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Hurricane Katrina: Why Did the Levees Fail?

Testimony of

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Before the

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Madame Chairman and Members of the Committee:

Good morning. My name is Peter G. Nicholson, and I am pleased to appear before you today to testify on behalf of the American Society of Civil Engineers[1] (ASCE) as you examine the effect of Hurricane Katrina on the infrastructure of coastal Louisiana, particularly the levee system that protects the city of New Orleans.

I am a member of ASCE and the chair of the ASCE Geo-Institute's Committee on Embankments, Dams and Slopes. I was asked by ASCE to assemble an independent team of experts to travel to New Orleans to collect data and make observations to be used to assess the performance of the flood control levees.

As engineers, our paramount concern is for the safety, health and welfare of the public. We believe there is a tremendous opportunity to learn from the tragedy of New Orleans to prevent future loss of life and property.

The purpose of our site visit was to make observations and gather information about the failure of the levees, including that data that would be lost ("perishable data") during the process of levee repair and the passage of time. This included evidence such as high water marks and indicators of overtopping, and evidence of any foundation movement or failure.

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[1] ASCE, founded in 1852, is the country's oldest national civil engineering organization. It represents more than 139,000 civil engineers in private practice, government, industry, and academia who are dedicated to the advancement of the science and profession of civil engineering. ASCE carried out Building Performance Assessments of the World Trade Center, the Pentagon and the Murrah Federal Building, and its technical assessments following earthquakes, hurricanes, and other natural disasters. The New Orleans levee technical group includes representatives appointed by the ASCE Geo-Institute and ASCE Coasts, Oceans, Ports, and Rivers Institute. ASCE is a 501(c) (3) non-profit educational and professional society.

One of the goals of the assessment team was to gather data in an attempt to determine why certain sections of the levee system failed and why others did not. These determinations may help to answer the question of whether the failures were caused by localized conditions or whether surviving sections of the system may be only marginally better prepared to withstand the type of loads that were generated by this event.

Following the first week in the field gathering data, we presented a press release on October 7, 2005, describing our initial observations concerning the performance of the levee system during and after Hurricane Katrina. We believe that our joint team knows, at least in principal, how the levees in New Orleans failed; the exact details await further analyses.

I. ASCE New Orleans Levee Assessment Team

The team assembled consisted of professional engineers from ASCE with a range of geotechnical engineering expertise in the study, safety and inspection of dams and levees. While in New Orleans and the surrounding areas, we examined levee failures as well as distressed and intact portions of the levee system between September 29 and October 15.

Our levee team was joined by another ASCE team of coastal engineers, including two colleagues from the Netherlands and Japan, both countries challenged by their geography to design against natural disasters from the sea, and another team primarily from the University of California, Berkeley, under the auspices of the National Science Foundation. Our three teams were joined by a U.S. Army Corps of Engineers' Engineering Research and Development Center (ERDC) team, led by Dr. Paul Mlakar. We would like to thank Dr. Mlakar and the ERDC team for their logistical support.

II. Observations by Sites and Areas

What we found in the field was very different than what we had expected, given what we had seen in the media reports. Rather than a few breaches through the floodwalls in the city caused largely by overtopping, we found literally dozens of breaches throughout the many miles of levee system. A number of different failure mechanisms were observed, including scour erosion caused by overtopping, seepage, soil failure, and piping.[2] As geotechnical engineers, we were particularly interested to find that many of the levee problems involved significant soil-related issues.

A. 17th Street Canal

At the 17th Street Canal breach, we observed intact soil blocks that had experienced large translation and heave. This movement would be consistent with a failure either of

[2] Piping, sometimes referred to as internal erosion, is a channel caused by the flow of water through a dam or embankment. It may increase rapidly and cause catastrophic failure of the embankment.

the soil embankment or the foundation soils beneath. There was no evidence of overtopping at this site. While we cannot yet determine conclusively the cause of the breach itself, this type of soil failure may well have been a significant contributing factor. Further investigation, together with analyses and review of the design and construction documents, should be of tremendous assistance in ultimately making these kinds of determinations.

