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NHERI EXPERIMENTAL FACILITY FOR COASTAL WAVES/SURGE and TSUNAMIS AT OREGON STATE UNIVERSITY

C. Higgins[(1)], D. Cox[(2)], and P. Lomonaco[(3)]

[(1)] *Drinkward Professor of Structural Engineering, School of Civil and Const. Eng., Oregon State Univ., chris.higgins@oregonstate.edu*
[(2)] *Professor, School of Civil and Construction Eng., Oregon State Univ., dan.cox@oregonstate.edu*
[(3)] *Director, Hinsdale Wave Research Laboratory, Oregon State Univ., Pedro.Lomonaco@oregonstate.edu*

Abstract

Through the Natural Hazards Engineering Research Infrastructure program (NHERI) established by the National Science Foundation in the United States, a suite of experimental facilities has been made available to the research community to advance the resilience of civil infrastructure and communities to coastal storm and earthquakes hazards. An experimental facility called the NHERI Coastal Wave/Surge and Tsunami Experimental Facility (CWST-EF) was created through this program that serves as a state-of-the-art engineering research, education, and outreach center related to tsunamis caused by earthquakes and coastal waves and surge caused by windstorms. CWST-EF includes two specialized large-scale resources for physical model testing of coastal systems: a large wave flume (LWF) and directional wave basin (DWB). The LWF is the largest of its kind in North America and can generate repeatable regular, irregular, tsunami, and user-defined waves. The LWF is used to induce and measure wave forces on constructed and natural ocean features at large Reynolds numbers, providing high resolution wave structure interactions with minimum distortion due to viscous effects. The DWB contains a multidirectional piston-type wavemaker with 30 independently-programmable servomotor-driven points. The wavemaker is also capable of generating repeatable regular, irregular, tsunami, and user-defined waves. These facilities are available to the research community to address grand challenges in tsunami and coastal windstorm surge and wave hazards that include built and natural environments.

Keywords: experimental; tsunami; surge; multi-hazard; NHERI

1. Introduction

The O.H. Hinsdale Wave Research Laboratory (HWRL), established at Oregon State University (OSU) in 1972, was awarded a National Science Foundation (NSF) grant to operate as an experimental facility (EF) within the Natural Hazards Engineering Research Infrastructure (NHERI) program. The facility at OSU is called the NHERI Coastal Wave/Surge and Tsunami Experimental Facility (CWST-EF). In this role, CWST-EF serves as a state-of-the-art engineering research, education, and outreach center related to tsunamis caused by earthquakes and coastal wave and surge caused by windstorms with two specialized large-scale resources for physical model testing of coastal systems. CWST-EF builds on OSU's past experience serving as the Tsunami Experimental Facility as part of the NSF Network for Earthquake Engineering Simulation (NEES) program from 2000 to 2004, and operated the NEES Tsunami Facility from 2004 to 2014. The laboratory is comprised of two large-scale facilities: a large wave flume and a multi-directional wave basin. Further, the laboratory is fitted with standard and state-of-the-art instrumentation and equipment for conducting large-scale, high quality testing of fluid-interaction experiments in the built and natural coastal environments. The NHERI program provides funding that allows access to these unique facilities to members of the US research community.

The overall vision for the CWST-EF is to increase the resilience of civil infrastructure and communities to coastal storms and tsunamis. Earthquakes and windstorms represent multi-hazards, and CWST-EF will contribute to the broader societal goals of reducing the loss of life and human suffering, decreasing direct economic damages, and increasing the rate at which socio-economic recovery can occur for coastal hazards. The other impacts of this work are expected to improve codes and standards for the design of civil engineering infrastructure subjected to these hazards as well as sustainable strategies for coastal protection. Such strategies include the evaluation of green infrastructure such as the role of coastal dunes and other aspects of the natural environment in hazard mitigation and resilience.

