Countermeasures Against Flood Damage of Buildings and Their Applicability

Nozomu Kiuchi[1], Taku Nakano[1]

[1]Building Research Institute, 1 Tachihara, Tsukuba, 305-0802, JAPAN

Correspondence to: Nozomu Kiuchi (n_kiuchi@kenken.go.jp)

Abstract. Within the concept of "Basin Flood Control" based on future climate change, devising ways to live in areas with a possibility of flooding, as well as regulations and guidance of buildings and land use, etc. should also be considered. This article explains the studies carried out by the Building Research Institute to investigate the cost-effectiveness of flood damage countermeasures at the building and site level based on the flood risk of the location. In the research, 3 cases were assumed; 1) when constructing a new wooden detached house, 2) when renovating an existing condominium, and 3) when a business office moves into the first floor of a RC building and a model examination of flood countermeasures was carried out. The "average expected payback period" is calculated to understand the relative necessity of flood countermeasures and their composition ratio are shown.

1. Recent flood damage of building in Japan

In Japan, typhoons and torrential rains are causing unprecedented flood damage also in urban areas. When houses encounter a flood, depending on the degree of flooding, residents may face a life-threatening danger, and most of all, they will have to deal with the heavy burden of cleaning, tidying up, and restoring buildings and household goods soiled or damaged, under sometimes outages of lifelines such as electricity, water, and sewage.

The impact of climate change on a global scale is behind the frequent and severe flood damage, and it is important for us as a society to adapt and prepare. Within the concept of "Basin Flood Control" based on future climate change, devising ways to live in areas with a possibility of flooding, as well as regulations and guidance of buildings and land use, etc. should also be considered.

2. Anti-flood measures for buildings

With respect to countermeasures to prevent water damage to buildings, efforts in Europe and the U.S. are leading the way, including the publication of a guidebook by FEMA (2014) in the U.S. and a book published by the Royal Institute of British Architects (Barsley, 2020). Various efforts have also been initiated recently in Japan.

However, it is not clear what level of countermeasures should be targeted for each location in these efforts, other than using hazard maps and maps of anticipated flooding zones as given conditions. Flood maps based on the Flood Prevention Law in some areas show extreme figures for large areas in urban areas, making it difficult to make realistic assumptions. The percentage of households residing in the assumed inundation zone (Level 1) with an assumed inundation depth of 0.5 m or greater that have actually been inundated above floor level since the beginning of this century is roughly 1/660, which is not considered to be significant, in average, unless the lives of the occupants are at risk (figure 1). This is even more so if a larger area (Level 2) is targeted.

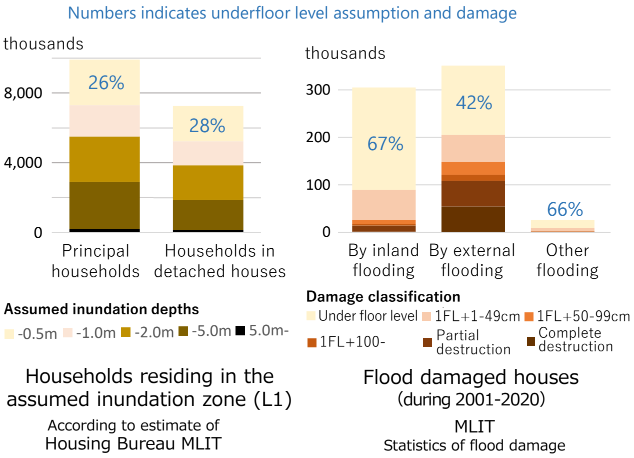


Figure 1 Assumed damage and statistical damage

3. Purpose and method of the study

Therefore, we considered that it is necessary to investigate the cost-effectiveness of flood countermeasures at the building and site level, based on the more specific flooding risks at each location.

