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# RESPONSE OF STRUCTURES AGAINST TSUNAMI FORCES UNDER DIFFERENT SOIL CONDITIONS

A. H. L.Swaroop[1], Sk.Yajdani[2] and S. R. K. Reddy[1]
[1]Department of Civil Engineering, Gudlavalleru Engineering College, Gudlavalleru, Andhra Pradesh, India
[2]Department of Civil Engineering, AU, Visakhapatnam, Andhra Pradesh, India
E-Mail: ahlscivil@gmail.com

## ABSTRACT

In the event of a major submarine earthquake, not only severe ground shaking but also high tsunami waves are expected causing a significant threat to coastal structures and community. Tsunami forces on structures mainly depend upon the configuration of the structure, tsunami run-up heights and soil conditions. In the present study, two structures; one a conventional school building and the other an elevated water tank with typical configuration of slender staging and top heavy mass, are chosen for the analysis. Lateral loads at different floor levels of the building and water tank are worked out for different tsunami heights using the guidelines provided by Harry Hey *et al*. Spring constants of different soils are determined using the formulae developed by Whitman and Richart. Base shears and displacements are obtained when these structures rest on different types of soils and the results are compared with the values obtained when the structure is assumed to be fixed at the base. Assuming linear elastic behaviour, SAP 2000 software is used for the analysis. From the result analysis, it is observed that the time period of slender structures (water tank) is more compared to stiff structures (Building) and these time periods decreases with increase of soil stiffness. It is further observed that, base shears increase with increase of soil stiffness and displacements decrease with increase of both structure as well as soil stiffness.

**Keywords:** tsunami, different soil conditions, school building, watertank.

## 1. INTRODUCTION

Tsunamis are long period ocean waves generated by earthquakes that occur below or near the ocean floor. Past history reveals that great earthquakes are considered to occur at tectonic plate boundaries, mostly along the coastal belts that rim the Pacific and Cross Southern Asia. On 26th December 2004, Indonesian submarine earthquake of magnitude 9.3 generated catastrophic tsunamis killing more than two lakh people and created a major economic impact on countries surrounding Indian Ocean. Such mega events reminded coastal community alert on the preparedness against initial ground shaking and subsequent effects followed by tsunamis.

Tsunamis have great erosional ability and they can strip beaches of sand and coastal vegetation. A fast moving water associated with the inundating tsunamis can destroy houses and other coastal structures. A tsunami generated by the Niigalta earthquake in 1964 caused damage to port and harbour facilities due to ground failure and liquefaction. During 1964 Alasica earthquake tsunami, the erosion of soil underneath the foundation caused settlement of many structures. Series of tsunamis in Japan in 1986 killed 27000 people. 1992 Nicaraguan, 1994 Java trench and 1998 Papa New Guinea and 2011 Tohaku tsunamis witnessed damage of structures due to soil erosion and scouring effects.

As most of the tsunamis are earthquake induced tsunamis, it is necessary that coastal structures should be designed considering earthquake and tsunami loads. Seismic and tsunami resistant analyses are complicated as the motion is transient and the forces are time dependent.
A review by Harry Yeh, Ian Robertson and Jane Pneuss (2005), suggested fluid forces exerted on a structure during a tsunami event can be evaluated in terms of hydrodynamic and impact forces for a given depth of inundation and the velocity of the approaching tsunami.

Generally in the analysis of coastal structures subjected to gravity or lateral forces, the structures are assumed to be fixed at the base. However, tsunami waves travel on ground before they struck the structures. Hence the response parameters like base shears and displacements depend upon the interaction between soil and the structure. Particularly in loose and marine soils these changes may be significant.

Though some guidelines are provided by FEMA, CCM and authors like Harry Yeh *et al*, there are no well established procedures for analysis of structures against tsunami forces when soil-structure interaction effects are considered.

In the present study, a school building and elevated water tank are chosen for a comparative study on how the response changes for different tsunami forces when similar structure rests on different soils. Soil stiffness parameters in the directions of vertical, horizontal and rocking are worked out using the equations suggested by Whitman and Richart (1967).

