Summary of Field Observations Relevant to Flood Protection in New Orleans, LA

Interim report to Task Force Guardian

by the

Interagency Performance Evaluation Task Force

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1. Introduction

Background: On 29 August 2005, Hurricane Katrina made landfall just to the east of New Orleans. This storm inflicted significant damage on the hurricane protection system for southeast Louisiana. The subsequent flooding has been a major catastrophe for the region and the nation.

The response of the Corps of Engineers to this disaster has included the activation of Task Force Guardian (TFG) with the responsibility to repair the damages to the hurricane protection system. In addition, the Chief of Engineers established an Interagency Performance Evaluation Task Force (IPET) comprised of leading experts in a comprehensive array of science and engineering disciplines charged with studying the response of the hurricane protection system during Katrina for lessons to be learned. A major focus of the IPET is to provide Task Force Guardian with timely insights into the design and construction of immediate repairs and for potential long-term improvements to the system.

This report is the first of a series of interim reports that the IPET will provide to Task Force Guardian to assist them in their work to repair and reconstitute flood protection in New Orleans. These interim reports and additional analyses will be finalized and integrated to create a final report of the IPET which will be released by 1 June 2006. The majority of the comments provided herein have been communicated informally to Task Force Guardian to expedite their application.

Hurricane Katrina was a very large storm. Sustained wind speeds at landfall were in the neighborhood of 147 miles per hour. The sustained wind speeds for the standard project hurricanes used to design many of the flood protection structures in and around New Orleans were in the neighborhood of 100 miles per hour. While wind speed alone is not a complete measure of the surge and wave environments experienced by specific structures, it is a clear indicator of the level of the forces to which the system was subjected. It is important to note that the observations contained herein are based on the performance of the system with respect to the forces imposed on the system by Katrina, not those that were the basis for the design of the structures.

Objective: The objective of this report is to provide Task Force Guardian with an independent assessment of the observations presented in the "Preliminary Report on the Performance of the New Orleans Levee Systems in Hurricane Katrina" released by the American Society of Civil Engineers and the National Science Foundation on 2 November 2005. The intent was to provide

Task Force Guardian with additional insights (beyond those gained from their own review) with regard to what aspects of the field observations presented in the report could be immediately applied to the repairs to the flood protection system and what aspects may need additional analyses prior to implementation.

Approach: The IPET Perishable Data Team, which was engaged in field data collection in conjunction with the ASCE and NSF sponsored teams, as well other key members of the IPET, reviewed the ASCE/NSF report and developed comments concerning the application of the primary observations in the report. The IPET team was comprised of Paul F. Mlakar, Ph.D., P.E., ERDC; Joseph B. Dunbar, ERDC; Mr. Ken Klaus, P.E., MVD; Reed L. Mosher, Ph.D., ERDC; George L. Sills, P.E., ERDC; and Noah Vroman, ERDC. Review and additional comments were provided by the Technical Director, John Jaeger, Ph.D., PE, and the IPET Director, Lewis E. Link, Ph.D., P.H.

The IPET comments are presented below in the context of the architecture of Chapter 8, Summary of Observations and Findings, of the ASCE/NSF report. Each paragraph of Section 8 of the ASCE/NSF report is presented, followed by (in italics) the IPET comments on the preliminary ASCE/NSF observation or finding.

2. Comments on ASCE/NSF Summary and Findings

ASCE/NSF: The storm surges produced by Hurricane Katrina resulted in numerous breaches and consequent flooding of approximately 75% of the metropolitan areas of New Orleans. Most of the levee and floodwall failures were caused by overtopping, as the storm surge rose over the tops of the levees and/or their floodwalls and produced erosion that subsequently led to failures and breaches.

a. The IPET team generally agrees with this statement.

b. *The primary impact of the storm was the surge and waves that created stress on the flood control structures. Just as the character and levels of the surge and waves varied with location, the character and level of the forces varied significantly depending on location and exposure to the storm. It is essential to understand these differences in forces to understand the performance of individual levee and floodwall sections. This is a primary focus of the modeling being done by the IPET.*

ASCE/NSF: Overtopping was most severe on the east side of the flood protection system, as the waters of Lake Borgne were driven west producing a storm surge on the order of 25 feet that massively overtopped levees immediately to the west of this lake. A second very severe storm surge occurred farther to the south, along the lower reaches of the Mississippi River, and significant overtopping produced additional breaches in this region as well.

a. The IPET team agrees in general with these field observations.

b. *The level of the storm surge is likely to be significantly different in different locations. The precise level of the surge from Lake Borgne remains to be determined, however, observations indicate that it was very large and caused*

significant overtopping of the levees in that area. The IPET is performing an in-depth analysis of the surge and wave action for the entire New Orleans as input to more specific analysis to determine the forces acting on the levees and floodwalls in different locations so that structural performance analyses can be accomplished.