There are various types of buildings and construction activities, with different hardware and software issues expected to be involved in flood countermeasures. So, we targeted detached houses, multi-family houses, and business premises as building types. For all the above cases, we examined the cost-effectiveness of flooding countermeasures based on the risk of the location, etc.

The study of the cost-effectiveness of flooding countermeasures was based on a desk study (model study) based on a model plan, with the cooperation of an architectural design firm with extensive experience in the design of the relevant buildings. We followed the undermentioned procedure for all the building types.

i. Interviews and on-site surveys were conducted on the actual status of inundation damage and inundation countermeasures for the relevant buildings, and the preconditions for the study, such as the direction of model plan preparation and outline of inundation countermeasures, etc. were organized.

ii. Model "standard plans" without flooding countermeasures or a typical plan for existing buildings (in the case of renovation) were prepared, and a trial design was conducted.

iii. Several alternative flooding "countermeasure plans" or flood retrofit plans were considered and trial designs were conducted. Realistic and generally applicable inundation countermeasures were applied.

iv. The cost of building the standard plan and the countermeasure plan was determined based on trial designs, by requesting estimates from builders and estimating from similar cases. The difference between the cost of the "standard plan" and the "countermeasure plan" or additional expenditure related to countermeasures was defined as the "cost" required for flooding countermeasures.

$$\begin{matrix}\textit{Additional} \\ \textit{expenditure}\end{matrix} = \begin{matrix}\textit{Expenditure of} \\ \textit{countermeasure plan}\end{matrix} - \begin{matrix}\textit{Expenditure of} \\ \textit{standard plan}\end{matrix} \quad (1)$$

v. For the standard plan and the countermeasure plans, the cost of repairing the building and the amount of damage to movable property such as furniture, fixtures, and merchandise (restoration cost) that would be required in case of inundation were estimated for each flood depth, and the difference between the standard plan and the countermeasure plans were defined as the "effect" associated with the flood countermeasures.

$$\begin{matrix}\textit{Reduction in} \\ \textit{restoration cost}\end{matrix} = \begin{matrix}\textit{Restoration cost} \\ \textit{of standard plan}\end{matrix} - \begin{matrix}\textit{Restoration cost of} \\ \textit{countermeasure plan}\end{matrix} \quad (2)$$

vi. In order to take into account the frequency of flooding, the expected annual average amount of damage reduction based on the probability of occurrence was calculated according to the calculation method of the "Flood Control Economic Study Manual" by MLIT.

$$\text{Expected reduction in restoration cost} = \sum^{\text{inundation level}} \left(\text{Reduction in restoration cost} \times \text{Occurrence probability} \right) \quad (3)$$

vii. The average expected payback period for the cost of inundation countermeasures was calculated by dividing the cost of inundation countermeasures by the expected annual average damage reduction amount, and this was used to compare the cost-effectiveness.

$$\text{Expected payback period} = \text{Additional expenditure} \;/\; \text{Expected reduction in restoration cost} \quad (4)$$

The "average expected payback period" is intended to be used as a guide for understanding the relative necessity of flood countermeasures, and therefore, is not intended to be calculated strictly. In addition, such as the mental distress of residents, loss of business premises, social costs, etc. are not taken into account, and should be considered in accordance with the purpose of use.

For the frequency of flooding by inundation depth (probability of occurrence), data equivalent to the assumed inundation depths (50 m grid) for internal and external flooding based on different rainfall probabilities published in the Shiga Prefecture "Site Safety Level Map" were used. Within the three scenarios included in the data, inundation depths for each location, the data from "overtopping breaches," which are said to account for 70% of all inundation, was used. Grid meshes with a certain risk of inundation were selected based on the conditions of a 2-year probability of a maximum inundation depth of less than 50 cm and a 200-year probability of 50 cm or more, and then meshes with a household density below a certain level were excluded and included in the study, depending on the target building type.

