Tidal Stations and Bench Marks: Tools for Spatial Information Managements

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Key words: tsunami, Tsunami Ready Tide Gauges, tidal bench marks, differential leveling and GPS observations.

SUMMARY

The Island of Puerto Rico has approximately 325 Km. of shore lines which are vulnerable to the occurrence of a tsunami generated by local earthquakes and submarine landslides. We are also at risk from regional Caribbean and distant Atlantic tsunamis. In order to register and document these types of phenomena we need to install a state of the art tsunami ready tide gauge network that can detect, record and analyze the data from sea level stations along with earthquake information. An innovative plan to install an alert system for tsunamis on the Island of Puerto Rico at strategic locations can be a critical step toward safety alert systems for the population. These sites are Arecibo, Fajardo, Guayanilla, Mayagüez, Yabucoa and the North coast of Vieques. A central recording system will be installed at the Puerto Rico Seismic Network to record and analyze the data from these and other tsunamis ready tide gauges that are going to be installed by National Oceanographic and Atmospheric Administration (NOAA) in Puerto Rico (San Juan, Parguera, Mona, Aguadilla, Vieques South and Culebra) and the Virgin Islands and the Tsunamis Ready Buoys to be installed in the Atlantic and the Caribbean.

The paper will describe the installations of the tidal stations and the tidal bench marks procedures and selections, in addition to the differential leveling and GPS observations.

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1. INTRODUCTION

The Puerto Rico Seismic Network (PRSN) at the Geology Department with in the College of Arts and Sciences of the University of Puerto Rico at Mayagüez, proposes to install a Puerto Rico Tsunami Ready Tide Gauge Network which will include 6 tsunami ready tide gauge stations and a central receiving station. The six tide gauge stations will be located in Arecibo, Mayagüez, Peñuelas, Yabucoa, Fajardo and Isabel II in Vieques. At the facilities of the Puerto Rico Seismic Network in Mayagüez a GOES base station will be set up to acquire the data from these and other sea level monitoring stations located in the Caribbean region and Atlantic basin, including the future National Oceanographic and Atmospheric Administration (NOAA) Tsunami Ready Tide Gauges and DART buoys. The sea level information will be integrated with the Early Bird earthquake detection system already in place at the PRSN and was installed as part of the Federal Emergency Management Agency (FEMA) funded Puerto Rico Tsunami Warning and Mitigation Program. All the stations will follow NOAA's National Ocean Survey (NOS) and NGS (National Geodetic Survey) standards and the National Tsunami Hazard Mitigation Program guidelines so the data can be fully integrated with other systems for monitoring tsunamis, storm surges, navigation, research and changes in sea level due to Global Climate Change. The data and information gathered by this network will benefit all Puerto Rico coastal communities which are at risk from tsunamis and sea level changes in general.

2. ABOUT PUERTO RICO

Puerto Rico was discovered on November 19, 1493 by Christopher Columbus, on his second voyage to the New World, bound for Hispaniola. He came upon the Island, calling it San Juan Bautista. At the time of its discovery, Puerto Rico was a point of contact between the Taíno Indians of the Greater Antilles and ferocious Caribe tribes that inhabited the Lesser Antilles. In 1508, a group of Spanish conquistadors arrived under the leadership of don Juan Ponce de León, who started the colonization and became the first governor. Near what is known today as San Juan Harbor, they founded San Juan, the second oldest city of the New World. On the Harbor of San Juan they built a walled city that, along with Cartagena de Indias of Colombia, became the great strongholds of the Spanish Main, and a leading defensive bastion of the vast empire. Puerto Rico was a point of departure for expeditions to colonize and explore America, as well as a depot for the trans-shipment of gold from the Indies to Spain.