ASCE/NSF: Overtopping was less severe along the Inner Harbor Navigation Canal and along the western portion of the Mississippi River Gulf Outlet channel, but this overtopping again produced erosion and caused additional levee failures.

a. *The IPET team agrees in general with these field observations.*
b. *This will also be part of the IPET in-depth analysis of the surge and wave action in the New Orleans area as a result of the hurricane. The general surge and wave environments will be conveyed into the channels and more refined physical and numerical modeling accomplished to deal with the affects of the complex geometries and flow patterns in these confined spaces. The resultant water levels and movements will be the basis for determining the expected behavior of these structures and provide a reference for understanding the observed behavior.*

ASCE/NSF: Field observations suggest that little or no overtopping occurred along most of the levees fronting Lake Pontchartrain, but evidence of minor overtopping and/or wave splashover was observed at a number of locations. There was a breach in the levee system at the northwest corner of the New Orleans East protected area, near the Lakeside Airport.

a. *The IPET team agrees in general with these field observations.*
b. *The breach near the Lakeside Airport observed by the ASCE/NSF team was at a complex transition that had sections of varying heights and features, i.e., levees and floodwalls.*

ASCE/NSF: Farther to the west, in the Orleans East Bank Canal District, three levee failures occurred along the banks of the 17th Street and London Avenue Canals, and these failures occurred at water levels below the tops of the floodwalls lining these canals. These three levee failures were likely caused by failures in the foundation soils underlying the levees, and a fourth "distressed" levee/floodwall segment on the London Avenue Canal shows signs of having neared the occurrence of a similar failure prior to the water levels having receded.

a. *The IPET concurs with these general observations. However, it should be noted that significant scour was noted at the southeast corner of the intersection of the Robert E. Lee Bridge and the London Avenue Canal in close proximity to the deformed section of wall across from the breach . Also, damages near the pump station at the head of the Orleans Canal appear to indicate overtopping.*

b. *The breaches at the 17th Street Canal and London Avenue Canal North and South are most likely due to a soil foundation failure. Extensive observations by a number of teams found no signs of major overtopping of these systems at the breach sites. These breaches are being examined in-depth by IPET so a complete*

understanding of the failure mechanism can be determined. A number of factors are being examined, individually and in combination, at each breach location. These factors include but are not limited to:

i. *The potential for differences between the as-built levee/floodwall structures and the construction plans and specifications;*
ii. *The shear strength, permeability and other properties of each soil horizon from the ground surface to depths greater than -60 feet below sea level;*
iii. *The nature of the soil materials in each horizon, i.e., whether the soils are natural deposits, engineered (compacted to prescribed moisture and density specifications) fill or non-engineered fill;*
iv. *The nature and extent of deleterious material inclusions within the soil horizons, such as tree stumps and other organic materials;*
v. *The soil-structure interaction to the forces imposed by Katrina;*
vi. *The effects of trees, swimming pools and other inclusions within and in close proximity to the right-of-way for the project;*
vii. *The proximity of each of these failures to bridges and the potential concentration of forces at specific wall sections; and*
viii. *The potential for differences between operations and maintenance practices and the Operations and Maintenance Manual for each project.*

c. *Boring and cone penetrometer tests have been taken at each of these sites to help characterize the specific subsurface conditions. Sections of the walls at each end of the breach sections and the failed remnants are being extracted to determine the exact dimensions and properties of the as-built structural elements, concrete, steel rebar reinforcement and steel sheet pile. Test pits may be excavated to provide direct visual evidence of the in-situ conditions adjacent to the failed zones and/or at the location of the deformed floodwall section across from the north breach at the London Avenue Canal. Precise surveyed cross-sections thorough the entire right-of-way immediately upstream and downstream of each failed section have been developed to define the geometry. Also, the most recent pre-Katrina cross-sections will be used to aid slope stability analyses both at the failed and intact sections of the outfall canals. These and perhaps additional measurements are needed to support an accurate representation of the conditions in the soil-structure interaction performance analysis.*

