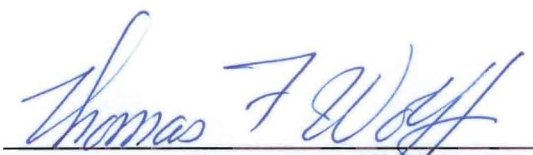
EXPERT REPORT

Geotechnical Analysis of the United States Corps of Engineers' Design, and Its Contractors' Construction of, the Lake Pontchartrain and Vicinity Hurricane Protection Project Structures Adjacent to the Mississippi River – Gulf Outlet, Gulf Intracoastal Waterway, and Inner Harbor Navigation Canal and their Performance During Hurricane Katrina



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CURRICULUM VITAE

BACKGROUND

This report reviews geotechnical issues related to the flooding of St. Bernard Parish, Louisiana, and areas of Orleans Parish in the Ninth Ward during and following Hurricane Katrina in 2005. These issues are raised in the case *Robinson, et. al. v. the United States.* Plaintiffs seek damages from the United States due to flooding during and following Hurricane Katrina, as a result of levee and floodwall breaches along the Inner Harbor Navigation Canal (INHC), the Gulf Intracoastal Waterway (GIWW) and the Mississippi River Gulf Outlet (MRGO). Design and construction of these levees was performed by the United States Army Corps of Engineers (USACE, or the Corps) through its contractors.

QUALIFICATIONS

I have more than 40 years experience in planning, design, and construction, and in the safety and reliability evaluation of levees and other navigation and flood control structures. Starting as a student intern with the St. Louis District of the USACE in 1967, I performed drafting and design calculations for levee work in Missouri and Illinois under the supervision of Corps geotechnical engineers. From 1970 to 1985, I was employed as a geotechnical engineer with the St. Louis District of the Corps and was involved in the planning, design, construction and safety evaluation of dams, levees and hydraulic structures in Missouri, Illinois and Louisiana. My work included an evaluation, and underseepage analysis, of the performance and reliability of 200+ miles of levees during the 1973 Mississippi River flood, and a portion of that work formed the basis of my report required for the Master of Science in civil engineering.

During my employment with the Corps, the work of the St. Louis District was reviewed by the Corps' Lower Mississippi Valley Division (LMVD) and the Office of the Chief of Engineers (OCE). These reviews involved the same offices, and in some cases the same personnel and time frame as reviews of the New Orleans District (NOD) levee designs at issue in the instant case. Consequently, I am very familiar with the Corps' review process at the time of design of the Lake Pontchartrain and Vicinity Hurricane Protection Project (LPVHPP). In addition to design work, I have also served on several Corps-wide committees that provided input to the development of Corps' computer programs for analysis and design of hydraulic structures, and that provided input to design guidance engineering manuals (EMs). In that capacity, I interacted with a number of personnel of the Waterways Experiment Station (WES, now Environmental Research and Development Center, ERDC) in Vicksburg, MS and also with personnel of OCE.

From 1986 to present, I have been on the faculty of the Department of Civil and Environmental Engineering at Michigan State University. Since 1998, I have served as Associate Dean of the College of Engineering. My relevant research and consulting funded by the Corps since 1986 includes the following:

- Research reports and draft engineering guidance related to the application of reliability and risk analysis in the evaluation and design of dams and levees.
- Research reports and draft guidance related to levee underseepage and reliability assessments of existing levees.

- Consultation on the application of reliability analysis to Hodges Village Dam (MA), Walter F. George Dam (GA, AL), Herbert Hoover Dike (FL), and Mississippi River Locks and Dams (MO, IL).
- Consultation on underseepage issues for the Chesterfield-Monarch levee in St. Louis County, MO.
- Acted as expert on consulting panel for Herbert Hoover Dike (FL).
- Acted as expert on consulting panel for underseepage criteria for Sacramento area levees (CA).

A complete curriculum vitae is provided in the Appendix.

I have been compensated for my work as an expert in this matter at the rate of $200.00 per hour.

DOCUMENTS REVIEWED

In preparing this report, I have reviewed a broad selection of documents, with particular emphasis on the following:

- Manuals and Design Guidance
    - The 1947 "Code for Utilization of Soils Data for Levees."
    - Engineering Manual (EM) 1110-2-1913, Design and Construction of Levees, 1978 and 2000 editions.
    - Design Memorandum No. 3, Lake Pontchartrain and Vicinity Hurricane Protection System, 1966
- Post-Katrina Forensic Reports
    - The Interagency Personnel Evaluation Team (IPET) report on Hurricane Katrina, especially Volume V – The Performance – Levees and Floodwalls
    - The Independent Levee Investigation Team (ILIT) report on Hurricane Katrina
    - The Team Louisiana Report on Hurricane Katrina
    - Wooley and Shabman, *Decision Making Chronology for the Lake Pontchartrain & Vicinity Hurricane Protection Project.*
    - *What Went Wrong*, report of the ASCE External Review Panel (ERP)
- Litigation-Related Documents
    - Plaintiffs' Court filings and related motions and documents
    - Various declarations and a deposition of Dr. Robert Bea, who is being called as an expert for plaintiffs
    - Declaration and Deposition of Dr. G. Paul Kemp
    - Depositions of USACE personnel
- Published Journal Papers
    - Papers in special edition of the ASCE *Journal of Geotechnical and Geoenvironmental Engineering*, May 2008 (see references). This volume was made public during the course of the litigation and this writer's involvement. It provides invited papers from civil engineers involved in Corps / IPET studies of the failures as well as from members of the ILIT team, and provides a concise and convenient source to review similarities and difference in these expert opinions.

- Other papers as noted in references and in this report throughout (e.g., soil boring logs, EMs, levee lift and construction records, design memoranda and other records necessary to obtain all relevant facts upon which to base informed opinions).

