INITIAL COMMENTS ON INTERIM (70%) IPET STUDY REPORT

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On March 10th the U.S. Army Corps of Engineers' IPET investigation released their second major report regarding their ongoing investigations of the performance of the New Orleans regional flood protection system during Hurricane Katrina. This report describes work still in progress, as their studies are now targeted to be nominally 70% complete.

We have been asked by numerous media representatives for our comments on this report. Our investigation team will carefully review this report, and it is not our policy to prematurely comment on complex issues without first taking the time necessary to be suitably secure in our views and findings.

At this early stage, however, there is clearly one key issue raised at the press briefing at which the interim report was presented that merits some initial comments at this time.

Unforeseen and Unforeseeable 17th Street Canal Breach

A key finding (to date) within the IPET studies is that the catastrophic failure of the levee and floodwall section at the 17th Street Canal was in part the result of two unforeseen issues: (1) the presence of an unusually weak layer of clays at the toe of the levee, and (2) the fact that the floodwall was pushed inboard (away from the canal) by the rising waters, creating a gap between the floodwall (and the sheetpile curtain upon which it was supported) and the adjacent levee embankment soils; water rushed into this gap, applied pressure against the lower sheetpiles, and pushed the embankment section (and the sheetpiles and floodwall) sideways. At the press briefing it was claimed that these were both unforeseen mechanisms and conditions, not previously reported in the literature. The clear implication was that the Corps was therefore not responsible.

This finding is singled out for highlighting in the Executive Summary, although the main text of the report itself does a better job of stating, in softer terms, what has been actually found to date in work that is clearly still ongoing.

With regard to the first issue; the U.S. Army Corps of Engineers had a masterful knowledge and understanding of the complex and challenging geology of this region in the 1950's, and their report by Kolb and Van Lopek (1958) is a landmark exposition of these challenging foundation conditions. Having taken the trouble to read and study this, and other available references, our field team went specifically in search of such weak foundation soil strata in our own field exploration (borings and sampling, as well as in-situ CPT testing) and laboratory testing program. The Corps should not claim that the weak foundation soil strata at the 17th Street canal breach site were unexpected, and that no prior publications would have disclosed this possibility. The IPET report has an extensive discussion of the geologic conditions in the area of the 17th Street canal and the references on which this discussion is based indicate that the nature of these soils should have been recognized; including the likely presence of weak clay layers. Indeed, it was the view of our investigation team (from the start) that the presence of such weak soil layers (both clays and organic soils) should be expected at numerous sites; such weak strata are often the geological result of previous strong hurricanes interacting with the marsh environment to form some of the key soils found at the site of the 17th Street breach.

With regard to the "unforeseen" nature of the mode of failure; the strong IPET statements of last Friday are also unfortunate. The Corps performed a very expensive full-scale field test of a "test section" of a levee and sheetpile-supported floodwall in 1985, just south of Morgan City (west of New Orleans), Louisiana in the Atchafalaya Basin. The levee embankment, and the sheetpile-supported concrete floodwall wall were sized and built to model conditions similar to those expected to be present along the 17th Street, Orleans, and London Avenue Canals, as well as along major portions of the Inner Harbor Navigational Channel (IHNC). This expensive field experiment was performed to develop insight for subsequent design of these vital New Orleans levee and floodwall sections in the years that followed (U.S. Army Corps of Engineers, Lower Mississippi Valley Division, Technical Report No. 1, *E-99 Sheet Pile Wall Field Load Test Report*, June 1988).

The purpose of the test as stated in this report was: "there are also no known existing field load test data that could be used to verify analysis of I-type floodwalls and little performance data is available on existing floodwalls since these walls have seldom been loaded to any degree by floodwaters. Therefore, it was considered advisable to pond water against a test section of floodwall, collect performance data, and use this data to reevaluate current design procedures for sheet pile walls."