As a result of the Spanish American War, Puerto Rico was ceded to the United States of America in 1898. The Jones Act of 1917 extended a United States citizenship to the people of Puerto Rico. In 1952 Commonwealth Status was adopted in the Island. Since 1947, Puerto

Rico has experienced a dramatic shift from an agricultural society to an industrialized one. This has resulted in significant economic growth that has positioned the Island as the showcase of the Caribbean. Its modern infrastructure, highly professional work force and industrial incentive programs have attracted foreign corporations to establish manufacturing facilities in Puerto Rico. To further stimulate Puerto Rico's economic growth, new alternatives are being forged to expand tourism activities to play an active role in the Caribbean and to diversify its industrial base. The Island is still developing new strategies to promote employment and economic growth. These efforts are led by the government and the private sector. Puerto Rico is one of the most pleasant and exciting places to live and to visit that can be found anywhere in the world.

3. ABOUT OUR UNIVERSITY

The University of Puerto Rico is a well established and a mature institution, with a total enrollment of over 69,000 students. The University consists of the Mayagüez Campus, the Medical Sciences Campus, and the Río Piedras Campus, which are dedicated to both undergraduate and graduate education; and the Colleges at Aguadilla, Arecibo, Bayamón, Carolina, Cayey, Humacao, Ponce, and Utuado which provide undergraduate education. Each autonomous institutional unit has a Chancellor as chief administrator and academic officer.

The University of Puerto Rico was created by an act of the Legislative Assembly on March 12, 1903 emerging as an outgrowth of the Normal School, which had been established three years earlier to train teachers for the Puerto Rican school system. In 1908, the benefits of the Morill-Nelson declared applicable to the island, fostered the rapid growth of the University. Eloquent evidence of that growth was the establishment of the College of Liberal Arts at Río Piedras in 1910 and the College of Agriculture at Mayagüez in 1911.

It was in the College of Agriculture where the Mayagüez Campus as we know it today had its origin. Credit for the establishment of the College is given to the joint effort of D. W. May (Director of the Federal Experiment Station), José de Diego, and Carmelo Alemar. A year later, the school received the name that it wore for 50 years: the College of Agriculture and Mechanic Arts. The strengthening and diversification of the academic programs at Mayagüez were recognized years later when, in 1942, as a result of a university reform, the campus was organized with a considerable degree of autonomy into the Colleges of Agriculture, Engineering, and Science under the direction of a vice-chancellor. The expansion continued through the 1950s when many programs flourished in the University. The College of Arts and Sciences and the Nuclear Center were established in Mayagüez. The Colleges of Humanities, Natural Sciences, Social Sciences, and Business Administration emerged in Río Piedras. The Schools of Medicine, Odontology, and Tropical Medicine were established in San Juan.

In 1966, the Legislative Assembly reorganized the University of Puerto Rico as a system of autonomous campuses, each under the direction of a chancellor. The College of Agriculture and Mechanic Arts became the University of Puerto Rico, Mayagüez Campus.

Today, the Mayagüez Campus of the University of Puerto Rico continues its development in the best tradition of a Land Grant institution. It is a co-educational, bilingual, and non-sectarian school comprising the Colleges of Agricultural Sciences, Arts and Sciences, Business Administration, Engineering, and the Division of Continuing Education and Professional Studies. The College of Agricultural Sciences includes the Agricultural Experiment Station and the Agricultural Extension Service. At present, the campus population is composed of 12,136 students, 1,336 regular staff members and 1,026 members of the educational staff.

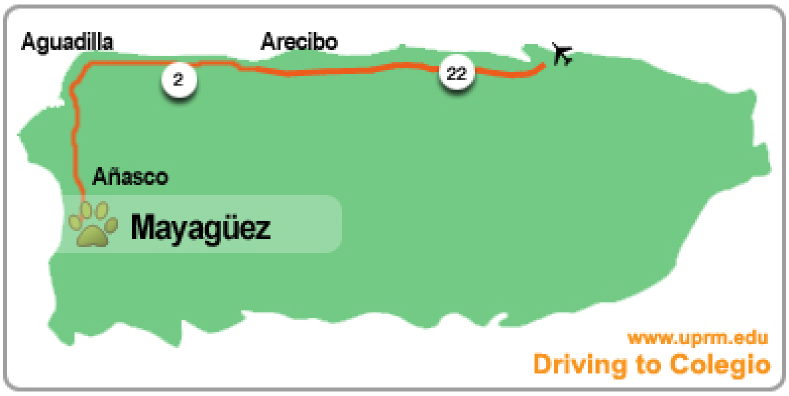

Figure 1 - The University of Puerto Rico at Mayagüez is located in the city of Mayagüez on the western side of Puerto Rico.