INTRODUCTION

During Hurricane Katrina in August 2005, large portions of the metropolitan New Orleans area flooded. Flooding occurred in the Ninth Ward of Orleans Parish and in St. Bernard Parish due to the breaching of levees and floodwalls along the Inner Harbor Navigation Canal (INHC) and the Mississippi River Gulf Outlet (MRGO). All post-Katrina expert reports agree that one of these breaches (north breach on the east side of the INHC) occurred prior to overtopping. Other locations were breached due to overtopping and associated erosion. The various post-hurricane studies differ on whether some of the breaches occurred prior to overtopping.

The Plaintiffs' complaint and their experts' declarations, reports and depositions allege that various deficiencies in the design and construction of hurricane protection levees and floodwalls along the IHNC and the MRGO led to significant and preventable damage in the protected areas behind these structures. Accordingly, the plaintiffs seek relief for these damages from the United States of America.

The INHC is a navigation channel constructed in 1918-1923 by the Port of New Orleans to connect the Mississippi River to Lake Pontchartrain. The lock and southern portion of the canal were leased to the Corps of Engineers starting in World War II and the Corps purchased the lock in 1986. The MRGO is a navigation channel constructed in 1960-1965 to connect the Gulf of Mexico (at an inlet or bay known as Lake Borgne) to the INHC.

This report will focus on the design, construction and maintenance of the flood control structures built pursuant to the Lake Pontchartrain and Vicinity Hurricane Protection Project (LPVHPP). This includes the state of the art for levee design over the course of the project, and the capability to analyze and numerically model the effects of storm surge, waves, and currents on soil erosion, slope stability, and seepage. Hurricane protection levees along the MRGO and INHC were constructed or raised over a period of decades starting in 1967. Because of the soft nature of the underlying soils, much of the levee construction was done in multiple stages to allow for settlement and strength gain due to soil consolidation. Figure 1 provides an overview of these channels and the adjacent levees and floodwalls. To assist in describing specific locations, the levees along MRGO have been divided into two reaches, with Reach One extending from the western end of the MRGO canal (where it joins the INHC) to the bend just west of the Bayou Bienvenue navigation structure, and Reach Two extending from the latter point eastward to Breton Sound.

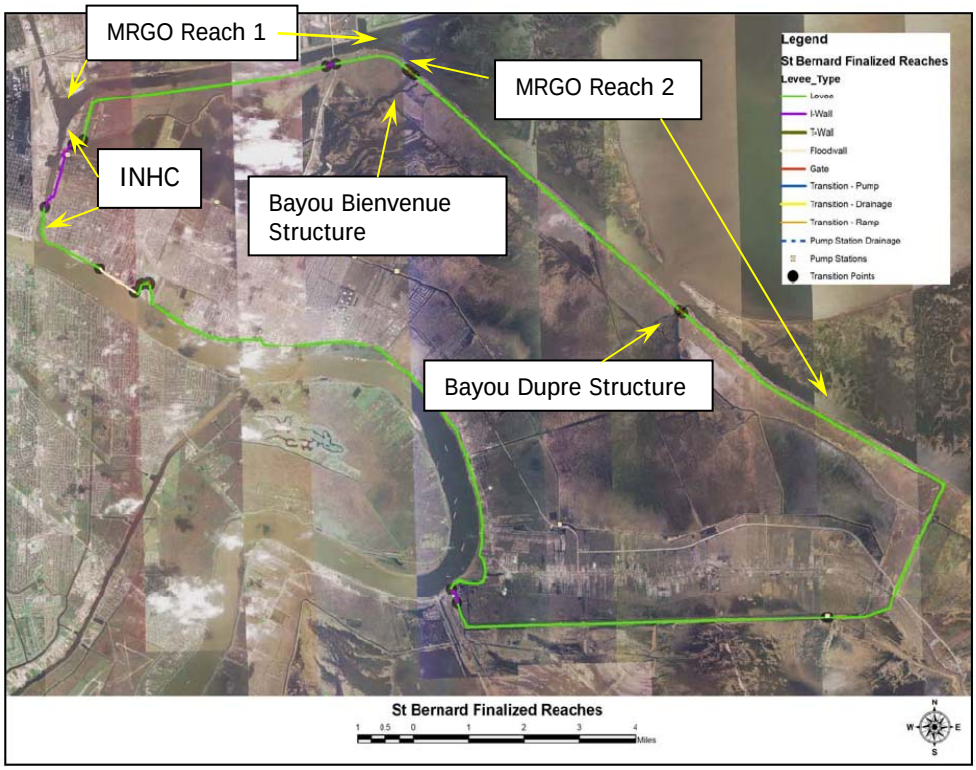


Figure 1. Location of Navigation Canals and Adjacent Levees
(Base figure from Figure 6-5 of the IPET Report)

This report also addresses a number of civil and geotechnical engineering issues related to the Hurricane Katrina event and subsequent engineering studies of the levees and floodwalls in the areas in question. The opinions I give herein are to a reasonable degree of scientific and engineering certainty.

PART I:
MISSISSIPPI RIVER GULF OUTLET (MRGO) LEVEES
AND CONTROL STRUCTURES

DEFINITION OF A LEVEE

An issue raised in this litigation is the very definition of a levee, and under what circumstances an earth embankment should be considered to be a levee. Opinions have been stated that there were "no 'levees' along virtually all of the MRGO St. Bernard Parish Reach 2," and plaintiffs' expert Dr. Robert Bea coined the term "earthen berm / spoil bank" (EBSB) to refer to these structures. These opinions are grounded in the concept that embankment soil materials must meet certain quality standards for an embankment to "qualify" as a levee. That is not the case. A levee is defined by its intended function, not the type of materials used in its construction.

