Structural Design Requirement on the Tsunami Evacuation Buildings

by

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ABSTRACT

This paper introduces a structural design method of tsunami evacuation buildings which was discussed after the 2011 Great East Japan earthquake due to the building damage from tsunami and enforced as a notification by Ministry of Land Infrastructure Transport and Tourism.

The ratio of the water depth to the design inundation depth in a hydro static tsunami load, which was 3.0 in the existing design guideline, can be basically selected among 3.0, 2.0 and 1.5 in accordance with the existence of the seaward obstacles and the distance from coasts or rivers. The tsunami wave pressure on the openings such as windows and doors can be negligible, and the design tsunami loads can be simply reduced in proportional with the aerial ratio of the openings on the frame directly tsunami affected. The interim guideline required to be taken into consideration of buoyant forces and impact loads by the debris. The tensile force on individual columns by the buoyancy can be derived from the volume of concrete and residual air in the buildings. The building should be designed to prevent a shear failure of the pile and overturning by the tsunami loads and the buoyant force. In afraid of the local damage on a vertical element by the debris, the residual frame should be able to support the redistributed axial load. The paper finally shows the requirement of base shear coefficient and length of the reinforced concrete building structures for tsunami evacuation buildings in a parametric study of the ratio and the inundation depth.

KEYWORDS: 2011 Great East Japan Earthquake, Buildings, Structural Design, Tsunami Loads

1.INTRODUCTION

The damage from tsunami in the Great East Japan earthquake of 2011 was one of the most disastrous tsunami Japan has ever experienced. A great many lives were lost and many towns were destroyed. For the recovery to proceed quickly, many studies from various points of view are being carried out. In this paper, the results of the examination concerning the structural design method of a tsunami evacuation building, which is included in the tsunami related studies, will be introduced.

Usually, evacuation to a high ground is a basic principle when tsunamis occur. If there is no high ground to evacuate to, a tsunami evacuation building will protect human lives instead of high ground. Therefore, it is required that tsunami evacuation buildings should have a reliable structure which is comparable to a high ground and the safety concerning the evacuation.

The contents of this paper are verifications of validity and examinations of some of the content which require review of structural design methods in "The Guidelines concerning the tsunami evacuation buildings etc. (hereafter, The Guideline [1])," based on the tsunami damage from the Great East Japan earthquake. This examination was carried out as collaboration between the Institute of Industrial Science, the University of Tokyo and the Building Research Institute.

2. A STRUCTURAL DESIGN METHOD FOR TSUNAMI EVACUATION BUILDINGS

Since the Central Disaster Prevention Council issued The General Principles for the Measures

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Table 1. Guideline for Structural Design of Tsunami Evacuation Buildings

1) Not to be collapsed : It has to be confirmed that the tsunami load on each floor of the building will never be higher than the horizontal proof stress. **2) Not to be overturned** : It has to be confirmed that overturning moment by the tsunami load will never be higher than the resistance moment considering buoyancy. **3) Not to be slided** : It has to be confirmed that the horizontal force will never be higher than the friction of the foundation or the horizontal proof stress of the piles. If the resistance against the horizontal displacement of the building can be expected, it can be included in the calculation. - It has to be confirmed that the pressure resistance components in the pressure taking side will not be destroyed by the tsunami wave pressure.

against Tokai Earthquake in May 2003, and The General Principles for the Measures against Tonankai and Nankai Earthquake in December 2003, the necessity of tsunami evacuation buildings, which contributed to the prevention of loss of human lives during tsunami disasters, is receiving more public awareness. Based on this status, the Building Center of Japan (BCJ) examined the structural design method for tsunami evacuation buildings as their independent research project for the 2004 fiscal year [2]. During their research period, the 2004 Indian Ocean Earthquake and Tsunami occurred in December 2004. Under such conditions, The Guideline which the Cabinet Office issued in June 2005, quoted the results of examination by The BCJ in its appendix II entitled "The Basic Way of Considering Structural Conditions."

