



## TSUNAMI SAFETY EVALUATION OF PUBLIC BUILDINGS IN SHIZUOKA PREFECTURE, JAPAN (PART2)

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### **Abstract**

Shizuoka Prefecture, Japan, has been implementing countermeasures against tsunami disaster to protect prefecture-owned public buildings. Such buildings have been designed and constructed in accordance with “Practical Guide on Requirement for Structural Design of Tsunami Evacuation Buildings (Ministry of Land, Infrastructure, Transport and Tourism, Japan, 2012 March)”, which was issued after the experiences of the 2011 Great East Japan Earthquake. Shizuoka Fisheries Technology Research Center is one of facilities designed and constructed in accordance with the Guide, which is located in the area subject to tsunami inundation at the event of earthquake. After practical application of the Guide to existing buildings in Shizuoka Prefecture to evaluate the safety to expected tsunami impact, the know-how and technical issues to be considered in the safety evaluation were compiled in the “Tsunami Safety Evaluation Manual for Existing RC and Steel Buildings in Shizuoka Prefecture”, where the safety index is defined to identify the safety margin to three different performance criteria of collapse, overturning, and lateral movement.

In this study, we evaluated the safety level of the Fisheries Center against expected tsunami inundation depths in accordance with the Shizuoka Prefecture Manual. The authors assumed a design tsunami inundation depth of 3.5 m based on the tsunami hazard map provided after the Earthquake Damage and Risk Assessment by Shizuoka Prefecture. The result showed that the ultimate inundation depth was found 6.9 meters, (i.e., a safety factor of 2 to the design inundation depth of 3.5 m) for collapse prevention which was most essential to discuss the building’s safety against the tsunami impact.

In addition to the tsunami safety evaluation above, this paper also introduces some ideas employed in designing the buildings at risk of tsunami inundation:

- (1) Design of piloti style elevated building (i.e., a structure raised on columns) with breakaway components  
Using breakaway components, the buoyancy forces and water pressure loads acting on structure was significantly reduced.
- (2) Mid-height eaves  
Eaves were provided on the second-floor level as shown in the photo to prevent tsunami splash-up and collision of drifting debris.
- (3) Scour prevention  
Exterior rigid floor slabs on the ground level, extended outside the structure, were provided to reduce the risk of scour.

It should also be noted that the working office space and facility equipment, which are important to disaster response and management, are located above the inundation risk height, and external stairways leading to the evacuation space is provided to serve as a tsunami evacuation building.

*Keywords: Tsunami resistance safety evaluation, Limit flood depth, Tsunami evacuation building*



## 1. Introduction

In Japan, the importance of ground measures against tsunamis, including tsunami evacuation buildings, was pointed out in the Tokai Earthquake Countermeasures Master Plan announced in May 2003 and the Tonankai and Nankai Earthquake Countermeasures Basic Plan announced on December of the same year. The Building Center of Japan conducted a study on tsunami guidelines based on these plans. In Indonesia in December 2004, tsunami damages were caused by an earthquake occurring off Sumatra Island. Through such a series of events, the Cabinet Office issued “Guidelines for Tsunami Evacuation Building”[1] in June 2005, which described the basic concept of structural requirements against tsunami forces when building a tsunami evacuation facility. A general design flow and its application example can be found in [2].

Furthermore, in order to mitigate the disasters caused by tsunami, “Act on Regional Development for Tsunami Disaster Prevention” was enforced in December 2011 after the Tohoku Region Pacific Coast Earthquake in March 2011 and the standards on tsunami safety assessment for tsunami evacuation facilities have been enacted.

Based on these, in this prefecture, structural designers, etc. conduct safety evaluation on tsunami resistance of individual buildings with reference to the “Tsunami Safety Evaluation Manual for Existing RC and Steel Buildings in Shizuoka Prefecture”[3] created in March 2015.

## 2. Estimated maximum tsunami inundation depth caused by Nankai Trough earthquake

Shizuoka Prefecture (about 3.7 million populations) is located almost in the center of Japan (Figure 1), extending 155km east to west and 118km north to south with area approximately 7,782km<sup>2</sup>. The coastline of the prefecture has a total length of about 500 km on the south coast. On the other hand, on the north side is a mountainous area consisting of 3,000m-high mountains represented by Mt. Fuji. The climate is generally a warm oceanic climate.