## 2. TSUNAMI EFFECTS

In principle, the calculation of wave force on a structure involves an integration of pressure and shear force over the exposed area of structure. Tsunami waves impose dynamic water pressures on coastal structures causing serious damage to the entire surrounding infrastructure located up to 4-10km distance in land. During 2004, Indonesia earthquake followed by giant tsunami and 2011 Tohoku earthquake followed by tsunami, it is observed that non-engineering R.C. structures, buildings with cellar floors and non-reinforced masonry buildings suffered extensive damage due to

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hydrodynamic and impact forces generated by tsunami. Though there are no established procedures for tsunami analysis till recent years and no significant research has been undertaken on design of structures against tsunamis, a draft of Indian standard has been developed to provide a guide line to professional engineers and government bodies for designing tsunami resistant coastal structures.

Though coastal structures are subjected to severe wind pressures, past research results show that impact of hydrodynamic, impulsive wave pressures are much greater than wind pressure. Hence in the present analysis wind force is not considered.

## 3. PROBLEM CHOSEN FOR STUDY

Two different types of coastal structures, one a school building with G+2 floors of size 32m x15m in plan with 3.5m height of each floor and the other, an elevated water tank having with slender staging and top heavy mass are chosen for obtaining response against tsunami vaves of different heights. The total force due to hydrodynamic and impact forces are determined using the equations developed by Harry Yeh et al and these forces are applied on the structure for analysis. Assuming that similar structure rests on different soils, the comparative study is carried out on response parameters like time period, displacement and base shear.

## 4. STRUCTURE SPECIFICATIONS AND GEOTECHNICAL PARAMETERS

### 4.1 Structure specifications

Type A Structure: A three storied school building of size 32m x15m in plan and 3.5m height of each floor with column size of 300 x500 mm and beam size 230x 600 mm for 6m spans and 230 x 400 mm for 4m spans as shown in fig1 .Slab thickness of 150 mm is provided at all floor levels.

Type B Structure: An elevated water tank of six lakh litres capacity is considered as another typical example for the analysis. It is supported by twelve columns of size 500mm x500mm connected well with a circular ring beam of 600mm x500mm at bottom and with bracings at equal intervals along the staging height of 14.75m above ground level as in Figure-2.

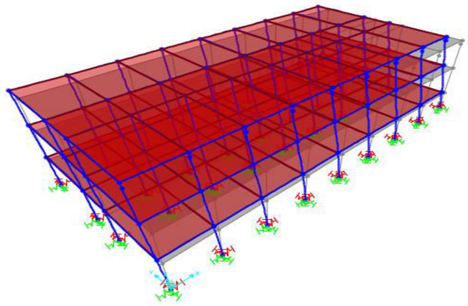

**Figure-1.** School building modelled in SAP 2000.

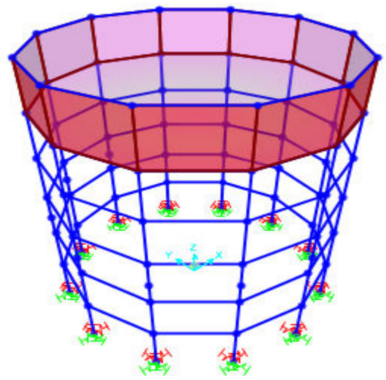

**Figure-2.** Water tank modelled in SAP 2000.

### 4.2 Geotechnical parameters

The importance of nature of sub soil on which the structure rests, plays a vital role on behaviour of the structure against tsunami impact. Tsunamis have great impact on soil erosion and causes scouring action beneath the foundations. The fast moving water associated with the inundating tsunami can destroy houses and other coastal structures. In the present study, soil-structure interaction effects are also considered assuming the structure rests on different types of soils. The type of soil, dynamic properties like mass density, Poisson ratio and shear modulus of soils for different shear wave velocities are worked out and presented in Table-1.The soil stiffness coefficient values in vertical, horizontal and rocking directions for both type A and Type B structures are worked out using the formulae developed by Richart and Lysmer (1970) and are presented in Table-2.