4. Study of each building type

4.1 Wooden detached houses

First, a study was conducted on detached houses, which are the dominant type of residence in rural areas, small and medium-sized cities, and suburban areas of large cities, where the percentage of inundation damage is high. Since many houses are made of wood in Japan and it is considered extremely difficult to take flood proof measures through renovation, measures were studied assuming the construction of a new wooden detached house.

Based on interviews and other information, the following 3 flooding countermeasure plans were considered for evaluation cost-effectiveness of reducing property damage: easy repair, waterproofing, and elevated floor. "Facilitate-restoration plan" focused on post-disaster smooth and inexpensive restoration. Improvement of inundation prevention and under floor workability, and reducing embroiled work in the components were considered. "Waterproof building plan" intends to prevent immersion from flood water up to the bottom of the hip window height, to reduce damage to the building and goods. Planned to shut off water from the hip wall and opening and prevent the backflow of drainage. "Elevated foundation plan" elevates floor height of the first floor to

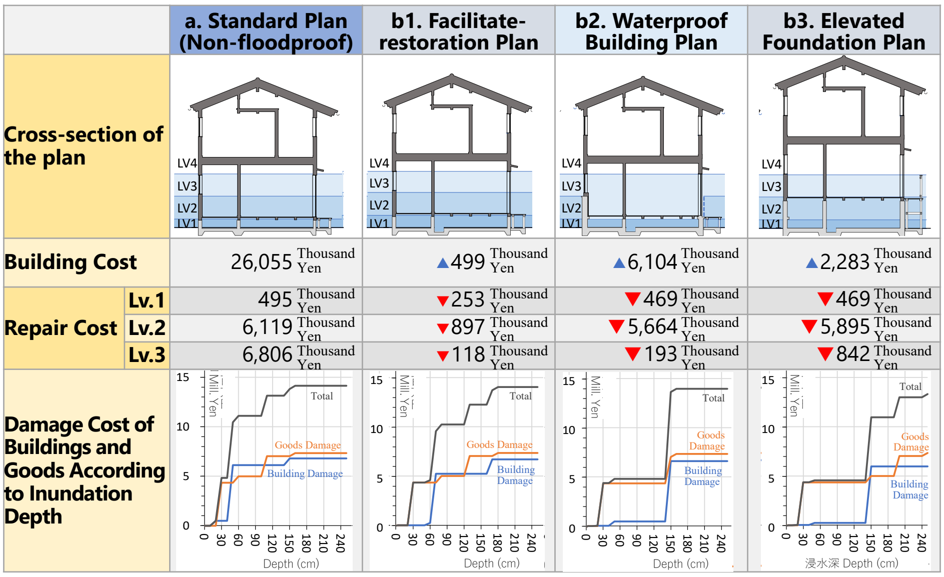


Figure 2 Summary of additional building and recovery costs for wooden detached houses

the top of hip wall height of the standard plan by high foundation, to prevent immersion and reduce damage to building and goods. External stairs steps shall be increased for entry and exit from the outside.

Figure 2 shows the summary of additional building and recovery costs for wooden detached houses, and Figure 3 the percentage of average expected payback period for the countermeasure plans. From the studies, it became clear that a certain degree of applicability was recognized for each flooding countermeasure proposal, depending on the inundation characteristics of the site. In terms of cost-effectiveness, it was found that inundation events with a depth of 50 to 100 cm and a probability of 2 to 50 years have a significant impact, and that it is essential to reduce the damage caused by these events.