Four plates (Pacific Plate, Philippine Sea Plate, Eurasian Plate, and North American Plate) are in complex contact beneath Shizuoka, and large and small earthquakes have repeatedly occurred at the plate boundary from long ago. Especially in the Nankai Trough off the Pacific coast, it is expected that an M8-9 class earthquake will occur with a probability of about 70% within the next 30 years and “The Shizuoka Prefecture Fourth Earthquake Damage Estimation”[4] which was prepared by Shizuoka Prefecture in 2013 also assumes occurrence of a large tsunami with height exceeding 20m if an earthquake of the largest class occur (Figure 2).

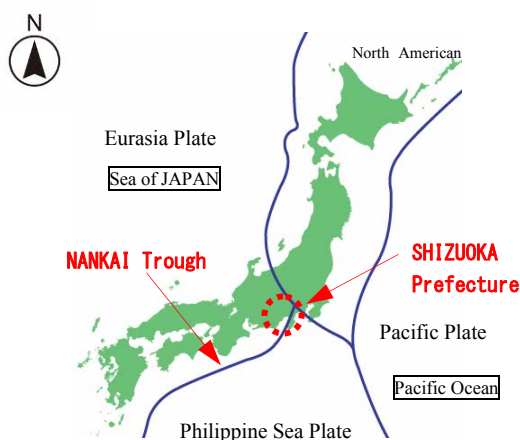


Fig.1 – Location of Shizuoka Prefecture in Japan

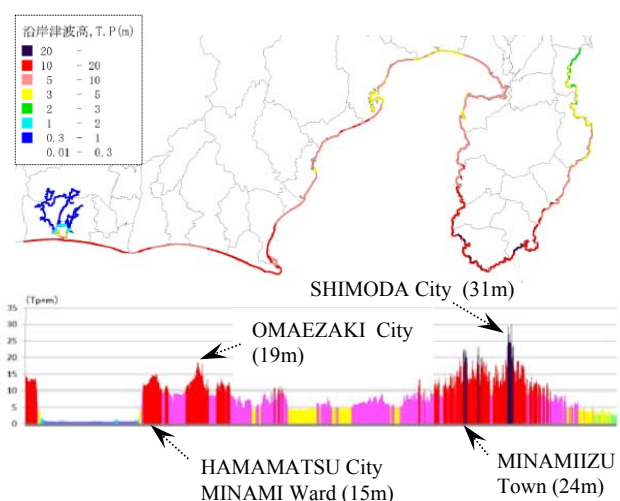


Fig.2 – Maximum estimated tsunami inundation at major cities in Shizuoka Prefecture



### 3. Method of tsunami resistance safety evaluation

#### 3.1 Creation of the “Tsunami Safety Evaluation Manual for Existing RC and Steel Buildings in Shizuoka Prefecture”

In Shizuoka Prefecture, it is estimated that up to about 96,000 victims will be caused by the tsunami after the Level 2 earthquake based on the Shizuoka Prefecture Fourth Earthquake Damage Estimation [4]. We are comprehensively promoting earthquake and tsunami countermeasures with the goal of reducing the number to approximately 80,000 by the end of March 2023.

Although many people live in coastal areas greatly affected by the tsunami in this prefecture, many areas are far away from hills where people can evacuate, so it is hoped that prefectural facilities will be used as tsunami evacuation buildings.

In this prefecture, in order to reduce tsunami casualties, we are encouraging cities and towns in the prefecture to conduct tsunami safety assessment for existing buildings with reference to the “Tsunami Safety Evaluation Manual for Existing RC and Steel Buildings in Shizuoka Prefecture” [3].

#### 3.2 Characteristics of the Tsunami Safety Evaluation Manual

Shizuoka Association of Architectural Firms created the “Tsunami Safety Evaluation Manual for Existing RC and Steel Buildings in Shizuoka Prefecture” [3] adding additional consideration to the guidelines on tsunami safety assessment provided by the government. The Characteristics of this manual are 1. Showing viewpoints in detail in the field survey, 2. Showing “determination of the presence or absence of barrier” which affects tsunami forces specifically utilizing knowledge of tsunami damage caused by the Tohoku-Pacific Ocean Earthquake, 3. Checking the characteristics of tsunamis and clarifying buoyancy concept in relation to tsunami forces, 4. Describing how to determine resistance against tsunami in detail, 5. Showing specific calculation examples, which are different from the national guidelines.