**Table-1.** Results of dynamic properties of different soils/Rocks.

| **Type** | **Description of soil or rock** | **Shear wave velocity Vs** (m/s) | **Mass density** (KN-sec$^2$)/m$^4$ | **Poisson's ratio** | **Shear modulus G** (KN/m$^2$ x10$^4$) | **Safe bearing capacity** (KN/m$^2$) |
|---|---|---|---|---|---|---|
| S1 | Soft clay | 60 | 1.70 | 0.45 | 0.61 | 40-60 |
| S2 | Medium sand | 150 | 1.85 | 0.40 | 4.16 | 120-150 |
| S3 | Weathered Rock | 400 | 1.90 | 0.30 | 30.4 | 280-300 |
| S4 | Hard rock | 1250 | 2.10 | 0.30 | 328.13 | 570-630 |

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**Table-2.** Soil spring (Stiffness) values as per Richart and Lysmer (1970).

| Direction | Spring (Stiffness) values | Equivalent radius |
|---|---|---|
| Vertical | $K_z = \frac{4Gr_z}{(1-\vartheta)}$ | $r_z = \sqrt{\frac{LB}{\pi}}$ |
| Horizontal | $K_x = K_y \frac{32(1-\vartheta)Gr_x}{(7-8\vartheta)}$ | $r_x = \sqrt{\frac{LB}{\pi}}$ |
| Rocking | $K_{\emptyset X} = \frac{8Gr_{\emptyset x}^3}{3(1-\vartheta)}$ | $r_{\emptyset x} = \sqrt[4]{\frac{LB^3}{3\pi}}$ |
| | $K_{\emptyset Y} = \frac{8Gr_{\emptyset x}^3}{3(1-\vartheta)}$ | $r_{\emptyset y} = \sqrt[4]{\frac{LB^3}{3\pi}}$ |

## 5. METHODOLOGY

The tsunami lateral forces are calculated using equations developed by Harry yeh for different run up heights of 3m, 6m, 9m and 12m and assumed that these lateral loads are applied at different floor levels of both type A and type B structures. The structures are modelled for tsunami loads at different floor levels and the analysis is carried out using SAP 2000 software when structures rests on different soil conditions. The results of response parameters like time period, base shear and displacement of different models are compared with the results obtained when the structure is assumed to be fixed at the base (FB).

## 6. RESULTS

The results of fundamental time periods, base shear and displacements for different tsunami heights are presented in Tables 3 and 4 and graphical representations are depicted in Figures 3 to 7

**Table-3.** Fundamental time periods of structures under different soil conditions.

| Type of soil | Time periods in sec | |
|---|---|---|
| | A' Type | B' Type |
| S1 | 0.510 | 0.840 |
| S2 | 0.420 | 0.610 |
| S3 | 0.290 | 0.460 |
| S4 | 0.170 | 0.370 |
| FB | 0.160 | 0.366 |

**Table-4.** Base shears and displacements for different tsunami run up heights.

| Run-up height R (m) | Types of soil S | Response parameters | | | |
|---|---|---|---|---|---|
| | | Displacements (mm) | | Base shears (kN) | |
| | | A' Type | B' Type | A' Type | B' Type |
| 3 | S1 | 0.51 | 1.42 | 53.96 | 57.56 |
| | S2 | 0.35 | 0.73 | 56.78 | 58.96 |
| | S3 | 0.31 | 0.68 | 63.53 | 59.77 |
| | S4 | 0.28 | 0.60 | 73.51 | 60.01 |
| | FB | 0.27 | 0.59 | 75.13 | 60.36 |
| 6 | S1 | 10.9 | 15.10 | 214.72 | 71.24 |
| | S2 | 10.2 | 13.78 | 215.22 | 75.08 |
| | S3 | 9.90 | 13.32 | 229.87 | 79.54 |
| | S4 | 7.98 | 12.14 | 251.45 | 81.42 |
| | FB | 7.76 | 12.01 | 253.11 | 82.34 |
| 9 | S1 | 36.03 | 56.30 | 314.14 | 82.73 |
| | S2 | 34.45 | 52.81 | 318.57 | 90.24 |
| | S3 | 33.90 | 52.13 | 324.58 | 96.54 |
| | S4 | 31.60 | 51.21 | 387.16 | 117.31 |
| | FB | 31.40 | 49.34 | 389.46 | 119.42 |
| 12 | S1 | 90.20 | 126.00 | 455.57 | 128.00 |
| | S2 | 86.90 | 119.37 | 458.04 | 136.24 |
| | S3 | 86.10 | 98.64 | 478.14 | 146.82 |
| | S4 | 85.01 | 74.61 | 489.23 | 166.00 |
| | FB | 84.90 | 74.24 | 491.24 | 168.12 |

