International Research Journal of Advanced Engineering and Science
ISSN (Online): 2455-9024

Mitigation of Tsunami Environmental Implications on Nuclear Facilities through Improvement of Seawall Design

N. M. Sirag
Egyptian Nuclear and Radiological Regulatory Authority

Abstract*— The preservation of man and the environment is one of the most important principles to be taken into consideration when designing a nuclear project. Therefore, the first objective of environmental design is to mitigate the effects of natural disasters on nuclear facilities. The tsunami is one of the most important environmental threats to nuclear plants built on sea coast. Therefore, the aim of this research is to study the environmental design of the sea wall as the first line of defense against the tsunami. On the base that the sea wall that protects the nuclear plant should be considered as a part of nuclear facilities design.*

This paper aims at studying criteria for seawalls design, history of sea defense design standards, and explaining the process of revision of design guidelines. A discussion of international approaches and their application to nuclear power plants is also provided.

Keywords— *Environmental Engineering - Architectural Design for Nuclear and radiological installation.*

I. INTRODUCTION

After tsunami event, much of the world's effort concentrated on protecting nuclear power plants against such events. Sea defense walls are curved coastal barriers that block the tsunami waves from flooding the area with water at power plant areas and redirect wave energy back towards the sea. The tsunami event has led to rethinking and revising the regulations of design for sea defense structures, and design codes. The new guidance emerging from this process is a valuable resource for other countries that tend to re-evaluate their own current environmental mitigation implications strategies.

Old concepts of seawall design have been revised and based on its concept, aiming to minimize damage, at the very least, protecting human lives. The seawall concept tends to restrict the quantity of water flowing into the area behind the nuclear installation, delaying the arrival of the tsunami behind the building structure. Hence, designs that can provide this toughness are necessary. 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. However, there are plenty of communities where people simply cannot evacuate in time, and constructing tsunami seawall defense buildings at strategic locations is, therefore, a vital means to effectively mitigate human damage.

To design and construct buildings resistant to tsunami loads, quantitative evaluations of tsunami load applicable to structural design is most essential. This paper presents the outline of the structural requirements for tsunami buildings stipulated. The relationships between structural size, required lateral strength, and tsunami inundation depth is also studied and discussed in the present study. Defense in Depth is a safety philosophy that guides the design, construction, inspection, operation, and regulation of all nuclear facilities. The central tenet of Defense in Depth is to protect the health and safety of the public and plant workers. The definition of a tsunami resistant design is stipulated to unlikely occur during the design service life of the facility, but would have severe impacts on the facility if it did occur, and it is appropriately set based on the degree of importance of the facility.

What is Defense in Depth?

The objectives of defense in depth include protecting the environment and ensuring the operational readiness of the facility. Successful Defense in Depth requires creating, maintaining, and updating multiple independent and redundant layers of protection for humans. Defense in Depth is implemented through a number of measures, including robust physical barriers, redundant and diverse safety systems, strong physical security, and emergency response readiness.

Shock waves that reverberated around the nuclear industry following the Fukushima Daiichi nuclear catastrophe urged designers to consider these risks. Waves can both push into the beach from the sea and drag back into the ocean or sea. Typically, a mound or hill of the berm builds up along the shoreline. At high tide, this is the only part of the beach that is above water, so the beach slope appears quite steep. As waves push into the shoreline, they erode a flat area in front of the berm called the “low tide terrace.” At low tide, this flat area is exposed, and the beach appears less steeply sloped (seen Figure 1).

Basic Concepts for the Design Criteria of Seawalls

The standard requires that the tsunami should be determined by either numerical analysis or on the basis of the history of the tsunami, the larger value is selected. This approach is in a sharp contrast to what was common in the 20th century where structural design had apparently been based upon tsunami magnitudes experienced. As for sea defense structures, seawalls specifically are designed to afford sufficient protection to coastal nuclear power plants and critical infrastructure. Seawalls, some of which were of 10 m or more in height, were built as a result of previous tsunamis to provide protection.