The collaboration research between the Institute of Industrial Science, the University of Tokyo and the Building Research Institute was carried out as the Building Standards Improvement promotion project No.40 in the 2011 fiscal year "A study of Improvement of Building Standards and others in the tsunami critical areas." In the collaboration research, the structural design method for tsunami evacuation buildings was taken up, which was in the "Guideline," and examined its appropriateness, selected contents which required review, and examined the description, based on the measured inundation depth, elements of buildings, and the damage status of the buildings which experienced tsunami exposure.

The results were reflected in "The interim guideline for the structural conditions of tsunami evacuation buildings etc, based on the building damage from the tsunami in the Great East Japan earthquake," [3]) which was an appendix of the technical advice (MLIT, Housing Bureau, Building Guidance Division No.2570, on Nov. 17, 2011) (we will call this "the interim guideline" and The Notification "Concerning setting the safe structure method for tsunamis which are presumed when tsunami inundation occurs," [4]) (MLIT notification No.1318, on Dec.27, 2011).

2.1 The Design Policy and the Point of Review

In the appendix II of "the Guideline," the Cabinet Office published "the basic way of considering the structural conditions," based on the results of BCJ's independent research. The table of contents reads; 1.1 The range for application, 1.2 Terms to use, 1.3 Structural design, 1.4 Calculation formula of tsunami load, 1.5 Combination of load, 1.6 The design of the tsunami contact surface, 1.7 examination for overturning and sliding. As you see, it is mainly the examination of how not to collapse, not to overturn or not to slide against the tsunami load. Also, it is necessary to confirm that the pressure-resistant components for the tsunami contact side (the side of a building which receives a tsunami load directly) shouldn't lose the resistance capacity against the horizontal force or vertical bearing capacity, and also it shouldn't be destroyed by the wave pressure.

In this review, the way of thinking mentioned above will be followed, as a guideline for structure design in tsunami evacuation buildings. So, concerning the design of tsunami evacuation buildings, an examination for the three conditions which are written in the Table 1 was carried out. Also, concerning the components on the tsunami contact side, they were classified into pressure-resistance components (the ones which shouldn't be destroyed when they received tsunami wave pressure) and non-pressure-resistance components (the ones which are allowed to be destroyed by tsunami wave pressure). And it will be examined if indeed the pressure-resistance components will not be destroyed by tsunami wave pressure.

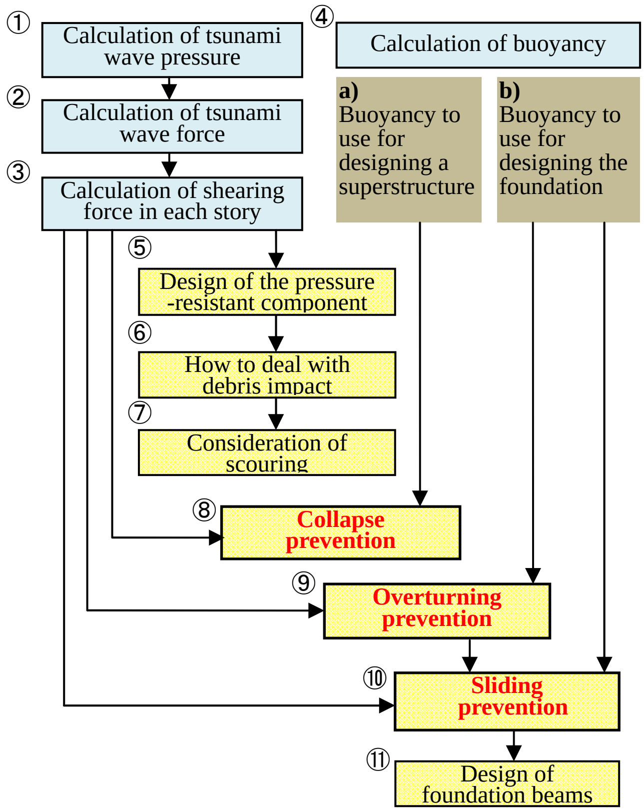


Figure 1. Process of the structural design of a tsunami evacuation building

2.2 Outline of the Structural Design for Tsunami Evacuation Buildings

The process of structural design is indicated in Figure 1. The design for tsunami evacuation buildings will be carried out in the following order. The details of 1), 2), 4) and 6) will be explained in "2.3 Calculation of tsunami wave pressure," "2.4 Calculation of tsunami wave power," "2.5 Calculation of buoyancy," and "2.6 How to deal with debris impact", respectively.