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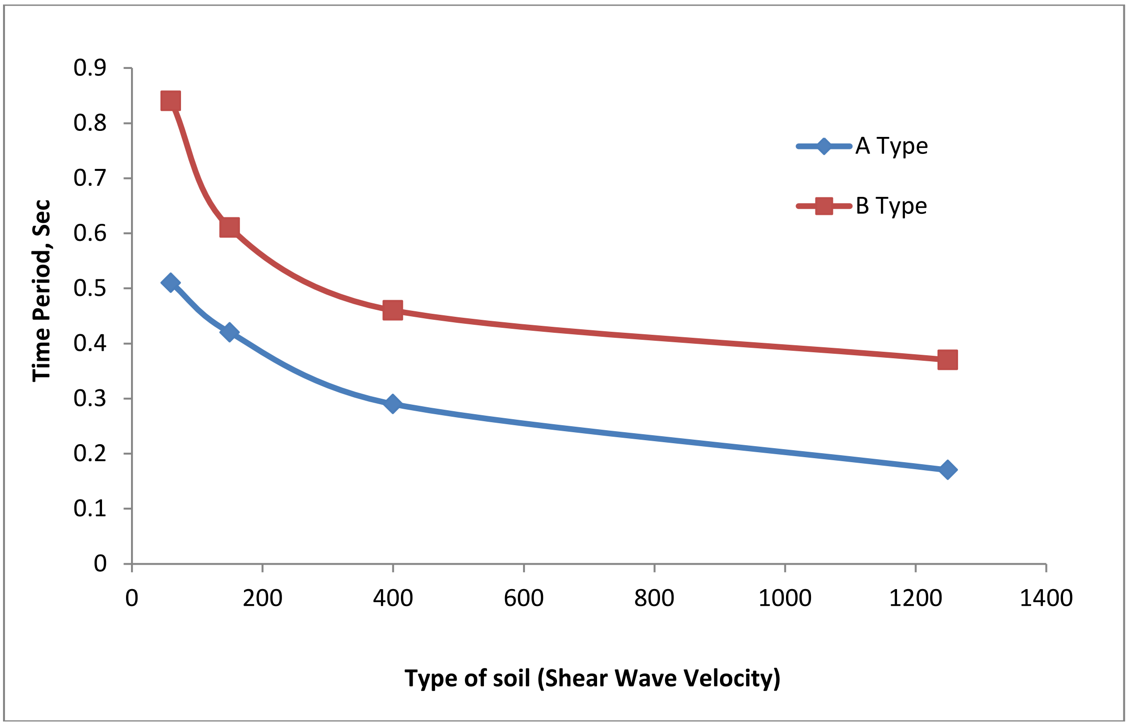


