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"Study on Progressive Collapse Analysis for Tsunami Hazards"

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Abstract-*A tsunami can be defined as a series of waves with a long wavelength and period (time between crests) usually generated by disturbances associated with earthquakes, landslides, volcanoes eruptions or meteor impact occurring below or near the ocean floor. In simple words Tsunami is a combination of two words derived from the Japanese language the characters "tsu" meaning harbor and "nami" meaning wave. Or in other words tsunami is the water waves which are generally caused by the submarine earthquakes. They are generally rare event but they cause terrible damage to life as well as to property. The occurrence of tsunami (like the one during Indian Ocean tsunami on December 26, 2004, the Sumatra earthquake in 2004 or the one during the Tohoku earthquake in Japan in 2011) caused devastating damages to the coastal structures and tremendous casualties. And in most of the cases the tsunamis are induced due to Earthquake forces hence it is necessary that coastal structures should be designed against both earthquake and tsunamis. This paper deals with the hazards associated with the earthquake forces and the tsunamis triggered due to these forces. Also extensive literature session is done to come to conclusions about the structures along the shorelines and coast. Also an attempt has been made in this paper for the future scope of work in this area.*

I. INTRODUCTION

For a country like India there are varieties of natural and manmade disasters. Among natural hazards, the most notable ones are earthquakes, cyclones, floods, droughts and landslides. Tsunami is an additional concern of safety after the super tsunami of 26th December, 2004. And as a matter offact India has a very long coastal line from the Kutch in Gujarat to West Bengal and the various Island groups that are exposed seas. Also the majority of the coastal areas fall under the moderate Seismic Zones III with some parts of Gujarat and the entire Andaman & Nicobar Islands coming under the most severe Seismic Zone V. Hence, it is important that one should prepare any mitigation and preparedness measures taken up in these coastal areas should also consider the multi-hazard nature of theseareas. It is also important to note that the entire coast line is not uniform in terms ofintensities of various hazards. The hazard intensities of earthquakes, floods and cyclonic storms in the west coast and the east coast vary widely.

VariousCodes and Guidelines for Tsunami
Before the Indian Ocean Tsunami, it was assumed that there was no need for the design of structures against tsunami-induced forces. This situation was due to the assumption that tsunamis are "rare" events, with significantly large return periods. The devastation that may be caused by a tsunami of a large magnitude can be catastrophic as demonstrated by the 2004 Indian Ocean event which induced significant structural damage on infrastructure, killing over 3,00,000 people and leaving an estimated 1.5 million homeless [15]
List of few codes are as below

- The City and County of Honolulu Building Code (CCH, 2000);
- The minimum Design Loads for Buildings and Other Structures; SEI/ASCE 7-02 (ASCE 7, 2002);
- The Federal Emergency Management Agency- "Coastal Construction Manual" (FEMA CCM, 2000);
- Federal Emergency Management Agency- "Guidelines for Design of Structures for Vertical Evacuation from Tsunamis" (FEMA P646, 2008);
- Tsunami draft code- 26/-8/2016

Tsunami Forces On Structures
There are three parameters essential for defining the magnitude and application of designing forces on structures:
a) Flow direction;
b) Inundation depth; and
c) Flow velocity.

These parameters mainly depend on:
1) Run-up height of tsunami and arrival time;
2) Coastal topography; and
3) Roughness of the coastal inland

II. LITERATURE REVIEW

Nayak S, Reddy M, Madhavi R, Dutta S [1] in their paper "Assessing tsunami vulnerability of structures designed for the seismic loading" concluded that when tsunami enters the shallow water i.e. approx. 30m the speed of tsunamiwaves diminishes.

They reported that for the multiple column effect, forces generally increase due to the blockage of flow by adjacent columns.They also found that seismic base shear force is greater than the tsunami force up to critical height and less than the tsunami force after critical height. Further they quoted that, critical height for a particular zone decreases with increase of response reduction factor R. It was found that critical heights obtained by considering seismic base shear calculated according IS 1893(Part1), ASCE7-05 and Eurocode8 and tsunami load obtained by FEMA55, CCH lies in the range of 1.2m–2.63 m for a masonry structures.

