Structural Design Requirements for Tsunami Evacuation Buildings in Japan

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Synopsis: The Great East Japan Earthquake that struck northern Japan in March 2011 caused devastating tsunami damage, both to property and human life. To evacuate inland or to elevated ground is the primary action immediately to be taken in coastal areas after a felt earthquake. But there are plenty of communities where people simply cannot evacuate in time, and constructing tsunami evacuation buildings at strategic locations is therefore vital means to effectively mitigate human damage. After the 2011 catastrophic tsunami event, a joint team of the Institute of Industrial Science, The University of Tokyo (IIS UTokyo) and the Building Research Institute (BRI) extensively inspected tsunami damaged buildings and investigated their lateral strength, structural type, site condition, observed damage etc. In November 2011, The Ministry of Land, Infrastructure, Transport and Tourism newly issued the Interim Guidelines on the Structural Design of Tsunami Evacuation Buildings considering new findings, improved knowledge, and various experiences learned through the repeated damage investigations (Guidelines 2011). This paper presents the outline of the structural requirements for tsunami evacuation buildings stipulated in the new Japanese Interim Guidelines 2011. Following the Guidelines 2011, the relationship between structural size, required lateral strength, and tsunami inundation depth is also studied and discussed herein.

Keywords: Tsunami, design, evacuation building, structural requirement

INTRODUCTION

The Great East Japan Earthquake that struck northern Japan in March 2011 caused devastating tsunami damage, both to property and human life. To evacuate inland or to elevated ground is the primary action immediately to be taken in coastal areas after a felt earthquake. But there are plenty of communities where people simply cannot evacuate in time, and constructing tsunami evacuation buildings at strategic locations is therefore vital means to effectively mitigate human damage.

To design and construct buildings resistive to tsunami loads, quantitative evaluations of tsunami load applicable to structural design is most essential. Since great earthquakes such as Tokai Earthquake and Tonankai-Nankai Earthquake significantly affecting coastal areas are expected to occur in the near future in Japan, the Central Disaster Prevention Council issued the General Principles for Countermeasures against Tokai Earthquake in May 2003 and against Tonankai-Nankai Earthquake in December 2003, respectively. Under such circumstances, the Building Center of Japan (BCJ) started a research project to discuss structural requirements for tsunami evacuation buildings and drafted a technical guide for their structural design in 2004 (BCJ Guidelines 2004) (Okada et al. 2004a and 2004b), which for the first time in Japan introduced a formula to compute tsunami loads expected to act on buildings and other structural requirements. The formula was developed primarily based on laboratory tests of 2-dimensional scaled models (Asakura et al., 2000) and examined through surveys of structures after the Indian Ocean Tsunami in December 2004 (Nakano 2007&2008). The Japanese Cabinet Office also set up a task committee to discuss requirements and criteria to design tsunami evacuation buildings and proposed design guidelines in 2005 (JCO Guidelines 2005) referring BCJ Guidelines 2004 mentioned above. However, few buildings had been designed based on these guidelines until 2011.

After the 2011 catastrophic tsunami event, a joint team of the Institute of Industrial Science, The University of Tokyo (IIS UTokyo) and the Building Research Institute (BRI) extensively inspected tsunami damaged buildings and investigated their lateral strength, structural type, site condition,

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observed damage etc. to review and verify the tsunami forces and to enrich design requirements and commentary described in the previous guidelines. The joint team proposed necessary revisions based on new findings, improved knowledge, and various experiences learned through the repeated damage investigations followed by intensive discussions. In November 2011, The Ministry of Land, Infrastructure, Transport and Tourism adopted the proposal and newly issued the Interim Guidelines 2011 on the Structural Design of Tsunami Evacuation Buildings (Guidelines 2011).

This paper presents the outline of the structural requirements for tsunami evacuation buildings stipulated in the new Japanese Interim Guidelines 2011. Following the Guidelines 2011, the relationship among structural size, required lateral strength, and tsunami inundation depth is also studied and discussed herein.

DESIGN PRINCIPLES AND INTERIM GUIDELINES 2011

The tsunami evacuation buildings can be affected by tsunamis from two sources, i.e., near-source-generated tsunamis and far-source-generated tsunamis. The first tsunami source would be the one that occurs following so called near-field earthquakes, which also would create severe and damaging ground shaking. The second source would be a distant earthquake that occurs far away from the coastal areas without any local earthquake effects. Following the 2011 event, the Japanese central and local governments have conducted extensive tsunami simulations using improved scientific data and methods, as well as considering inundated areas due to recent and historic tsunami events, to provide rational tsunami hazard maps which are of primary help for earthquake and tsunami disaster mitigation planning. As will be described later, the tsunami loads are in general given considering the tsunami inundation depth that appears in the regional hazard maps provided by the local government.

The tsunami evacuation buildings are primarily required to have the capacity to resist anticipated tsunami loads without collapse, overturning, or lateral movement for the life safety of evacuees. Figure 1 shows a basic flow of structural design procedure. As was often found after the 2011 tsunami disaster, the performance of a building during tsunami inundation is significantly affected by buoyancy in addition to the tsunami flow, and uplift due to buoyancy should be carefully taken into account in the design. The structural safety and integrity is the primary concern for the tsunami evacuation building, but it should also be noted that the refuge areas should be located well above the elevation considering possible splash-up during tsunami impact and inherent uncertainty in estimating tsunami run-up elevation.