4. ABOUT PUERTO RICO TSUNAMI READY TIDE GAUGES PROJECT

During the past decades and especially on December 26, 2004 we have all witnessed the devastation that can be caused by tsunami waves. As part of the lessons learned, new techniques that can help in case of a future tsunami have been designed. In terms of warning systems, time is a critical factor in these natural events. To avoid the unexpected presence of these waves and alert citizens ahead of time, the use of Tsunami Ready Tide Gauges is of great help. The West Coast and Alaska and Pacific Tsunami Warning Centers (WCATWC and PTWC) use data from these instruments along with those from the Tsunami DART buoys and seismic stations to decide whether or not it is necessary to issue tsunami information, warning or watch messages and to cancel these messages once they have been issued. Although some stations will be upgraded and installed by NOAA in Puerto Rico and the Virgin Islands, additional stations are needed and a center which can receive and analyze this potentially critical data on the island needs to be established.

The Island of Puerto Rico has approximately 325 Km. of shore lines which are vulnerable to the occurrence of a tsunami generated by local earthquakes and submarine landslides. We are also at risk from regional Caribbean and distant Atlantic tsunamis. In order to register and document these types of phenomena we need to install a state of the art tsunami ready tide gauge network that can detect, record and analyze the data from sea level stations along with earthquake information. An innovative plan to install an alert system for tsunamis on the Island of Puerto Rico at strategic locations can be a critical step toward safety alert systems for the population. These sites are Arecibo, Fajardo, Guayanilla, Mayagüez, Yabucoa and the

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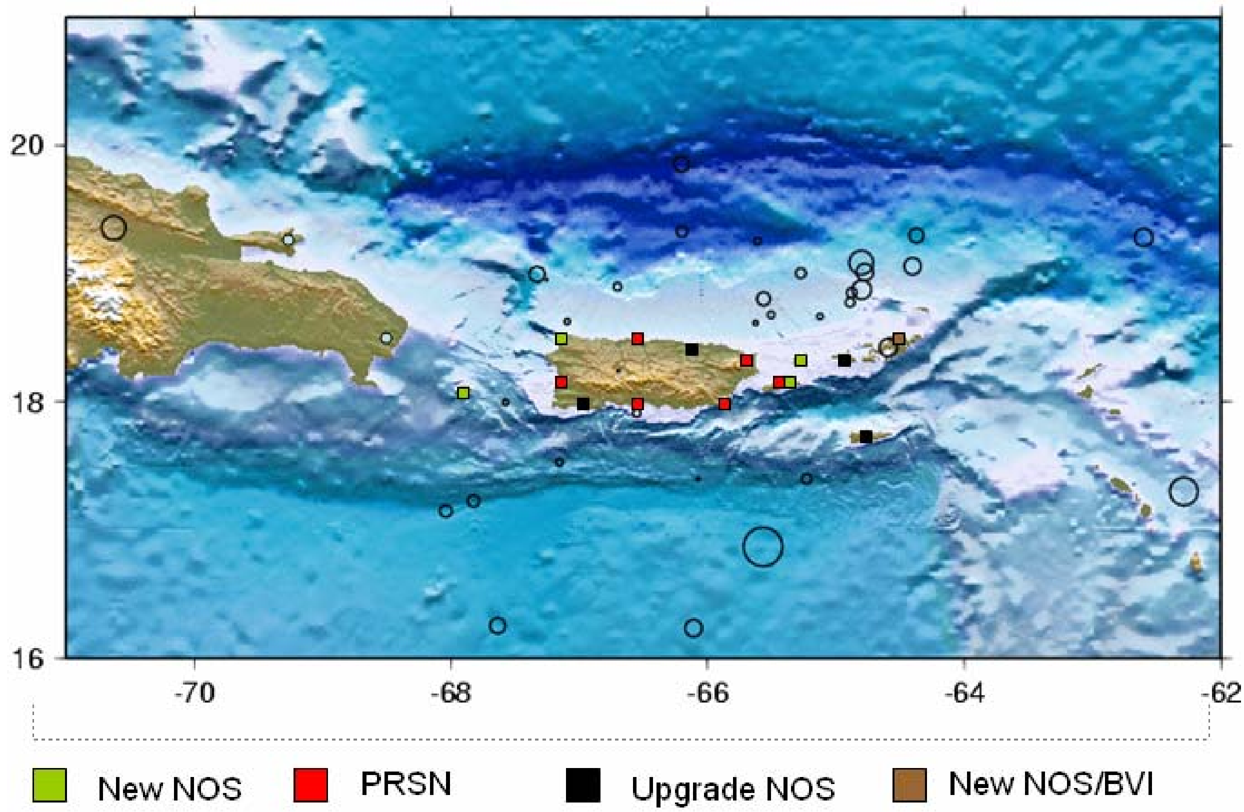