Corps' Definition

The Corps of Engineers' definition of *levee* is given in the Corps' EM 1110-2-1913 (2000), *Design and Construction of Levees*, section 1.5.a.1. Identical wording is found in the 1978 version. The definition does not include any qualification with respect to material quality or composition. It simply defines levee in terms of intended function:

> *The term levee as used herein is defined as an embankment whose primary purpose is to furnish flood protection from seasonal high water and which is therefore subject to water loading for periods of only a few days or weeks a year.*

Any earth embankment running generally parallel to a water body, and intended to prevent flooding from temporary high water stages, is routinely referred to as a levee. Whether that levee is of sufficient quality to perform as intended is another matter, but the term *levee* relates to intended function, not to quality or type of construction materials. The term *berm* is usually used to refer to a wide, low embankment placed against a larger and steeper embankment to provide an additional measure of stability.

Design Documents

In General Design Memorandum No. 3 (USACE, 1966), the structures in question are consistently called levees throughout the text and drawings. [In the same document, the term *berm* is used consistently with the definition above. For example, on page 32, paragraph 46, the GDM states that the levee side slopes will be "5 on 1 down to the berms at El. 9.0. The berms will slope 30 on 1."] Also, Plate 23 shows the term berm used as a low, broad earth mass to the side of the main embankment. Dr. Bea does not address these definitions but rather treats this memorandum as a decision to build "piles of dirt" rather than levees. (Bea 702c Dep. 129:3-12.) He constructs his own term "earthen berm/spoil bank" or "EBSB" specifically for the purpose of this litigation. (*Id*. at 18:18-19:3.) He does however, conclude that the structures are part of the LPVHPP and thus are flood control structures for purposes of hurricane protection. (*Id*. at 79:17-80:10.)

Further, the numerous sets of plan drawings and specifications issued for construction all refer to the structures as levees. For example, titles on the contract drawings for the levees along the northwest end of MRGO Reach 2 spanning the period 1968 to 1985 include the authorized project name and the term "levees." Following are several examples:

> Lake Pontchartrain, Louisiana and Vicinity, Chalmette Area Plan, Hurricane Protection Levee, First Lift, Sta. 387+40 to 523+00 (Not Continuous) January 1968; Second Lift Sta. 370+00 to 682+00, St. Bernard Parish, LA April 1972; First Enlargement, Sta. 360+70 to Sta. 699+00 (Non Cont.), St. Bernard Parish, LA, July 1980; Second Enlargement, MRGO B/L Sta. 380+50 to Sta. 692+50+00, St. Bernard Parish, LA, May 1985

The design documents demonstrate and prove that the Corps of Engineers designed, and contracted to have built, a system of levees along the MRGO which were incorporated within the hurricane protection system with the intent of protecting St. Bernard Parish, New Orleans East, and the Lower Ninth Ward from hurricane flooding.

Post-Katrina Reports

The report by the Interagency Project Evaluation Team (IPET, 2006), commonly referred to as the IPET report, consistently uses the term levees.

The report by Seed, Bea, et. al. (2006) for which the authors are referred to as the "Independent Levee Investigation Team" (ILIT report) consistently uses the term "levees." This report has 35 co-authors.

The report by VanHeerden, Kemp, et. al. (2006), commonly called the "Team Louisiana Report," also consistently uses the term levees. This report has ten co-authors.

The published book by the American Society of Civil Engineers, *The New Orleans Hurricane Protection System" What Went Wrong and Why?*, intended for general audiences, consistently uses the term levees.

The Plaintiffs' expert who has coined the phrase "EBSB" has admitted in sworn testimony in his deposition that he made up the term for purposes of this litigation. (Bea 702c Dep. 18:18-19:3.) I conclude that all known engineers and scientists preparing post-Katrina reports, including the plaintiffs' expert when writing outside of this litigation, consistently refer to earthen flood control structures as levees, without qualification.

Other Sources

A review of standard dictionaries also leads to the conclusion that the definition of levee is cast solely in terms of *intended function*, not in the ability of the structure to actually perform that function. Further the pairing of the terms *earthen berm* and *spoil bank* appears to be unprecedented. The term *berm* is usually used to refer to a wide, low embankment placed against a larger and steeper embankment to provide an additional measure of stability. The term *spoil*

bank is normally used to refer to any deposit of dredged or hauled materials removed from an excavation. The levees along the MRGO were in fact constructed with significant amounts of dredge spoil; the levees included berms, but were not in their entirety berms. *See also* Corps' Policy Guidance Letter No. 26, Dec. 23, 1991 (discussing benefit determinations for existing levees).

Conclusion

The word *levee* refers to *intended* function, not whether an earth embankment is sufficiently adequate or reliable to perform that intended function successfully, or to perform beyond its design specifications. This conclusion is consistent with the Corps' usage as defined in the levee design EM, the design documents for the LPVHPP levees, and post-Katrina reports by a number of different and independent authors. The expected adequacy or reliability of a Corps' levee to perform its intended function is addressed by design criteria and the design review process, not by the nomenclature. Moreover, all levees under discussion in this litigation, *Robinson*, are incorporated into and are an integral part of the LPVHPP.

DESIGN AND CONSTRUCTION OF THE MRGO LEVEES

The design and construction of levees pursuant to the LPVHPP followed established USACE guidance and are consistent with engineering standards existing at the time these levees were designed and constructed.

Mississippi River Gulf Outlet (MRGO) Project

This section provides a review of the design and construction of the MRGO levees, focusing on Reach 2, from the Bayou Bienvenue Control Structure to about Station 995+00, where the levee turns southward toward Violet, Lousiana.

- On May 5, 1948, House Document 245, 82nd Congress, second session included a report from the Chief of Engineers.

- On March 29, 1956, by Public Law 84-455,the MRGO project design was approved and construction authorized substantially in accordance with the Chief of Engineers' report in House Document 82-245. The authorization provided for a deep draft waterway of 36-ft. depth and 500-ft. bottom-width; and when economically justified, a new lock in the vicinity of Meraux, LA or replacement of the existing lock at the entrance of the Inner Harbor Navigation Canal (IHNC) with the Mississippi River.

