FAILURE OF LEVEE SYSTEMS SURROUNDING GREATER NEW ORLEANS DURING HURRICANE KATRINA.- PRELIMINARY ASSESSMENT

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Written Testimony, Ivor Ll. van Heerden, Ph.D.
Head, State of Louisiana Forensic Data Gathering Team
Director, Center for the Study of Public Health Impacts of Hurricanes
Deputy Director, LSU Hurricane Center
Louisiana State University
Baton Rouge, LA 70803

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Abstract

Hurricane Katrina made landfall in Louisiana at 6:10 am on Monday 29th of August, 2005. After the storm 85 % of greater New Orleans was flooded, and about 1000 persons had lost their lives and approximately 100,000 families were homeless, being mostly families that had heeded the evacuation orders. The hurricane protection system that all residents of New Orleans depended upon; their security from surge floods; had failed catastrophically with over twenty breachings or breaks.

The flooding of New Orleans represents two separate flooding events, distinct in time, space and intensity. In eastern New Orleans levee failure accompanied a surge overtopping event, flooding surrounding communities; in western New Orleans catastrophic levee failure caused the flooding. Preliminary findings by the State of Louisiana Forensic Data Gathering Team are that in the case of the 17th Street Canal, London Ave Canal and the Industrial Canal, levee collapse and flood breaching reflected unstable soil conditions and a lack of foundation support and water percolation seals, given the soft, porous and highly organic nature of the soils. In the case of the Industrial Canal, levee overtopping may have hastened the structure's collapse.

ADCIRC Storm Surge Modeling

The Hurricane Public Health Research Center at LSU has developed an operational version of the ADCIRC storm surge model that has been in use since 2002 in support of hurricane emergencies. Basically, we take an official advisory from the National Hurricane Center and then convert that meteorological data via a super computer and the necessary numerical computational code into a graphic that represents the expected surge for that particular advisory. Each surge model run takes 5-7 hours to complete from the time of the National Hurricane Center advisory is posted on the Internet till the time we put our output on the Internet (www.hurricanne.lsu.edu/floodprediction/). Our output is sent to a large listserve consisting of emergency management officials from Federal, State, and local government, NGO's and the media. The same product is sent to the Louisiana State University (LSU) staff at the State Emergency Operations Center (EOC) in Baton Rouge where all officials are briefed on the latest surge model outputs. At 10:00

pm on Saturday 28th August 2005, 32 hours before landfall, we put out an email and warned that New Orleans would flood as the surge would overtop the levee system especially in Orleans East and St Bernard Parish. We warned that we expected levee erosion. We also reminded the emergency managers assembled at the State EOC that during Hurricane Betsy (1965) the Industrial Canal had been breached and that if we lost levees the flooding would be far more severe than the model depicted.

The ADCIRC model is an ideal forensic tool as it allows us to hindcast the actual surge conditions for any hurricane at any point in the study area and can generate a hydrograph – a graph of how the water level changed with time during the surge event.

Nature of the Surge Event

The surge due to Hurricane Katrina consisted of two distinct flooding events, separated in time, space and intensity. East of the track the surge of 15-18 feet above sea level reflected that caused by the winds of a Category three or four storm (120 mph). West of the eye and especially over Lake Pontchartrain the maximum surge was 10-11 feet and winds those of a Category 1 storm (72-76 mph). The surge on the east side rose much quicker and peaked before that on Lake Pontchartrain. We have been collecting data from stopped hand dial clocks in order to determine just when each levee section failed. While the 'stopped clock' data is still preliminary we will present some of the times.

General "I" Wall Levee Design

The "I" wall levees consist of linked steel pilings approximately 18 inches wide hammered into the ground to a set depth and then a concrete wall (monolith) is built over the upper few feet of the steel pilings. Reinforcing bars are passed through holes in the sheet piling and then cemented into the monolith structure. At least one contractor complained the structure was not stable due to the soft soils.

The 17th Street Canal Breachings

The original canal was dredged in the 1890's and the material excavated from the canal placed along the banks. The "I" walls that failed were built in the early 1990's. At the time of construction the original sheet piling was driven down into the ground. Shortly thereafter, because off an approaching storm, the pilings were all pulled out back up to their original elevations. Once the storm threat was over the pilings were then pushed back into the soft soil. These actions of push, pull, and then push greatly weakened the soils. Based on the design memorandum that we found in the files of the Louisiana Department of Transportation and Development, the pilings at the breach extended to a depth of 10 feet below sea level. At or around the time the pilings were being resunk the canal was dredged to a depth of 18.5 feet below sea level. Thus there was a linear depth of 8.5 feet of canal that was not "blocked" by sheet piling allowing the potential of a lateral flow of water under the pilings from the canal. According to local residents, their back yards adjacent to the canal were at times quite wet even when there had been no rains, suggestive of a canal seep, i.e. water making its way from the canal via seeps into their yards – a sign of trouble to come?.