#### 3.3 Construction of prefectural facilities in the tsunami inundation area

In this prefecture, when considering rebuilding of a prefectural facility in the area subject to tsunami inundation, we consider relocating outside tsunami inundation area in principle. However, when it is necessary to construct in assumed tsunami inundation areas, we conduct structure examinations in order to be a safe facility against tsunami.

### 4. Tsunami Safety Evaluation of Shizuoka Fisheries Technology Research Center

#### 4.1 Purpose of Tsunami Safety Evaluation

When Shizuoka Fisheries Technology Research Center built in the Kogawa district of Yaizu city in 1971 was considered rebuilding because of its lack of earthquake resistance, it was found that Yaizu Fishing Port Management Office built in the nearby Yaizu old port in 1972 was lack of resistance of large waves. As it is impossible for both facilities to relocate outside tsunami inundation area, they were relocated to Iwashigashima, Yaizu city, which is subject to tsunami inundation.

This facility is required early recovery when a large-scale disaster occurs because this facility has the function of Yaizu Fishing Port Management Office. Therefore, structural planning of these facilities was compliant with “Practical Guide on Requirement for Structural Design of Tsunami Evacuation Buildings” [5] to withstand expected tsunami impact so that office function can be maintained and used as a tsunami evacuation building when during tsunami disaster.

In this chapter, we conduct Tsunami Safety Evaluation for Shizuoka Fisheries Technology Research Center designed with consideration for tsunami safety with reference to the “Tsunami Safety Evaluation Manual for Existing RC and Steel Buildings in Shizuoka Prefecture” and check the these facilities' margin for tsunami by finding the ultimate inundation depth shown in this manual.



## 4.2 Outlines of the building; Shizuoka Fisheries Technology Research Center

Table 1 – Outlines of Shizuoka Fisheries Technology Research Center

Building location	Iwashigashima, Yaizu city
Use districts	Quasi-industrial districts
Structure/ Size	RC building, Four floors
Building Area	1,389 m <sup>2</sup>
Total floor area	3,215 m <sup>2</sup>
Anti-tsunami plan	Assume a design tsunami inundation depth of 3.3m caused by the level 2 earthquake based on the Shizuoka Prefecture Fourth Earthquake Damage and Risk Assessment. Implement a structure planning compliant with “Practical Guide on Requirement for Structural Design of Tsunami Evacuation Buildings”



Fig.3 – The whole view of the facility

### 4.2.1 Floor plan of Shizuoka Fisheries Technology Research Center

At the construction site, a design tsunami inundation depth caused by the large earthquake (Level 2 earthquake) based on the Fourth Earthquake Damage and Risk Assessment by Shizuoka Prefecture is assumed to be 3.3m (Figure 4). Therefore, the second floor (GL+6.1m) is set to be the safety evacuation floor and the office is located on the second floor and higher floors (Figure 5 ~ 8).

In order to reduce the tsunami force on the structure, the frontage shape is narrow in the direction of the tsunami (from east to west). By making the plan as rectangular as possible, we aimed to prevent the building from overturning and movement (Figure 5, 9).