In designing individual members, they are first categorized as either breakaway or non-breakaway components. Breakaway components are allowed to fail under a specific tsunami load without causing damage to the building system. This concept is employed because it is deemed impractical to design all members and their connections strong enough to resist the maximum considered tsunami event from technical and economical point of view. Structural components, however, should be designed as non-breakaway to resist and transfer the forces acting on them.

Tsunami debris impacts and scour are also essential issues in designing tsunami evacuation buildings. When tsunamis propagate inland, destructive waves can carry debris creating high impact loads and cause extensive damage to timber houses although they may generally cause local damage to reinforced concrete buildings. Due to uncertainties involved in the estimate of impact forces associated with waterborne debris, the Guidelines 2011 incorporate considerations of the *missing column strategy*, which also appears in the Japanese Seismic Evaluation Standard (JBDPA 1977), to reduce the potential for progressive collapse if one column is severely damaged and loses its vertical load carrying capacity.

Tsunami scour depth is generally difficult to predict because of the many variables that govern the scour mechanism. Deep concrete foundations (pile foundations) should be provided for the tsunami evacuation buildings instead of shallow foundations such as mat foundations, because of the scour

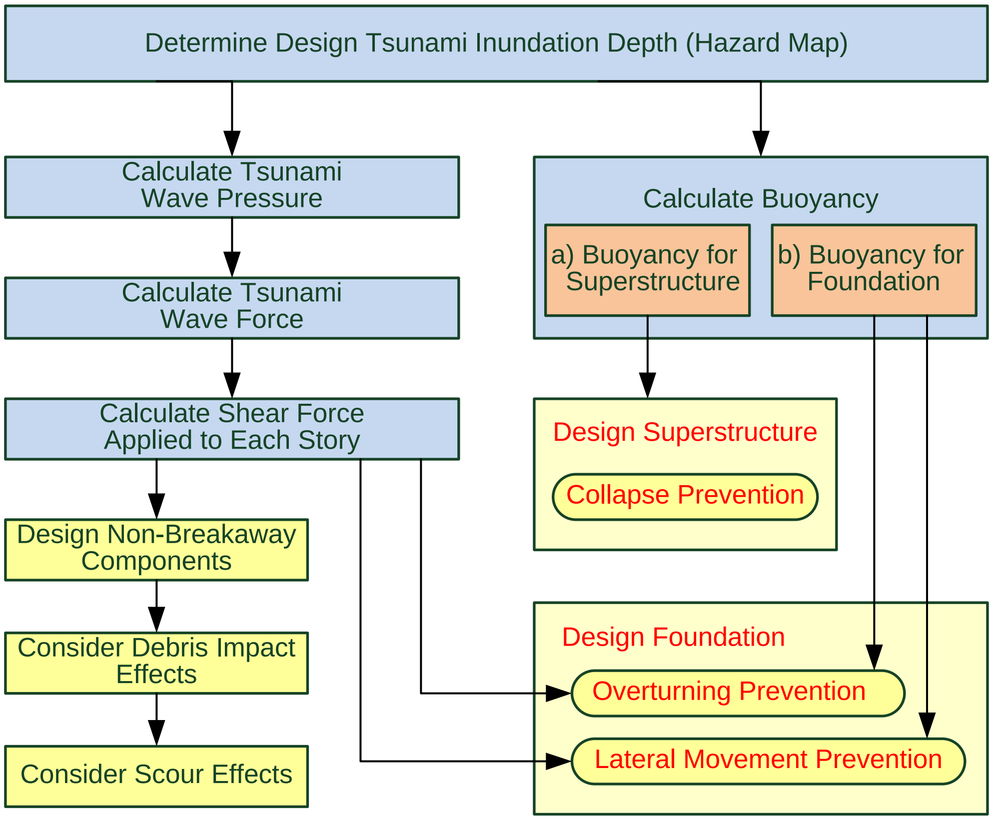


Figure 1. General structural design procedure. (after NILIM 2012)

potential that can occur during a tsunami.

KEY ISSUES FOR STRUCTURAL DESIGN OF TSUNAMI EVACUATION BUILDINGS

Tsunami wave pressure and its profile

It is well accepted that the tsunami wave pressure acting on structures and its profile are complicatedly dependent on the tsunami inundation depth, velocity, water flow to and around the structures, etc.

Tsunami evacuation buildings may be often constructed inland where complicated effects on the buildings may be caused by existing structures, and the tsunami velocity at each construction site, therefore, is not necessarily predicted with a reliable value due to local effects. In addition, the tsunami inundation depth shown in tsunami hazard maps provided by the local governments is the primary and in general the only source currently available to determine the tsunami loads in Japan.

