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Hurricane Katrina and Ocean Engineering lessons learned

1. Introduction

After the completion of the Interagency Performance Evaluation Task (IPET) force study described later in this volume, the idea of publishing this Special Issue (SI) was conceived by me in 2007 and proposed to Professors R. Cengiz Ertekin and Atilla Incecik, Chief Editors of Ocean Engineering journal. I contacted the Editors to explore the possibility of publishing an SI in OE on this high-visibility subject that had affected millions of lives in the United States and attracted attention of others worldwide. I proposed the SI to be limited to the scope of IPET study and consist of papers based on research and engineering works that the IPET project undertook.

The Editors were very much in favor of the proposal, encouraging me to move ahead with the planning, while they were working on budgeting and other related matters with the publisher. Upon this assurance and support, I contacted Drs. Donald T. Resio and Robert G. Dean, the co-leads of one of the tasks of the IPET study, and their response was positive, offering me their assistance. Subsequently, I asked them for a list of papers, contributors, and abstracts. With the review of papers completed in September 2009, this SI became a 2-year project. I could not have done this alone. Many people contributed to the success of this SI, and let me acknowledge all the key players involved.

I am grateful to Drs. Resio and Dean for their support during this challenging effort; they submitted the topics for papers and selected the contributors. The Special Issue could not have happened, of course, without the authors of the papers. As expected, I had the most contact with the authors of manuscripts. They provided me information sought by reviewers, answered questions, and revised their papers numerous times. I apologize to them if I was at times pushy and demanding, and truly appreciate their professionalism and friendship. Thanks to their timely collaboration that made this SI possible.

I would like to thank my 63 peer reviewers, who were the key persons in the process of creating the special issue at the highest standards expected of peer-reviewed papers. Without their input, the present task would have been impossible. I am grateful to all the reviewers for their invaluable contributions; they voluntarily spent their valuable times to help, and many provided me multiple reviews in a three-round review process. They are not listed to ensure anonymity, nevertheless their efforts are deeply appreciated.

I would like to thank both Chief Editors of the OE journal, Professors Ertekin and Incecik, for their help throughout this endeavor. I like to thank the staff of Elsevier Publications Department, who came to my help when required. In particular, I would like to acknowledge the continual expert help that I received from Mr. Jeff Rossetti, the capable OE Journal Publication Manager, and without his expertise, this SI could not have been completed on time.

I also would like to thank the managers of the US Army Research and Development Center, Coastal and Hydraulics Laboratory, for providing me sources to perform my Guest Editor duties. Lastly, special thanks and appreciation are extended to my wife, Kay K. Demirbilek, who most endured my long hours, and helped me mentally and emotionally while I was working in this demanding assignment.

2. Objectives

To disseminate key findings from research and engineering works conducted by the IPET task force to scientific and engineering communities worldwide. The intent for an SI type publication was to provide a forum for scientific dialogue and exchange of information that have emerged from the IPET study, to give researchers worldwide opportunity to access sources of IPET products, to allow a chance to critique works performed, to conduct follow-up research that can lead to alternative solutions and improved methods to help engineers, planners and decision makers. The ultimate goal is to help humans prepare for and deal with potential consequences of severe hurricanes in the future.

3. Background

The hurricane season in USA runs between June 1 and November 30, and peak hurricane activity generally is between mid-August and mid-October. In an average year, there have been about 10 tropical storms developed in the Gulf of Mexico, Caribbean Sea, or Atlantic Ocean since 1950, and only six storms became hurricanes. Approximately five hurricanes hit the United States mainland in a typical 3-year span, with two designated as major hurricanes (Categories 3–5). The southeastern United States is the region most vulnerable, and the States most likely to be hit by a major hurricane are the states of Florida, Alabama, Mississippi, Louisiana, and Texas.

Hurricane Katrina was the most destructive natural disaster in the US history. The overall destruction and catastrophic flood caused by this large and powerful hurricane vastly exceeded that of three other major disasters: the 1871 Chicago Fire, the 1906 San Francisco Earthquake and Fire, and the 1992 Hurricane

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Andrew. Katrina's devastating effects on the US economy were felt well before the storm reached the Gulf Coast on 29 August 2005. The approaching Hurricane Katrina first battered the offshore energy infrastructure in the Gulf of Mexico, forced the evacuation of more than 82 percent of 800 manned oil platforms, and reduced oil production by more than a half. It must be noted that about 75 hurricanes of Katrina's strength at landfall (e.g., Category 3) have hit the mainland United States since 1850, roughly once every 2 years. What was unique about Katrina was that it was not a typical hurricane, its size was larger than most. Comparatively, Hurricane Camille was a Category 5 storm that devastated the Gulf Coast in 1969, with higher wind speeds exceeding those of Katrina at landfall, but Katrina's hurricane force winds extended over 100 miles from its center as compared to Camille's hurricane force winds only extended 70 miles from its center. Because of this size difference, Hurricane Katrina's storm surge affected a larger area, impacted nearly 93,000 square miles across 138 parishes and counties, much more than did Hurricane Camille's, while both storms had different storm surges (maximum 22.4 feet vs. 28 feet for hurricane Cammille and Katrina, respectively). It must be noted that the 1900 hurricane caused 6,000 (or more) deaths.