**Figure-3.** Graph shows soil type vs time periods.

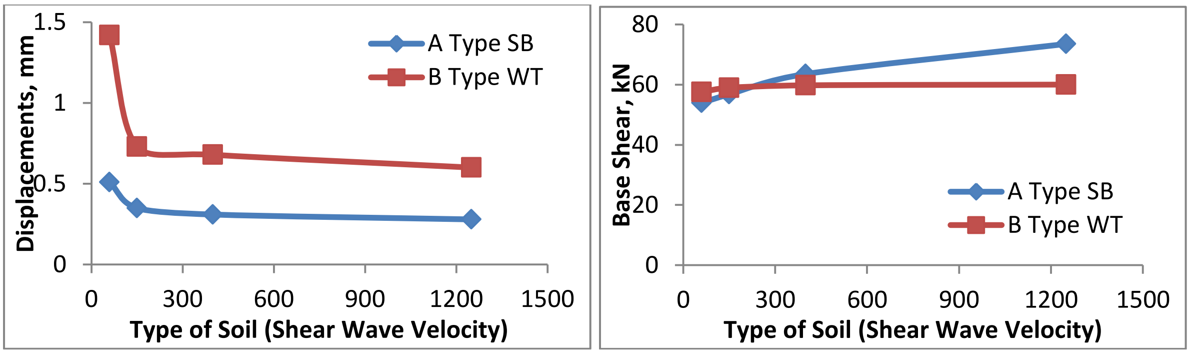


**Figure-4.** Graph shows soil types vs displacements and base shear's for 3m run-up height.

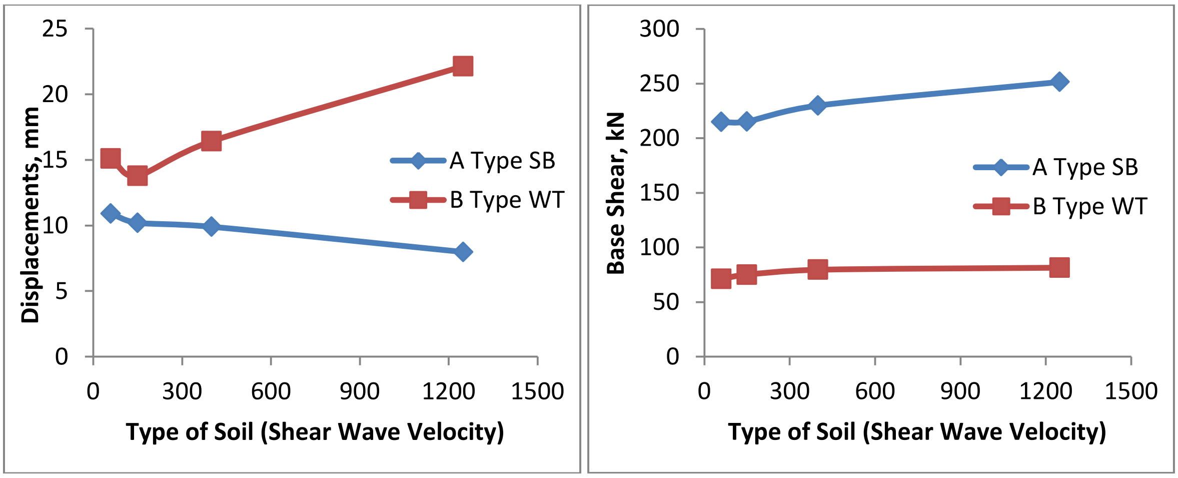


**Figure-5.** Graph shows soil types vs displacements and base shear's for 6m run-up height.

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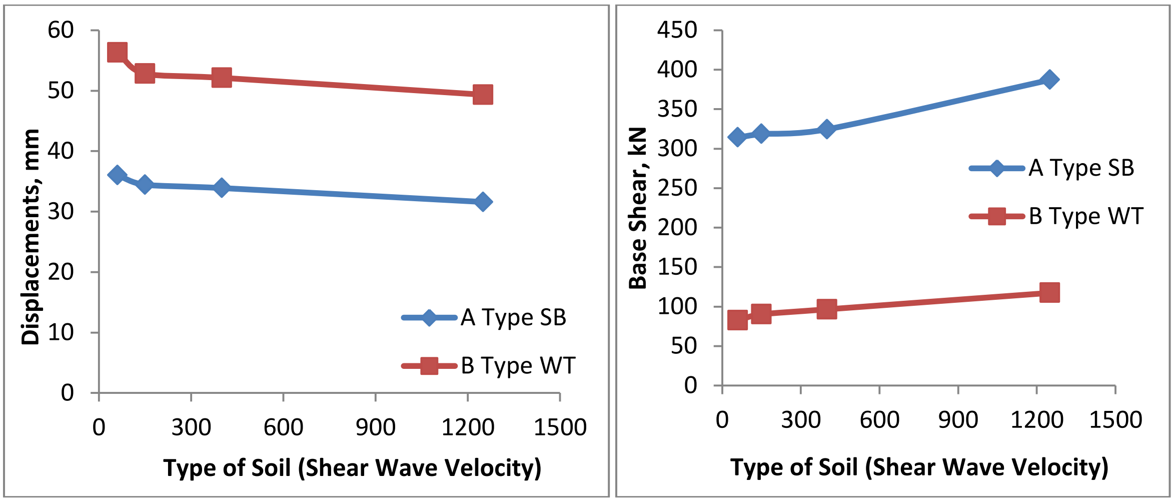