2. Experimental Facilities

The experimental facilities available at CWST-EF are the large wave flume and the directional wave basin. The Large Wave Flume (LWF), shown in Figs. 1a and 1b measures 104 m long and 3.7 m wide, with 4.6 m high walls and a maximum still water depth of 2.74 m (maximum still water depth for tsunami generation is 2 m). The LWF is the largest of its kind in North America and among the top 10 worldwide in terms of system performance. The LWF makes use of a piston-type wavemaker with a programmable hydraulic actuator capable of generating repeatable regular, irregular, tsunami, and user-defined waves. The stroke of the actuator is 4.2 m, and the wave board is dry-back (water on one surface only). The wavemaker is operated with periods ranging from 1.0 to 20 seconds and with a maximum wave height of 1.6 m at 4 seconds. Active reflected wave cancellation is provided by a wave profile measurement at the wave generator, serving as an input to wave board velocity control. This simulates the open boundary condition at sea, minimizing reflection off the wave generator and maintaining the quality of the incident wave environment. The LWF is used to induce and measure wave forces on constructed and natural ocean features at large Reynolds numbers, providing high resolution wave structure interactions with minimum distortion due to viscous effects. A powered carriage with full cross-shore traverse services the flume. The carriage supports a vertical instrument deployment frame and allows for video and lighting applications. The floor of the flume consists of moveable segmented slabs to alter the slope and depth of the flume for different needs.

Fig. 1a – Image of LWF looking toward wavemaker.

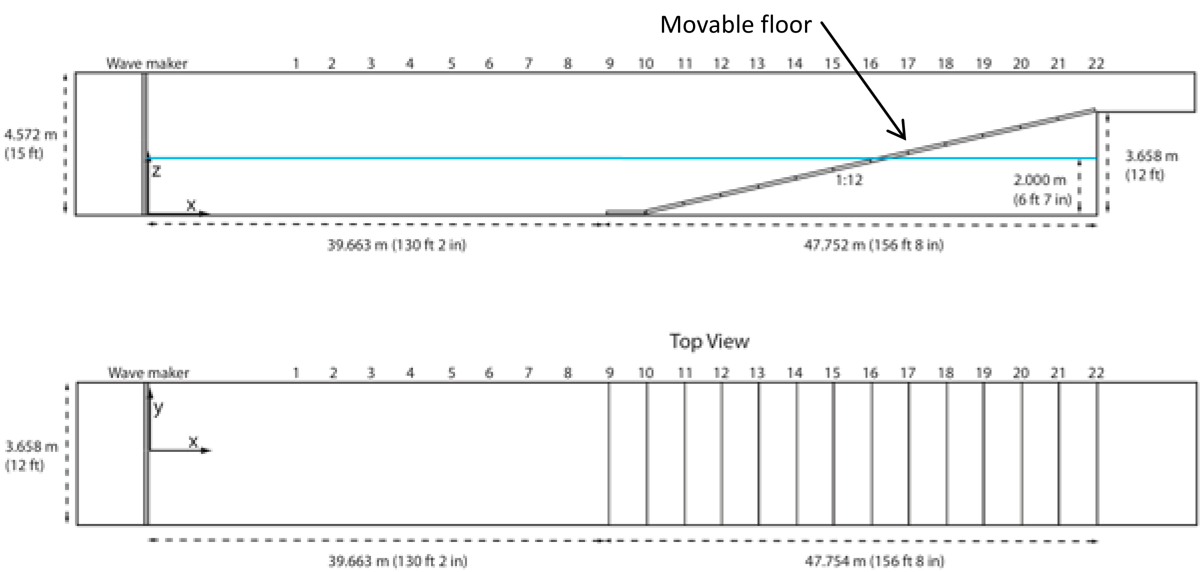

Fig. 1b – Overall elevation (top) and plan (bottom) views of the LWF.

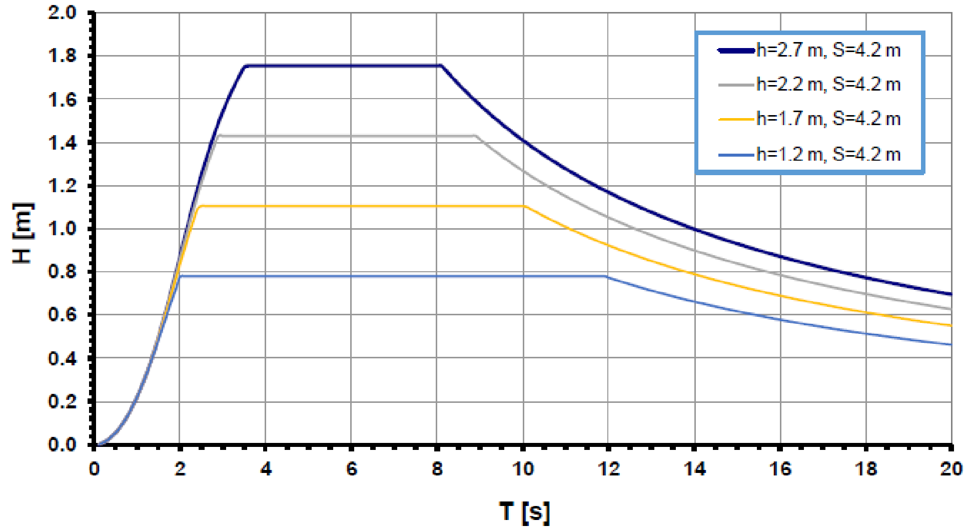

Fig. 1c – Design performance curves for regular waves in LWF over different wave periods (H is wave height, h is the still water depth, and S is the stroke of the wavemaker).

