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CONSIDERING TSUNAMI LOAD EFFECT IN THE PHILIPPINES

Reynaldo Velasco
Onshore Structural Engineer, Fluor Corporation, Philippines
reynaldo.velasco@fluor.com

Alexander Gutierrez
Onshore Structural Engineer, Fluor Corporation, Philippines
alexander.gutierrez@fluor.com

Medeline Pangilinan
Onshore Structural Engineer, Fluor Corporation, Philippines
medeline.pangalinan@fluor.com

Ferdinand Loren
Offshore-Structural Engineer, Fluor Corporation, Philippines
ferdinand.loren@fluor.com

ABSTRACT: The Philippines being composed of several islands are often exposed to tsunami hazards along its coastline and its adjacent vicinity. Due to the unusual load and lack of data to such event, many civil-structural engineers generally focus their attention on wind and earthquake loading forces. In addition, the distinction between onshore and offshore structure added to the notion that such forces of the sea should be dealt with by the offshore discipline or ports and harbor engineers. However, at this point of time, we have seen events where the sea is encroaching aggressively beyond its boundaries in the form of tsunamis; exposing onshore structure helplessly without the appropriate resistance. In this regard, the need to design the onshore structure exposed to the tsunami event should now be part of the onshore civil-structural engineering scope. The paper intends to show some recommended hydrodynamic load equations due to the load effect of the tsunami. It also wanted to create awareness of the ASCE/SEI 7 Standards Committee of their proposed new Chapter 6, providing guidelines in the application of tsunami loads on its 2016 edition. In addition, the paper encourages the use of the, "Tsunami Hazard Map" prepared by PHIVOLCS (Philippine Institute of Volcanology and Seismology) and DOST (Department of Science and Technology) within the Philippine setting. Although some area on the map may impose a "no build zone", building code update considering the tsunami load effect may mitigate such restriction along coastal areas.

1. Introduction

A near - shoreline structure such as permanent buildings were built under the understanding that only wind and earthquake are among the major loads that can affect the strength and integrity of the structure during a catastrophic event. Wave action of the sea, which is often times, relates to coastal protection structures such as breakwaters, seawalls and revetment were assigned to the technical expertise of the ports and harbor engineers. Structural engineers for buildings in the Philippines are mostly not aware that tsunami load effect or the hydrodynamic load effect of a tsunami can be a major load against a building structure. This premise was based on the lack of regulatory code in the building code mentioning the consideration of tsunami loads under a tsunami-prone coastal area. In addition, the occurrence of tsunami is very rare event in the Philippines, which may occur again for several hundreds of years in which case local people in a certain town may have forgotten such history and completely ignore its possible return in the future. However, the Philippines are composed of several thousands of islands; such dangerous event with small probability of occurrence cannot be simply ignored.

One of the well-known tsunami events in the Philippine history is the, "Tsunami of 1735" at Baler in Aurora province. A narration by Jose Maria A. Cariño in her "Baler during the Spanish Occupation" found in the General Information on the website *www.aurora.ph,* narrates the following: **"**The current site of Baler is no longer the original site of the town as founded by Father Blas Palomino. During the event of December 26 and 27, 1735, two Franciscan priest, Father Lucas de la Resurreccion and Father Jose de San Rafael, witness the terrible event as they described, 'Having started at around nine in the evening, a great storm occurred with bolts of lightning and thunder and a great abundance of water, such that in less than five hours it sank and inundated all the outskirts of the town. The amount of water was such that when it reached the floor of the convent, and having flooded all the houses, the water exploded in the middle of the town at two in the morning. The wave carried out the town center to the sea, houses, convent and church became part of the coconut plantation that existed in the southern portion of the town near the kitchen of the convent' ".

History of the town tells us, that few families survived this event by swimming through the floodwaters and waves towards a hill where the hermitage of the Franciscans was located. Among the families that survived were the Angara, Bijasa, Bitong, Carrasco, Lumasac, and Poblete. Most of the surviving families transfer to other towns due to this incident, except the Angaras and Lumasacs which moved to a higher ground in Baler.