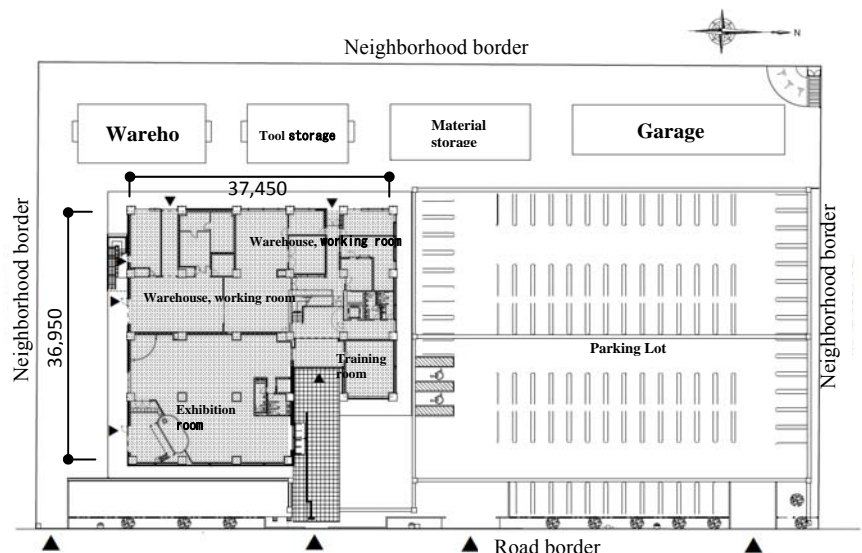
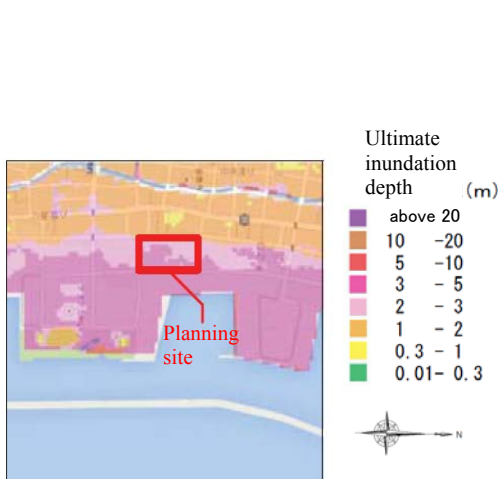


Fig.4 – A design tsunami inundation depth around the planned location

Fig.5 – Layout plan and ground floor plan (unit : mm)

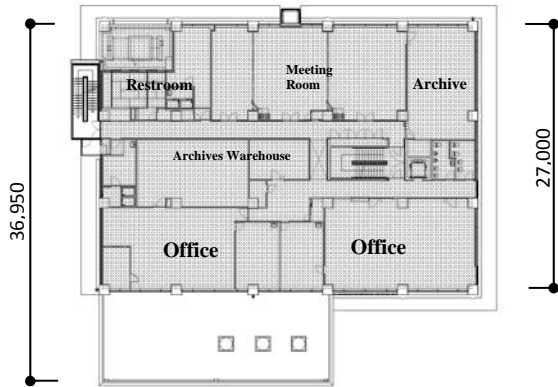


Fig.6 – Second Floor plan (unit : mm)

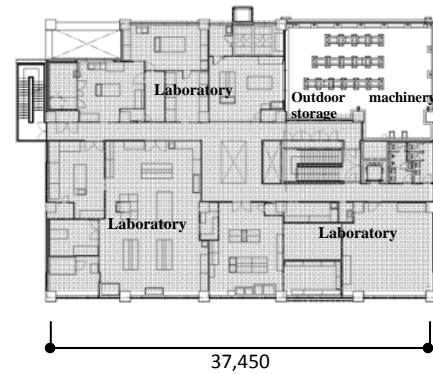


Fig.7 – Third Floor Plan (unit : mm)

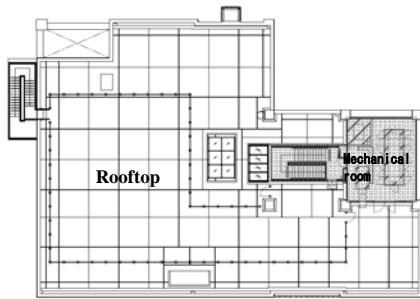


Fig.8 – Fourth Floor Plan



Fig.9 – East Elevation (unit : mm)

### 4.3 Method of tsunami resistance safety evaluation

Tsunami resistance safety is evaluated with reference to the “Tsunami Safety Evaluation Manual for Existing RC and Steel Buildings in Shizuoka Prefecture”[3], and check the these facilities' margin for tsunami by finding the ultimate inundation depth which is also proposed in “Tsunami Resistance Safety Evaluation of Prefecture-Owned Public Buildings” [6].

In tsunami resistance safety evaluation of buildings against the design tsunami inundation depth, the relationship between collapse, lateral movement, and overturning against the tsunami forces is supposed as shown in Figure10.

