EFFECTIVENESS OF TSUNAMI MITIGATION STRUCTURES ON UNDERUTILIZED URBAN AREAS: A CASE STUDY ON REDUCING DAMAGE CAUSED BY TSUNAMI TO BUILDINGS

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INTRODUCTION

Earthquakes accompanied by tsunami occur in the Nankai Trough in every 100 to 200 years, the most recent one being the 1946 Showa-Nankai Earthquake, which occurred approximately 80 years ago. In addition, the 2011 Great East Japan Earthquake revealed the existence of earthquakes with an event probability of more than 1000 years. Hence, there are concerns that a Nankai Trough Mega Earthquake may occur soon, and may cause widespread damage. This demands not only functional enhancement of seacoast environments, but also pre-disaster recovery planning that includes evacuation drills and securing evacuation sites in coastal areas. One of the most effective measures for this is relocation to higher ground in urban areas. However, financial restrictions and topographical conditions do not make relocation to higher ground easy. Thus, new countermeasures must be investigated that can facilitate early recovery and reconstruction. We believe that reducing the collapse and washing away of buildings due to tsunamis in densely populated areas could be one of the ways to approach this problem. Here, we find that the risk of building collapse and washing away depends on the type of building[1)] and inundation height. Thus, inundation due to tsunami must be lowered to avoid the low risk of collapse or wash away. Therefore, we look at the example[2)] of Miyagi Prefecture amid the lessons of the Great East Japan Earthquake, and expand upon the idea of multiple countermeasures to cover the urban areas. Specifically, low-lying underutilized lands in urban areas must be utilized to provide multifunction disaster prevention facilities enabling multiple countermeasures. Based on the above-mentioned points, the purpose of the present study is to propose multiple tsunami countermeasures for urban areas and numerically investigate their effects. Thus, we conducted a case study in a port town with a small river, which is an area where disasters are a concern.

STUDY METHODS

The target area was Hiwasa, an urban area in the town of Minami, located in the southern part of Tokushima Prefecture. It is presumed that this area would suffer damage from a Nankai Trough Mega Earthquake, though it is highly inhabited[3)].

The study is divided into the following three stages. The first is a field survey of living conditions in presumed tsunami flood-prone areas. In addition, we interviewed two residents of the town, and confirmed the existence of low-lying underutilized areas.

The second is the proposal of multiple countermeasures for use in urban areas. We proposed three countermeasures based on local living conditions and the status of area utilization. Figure 1 shows the deployment of these countermeasures: (1) A multi-purpose hill built on the ground. The hill extends 80 m north and south, and 27 m east and west. Its eastern side has a slope of approximately 50%, while its western side has one that is approximately 20%. (2) Renovation of a fishery warehouses into high-quality buildings for fishing facilities. Presently, there are about 30 warehouse buildings, which will be replaced with two to three-story robust buildings 11 m in height and 19 m × 54 m and 25 m × 33 m in building area. (3) Installation of a movable land lock on the road. Since it is expected that a tsunami would wind around from the hill side, it can be dealt with by providing a land lock on the hill side. Its proposed height is 6 m on the northern side and 5 m on the southern side.

Third is inundation calculation in the event of a tsunami. In this study, we used JAGURS[4)], a tsunami analysis model based on nonlinear wave theory. Figure 2 shows the analysis target area, and Table 1 lists the settings at the time of analysis. Building shape is expressed as line data, and by changing this height we used wooden building collapse (total collapse at inundation height 2 m) and non-collapse as settings. We used a fault parameter assuming Nankai Trough Mega Earthquake as per the Central Disaster Prevention Council for the wave source (Case 3). In addition, for calculation, we envisaged five cases (Case A to Case E (Table 2)), and compared and discussed Case A (existing topography) and Case E (hill, warehouse renovation, land lock). For evaluation indices, we used maximum inundation height to be less than 2.0 m and maximum flow rate to be less than 4.2 m/s in densely populated urban areas. These evaluation indices are numerical values approximating the risk of collapse and washing away of wooden building[1)].