A 200-foot long flood wall section was constructed using PZ 27 sheet piles (with 23 foot penetrations) on the landside berm of the Item E-99 East Atchafalaya Basin Protection Levee. The sheetpiles and foundation soils were instrumented, and a cofferdam was constructed so that the water level could be progressively raised on the outboard ("water") side of the floodwall. The foundation soils consisted of normally consolidated soft, highly plastic clays; foundation conditions that were well-chosen to represent approximately the conditions expected beneath the sections subsequently to be designed and constructed in New Orleans. As it turns out, the foundation soil strengths at this "test" section were actually quite similar to those at the 17th Street Canal breach site.

The water level on the outboard side of the test section was progressively raised to the 8-foot maximum "safe" design height determined using a conventional limit equilibrium undrained soil shear strength analysis and a factor of safety of FS = 1.25. As the water level approached 8 feet, however, there was a rapid and dramatic increase in the deflections at the heads of the sheet piles indicating that failure was imminent (see Plate 23 in the test report cited). The maximum stresses in the sheet piles at this point were in the range of 10,000 pounds per square inch, well below the steel's yield and ultimate strengths (clearly indicating that failure was developing in the supporting soils). The measured deformations of the sheet piles showed almost rigid body rotation of the sheet piles (see Pates 25 - 28). The measured deformations in the soils adjacent to the sheet piles showed that a tension gap developed between the sheet piles and the soils, allowing water to flow in between the sheet piles and the soils and exerting additional hydrostatic pressures on the piles. In simple terms, this was exactly the "unforeseen" mode of failure recently reported by the IPET.

Experimental data from this test were subsequently analyzed extensively by the Corps of Engineers Waterways Experiment Station (WES), and multiple Corps of Engineers reports were issued that resulted in significant recommended revisions to the analytical methods and processes used to analyze both the soils supporting the sheetpiling and concrete floodwalls, and the sheetpile/floodwalls themselves. Results from these studies were later even more widely reported in the Electronic Journal of Geotechnical Engineering (EJGE) in two papers titled "Soil Structure Interaction Effects in Floodwalls," and "Shear Ring Method for Soil-Structure Interaction Analysis in Floodwalls" published in 1997 (www.ejge.com). The first of these papers succinctly observed (page 10): "As the water level rises, the increased loading may produce separation of the soil from the pile on the flooded side (i.e., a 'tension crack' develops behind the wall). Intrusion of free water into the tension crack produces additional hydrostatic pressures on the wall side of the crack and equal and opposite pressures on the soil side of the crack." Thus, there would seem to be little justification for the contention that the sheetpile failure mode disclosed by the recent IPET analyses had not previously been seen, or published, and that it could not have been anticipated.

The WES reports and the subsequent EJGE articles recommended substantial revisions in how levee deformations and sheet pile deformations and stability were analyzed. Our work thus far has failed to failed to find that these revisions were incorporated into the design methods actually used for the sheetpile-supported flood walls for the drainage canals in New Orleans.

It is inaccurate to state that this mechanism "discovered" during the IPET studies differs strongly from the findings of the NSF sponsored team. As a result of our field and analytical studies performed starting in October 2005, we have been discussing this "cut the cake in half and slide it sideways" failure mode with IPET, with the ASCE Field Investigation Team, and with the press since last October. Like IPET, we currently consider it to be the apparent mode of failure at this key site; the probabilities of failure associated with this mode of failure are close to unity for a surge elevations of 8 to 10 feet. Armed with the invaluable hindsight provided by the Corps' field test at Atchafalia in 1988, and equally valuable field observations from several of the failure and breach sites in New Orleans, we have been analyzing this mode from the start.

Two additional failure modes also show very low factors of safety and corresponding high probabilities of failure under the loading imposed by the rising canal waters at the 17^{th} Street Canal breach site. We are still studying this, and are currently planning to issue our next report documenting this work in early May, but our studies to date show that either of these other two failure modes would likely have also caused the failure if the "cut the cake in half" mode had not beaten them to it.