Yoshinobu Tsuji, et al [2] conducted a field surveyed and interrogated people of on over 40 islands of Flores during December 29, 1992 to January 5, 1993. After completing their survey they published the report in the form of paper titled "Damage to Coastal Villages due to the 1992 Flores Island Earthquake Tsunami".

After the survey they found the height of the tsunami was only 2.5-3.2 m above mean sea level. Maximum run-up was 2.3m. Palm trees forest was effective in dissipating the tsunami energy, there by mitigating the human toll. People were more swiftly killed by the tsunamis than by the earthquake

.

Ian Robertson[3] researched on "Structural Analysis of Selected Failures Caused by the 27 February 2010 Chile Tsunami" and found that the highest inundation heights recorded by ITST (International Tsunami Survey Teams) groups were generally in the 10–12 meter range (EERI 2010).He also found that for well-defined structural element failures at sites where inundation depth was measured, it was easy to evaluate the hydrodynamic loading required to cause these failures and derive estimated lower bound flow velocity overland during the event.He specifically mentioned that tsunami debris impacts and foundations deserve greater attention in research and design provisions greater attention in research and design provisions.

Azadbakht M and Yim S [4] reported a paperon "Estimation of Cascadia Local Tsunami Loads on Pacific Northwest Bridge Superstructures" and found that, on average, a large seismic event in the Cascadia Subduction Zone (CSZ) occurs once every 500 years.

They developed numerical model and concluded that the maximum tsunami horizontal and downward vertical loads occurred approximately simultaneously.The magnitudes of the tsunami horizontal and downward vertical loads were significantly affected by the water free-surface elevation at the seaside of the bridge cross section. The initial impact of a tsunami on a bridge superstructure did not lead to a significant uplift force when the bridge cross section had a seaward slope.

Analyses of a deck-girder bridge with a closed railing system showed average increases of 33, 15, and 77% in the maximum tsunami horizontal, downward vertical, and uplift forces, respectively, compared with the corresponding open rail system.

Gary Y. K. Chock [5], researched on "Design for Tsunami Loads and Effects in the ASCE 7-16 Standards' and found that the public safety risk has been only partially mitigated through warning and preparedness of evacuation. He also established that structural design of buildings and structures include requirements for the following tsunami effects:

- Unbalanced lateral forces at initial flooding;
- Buoyant uplift based on displaced volume; and
- Residual water surcharge loads on elevated floors;
- Drag Forces, per drag coefficient Cd for structure size and element shape;
- Lateral impulsive forces of tsunami bores:
- Hydrodynamic pressurization by stagnated flow
- Shock pressure effect of entrapped bore impulse;
- Poles, passenger vehicles, medium boulders are always applied;
- Shipping containers and boats apply if structure is in proximity to hazard zone; and Extraordinary impacts of ships only where in proximity to Risk Category III and IV structures;
- Local scour and soil pore pressure softening effects on the foundation; and
- General erosion
- Probabilistic offshore tsunami amplitude maps and tsunami design zone inundation maps were given to establish the basis of design;
- Procedures for tsunami inundation analysis utilize the design map values of offshore tsunami amplitude or the run up and inundation limit from the tsunami design zone map;
- Structural loading and analysis techniques for determining building performance are in turn calculated from the site's basis of design parameters of inundation depth and flow velocity;

Ian Nicol Robertson [6] in his paper "Prototypical Building Design for Tsunami Loading" developed a prototypical building which was designed for various seismic design categories and soil conditions in accordance with IBC 2006 and ACI 318-08.

Based on the results of his study, the following conclusions were drawn:

- Multi-story reinforced concrete residential and office buildings can be designed to survive the tsunami flow scenarios assumed in this study. They can therefore provide refuge through vertical evacuation.
- Tsunami design resulted in less than 8% increase in reinforcing steel weight and less than 3% increase in concrete volume for the buildings.
- Special moment-resisting beam-column frame systems designed for high seismic conditions may not require any upgrading to resist tsunami loads.
- Out-of-plane shear of structural walls due to tsunami loads may require the addition of shear reinforcement in the form of headed studs. Alternatively the wall thickness may need to be increased.
- Debris impact due to a shipping container will likely exceed the shear and bending capacity of individual columns. It was recommended that the building be designed to prevent progressive collapse in the event of column failure.