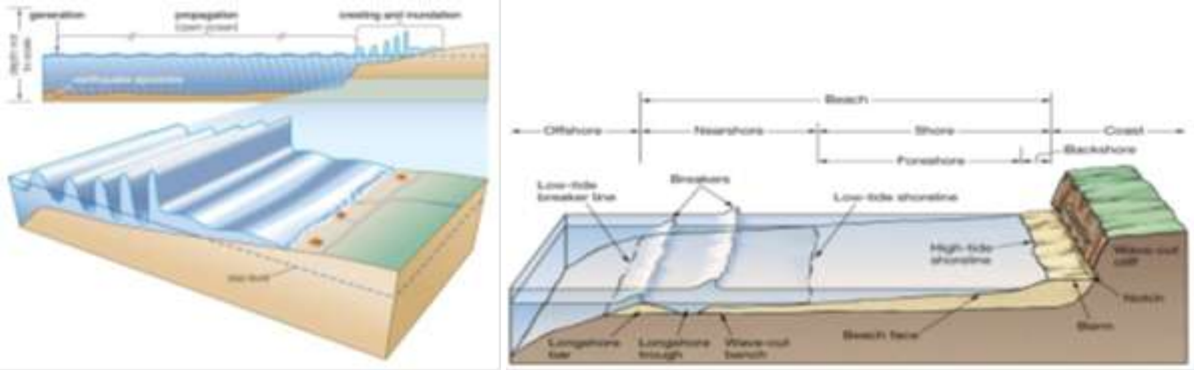


Figure 1. The Feature of the Beach Profile
Generation Process of tsunami waves. source: (IOC 2008)

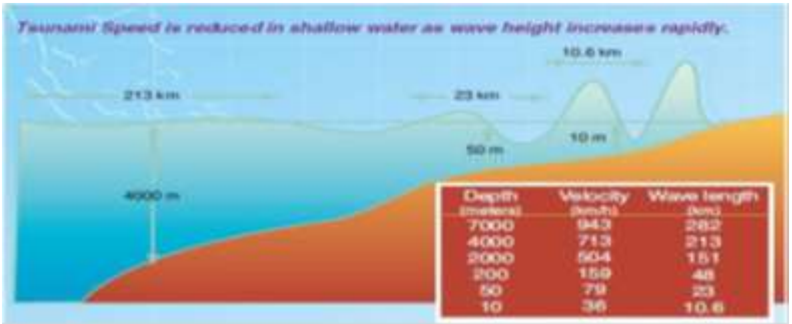


Chart Figure 1. of the relation between different tsunami characteristics. source: (IOC 2008)

*****These prescribe the re-quired technical criteria that should be applied in the construction, renovation or maintenance of facilities [65](S. Takahashi, M. Mizuguchi, Y. Goda, Japanese technical standards for mar-itime facilities, Proceedings of Coastal Structure, '99, vol. 2, 1999, 1049–1058.)

Description characteristics

Construction of hard structures such as seawalls barriers are hard defense structures which are built parallel to the shoreline in coastal areas which are subjected to erosion due to sliding of soil as a result of high wave action and coastal flooding. The physical form of these structures is highly variable; seawalls can be vertical or sloping and constructed from a wide variety of materials. They may also be referred to as revetments. Seawalls are frequently used in locations where further shore erosion will result in excessive damage, most are continually under severe wave stress. Seawalls usually have a deep foundation for stability. Seawalls vary in type and may include steel sheet pile walls, monolithic concrete barriers, rubble mound structures, brick or block walls or gabions (wire baskets filled with rocks). Some typical seawall designs are shown in Figure 2. Seawalls are typically, heavily engineered, inflexible structures and are generally expensive to construct and require proper design and construction supervision (UNFCCC, 1999).

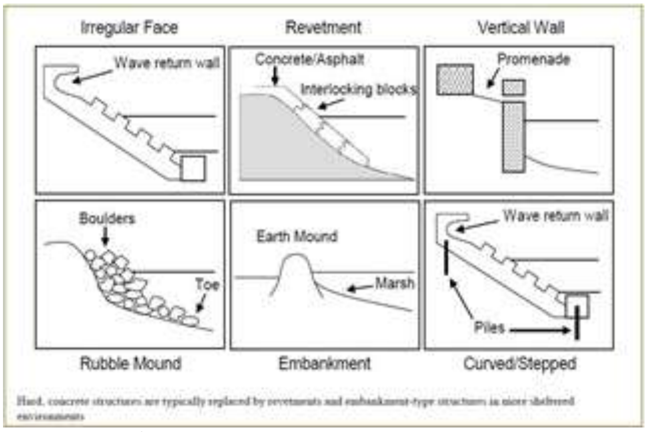
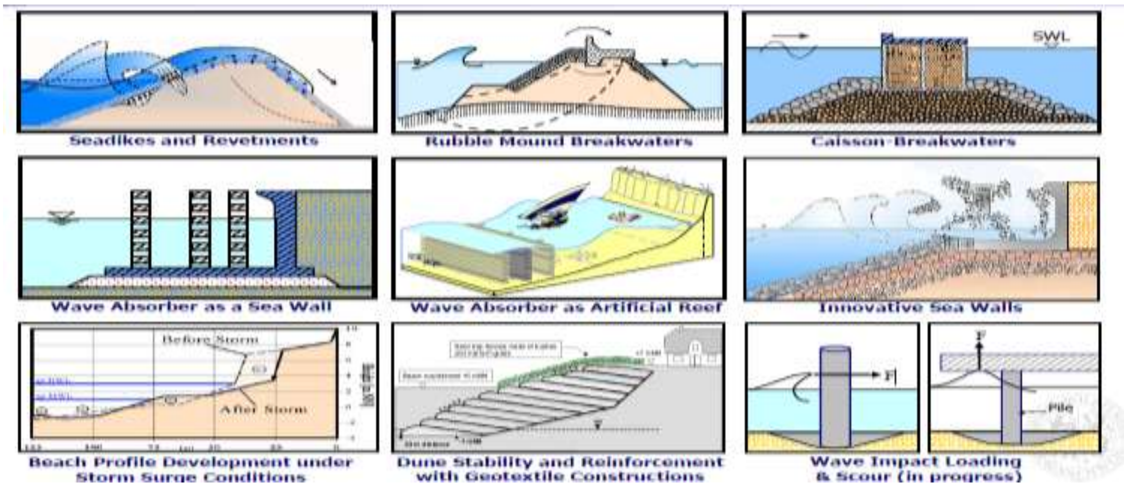