ASCE/NSF: One common mode of both failure and damage was the erosion of soils at the land side toes of floodwalls as water cascaded over the tops of the concrete floodwalls atop the earthen levees. This was a problem at many I-walls, but was not a problem at most T-walls as the concrete base stems of the inverted T-wall sections acted to deflect the overtopping waters. T-walls also were constructed with more substantial and robust supporting foundations. At a number of I-walls, the waters overtopped and then cascaded down the inboard side, producing very sharply etched erosional trenches, of varying depths, in the soils at the land side toes of the walls. That erosion reduced the lateral soil support otherwise offered at the land side sides of the

walls, and reduced the walls' ability to withstand the elevated lateral forces exerted by the risen waters on their water sides.

a. *The IPET team agrees in general with these field observations.*
b. *Observations indicate that water overtopping the floodwalls and the levees led to extensive scour and erosion in some locations, which may ultimately have resulted in breaches in the flood protection system. This was most dramatic along the Inner Harbor Navigation Canal adjacent to the Lower 9th Ward where the I-wall (floodwall) was breached. It appeared that water flowing over the floodwall scoured and eroded the levee on the protective side of the I-wall, exposing the supporting sheet piles and reducing the passive resistance. The erosion appeared to be so severe that the sheet piles may have lost all of their foundation support, resulting in failure. Perhaps the best evidence of this scour can be seen along the unbreached reaches of the I-walls on the Inner Harbor Navigation Canal where U-shaped scour trenches could be found adjacent to the I-walls. As the scour increased, the I-wall may have moved laterally and leaned to the protective side, causing the scour trench to grow as the water began shooting farther down the slope until sufficient soil resistance was lost and the wall was carried landward. I-walls along the Mississippi River Gulf Outlet and the Mississippi River in Plaquemines Parish show similar response to overtopping where the greater the scour, the greater the lateral translation and tilting of walls.*
c. *The IPET will study these breaches to determine the amount of scour that would lead to a critical loss of support and instability. The results of this assessment will be used in examining the behavior of other I-walls along the Gulf Intracoastal Waterway and the Mississippi River in Plaquemines Parish.*
d. *While it appears that overtopping of the I-walls led to significant scour and possible breaching in multiple cases, it appears that if overtopping of T-walls did occur, it did not lead to extensive scour and erosion on the protective side of the floodwalls. Generally scour behind T-walls was less than that of I-walls because of the T-walls base slab that extended 4 to 6 feet beyond the vertical wall preventing immediate erosion on the protective side. However, there were some T-walls that had significant scour, but none showed evidence of distress or movement either lateral or rotational. There was one T-wall failure in Plaquemines Parish where the wall was undermined from a large adjacent scour.*

ASCE/NSF: A second issue noted at a number of both failed and distressed levee sites was an inconsistency in crest heights when multiple flood protection system elements came together. Often there were differences in crest heights between earthen embankment sections and adjacent concrete structural sections. Sometimes two adjacent concrete wall sections differed significantly in height.

a. *The IPET team agrees in general with these field observations.*
b. *A common problem observed throughout the flood protection system was the scour and washout found at the transition between structural features and earthen levees. In some cases, the structural features were at a higher elevation than the connecting earthen levee, resulting in scour and washout of the levee at the end of the structural feature. At these sites, it appears the dissimilar geometry*

concentrated the flow of water at the intersection of the levee with the structural feature, causing turbulence that resulted in the erosion of the weaker levee soil. A practical approach to integrating protection in these transitions would reduce vulnerability of failure in the future.

ASCE/NSF: Considerable erosional distress and a number of failures were noted at transitions between different earthen levee and concrete structural segments. Many of these areas of erosion appeared likely to have been related to inadequate transition details (e.g. insufficient overlap, etc.), but these were also commonly exacerbated by inconsistencies in crest heights that tended to concentrate overtopping flows at vulnerable transition locations.

a. *See the response to the previous finding.*

ASCE/NSF: Another repeated issue noted in these field investigations was the potential hazard posed by "penetrations" through the perimeter flood protection systems required in order to permit through passage of trains or other surface transit (e.g. roads, port vehicles, etc.). This produced additional transitions between disparate sections and also disjointed responsible authorities/agencies/owners at adjoining perimeter flood protection elements. At sections where infrastructure elements were designed and maintained by multiple authorities, and their multiple protection elements came together, the weakest (or lowest) segment or element controlled the overall performance.