Abdullah Keyvani [7] in his paper "Progressive Collapse of RC Frames Due to Heavy Impact Loads of Tsunami" quoted that progressive collapse is a relatively rare event, as it requires both an abnormal loading to initiate the local damage and a structure that lacks adequate continuity, ductility and redundancy to resist the spread of damage.
He compared the results of two analytical models with the experimental results. One of them was common and simplified Idealized Component Load-Deformation curve based on the FEMA 356, and the other was FEH method. Material nonlinearity models, which were able to demonstrate the specifics of progressive collapse such as catenary action, axial-moment (P-M) interaction of beams during catenary action, and reflecting the stages of progressive col-lapse, considered as proper model for progressive collapse analysis. Comparison curves demonstrated the predominating capability of FEH method in verifying the experimental results.
In addition, FEH method was able to consider the P-M interaction in beam elements due to the catenary action and tensile forces in beams. In contrast, FEMA 356 hinges were so conservative in comparison with the experimental data, and were not able to provide some comparable results such as strain response details. Also FEH method was neither sophisticated for research and/or practical purposes, nor unreliable. This method can be used as one of the proper equivalents for material nonlinearities especially for progressive collapse analysis.
Ian N. Robertson et al [8] researched and published paper titled "Lessons from Hurricane Katrina Storm Surge on Bridges and Buildings". After the survey and analysis they drew the following conclusions.

- Many engineered structures in the Katrina inundation zone experienced only nonstructural damage at the lower levels due to the storm surge and storm wave action. A number of structures experienced significant structural damage due to the effectsof the coastal inundation.
- Bridge decks and structural floor systems submerged during coastal inundation were subjected to significant hydraulic loads, including hydrostatic uplift due to buoyancy, which was amplified by the effect of entrapped air, and hydrodynamic uplift due to vertical wave action.
- Deck segments of low-level bridges in regions subjected to coastal inundation should be restrained against uplift and provide with shear keys designed to resist all anticipated lateral loads, ignoring the contribution of gravity-induced friction. Bulkheads and blocking should be designed to allow air to escape from below the deck, thereby reducing the volume of trapped air when submerged.
- Restraint systems for floating structures such as barges should be designed to permit water elevation changes anticipated during the design event. The restraint systems should also be designed for the lateral loads induced by the surge and wave action.
- Standard shipping containers should be considered as the design debris in many developed coastal areas.
- Multistory buildings should be designed for progressive collapse prevention in the event of unforeseen damage to individual structural elements at the lower levels.
- Building and bridge foundations must be designed to accommodate scour induced by the surge and wave action. Scour results from both shear-induced particulate transport and liquefaction-induced soil flow.

III. CRITICAL REMARKS

- The numerical model which were developed either over-estimated or under-estimated the tsunami and seismic forces on the buildings.
- From the historic events one can know about the maximum inundation height and run up length of the wave, but the wave velocity is still difficult to measure at the time of impact.
- Also the direction in which the waves will impact the structures can still not be predicted.
- Though the "Alternative load path method" was developed but still its proper implementation and simple guidelines needs to be revised for its easy implementation.
- Though theprogressive collapse is a relatively rare event, as it requires both an abnormal loading to initiate the local damage and a structure that lacks adequate continuity, ductility and redundancy to resist the spread of damage, but attempts has not been made to find a simpler way to analyze the progressive collapse.
- For the evacuation of the people in the building affected with tsunami force proper guidelines considering the wave time before the warning should be designed.

- Unlike the IS 13920 (ductile detailing for reinforced concrete structures) there are no Indian standard codes to follow for the construction of tsunami resistant structures along the shoreline and coastal lines.
- Special chapter on progressive collapse of the structure for the tsunami and seismic loading should be added in the presently available Tsunami draft codes.
- Among several waves striking the shorelines and on coastal structures the prediction of the largest wave amongst them is still yet to be studied.
- Apart from the Mangrove trees for the shelter and protection of coastal structures other compatible vegetation should be found out.
- Tsunami-induced forces and the impact of debris are not properly accounted for in the existing codes and significant improvement is needed.