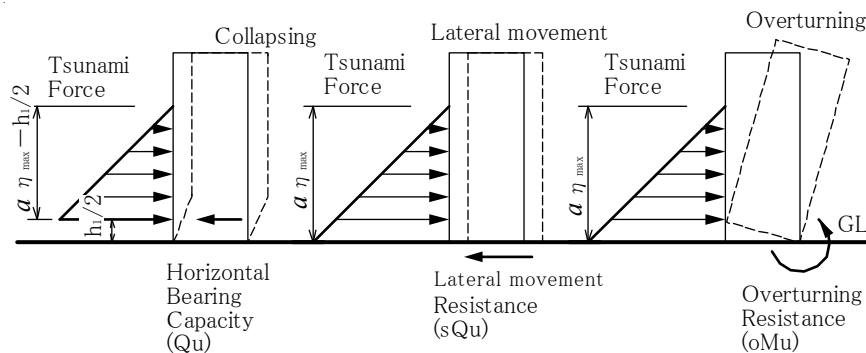


Fig.10 – Relationship between collapse, lateral movement, and overturning against tsunami forces



#### 4.3.1 Tsunami wave water pressure and tsunami force

The tsunami wave water pressure applied on the building was calculated using Eq.(1) based on the design inundation depth and impact factor assuming the water pressure indicated in Figure 11. Here, it is calculated as impact factor  $a = 3.0$  because there is no barrier around the building.

The tsunami force was calculated using Eq.(2). In addition, the tsunami force was reduced by the rate of the total opening area to the total area of elevation if there were openings on the elevation which is the surface subjected to pressure (however, 70% of tsunami force before reduction was consider the lower limit). Tsunami force for either half of the floor heights of upper and lower floors was applied on the position of each floor.

$$q_z = \rho g (ah - z) \quad (1)$$

$$Q_z = \rho g \int_{z_1}^{z_2} (ah - z) B dz \quad (2)$$

Here,

- $q_z$ : Tsunami wave water pressure assumption in the direction of tsunami ( $\text{kN/m}^2$ )
- $\rho$ : fluid density of water ( $\text{t/m}^3$ )
- $g$ : Gravitational acceleration ( $\text{m/s}^2$ )
- $a$ : Impact factor (according to Table 1)
- $h$ : Design inundation (m)
- $z$ : Height of the corresponding part ( $0 \leq z \leq ah$ ) (m)
- $Q_z$ : Tsunami force in the direction of tsunami advance for design (kN)
- $B$ : Width of building subjected to pressure in the corresponding section (m)
- $z_1$ : Minimum height for the surface subjected to pressure ( $0 \leq z_1 \leq z_2$ ) (m)
- $z_2$ : Maximum height for the surface subjected to pressure ( $z_1 \leq z_2 \leq ah$ ) (m)

Table 2 – Setting of impact factor “ $a$ ”

Barrier for tsunami		No barrier
Distance from seashore, river, etc		$a = 3.0$
more than or 500m	less than 500m	
$a = 1.5$	$a = 2.0$	

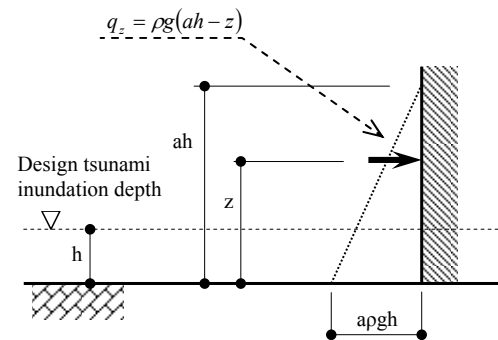


Fig. 11 – Tsunami pressure

#### 4.3.2 Buoyant force

The buoyant force applied on a building was taken into consideration when water flowed into the building because there are many large sash openings on the outer wall in the inundation depth range of the building and water is likely to flow into the building soon when water fills around the building (Fig.12).

#### 4.3.3 Horizontal bearing capacity

The horizontal bearing capacity of a building was calculated through nonlinear incremental loading analysis applying the hydrostatic force distribution with the impact factor “ $a$ ” and inundation depth “ $h$ ” as the vertex (Figure 11), and the horizontal bearing capacity at story deformation angle about 1/200 which no large rigidity deterioration had occurred was adopted.