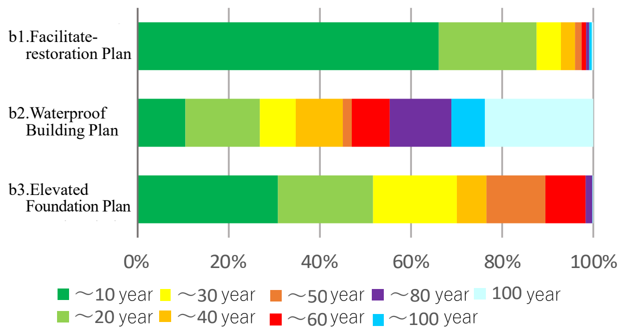


Figure 3 Average expected payback period (detached)

4.2 Condominiums

Next, target was condominiums, which occupy a large proportion of residences in urban areas of large cities. The study focused on the flood-proof renovation of existing condominiums, which has been of growing interest since the damage caused by 2019 Typhoon Hagibis (functional shutdown due to flooding in the basement electrical room). The study was based on the following two types of condominiums, one located in the city center or near a station and the other in a suburban residential area, and a typical condominium model was set up (Figure 4).

3 levels of inundation were considered, and flood path and inundation areas were speculated, and repair costs, and countermeasure location and costs were studied. Figure 5 shows the summary of countermeasure and repair (damage) costs for different level of flooding and countermeasures, and the percentage of average expected payback period for the countermeasure plans are shown.

As a result of the study, it was found that there is a high need to prioritize measures for flooded areas and flood routes that require a large amount of repair costs, and measures for vulnerable facilities such as pit-type parking lots, and that measures for flooding events with a probability of 10 to 30 per year are cost-effective.

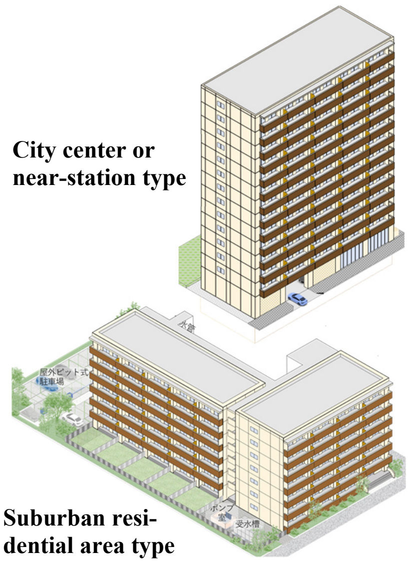


Figure 4 2 model type of condominiums

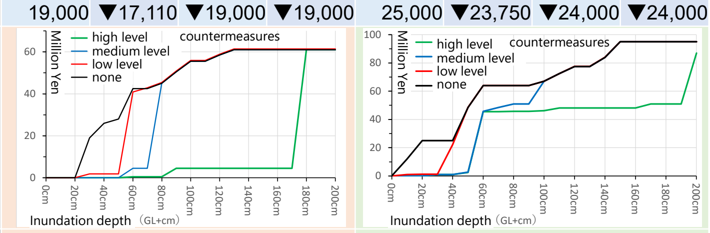
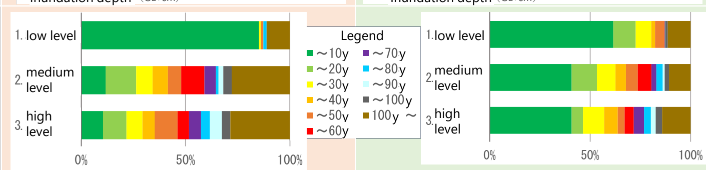
		City center location				Surburban location			
Countermeasure		None	Low	Medium	High	None	Low	Medium	High
Above cost		–	390	17,750	30,650	–	4,050	21,700	32,150
Repair cost according to inundation level	Higher	61,000	△390	0	0	95,000	△50	0	▼46,800
	High	61,000	△390	0	▼56,500	95,000	△50	0	▼46,800
	Medium	28,000	▼26,110	▼28,000	▼28,000	48,500	△50	▼45,800	▼46,000
	Low	19,000	▼17,110	▼19,000	▼19,000	25,000	▼23,750	▼24,000	▼24,000
Damage cost of buildings according to inundation depth									
Average expected payback period									

Figure 5 Summary of additional building and recovery costs, etc. for condominiums

4.3 Business premises

Finally, from the perspective of recovery and reconstruction of flood-damaged areas, we considered it important not only to protect homes and livelihoods, but also the business premises that support the local economy and liveliness, so we conducted a study for this building type. We assumed the case of a small business premises occupying the first floor of an RC building in occasion of interior construction (infill).