Figure 2: Variation in design types of seawalls. Source: Adapted by Linham and Nicholls (2010) from French, (2001)

From the above structures rubble mounds constructed using granite boulders is the commonest in Sri Lanka. However, during the tsunami, they did not protect the coastal infrastructure within the coastal belt, Plate 1. Therefore, revetments, vertical walls and the seawalls with irregular face with a wave return wall would be the hard defense structures that could be considered as the most suitable designs for coastal belts that need protection against high wave action and storm surge.



Furthermore, as indicated in the Figure 2, if seawalls could be coupled with soft barriers and such soft barriers could be artificially transplanted within the irregular depressions on the hard defense structures or if they could be designed to give a terraced appearance, such structures will enhance the effect of hard structures against wave action.

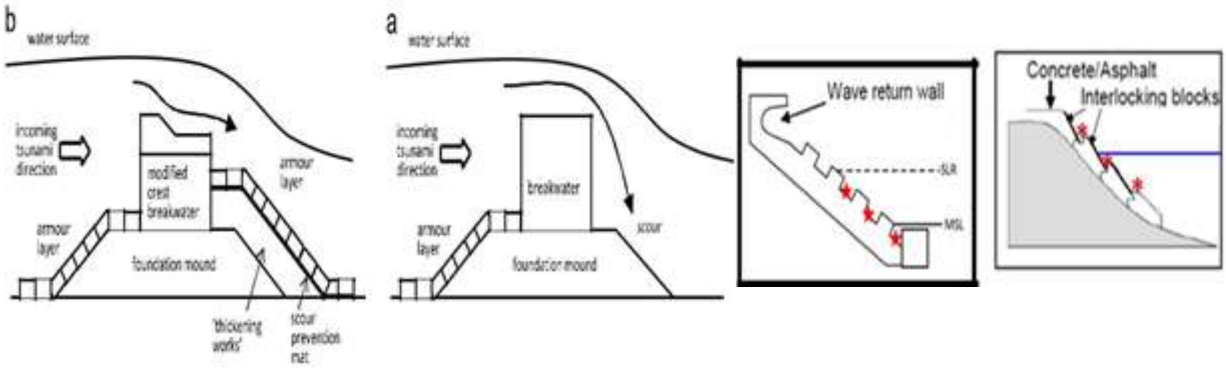


Figure 3: Modified drawing of a seawall with a structure that helps the return of the waves

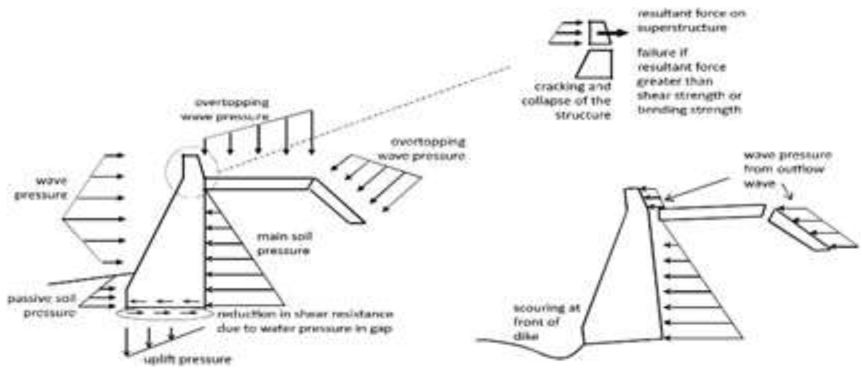


Figure 4: Caisson breakwater section (a) former design (b) recommended design for a ‘strong breakwater' able to resist a tsunami beyond the design height (based upon [44]).