The Directional Wave Basin (DWB) is 48.8 m long and 26.5 m wide, with 2.1 m high walls and a maximum still water depth of 1.37 m (maximum still water depth for tsunami generation is 1 m). It is constructed as a reinforced concrete reservoir, with a 15 cm wall and floor thickness. A vehicle access ramp, 3 m wide, allow equipment and materials to be transported conveniently into and out of the basin. A bridge crane with a capacity of 7.5 tons spans the length and width of the DWB to position models and to facilitate instrumentation. Floor inserts are placed in rows at 1.22 m spacing to affix specimens and instrumentation throughout the basin. The DWB wavemaker is a multidirectional piston-type with 30 independently-programmable servomotor-driven points. Each drive point has a maximum stroke of 2.1 m and a maximum velocity of 2 m/s. The wavemaker is capable of generating repeatable regular, irregular, tsunami, and user-defined waves, and has the same active reflected wave cancellation system as the LWF. Example performance curves are shown for the DWB in Fig. 2c.

The wave generation and control system for both the LWF and DWB were developed by MTS Corporation. The system is very robust and strongly related to the specific hardware. Software has been, therefore, developed and maintained by MTS whenever it is required. The wave generation software allows the input of user-defined drive signals. This allows the inclusion of recent developments and to incorporate new wave generation techniques under development, increasing the flexibility and capability of the CWST-EF.

Fig. 2a – Image of DWB looking toward wave-maker.

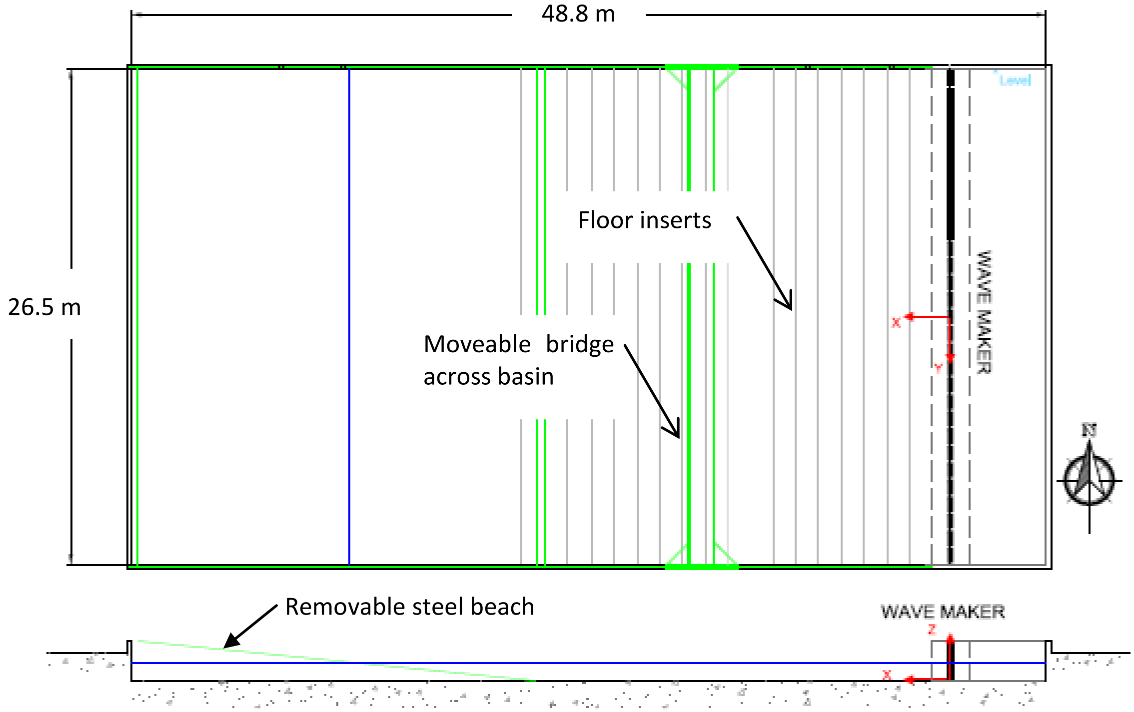

Fig. 2b – Overall plan (top) and elevation (bottom) views of the DWB.