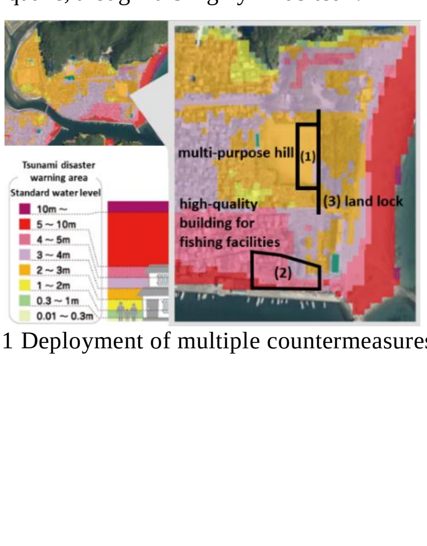

Fig. 1 Deployment of multiple countermeasures

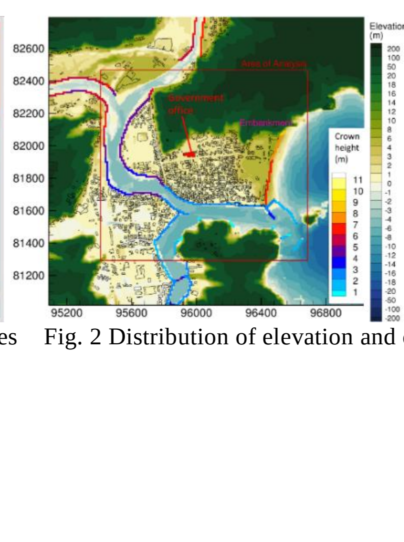

Fig. 2 Distribution of elevation and depth, crown height

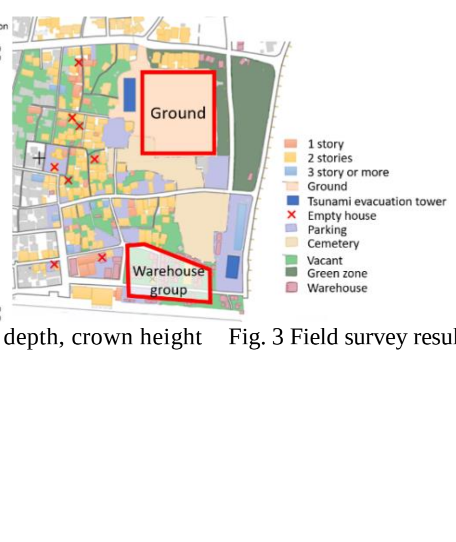

Fig. 3 Field survey results

Table 1 Settings at time of analysis

SETTING	
Area of calculation	Western Japan
Analysis target area	Southern part of Tokushima Prefecture
Spatial resolution	about 1m
Building shape	Represented as line data
Wave source model	The Central Disaster Prevention Council assumes a Nankai Trough megathrust earthquake
Standard water level	Syzygy Mean High Tide Level TP=0.917(m)
Levee breach condition	Total collapse after overflow
Tsunami overflow over non-collapsed buildings	unconsidered

Table 2 Calculation cases

	Case A	Case B	Case C	Case D	Case E
① multi-purpose hill		○		○	○
② high-quality building for fishing facilities			○	○	○
③ land lock					○

RESULTS AND DISCUSSION

1. Field survey

Figure 3 is a plot of results obtained from the field survey. This area is said to be experiencing increased depopulation, but as shown in Fig. 3, there are relatively few empty homes here (8 out of 130), indicating that it is mostly inhabited. Moreover, we could not confirm if there were two or more empty houses in a row; furthermore, many empty homes were surrounded by other houses. Hence, we decided that it would be difficult to use empty homes and their land for one of our countermeasures. However, there were low-lying underutilized areas, including the ground and warehouses along the river.

2. Evaluation of conformity of the proposed multiple countermeasures with regional characteristics

Focusing upon low-lying underutilized areas, we confirmed the conformity of the proposed multiple countermeasures with the masterplan for the area. Figure 4 shows these images. The basic philosophy of this masterplan is "urban development by harmonizing the bounty of nature, history, and urban functions"[2].