Considering the current state of practice and simplicity point of view, the tsunami pressure profile is tentatively defined in the form of equivalent hydrostatic pressure as shown in Eq. (1), which is in the analogous form shown in the previous BCJ Guidelines 2004 and JCO Guidelines 2005. In Eq. (1), a water depth coefficient a is employed and its value can be any one of 1.5, 2.0, or 3.0. The value of coefficient a is primarily 3.0 unless tsunami energy dissipation is expected, which is based on the 2-dimensional hydraulic test results of scaled model (Asakura et al., 2000) to simulate and evaluate tsunami loads acting on inland buildings.

Figure 2 illustrates the background concept employed in Eq. (1). The design tsunami pressure distribution acting along the structure's height is assumed a triangular shape with the height reaching 3 times of the design tsunami inundation depth h (i.e., a = 3.0 in Eq. (1)) and the pressure at the bottom is assumed 3 times of the hydrostatic pressure. The equation form shows that the influence of water velocity is implicitly incorporated in the coefficient a larger than 1.0. The coefficient a is also investigated through the relationship between observed damage and structural resistance found in coastal areas after the Indian Ocean Tsunami in 2004, and the value of 3.0 is found rational to avoid serious damage to structures unless hit by tsunami debris.

$$q_z = \rho\, g\, (a\, h - z) \tag{1}$$

where,

q_z : intensity of tsunami pressure at height z (kN/m^2),
ρ : density of water (1.0 t/m^3 assumed herein),
g : gravitational acceleration, 9.8 (m/s^2),
a : water depth coefficient. The value of a is primarily 3.0 but can be reduced if the building is located in the condition shown in Table 1 and Figure 3.
h : design inundation depth (m),
z : location of acting pressure measured from the ground ($0 \leq z \leq a\, h$) (m).

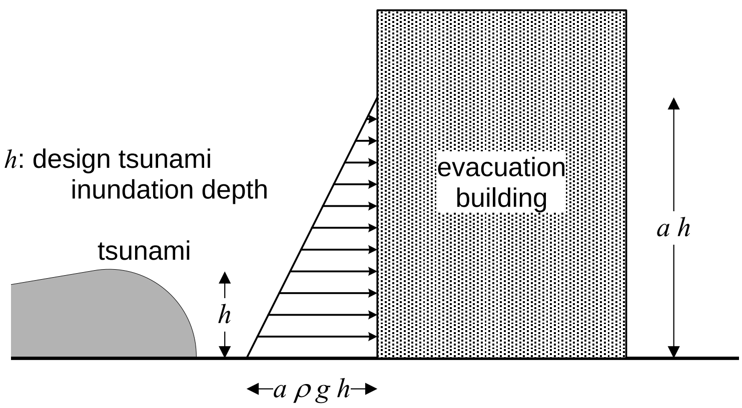


Figure 2. Design tsunami pressure distribution.

Following the 2011 event, damage surveys have been made by various institutes and research organizations. IIS UTokyo and BRI including the author also made extensive damage investigations to verify the value of a in the analogous way employed in surveys after the 2004 Indian Ocean Tsunami (Nakano, 2007&2008), and found the value is smaller than those obtained after the Indian Ocean Tsunami. This is probably because structures investigated after the Indian Ocean Tsunami were located just close to the shorelines without any coastal structures such as seawalls, bulkheads and revetments to dissipate tsunami energy and high tsunami waves therefore directly attacked the structures. In determining design values, however, it is also essential to carefully consider uncertainties associated with natural hazard, local effects due to building location as well as evidences found in experiments (Asakura, 2000) and field surveys such as Indian Ocean Tsunami (Nakano 2007&2008). The primary value of coefficient a in the Guideline 2011 is therefore determined 3.0 while it can be reduced to 2.0 or 1.5 due to the presence of tsunami energy dissipation or deflection structures and the distance from the shoreline. In reducing the coefficient a, the following two evidences found after the 2011 event are considered.

(1) The coefficient a for buildings with energy dissipation or deflection structures (either onshore or offshore structures) could be roughly 1/1.5 of that for those without such structures.
(2) In areas where the distance from a shoreline or riverbank is farther than 500m, the coefficient a could be around or less than 1 although the limited number of data. It should also be noted that the observed tsunami inundation depth has wide scatterness around the simulated values and is often as high as 1.5 times of simulations.

In the Guidelines 2011, the primary value of 3.0 for the coefficient a is reduced to 2.0 (= 3.0 / 1.5) when tsunami energy dissipation or deflection structures facing the ocean are provided and to 1.5 (= 1.0 x 1.5) when the building is located 500m or farther from the shoreline or riverbank. Table 1 and Figure 3 summarize the proposed value of coefficient *a* in the design equation Eq. (1).

Table 1. Water depth coefficient *a*.