Hurricane Katrina's winds and storm surge overwhelmed the protective infrastructure in and around the City of New Orleans, and damaging residential and commercial business property in the city and neighboring east and west coastal communities and many miles inland. The storm surge overwhelmed levees all along the lowest reaches of the Mississippi River and the edges of Lake Pontchartrain, flooded large parts of New Orleans, which sits mostly below sea level, due to levee failures that occurred on the 17th Street Canal, the Industrial Canal, and the London Avenue Canal. Nearly 80 percent of the city was flooded. But, Katrina's extent of destruction was widespread beyond the limits of New Orleans, and many small and large towns and cities were destroyed or heavily damaged up and down the Gulf Coast and miles inland, from Morgan City, Louisiana, to Biloxi, Mississippi, to Mobile, Alabama, where Katrina's wind, rain, and storm surge demolished infrastructure, homes and businesses. Large parts of the coastal areas of these States were devastated. For example, approximately 80 miles across the Mississippi Gulf Coast was largely destroyed, including the town of Waveland in Mississippi had no inhabitable structures after the storm.

What was different about Hurricane Katrina and what went wrong? Hurricane Katrina evolved in approximately 1 week time to impact the coastal and mainland USA. It formed on 23 August 2005 as a tropical storm (e.g., winds between 39 and 73 mph) off the coast of the Bahamas, grew into a catastrophic hurricane (e.g., wind speeds between 74 and 200 mph), made landfall first in Florida and then along the Gulf Coast in Mississippi, Louisiana, and Alabama, and caused devastation and human suffering previously not seen in the history of USA. The storm caused significant physical destruction along its path before making a landfall on the Gulf Coast the morning of 29 August 2005 and flooding the historic city of New Orleans, ultimately killing more than 1300 people, and becoming the most destructive natural disaster in US history. While Americans watched on television the events unfold, the Nation saw with disappointment and frustration the seeming inability of the local, State, and Federal governments to respond effectively to the crisis. It was Hurricane Katrina and the subsequent sustained flooding of New Orleans that exposed significant flaws in Federal, State, and local preparedness for catastrophic events, requiring revision of emergency plans at all levels of government to coordinate and integrate State, local, and private sector partners. These individual plans were put to the ultimate test, and all came up short. Important lessons were learned by planners, politicians, and millions of Americans realized the need to protect themselves and their families, and not to depend on local, State and Federal government.

A brief explanation of the "100-year flood" is provided here to facilitate a clear understanding of technical material presented in 13 papers in this SI. It is emphasized that a flood level with an annual exceedance probability of p will be equaled or exceeded at an average rate of once every $1/p$ years. As an example, a 100-year flood is very frequently used in United States as a benchmark for catastrophic flooding. This is a magnitude of flood that has a 1 percent chance of being exceeded in any given year. As such, it would be possible that several 100-year floods can occur within a few years at a coastal region exposed to hurricanes. On the other hand, a region may not experience a 100-year flood for several hundred years, while the long-term average rate will be once every 100 years. Perhaps the term "100-year event" is somewhat misleading because it is not an event that will occur once every 100 years, and instead it is an event that has a 1 percent chance of occurring each year. Likewise, the 100-year hurricane could occur more than once in a relatively short period of time, or never, in a hundred year.

The probability of occurrence of flood events or return period of hurricanes can easily be estimated. Consider a citizen in Mississippi coast who lives in a region designated to be in the 100-year flood plain, and assuming the person plans to reside in a home for 30 years. The probability of being flooded at least once over a 30-year period is given by $1-(1-0.01)^{30}\sim 25$ percent, meaning that there is a 25 percent likelihood for this home to be affected by a 100-year flood event. Comprehensive treatment of flood vulnerability methodologies are provided later in this SI.