1) Calculation of tsunami wave pressure:
Tsunami wave pressure should be calculated as the static water pressure whose height equals the inundation depth multiplied by water depth coefficient "a."

2) Calculation of tsunami wave force:
Tsunami wave force should be calculated by integrating tsunami wave pressure into the direction of height, considering the decreasing effect of wave pressure because of the openings. Tsunami wave force, which works on each floor of a building, should be calculated by wave pressure from the middle of the height of the floor which is a level below to the middle of the height of the floor concerned, by dividing all the tsunami waver force working on the floor level of each floor.

3) Calculation of shearing force in each story:
The shearing force due to tsunami wave force in each story should be calculated by summing up all the tsunami wave force in all the stories above the concerned floor.

4) Calculation of buoyancy:
There are two kind of buoyancy to calculate.

a) Buoyancy to use for designing a superstructure:
In the examination of collapse, the buoyancy to use for designing a superstructure should be calculated as the sum of the buoyancy for the cubic volume of the structural body under the inundation depth which works on the structure and the buoyancy of air under the floorboard, under the conditions in which a certain amount of water has come into the building from the openings on each floor according to the inundation depth.

b) Buoyancy to use for designing the foundation:
In the examination of overturning and sliding, the buoyancy to use for designing the foundation usually should be calculated by taking the buoyancy for the whole building as working on the bottom of the foundation with an assumption that no water has come into the building.

5) Designing the pressure-resistant component:
It has to be confirmed that columns and walls,

which are pressure-resistant components, should not be destroyed by wave pressure, which works against them. It also has to be confirmed that the bending moment and shear force by wave pressure should never go over the flexural capacity and shear capacity of each of the components, respectively.

6) How to deal with debris impact:
It has to be confirmed that the building will not lose its vertical supporting capacity by debris impact by examining if the axial force supported by a column can be transferred to the neighbor column via the beams attached, assuming the case in which the exterior columns were destroyed by drifting objects.

7) Consideration of scouring:
Prevention measures against scouring, such as having a pile foundation to prevent the superstructure from tilting, or hardening the ground with concrete, should be considered.

8) Collapse prevention:
It has to be confirmed that the horizontal capacity obtained by pushover analysis using tsunami water force obtained by 2) as external force distribution and considering the buoyancy obtained by 4-a), should go over the shear force in each story, which is gained in 3).

9) Overturning prevention:
Each support reaction under the foundation (=axial force of the piles) can be calculated by adding the support reaction by pushover analysis using the tsunami wave power by 2) as external force distribution (no buoyancy included) to the buoyancy which works on each support which can be calculated by dividing the 4-b) buoyancy with the accumulative area. Then, concerning the tension pile, it has to be confirmed that the value is lower than the ultimate tensile capacity (it should be the lesser value in the tensile capacity of the pile or friction of the area surrounding the pile) of the pile. Or concerning the compression pile, the value has to be lower than the ultimate axial bearing capacity of the pile.

10) Sliding prevention:
It has to be confirmed that the horizontal capacity of the piles according to N-M relationships, here the axial force N is obtained by 9), will go over the tsunami load which works on the pile obtained by 3).

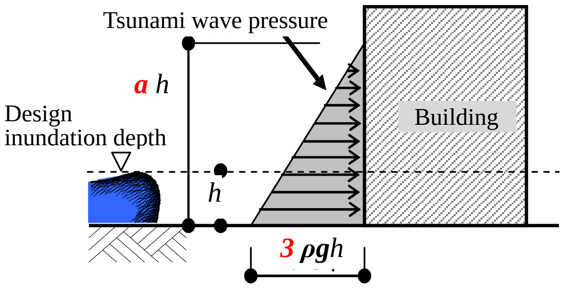
11) Designing the foundation beam:
The foundation beam has to be designed for the force of the superstructure plus the force which is accumulated in the force of the piles.