Today, Baler is known as among the, "top surf spots" in the Philippines. A wave, with a height of nine-feet attracts hundreds of surfers during the surfing season from September to February. One of the most famous hotels today is the Costa Pacifica owned by former Senator Edgardo J. Angara a lineage of the family that survived the 1735 tsunami. Figure 1 and Figure 2 shows some of the typical views and activities at Baler.

According to the 2010 census, Baler has a population of 36,010 people. The sea, which they consider a threat to them, now becomes a friend. However, before history may all be forgotten, Baler town is still a tsunami-prone area under the Tsunami Hazard Map of the Philippine Volcanology (PHILVOCS) and Department of Science and Technology (DOST) as of today.

Photo By: www.travelphil.com

Figure 1 – Sabang Beach Boardwalk, Baler, Aurora Province

Photo By: Rey Velasco

Figure 2 – Surfing is the main water sports in Baler, Aurora Province

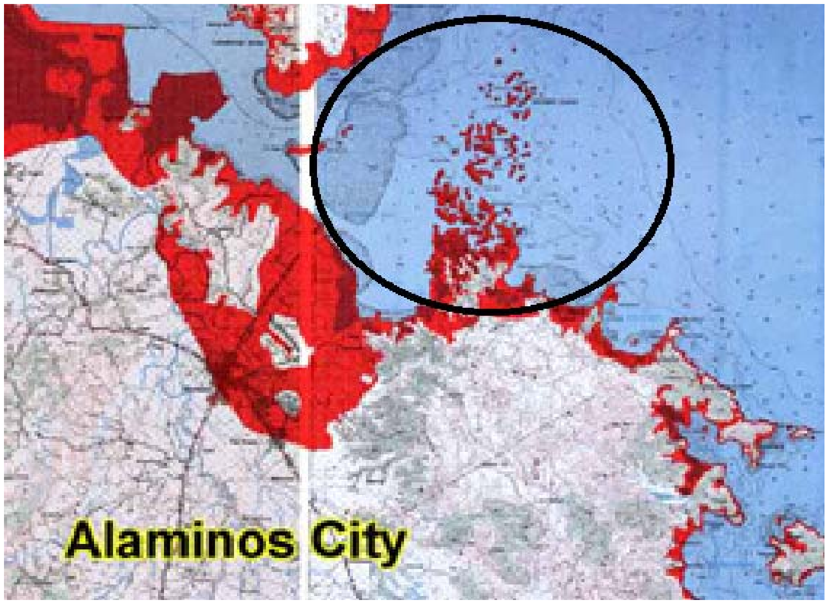
2. Philippine Tsunami Hazard Maps and “No Build Zone” Mitigation

The Philippine Institute of Volcanology and Seismology (PHIVOLCS) prepared a tsunami hazard map based on a known source like trenches and troughs in the Philippine Sea under a worst case scenario of a magnitude 8.0 earthquake. REDAS (Rapid Earthquake Damage Assessment System) software was used to model the tsunami based on empirical equations of Abe (1989), Hall and Watt (1953), Pist (1995), and Hills and Mader (1999).

Since the Philippines are composed of several islands, some small islands were fully covered by the inundation area from the modeling results. An example of this is the hundred islands of Pangasinan, wherein these islands are the main tourist attraction in the province. Mostly the tourists that go to these islands also stay there for an overnight rest either by a tent or by a local stay-in hut. Figure 3 shows a caption of the portion of the City of Alaminos with area in a red covering the inundation zone. A photo of the small islands known as “hundred islands” is also shown.

The Philippine Water Code does not allow structures to be built 40 meters from the highest tide mark in a shoreline. After the typhoon “Yolanda” (Haiyan) the Department of Environment and Natural Resources (DENR) activated the guideline in some areas of the affected city of Tacloban. However, the office of the President through its Office of the Presidential Assistant for Rehabilitation and Recovery (OPARR), has announced the “no-build” zone shall be changed into “no-dwelling” zone. This was then further categorized by OPARR into ‘safe’ and ‘unsafe’ zone since there are structures within this 40 meter distance that are used for livelihood and income of the local government in the area.