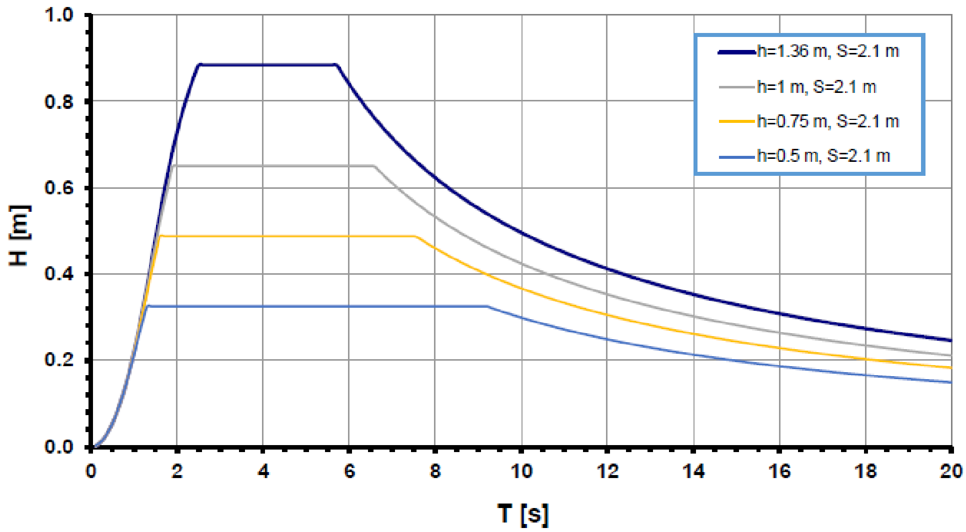

Fig. 2c – Design performance curves for regular waves in DWB over different wave periods (H is wave height, h is the still water depth, and S is the stroke of the wavemaker).

CWST-EF is equipped with a suite of in-situ instrumentation. The free surface is observed with surface-piercing wire wave gages and ultrasonic range finders. Water particle velocities are observed with up to 16 acoustic Doppler velocimeters. Fluid pressures are observed with strain-gage-based pressure sensors, and total loads on structures are observed with load cells at capacities up to 222 kN. CWST-EF is capable of deploying these sensors in fixed locations or from movable instrument platforms that span either the LWF or the DWB. It is equipped with survey and bathymetric profiling instrumentation for locating sensors in the tanks or for observing erosion or deposition of the bed. Observations are made using a data acquisition system (DAQ) that is synchronized with UTC (Coordinated Universal Time) and across multiple runs of the same wave conditions to provide synoptic data sets. The DAQ is operated on a University-wide site license of National Instruments LabVIEW and updated and tested annually. CWST-EF also operates remote-sensing instrumentation including stereo (3D) PIV and surface tracking, six DOF motion capture, and HD video cameras for tracking wave runup or large-scale hydrodynamic features. Where applicable, all instrumentation is regularly and traceably calibrated.

Experimental observations are immediately recorded to disk on the DAQ and then pushed to an intermediate processing system, which records an additional copy to disk before sending it on to a private backed-up server at CWST-EF and also to a second backed-up server running a secure web-based interface. Researchers can immediately access the data via this interface as soon as an experimental trial is completed. Additionally, an entire project's worth of data is archived to disk and provided to researchers prior to their departure from the facility.

3. Science Plan

Hurricanes Sandy in 2012, Ike in 2008, and Katrina and Rita in 2005 have underscored the significant and growing risk to coastal communities due to wind hazards [1,2,3]. Hurricane-induced economic losses in the United States (US) have increased steadily over the past 60 years and are now $35.8B annually. Approximately 50% of the US population lives within 50 miles of a coastline, and the physical infrastructure to support this population was estimated in the 1990s to be over $3 trillion in the Gulf and Atlantic regions. These problems are compounded by global climate change resulting in increased sea levels and in the intensity and frequency of extreme windstorms. Related to the overland flow conditions brought about by hurricanes, tsunami inundation can have devastating consequences as seen in recent tsunamis in the Indian Ocean (2004), Samoa (2009), Chile (2010), and Japan (2011). Several states including Alaska, Hawaii, Washington, Oregon, California and the territory of Puerto Rico are vulnerable to tsunami hazards, and the US Pacific Northwest is threatened by the earthquake and near-field tsunami hazard generated by the Cascadia Subduction Zone [4]. Immediate life safety remains the most critical issue, with potential loss of life in excess of 10,000 people in the Pacific NW because tsunami evacuation plans in most communities are based on far-field tsunami scenarios from the 1960s and ignore shelter-near-place options through vertical evacuation.

