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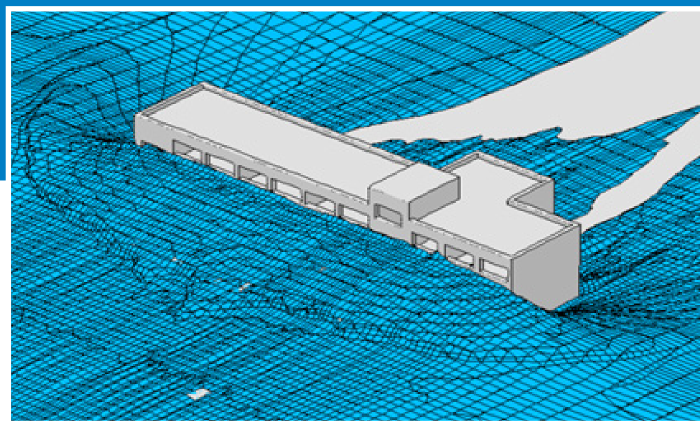

# Proceedings of the First ACI & JCI Joint Seminar: Design of Concrete Structures Against Earthquake and Tsunami Disasters


Editors:
Kyuichi Maruyama and Andrew W. Taylor


SP-313


American Concrete Institute
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The papers in this volume have been reviewed under Institute publication procedures by individuals expert in the subject areas of the papers.



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## Preface

The First American Concrete Institute (ACI) and Japan Concrete Institute (JCI) joint seminar was conceived as a vehicle for promoting collaboration and cooperation between two organizations that are dedicated to the global advancement of concrete technology. In September 2012 ACI President James Wight, and ACI Executive Vice President Ronald Burg, visited the headquarters of JCI and discussed ways to promote collaboration between ACI and JCI with JCI President Taketo Uomoto and JCI Executive Directors. A joint ACI and JCI technical seminar was proposed as a way to share knowledge and foster collaboration between the two organizations. Subsequent discussions between Ronald Burg and JCI Executive Director Kyuichi Maruyama led to a joint seminar planning meeting, held at the ACI convention in Minneapolis, Minnesota, in April 2013.

This volume contains the technical papers presented at the First ACI & JCI Joint Seminar, held in Waimea, Island of Hawaii, Hawaii, July 16 to 18, 2014. The theme of the joint seminar was "Design of Concrete Structures Against Earthquake and Tsunami Disasters." Five papers were presented by authors from ACI, and five papers from JCI. Three papers are related to tsunami loads and structural design requirements, and seven are related to seismic analysis and design.

The three papers on tsunami effects included a summary by Nakano of structural design requirements for tsunami evacuation buildings in Japan; an overview by Chock of the new tsunami load and design requirements in the United States; and a study by Maruyama et al. on the evaluation of tsunami forces acting on bridge girders.

The seven papers on seismic effects addressed topics ranging from seismic design standards to innovative methods of construction for seismic retrofit. Parra-Montesinos et al. presented the results of experiments on fiber-reinforced coupling beams, as well as design guidelines. Teshigawara discussed JCI contributions to the ISO Standard for seismic evaluation and retrofit of existing concrete structures. A summary of a project on the use of high-strength reinforcement for seismic design was presented by Kelly et al., including findings that are based on extensive prior research on high-strength reinforcement in Japan. Shiohara described the results of a study that supports the new Architectural Institute of Japan (AIJ) Standard for Seismic Capacity Calculation, with a focus on beam-column joints and collapse simulation. Matamoros presented a study of factors that affect drift ratio at axial failure of nonductile reinforced concrete buildings. A study of the seismic response of reinforced concrete bridge piers, including the effects of interaction between piles and soil, was presented by Maki et al. Finally, French et al. discussed an overview of lessons learned from laboratory testing of reinforced concrete shear walls.

The day after the joint seminar a meeting was held between ACI and JCI officials to discuss future collaboration and joint seminars. Representing ACI were President William E. Rushing, and the ACI Executive Vice President, Ronald Burg. Representing JCI were President Hirozo Mihashi, and Chair of the JCI Committee on JCI-ACI Collaboration, Kyuichi Maruyama. It was resolved to hold a second joint seminar, to be hosted by JCI in Tokyo, in conjunction with the 50th anniversary celebrations of the founding of JCI on July 13, 2015. In addition, subsequent discussions between ACI and JCI led to plans for the third joint seminar, to be hosted by ACI at the ACI Convention in Anaheim, California, in October 2017.