The proposed long-term and strategic solution to this issue of no-dwelling zone is the formulation of land-use policy. Participating agencies, both government and non-government institution agrees that the land-use policy should be a “science-based” policy and “area-specific”. The policy should recognize and respect both existing legal and customary tenant’s rights. To develop such policy the complex nature of livelihood and ecological viability should be understood well.



Source: Tsunami Hazard Map (PHIVOLCS/DOST)

Photo By: Rey Velasco

Fig. 3 – Snapshot of Tsunami Inundation Map and Photo of Hundred Islands of Alaminos City

3. Considering Tsunami Loads and Mitigation Approach under the Philippine Setting

The proposed long-term and strategic solution in the identification of no-dwelling zone under the land-use policy is expected to be too complex and difficult to implement. This is because most of the livelihood and economic components of most cities in the provinces in the Philippines are located near the shoreline coast of its region. Currently, both government and private sectors have their infrastructure located near the shoreline coast. In most cases, for example, are ports and harbors, airports, hotels and business establishments in cities. Under a worst earthquake scenario using the PHIVOLCS hazard tsunami map, most major town and cities in the provinces are covered by the tsunami inundation zone or area which can extend for several kilometers to low lying areas. To mention a few, these will include, Baler of Aurora Province, Tacloban City of Leyte island, Zamboanga City of Zamboanga province, Pagadian City of Zamboanga Del Sur province, Alaminos City of Pangasinan province, and San Fernando City of La Union province.

To mitigate the damage of a tsunami event, the following are some of the alternatives under the Philippine settings:

1. Tsunami wall. Providing tsunami walls along the perimeter of shorelines and river beds are best for cities and towns within the inundation zones or areas covered by the tsunami hazard maps. However, the costs of this infrastructure cannot be easily provided by the city government unless the income of that city is fully substantial to cover such costs. In addition, opposition regarding impact on tourism, environment, fisheries and marine life is among the issues confronted in building such structure. Figure 4 shows a tsunami/flood wall of Aji River in Osaka, Japan.

Photo By: Rey Velasco

Fig. 4 – Tsunami/Flood Wall at Aji River, Osaka, Japan

2. Designated vertical refuge structure. Existing multi-storey buildings which can be identified as a potential refuge building should be designated by the building official as a tsunami refuge center open to the public during an emergency tsunami event. In addition, local government should also construct their own refuge center during such event, with good consideration regarding distances or spacing with other designated refuge centers. Figure 5 shows an elevated structure used as picnic cottage and shelter in one of the islands at Alaminos City. The structure can be used as a vertical refuge during a tsunami event.

Photo By: Rey Velasco

Fig. 5 – Elevated Shelter at Quezon Island Resort, Alaminos City, Pangasinan, Philippines

3. Tsunami signage. The use of signage for information about tsunami zone areas and providing warning and direction during evacuation are expected to be an effective and economical measure. The local government can easily implement such posting, but the negative impression of certain prominent tourist destination may provide some negative impact in attracting tourist in some areas.