- On April 30, 1957, the New Orleans District transmitted the first design memorandum, DM 1-A, Channels, to the Lower Mississippi Valley Division (LMVD).

- Design memorandum 1-B, Channels, was transmitted to the LMVD on September 15, 1958, and a revised DM 1-B was submitted on May 14, 1959. This revised DM provided the design of the MRGO Reach 2, the area of interest for this section of this report. It included recommendations for 1V (vertical) on 2H (horizontal) channel slope and a berm

width of 90 ft. In paragraph 18, the berm width refers to the distance between the top of the channel cut and the toe of retaining dikes for dredge spoil. The DM notes that the soil conditions limit the height of retaining dikes to about 6 to 7 ft. and the height of dredge spoil to about 10 ft., with slopes of about 1V on 40H. It also states that construction is expected to occur in segments between 1959 and 1965.

- Regarding erosion protection for the channel, DM 1-B states (p. 5*) No channel protection is recommended initially; however, erosion due to wave wash in open areas can be expected in the upper part of the channel slope where the peat and highly organic clays are exposed. Protection for this area can be provided if and when the need for it becomes necessary. No channel protection is included in the overall cost of the project. It is presumed that sufficient rights-of-way will be furnished by local interests to preclude the use of channel protection, or that additional rights of way will be furnished if the need arises.*

Opinion: Thus, at least as early as 1958, the Corps of Engineers anticipated erosion of the MRGO banks in the course of keeping the channel open for navigation.

Authorization of the Lake Pontchartrain and Vicinity Hurricane Protection Project (LPVHPP)

On October 27, 1965, Public Law 89-298 authorized the LPVHPP, which included the levees and floodwalls providing hurricane protection in St. Bernard Parish, New Orleans East, and the Lower Ninth Ward. The authorization provided for construction of a hurricane protection system substantially in accordance with the letter of the Secretary of the Army dated July 6, 1965. A number of key points in the District Engineer's report are relevant to the analyses herein and are noted below.

- Page 20 of the report contains a glossary that defines terms such as design hurricane and standard project hurricane.

- Page 30 states that regional subsidence in the area has been about 0.4 ft per century, which would be 0.04 ft. (or about one-half inch) per decade, and that additional subsidence has occurred where marsh and swamp lands have been reclaimed and drained. As noted in the IPET report, the actual rate of subsidence in the last few decades has been significantly greater.

- On page 46, the central pressure index is provided for the standard project (design) hurricane (SPH) at 27.6 inches of mercury (935 millibars), with maximum sustained winds of 100 mph at a 30 mile radius from hurricane center. The IPET report notes that Hurricane Katrina reached a minimum pressure of 902 mb (26.6 in. Hg) from hurricane center and maximum surface winds of 139 knots (160 mph). At the time it made landfall, the central pressure index was 923 mb (27.3 in. Hg) and surface winds of 102 knots (117 mph). It is well-documented that Katrina significantly exceeded the design hurricane. Even though its wind speed diminished as it approached New Orleans, the storm surge and waves remained substantially greater than the SPH design parameters.

- Page 53 notes that the MRGO project was 20 percent complete in 1961.

- Page 65 (and also Plate 3) shows that the levee height in the MRGO area would be 16.0 ft east of Paris Rd. The Corps later changed this height to 17.5 ft.

- The same page notes that expected foundation settlement would require construction in one to six lifts, with an approximate period of two years between lifts to allow for settlement and consolidation of materials.

- Page 134, recommends that the expected frequency of the (design) standard project hurricane be considered 1 in 200 years.

Design Guidance and Practice in 1966

The 1966 General Design Memorandum (GDM) No. 3, Lake Pontchartrain and Vicinity, Chalmette Area Plan provided the overall design of the flood protection works for St. Bernard Parish. Similar General Design Memoranda were developed for the Citrus Back and New Orleans East Back Levees protecting the southern frontage of New Orleans East. No Corps' Engineer Manual (EM) on levee design was available at that time as the first levee EM was not published until 1978. There was relatively little guidance available with respect to levee and floodwall design in 1966 at the time GDM No. 3 was prepared because the application of geotechnical engineering to levee design was still in its early development at that time. The following are the general guidelines extant during the design of the LPVHPP levees in St. Bernard Parish, New Orleans, East, and the Lower Ninth Ward.

1947 Code for Utilization of Soils Data for Levees

The Mississippi River Commission, Vicksburg, MS, published this guidance in April 1947. The introduction states that it is an update of a similar 1941 document. Note that the Mississippi River Commission has responsibility for the Mississippi River and Tributaries (MR&T) project, and the document was specifically written for river levees, not hurricane protection levees.

The 1947 "code" did not require slope stability analyses in most cases, and understanding of soil shear strength and slope stability analyses was still in its early stages at that time. It did suggest (paragraph 64) a factor of safety of 1.3, except where weak soils made this factor impractical. The code stated that the Corps had previously used different standard sections for "compacted" and "uncompacted" fills and introduced a third concept, an intermediate-sized section for soils with a moderate degree of compaction at natural water content (in the Lower Mississippi Valley Division (LMVD), this later became known as "semicompacted.") Paragraph 32, emphasizes that:

> *Moisture control in levee construction has been and will be impractical. This view is generally entertained by all offices interested in levee construction in the Lower Mississippi Valley. There are many jobs on which the water content of the soil is too high to permit 100 percent standard Proctor compaction being obtained, but yet the soil can*

be compacted to a worthwhile degree. One of the primary reasons for type 2 construction is to obtain, at a minimum cost, the maximum practicable compaction on soils containing excess moisture.

Paragraph 34 of the code states:

…satisfactory levees can be constructed of uncompacted material. However, in some instances compacted impervious facings should be added, and a larger cross section provided to achieve parity with compacted levees. Therefore, the uncompacted section is retained for use where any form of compaction is obviously impracticable, or as an emergency measure, where the soil is too wet for compaction.