Figure 2 Distribution of tsunami ready tide gauge stations in Puerto Rico and the Virgin Islands.

The data gathered will be analyzed along with earthquake information to decide whether or not tsunami warnings or watches should be issued and when to cancel them if they have been issued. These systems have also proven to be very effective to avoid false alarms. The tsunami protocols will be reviewed, the public will continue to be educated and a prototype siren will be installed to complete the Puerto Rico Tsunami Warning System.

All sites will fulfill the requirements of the National Oceanographic and Atmospheric Administration (NOAA), National Ocean Service (NOS), Center for Operational Oceanographic Products and Services (CO-OPS) network and follow the guidelines of the National Tsunami Hazard Mitigation Program. The Geostationary Operational Environmental Satellite (GOES) system will be used to transmit all the data from the stations, not only to the PRSN, but any agency that uses this technology including the San Juan Forecast Office of the National Weather Service which would transmit the tsunami messages and the PTWC which provides tsunami warning guidance to Puerto Rico and the WCATWC which backs up the PTWC.

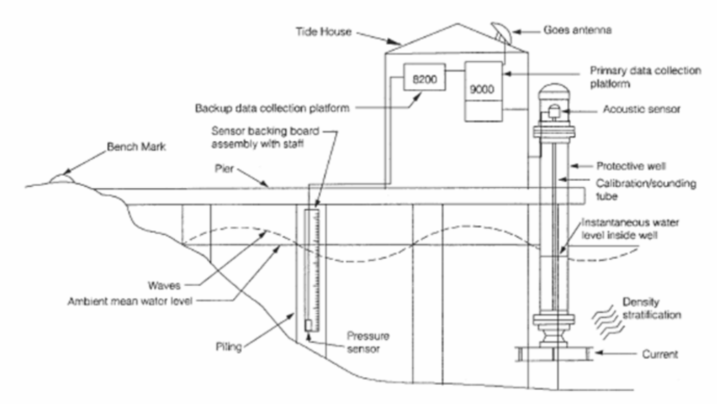

Figure 3 Typical Tide Station Components

Figure 4 Mayagüez Port Tide Station

4.1 Data Logger and Software

The NOS tide stations are based on the Sutron Xpert series of data loggers. The XPerts include specialized software to collect data from the primary and redundant gages, log the data in flash memory, and format standard data messages for transmission over the GOES satellite system. Stations support self-timed reporting at intervals of either one hour or every six minutes. The six-minute transmissions are a requirement for tsunami ready tide gauges.

The software includes algorithms for detecting the sudden drop in water surface normally associated with Tsunamis. Each station can provide special data reports when Tsunamis are detected.