**Figure-6.** Graph shows soil types vs displacements and base shears for 9m run-up height.

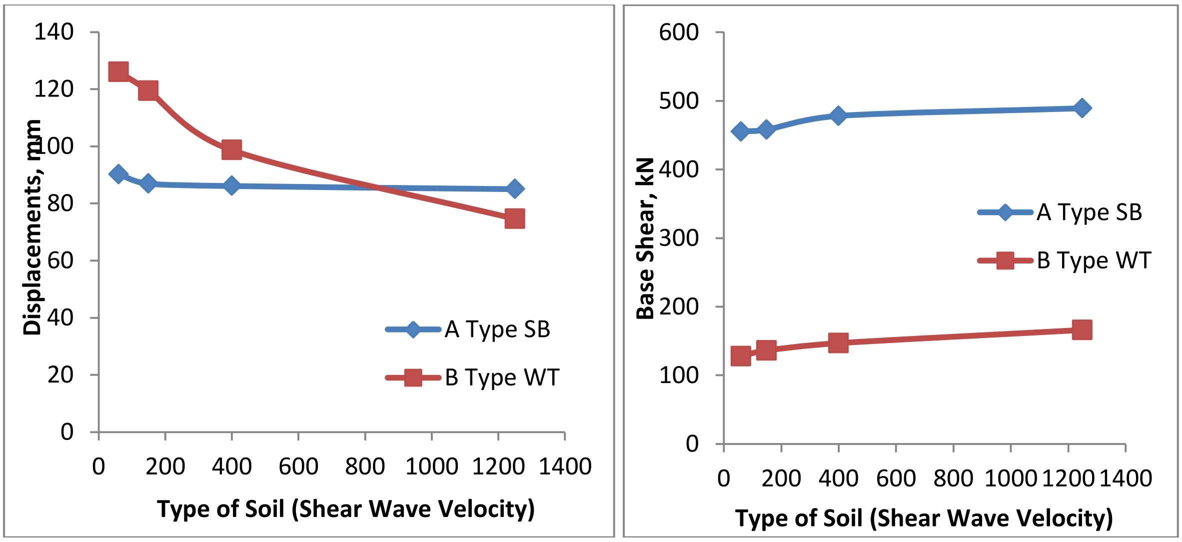


**Figure-7.** Graph shows soil types vs displacements and base shears for 12m run-up height.

## 7. CONCLUSIONS

a) Impact of Tsunami forces on structures depend up on the strength, rigidity particularly at lower levels, tsunami wave height, cross sectional dimensions.

b) Displacements gradually decrease from clay to hard rork in both the structures and the percentage of variation is also very high in loose soils when compared to the fixed base conditions.

c) Displacements are found increasing rapidly for higher run up heights in all types of soils.

d) Time periods for both type of structures are gradually decreasing from clay to hard rock

e) Base shears are gradually increasing from clay to hard work in both the structures and the percentage of this variation is also very high in loose soils when compared with fixed base conditions. This is because, the loose soils absorb more energy compared to hardrock during earthquake motion.

f) High magnitude tsunami force results for high lateral displacements and in turn may lead to scouring and sometimes collapse of structures.

g) In general, it can be concluded that structure resting on stiff soils or rock behave well during tsunamis than structures resting on loose soils.

## REFERENCES

[1] M Roopa *et al.* 2015. Soil Structure Interaction Analysis on a RC Building with Raft foundation under Clayey Soil Condition. International Journal of Engineering Research and technology. 4(12).

[2] AHL Swaroop *et al.* 2016. Response of Coastal Structures against Tsunami Forces and Mitigation Measures. International Journal of Innovative Research in Science, Engineering and Technology. 5(4): 5884-5889.

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[3] I.S. 1893 (Part-I). 2002. Criteria for Earthquake Resistant Design of Structures. Fifth Revision.

[4] Reddy S.R.K. *et al.* 2006. Terrain Evaluation and Influence of Soil-Structure Interaction on Seismic Response of Structures in Urban Environs. Proc. of 3rd International Conference on Protection of Structures against Hazards: Italy. pp. 235-242.

[5] Tsuneo Okada and Camfield. 2005. Tsunami loads and Structural Design of Tsunami Refuge Buildings".

[6] Tsutsumi A; *et al*. 2000. Near Shore flow velocity of southwest Hokkaido Earthquake Tsunami. Journal of Waterway Port, Coastal and Ocean Engineering. pp. 136-143.

[7] Yeh. H; Robertson. I and Preuss. J. 2005. Development of design guidelines for structures that serve as tsunami vertical evacuation sites. Report No.2005-4, Washington State Department of Natural Resources.

[8] Oregon Solomon C. Yim, F.ASCE; Yong Wei; Mohsen Azadbakht; Seshu Nimmala; and Tanarat Potisuk. Case Study for Tsunami Design of Coastal Infrastructure: Spencer Creek Bridge.

[9] M. Rueben; D. Cox; R. Holman; S. Shin; and J. Stanley. Optical Measurements of Tsunami Inundation and Debris Movement in a Large-Scale Wave Basin.