Types of Seawalls

Seawalls are engineering coastal defense structures which are designed to protect the coast against tsunami. The design of seawall depends on various physical or specific local conditions such as coastal position or available spaces, appropriate forms or types of the seawall structure (fig. 1) The most common materials used for seawalls construction are: reinforced concrete, steel, gabions or boulders, which can withstand the massive force of waves' energy.

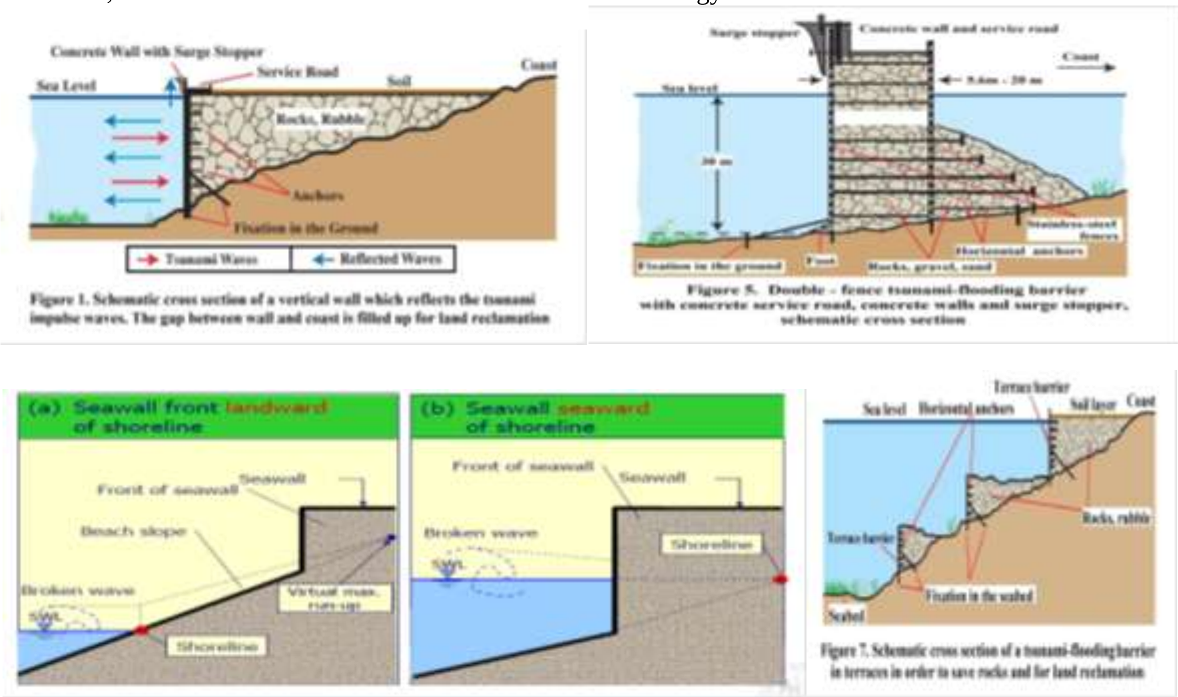


Figure 5: Loading diagram of sea dikes (translated from [43]).

1. Vertical Wall

The vertical wall type, as its name indicates, is designed to protect the shore with vertically standing wall. The major advantage of this type is that it requires less space compared to other types of seawalls. Moreover, this type of wall is relatively simple to design and construct. On the contrary, due to its verticality, it is less efficient in dissipating waves' energy and thus, it is prone to suffer damages in short period. Furthermore, the clapotic waves (vertical movement of waves) can erode the toe of the wall. The curved form could help to mitigate these aspects and provide the enhanced protection for the toe of the wall.

2. Sloping Wall

Sloping or stepped seawalls are designed to dissipate more efficiently the waves' energy compared to the vertical wall type. It typically requires more spaces (20-40m) and materials to construct this type of wall. However, there are usually flat area on top of the slopes and people could usually access and walk on that space.

3. Mound

This type typically uses heavy chunk of rocks such as granite, lime stones or other materials such as concrete blocks to protect shorelines against tides or erosion. This type takes the form of riprap or revetments and is suitable for less demanding setting where lower energy and erosional processes are expected. Due to the porosity between rocks, it can filter through the water after dissipating the wave energy. This option has a great advantage in the cost and the simplicity of design and engineering process. In general terms, a breakwater refers to a structure in a harbor which is designed to mitigate the coastal erosion and to break the force of wave action to provide safe harborage for vessels.

***** *1. GeoResources. (2001) Coastal management. Retrieved online 18 April 2011 from: http://www.georesources.co.uk/coastman.htm*
2. Clarke, J R. 1994. Integrated Management of Coastal Zones. Fao Corporate Document Repository, USA.
3. Beer, Tom (1997). Environmental oceanography. Boca Raton: CRC Press. p. 44.