Future NSF-Sponsored Investigation Team Developments

Our NSF-sponsored Independent Levee Investigation Team (ILIT) has grown in numbers through the course of this investigation, and currently includes 34 very dedicated and accomplished individuals. The team includes a large number of leading experts across a diverse range of fields. Team members hail from six states, and they come from universities, private engineering firms, and state and federal agencies.

As a group, the investigation team has very impressive prior experience with forensic studies of major disasters and catastrophes. For example, the team members have previously investigated catastrophic damages caused by 12 major earthquakes and 8 major hurricanes (both domestic and foreign), 14 dam failures, more than a dozen levee failures, numerous landslides, one tsunami, the pivotal Kettleman Hills waste landfill failure, the Challenger and Columbia space shuttle disasters, the Exxon Valdez tanker disaster, and a number of major offshore oil platform and pipeline failures. They are very experienced at the delicate and deliberate art and science of piecing their way through the devastation, carefully and professionally, and figuring out what had happened, and why - the art and science of engineering forensics.

The caliber of these assembled experts is such that we could never possibly have afforded to hire them. Instead, excepting a handful of graduate research students who are working for very low wages, these world class experts all volunteered, and they are working pro bono (for free.) They do this for the intellectual challenge, for the camaraderie of a very special group of accomplished colleagues, for the chance to make a positive difference, because it is important, and most importantly because it is the right and necessary thing to do. In the still-ongoing absence of a properly funded independent National investigation fully independent of the Corps, we are forced to do our best to fill this important void.

Our investigation team, with their considerable previous experience with forensic studies of major disasters, learned long ago that it is folly to attempt to separate "human factors" and "organizational/institutional" issues from simple physical/mechanical issues. That would be like watching an episode of CSI on TV in which the investigators simply count the number of bullet holes and measure their diameters, without ever considering who might have fired the gun, and what their motivation might have been. As a result, the scope of our studies is considerably broader than that of the current IPET studies, as we have been studying human factors and organizational/institutional issues (in addition to physical/mechanical issues) from the start.

Our current studies are directed towards answering three main sets of questions as follow:

1. **What happened?** What events transpired during Hurricane Katrina and during its aftermath? How did the regional flood protection system perform? What were the successes, and what were the shortcomings and failures? What mechanisms and forces, etc., led to these performances?

2. **Why did this happen?** What were the underlying issues that led to the observed performance of the system elements? What were the influences of regional and local geology? How did the history of the evolution of the flood protection system contribute to its performance? What were the design assumptions, engineering studies and analyses, etc., and what effect did these have on the performance of the system elements? What over-arching organizational, institutional, political and funding issues may have played a role?

3. **What can be done to ensure that a similar catastrophe does not recur in the future?** Our next report will present findings and recommendations regarding a number of focused areas for improvement of the conceptual design, analysis and engineering design, and construction and maintenance of such a system. This report will also present preliminary findings and recommendations regarding changes in organization of the overall governmental/institutional "system" responsible for the conception, design, construction, operation and maintenance of the complex regional flood defense system, as well as the making of political decisions regarding levels of protection to be provided, and the provision of funding to support the creation and operation/maintenance of such a system.

Our findings to date indicate that many things went wrong with the New Orleans flood protection system during Hurricane Katrina, and that the resulting catastrophe had it roots in three main causes: (1) a major natural disaster (the Hurricane itself), (2) the poor performance of the flood protection system, due to localized engineering failures, questionable judgements, mistakes, etc. involved in the detailed design, construction, operation and maintenance of the system, and (3) more global "organizational" and institutional problems associated with the governmental and local organizations jointly responsible for the design, construction, operation, and maintenance including timely funding and other critical resources provided for of the overall flood protection system.

Our findings to date indicate that no one group or organization had a monopoly on responsibility for the catastrophic failure of this regional flood protection system. Many groups, organizations and even individuals had a hand in the numerous failures and shortcomings that proved so catastrophic on August 29th. It is a complex situation, without simple answers. Attempts to assign blame, or to deflect it, are premature at this stage and should await the completion of the studies currently in progress.

We are planning to release our next report to the National Science Foundation, and to the public, in early May in New Orleans.