2.3 Calculation of Tsunami Wave Pressure

The “Guideline,” taking the water depth coefficient “*a*” for 3 as indicated in Figure 2, gave tsunami wave pressure which is three times the inundation depth on a side of the building for design.

This is something that Asakura et. al. [5] suggested concerning the tsunami wave pressure which works on a building by the tsunami which surged over the land beyond the upright seawalls. It was based on the results of their experiments with models in which they had many variations of wave characteristics such as wave height or cycle, slope steepness of the water way and the position of the building, the wave pressure distribution was a triangular distribution, and the maximum height was about three times the inundation depth. This means that this formula for tsunami wave pressure calculation by static water pressure invisibly includes the influence from water velocity. It is considered that some other experiments and suggested formulae can be classified into the “safe” side by the idea mentioned above. Also, Nakano [6] investigated this idea by the data of buildings which had tsunami damage in the 2004 Indian Ocean Earthquake and Tsunami, and it has been proved that they are almost approximate.

In this examination, according to our field survey, we took the number “3,” in the method of tsunami wave pressure calculation in the “Guideline,” for fluctuating numbers because of the power of tsunami. Therefore, we took this “3” for “*a* (water depth coefficient),” and examined this “*a*” based on the actual status of damage. In the examination, the lateral capacity of damaged structures corresponding to the type of failure are estimated firstly, and the water depth coefficient “*a*” is calculated under the assumption that the calculated shearing force at base should be equal to the



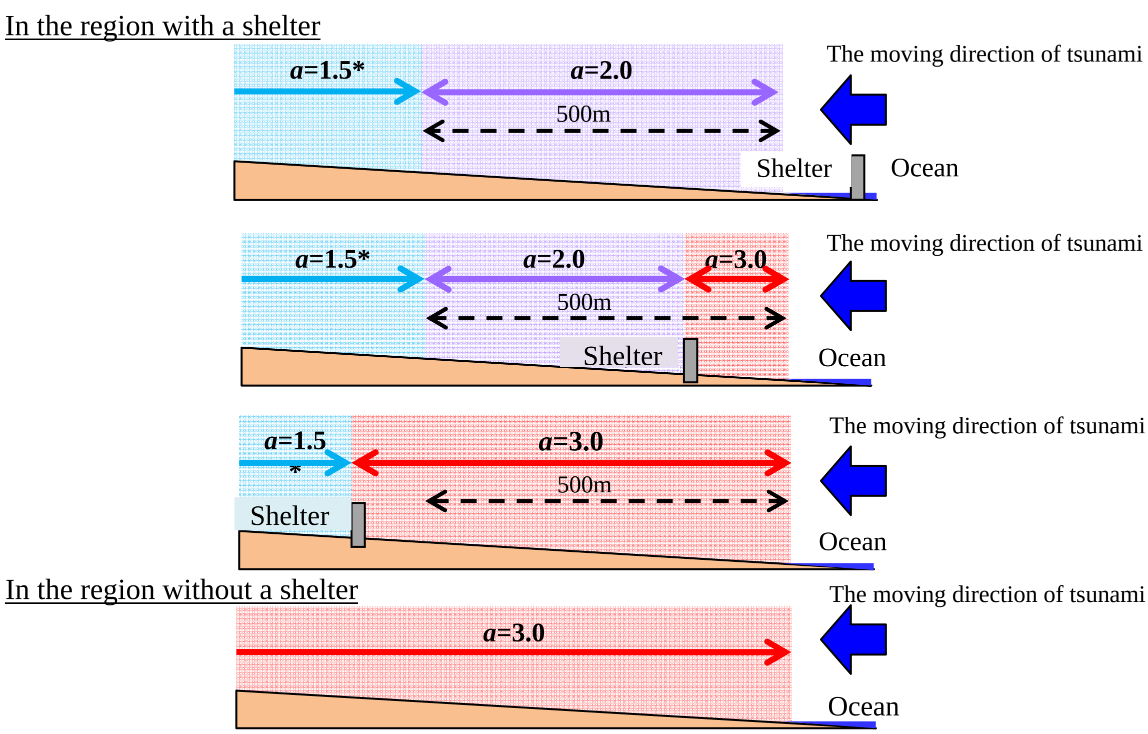
a : Water depth coefficient
h : Design inundation depth (m)
ρ : The mass of unit volume of water (t/m^3)
g : Gravitational acceleration (m/s^2)