Considering the diversity of room and equipment configurations and fixtures by business type, 4 business types and models were assumed: offices, retail stores, restaurants, and small clinics. A secondary watertight compartment was installed in the room, in case the primary watertight compartment does not function.

The same study procedures as for other building types were used, and ideas for industries with high applicability were presented. Figure 6 shows the image of the floodproof plans, and Figure 7 the summary of the studies.

As a result, the applicability of flooding countermeasures depends, on the flooding risk of the business premises, the

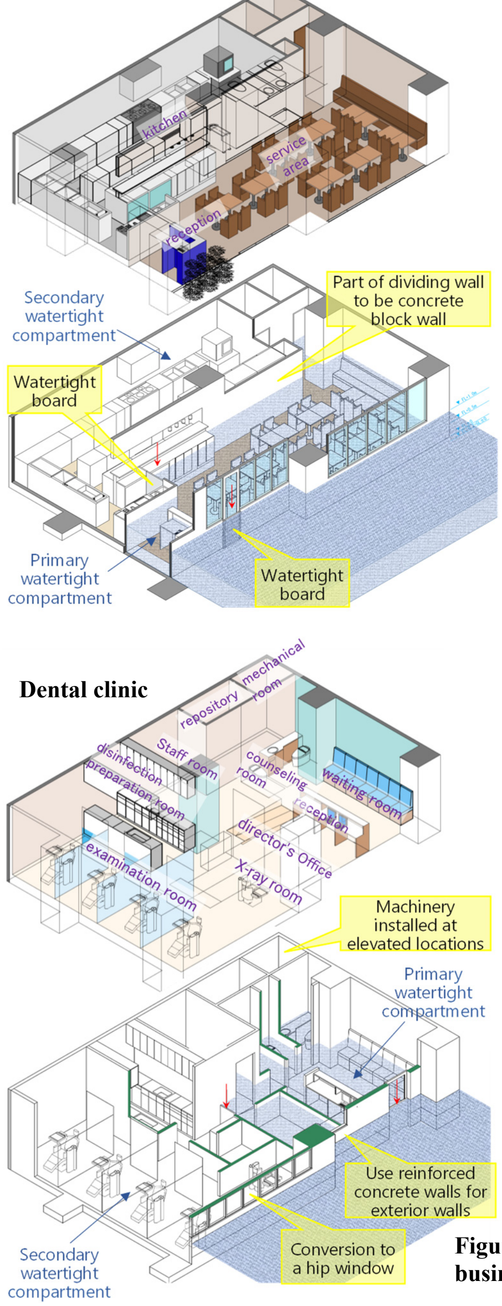
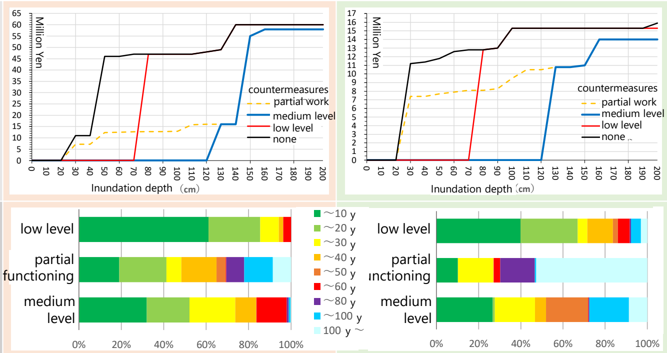


Figure 6 Isometric image of floodproofing of business premises as of restaurant and dental clinic