#### 4.3.4 Lateral movement

The lateral movement resistance of a building was to be calculated depending on the foundation type. Since the foundation of this building uses cast-in-place piles, the shear resistance capacity of the piles was evaluated (Figure 13).

#### 4.3.5 Overturning

The overturning moment of a building was compared with the resistant moment by the total building weight subtracted with the buoyant force. The tensile strength of the piles was not considered because the safety of overturning was confirmed for consideration of the building weight only (Figure. 13).

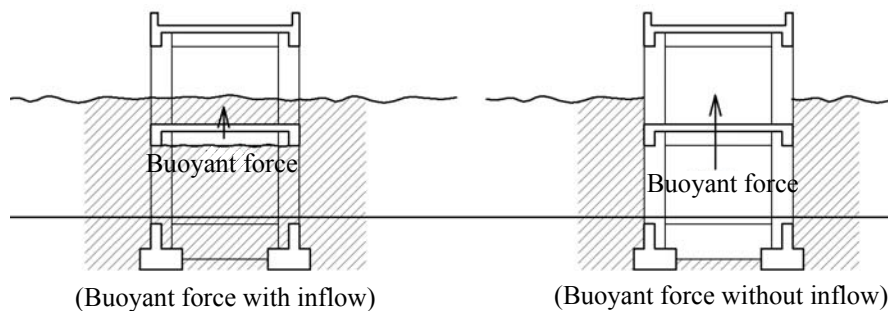


Fig. 12 – Buoyant force caused by seawater inflow/no inflow

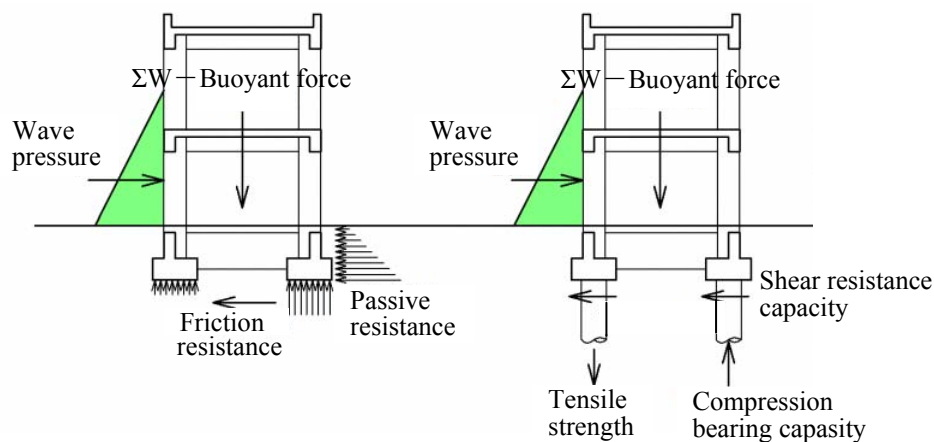


Fig. 13 – Lateral movement and overturning resistance

#### 4.3.6 Ultimate inundation depth

When we define the tsunami resistance performance (possibility of collapsing, sliding and overturning against the tsunami force) as the index-value for ultimate inundation depth as  $\alpha$ , the ratio of ultimate inundation depth against the design inundation depth ( $h_{\max}/h$ : allowance) can be expressed by Eq.(3) and Eq.(4).

$$\text{For collapsing, For lateral movement : } h_{\max}/h = \alpha^{0.5} \quad (3)$$

$$\text{For overturning : } h_{\max}/h = \alpha^{(1/3)} \quad (4)$$

Here,  $h$  : design inundation depth (m)  
 $h_{\max}$  : ultimate inundation depth (m)  
 $\alpha$  : tsunami resistance index value



#### 4.4 Results of tsunami resistance safety evaluation of the building to be evaluated for Shizuoka Fisheries Technology Research Center

As a result of tsunami resistance safety evaluation, it was found that horizontal bearing capacity, lateral movement and overturning resistance of this building were big enough. Also, we confirmed that there is no columns to make the building collapse even if the columns were broken by a collision object like a ship. Moreover, we found that horizontal bearing capacity and lateral movement resistance had a lower index value than overturning resistance when we calculated the ultimate tsunami inundation depth based on the “Tsunami Safety Evaluation Manual for Existing RC and Steel Buildings in Shizuoka Prefecture” [3]. Horizontal Bearing Capacity determined the value of the ultimate tsunami inundation depth, 6.9m. This depth is about twice as deep as the design tsunami inundation depth, so this building is safe enough against the tsunami impact (Table 3).