a. *The IPET team agrees in general with these field observations.*
b. *Levees are series systems in that the parts of the system must all perform to be effective. The performance evaluation underway by IPET looks at the protection as a system composed of levees, walls, pumping stations, gates, and access "penetrations." The system provides protection by controlling flood water as it seeks paths under, over, and through the protection elements. The complications of multiple structure types and performance levels will be addressed as part of the performance evaluation. The issue of multiple governance and jurisdictional authorities is beyond the scope of the IPET and the reconstruction effort and should be addressed as a policy issue.*

ASCE/NSF: Finally, three major breaches, and at least one significantly "distressed" levee/floodwall section, occurred at sites along the 17th Street and London Avenue Canals which were clearly not overtopped. Currently available evidence suggests that the flood surge at these sites was on the order of 2 to 3 feet short of overtopping the floodwalls at these locations. Two of these failures were likely the result of stability failures within the embankment or foundation soils at or below the bases of the earthen levees. This would be consistent with instability due to under seepage flow, and resultant reduction of shear strength at the bases of the inboard sides of the earthen levee embankments, as well as the lateral "push" exerted against the sheet pile/floodwall diaphragms by the elevated waters on the canal sides of these wall systems. Evidence of piping erosion at two of these sites serves to illustrate the severity of the under seepage at high water stages. Another possibility that also needs to be investigated, however, is the potential presence of a weak stratum or soil unit (either within the lower embankment, or in the underlying foundation soils) with sufficiently low shear strength that it might have failed even without weakening due to under seepage flows. Piping or internal erosion, possibly initiated

or exacerbated by the uprooting of trees on or near the levee, may also have been the cause of the London Avenue Canal failure.

a. *The IPET team agrees in general with these field observations.*
b. *Based on field observations, it appears that overtopping was not the primary cause of failure. There are a variety of factors that may have led to the failures, and each warrants a thorough evaluation. A number of factors are being examined, individually and in combination, at each breach location. These factors include but are not limited to:*
    i. *The potential for differences between the as-built levee/floodwall structures and the construction plans and specifications;*
    ii. *The shear strength, permeability and other properties of each soil horizon from the ground surface to depths greater than -60 feet below sea level;*
    iii. *The nature of the soil materials in each horizon, i.e., whether the soils are natural deposits, engineered (compacted to prescribed moisture and density specifications) fill or non-engineered fill;*
    iv. *The nature and extent of deleterious material inclusions within the soil horizons, such as tree stumps and other organic materials;*
    v. *The soil-structure interaction to the forces imposed by Katrina;*
    vi. *The effects of trees, swimming pools and other inclusions within and in close proximity to the right-of-way for the project;*
    vii. *The proximity of each of these failures to bridges and the potential concentration of forces at specific wall sections; and*
    viii. *The potential for differences between operations and maintenance practices and the Operations and Maintenance Manual for each project.*
c. *Stability failures within the embankment or foundation soils at or below the bases of the earthen levees are possible failure mechanisms. Instability due to underseepage flow reducing the shear strength of the levee embankments while subjected to lateral loads from water in the canal pushing on the floodwall is one possible mechanism as a weak stratum or soil unit is another. To determine the probable failure mechanisms at the three breaches, IPET is conducting detailed characterization of both the forces imposed on the structures and the structures themselves. These information will be used in physical and numerical models to assess the probable causes of the failures and the most likely failure mechanisms. Each breach will be examined individually because of the potential for different dominant mechanisms or combinations of factors.*

ASCE/NSF: The third breach site (London Canal, South Breach) was massively eroded, leaving relatively little evidence to examine, and it is less clear what the failure mechanism was at this location. Instability of the inboard side of the earthen levee embankment, again possibly associated with under seepage and the lateral push of the outboard side canal water levels, or with seepage erosion and piping, would be consistent with the data and observations made at this site, however, and with photos taken shortly after the failure.

a. *The IPET team agrees in general with these field observations.*
b. *It is currently unsubstantiated what the failure mechanism was at the London Canal, South Breach. Based only on field observations without engineering*

analysis at this time, there are multiple possible failure mechanisms. Instability of the inboard side of the earthen embankment, possibly associated with underseepage, seepage erosion, and piping, is a possibility. The IPET analyses will consider all possible mechanisms in determining the most probable cause. Contributing factors may also include the influence of swimming pools, hot tubs, and trees adjacent to or built into the inboard levee toe.