It is hoped that this collection of papers will serve to advance the state of analysis and design of concrete structures against earthquakes and tsunamis in both the United States and Japan, and that it will serve as a model for future collaboration between ACI and JCI.

Kyuichi Maruyama
JCI Co-Editor

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# Structural Design Requirements for Tsunami Evacuation Buildings in Japan

**Yoshiaki Nakano**[1]

**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

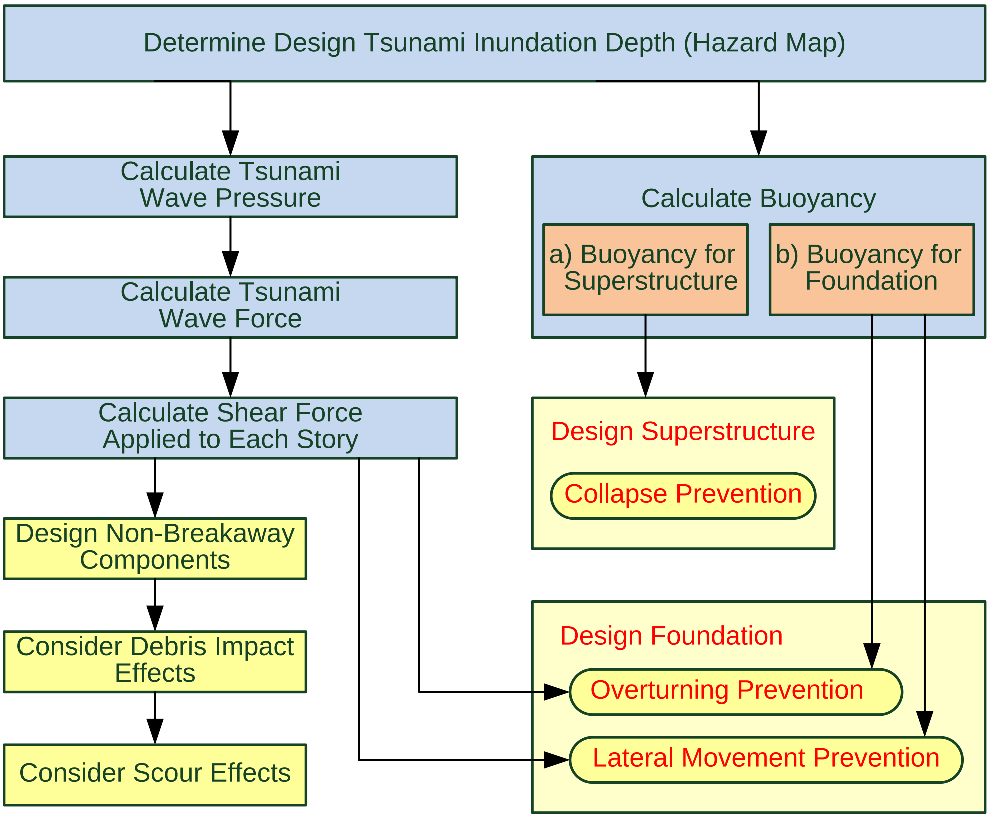


Figure 1. General structural design procedure. (after NILIM 2012)

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.

$$q_z = \rho\, g\, (a\, h - z) \qquad (1)$$

where,

- $q_z$ : intensity of tsunami pressure at height $z$ (kN/m$^2$),
- $\rho$ : 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 ($0 \le z \le a\,h$) (m).

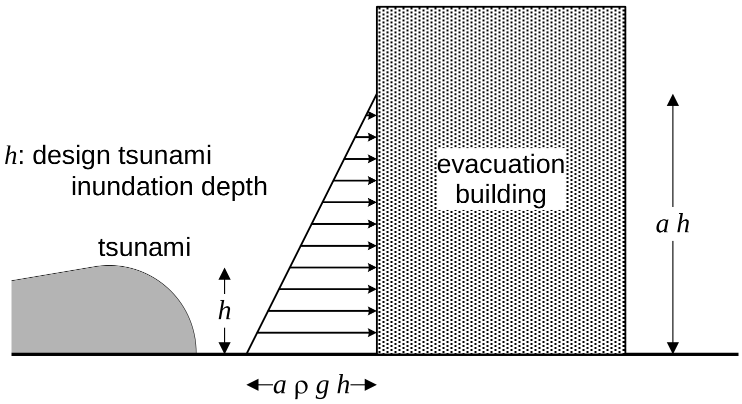


Figure 2. Design tsunami pressure distribution.

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)