Paragraph 41 states:

Variations from the proposed standard levee sections will be necessary at certain locations to fit conditions peculiar thereto. The design for a hydraulic fill section should be special for the location and conditions under consideration.

Paragraph 43 states:

All levee sections, except riverside enlargements, may allow placement of sand on the landside, keeping in mind that the levee section must grade more permeable to the landward. The amount of sand should not exceed approximately two-thirds of the cross-sectional area of the levee. Levees constructed entirely of sand must have a watertight riverside blanket facing or an impervious central core.

Paragraph 51 states:

Through seepage in the present (1947, Mississippi River) mainline levee seldom offers a serious problem.

Paragraph 53 states:

Where a relatively thin (with respect to levee height) impervious top stratum is present above a highly pervious substratum of sand, conditions favorable to dangerous underseepage are present.

Paragraphs 54 through 63 further describe alternatives to control underseepage. Paragraph 65 states:

Where feasibly (sic) and necessary, the procedure for constructing levees over very weak foundations in two or more stages is warranted and should be continued. On occasion it may be necessary to use two or more stage construction, due to very wet levee material.

Opinion: There are a number of messages from the 1947 levee code that are relevant to the Katrina analysis. These include:

- 1.3 was a “target” factor of safety for slope stability, but lower values could be used where weak soils made this impractical.
- The Corps constructed levees of “uncompacted” materials, but attempted to achieve some degree of compaction of soils of natural (often high) water contents.
- The use of hydraulic fills was an established method used for levee construction.
- Levees could include up to two-thirds sands. Pure sand levees needed waterside protection only.
- Underseepage concerns were focused on foundations where thin, semipervious top blankets overlaid thick pervious substratum soils.
- Construction in stages over weak, compressible soils was a well-established practice.

1966 Paper by Kaufman and Weaver

In August 1966, the American Society Civil Engineers (ASCE) held a conference in Berkeley, California entitled *Stability and Performance of Slopes and Embankments* and published proceedings in a volume with the same name (ASCE, 1966). Robert I. Kaufman and Frank J. Weaver presented a paper entitled “Stability of Atchafalaya Levees,”. At that time, Kaufman was the chief of the Geology, Soils and Materials branch of the Corps’ LMVD and Weaver was an engineer in that branch. Later, Kaufman became the Assistant Chief of Engineering and Weaver became branch chief. While this ASCE paper discusses river levees some distance west of New Orleans, it is significant because it describes in some detail the hydraulic fill and stage construction procedures also used later for the levees along MRGO.

On page 180, these engineers state:

> *Levee construction in the southern part of the* [*Atchafalaya*] *basin has been in progress for the past 25 to 30 yr. These levees were constructed by placing a hydraulic fill, shaping it into a levee, pumping more fill and shaping it, and then raising the crown by adding relatively thin lifts. After placing each fill or fill lift, sufficient time had to be allowed to enable the lift and foundation to consolidate and strengthen before another lift could be added without inducing a shear failure in the levee….*
>
> *… The cumulative settlement of the west guide levee averages about 8 ft. in the southern part of the basin and in some reaches is 15 ft. These are large settlements for levees which are to have a net height of only 20 to 25 ft. above the ground surface.*

This paper regarding the Atchafalaya levees further documents that, by 1966, the NOD and the LMVD of the Corps already had decades of experience with levees on soft Louisiana soils and the problems associated with keeping them at desired grades. Because of the time required to achieve final grade, Weaver and Kaufman describe a “compromise plan” used for the Atchafalaya levees. This involved building a large stability berm and then quickly building a levee to or above design grade to provide a high degree of flood protection. After the foundation consolidated and the levee settled, lift construction would then be used to bring the levee back to final grade.

Opinion: The Kaufman and Weaver paper provides further documentation of Corps' levee design and construction methods in Louisiana just prior to the design of the MRGO levees. The concept of building on soft compressible soils by first building a very wide and flat embankment by hydraulic fill, and then raising it by re-shaping it in stages over time, was an established practice in 1966.

November, 1966 Lake Pontchartrain and Vicinity, GDM No. 3, Chalmette Area Plan

GDM No. 3 documents the design of the levees along Reach 2 of the MRGO and is in accordance with available Corps guidelines and acceptable engineering practices regarding geotechnical considerations.

Review Process

The numerous letters of "indorsement" (Army spelling) bound in the front of GDM No. 3 illustrates how the design of Corps projects in the relevant timeframe involved a series of multiple reviews. The District Office (here the NOD) first documented the design of a project or major feature in a Design Memorandum and subsequently submitted it to the Division Office (LMVD). The Division office reviewed the design and commented, in a cover letter termed the first indorsement, and forwarded the Design Memorandum along with the cover letter to Headquarters, Office of the Chief of Engineers (OCE). OCE then would comment (second indorsement) and return the DM to LMVD, who would then write the third indorsement letter back to the district. This process would continue until all comments were resolved among the three levels of Corps offices. For GDM No. 3, the review correspondence chain extends through a ninth indorsement on June 22, 1967. A separate letter follows regarding modification of the plan that concludes in an eleventh indorsement on November 22, 1967. A similar review process occurred for the GDMs pertaining to the Citrus Back and New Orleans East Back levees.

The result of the comments and replies in these indorsements is that the ultimate design represented a convergence of experience-based opinion and judgment from multiple engineers at multiple levels within the Corps and with coordination and input from local entities. These engineers agreed upon a safe and economical design based on available guidelines and general knowledge in the civil engineering community. The indorsements reflect the deliberations and judgments related to addressing the specific characteristics, challenges and practicalities of designing the specific project in the available area. This includes the hydrodynamic loading conditions that the project was designed to withstand.