Table 3 – Tsunami resistance safety evaluation results

Site conditions	Design inundation depth	3.3m (based on the Shizuoka Prefecture Fourth Earthquake Damage Estimation) 3.5m (a design tsunami inundation depth)				
	Height above sea level	TP+2.0m				
	Distance from seashore/river	120m from the east coastline				
	Barrier	No barrier exists				
	Impact factor “a”	3.0				
Tsunami Resistance Performance	Direction of tsunami	X (from South)	X (from North)	Y (from East)	Y (from West)	Judgment
	Horizontal Bearing Capacity	4.31	3.84	4.01	3.88	OK (>1.0)
	Lateral Movement Resistance	3.87				OK (>1.0)
	Overturning Resistance	19.10	16.00	14.40	18.80	OK (>1.0)
	Pressure resistant members	1.68 (Outer Column)				OK (>1.0)
	collision hazard	No members cause building collapse by collision object				
	Scouring around	No possibility				
	Evacuation floor	The first floor is the inundation floor 2nd floor or higher can be used for safety evacuation floor				
	Comprehensive evaluation	Low risk of collapse / Lateral movement / Overturning / Other against tsunami				
Note						
<ul style="list-style-type: none"> <li>• Horizontal bearing capacity of the whole building is considered enough in both directions</li> <li>• Lateral movement and overturning will not occur for all force directions</li> <li>• If the outer columns were broken by a collision object, safety of building against collapse can be ensured.</li> <li>• The ultimate tsunami inundation depth can be estimated as 6.9m by horizontal bearing capacity</li> </ul> <p>Horizontal bearing capacity : <math>\sqrt{3.84} \times 3.5 = 6.9\text{m}</math></p> <p>Lateral Movement Resistance : <math>\sqrt{3.87} \times 3.5 = 6.9\text{m}</math></p> <p>Overturning Resistance : <math>\sqrt[3]{14.4} \times 3.5 = 8.5\text{m}</math></p>						



## 5. Ideas against tsunami

In designing Shizuoka Fisheries Technology Research Center, further ingenuity was expressed in the planning and the details in addition to consideration of tsunami resistance (Table 4) (Figure 14 – 18)

It is expected that further ingenuity as well as structural consideration of tsunami resistance increase the safety against tsunami confirmed by calculation of the ultimate inundation depth.

Table 4 – Ingenuities against Tsunami

1	the piloti style elevated building for inundation floor	Using breakaway components and making flow paths in the building, the buoyancy forces and water pressure loads acting on structure was significantly reduced.
2	Office location	The height of the first floor is 6 meters and offices and a disaster response office are located in the second floor, which is above the inundation height (Figure 5 – 8)
3	Equipment arrangement	Equipment such as power supplies, electric lights, sanitation, air conditioning equipment, etc. which are used by a disaster response office in case of emergency were arranged above the inundation risk height, which makes it possible to maintain the function of these equipment (Figure 7, 8)
4	Mid-height eaves	Eaves were provided on the second-floor level to prevent tsunami splash-up and collision of drifting debris.
5	Scour prevention	Installation of slab integrated with the structure within 2m from the outer wall reduces the risk of scour against tsunami
6	Temporary evacuation to rooftop	A direct access staircase from the ground to the rooftop is set up outdoors and an evacuation space is set up on the roof allows people including local residents to evacuate temporarily to the rooftop.

