(Written comments by Dr. Ed Link, IPET Director, on presentation of the IPET Draft Final Report)

Performance Evaluation of the New Orleans and Southeast Louisiana Hurricane Protection System

Interagency Performance Evaluation Task Force

Draft Final Report, June 1, 2006

The Interagency Performance Evaluation Task Force (IPET) today is releasing this draft final report of its performance evaluation of the New Orleans and Southeast Louisiana Hurricane Protection System during Hurricane Katrina. Our sincere hope is that the results of this report, used already in the repairs of the system, the assessments of the undamaged portions of the protection system, and being incorporated in design guidance for future protection projects in the area, will help such a tragedy from ever occurring again.

This comprehensive evaluation was conducted by the IPET, a distinguished group of more than 150 government, academic, and private sector scientists and engineers who dedicated themselves solely to this task for the last eight months. IPET applied some of the most sophisticated capabilities available in civil engineering to understand what happened during Katrina and why. This included two of the world's largest centrifuges and one of the Department of Defense's newest supercomputers. But the most important capability, by far, was the diverse experience and expertise of the many people that comprised IPET.

While IPET was created by Lt. Gen. Carl Strock, the Chief of the U.S. Army Corps of Engineers, its work was peer reviewed literally on a weekly basis by an equally distinguished review panel of the American Society of Civil Engineers. This built in quality and relevance from the beginning.

The purpose of the IPET was not just new knowledge, but immediate application of that knowledge to the repair and reconstitution of protection in New Orleans. IPET results were transferred and applied as quickly as possible to the repairs of the system. This transfer was greatly facilitated by the direct participation on IPET teams by professionals from Task Force Guardian, Task Force Hope and the New Orleans District. We believe the IPET findings and lessons learned, together with those of others, will be an effective platform for improvements to engineering practice and policies dealing with hurricane protection.

This report is being provided as a draft, offering provisional final results for the entire spectrum of the work accomplished, with the notable exception of the risk and reliability assessment, which, at the request of the ASCE External Review Panel, is undergoing validation and peer review and should be released later this month or in July at the latest.

This draft report will receive final reviews by the American Society of Civil Engineers External Review Panel and the National Research Council Committee on New Orleans

Regional Hurricane Protection Projects. The results of those reviews will be incorporated into the IPET final report, which is expected to be released in September 2006.

From the beginning, IPET was charged by the Chief of Engineers and the Assistant Secretary of the Army for Civil Works to work in an open environment and provide maximum exposure for public awareness. Report 1, published in January, presented a detailed scope of work, and Report 2, published in March, provided an update on the analysis and interim results. Since then additional interim reports were released, such as the failure mechanisms for the London Avenue Canal and the Inner Harbor Navigation Canal breaches. The majority of IPET information and documents were placed on the public Web site, *https://IPET.wes.army.mil*. At this time, there are more than 4300 documents on this site.

There are nine volumes in this draft final report. They are designed to provide a detailed documentation of IPET's technical analyses and associated findings. The volumes are organized around major technical tasks that together provided an in-depth, system-wide assessment of the behavior of the hurricane protection system and the lessons learned that were incorporated into the repairs and that are being integrated into the continuing efforts to improve the system in the future. All nine volumes are available publicly on the IPET web site.

The volumes and their individual focus areas are as follows:

- Volume I: Executive Summary and Overview – Summary of findings and lessons learned. Overview of performance evaluation activities and reports.

- Volume II: Geodetic Vertical and Water Level Datum – Update of geodetic and water level references for the region and determining accurate elevations for all critical structures.

- Volume III: The Hurricane Protection System – Documentation of the character of the hurricane protection system, including the design assumptions and criteria, as built and maintained condition.

- Volume IV: The Storm – Determining the surge and wave environments created by Katrina and the time history and nature of the forces experienced by protection structures during the storm.

- Volume V: The Performance – Levees and Floodwalls – Understanding the behavior of individual damaged structures and development of criteria for evaluation of undamaged sections. Providing input to repairs and ongoing design and planning efforts.