According to the "Guidelines," the water depth coefficient "*a*" in the figure is 3, and the hydrostatic pressure which is three times the inundation depth for design is given. But in this examination, "*a*" was investigated based on the actual damage.

Figure 2. Calculation of the tsunami wave pressure

Table 2 Water depth coefficient "*a*"

	With a shelter		No shelter
Distance from seashore or rivers	More than 500m	Less than 500m	Doesn' t matter
Setting the water depth coefficient ***a***	1.5	2	3



**In the region which doesn't have the fluid speed increase, "a" can be reduced into 1.5.*

Figure 3. Relation between the water depth coefficient "a" and the existence of a shelter or distance from seashore and rivers

capacity of the structure when the static water pressure distribution was assumed, by using the measured inundation depth of the site.

Also, as a result of hearing tsunami specialists' opinions, one idea stands out, that since the water power of the tsunami in the Great East Japan earthquake is not necessarily the largest volume we can think of, it is not appropriate to revise the maximum value of tsunami wave pressure only from the damage, under evaluation was indicated. Therefore, it is decided to examine the conditions which can decrease the water depth coefficient "*a*" by taking the existing knowledge "static water pressure which equals three times the inundation depth for designing," for the case whereby the maximum wave pressure works.

The Formula of Tsunami Wave Pressure Calculation: The formula (1) is the tsunami wave pressure calculation which was obtained as the result of the investigation based on the field survey. And Figure 3 is a schema of the water depth coefficient "*a*." Also, the (a) and (b) are the details concerning the water depth coefficient examination.

$$qz = \rho g\,(ah - z) \qquad \text{-----------------------------} \quad (1)$$

In this formula,

- ρ : The mass of unit volume of water, 1.0 (t/m^3)
- g : Gravitational acceleration, 9.8 (m/s^2)
- h : Inundation depth for designing (m)
- z : The height of the concerning part from the ground level ($0 \leq z \leq ah$) (m)
- a : Water depth coefficient. If it is confirmed that the Froude number $Fr = u/\sqrt{g\eta}$ is less than 1.0 clearly, "*a*" can be 1.5. ("u"= tsunami velocity, η=inundation depth)

(a) <u>Examination of water depth coefficient from the view of influence of shelters</u>:
The case whereby there are shelters which can reduce tsunami wave power between the building and the tsunami was taken up, as a condition to decrease the water depth coefficient "*a*." In the examination, other structures, seawalls at the mouth of the bay, and tide embankments which are high enough against tsunami (assuming more than half the height of tsunami) are considered as shelters which can be expected to reduce wave power. As a result, it was found out that if there is a shelter which can be expected to reduce tsunami wave power, the water depth coefficient "*a*" will be reduced into 1/1.5 compared with the case without any shelter. Therefore, it can be concluded that if there is a shelter which can be expected to reduce tsunami wave power, the water depth coefficient can be 3/1.5, which equals 2.

Also, since some of the seawalls at the mouth of the bay and tide embankments were destroyed, it is difficult to define the effect specifically. Therefore, facilities and buildings which are in the direction of the tsunami with tsunami evacuation buildings were compared.