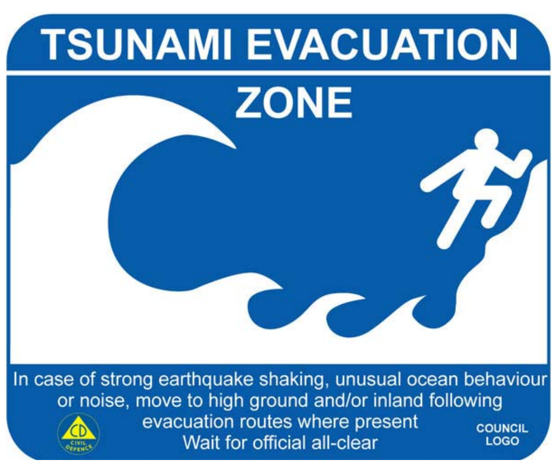


Fig. 6 – Sample of Tsunami Signage from New Zealand

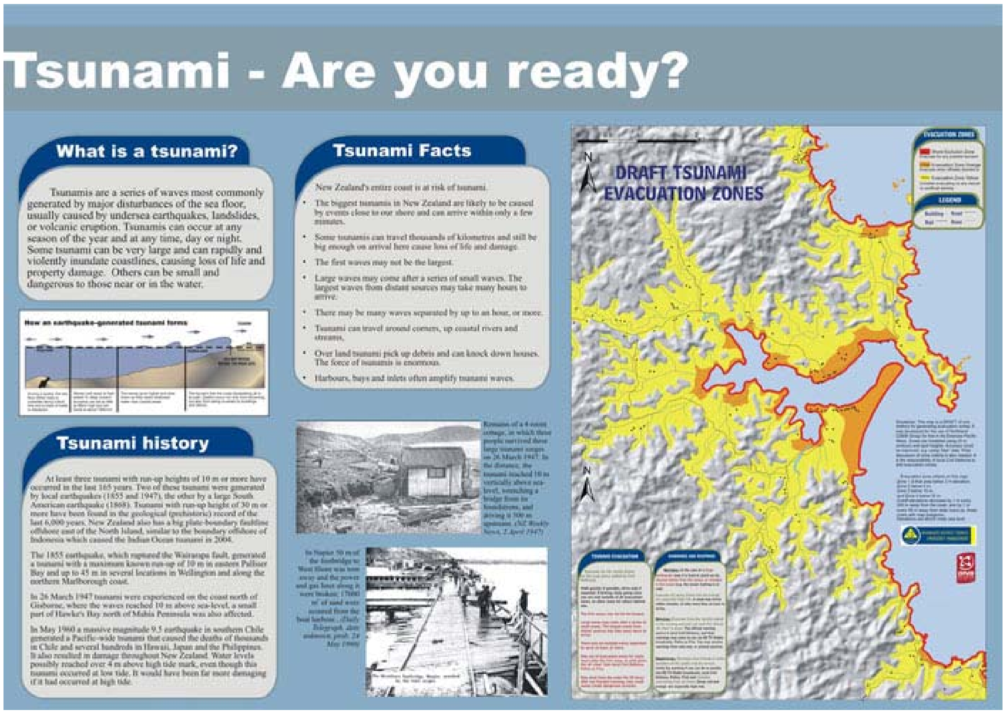


Fig. 7 – Sample of Tsunami Information Board of New Zealand

4. Building code consideration regarding tsunami hazard area. The information provided by PHIVOLCS and DOST in the form of "Tsunami Hazard Maps" provides vital information for Civil and Structural engineers in planning their roads, bridges and buildings in a tsunami prone area. The in-coming issuance of ASCE 7-2016 with Chapter 6 – Tsunami Loads and Effects, is expected to incorporate the loads associated to tsunami as part of a regular building code for ASCE code practitioner.

3.1 A Simple Tsunami Load Approach for Building Structure under the Philippine Setting

The political and legal aspect of implementation of having to mitigate a tsunami event may take a while and even be forgotten before another event comes in. However, for owners and investors intending to build a new structure, they should include the loads involved for a tsunami resistant structure. Consideration for tsunami prone area will at least need the following basic information:

1. Tsunami Hazard Map from PHIVOLCS/DOST,

2. Topographic Map from the National Mapping & Resource Information Authority (NAMRIA) under the Department of Environment and Natural Resources (DENR),

3. Reference equations for Debris Impact, Surge Force, Drag Force, Hydrostatic Force and Buoyant Force.

Equations for item (3) and its corresponding coefficients can be found in different codes such as, The Federal Emergency Management Agency (FEMA P-646), The Federal Emergency Management Agency Coastal Construction Manual (FEMA P-55), The City and County of Honolulu Code (CCH), Structural Design Method of Buildings for Tsunami Resistance (SMBTR) and the anticipated ASCE 7 –2016 Chapter 6. Other available option to tsunami risk analysis study can be performed by specialty agencies/consultants to cover a more detailed report for item (1).

Tsunami loads are classified into two scenarios: (1) Initial Impact and (2) Post Impact. Figure 8 shows a schematic diagram of forces showing the two load scenario. It should be noted that the live load arrangement on top of the highest habitable level should also be considered. In addition, the location of these hydrodynamic forces is shown based on the anticipated inundation depth, h.