In general, the Division review provided for consistency across the Districts in the Mississippi River Valley in addressing site specific issues, while the Headquarters review often focused more on policy and project planning details. In most cases, reviewing engineers in the division office had significant experience in a district office prior to employment at the Division level.

Levee Grades

GDM No. 3, paragraph 12, states that the net levee grades were revised upward based on studies following Hurricane Betsy in 1965. Paragraph 14 anticipates the design wind tide level in Reach

2 to reach between 12.5 and 13 ft., with an allowance of 4.3 to 4.7 ft. for anticipated wave runup. This yields a net grade of 17.5 ft. This represents a 1.5 ft. increase from the authorization report to Congress based on changes to the design hurricane.

Paragraph 20 states that the rate of regional subsidence is estimated as 0.4 ft. per century (0.004 ft. per year). This matches the language in the authorizing document.

Soils

Paragraph 26 of DM3 identifies soils to be used in levee construction. In the area paralleling the MRGO, the natural Recent (geologic era) soils are described as having been covered with hydraulic spoil from the excavation of the MRGO. These recent soils consisted of "generally, and in varying strata, of organic clays (OH), peat (PT), fat clays (CH), some lean clays (CL), some clayey sands (SC) and rare spots of fine sand (SP)."

Soil boring logs on Plates 11 to 14 show the top 10 feet of ground under the proposed levee (i.e., the "Recent" soils) primarily composed of soft and very soft fat clay (CH) with some peat (PT). Due to having been obtained from the MRGO, the hydraulic spoil above the Recent soils are themselves displaced Recent soils with similar composition. This is consistent with the Corps guidelines for the design and construction of levees.

Seepage and Uplift

Paragraph 31 of GDM No. 3 states: "Based on the soil conditions along this part of the project and the short duration of hurricane floods, hazardous seepage or hydrostatic uplift on the protected side is not anticipated."

Opinion: The reference to "soil conditions" in GDM No. 3, paragraph 31, suggests that fat clays and organic clays predominate the foundation and fill materials. Consequently, there is no well-defined subsurface pervious strata. Regarding the "short duration of hurricane floods," the designers had experience with satisfactory performance of river levees on similar soil conditions, where water levels would be at flood stage for weeks or more. Thus, for the expected conditions of the LPVHPP, the soil conditions should have been adequate to resist short duration loadings expected from the design hurricane.

The sixth indorsement to the GDM No. 3, page 18, April 12, 1967 mentions Mr. Robert Kaufman's attendance at a design conference. In addition to his work on the 1966 slope stability paper already mentioned, he worked on the underseepage research at the USACE Waterways Experiment Station in the 1950s that set the standards for underseepage design in the Corps. His 1956 ASCE paper with C.I. Mansur, *Underseepage, Mississippi River Levees, St. Louis District*, received the 1958 Thomas Fitch Rowland Prize of the ASCE, and was reprinted by ASCE in an anthology of award-wining papers of the 1950s. It remains today one of the most widely-cited papers on levee underseepage. The analytical methods in the paper focus on the foundation conditions of a thin semipervious top stratum overlying a thick, pervious substratum - the Corps' soil profile of common concern for potential underseepage. These are not the conditions along the MRGO. It is highly significant that an underseepage expert such as Mr. Kaufman was one of

the reviewers of the 1966 GDM No. 3 and raised no objection to the short statement from GDM No. 3 paragraph 31. This reflects the strength of the engineers' judgment that underseepage would not be of concern for the MRGO or LPVHPP projects.

Post Katrina investigations and inspections do not provide any evidence that seepage or uplift occurred on any levee relevant in Robinson, including, but not limited to those levees that breached along the MRGO and the IHNC.

Erosion Protection

Paragraph 36 of GDM No. 3 states:

> *Due to the short duration of hurricane floods and the generally erosion resistant nature of the soil along this project, no erosion protection is considered necessary along the leveed portion of the project. Riprap protection is considered necessary around the structures at Florida Ave.*

Opinion: This conclusion likely is based on the fact that the soils to be used in the levees were expected to contain significant amounts of clay. No quantitative means of predicting erosion over time under wave forces were available in 1966. Indeed, no practical, reliable, widely-accepted means of such analysis and prediction is available even today.

Levee Stability

Paragraph 38 of GDM No. 3 provides a detailed description of the stability analyses performed to design the phased construction sequence of the MRGO levees and their final configuration. Notable details include the following:

- Over a five to seven year period before levee construction, spoil from MRGO excavations had been placed to elevations varying from +5 to +12 ft. The spoil area was 2,000 to 4,000 ft . wide, paralleling the MRGO. Soil borings indicated that the weight of the spoil had depressed the original surface 5 to 10 ft. The levee designers properly concluded that significant foundation consolidation and strength gain had occurred.

- "Lifts" involved bringing new materials to the site after earlier-placed materials had settled. "Shapings" involved reworking previously placed material into a different (steeper) cross-sectional shape.

- Each lift or shaping was intended to be stable to a factor of safety of at least 1.3.

- A detailed analysis of consolidation and strength gain over time was performed for each lift or shaping and predicted strength values were obtained for slope stability analyses before placing the next lift or reshaping.

Opinion: The designers had full knowledge of the difficulties of building on and with soft, compressible soils, and made detailed design analyses to develop a phased construction sequence

that would be stable over the extended construction period. I conclude that the levees were designed according to the best practices at the time and that the breaches did not result from instability attributable to a negligent design.

Levee Construction

GDM No. 3, paragraph 39, describes the planned method of levee construction. It states that:

- Dredged material from the MR-GO would be used to construct the lifts along Reach 2. This is also noted on Plate 23 of GDM No. 3.

- Lifts would be made as high and narrow as stability permitted. For much of the area, all of the required material would be placed in one lift, but would require a number of subsequent reshapings.