(b) <u>Examination of the water depth coefficient from the view of influence of distance from seashore or rivers</u>:
Secondly, the distance from seashore or rivers is taken as a condition to reduce the water depth coefficient "*a*." As a result of the examination, it was confirmed that the power of tsunami (Froude number, Fr) is decreased in proportion to the distance from seashore or rivers. For example, if it is more than 500m away from seashore or rivers, it can be considered that *a*=about 1.0. Since the data from the field survey is limited, the calculation of capacity is a result of simplified calculation, and there is dispersion between the inundation depth from tsunami simulation and the measured inundation depth, it is decided to give the result of the field survey about 1.5 times of margin. Therefore, if there is a shelter and it is more than 500m away from seashore or rivers, the water depth coefficient can be 1.5. Also, it is necessary to check if there is any element to increase the speed of the current, such as positioning the buildings which gather water velocity or down-grade around the building.

2.4 Calculation of Tsunami Wave Force

In this section, the method to calculate tsunami wave power from the tsunami wave pressure which is obtained in 2.3, and the way of treating structural openings for the calculation are explained. From the tsunami wave pressure which is calculated by the method, shear force on each story of the building, support reaction of the building, and the horizontal force which works on the foundation of the building can be calculated. And by using the method in Table 1, it can be confirmed that collapse, overturning, and sliding will not occur. Also, to confirm that the pressure-resistant components on the pressure receiving side will not be destroyed, the wave power which works on the pressure-resistant components can be calculated by the following method.

<u>1) The formula of tsunami wave force calculation</u>:
Tsunami wave force can be calculated in the formula (2), assuming that the tsunami wave pressure in the formula (1) occurs at the same time.

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

In this formula,

- Q_z : The tsunami force (kN)
- B : The width of the pressure receiving side of the concerning part (m)
- z_1 : The minimum height of the pressure receiving side $(0 \le z_1 \le z_2)$ (m)
- z_2 : The maximum height of the pressure receiving side $(z_1 \le z_2 \le ah)$ (m)

The tsunami wave pressure which is indicated in the formula (1) expresses tsunami wave force per unit area. Therefore, tsunami wave force can be calculated by integrating tsunami wave pressure for the pressure impact area. The formula (2) is the one tsunami wave force calculation where the minimum height of the pressure receiving side is z1 and the maximum height is z2. Since in some cases the width B is not fixed according to the height, if it is the case, it is recommended to be cautious in integrating it by using the width according to the height of the pressure receiving side.

<u>2) How to treat the openings</u>:
When a tsunami works on a building, window glass is destroyed and the wave force which works on the structure will be reduced compared to the case in which the pressure receiving side is made of pressure-resistant components entirely. This means that tsunami wave force can be reduced by openings in the external wall such as windows, doors, and shutters (which is on the pressure receiving side and is made of non-pressure-resistant components). Also, it was found a steel construction which overturned because the exterior wall made of ALC panels survived and received very strong tsunami wave force. Therefore, it should be a principle that the cladding with a steel framework is treated as a part which receives tsunami wave pressure. Also, it is possible to treat them as structures with openings because it may be destroyed at an early stage, but if it is the case, it has to be carefully confirmed that the cladding will be certainly destroyed or come off.

One of the following can be adopted as a method of reducing tsunami wave force because of openings;

- To calculate tsunami wave force by excluding the width of opening parts from the width of the pressure receiving side of each height. (the formula (2)),
- Tsunami wave power multiplied by the area which excludes the opening area from the pressure taking area (= 1- ratio of the opening on the pressure receiving side).

These two methods are compared for the cases when the ratio of opening area changes in the direction of the height. And it is confirmed that the gap between the two methods was within a 10% maximum. Therefore, these two methods can indicate almost the same amount of reduction.

Also, according to the sample which we examined the reduction of wave power by openings with a numerical simulation, the wave force will be reduced more, if the ratio of the opening becomes larger. But, if it is over 30%, since there are interior walls, the reduction of wave force will reach the limit. Based on this result, it can be said that the lower limit of wave power should be about 70% in cases in which there is no opening on the building. Therefore, it is very important to provide routes for water stream and outlet within the building as far as possible [7].