Countermeasure		Dentist None	Dentist Low	Dentist Medium	Dentist Partial work	Real estate office None	Real estate office Low	Real estate office Medium	Real estate office Partial work
Above cost		–	2,600	8,600	8,600	–	2,500	6,800	6,800
Repair cost according to flood level	GL+50cm	46,000	▼46,000	▼46,000	▼33,610	11,800	▼11,800	▼11,800	▼4,100
	GL+100cm	47,000	0	▼47,000	▼34,070	15,300	0	▼15,300	▼5,800
	GL+150cm	60,000	0	▼5,000	▼5,000	15,300	0	▼4,300	▼4,300

Damage cost of buildings according to inundation depth

Average expected payback period



Countermeasure		Restaurant None	Restaurant Low	Restaurant Medium	Restaurant Partial work	Retail shop None	Retail shop Low	Retail shop Medium	Retail shop Partial work
Above cost		–	2,700	7,300	7,300	–	2,600	3,200	6,800
Repair cost according to flood level	GL+50cm	13,200	▼13,200	▼13,200	▼13,200	12,900	▼12,900	▼12,900	▼300
	GL+100cm	16,200	△100	▼16,000	▼9,300	22,600	0	▼22,600	▼800
	GL+150cm	19,200	0	▼4,700	▼4,700	26,100	0	▼1,100	▼1,100

Damage cost of buildings according to inundation depth

Average expected payback period

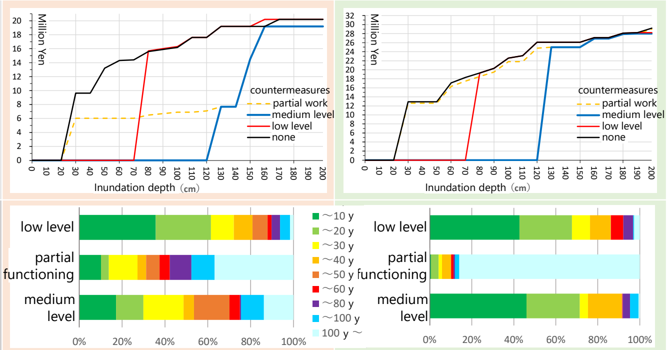


Figure 7 Summary of additional building and recovery costs etc. for business premises

amount of expensive fixtures and equipment that can cause damage at shallow flood levels, whether they are located in an area where they can form a secondary watertight compartment, whether there are few obstacles for employees and others to install watertight panels, and whether cost recovery can be considered over a long period of time. In the four industries considered, the applicability of high-level flooding countermeasures is widely recognized in small clinics that meet the latter four conditions, and in other industries, there is a certain degree of location conditions that allow the applicability of flooding countermeasures. In other industries, there are certain location conditions where the applicability of flood countermeasures can be recognized.

5. Conclusion

As a result of the above, it was demonstrated through the presentation of major trial design drawings, etc., that flooding countermeasures with a certain degree of applicability can be realized in the three building types and situations considered. In addition, we demonstrated that it is possible to study the cost-effectiveness of inundation countermeasures by using the maximum inundation depth information by frequency using the analysis methods and procedures described in this report. It was also found that even in the case of large inundation estimates based on the expected maximum rainfall and planned scale rainfall indicated by hazard maps, it is possible to effectively reduce the expected annual damage by implementing measures to prepare for more frequent inundation.

The most effective way to prepare for the frequency and depth of inundation depends on the type of inundation risk of the subject site, the form and cost of the measures required for the building conditions, and the vertical distribution of equipment and movable property inside and outside the building. However, in relatively many cases where flooding risk is recognized, it was found to be reasonable to first prepare for flooding at a minimum of 30 to 50 cm above the floor, which can be addressed with sandbags (water bags) or simple watertight boards, and then to consider countermeasures in stages for greater flooding depths, depending on the type of flooding risk. For example, the business studied in Chapter IV is a project that is designed to reduce the risk of flooding.

It is expected that these findings will be used in the future to advance the study and practice of building-level flood countermeasures for various building types and situations, including those not covered in this study.

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