ASCE/NSF: Additional studies will continue to be performed at most of the breached and distressed locations, and these will enable better definition of embankment and foundation soil conditions and appropriate seepage flow and shear strength characteristics. The precise soil strata and most critical mechanisms that led to the observed failures at a number of sites remain to be conclusively determined.

a. *Concur. The IPET performance evaluation and external review by the American Society of Civil Engineers will provide credible, objective engineering and scientific answers at the breached and distressed locations. A better definition of embankment and foundation soil conditions, seepage flow, and shear strength conditions will be provided. The IPET will determine the most probable cause for the critical mechanisms that led to the observed failures.*

ASCE/NSF: Significant additional field investigations (including CPT probes, borings and sampling, etc.) as well as laboratory testing are already underway under the auspices of the USACE at many of the key sites, and the USACE has agreed to openly share the results of these field and laboratory studies with our investigation teams. Similarly, the ASCE and NSF-sponsored investigation teams have met a number of times with the USACE levee investigation team from ERDC, as well as with representatives from the New Orleans District of the USACE, and have jointly developed lists of requested background documents including site investigation reports and boring logs, laboratory test data, design memoranda (including original design calculations and analyses), as-built section specifications and details, maintenance and field inspection records, etc. for many of the breached and heavily "distressed" levee and/or floodwall sections, and the USACE has promised to provide these as quickly as practicable.

a. *Concur. Completed boring records, test results and other data have and will be shared with the ASCE and NSF sponsored investigation teams. The IPET and ERP will share lessons learned with the public in a timely fashion as facts become known and analyses are validated. To date, more than 235 boxes of design and construction records on the New Orleans hurricane protection system have been collected. These hard copy records are being scanned and digitized as rapidly as possible. All releasable documents from this effort are posted on the public web site, https://ipet.wes.army.mil. 0ver 220 documents have been posted for public information as of 22 November 2005, including 75 Design Memos, 109 Plans and Specifications, and 32 Reports. It is our intent to post all releasable documents to the greatest extent possible. The efforts of TFG and the New Orleans District are greatly appreciated in this effort. It is hoped that information obtained from others will continue to be shared with IPET and made available to the public as was the ASCE and NSF "Preliminary Report on the Performance of the New Orleans Levee Systems in Hurricane Katrina on August 29, 2005."*

ASCE/NSF: Major repair and rehabilitation efforts are underway to prepare the New Orleans flood protection system for future high water events. The next hurricane season will begin in June 2006. Preparing the levees for the next hurricane season, however, should also include a review of how the system performed during Hurricane Katrina, so that key lessons can be learned and then used to improve the performance of the system.

a. *The response of the Corps of Engineers to this disaster has included the activation of Task Force Guardian (TFG) with the responsibility for the reconstruction of the hurricane protection system. The Chief of Engineers established an Interagency Performance Evaluation Task Force (IPET) and an American Society of Civil Engineers External Review Panel (ERP) charged with studying the response of the system in Katrina for engineering lessons to be learned. The IPET and ERP will share lessons learned in a timely fashion as analysis begins and facts become known and validated. The process for providing input to Task Force Guardian includes frequent informal communications and written interim reports that condense and organize information on particular topics or issues.*

ASCE/NSF: Based on our observations, a number of initial comments are warranted concerning the rebuilding and rehabilitation of the levee system.

a. *See comments below.*

ASCE/NSF: Although it is somewhat customary to expect levee failures when overtopping occurs, the performance of many of the levees and floodwalls could have been significantly improved, and some of the failures likely prevented, with relatively inexpensive modifications of the levee and floodwall system details. The addition of overtopping erosion protection at the land sides of the floodwalls through the provision of riprap, concrete splash slabs, or even paving of the ground surface at the inboard faces of the levee crest floodwalls might have been effective in reducing this erosion, and might have prevented some of the failures observed.