2.5 Calculation of Buoyancy

1) <u>The way of thinking buoyancy</u>:
Strong buoyancy works on a building which has small openings. A building which might float in the water was actually found. Since the general

unit weights of steel structure and RC structure are 8 kN/m^2 and 13 kN/m^2 each, the building's own weight will be canceled if there is more than 80cm or 130cm of air layer on each story, respectively. Since not much water can flow in the building which has extremely small openings such as a refrigerated warehouse, the building will be easily floated if the speed of increase of the inundation depth is fast. In most of the overturned building, the ratio of opening on the exterior wall was lower than 0.2.

On the other hand, it is found air gathering spots under the floor slab which was equal in the length to the hanging partition wall even in a building which has a certain amount of openings. Also, by having the inside of the building inundated, the density of the structure will be smaller as much as the density of water (≒1.0). Hence, this much buoyancy has to be considered even in the case if water flowed into the building. Also, if there is a part in which there is no air outlet (ex. Cores), it is better to consider the buoyancy which is equal to its cubic content.

When buoyancy works on a building, the resistance of weight against overturning will be smaller. Also, the friction on the bottom of the foundation against the sliding will be diminished as well. And in the piles and columns of RC structure, since the axial force is reduced, the flexural strength and shear strength will be decreased. In this way, the influence of buoyancy is extremely large.

2) <u>The method to calculate buoyancy</u>:
It is desired that the way of water flowing into the building from openings must be considered precisely to calculate buoyancy. However, since the description hasn't been clarified yet, we decided to adopt the following method to consider buoyancy as an assumption for safe side.

a) In designing the superstructure for collapse prevention, the buoyancy of when calculating the horizontal force on each story, should include enough water flow into the building from the openings of each floor in proportion to the inundation depth. The buoyancy can be calculated as a sum of the buoyancy for the volume of the building elements under the inundation depth which works on the structure, and the buoyancy of dead air space under the floor slab. Since the axial force will be minimum when there is water in the building, the flexural strength of columns in RC structure and the lateral capacity on each story will be calculated as smaller. Therefore it can be said it's safer. Also if it is possible to calculate the lateral capacity of each story as safer, the buoyancy of the status can be used.

b) When designing a foundation for overturning and/or sliding prevention, the buoyancy in the calculation of the axial force on the piles or friction on the foundation should be calculated as taking the buoyancy for the amount of cubic content of the building for working on the bottom of the foundation. It was confirmed that the tsunami with a depth which was as deep as the maximum inundation depth impacted, at one push, into the Sendai Plain at this time. In this case, though the tsunami water went around buildings, not much water could flow into buildings. Therefore it can be said that buoyancy easily worked on the buildings. Also, since water flowing into buildings with fewer openings is always slow, it can not be said that water flows in according to the inundation depth. Hence, as a measure for safety by considering these uncertain elements, it should be a principle to consider the buoyancy for the amount of the cubic content of the building at this moment.

2.6 How to Deal with Debris Impact

There are various kinds of drifting objects in a tsunami disaster, such as driftwood, automobiles, containers, vessels, pieces of destroyed buildings. Several different methods to calculate the impact force of collision between a building and a drifting object are proposed. However, the calculated values of each method are very different from each other, and the kinds of objects were limited. Therefore, a united evaluation method, which can meet various situations, hasn't been established yet. Also, by calculating with the

	The inundation depth and the number of stories of a building		
	5m（4F）	**10m（5F）**	**15m（7F）**
***a*=3.0** **Short direction（span=12m）** **Long direction（C_B=0.3）**	**C_B-0.97** **Length 40m**	**C_B-2.83** **Length 36m** **（C_B=1.0）**	**C_B-4.56** **Length 54m** **（C_B=1.0）**
***a*=2.0** **Short direction (span=12m)** **Long direction（C_B=0.3）**	**C_B-0.38** **Length 15m**	**C_B-1.44** **Length 60m**	**C_B-2.42** **Length 54m** **（C_B=0.55）**
***a*=1.5** **Short direction (span=12m)** **Long direction（C_B=0.3）**	**C_B-0.30** **Length 9m**	**C_B-0.78** **Length 33m**	**C_B-1.36** **Length 54m**

◎ means the level which can corresponded to the current earthquake resistance design. ○ means the level which requires some means to increase the strength, and △ means the level which requires special means to increase the strength of the superstructure, the piles, and the foundation decisively .