Energy Dissipation Structures Provided		No Energy Dissipation Structures (at any distance from shoreline or riverbank)
Distance from shoreline or riverbank		
Distance ≥ 500m	Distance < 500m	
1.5	**2.0**	**3.0**

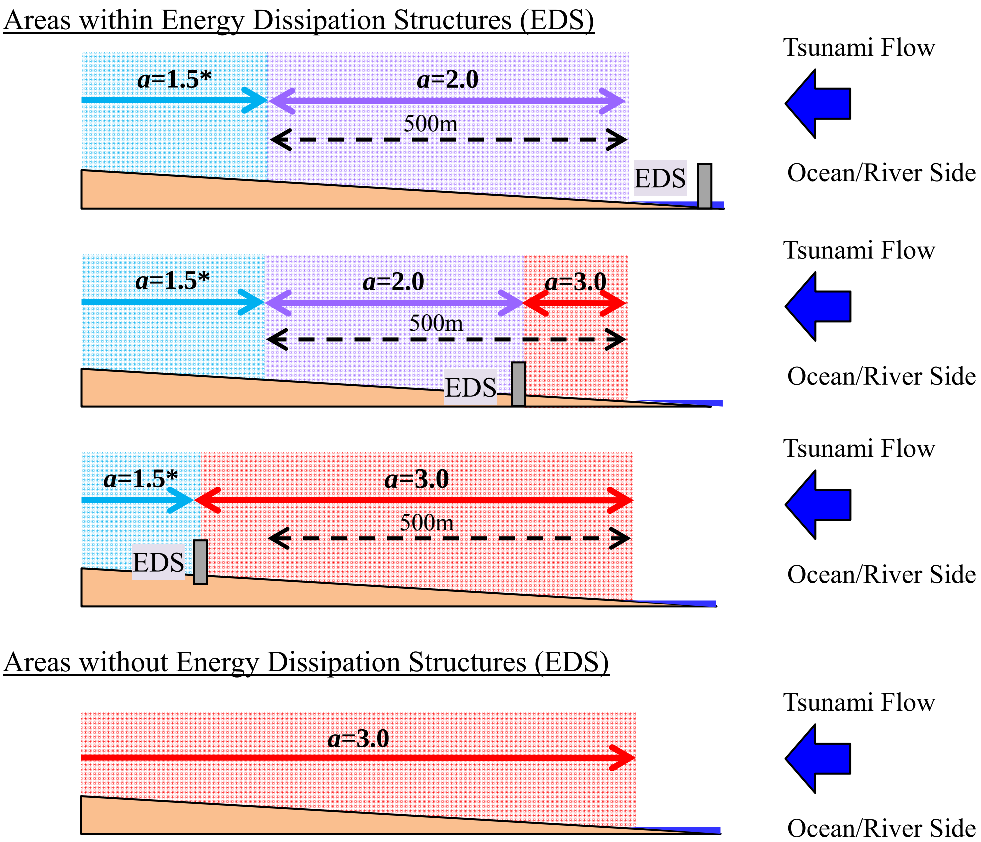


Figure 3. Water depth coefficient *a* considering energy dissipation structures and distance from shoreline or riverbank. (after IIS UTokyo 2011)

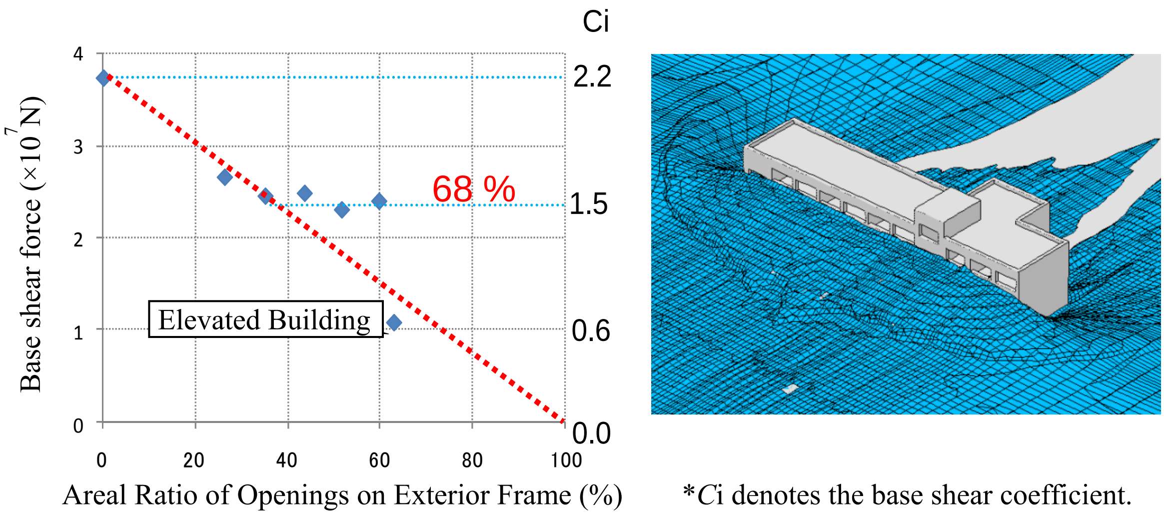
Tsunami force acting on components

The tsunami wave force can be calculated by integrating its acting pressure shown in Eq. (2) considering the pressure-exposed surface area and the pressure distribution along the height of the building concerned. In calculating the force acting on a building, the contribution of nonstructural components such as standard residential entry doors, shutter doors, windows on an exterior frame, which are expected to fail during the early phase of tsunami exposure and therefore considered *openings*, can be neglected. It should be noted, however, that the reduced force acting on an exterior frame should not be less than 70% of that without such openings because the presence of interior structural walls and other members may cause less effective response in reducing the tsunami force on a building. Figure 4 shows numerical simulation results on the relationship between force reduction and opening ratio. It shows that the force acting on the model structures can be reduced with increase in its opening ratio but the reduction may have a lower bound value of around 70% due to interior wall contribution except for an elevated building.