1. Unlike a natural harbor which is protected by its topographic features such as headlands or reefs, an artificial harbor needs a breakwater to ensure the safe and calm berthing. While a seawall structure is constructed onshore along the shoreline, a breakwater is built inshore shallow waters. Typically, one end of a breakwater is attached to the shore, but it could also be detached up too few hundred meters from the shoreline.

Besides the ordinary roles mentioned above, a breakwater can also play an important role in the context of disa-ster mitigation, especially associated with tsunami. For instance, it was recognized that the breakwater inshore in Kiamichi port in Iwate Prefecture, which was constructed as the deepest harbor breakwater in the world (63m), did actually alleviate the tsunami disaster on March11, 2011. According to this simulation, the tsunami height would have been 13.7m if there were no breakwater, whereas it was actually 8.1m thanks to the mitigation effect of the breakwater. Furthermore, the time the tsunami wave needed from the observation point at 20km offshore to the overtopping of seawall at the coastline was 34 minutes in the actual case with the breakwater, while it would have been 28 minutes if there were no breakwater. The 6 minutes difference could be critical for

people to gain extra time for the eventual evacuation. Although the degree of this effect may vary depending on the particular site conditions, the effect of a breakwater, as one layer of disaster prevention, should be further studied and taken into consideration.
Fig. 1 Tsunami mitigation effect of breakwater

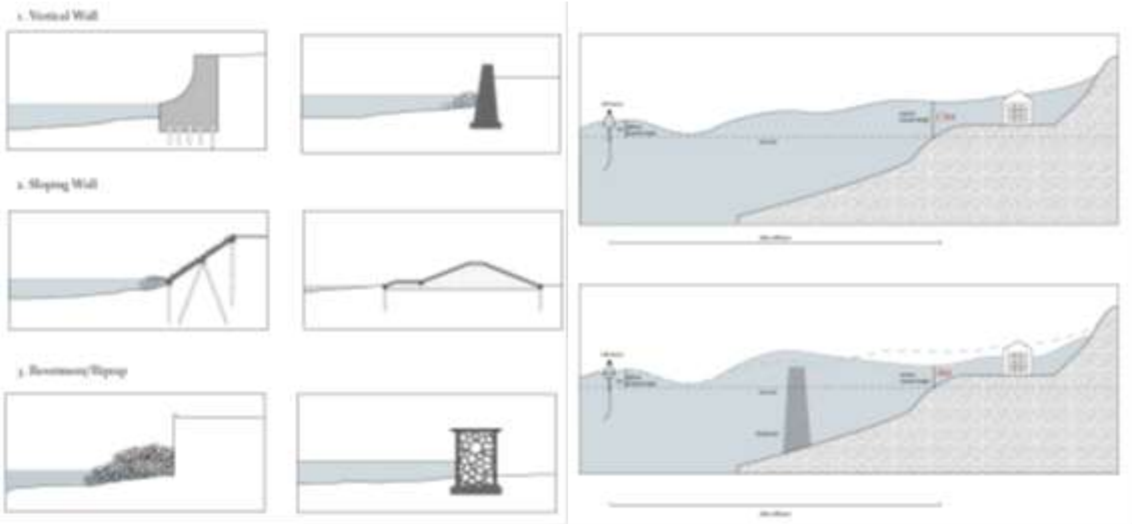


Figure 6,7 source: Ministry of land, infrastructure, transport and tourism, http://www.mlit.go.jp/hakusyo/mlit/h22/hakusho/h23/html/k1112ce0.html

Types of Breakwater

In principle, a breakwater structure absorbs the wave action in similar fashion as a seawall, either by resisting with the mass (e.g., typically with caissons), or by dissipating with the slope or with the interlocking blocks (e.g., with concrete or rock armor units). The following are 4 major types of permanent breakwater structures:

1. Caisson Type

A caisson is a large watertight chamber typically made of concrete. A caisson breakwater uses the mass of the caisson and the infills to resist the overturning forces of the waves. The sides of the caisson are usually vertical and vessels can be berthed on the inner side of the breakwater. The caisson is placed either on a rubble foundation (which could be sloped to dissipate the wave energy) or other type of thin bedding layer. The construction, caisson type is relatively more expensive to construct in shallow water, whereas it can offer a significant saving over revetment type in deeper water due to saving materials.

2. Stacking Concrete Block Type

This type uses a series of concrete mass blocks which are then vertically stacked one upon another. As is the case in the caisson type, this is also based on the principle of mass to resist the waves' energy and it usually has vertical sides to allow vessels to anchor in the harbor.