First, we establish the conformity of hill installation and urban development. By installing a hill and planting native trees, it is possible to ensure a large green area that will help preserve the natural landscape. The ground-side slope of the hill would be gradual. Hence, it is possible to use a wide open-space integrating the ground and hill. For example, the hill can be equipped with seating for spectators for sporting events. In this way, we can secure green space for local residents to relax and interact with each other, contributing to a lively atmosphere.

Next, we discuss the effects of renovating the warehouses and urban development. Fishing promotion measures are recommended for this area. Its purpose is to revitalize the local industry by creating a system that provides fresh food to the residents and visitors. Hence, renovating the warehouse group and using it as a market and commercial facility will revitalize the local industry and improve convenience. In addition, harmony between nature and urban functions may be achieved by greening the rooftops and walls of buildings.

Finally, the installation of land lock and its effects of urban development are discussed. Presently, land locks are used in towns along coastal areas and rivers. However, the proposal here is not to install anything on urban roads, which is a novel idea. Since this does not interfere with regular traffic, it contributes to the formation of safe road spaces. Furthermore, it operates in the event of a disaster, and expected to preserve the town's historical landscape.

Based on the above-mentioned points, the proposed countermeasures seem to conform to the masterplan for the area. In addition, the (1) hill and (2) warehouse renovation can contribute to green infrastructure, providing a habitat for organisms and plants, and help mitigate global warming.

3. Numerical investigation

In this section, the analysis results of the inundation height and flow rate in Case A (existing topography) and Case E (hill, warehouse group renovation, land lock) are described. Figure 5 shows differences in the maximum inundation height (Case E - Case A). In this figure, red indicates high inundation, and blue indicates areas of low inundation. Here, we find that the multiple countermeasures yield tsunami inundation reduction effects in densely populated areas. In addition, Fig. 6 shows an area with a maximum inundation height of less than 2.0 m, which is the evaluation standard for the collapse and washing away of wooden buildings in Case E. In the section bound by the red dotted line, the inundation height was 2.0 m or more in Case A, but reduced to less than 2.0 m in Case E. However, the maximum inundation height was never less than 2.0 m in any of the urban areas. Consequently, we found that the extent of effects from the multiple countermeasures proposed in this study alone were limited. Figure 7 shows an area with a maximum inundation height of less than 3.5 m. The section bounded by the red dotted line is different for Case A and Case E. In this section, the maximum inundation height was 3.5 m or more in Case A, but reduced to less than 3.5 m in Case E. Here, the maximum inundation height of less than 3.5 m is the numerical value at which a wooden building collapses, but there is a high possibility that a reinforced concrete or other non-wooden structure would hold out[1]. This suggests a higher possibility of local recovery if multiple countermeasures are combined with different building structures.

Next, the results for maximum flow rate are discussed. Figure 8 shows an area in which the maximum flow rate was less than 4.2 m/s, which is the evaluation standard for the collapse and washing away of wooden buildings. There are differences in the areas bound by the red dotted line and the section bound by the yellow dotted line when Case A and Case E are compared. The area with a flow rate of 4.2 m/s or above in the section bound by the red dotted line is an area where the rate decreased to less than 4.2 m/s. This area is the hinterland of the multiple countermeasures proposed. However, the section bound by the yellow dotted line is an area of increased flow rate, located adjacent to the proposed multiple countermeasures. This appears to be due to the tsunami winding around from the side. Consequently, more multifaceted protection is needed.