$$Q_z = \rho\, g \int_{z1}^{z2} (a\,h - z)\, B\, dz \qquad (2)$$

where,

Q_z : design tsunami wave force (kN),
B : width of pressure-exposed surface (m),
z_1 : minimum height of pressure-exposed surface ($0 \leq z_1 \leq z_2$) (m),
z_2 : maximum height of pressure-exposed surface ($z_1 \leq z_2 \leq a\,h$) (m).



*Ci denotes the base shear coefficient.

Figure 4. Relationship between base shear force and areal ratio of openings. (Okuda et al. 2008)

This limit of 70%, therefore, does not apply to columns provided in the open space of a piloti style building, i.e., a building raised on columns, to allow for tsunami passage beneath the building. It should be noted, however, that such an elevated building can significantly increase the potential for the ground shaking damage, and should be most carefully designed and constructed to properly resist damaging ground shaking.

The force calculated above is applied to confirm the safety of a whole building against collapse, overturning, and lateral movement as well as of non-breakaway components. To examine the force vs. displacement performance of a whole building to the expected tsunami event, a pushover analysis is generally performed using the force distribution defined in Eq. (1). It should be noted that tsunami waves have much longer periods than earthquake shakings and tsunami evacuation buildings should

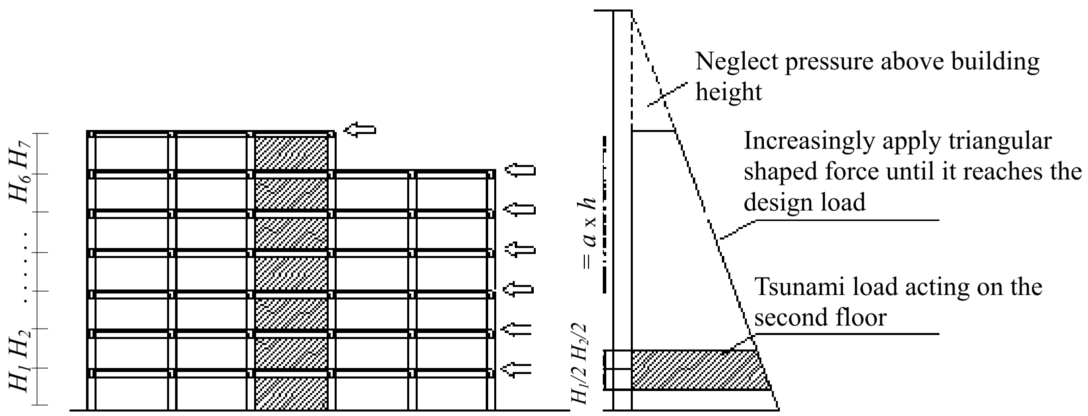


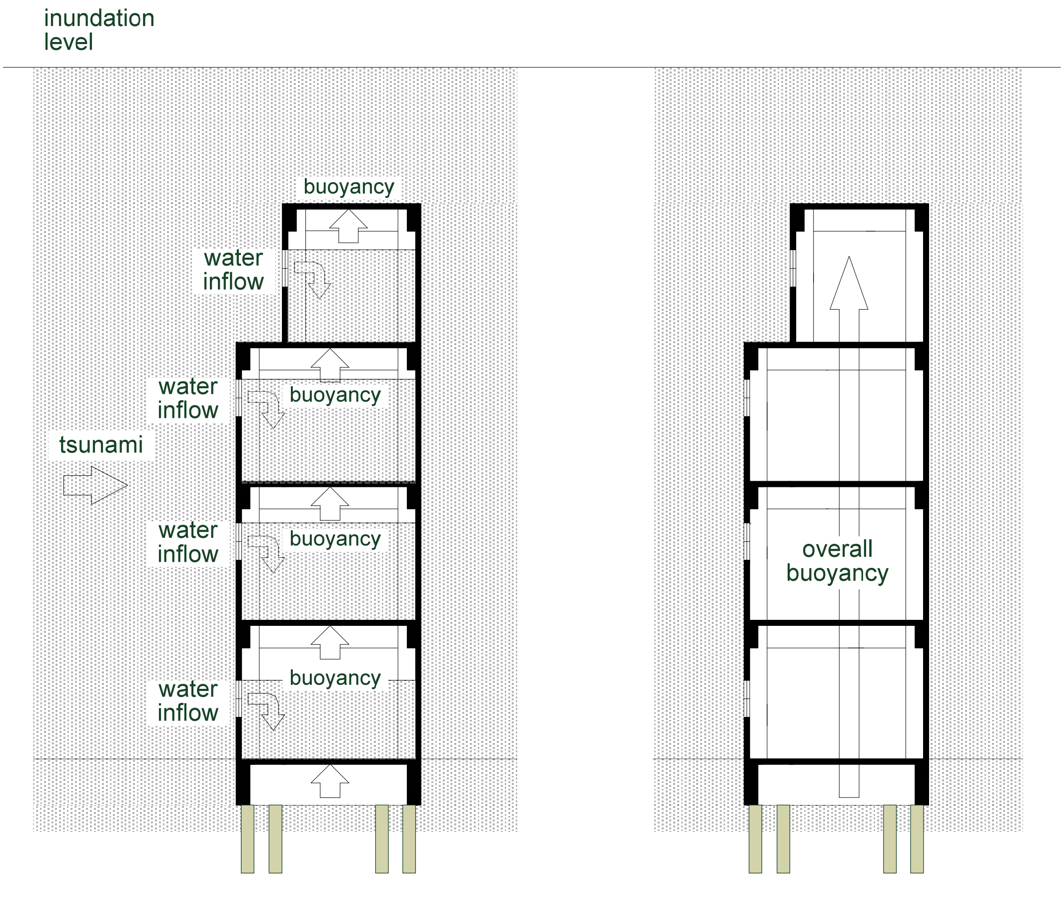
Figure 5. Tsunami load applied to each floor in pushover analyses. (after NILIM 2012)