3. Wave Dissipating Block Type

There are many different forms of wave-dissipating blocks which are designed to dissipate the force of incoming waves. The significant difference in comparison with the previous two types is that it allows water to flow through the pores of the interlocking block elements rather than resisting it. In Japan, the word "tetrapod" is often recognized as a generic name for wave-dissipating blocks regardless of their shapes. It is estimated that almost 50 percent of Japan's 35,000 kilometer coastline has been covered by Tetrapod's and other forms of concrete blocks.

4. Combination Type

Keeping the basic principle (resist/dissipate) in mind, there could be many more variations of breakwater by combining two or more elements of those mentioned above. For instance, the wave dissipating block could be used in combination with the caisson to further enhance the performance of the breakwater.

Movable Breakwater

Besides the permanent breakwater types mentioned above, there are also some exceptional types which can be put in operation only when tsunami actually arrives. Despite the fact that those types are not yet widely in use, it is worth mentioning the upcoming technologies and its potential in the disaster prevention. The following are two different types of such leading-edge movable types of breakwater.

1. Vertical Telescopic Type (fig.9)

The basic idea behind this type is that a breakwater can be "activated" and raised only in the event of tsunami or storm surge. The vertical telescopic breakwater (VTB), as its name indicates, works as a telescopic structure and it is comprised of lower and upper steel piles. The upper pile is operable and can be raised or lowered into the lower pile. The upper piles are aligned so as to provide a wave barrier. Since the diameter is slightly larger for the lower piles, small gaps of few centimeters remain in the upper piles. The lower piles, which are installed in the seafloor, are linked to air pipes from an air supplying facility on land. Air supply is provided to the inside of the upper piles and the upper piles begin to move upward when the internal air pressure in the piles surpasses the weight of the piles. To lower the piles back, it is necessary to vent the air from the upper piles from the exhaust valve installed at the top of the piles.

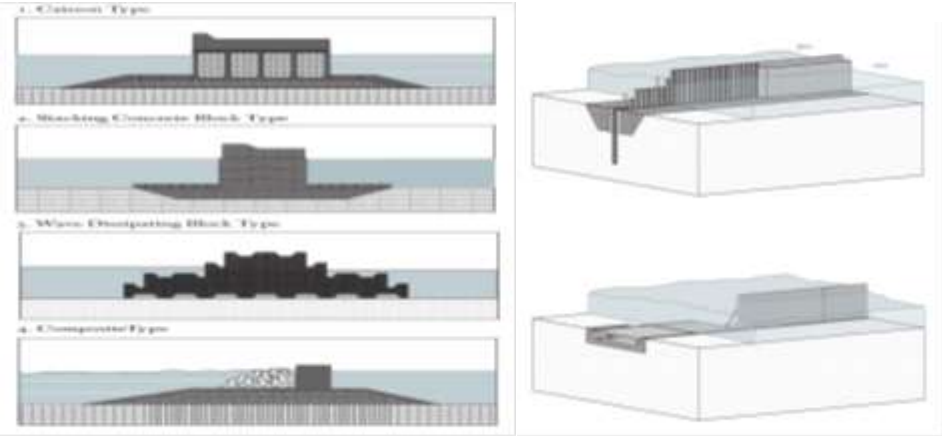


Figure 8: Breakwaters with vertical and inclined concrete walls

** 1. Burcharth, HF 2003, Breakwaters with Vertical and Inclined Concrete Walls: Report of Working Group 28 of the Maritime Navigation Commission. PIANC General Secretariat, Brussels.*
2. Nagi M. Abdelhamid, Design of Breakwater, http://www.unimasr.net/ums/upload/files/2013/Mar/UniMasr.com_d62d82175df 7542f 23f 6483f 962c2538.pdf
3. Stephen Hesse, "Loving and Loathing Japan's Concrete Coasts, Where Tetrapods Reign", The Japan Times on July 22, 2007.

2. Flap Gate Type

The flap gate breakwater is another new type structure for coastal disaster reduction. In common with the vertical telescopic type, it lies on a seafloor under normal conditions, but lifts up with buoyancy when a tsunami or storm surge actually occurs. It is made up of a series of doors along the seafloor which are rotated and lifted up to form a continuous wave barrier. It serves for two purposes; as a breakwater for tsunami or in flood disaster mitigation by controlling water level change and as a breakwater designed to ensure the calmness of the berthing. The flap gate operates by a hydraulic cylinder positioned underneath the gates. These two movable types of breakwater could be an interesting alternatives for the tsunami disaster prevention where there is a dispute concerning the visibility of the ocean. Unlike the permanent vertical wall, it does not interrupt the view under normal condition and the physical continuity from the land to the ocean can be maintained.
Direction of the axis of the breakwaters