a. *The IPET concurs with the ASCE/NSF general observations and that erosion protection at the land side of floodwalls might have prevented some of the failures observed.*
b. *The degree of dependence of overtopping versus wave action on the scour and erosion of the levees is yet to be determined. Based on the field observations, for the reconstruction of levees, consider the possibility of using some type of erosion protection against overtopping and waves where significant erosion occurred during Hurricane Katrina. The possibilities include riprap, concrete mats or slabs, or paving on the protected side slope. Reaches or locations that will be subjected to large waves should possibly include such protection features on both slopes. The in-depth IPET analysis of storm surge and wave environments (currently underway by IPET) will provide specific input on where structures will most likely be subjected to larger than expected surge and wave conditions. Consideration should also be given to constructing these levees where appropriate with CH clay soils to improve their survivability chances.*

ASCE/NSF: As the New Orleans regional flood protection system is now being repaired and rebuilt, it would appear advantageous to plan crest heights in a systematic and deliberate way, so that if and when overtopping does occur, it occurs preferentially at the desired locations along any given section of levee/floodwall frontage. Sections designed to better resist overtopping and erosion should take the larger share of the overtopping flows. Similarly, the transitions between disparate levee/floodwall sections (e.g.: transitions between earthen levees, sheet piles, and/or concrete wall sections) should be more robustly designed and constructed (e.g. with more pronounced overlap, or embedment, of transitional sheet pile walls within adjacent earthen levee sections, etc.), so that such transitions do not represent locations of potential weakness in otherwise contiguous perimeter flood protection system.

a. *The IPET team in general agrees with the ASCE/NSF recommendation based on field observations.*
b. *The utility of adjusting crests heights so that if and when overtopping occurs, it occurs at desired locations should be considered. However the uncertainties of where to locate and how to size spillway dimensions requires deliberate consideration that may not be possible within the time constraints of repairing the damaged areas for the hurricane protection system prior to the 2006 hurricane season. If it is determined that spillways should be installed within specific sections of the levee and floodwall system, this can readily be done subsequent to the immediate repairs.*
c. *Areas where two different types of protection features join have been observed to be vulnerable if they are not integrated appropriately. Addressing these transitions is an important aspect of creating a more resilient system. The performance of these transitions could be improved by fully embedding the connecting walls of the structural feature in the levee and using the levee to transition the difference in elevation from the structural feature to the main section of the levee. In a few cases, observations indicated that this type of transition performed successfully. The embedded area and the transition to the main section of the levee may require some type of erosion protection such as grouted riprap or concrete erosion mats. The ongoing in-depth analysis will provide some insights on alternative approaches that can be considered by Task Force Guardian.*

ASCE/NSF: Regardless of the modes or causes of the various failures, it should be also be noted that emergency operations to close some of the breaches were seriously hampered by the difficult access to the breach sites. The USACE EM 1110-2-1913, "Design and Construction of Levees," Section 8-9, specifically addresses access roads on levees, and their need for "the general purpose of inspection, maintenance and flood-fighting operations." The majority of the levee miles constructed by the USACE in the United States meet these requirements. In the planning process, the cost of providing a roadway width at the top has sometimes led to significant discussion in formulating a project. Nevertheless, the policy remains.

a. *The IPET team concurs with the ASCE/NSF statement. Given the logistical difficulties in accessing and sealing the breaches to unwater flooded areas, TF Guardian should carefully reconsider the guidance in* EM 1110-2-1913.

ASCE/NSF: In the case of New Orleans, which likely had one of the most developed urban areas behind any USACE levee system, most capability for high-level access at many locations had been foregone when it was decided to put the I-walls in the existing levee crowns, so as not to require any significant amount of additional right-of-way. When the need for emergency operations came, many years later, these decisions resulted in very significant increases in time and cost to affect the needed closures.

a. *The IPET team in general agrees with the ASCE/NSF statement. See response for the previous finding.*

ASCE/NSF: Areas in which piping erosion occurred, including reported instances of piping along the MRGO frontage, suggest that there are areas of foundation that were weakened to a state worse than "pre-Katrina". Similarly, there may be additional sections like the west bank across from the North breach on the east side of the London Avenue Canal that were distressed (but did not fully breach) and are in need of remedial work. It is important to remember to check, and to repair as necessary, levee sections that may have been damaged but that did not fail as part of the current repair operations.