properly resist such tsunami-induced forces. Figure 5 shows an example of tsunami loads applied to a building during pushover analyses. Unlike general seismic design, tsunami evacuation buildings therefore need to be more emphasized on their resistance rather than ductility due to the differences in shaking and tsunami characteristics.

Buoyancy effects

Uplift due to buoyancy has the effect of reducing the total weight of a building, which may significantly impact the resistance for overturning and lateral movement. After the 2011 tsunami event, 8 overturned buildings are investigated and found to have a small opening ratio of less than 0.3. Rising water will pose significant effects on uplifting and overturning of such building during rapid inundation. Furthermore the reduction of the weight also leads to the reduction of lateral strength of structural members.

Buoyancy is affected by the volume of water flowing into a building but it may be generally difficult to precisely predict the water inflow during a tsunami inundation in the design stage. In addition to the volume of displaced water of a submerged building and its components, the additional volume of water displaced by air trapped below the floor framing system, which was very often found in the inundated buildings after 2011 event, can significantly contribute to the buoyancy. Considering the average unit weights of each floor in steel buildings and reinforced concrete buildings in Japan are 8 kN/m^2 and 13 kN/m^2, respectively, the excluded water height of 0.8 m and 1.3 m in each story of a box-type building may lose the downward resistance by self-weight, and uplift forces from buoyancy therefore should be carefully taken into account. In the Guidelines 2011, the following assumptions as shown in Figure 6 are employed for the safe side design.



a) Buoyancy for superstructure design b) Buoyancy for foundation design

Figure 6. Buoyancy assumptions in the Guidelines 2011. (after NILIM 2012)

a) In computing lateral strength of structural members for collapse prevention, buoyancy due to water volume displaced by the members and additional buoyancy due to air trapped below the floor system should be considered to assume minimal axial force contributing to the member resistance. (Figure 6 a))
b) In computing axial forces acting on foundation piles against overturning and friction resistance between foundation and superstructure against lateral movement, potential uplift from the overall buoyancy of the building should be considered to assume maximal uplift forces for the foundation design. (Figure 6 b))

Design of components

Components on the exterior frames are directly exposed to tsunami pressure, and they are categorized either as breakaway or non-breakaway elements. A breakaway component is not part of the structural support of a building and is intended through its design and construction to collapse under a specific tsunami load without causing damage to the building system. Nonstructural components on exterior frames that are directly exposed to tsunami wave pressure are considered breakaway panels and the tsunami loads acting on them can be accordingly reduced if the allowable loading resistance of the components can be given and is lower than tsunami loads. In particular, the contribution of standard residential entry doors, shutter doors, windows on an exterior frame that are expected to fail during the early phase of tsunami attack can be neglected in calculating tsunami loads acting on a structure. Other nonstructural components may be considered breakaway panels and need not to be designed to resist the anticipated tsunami loads but structural components (and therefore the entire structure) supporting them should be designed to effectively resist the loads transferred by such nonstructural components before they fail. Structural components are non-breakaway components and should be properly designed to resist the design tsunami load.

Debris impacts

When tsunamis propagate inland, destructive waves can carry debris such as log, vehicles, boats, vessels, shipping container, etc. creating high impact loads. Various types of tsunami-driven debris impact on structures during tsunami inundation. Several different formulas to compute impact forces are proposed. However, the computed values are in general highly dependent on each proposal. Due to uncertainties involved in the estimate of impact forces associated with waterborne debris, missing column strategy is employed in the Guidelines 2011 to minimize the possibility of progressive collapse of the structural system. Because the missing column strategy has been also employed in the Japanese Standard for Seismic Evaluation of Existing RC Buildings since its publication (JBDPA 1977) and has been widely applied to evaluate buildings throughout Japan, the progressive collapse prevention concept and its criteria are therefore well accepted by building engineers in Japan.