The 17th Street breach occurred at approximately 10:15 am on the 29th August, 2005, one hour after the peak of the surge when the water level was about 9 feet above sea level. During Katrina a 200 foot section of the levee slid sideways 35 feet in a classical example of a lateral slide failure – a pressure burst. Adjacent to this slide the levee wall segments, that were not interlocked, were flattened by the flow, a number seemingly shearing off their piling foundations. A lateral slide of this nature with some rotation of the levee wall segments during the slide occurs because of foundation failure. A 200 linear foot length of levee slide is indicative of catastrophic structural failure. The backyards of residents adjacent to the levee were heaved up and a former flat terrain was now made up of hummocky dunes – homes, cars and buildings were all heaved up into strange skewed juncture positions by the 'bull dozing' of the levee slide.

The levee at the breach was built on top of a highly organic marsh and peat with soft clays – a very porous and weak medium. This highly organic soil was used to create the levee embankment when the canal was originally excavated. A sand layer is present 30 feet below the surface. Once this former swamp was drained for development, the organic matter in these originally flooded soils would have decomposed rather rapidly due to exposure to the air (oxygen) and would have lost some of their strength as well as becoming more porous. Potential conduits for water percolation from the canal between the bottom of the pilings and the canal floor, under pressure of the Katrina surge, would have been via the porous and weak soil embankment; the peat old marsh layer; and even the deeper lying sands. Our preliminary finding is that this canal levee "I" wall design in these very weak soils and substratum, was an accident waiting to happen. At the very least the sheet piling should have been sunk to 60 feet below sea level.

<u>London Ave (West) Filmore Breach</u>

The "I" wall design of the levee at this breaching is basically the same as that at the 17th Street Canal site. The steel pilings appear to have extended to about 11.4 feet below sea level. Once again the canal floor was substantially deeper than the piling being 18-19 feet below sea level. The levee breach is a smaller version of what happened on the 17th Street Canal, there was a lateral slide of the levee embankment and "I" wall and a heave of the back yards of local residents adjacent to the heave. The wall segments on either side of the slide collapsed downwards with the flow. Because the underlying substrate consisted predominately of old beach sands, an enormous amount of sand was carried by the flood into the subdivision at the breach.

The levee at the breach was built on top of a highly organic marsh and peat – a very porous and weak medium. This highly organic soil is believed to have been used to create the levee embankment when the canal was originally excavated. A 50 foot thick sand layer is present 10 feet below the surface. These sands are very porous. Once this former swamp was drained for development, the originally flooded organic soils would have decomposed rather rapidly due to exposure to the air (oxygen) and would have lost some of their strength as well as becoming more porous. The sand layer appears to have been exposed on the floor of the canal after it was dredged around 1990. Potential conduits for water percolation from the canal between the bottom of the pilings and the canal floor, under pressure of the Katrina surge, would have been via the porous and weak soil

embankment; the peat old marsh layer; and especially the deeper lying sands. Sand boils and even blowouts through the substrate under the sheetpile will explain most of the sand in the adjacent residents' back yards. Our preliminary finding is that this canal levee "I" wall design in these very weak soils and substratum, was an accident waiting to happen. At the very least the sheet piling should have been sunk to 80 feet below sea level.

The east bank levee of the London Ave canal at Filmore is bowed, tilted back and cracked in a number of places. There is evidence of sand boils, heaves, and other signs of soil instability. The question could be asked why the walls did not fail at this point? It appears that the sheet piling was sunk to a depth of 26 feet on the east side of the canal at Filmore as against the 11.4 feet where the west breach occurred. This relative difference in sheet piling depth may indicate why the east side at Filmore did not fail, but nevertheless even sheet piling to a depth of 26 feet below sea level was not sufficient.

London Ave (East) Mirabeau Breach

The "I" wall design of the levee at this breaching is basically the same as that at the 17th Street canal breaching. The steel pilings appear to have extended to about 26 feet below sea level. The levee breach is similar to that of Filmore except the extent of any heave is unknown. Because the underlying substrate consisted predominately of old beach sands, an enormous amount of sand was carried by the flood into the subdivision at the breach.