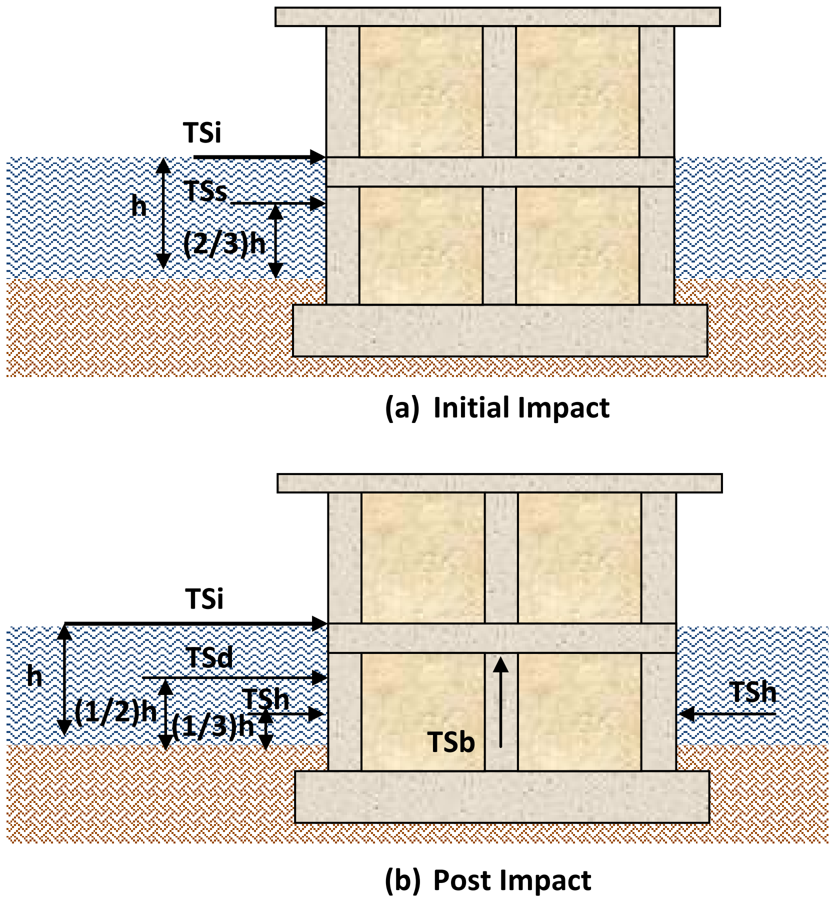


Fig. 8 – Tsunami Two Loading Scenario (Nouri et al., 2007)

One of the most important variables that need to be resolved first before solving the tsunami forces is the depth of inundation of the structure. Figure 9 shows an inundation elevation of tsunami wave as it enters inland. The information needed to determine the tsunami run-up elevation, *R* and ground elevation at the base of the structure, *Z* can be determined from the Tsunami Hazard Map of PHIVOLCS/DOST and the Topographic Map of NAMRIA/DENR. Note that this approach is based on the condition that the coastal inundation has an inland topography of a gradually elevated slope as assumed by FEMA P646. However, in the availability of a computer generated simulation report, it is important to use the generated data for more accurate information. Once the variable *R* and *Z* has been established, the other variables such as bore velocity, inundation depth, impact, surge, drag, buoyant force and hydrostatic forces are resolved by the following equations and coefficients.

Bore Velocity (Yeh 2006)

$$U \; = \; \sqrt{2 \, g \, R \, \left[1 - \left(\frac{Z}{R}\right) \right]} \tag{1}$$

Where: U = bore velocity, (m/s)

g = gravitational acceleration (9.81 m/s^2)

Z = ground elevation at base of structure, (m.)

R = run-up elevation, (m.)

Inundation Depth

$$h = g \, R^2 [\, 0.125 - 0.235 \left(\frac{Z}{R}\right) + 0.11 \left(\frac{Z}{R}\right)^2 \,] \left[\frac{1}{U^2}\right] \tag{2}$$

Where: h = inundation depth, (m.)