Scour effects

Scour around shallow foundations can lead to failure of the supported structure or structural element. In general, tsunami scour depth is difficult to predict because of the many variables that govern the scour mechanism. The current Guidelines 2011 give consideration to scour, but do not provide guidance for calculating the scour depth. To minimize the undesirable effects of scouring on the structural system, as well as of liquefaction induced differential settlement, deep concrete foundations (pile foundations) should be provided for the tsunami evacuation buildings instead of shallow foundations such as mat foundations, because of the scour potential that can occur during a tsunami. Deep concrete foundations extended well below the anticipated scour depth would be the most appropriate building support method. Concrete buildings better survived the tsunami inundation as observed in the 2011 Great East Japan Earthquake.

STRUCTURAL DIMENSION AND RESISTANCE REQUIRED FOR TSUNAMI EVACUATION BUILDINGS

The Guidelines are applied to roughly estimate the structural dimensions and resistance required for the tsunami evacuation buildings. In this example study, a multistory RC apartment house with 3.5m height in each story, which has a 12m long wall-frame system in short direction and a frame system with a resistance C_{BX} of 0.3 in terms of base shear coefficient in long direction, respectively, is investigated. Parameters are 1.5, 2.0, and 3.0 for the water depth coefficient a and 5m, 10m, and 15m for the inundation depths h, respectively. Considering different combinations of water depth coefficient a and inundation depth h, the design tsunami load is computed in accordance with the Guidelines 2011, where the example building is assumed to have an opening ratio of 0.3 (i.e., tsunami load reduction is 0.7). Then the required resistance C_{BY} in terms of base shear coefficient in short direction and the building length in long direction, are respectively computed, assuming the building is resistive enough to the overturning and lateral movement. Since building engineers in general are well familiar with seismic design but are not with tsunami design, the results are compared to the conventional seismic design procedure. Table 2 summarizes the results. It should be noted that the minimal number of stories for the evacuation building (or the elevation of tsunami refuge areas) is determined from the following equation considering possible splash-up and one story height for additional allowance for freeboard since the highest splash-up at the front face of a building during tsunami impact was 4 m in the field survey after 2011 event (IIS UTokyo 2011). In Eq. (3), the each story height is assumed 3.5m.

$$N_{min} = \text{round up}\,[\,(h + 4.0(\text{m})\,)\,/\,H\,] + 1 \tag{3}$$

where,

N_{min} : number of stories required to the building concerned,
h : design inundation depth (m),
H : story height (m) (3.5 m assumed herein).

The required base shear coefficient C_{BY} in short direction is 0.97 at maximum for h=5m (i.e., 5m deep inundation) and is 0.78 for h=10m and a=1.5, respectively, and the building can be designed in the analogous way of standard seismic design practice under these design loads. However, C_{BY} increases to 1.44 and the building should be 60m long for a=2.0, and the strength should be higher than required in the standard seismic design practice. Furthermore, C_{BY} is 2.83 for a=3.0, and foundation structures would require significantly high resistance as well as superstructure. The building requires much higher resistance for h=15m, as shown in the table.

Table 2. Required base shear coefficient C_{BY} in short direction and building length in long direction under different combinations of water depth coefficient a and inundation depth h.
(after Fukuyama and Nakano 2013)

	Inundation depth *h* (required minimal number of stories)		
	5m (4F)	**10m (5F)**	**15m (7F)**
***a*=3.0** **Short direction (12m long)** **Long direction (C_{BX}=0.3)**	◎ **C_{BY}=0.97** **40m long**	△ **C_{BY}=2.83** **36m long** **(if C_{BX}=1.0 provided)**	△ **C_{BY}=4.56** **54m long** **(if C_{BX}=1.0 provided)**
***a*=2.0** **Short direction (12m long)** **Long direction (C_{BX}=0.3)**	◎ **C_{BY}=0.38** **15m long**	○ **C_{BY}=1.44** **60m long**	△ **C_{BY}=2.42** **54m long** **(if C_{BX}=0.55 provided)**
***a*=1.5** **Short direction (12m long)** **Long direction (C_{BX}=0.3)**	◎ **C_{BY}=0.30** **9m long**	◎ **C_{BY}=0.78** **33m long**	○ **C_{BY}=1.36** **54m long**

*Each symbol denotes;
◎: Standard seismic design practice can apply,
○: Standard seismic design practice can apply but supplemental considerations are needed to increase strength, and
△: Special considerations are needed to provide enough strength to foundation structure and superstructure.

In the case study above, the building is assumed to have appropriate safety for overturning and lateral movement. A recent research (Ohta et al. 2013) proposes a simplified procedure to quick identify the most critical design condition among superstructure's resistance, overturning and lateral movement. The procedure is applied to existing RC buildings and the results point out that the resistance of overturning or lateral movement is generally less than the superstructure's resistance, and that rational schemes to effectively improve their resistance of overturning and lateral movement need to be developed.