4. Contents of SI

The SI is a collection of 13 papers produced from the investigation undertaken in the IPET study. The papers in this SI summarize the results of forensics, experimental and theoretical investigations on the fundamental aspects of five specific issues IPET was tasked to investigate. In the order of appearance, the papers are: The Anatomy of a Disaster, An Overview of Hurricane Katrina and New Orleans; Climatological Characteristics of Landfalling Hurricanes for Wind, Wave, and Surge Hazard Estimation; Reconstruction of Hurricane Katrina's Wind Fields for Storm Surge and Wave Hindcasting; Potential Impact of Sea Level Rise on Coastal Surges in Southeast Louisiana; Physical Model Study of Wave and Current Conditions at 17th St Canal Breach Due to Hurricane Katrina; The potential of Wetlands in Reducing Storm Surge; A Hydrodynamics-based Surge Scale for Hurricanes; Analysis of the Coastal Mississippi Storm Surge Hazard; Development of Storm Surge Which Led to Flooding in St. Bernard Polder during Hurricane Katrina; Erosional Equivalences of Levees: Steady and Intermittent Wave Overtopping; Quadrature-Based Approach for the Efficient Evaluation of Surge Hazard; Efficient Joint Probability Methods for Hurricane Surge Frequency Analysis; An Application of Boussinesq Modeling to Hurricane Wave Overtopping and Inundation.

5. The IPET study

This unique and specialized study was performed between September 2005 and September 2006 to evaluate the performance of flood protection systems following the devastation caused by Hurricane Katrina throughout the coastal areas of Mississippi, Louisiana, Alabama and Texas, with most damage occurring in and around the City of New Orleans and neighboring towns. The task force consisted of inter-government agencies, academics and private industry contributors. An External Review Panel of experts by the National Research Council and American Society of Civil Engineers (ASCE) was setup to guide and evaluate the IPET task force.

The IPET work presents a methodological framework for the estimation of coastal vulnerability to storm impacts at two scales, regional and local. It estimates the physical coastal vulnerability through the quantification of storm event and resulting consequences due to failure of flood protection systems. The focus of the IPET study was on performance evaluation of New Orleans and Southeast Louisiana hurricane protection system. The mission of IPET was to provide credible and objective scientific and engineering answers to fundamental questions about the performance of the hurricane protection and flood damage reduction system in the New Orleans metropolitan area. The five specific tasks IPET was charged to investigate were:

1. The Flood Protection System: What were the design criteria for the pre-Katrina hurricane protection system, and did the design, as-built construction, and maintained condition meet these criteria? What were the design assumptions and as-built characteristics of the primary components of the flood protection system? What records of inspection and maintenance of original construction and post Katrina repairs are available that document their conditions? What subsurface exploration and geotechnical laboratory testing information were available as the basis of design, and were these conditions verified during construction? Were the subsurface conditions at the locations of levee failures unique, or are these same conditions found elsewhere?
2. The Storm: What were the storm surges and waves used as the basis of design, and how do these compare to the storm surges and waves generated by Hurricane Katrina?
   What forces, as a function of location and time, were exerted against the hurricane protection system by Katrina?
3. The Performance: How did the floodwalls, levees, pumping stations, and drainage canals, individually and acting as an integrated system, perform in response to Hurricane Katrina, and why? What were the primary failure mechanisms and factors leading to failure for those structures suffering catastrophic failure during the storm? What characteristics allowed components of the system to perform well under exceptional loads and forces? What was the contribution of the pumping stations and drainage system in the dewatering of flooded areas? What areas or components of the flood protection system have sustained damages that reduce their protection capacity and may need some reconstitution of capacity?
4. The Consequences: What have been the societal-related consequences of the Katrina-related damage? How are local consequences related to the performance of individual components of the flood protection system? What would the consequences have been if the system would not have suffered catastrophic failure? What are the consequences of Katrina that extend beyond New Orleans and vicinity?
5. The Risk: Following the immediate repairs, what will be the quantifiable risk to New Orleans and vicinity from future hurricanes and tropical storms? What was the risk to New Orleans and vicinity from hurricanes prior to Katrina? On June 1, 2006, what will be the condition and engineering integrity of the New Orleans hurricane protection system, including structural repairs?

Additional information about the IPET study is available from its official website: https://ipet.wes.army.mil/

In closing, this SI is a tribute in part to those who have endured Hurricane Katrina's enormous impact on their families, lost their lives, suffered damages and continue to be affected by lasting consequences of this tragic event. It is also hoped that information provided in this technical publication can be used in helping people still suffering, recovering and rebuilding their lives and communities along the coasts of Louisiana, Mississippi, Alabama and Texas. While some future storms will exceed design capacities, it is hoped that the papers in this volume will reduce, to the maximum extent possible, tragedies of the magnitude of Hurricane Katrina. The information provided in this SI should also help planners and decision makers to improve their preparedness and emergency response measures that will lessen future hurricane damages on their communities.

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