NOS will not certify a data logger/GOES transmitter combination as a tide/tsunami station without the software to generate the formats. Stations cannot be incorporated into the NOS network without the formats. The NOS GOES data transmission format has been under development and refinement since June of 2001. For tsunami purposes the new 6-minute interval transmissions will be used.

4.2 Leveling and Monumentation of the Tide Gauge Stations

The leveling and monumentation will be done by the Land Surveying Program of the Civil Engineering and Surveying Department of the College of Engineering. Quality of leveling is a function of the procedures used, the sensitivity of the leveling instruments, the precision and accuracy of the rods, the attention given by surveyors, and the refinement of the computations. To perform vertical control levels with the electronic digital/barcode leveling systems at water level stations we will follow the User's Guide for Electronic Levels of NOAA, January 2003. It is intended to supplement the *User's Guide for the Installation of Bench Marks and Leveling Requirements for Water Level Stations (User's Guide).* This document only addresses those standards and specifications that differ from conventional three wire level methods covered by the *User's Guide.* Electronic leveling performed at water level stations shall adhere to Federal Geodetic Control Subcommittee (FGCS) Standards and Specifications. Any requirement not addressed can be assumed to be unchanged. Reference is made in this document to *"Input Formats and Specifications of the National Geodetic Survey Data Base"* (NGS Bluebook), September 1994.

Second-order, class I levels shall be used in connections at all primary and secondary control stations. Although third-order levels may be used at all other stations, the on-site, self checking capability inherent in second-order levels warrants its use if at all feasible. The following tolerances shall be observed in leveling at all stations: maximum length of sight, 60m (197 ft.) for 2^{nd} order, class I; max~ difference in length of forward and backward sights; 5m (16 ft.) per setup (2^{nd} order, class I); maximum closure between forward and backward runnings, 6 mm $\sqrt{K}$, (0.025 ft. $\sqrt{M}$) per section and line (2^{nd} order, class I); minimum ground clearance of line of sight, 0.5 m (1.6 ft.) for 2^{nd} order and 3^{rd} order, and determination of temperature gradient for vertical range of line of sight at each setup, for 2^{nd} order only.

Figure 5 Digital Photograph of the Tidal Bench Mark 9394A at Mayagüez Port

4.3 GPS Observation

The Global Positioning Systems (GPS) observations will be done by the faculty and students of the Land Surveying Program of the Civil Engineering and Surveying Department of the College of Engineering. Project documentation and data submission will require the following information to be submitted to CO-OPS at the end of the project so that proper information can be forwarded to the NGS (refer to the User's Guide for GPS Observations). Most of the information is used to submit the GPS data to NGS. In addition to the log, data must comply with the "Data Submission to NGS Section" of NGS-58 and the "Input Formats and Specifications of the National Geodetic Survey (NGS) Data Base" to become part of the National Spatial Reference System (NSRS).

Figure 6 GPS Observation at the Tidal Bench Mark 9394D at Mayagüez Port

REFERENCES

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BIOGRAPHICAL NOTES

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Ms. Linda L. Vélez-Rodríguez has a BS in civil engineering from the University of Puerto Rico at Mayagüez and an MS degree in geodetic science from The Ohio State University at Columbus, Ohio, USA. Ms. Vélez-Rodríguez is a full professor at the Land Surveying Program of the Civil Engineering and Surveying Department of the University of Puerto Rico at Mayagüez. She is also a Licensed Professional Engineer and Professional Land Surveyor in Puerto Rico. She participates in conferences, seminars, and workshops, as well as contributing numerous articles to technical journals published by the Puerto Rico's Engineers and Land Surveyors Association and others. In addition to teaching, she does consulting as expert witness in Land Surveying cases. She is a member of the Editorial Advisory Board of the Journal Surveying and Land Information Systems, published by the American Congress on Surveying and Mapping, a "Geodetic Liaison" for the National Geodetic Survey since 1999, as part of the Memorandum of Understanding between National Oceanic and Atmospheric Administration (NOAA) and University of Puerto Rico at Mayagüez.

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