B. London Avenue Canal – North

At the north breach on the London Avenue Canal, we observed a large displaced soil mass, which had been heaved nearly vertically over six feet, apparently indicating the toe of a rotational-type soil failure. Again, there was no evidence of overtopping at this site. Field inspection also showed a large amount of sandy soil deposited in the neighborhood landward of the breach, which is believed to be material from the foundation beneath the embankment together with material scoured from the canal bottom. This is consistent with the soil profiles provided to us which showed sand in the subsurface near this location. Under high water pressure, the flow through this type of material can be significant, which is known to cause internal stability problems.

C. London Avenue Canal – North, Across from Breach

Of particular interest was the levee section almost directly across from the north breach on the London Avenue Canal, where we observed a floodwall and underlying embankment that was in severe distress.

This site provided an excellent case study demonstrating multiple, concurrent failure mechanisms. It was observed that this section of floodwall was distressed to the point that it appeared that it might have been approaching failure when the water loading was relieved as the other breaches occurred. The wall was badly out of alignment and tilting landward; as a result of the tilt, there were gaps between the wall and the supporting soil on the canal or waterside. Also observed were evidence of soil movement, seepage and piping, as indicated by a series of sinkholes near the crest, together with "boils"[3] and heave at or near the inboard toe[4] of the embankment.

D. London Avenue Canal – South

To the south was another breach on the London Avenue Canal. That breach had apparently cut so deeply that huge volumes of sandy material had been scoured from the canal bottom and then deposited up to five feet deep extending hundreds of feet into the neighborhood. Very little evidence remained to be gathered at this site and the causes and mechanisms of the breach may never be known. It was, however, again

[3] A boil (or "blow") is a flow of soil, usually in the form of fine sand or silt, into the bottom of an excavation. The flow is forced in by water or water and air under pressure. It may increase rapidly and cause catastrophic failure.

[4] The toe is the base of the slope (in the case of dam or levee) on the side away from the water.

demonstrated by high water marks that the floodwall most likely was not overtopped at this location.

E. Outside New Orleans

It is important that the impact of the levee breaches outside of the city of New Orleans not be overlooked. Many sections of the system were severely tested by overtopping from a direct onslaught of the storm surge. Many portions of these levees were breached or severely distressed, causing severe flooding and, in many cases, complete destruction of thousands of neighborhood homes. Some of the levee sections were nearly obliterated and were observed to have been constructed of highly erodable materials.

III. Hurricane Katrina: Why Did the Levees Fail?

A. The Levee Failures

Hurricane Katrina was a catastrophic storm that made landfall in the Gulf Coast near the Louisiana and Mississippi border with wind speeds near 150 mph. But the damage in New Orleans due to the high winds and rain paled in comparison to the devastation resulting from the flooding.

The hurricane produced a storm surge that varied considerably depending on location, including the combined effects of orientation, geography, and topography with respect to the forces of the passing storm. Hydraulic modeling of the surge, verified by the most part by our own field observations of high water marks, show that essentially two significantly different levels of storm surge impacted the levee system.

As the storm passed to the east of New Orleans, the counterclockwise “swirl” of the storm generated a large surge from the Gulf of Mexico and Lake Bourne that impacted the eastern facing coastal areas of the New Orleans area and lower Mississippi delta. The surge was then concentrated into the channels of the Mississippi River Gulf Outlet (MRGO) that fed into the Inner Harbor Navigational Channel (IHNC). The funneling of the surge in these channels resulting in widespread overtopping of the levees.