At the time of Hurricane Katrina, levee construction was not fully complete. A 2001 report entitled *Geotechnical Investigation, Chalmettee Area Plan, Bayou Bienvenue to Bayou Dupre* presents a plan for a final lift involving compacted clay fill. However, funds were not made available for this final lift.

Foreshore Protection

GDM No. 3, paragraph 50, states that:

- The banks of the MRGO were expected ultimately to stabilize at a slope not flatter than 1V on 3H.

- Significant erosion of the foreshore area between the levee and the channel bank via ship-generated waves could pose a threat to the stability of the levee if this erosion reached the levee slopes situated several hundred feet from the bank of the MRGO.

Later, in the sixth indorsement to GDM No. 3, the New Orleans District decided to perform stability analyses with the assumption that the entire foreshore area had eroded away.

Opinion: After review by multiple levels of Corps engineers experienced in flood protection and wave action, there was no perceived need for foreshore protection as a result of ship-generated waves. The stability analyses under the assumption that the entire foreshore area had eroded away emphasize that maintaining levee stability motivated the analyses, not underseepage, nor any need to maintain the MRGO footprint. This further emphasizes the conclusions from GDM No. 3, paragraph 36, that the soil conditions and short time frame of hurricane loadings would not warrant erosion protection on the face of the levee. This design is consistent with the available Corps guidance and general standards and practices in the civil engineering community.

Plan and Profile Drawings, and Boring Logs

GDM No. 3, plates 11 through 14, are the design plan and profile drawings for the section of Reach 2 between Bayou Bienvenue and Bayou Dupre. The plates include logs of soil borings generally taken along the levee alignment. The logs consistently show the foundation conditions to be composed of thick deposits (tens of feet) of soft to very soft fat clays (CH), with some areas of organic clay (OH) and peat (Pt).

The top 10 to 20 ft. of these materials are spoil material from the earlier MRGO excavations, and they are substantially similar to the deeper underlying in-situ materials. Additional borrow material dredged from the MRGO consisted of primarily fat clays (CH). Predominantly fat clays (CH) in the foundation would indicate no concerns for underseepage in the foundation, and no concerns for erodibility when used as levee fill material. As previously noted, erodibility was not a concern due to the materials (fat clays, CH) and short duration of hurricane surge levels.

Design Section Drawings

GDM No. 3, plates 23 through 25, show design sections for the levee along the MRGO. In general, the design called for the levees to have a 10 ft. wide crown (top of levee) at elevation 17.5 ft., with 1V on 5H side slopes down to elevation 9 ft., where a 1V on 30H stability berm is provided. Plate 23 shows that fill material will be obtained from selected areas of the MRGO channel.

Lift and Shaping Details

Plate No. 65 of GDM No. 3 provides the detailed plan for placing lifts and reshaping of the levees along the MR-GO. Planned construction would involve as many as four phases over 13 years, and total settlement of as much as 8 ft. (Sta. 807+00 to 978+00**).**

Summary Opinions on GDM No. 3: GDM No. 3 is the primary design document for the MRGO levees. The following comments are reiterated:

- The review process documented in the indorsements reflects review and deliberations about the design by engineers at two distinct levels above the district designers. These reviewing engineers determined that the design was safe, appropriate and economical, and that it met existing Corps guidelines.
- The assumed rate of subsidence was based on information available and was believed to be a reasonable estimate.
- Seepage was considered and determined not to be a problem that required specific studies. That decision making process involved engineers considered to be the experts within the Corps and the United States.
- The Corps considered erosion protection for the levees and appropriately determined that grass would be adequate due to the short term hurricane loadings and the predominance of fat clay (CH) in the levee construction materials.

- The Corps was familiar with the challenges of building on soft foundations with soft soils, and designed the MRGO levees with a well-established construction plan that required phased placements and reshapings over an extended period of time.

March 1967, First Lift, Sta. 594+00 to 770+00

This levee lift was between Bayous Bienvenue and Dupre. Included in the construction plans and specifications were soil boring logs for the area of the proposed work. These logs generally show the foundation materials to be thick deposits of soft to very soft fat clays (CH) with some organic clays (OH), silts (ML) and peat (Pt). The first lift construction involved building retaining dikes about 400 ft apart, and pumping hydraulic fill between them to elevations of +13 to +16.5 ft. with 1V on 30H slopes from the center to the retaining dikes.

January 1968, First Lift, Sta. 387+40 to Sta. 523+00

This work occurred southeast of Bayou Bienvenue. The relevant construction plans include logs of soil borings taken along the levee alignment in 1966. Similar to the reach above, the logs generally show the foundation materials to be thick deposits of soft to very soft fat clays (CH) with some organic clays (OH), silts (ML) and peat (Pt). Also similar to the above, the first lift construction involved building retaining dikes about 400 ft apart, and pumping hydraulic fill between them. In this reach, the top elevations of the first lift were to be elevation +12 ft. with 1V on 30H slopes from the center to the retaining dikes.

Borrow material from the MRGO channel was shown to be available from elevation -39 to -60 ft. This contract also involved providing a closure at Bayou Villere which included shell fill flanked by hydraulic fill on either side. Subsequent fills and reshaping would put the shell fill in a “core” location not accessible by floodwaters.

April 1970, First Lift, Sta. 770+00 to Sta. 995+00

This item of work occurred southeast of Bayou Dupre. The construction plans include logs of soil borings taken along the levee alignment in 1967. The logs show the foundation materials to be primarily soft to stiff fat clays (CH) with some silt strata, and in some cases, underlying silts (ML).

Similar to other reaches, the first lift construction involved building retaining dikes (in this area, only about 265 ft. apart) and pumping hydraulic fill between them. The top elevations of the first lift were to vary from elevation +13 to +17 ft., with 1V on 30H slopes from the center to the retaining dikes.

Borrow material from the MRGO channel was shown to be available from elevation -40 to -60 ft. These drawings also include logs for soil borings taken in 1956 for the location that became the MRGO channel. From elevation -40 to -55 ft., the soils were predominately soft fat clays (CH) with some silt strata.