a. *The IPET team in general agrees with the ASCE/NSF statement.*
b. *A component of the in-depth IPET analysis will be an assessment of the residual capacity of the flood protection system. This will in part be through the projections of the types and levels of forces that each structure experienced, the results of the visual inspections and post storm evaluations made by the IPET, New Orleans District, Task Force Guardian and other field teams, and structural performance modeling that relates structure characteristics to protection capability. Detailed inspection of the entire hurricane protection system using appropriate remote sensing, surveying, inspection and investigation techniques and equipment implemented and analyzed by properly trained and experienced professionals is recommended to identify those structures that have been weakened but have little visual evidence of degradation.*

ASCE/NSF: Levees are "series" systems, where the failure of one component (levee segment) equates to failure of the system. They have less redundancy than many other engineered systems. In the case of the canal levees, the three "weakest links" failed, and the "fourth weakest link" (near the north end of the London Avenue Canal, on the east bank) experienced a near failure. Should these and any other damaged sections be repaired, the fact remains that the "next weakest link" (and so on) has not yet been tested to its design water height. The failure of these levees at less than their design water height warrants an overall review of the design of the system.

a. *The IPET team conditionally agrees with this statement.*
b. *The specific water levels and forces to which the levee and floodwall sections were subjected have not been determined and are the focus of the detailed analysis work of the IPET team. The failure mechanisms and the overall performance of the sections of floodwall and levee that failed will be examined in detail. The understanding of the forces, structure characteristics, and expected*

and observed behavior will provide valuable insights for assessing the integrity of related structures.

ASCE/NSF: In the short-term, as interim levee repairs continue, consideration should be given to retaining the use of sheet piles placed against the bridges at the north ends of the 17th Street and London Avenue canals to control storm and tidal surges. Until the levees in these canals are more fully repaired and/or more permanent canal surge check structures are emplaced, having the ability to rapidly prevent storm surges down these canals is still needed.

a. *The IPET team agrees in general with this statement.*
b. *The effectiveness of sheet pile or other barriers at the lake ends of the canals will be evaluated by IPET and recommendations provided with regard to the degree of protection against storm surge that those measures might provide.*

ASCE/NSF: The USACE, like other public agencies, commonly uses Independent Boards of Consultants to review the adequacy of the design and construction (and remediation) of major dams. The levee system in New Orleans actually protects more life and property than almost any major dam in the United States. Accordingly, we believe that the Corps should retain an Independent Board of Consultants to review the adequacy of the interim and permanent levee repairs being carried out in the aftermath of Hurricane Katrina.

a. *This statement is beyond the scope of the IPET and relates to Corps of Engineers policies and practice. Independent review of the analyses and recommendations of the IPET will be made by an external review panel directed by the American Society of Civil Engineers and an independent review panel under the auspices of the National Research Council.*

ASCE/NSF: The ASCE and NSF-sponsored levee assessment team(s) have already been instrumental in providing insights and recommendations for mitigating potentially serious deficiencies in the temporary/emergency repairs at a number of breached sections. It is anticipated that additional potentially important lessons will be learned in the months ahead as these investigations continue, and that some of these lessons are also likely to be useful in moving forward with the ongoing repair and long-term rebuilding of the New Orleans regional flood protection systems. Such lessons will continue to be passed along as quickly as practicable. As much of the population is currently being permitted to re-occupy portions of the New Orleans area, doing everything possible to ensure the safety of these people and their neighborhoods must continue to be the highest priority.

a. *The IPET team vigorously agrees that everything possible should be done to reconstitute an effective and resilient flood protection system for the New Orleans area. Such protection is currently limited to that authorized by Congress. A component of the IPET analysis will be an assessment of the risk and reliability of the New Orleans and vicinity flood protection system, prior to Katrina and after immediate and planned repairs to the damaged flood protection structures. This will provide a clearer perspective of the overall performance capacity of the system for use by individuals and governments in their decision making.*

3. Summary

Overall, the ASCE/NSF report is an excellent synopsis of the performance of the hurricane protection system's response to Hurricane Katrina that will materially assist in providing the knowledge and insights necessary to reconstitute flood protection in New Orleans. There are a number of observations that can be and are being applied immediately in the reconstruction efforts. Others are well founded but will require more detailed analysis to create the understanding necessary for application. The ASCE/NSF findings are in fact very consistent with the perceptions and observations made by the IPET Perishable Data Team. The ASCE/NSF report includes a few policy oriented recommendations that are not addressed here because they are outside the scope of the IPET analysis of flood protection system performance and should be evaluated by others.

Respectfully Submitted,

Lewis E. Link, Ph.D., PH
Director,
Interagency Performance Evaluation Task Force