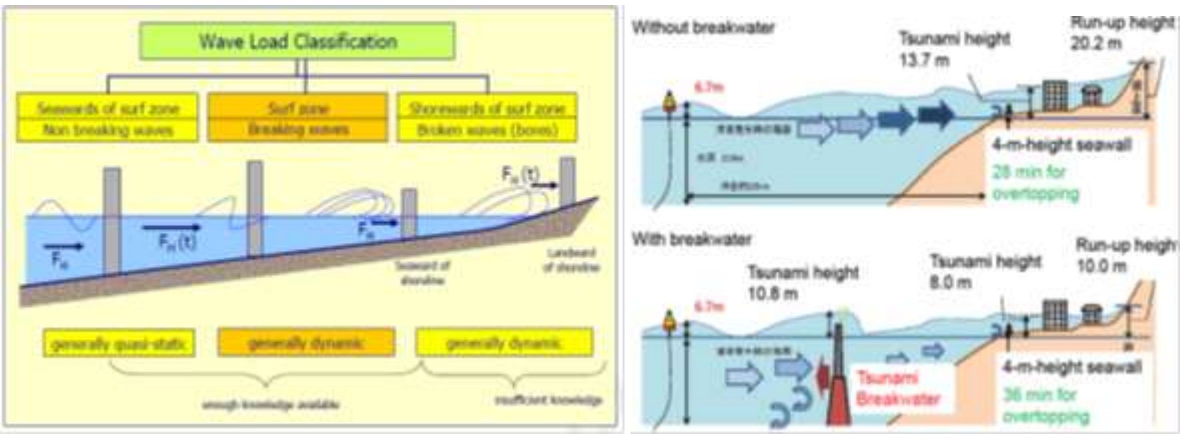


Figure 9: Tsunami impact reduction performance of the Kamaishi breakwaters (PARI, 2011)

The blocks rose 6 m above sea level and were designed to protect the city from a 5.6 m high tsunami. A tsunami height of 6.7 m was measured at a GPS station in Kamaishi Sea. On the basis of these data, two simulations were performed for cases with and without breakwaters (PARI, 2011). The results reveal thatthe height (mean sea level, MSL) of the tsunami was 10.8 m in front of the blocks and 2.6 m behind the blocks.Therefore, the blocks helped to reduce the tsunami height by 8.2 m (Figs. 9). With regard to inundation by the tsunami, the breakwaters reduced the tsunami height (at the shoreline) from 13.7 to 8.0 m and reduced the runup height from 20.2 to 10.0 m (PARI, 2011). Because of the strong current in the 30 cm spaces between the blocks, the rock foundation was damaged. Eventually, *70 % of the blocks were destroyed.

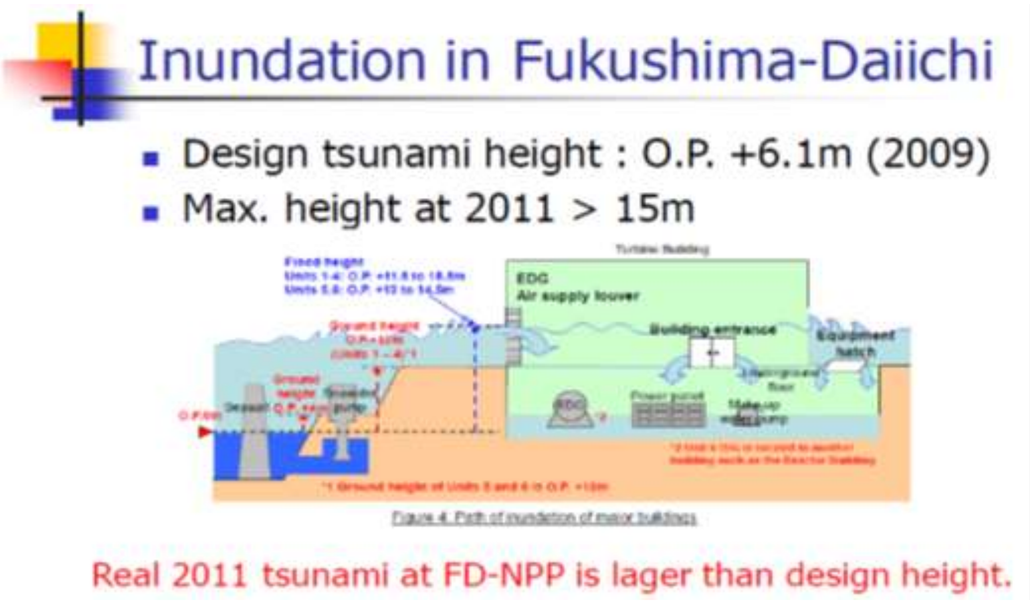
Design Principles Guidelines

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.

Tsunami Force Acting on Components

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.

The tsunami wave force can be calculated by integrating its acting pressure 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. That 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. 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, It should be noted that tsunami waves have much longer periods than earthquake shakings and tsunami evacuation buildings should.