Tsunami Impact Load Due to Debris

There are several equations that can be used for more detailed assumptions of possible debris. One alternative is to use the FEMA P646/2012 equation.

$$TSi = 1.3 \, U \, \sqrt{k \, m_d \, (1 + c)} \tag{3}$$

Where: TSi = tsunami impact load, N

k = effective stiffness,(2.4 x10^6 N/m for drift wood)

m_d = mass of debris, (450 kgs for drift wood)

c = hydro mass coefficient, (zero for drift wood)

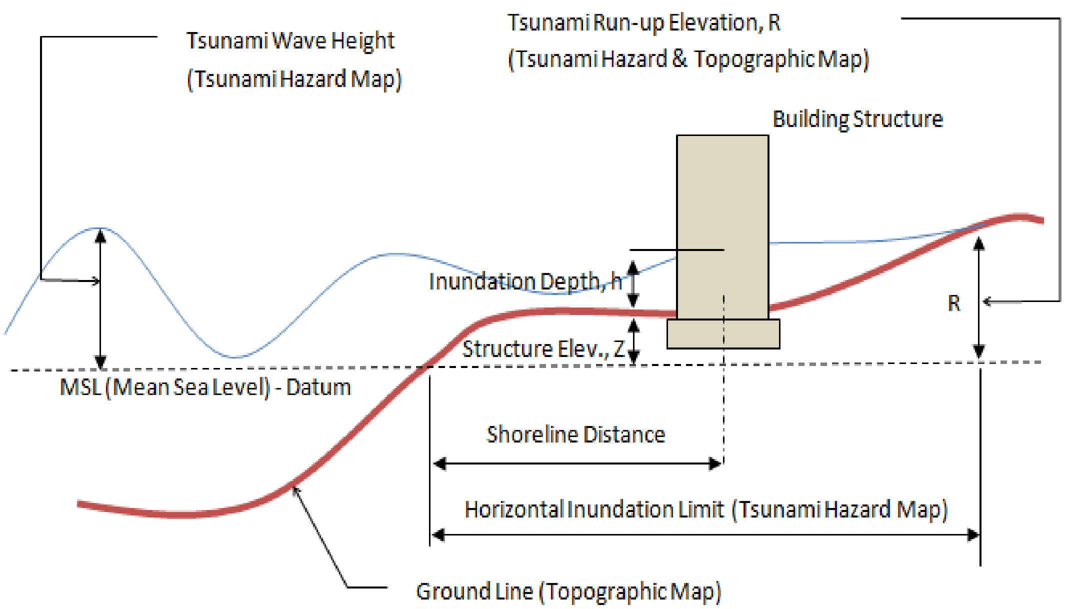


Fig. 9 – Graphical Derivation of Inundation Depth, h

Tsunami Surge Load

$$TSs = Ci\ \rho g h^2 b \qquad (4)$$

Where: TSs = tsunami surge force, (N)

C_I = 4.5 coefficient from CCH

ρ = density of seawater with silt and debris, (1100 kg/m^3)

b = width of the structure normal to the force, (m.)

Tsunami Drag Load

$$TSd = \left(\frac{1}{2}\right) \rho\ Cd\ A\ U^2 \qquad (5)$$

Where: TSd = tsunami drag force, (N)

Cd = drag coefficient, (2.00 maximum)

A = projected area normal to the direction of the flow, (m^2)

Tsunami Buoyancy Force

$$TSb = \ \rho\ g\ V \qquad (6)$$

Where: TSb = tsunami buoyancy force, (N)

V = volume of water displaced by the structure, (m^3)

Tsunami Hydrostatic Force

$$TSh = \left(\frac{1}{2}\right) \rho\ g\ \left[h + \left(\frac{U^2}{2g}\right)\right]^2 \qquad (7)$$

Where: TSh = tsunami hydrostatic force on the wall, (N/m)

4. Conclusion

Tsunami event is a rare event in the Philippines and is considered to be local along shoreline areas only. However, current studies with the use of forecasting tools shows that this event can encroach inland, particularly to tsunami prone areas whose elevations are less than 15.00 meters above sea level. Although the government would like to mitigate this event through a “no build zone” and “no dwelling zone”, land use policy, it can be easily understood that such approach is too complex and difficult to implement. In this regard, the remaining alternative is to mitigate the danger by providing the least inexpensive alternative. These alternatives may be in the form of posting tsunami signage, tsunami load consideration for new buildings, and the construction of a vertical refuge structure for selected public places.

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