In contrast, a somewhat separate surge that originated in Lake Pontchartrain was generated in part by the flow in from the Gulf of Mexico but also from the north winds across the lake. As shown by the models and field evidence, this surge, which impacted the lakefront and three canals within the central part of the city, was notably less severe. Field data indicated that the surge levels from the lake did not reach the elevation of the lakefront levees and was well below the top height of the floodwalls bordering the interior canals where three notable breaches occurred.

Where the storm surge was most severe, causing massive overtopping, the levees experienced a range of damage from complete obliteration to intact with no signs of distress. Much of the difference in the degree of damage can be attributed to the types

of levees and the materials used in their construction. The majority of the most heavily damaged or destroyed earthen levees that we inspected were constructed of sand or “shell fill” which was easily eroded.

At some of these locations the earthen embankments were simply gone. Those with embedded sheetpiles faired only marginally better and were often breached as well. Further inland, in the western portion of the MRGO and along the Inner Harbor Navigation Canal, the degree of overtopping was less severe but again resulted in a number of breaches. Many of these breaches occurred through I-wall structures that were severely scoured on the landside as a result of overtopping. These scour trenches undermined the support of the levee floodwalls and reduced the ability of the walls to withstand the forces of the water on their outer surfaces. Localized concentrations of overtopping water flow or possible localized weaker soils may have been responsible for why certain portions of the system were breached while others remained intact.

Another commonly observed problem was the frequent presence of “transitions” between different sections of the levees. There were a number of different types of these transitions that appeared to have caused problems, including inconsistent crest heights, change in levee type (I-wall vs. T-wall), change in material (concrete, steel sheetpile, earth), and transitions where certain rights-of-way resulted in penetrations of the flood control system.

Where levees were overtopped, the weaker material at the point of transition (i.e., earth to concrete, sheetpile to concrete, earth to sheetpile) would be more susceptible to failure. Many of the problems we observed appeared to have been related to transition details and were often exacerbated by inconsistent crest heights, particularly where the weaker material had the lower height. Many of these transitions were found at sections where infrastructure elements designed and maintained by multiple authorities, and their multiple protection elements, came together, and the weakest (or lowest) segment or element controlled the overall performance.

Finally, three major breaches, and at least one significantly distressed levee-floodwall section, were investigated at sites along the 17th Street and London Avenue canals which, as explained before, were clearly not overtopped.

Obvious soil failures within the embankment or foundation soils at or below the bases of the earthen levees had occurred at two of the breaches. At the distressed section, seepage and piping were evident. These types of soil instabilities appear likely to have been responsible for failure of these wall systems.

Evidence of piping erosion at one these sites serves to illustrate the severity of the underseepage at high water stages. Another possibility that also needs to be investigated, however, is the potential presence of a weak soil unit (either within the

lower embankment, or in the underlying foundation soils) with sufficiently low shear strength that it may have failed.

Additional studies will need to be performed at these breached and distressed locations to better determine embankment and foundation soil conditions, and appropriate seepage flow and shear strength characteristics, so that the mechanisms that led to the observed failures at these sites can be conclusively determined.

B. Recommendations

Preparing the levees for the next hurricane season should include a review of how the system performed during Hurricane Katrina, so that key lessons can be learned to improve the performance of the system. Based on our observations, a number of initial comments are warranted concerning the rebuilding and rehabilitation of the levee system.

While levee failures may be expected when overtopping occurs, the performance of many of the levees and floodwalls may have been significantly improved, and some of the failures likely prevented, with relatively inexpensive modifications of the levee and floodwall system.

The following specific points need to be dealt with in New Orleans:

- The levees need additional overtopping protection at the inboard sides of the floodwalls to minimize erosion.

- Crest heights of the levees need to be planned 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's floodwall frontage where the walls are more robust or designed to better resist overtopping.

- Transitions should be improved so that they do not represent locations of potential weakness in otherwise contiguous perimeter flood protection systems.

In addition, larger issues should be addressed as well.

- ASCE believes that Congress should enact a National Levee Inspection and Safety Program modeled on the successful National Dam Safety Program. The levee program should include a national inventory of levees, particularly those that protect large, heavily populated urban areas.