- Volume VI: The Performance – Interior Drainage and Pumping – Understanding the performance of the interior drainage and pumping systems with regard to extent and duration of flooding. Examination of scenarios to understand system-wide performance.

- Volume VII: The Consequences – Determination of the economic, human safety and health, environmental, and social and cultural losses due to Katrina. Examination of scenarios to understand implications of losses and possible recovery paths on future risk.

- Volume VIII: Risk and Reliability – Determination of the inherent risk for all parts of the system prior to and following Katrina. Provision of capability for risk-based decision support for continuing improvement and development of hurricane protection.

- Volume IX: Supporting Appendices – Documentation of information resources and management, program management, and communications.

The IPET did not examine organizational or jurisdictional issues that impact the effectiveness of the physical system. These issues are being examined by the Corps of Engineers initiated Hurricane Katrina Decision Chronology Study, being conducted by a separate group of investigators. Other teams of investigators outside the Corps are also examining and contributing insights to these issues.

The IPET findings and lessons learned are presented in detail in the individual Volumes of the report and summarized in Volume I, the Executive Summary and Overview. A unique aspect of the IPET work is that the results are in many cases, already “in the ground” in the repairs that have been accomplished. They are also incorporated into the planning and design processes that are being used to complete the system. The analytical tools and information will be transitioned to the Louisiana Comprehensive Protection and Restoration Study and other Corps offices to develop effective approaches for higher levels of protection.

Overarching Findings

The system did not perform as a system. The hurricane protection system in New Orleans and southeast Louisiana was a system in name only. The system’s performance was compromised by the incompleteness of the system, inconsistency in levels of protection, and the lack of redundancy. Incomplete sections of the system resulted in sections with lower protective elevations or transitions between types and levels of protection that were weak spots. Given that hurricane protection is typically a series system, the failure of the weakest component causes the failure of the system. Inconsistent levels of protection were caused by differences in the quality of materials used in levees, differences in the conservativeness of floodwall designs, and variations in structure protective elevations due to subsidence and construction below the design intent (due to error in interpretation of vertical elevation datum information). Systems also need redundancy, a second tier of protection to help compensate for the potential failure of the first tier. Pumping is a form of redundancy; however, the pumping stations are not designed to operate in major hurricane conditions nor are they part of the hurricane protection system. Armoring the back sides and crests of levees and the protected side of floodwalls would have added significant redundancy and reduced breaching. Surge gates at the mouths of the outfall canals are also an excellent example of providing redundancy.

The storm exceeded design criteria, but the performance was less than the design intent. Sections of the hurricane protection system were in many ways overwhelmed by Hurricane Katrina, such as the Gulf Intracoastal Waterway levees along New Orleans East and the levees in St. Bernard and Plaquemines Parishes. The combination of record high surge and long period waves exceeded the design conditions and devastated the levees in these areas. This devastation, however, was aided by incomplete protection, lower than authorized structures, and levee sections with erodible materials. While overtopping and extensive flooding from Katrina were inevitable, a complete system at authorized elevations would have reduced the losses. The designs were developed to deal with a specific hazard level, the Standard Project Hurricane as defined in 1965; however, little consideration was given to the performance of the system if the design event or system requirements were exceeded.

At the 17th Street Canal, two sites on the London Avenue Canal and at one site within the Inner Harbor Navigation Canal, foundation failures occurred prior to water levels reaching the design levels of protection. This caused breaching and subsequent massive flooding and extensive losses. These were all I-wall structures with a common failure mode that involved the formation of a gap on the canal side of the floodwall that precipitated and accelerated the failure in the foundation materials. These structures' designs were marginal with respect to practice, the uncertainty inherent in the variable geological conditions and the hurricane hazard for the area.

Two other sites within the Inner Harbor Navigation Canal experienced I-wall breaches due to overtopping and scour behind the walls, which reduced the stability of the structures. The storm surge levels in this canal exceeded the design levels, and lower structure elevations, reduced over two feet by 35 years of subsidence, contributed to the amount of overtopping that occurred.