CONCLUSIONS

Structural design requirements for tsunami evacuation buildings newly issued in 2011 as the Interim Guidelines (Guidelines 2011) are presented. The Guidelines 2011 generally follow the basic concept found in the previous BCJ Guidelines 2004 and JCO Guidelines 2005 but revisions are made based on the extensive damage surveys made by the IIS UTokyo-BRI joint team including the author. Although the tsunami pressure formula is simply expressed by the form of equivalent hydrostatic concept, the pressure can be reduced depending on the presence/absence of tsunami energy dissipation structures and the distance of the building from shoreline or riverbank. Technical comments and design considerations are also described to help engineers for practical application. However, there still remain design issues to be examined and described more quantitatively such as effects of tsunami velocity on its pressure acting on structures, those of areal ratio of openings on force reduction, forces acting on columns in open space beneath the elevated building, tsunami debris impacts, etc. Further investigations related to the above issues are still on-going for the next revision of the Guidelines.

REFERENCES

Asai, T., Nakano, Y., Tateno, T., Fukuyama, H., Fujima, K. Sugano, T., Haga, Y. and Okada, T. (2012). "Tsunami Load Evaluation Based on Field Investigations of the 2011 Great East Japan Earthquake.", *Proceedings of the 15th World Conference on Earthquake Engineering (DVD)*, September 24-28, Lisbon, Portugal.

Asakura, R., Iwase, K., Ikeya, T., Takao, M., Kaneto, T., Fujii, N. and Omori, M. (2000). "An Experimental Study on Wave Force Acting on On-Shore Structures due to Overflowing Tsunamis.", *Proceedings of Coastal Engineering*, Japan Society of Civil Engineers, 47, 911-915. (in Japanese)

Fukuyama, H. and Nakano, Y. (2012). "Structural design requirement on the tsunami evacuation buildings.", *structure*, No. 123, JSCA(Japan Structural Consultants Association), 50-53. (in Japanese)

IIS UTokyo/Institute of Industrial Science, The University of Tokyo (2011). "Interim Report of the Building Standards Improvement Project No. 40, *A Study on Improvement of Building Standards in Tsunami Hazard Areas."*, http://www.mlit.go.jp/common/000172791.pdf (interim report) and 000172792.pdf (interim report part2). (in Japanese)

JBDPA/The Japan Building Disaster Prevention Association (1977, 1990, and 2001(in Japanese) and 2005 (in English)). "Standard for Seismic Evaluation of Existing Reinforced Concrete Buildings."

JCO/Task Committee under the Japanese Cabinet Office (2005). "Design Guidelines for Tsunami Shelters." (in Japanese), http://www.bousai.go.jp/oshirase/h17/050610/guideline.pdf

MLIT/Ministry of Land, Infrastructure, Transportation and Tourism (2011). "Interim Guidelines on Structural Requirements for Tsunami Evacuation Buildings Considering the Great East Japan Earthquake.", *Annex to the Technical Advice*, MLIT, Housing Bureau, Building Guidance Division, No. 2570, Nov. 17, 2011.

Nakano, Y. (2007). "Design load evaluation for tsunami shelters based on damage observations after Indian Ocean Tsunami disaster due to the 2004 Sumatra Earthquake.", *Journal of Architecture and Building Science*, Architectural Institute of Japan, **13: 25**, 337-340. (in Japanese)

Nakano, Y. (2008). "Design load evaluation for tsunami shelters based on damage observations after Indian Ocean Tsunami disaster due to the 2004 Sumatra Earthquake.", *Proceedings of The 14th World Conference on Earthquake Engineering (CDROM)*, Paper ID 15-0008, October 12-17, 2008, Beijing, China.

NILIM/National Institute for land and Infrastructure Management (2012). “Commentary on Structural Requirements for Tsunami Evacuation Buildings.” (in Japanese), http://www.kenchiku-bosai.or.jp/seismic/tsunami_text.html

Ohta, T., Sakuta, J., Mochizuki, S., Yanagi, T., Choi, H., And Nakano, Y. (2013). “Fundamental Study on Simplified Estimation of Tsunami Resistant Capacity of Reinforced Concrete Buildings (Part1. Feasibility Study on Tsunami Capacity of Existing Buildings and Part2. Verification of Simplified Estimation).”, *Summaries of technical papers of Annual Meeting*, Architectural Institute of Japan, Structures IV, 649-652. (in Japanese)

Okada, T., Sugano, T., Ishikawa, T., Ogi, T., Takai, S. and Hamabe, T. (2004a). “Structural Design Method of Building to Seismic Sea Wave.”, *No. 1 Preparatory Examination. Building Letter*, The Building Center of Japan. (in Japanese)

Okada, T., Sugano, T., Ishikawa, T., Ogi, T., Takai, S. and Hamabe, T. (2004b). “Structural Design Method of Building to Seismic Sea Wave, No. 2 Design Method (a Draft).” *Building Letter*, The Building Center of Japan. (in Japanese)

Okuda, Y. and Sakata, M. (2008). “Simulation of Tsunami on a Building part 2: Effects of Openings of a Building.”, *Summaries of technical papers of Annual Meeting*, Architectural Institute of Japan, B-1, Structures I, 77-78. (in Japanese)