- ASCE supports the efforts to reduce coastal land loss in the Louisiana coastal area, an area that has been named America's Wetland because of its national importance. ASCE urges continued support of the existing program for Louisiana

coastal wetlands, funded by the Coastal Wetlands Planning, Prevention, and Protection Act (CWPPPA). ASCE also supports the ongoing effort to implement the comprehensive Louisiana Coastal Area (LCA) Program, which will further reduce land loss and provide additional preservation.

- We must discourage new development in the floodplain unless there is a pressing need for it and adequate protection can be provided. Population centers must be given a higher level of protection than most now have.

- We must use all the tools available to reduce damages. This means use of not only structural means such as levees, floodwalls, and dams, but also non-structural approaches such as flood resistant design, voluntary relocation of homes and businesses, revitalization of wetlands for storage, and use of natural barriers such as the Louisiana wetlands.

- Congress needs to consider seriously whether to establish a more stringent national flood control policy that emphasizes the need to protect human life from a 500-year flood.[5]

- The American Society of Civil Engineers (ASCE) believes Congress should establish an independent advisory panel to envision the future of the Gulf Coast and to recommend ways to begin the rebuilding of the areas that were devastated by Hurricane Katrina on August 29. The panel should consist of technical experts from a number of disciplines who would provide an objective review of all design and construction issues relating to the reconstruction of the areas covered by the President's major disaster declarations for Louisiana, Mississippi, and Alabama. The unpaid body would cooperate with and advise all federal, state, and local agencies involved in the reconstruction effort in the affected region.

  As we see it, the Advisory Group charter would:

  - Work as the primary advisor to all state and local governments on the rebuilding of the region, with the primary goal of helping hundreds of thousands of present and future residents of the areas to enjoy a secure and prosperous future.
  - Consist of experts from engineering, architecture, urban planning, and other design and construction-related fields.

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[5] A 500-year-flood is so big and rare that it will normally happen only once every 500 years. That doesn't mean that a 500-year-flood can't happen the year after a 500-year-flood. Every flood season has exactly the same chance—one in 500—of producing a 500-year-flood, even in area that experienced a 500-year-flood the season before. In other words, it is the flood that has a 0.2 percent chance of occurring every year. A 100-year flood, on the other hand, is used by the National Flood Insurance Program as the standard for floodplain management and to determine the need for flood insurance. A 100-year flood is based on a one percent chance of a flood's occurring in a given year.

- Develop recommendations that would include strategies to minimize the impact of future storm events and other natural hazards.
- Provide expert advice on the design and construction of the region's damaged public facilities, including port and harbor installations; lifelines; wastewater and drinking-water plants; airports and airfields; waste-management and disposal facilities; mass transit and public transportation services; roads, bridges, and tunnels; public buildings; and other key infrastructure.
- Ensure that the reconstruction efforts take into account the latest technologies in the prevention and mitigation of future harm to public and private buildings from severe windstorms and floods.
- Serve as link to federal agencies working in support of the reconstruction effort.
- Function in an advisory capacity only, having no authority to mandate particular design, construction, or environmental solutions.

IV. Conclusion

Other potentially important lessons will be learned in the months ahead, and that some of these 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.

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.

Madame Chairman, this concludes my testimony this morning. I would be pleased to answer any questions you may have.

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Peter G. Nicholson, Ph.D., P.E., M.ASCE, is a Professor at the University of Hawaii at Manoa and chairs the Embankments, Dams and Slopes Committee for the Geo-Institute (G-I) of the American Society of Civil Engineers. He earned a Bachelor's degree in Geology and Geophysics from Yale University as well as a Masters and Ph.D. from Stanford in Civil Engineering and Geotechnical Engineering. He is a licensed Professional Engineer in Hawaii with more than 20 years' experience with dams and levees in Utah, California, and Hawaii.