The overall vision for CWST-EF is to support the broader vision of NHERI to increase the resilience of civil infrastructure and communities to coastal windstorms and tsunamis. Resilience is the ability of a system to absorb and recover from a sudden disturbance (e.g., [5]). When a hazard occurs, there is a sudden loss of system functionality, and the remaining available portion of the system functionality is called robustness. The time required to restore the system functionality is the rapidity. The goal for infrastructure resilience is to lessen the impact (increase robustness) and return the system to the pre-hazard state quickly. A system can be made more resilient by adopting mitigation strategies before the hazard occurs or adaptation strategies after the hazard occurs. CWST-EF supports the NHERI vision by (1) enabling breakthrough discoveries that increase community resilience to coastal windstorms and tsunamis and (2) enables development of new mitigation strategies to increase system robustness and future adaptation strategies that can improve the rate of recovery. Research outcomes from experimental work at CWST-EF will produce major benefits and broader impacts that include reduced loss of life, injury and suffering; reduced direct economic damages; and faster recovery for economic and social well-being.

4. Grand Challenges

4.1 Hurricane Surge and Waves

Hurricanes and other coastal windstorms are extreme hazards with three main elements: (1) elevated surge and waves, (2) high winds, and (3) intense rains that threaten near-coast structures and critical lifelines such as bridges, roads, power and communication, and water supplies. CWST-EF will play an essential role in providing breakthrough understanding of the dynamics of elevated surge and waves on the natural and built environment. In a recent workshop report to develop a research roadmap for reducing the impact of windstorms and coastal inundation (NIST, 2014), research topics were grouped into four categories: (1) hazard identification, (2) loads and effects, (3) structure resistance, and (4) performance-based design. CWST-EF can be used to primarily impact the last three of these needs.

4.2 Tsunami Inundation

The tsunami hazard follows a sequence of generation, propagation, and inundation. Generation refers to the creation of the sea disturbance which is an active research area by seismologists and marine geologists. Propagation refers to the movement of the disturbance across the sea, which is generally considered a ‘solved’ problem. Inundation refers to the overland flow of the tsunami through the natural and built environment. Understanding the inundation phase remains a Grand Research Challenge, particularly in estimating the loss of life and immediate infrastructure damage or the system robustness. The loss of life issue for tsunamis is complex because the evacuation time of approximately 30 minutes is long enough for people to take action (unlike earthquakes) but too short for advanced warning and evacuation strategies (like hurricanes). Accordingly, the optimum evacuation scenario is likely to be a combination of shelter-in/near-place (like earthquakes) and shelter out of the hazard zone (like hurricanes). The role of engineering will be to develop mitigation strategies such as vertical evacuation to enable immediate life safety (e.g., [6]). These strategies are particularly important for vulnerable populations due to age, mobility issues, and economic factors. However, the design and placement of vertical evacuation requires a high degree of confidence in the inundation levels and flow velocities for a particular site. In addition to the loss of life issue, a second Grand Research Challenge surrounds the multi-hazard of combined earthquake and tsunamis. Overland flow, related to hurricane surge for example, can also be applied to tsunami flow. The flow through and around the built environment is particularly vexing because the constructed environment deteriorates as the hazard progresses, creating a nonlinear system where the robustness of a particular building is dependent on robustness of the surrounding buildings, protective systems such as seawalls, or natural buffers like beaches, dunes, and ‘green’ infrastructure.

5. Conclusions

CWST-EF will serve as the reference facility for basic and applied research in physical model testing of hydraulic-structure-sediment interactions under the effect of earthquakes and windstorm events, such as tsunamis and hurricane surge and wave hazards consistent with the science plan. The primary goal of CWST-EF is to be an integral part of NHERI, providing the following: access to unique, large-scale experimental test facilities through a transparent process coordinated by NHERI, expert advice on experimental design and implementation to achieve research objectives of the user community, high quality data to researchers with traceable standards, efficient scheduling and cost-effective use of the facility and upholding health and safety standards for the staff and visiting personnel, as well as fostering the inclusion of underrepresented groups.

7. Acknowledgements

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