Another site on the west side of the Inner Harbor Navigation Canal breached from overtopping and scour of a levee. The elevation of the levee was lower than adjacent areas (another example of the incomplete system with transitions), which added to its vulnerability.

The flooding and the consequences of the flooding were pervasive, but also concentrated. Consequences of the flooding and the associated losses were greater than any previous disaster in New Orleans and, in themselves, create a formidable barrier to recovery. Loss of life was concentrated by age, with more than 75 percent of deaths being people over the age of 60. Loss of life also correlated to elevation, in terms of depth of flooding, especially with regard to the poor, elderly and disabled; the groups least likely to be able to evacuate without assistance.

The majority of the flooding, approximately two-thirds by volume in Orleans (east bank) and St Bernard Parishes, and half of the economic losses can be attributed to water flowing through breaches in floodwalls and levees. Losses, and in many respects recovery, can also be directly correlated to depth of flooding and thus to elevation. In some areas flooded by Katrina where water depths were small, recovery has been almost complete. In areas where water depths were greater, little recovery or reinvestment has taken place.

Another concentration of consequences is in the nature of the losses. Twenty five percent of residential property values were destroyed by Katrina, and this loss represents 78 percent of all direct property damages. Non-residential properties suffered a 12 percent loss in total value or half the rate of residential. Clearly, residential areas were more prone to flooding.

The repaired sections of the hurricane protection system are likely to be the strongest parts of the systems until the remaining sections can be similarly upgraded and completed. Since there are many such areas where the protection levels will be the same as before Katrina, the New Orleans metropolitan area remains vulnerable to any storm creating surge and wave conditions similar to those of Katrina. An objective of the risk and reliability analysis is to understand the relative vulnerabilities of the various drainage areas of New Orleans and to identify the primary sources of those vulnerabilities.

Overarching Lessons Learned

The IPET analysis provides broad insights into the many aspects of the New Orleans and vicinity hurricane protection system and why the system performed as it did during Hurricane Katrina. Integration of a number of these principal lessons learned provides some strategic insights for the future protection in southeast Louisiana and for hurricane and flood protection projects in general.

Resilience. It is clear that a resilient hurricane protection system provides enormous advantages. Resilience in this case refers to the ability to withstand higher than designed water levels and overtopping without breaching. Approximately two-thirds of flooding and losses were the result of breaching, i.e., the significant loss of protective elevation in structures. While overtopping and rainfall alone from Katrina would have created dramatic flooding and losses, the difference is staggering in many regards. Reductions in losses of life, property, and infrastructure, associated reductions in the displacement of individuals, families, and the workforce, coupled with reduced disruption to businesses and social and cultural networks and institutions, would have a dramatic impact on the ability of a community and region to recover. Resilience has not been easily justified using the methodologies that emphasize net economic benefits. It was not an obvious element in the New Orleans Hurricane Protection System design.

It is important to view resilience as time-dependent due to changes in requirements for protection (i.e., changes in potential consequence) or changes in the hazard (climate dynamics or changes in the nature of the protection system and subsidence). Resilience must be part of the adaptive nature of a system and be reviewed frequently as a fundamental character of the design and capacity of the system. Three main principles are suggested:

- Designs conservative enough to appropriately account for the unknown and flexible enough to be augmented as hazards or requirements change.

- Performance redundancy such as armoring levees to prevent scour from overtopping that leads to failure and breaching.

- Integrated systems approach to protection, from design, construction, operation (including pumping), maintenance, and emergency operations perspectives.

System performance. Planning and design methodologies need to allow for an examination of system-wide performance. The piecemeal development of the New Orleans Hurricane Protection System provided a system in name only. The systems approach should have a time dimension to allow consideration of the potential changes in requirements or conditions over the life of the project and to examine approaches to build in adaptive features and capabilities. Subsidence, changing population demographics, and the changing patterns of hurricane intensity and frequency are obvious examples of the time-dependent challenges hurricane protection systems face. All components that contribute to the performance of the overall system must be treated as an integral part of the system. For any given drainage basin, the protection is only as robust as the weakest component of the system and how effectively the various components that are interdependent operate together.