Recommendations for Design Requirements

- Coast conservation department should collaborate with engineers and marine scientists from research & academic institutions when designing most suitable defense structures.
- design criteria should be made available for research on construction of seawalls and revetments with suitable designs to accommodate barriers and to explore the possibilities of using low cost, however strong constructions which could stand the forces of tsunami waves.
- When establishing a nuclear plant on the coast, consideration must be given to studying the nature of the region and the history of natural disasters.
- Engineering studies of different designs of appropriate seawalls for the project site

- Applying the most important standards of environmental engineering design of seawalls of the defense line in terms of potential distance from the plant, appropriate height, angle of inclination and suitable and available building materials.
- Observe and balance in design between the strength and height of potential waves with the angle and height of seawall inclination

II. CONCLUSIONS

Structural design requirements for tsunami Seawall newly issued in 2011 as the Interim Guidelines (Guidelines 2011) are discussed. The Guidelines of 2011 generally follow the basic concept found in the previous BCJ Guidelines 2004 and JCO Guidelines 2005. However, there are still design issues to be examined and described more quantitatively such as effects of tsunami velocity on its pressure acting on structures, etc.

After this study for criteria seawalls design, history of sea defense design standards and new criteria very simply and widely applicable. Further investigations related to the above issues are still on-going for the next revision of the Guidelines.

REFERENCE

[1] Implications ofthe2011GreatEast JapanTsunamionseadefencedesign Alison Raby a,n, JoshuaMacabuag b, AntoniosPomonis c, SeanWilkinson d, Tiziana Rossetto.
[2] Formation of Beach Profile with the Design Criteria of Seawalls Edward Ching-Ruey LUO Department of Civil Engineering, National Chi-Nan University.227 Gan-Cherng St. Taichung 40843, Taiwan *Corresponding Author: edward.luo@msa.hinet.net
[3] Tsunami-Resistant Design Guideline for Breakwaters, KOIZUMI Tetsuya, Director, Port and Harbour Departmen
[4] T. Arikawa, M. Sato, K. Shimosako, I. Hasegawa, G.S. Yeom, T. Tomita, Failure mechanism of Kamaishi breakwater due to the Great East Japan Earthquake Tsunami, in: Proceedings of the 33rd International Conference on Coastal Engineering, Santander, 2012.
[5] T. Arikawa, K. Shimosako, Failure mechanisms of breakwaters due to tsunami; a consideration to the resiliency, in: Proceedings of the 6th Civil Engineering Conference in the Asia Region, Jakarta, August 2013.
[6] O. Aydan, An overview of the M9.0 earthquake off the Pacific Coast of Tōhoku region of Japan on March 11, 2011 and its lessons, Tokai University, Shizuoka, Japan, 2011 (July 27, 2011) http://www.jsce.or.jp/committee/eec2/eq_report/ 201103tohoku/aydan1.pdf.
[7] A. Bradbury, J. Rogers, D. Thomas, The Toe Structures Management Manual, Environment Agency, Bristol, U.K, 2012.
[8] H.F. Burcharth, S.A. Hughes, Types & functions of coastal structures, in: S. Hughes (Ed.), Coastal Engineering Manual, Part VI-2, Design of Coastal Elements, Engineering Manual EM 1110-2-1100, U.S. Army Corps of Engineers, Washington, DC, 2002.
[9] F. Camfield, Tsunami Engineering, US Army Corps of Engineers, Special Report No. 6, Coastal Engineering Research Center, 1980.
[10] CCEJ, Design Manual for Coastal Facilities, Out of print but front cover shown at: ⟨https://www.jsce.or.jp/publication/e/book/p474.html⟩, 2000 (May 29, 2014).
[11] S.J. Day, C.J. Fearnley, Destructive interactions between mitigation strategies and the causes of unexpected failures in natural hazard mitigation systems, in: AGU Fall Meeting, vol. 1, p. 1759 (Abstracts).
[12] eDF, Hinkley Point C: Somerset Chamber Business Breakfast, October 11, 2012. ⟨http://www.hinkleysupplychain.co.uk/wp-content/uploads/2010/12/Somerset-Chamber-Abbey-Manor-11th-October.pdf⟩, 2012, (June 27, 2014).
[13] eDF, Hinkley Point C FAQs. ⟨http://www.edfenergy.com/energy/nuclear-new-build-projects/hinkley-point-c/faq⟩, 2014 (June 25, 2014).
[14] EEFIT, Recovery Two Years After the 2011 Tōhoku Earthquake and Tsunami: A Return Mission Report by EEFIT. ⟨http://www.istructe.org/webtest/files/23/ 23e209f3-bb39-42cc-a5e5-844100afb938.pdf⟩, 2013.
[15] 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)
[16] 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)
[17] 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.
[18] 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
[19] 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)
[20] 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)
[21] 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)