The levee at the breach was built on top of a highly organic marsh and peat – a very porous and weak medium. This highly organic soil is believed to have been used to create the levee embankment when the canal was originally excavated. A 50 foot thick sand layer, very porous, is present 10 feet below the surface. Once this former swamp was drained for development, the originally flooded organic soils would have decomposed rather rapidly due to exposure to the air (oxygen) and would have lost some of their strength as well as becoming more porous. The sand layer appears to have been exposed on the floor of the canal after it was dredged around 1990. The main conduit for water percolation from the canal under these 26 foot deep pilings, due to the pressure of the Katrina surge, would have been via the beach sands. The walls segments all sag and dip down towards the center of the breach. Those in the center appear to have collapsed outwards. The sagging and dropping (lowering) of the wall segments as one approaches the center of the breach suggests that there was a blowout due to water under pressure escaping from the canal below and under the pilings using the porous sand layer as the pathway. The blowout and subsequent loss of sand substrate would create a void that the wall segments would then collapse into and in this way the structural integrity of the "I" wall segments was destroyed. The huge amounts of clean white sand to be found in the subdivision adjacent to the breach attest to this failure mode. So even though the sheet piling was deeper than at the Filmore West breach, it was still not deep enough. Thus it can be considered that the bowed and tipping wall segments, with sand boils and small heaves on the east bank opposite from the Filmore breach, are indicate of an earlier stage of the Mirabeau breach. If it had not failed at Mirabeau it would have failed at Filmore on the east side. Again this explains most of the sand in the adjacent residents' back yards.

Our preliminary finding is that this canal levee "I" wall design in these very weak soils and substratum, was an accident waiting to happen. At the very least the sheet piling should have been sunk to 80 feet below sea level.

Industrial Canal Breachings

The "I" wall design of the levee at this breaching is basically the same as that at the 17th Street canal breaching. The steel pilings appear to have extended to about 10 feet below sea level. The canal is much deeper than 10 feet below sea level. There are two major breachings on the Industrial Canal south of its junction with the Gulf Intra Coastal Waterway. The breachings appear to have occurred before the peak of the surge when the water level was at the top of the levee wall (7:15 am).

On first inspection, because of the scour trench (generally 3x4 feet) behind the levee wall (landward side), one can assume that the failure was due to the scour trench excavating its way down to the base on the pilings and then the whole system failed catastrophically due to the pressure of the water. However, if one inspects the wall segments between the two breaches, the scour trench seems to be fairly uniform in size but one sees that the levee wall has two areas with very distinct bows and the walls are tilted backwards - features similar to the London canal on its east side at Filmore. Inspection of the soil embankment on the canal side of these bowed sections reveals that the soil is highly cracked, that long wide sections of soil have slipped down about 12 – 18 inches and there is evidence of 'down percolation holes'. These are scour-like structures created when the water under pressure moves down the cracks and eventually finds its way under the piling and starts to scour a passageway leading to sand boils which then sets the stage for a failure.

The levee at the breaches was built on top of a 10-foot thick highly organic marsh and peat with very soft clays – a very porous and weak medium. This highly organic very soft clay soil is what was used to create the levee embankment when the canal was originally excavated. A layer of very soft to soft clays with silt and sand lenses is present 15 feet below the surface. Once this former swamp was drained for development, the originally flooded organic soils would have decomposed rather rapidly due to exposure to the air (oxygen) and would have lost some of their strength as well as becoming more porous. Potential conduits for water percolation from the canal between the bottom of the pilings and the canal floor, under pressure of the Katrina surge, would have been via the porous and weak soil embankment; the peat old marsh layer; and even the deeper lying clays with porous sand and silt lenses. The down percolation holes created due to the tilting of the walls under pressure of the surge would also have weakened the levee system. It is very important to note that the soil borings all indicate very soft or soft clays, not ideal foundation material.

While the ADCIRC data indicate the failure of these Industrial canal levees occurred at the time overtopping had just started to occur; overtopping would have helped to weaken the soil embankment behind the levees. Just why the levees failed exactly where they did is still a question to be answered, but the failure of the Industrial Canal levees is indicative that this canal levee "I" wall design in these very weak soils and substratum,

was an accident waiting to happen. At the very least the sheet piling should have been sunk to 70 feet below sea level.

Conclusions

While Hurricane Katrina was a major hurricane, our preliminary findings are that failure of the 17th Street and London Ave canal levees was due to a design that did not account for the very weak nature of the soils. The design criteria of these levees was not exceeded. The design also did not take into account the very high porosity and permeability of these soils. It was a geotechnical engineering failure.

The same conclusion can be made for the Industrial Canal levees that failed during Katrina, although surge overtopping no doubt enhanced their collapse.

Most of the flooding of New Orleans was due to man's follies. Society owes those who lost their lives, and the approximately 100,000 families who lost all, an apology and needs to step up to the plate and rebuild their homes, and compensate for their lost means of employment. New Orleans is one of our nations jeweled cities. Not to have given the residents the security of proper levees is inexcusable.