Risk. A risk-based planning and design approach would provide a more viable capability to make informed decisions on complex infrastructure such as hurricane protection systems. The traditional approach, used for the New Orleans protection system, is component-performance-based that uses standards to define performance and relies on factors of safety to deal with uncertainty. It is difficult to examine the integrated performance of multiple components, and standards are usually limited to past experience. Risk-based planning is systems-based, requiring that the entire system be described in consistent terms and explicitly, including uncertainty. Component performance is related to system performance as well as the consequences of that performance.

The risk-based approach uses factors such as loss of life, environmental losses, and cultural consequences in decision making without reducing all factors to one measure, such as dollars. As applied for the IPET risk assessment that will be released later, it allows aggregation and de-aggregation of information to address issues at different scales, providing a useful tool for collaborative planning between responsible agencies at different levels. Most importantly, risk and reliability allows decision makers to understand the relative levels of vulnerability that specific areas face, the nature of the consequences (e.g., loss of life, economic loss or environmental loss), and to understand the source of the vulnerability.

Knowledge, technology and expertise. The history of the planning, design, and performance of the Hurricane Protection System in New Orleans also points out a dilemma in engineering. While new pieces of knowledge were available over time that were relevant to the ultimate performance of the I-walls on the outfall canals, the pieces were not put together to solve the puzzle of the failure mechanism that occurred.

The Corps' own testing of sheetpile floodwalls (E-99 Sheet Pile Wall Field Test Report, June 1988) was not directed at the global stability of I-walls, but with hindsight, some of the behavior observed was indicative of the wall deflections that led to formation of the gap. Similarly, late in the 1990s, research published in part by the Waterways Experiment Station discussed the need to include hydrostatic water pressures with regard to a gap forming in the numerical modeling of sheetpile floodwalls. Work not directly related to levees or floodwalls in England discussed the deflection and hydrostatic water pressure problem for earth retaining walls. How do these puzzle pieces get placed together to create knowledge for designers, and how do designers and reviewers get access to this information? How does the research or testing community become aware of applications, perhaps different from their original purpose, for their new knowledge?

Part of the solution relates to the amount of overall effort and resources put into the search for new knowledge and capabilities to deliberately update design criteria and planning capabilities. The solution is not simply more research or more outreach alone, it is the ability of the design/construction and research communities to work together in an environment that enables collaboration and experimentation with new knowledge and approaches to old and new problems. There has been a distinct loss in resources expended in this area, particularly in the domain of hurricane and flood protection and specifically in the geotechnical fields that are at the heart of the levee and floodwall performance issues in Katrina. The focus on "standards" may in fact also deter this process. Standards imply stability and constancy, when in fact the concept of "guidelines" may be more appropriate, allowing and encouraging customization and adaptation as new knowledge emerges. In either case, standards and/or guidelines need to be refreshed at a greater and greater frequency as the generation of new knowledge continues to accelerate.

The other dimension to this issue is expertise. As technology accelerates and engineering practice evolves at an increasing pace, it becomes more difficult to maintain the level of technical expertise necessary to cope with the ever more complex issues, such as water resources. Significant measures are needed to re-emphasize technical expertise and renewal of that expertise as the engineering practice evolves. These measures must be part of the culture of organizations and cover the entire profession to ensure that the total team addressing priority issues, such as hurricane protection, are working from the latest knowledge and professional practice. The Corps of Engineers should be a leader in this area.

Closing

The Interagency Performance Evaluation Task Force offers this report and its findings as a contribution to the well being of the people of New Orleans and southeast Louisiana and the reconstitution of effective hurricane protection for their future. We hope that implementation of these findings will help prevent such an event from ever happening again.

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