countermeasures are applied. It is difficult to modify the topography in a

Table. 2. Summary of the study

			River flooding		Inland flooding	
			Countermeasure for mitigate occurrence of disaster	Countermeasure for mitigate damage of disaster	Countermeasure for mitigate occurrence of disaster	Countermeasure for mitigate damage of disaster
District scale	Damaged cases		This case was damaged because no action is taken against the risks caused by topological features	This case was damaged because no action is taken against the risks caused by topological features	This case was damaged because no action is taken against the risks caused by topological features	This case was damaged because no action is taken against the risks caused by topological features
	Prepared cases		This case is storing stormwater in schoolyard in response to flood experiences. Primary Expected Effect →	Secondary Effect This case was not damaged even though no action is taken	This case was not damaged even though no action is taken	This case was not damaged even though no action is taken
Building scale	Damaged cases		This case was not damaged even though no action is taken	This case was not damaged even though no action is taken	This case was damaged because no action is taken against the risks caused by topological features	Damage was worsened by the particular layout of the loading dock and the storage of the collection on the basement floor in relation to the topographical features of the surrounding area
	Prepared cases		This case is storing stormwater in parking lots in response to flood hazard map.	This case was reduced damage successfully by placing the primary functions of the building on the elevated level	This case prepared new reservoir(Kiriri Park) to mitigete occurrence of disaster after the disaster in 2018 Primary Expected Effect →	This case was not damaged even though no action is taken Secondary Effect

large scale in all the cases, and thus, this option is not realistic in the both scales. Therefore, it is necessary to consider a countermeasure to respond to the specific demands and/or constraints due to the scale at which the countermeasures are applied. In the scale of district, a countermeasure can be taken not only for a single site or building, but also for the surrounding area. Therefore, it is possible to design buildings in such a way that they are placed to avoid locations with higher risks in the district. In the scale of building, risks caused by topographical features that surround the site should be considered in addition to the risks within the site. Therefore, it is possible to design buildings in such a way that they prepare for the potential risks in the site. In conclusion, through the examination of risks caused by topographic features in the four cases, we clarified the differences and/or similarities of the effective countermeasures in the two scales.

As also discussed in the previous paper, the countermeasures are categorized according to the two types of flooding: River flooding and Inland flooding. Next, considering the function of the countermeasures for the Prepared cases, they can be classified into two categories: “Countermeasures to mitigate the occurrence of disasters” and “Countermeasures to mitigate the damage of disasters.” Based on these classifications, the results are summarized in Table 2. Table 2 shows that the damages were caused by the lack of necessary actions in the Damaged cases. On the other hand, we found that the Prepared cases were successful in mitigating the damage of disasters or mitigating the occurrence of disasters by implementing the other countermeasures. In addition, as the orange arrows indicate in Table 2, the Prepared cases include some special cases in terms of the classification of their function. In some special cases, it is focused on one of the two countermeasures instead of covering both. In these cases, they focused on the “Countermeasures to mitigate the occurrence of disasters” as their primary expected effect. We found these countermeasures also reduced the damage of disasters as a result. Therefore, even though the primary expected effect was “to mitigate the occurrence of disasters,” the countermeasure successfully created the secondary effect “to mitigate the damage of disasters.” This finding suggests that the secondary effect could be considered when a countermeasure is implemented for its primary expected effect.

It is difficult to prepare countermeasures that are effective for all the possible factors with constraints of budget and time. As mentioned above, the different countermeasures are effective according to the scale of the cases. Based on the findings that are applicable in these situations, it is important to consider countermeasures with a perspective that includes views for the secondary effects as mentioned in the previous paragraph. Therefore, it is necessary to conduct a more detailed and developed study that examines the relationship between the primary expected effects and the secondary effects. In this study, we examined the relationship between risks caused by topographic features and damages found in the Damaged cases, focusing on the damaged sites. However, it is necessary to conduct a more detailed and developed study to identify locations where damage is expected to occur, including areas that have not been damaged. In addition, it is important to address issues in communication with residents in the area to share the risks caused by topographical features and the effectiveness of the countermeasures.

Acknowledgment

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Notes

*1 Official information from Miyoshi Civic Hall Kiriri states that the parking lot can store water to a depth of about 100 mm, for a total of 670 m^3. However, it is physically possible to store water to a height of about 1 m, a total of approximately 7,000 m^3.

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