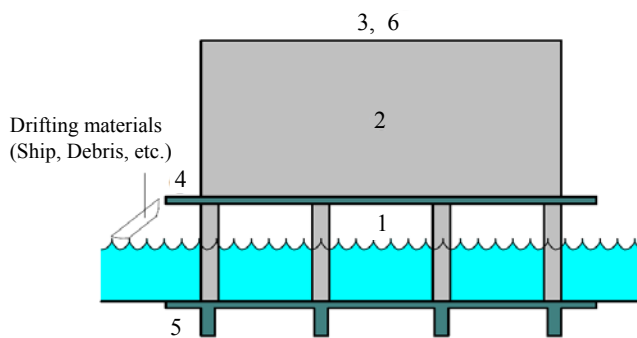


Fig.14 – Ingenuity

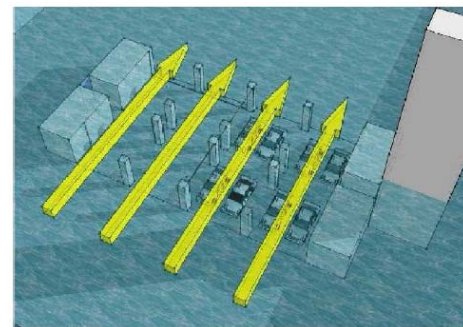


Fig.15 – Conceptual view of the piloti style with breakaway components



Fig.16 – Ingenuity



Fig.17 – Rooftop evacuation space



Fig.18 – External stairway



## 6. Conclusion

This study conducted tsunami resistance safety evaluation for Shizuoka Fisheries Technology Research Center built in the area subject to tsunami inundation using the evaluation method proposed in “Tsunami Safety Evaluation Manual for Existing RC and Steel Buildings in Shizuoka Prefecture” [3] and “Tsunami Resistance Safety Evaluation of Prefecture-Owned Public Buildings” [6] and confirmed that this building is safe against tsunamis. Also, this study confirmed that allowance of the ultimate inundation depth is twice as deep as the design inundation depth.

Although we did not take into consideration in the safety evaluation, we introduced various details that were applied to the building in order to ensure the anti-wave characteristics more reliably.

In Large earthquake (Level 2 earthquake) based on the Shizuoka Prefecture Fourth Earthquake Damage Estimation [4], it is estimated that the area where the inundation depth is 1m or more will exceed 100km<sup>2</sup> in the prefecture and many buildings will suffer from tsunami. We hope to increase the number of safe buildings against tsunami with reference to method of tsunami resistance safety evaluation in this study and use these buildings for tsunami evacuation and we hope that the lives of more citizens of the prefecture will be saved.

## 7. Acknowledgements

This report has been prepared based on the outcomes of Prefectural building tsunami resistance performance evaluation committee, special committee on tsunami resistance performance evaluation at Shizuoka Association of Architectural Firms, and tsunami resistance performance evaluation manual preparation committee on existing buildings (especially the chairperson: Professor Yoshiaki Nakano of Institute of Industrial Science, The University of Tokyo). We hereby express our gratitude to all the parties involved.

## 8. References

- [1] The Cabinet Office (2005): *Guidelines for Tsunami Evacuation Building*.
- [2] Yoshiaki Nakano (2017): *Structural Design Requirements for Tsunami Evacuation Buildings in Japan*. SP-313, Proceedings of the First ACI & JCI Joint Seminar: Design of Concrete Structures Against Earthquake and Tsunami Damage (Editors: Kyuichi Maruyama and Andrew W. Taylor), pp. 1.1 - 1.11, American Concrete Institute, 2017 March.
- [3] Shizuoka Association of Architectural Firms (2015): *Tsunami Safety Evaluation Manual for Existing RC and Steel Buildings in Shizuoka Prefecture*.
- [4] Shizuoka Prefecture (2013): *the Shizuoka Prefecture Fourth Earthquake Damage Estimation*
- [5] Land Technology Policy Research Institute, Ministry of Land, Infrastructure and Transport, Building Performance Standardization Association(2012): *Practical Guide on Requirement for Structural Design of Tsunami Evacuation Buildings*.
- [6] Toshiyuki Yanagi, Yoshiaki Nakano, Joji Sakuta, Shigeto Mochizuki, Takesi Sakaguchi (2017): *Tsunami Resistance Safety Evaluation of Prefecture-Owned Public Buildings*, 2017 16<sup>th</sup> World Conference on Earthquake, Santiago, Chile.