Fig. 4 Images of proposed multiple urban countermeasures (Left: hill, Middle: Robust fishing facility, Right: Land lock)

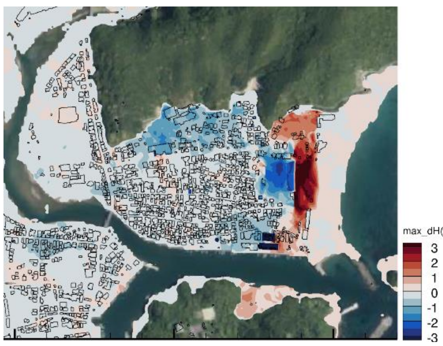

Fig. 5 Maximum inundation height (difference diagram)

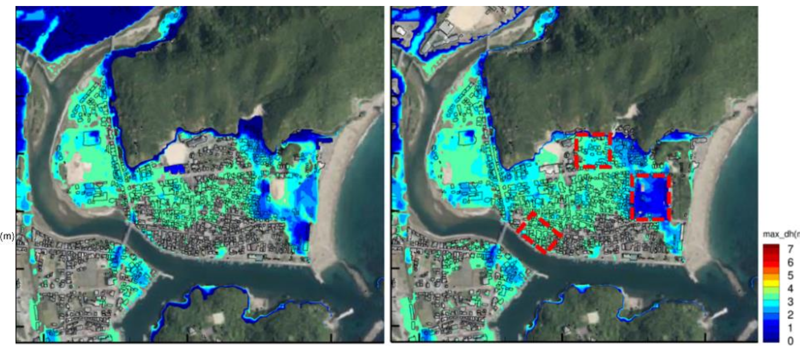

Fig. 7 Maximum inundation height less than 3.5m (Left: Case A, Right: Case E)

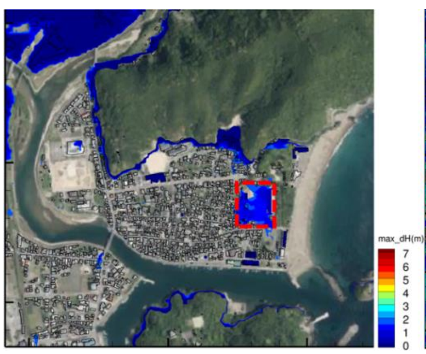

Fig. 6 Maximum inundation height less than 2.0 m (Case E)

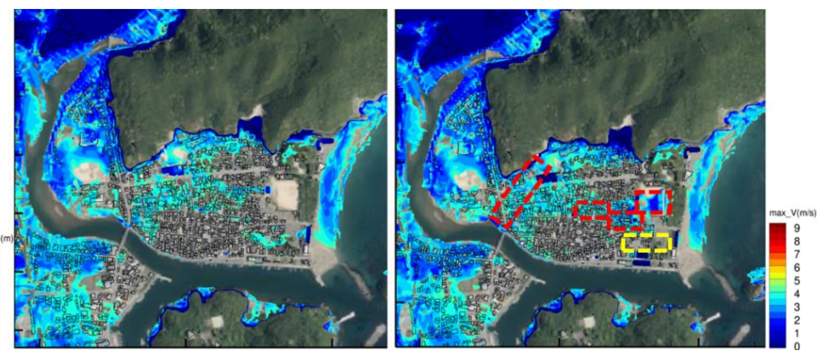

Fig. 8 Maximum flow rate less than 4.2 m/s (Left: Case A, Right: Case E)

We can conclude that the proposed multiple countermeasures in urban areas yielded tsunami reduction effects in the hinterlands, suggesting a means of raising the possibility of local recovery. However, these effects do not manifest in all the hinterlands, and there are also areas that are affected negatively with increased inundation. Therefore, in reality, recovery requires preferential placement in front of core facilities essential for recovery, and discussing the arrangement of urban facilities with tsunami reducing function in tandem with location optimization policies.

CONCLUSION

We studied multiple countermeasures in the urban area of Hiwasa in the town of Minami, located in the southern part of Tokushima Prefecture. We proposed three countermeasures based on the current land utilization conditions, and established their conformity with the masterplan. Then, we found disaster mitigation effects in the form of reduction in inundation height and flow rate in the hinterlands. However, there were also places where effects were due to tsunami. Consequently, there is a future need to optimally design the urban areas combining multiple countermeasures and different building structures.

ACKNOWLEDGMENT

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