Figure 4. Base shear coefficient C_B in the short direction and length in the long direction which are required of the building for each inundation depth

methods which have been proposed thus far, in some cases when drifting wood or a container has hit, even a RC column could be failed [7].

Therefore it is decided to confirm that the axial force supporting capacity will not be lost by transferring it to next column or wall via beams if a column was failed by debris impact. Generally, it is not necessary to consider the situation in which two or more columns are failed at once. But, in case the drifting object must be huge, such as a vessel, we have to consider a method to confirm the building will not collapse if the exterior columns are destroyed. Also, to build protective equipment or facilities from debris impact could be a measure from the planning side.

3. CONDITIONS WHICH ARE REQUIRED FOR TSUNAMI EVACUATION BUILDINGS

The proposed structural design method for tsunami evacuation buildings was examined how much strength and size are required against a large inundation depth, like the one we experienced in the Great East Japan earthquake. In this examination, an RC apartment house with multistory walls in short direction with span of 12m and frame structure for the long direction with the demand base shear coefficient of 0.3 was taken, which meets code requirements for seismic safety. The water depth coefficient *a*=1.5, 2.0, and 3.0, the inundation depth = 5m, 10m, and 15m are assumed. Then the base shear coefficient (C_B) for the short direction to meet the conditions of this method was calculated, and also the length of the long direction for each combination of the water depth coefficient “*a*” and the inundation depth was calculated. The height of each story of the building is 3.5m, and the ratio of openings is 0.3 were assumed. According to the result, when the inundation depth was 5m, even by setting *a*=3.0, the C_B for the short direction is 0.97.

It is acceptable to calculate with the root 1 in seismic calculation, which is used for structures with many walls and requires $C_B \geq 1.0$. When the inundation depth was 10m, the short direction in case of *a*=1.5 can be correlated by the calculation by the root 1. But if it is *a*=2.0, the C_B of the short direction will be 1.44 and the required length of the long direction will be 60m. Therefore, the strength for both directions requires it to be much greater than the value in the usual earthquake-resistance design. Also, the short direction in case of *a*=3.0 requires C_B=2.83. So, some special means to make the strength greater will be needed not only for the superstructure but also for the piles and the foundation. If the inundation depth hit 15m, even when *a*=1.5 much greater strength than the usual cases will be required. If *a*=2.0 under the same condition, it is clear that some special means to increase the strength of the superstructure, the piles, and the foundation significantly, have to be taken. The short direction in case of a=3.0 requires C_B=4.56, which is extremely great in strength.

The above was an examination of collapse, but since the structural design method of a tsunami evacuation building requires so-called "secondary designing," which corresponds to the ultimate capacity design even on the piles and the foundation, the piles have to have much greater lateral capacity and tensile resistance, compared with one designed by the allowable stress calculation.

Figure 4. summarized what was mentioned in this chapter by ◎, ○, and △. ◎ means the level which can corresponded to the current earthquake resistance design. ○ means the level which requires some means to increase the strength, and △ means the level which requires special means to increase the strength of the superstructure, the piles, and the foundation decisively.

4. CONCLUSION

In this paper, the structural design method in "The Guidelines concerning the tsunami evacuation buildings etc.," which was issued in 2005 was reviewed. The results are reflected in "The interim guideline for the structural conditions of tsunami evacuation buildings etc." and Notification "Technical advice how to design a building which has a safe structural proof stress against tsunami." These are based on the examination in the fiscal year of 2011. However, concerning the structural design method of tsunami evacuation buildings, there are still many tasks to clarify, such as the tsunami wave pressure calculation by considering the tsunami fluid velocity, the condition of the calculation, how to treat the openings, measures for treating drifting objects, measures for scouring, and knowledge for how to treat piloti, and so on. We are going to continue our technical research to establish the rational method to calculate these phenomena properly.

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