IV. FURTHER SCOPE AND FUTURE STUDY

- There should be provisions of codes especially for tsunami resistant structures.
- New and various numerical modeling shall be developed for tsunami loadings.
- New and improved ways to create general awareness among the people should be done.
- Progressive collapse analysis for the tsunami hazards and its vulnerability should be done.
- Significant improvement in the existing codes fortsunami-induced forces and the impact of debris.

REFERENCES

RESEARCH PAPERS

[1] Sanket Nayak , Mudireddy Hari Obula Reddy, Rangoli Madhavi, Sekhar ChandraDutta "Assessing tsunami vulnerability of structures designed for seismic loading" School of Infrastructure, Indian Institute of Technology Bhubaneswar 2013.
[2] Yoshinobu Tsuji et.al "Damage to Coastal Villages due to the 1992 Flores Island Earthquake Tsunami" inBirkhiuser Verlag, Basel.1995
[3] Ian Robertson, Gary Chock, M.EERI, and Juan Morla "Structural Analysis of Selected Failures Caused by the 27 February 2010 Chile Tsunami" in the year 2010 in Earthquake Engineering Research Institute, university of Hawaii at manoa.2010
[4] Mohsen Azadbakht and Solomon C. Yim "Estimation of Cascadia Local Tsunami Loads on Pacific Northwest Bridge Superstructures in American society of civil engineers(ASCE).
[5] Gary Y.K. Chock, Ian Robertson, H. Ronald Riggs "Tsunami Structural Design Provisions for A New Update of Building Codes and Performance-Based Engineering"in American Society of Civil Engineers (ASCE), 2011
[6] Gary Y. K. Chock and Dist.M.ASCE "Design for Tsunami Loads and Effects in the ASCE 7-16 Standards' in American Society of Civil Engineers. 2016
[7] Ian Nicol Robertson"Prototypical Building Design for Tsunami Loading" in Research Gate. 2015
[8] Abdullah Keyvani Leila Keyvani"Progressive Collapse of RC Frames Due to Heavy Impact Loads of Tsunami" in Open Journal of Civil Engineering, Scientific Research. 2013
[9]Ian N. Robertson, H. Ronald Riggs, Solomon C. S. Yim and Yin Lu Young "Lessons from Hurricane Katrina Storm Surge on Bridges and Buildings" in Journal Of Waterway, Port, Coastal, And Ocean Engineering, ASCE. 2007
[10] EERI -1, The Great Sumatra Earthquake and Indian Ocean Tsunami of December 26, 2004, EERI Special Earthquake Report — March 2005.
[11]EERI -2, the Great Sumatra Earthquake and Indian Ocean Tsunami of December 26, 2004, EERI Special Earthquake Report — April 2005.
[12] Okada T, Sugano, Ishikawa, Takai & Tateno, Tsunami Loads and Structural Design of Tsunami Refuge Building, www.bcj.or.jp / src / c05_research / results /tsunami2006_1.pdf, 2006
[13] Okal E A and Synolkis C E, Far-Field Tsunami Hazard from Mega-thrust Earthquakes in the Indian Ocean, Geophysical Journal Institute, Vol. 172, pp. 995-1015, 2008
[14] Pacheco K, Evaluation of Tsunami Loads and Their Effect on Reinforced Concrete Building, University of Hawaii, M.Sc. Thesis, 2005
[15] DR. V.M. Patel ―Computer Aided Analysis & Design Of Structures In Tsunami Prone Area‖, Faculty of Engineering and Technology, Ganpat University, Kherva, Doctoral Thesis, 2011

CODES

[1] Tsunami Draft Code by Bureau of Indian Standards on 26/08/2016
[2] Guidelines for Design and Construction of Cyclone/Tsunami Shelters by Go I-UNDP Disaster Risk Management Programme Ministry of Home Affairs Government of India in year 2006.
[3] National Disaster Management Authority- Management of Tsunamis by GOI in August 2010.