Opinion: The MRGO borrow area soil boring logs support that the levee materials were primarily fat clays (CH) of greater erosion resistance than sands and silts, and of lower permeability.

April 1972, Second Lift, Sta. 370+00 to Sta. 682+00

This construction project ran generally from Bayou Bienvenue to Bayou Dupre. The drawings include the 1966 soil borings used in the construction of the first lift in this area, plus additional soil borings taken in 1971. No significant differences are noted in the newer borings. The 1971 soil boring logs again show the foundation materials to be thick deposits of soft to very soft fat clays (CH) with some organic clays (OH), silts (ML) and peat (Pt).

The construction involved raising the levee section using hydraulic fill from about elevation 10 ft. to elevation 18 ft. The borrow material from the MRGO channel came from as deep as elevation -70 ft.

March 1978, Engineering Manual, EM 1110-2-1913, Design and Construction of Levees

Engineering Manuals Provide Basic Principles and Guidance. This 1978 Engineer Manual provides basic principles and guidance for design and construction of levees. In March 1978, the Corps first published its engineer manual (EM) on the design and construction of levees. The transmittal letter to the district offices provides two important statements about its purpose and use:

> *1. Purpose. The purpose of this manual is to present basic principles used in the design and construction of levees.*
>
> *3. General. This manual is intended as a guide for designing and constructing levees and not intended to replace the judgment of the design engineer on a particular project.*

Opinion: Corps' Engineer Manuals (EMs) provide guidance, not hard and fast rules. They are typically based on substantial experience with previous structures within the Corps, but recognize that site and project-specific factors influence levee design and construction. Deviations from EMs are typically considered in a multi-level review process (discussed earlier) and are documented in indorsements to design memoranda. That is the case for the levees along MRGO, where the design and its review were documented in the 1966 GDM No. 3.

Slope Stability Safety Factors

Table 1 below shows slope stability factors used in GDM No. 3, and compares those recommended in the 1978 EM to those shown in the 2000 revision of the EM.

Table 1
Factors of Safety for Slope Stability

Case	1966 (GDM #3)	1978 (EM)	2000 (EM)
End of Construction	1.3 (para 30b)	1.3	1.3
Sudden Drawdown	--	1.0	1.0 to 1.2
Intermediate River Stage	--	1.4	--
Steady state from full flood stage	--	1.4	1.4
Earthquake	--	1.0	--

Opinion: The factor of safety criteria for the end-of-construction condition used in the 1966 design memorandum also is consistent with the Corps-wide guidance published in the 1978 EM. The sudden drawdown, intermediate river stage, and steady state full flood cases are not applicable in this instance because the hurricane protection levees were expected to have water loads only for very short durations. Earthquakes were determined not to be a concern in the design and construction of the LPVHPP levees.

Erosion Protection

The 1978 EM, Section 7-6, pages 7-9 to 7-10, addresses protection of riverside slopes to withstand the erosional forces of waves and stream currents. It states:

> *The protection needed on the riverside slope to withstand the erosional forces of waves and stream currents will vary, depending on a number of factors, including*
>
> - *… length of time that floodwaters are expected to act against a levee. If this period is brief, with water levels against the levee continually changing, grass protection may be adequate, but better protection may be required if currents or waves act against the levee for a longer period.*
> - *The relative susceptibility of embankment materials to erosion. Fine-grained soils of low plasticity (or silts) are most erodible, while fat clays are the least erodible*
> - *Requirements for slope protection are reduced when riverside levee slopes are very flat as may be the case for levees on soft foundations.*

- *Sometimes it may be concluded that low cost protection, such as grass cover, will be adequate in general for a levee reach, but with a realization that there may be limited areas where the need for greater protection may develop under infrequent circumstances. If the chances of serious damage to the levee in such areas are remote, good engineering practice would be to provide such increased protection only if and when the actual problems develop…*

Published twelve years after construction commenced on the LPVHPP, the above first, second, and third bullets in this EM continue to consider grass protection on the water side slope of the levees to provide sufficient erosion protection (short duration water levels, flat slopes and presence of fat clays) - - such as during a hurricane. The fourth bullet supports the point that location-specific experience remains a factor in judgmental design decisions. Levee design is not simply based on mathematical prescription.

Opinion: Nowhere in the 1978 EM guidelines is there a mandate for the Corps to incorporate specific erosion protection measures to a levee's landside slope to protect against failure in the event of overtopping. In my opinion, The Corps exercised the appropriate judgment necessary in following its guidelines and accepted engineering practices with respect to providing erosion protection to the LPVHPP levees.

Levee Materials

The 1978 EM, section 4-2.a states:

> *Material type. Almost any soil is suitable for constructing levees, except very wet, fine-grained soils or highly organic soils. In some cases, though, even these soils may be considered for portions of levees. Accessibility and proximity are often controlling factors in selecting borrow areas, although the availability of better borrow materials involving somewhat longer haul distances may sometimes lead to the rejection of poorer but more readily available borrow."*

Section 6-1.a.(1), Embankment Geometry states:

> *(1) Type of construction. Fully compacted levees generally enable the use of steeper slopes than those of levees constructed by semicompacted or hydraulic means.*

Section 6-3.b.(3) states:

> *Hydraulic fill consisting of fine-grained soils is usually restricted to construction of stability or seepage berms with a central levee zone constructed of hauled borrow by the semicompacted method.*

Section 4-2.a indicates that an engineer should take into account the availability and haul distance of soil for levees when considering a levee's design and construction. Section 6-1.a(1)

clearly and unequivocally recognizes that hydraulic fill was in 1978 still an acceptable source of levee borrow material.

Opinion: While the wording in 6-3.b.(3) seems to rule out the type of construction used on the MRGO levees, this is not the case. Section 6-3.b refers to construction using sand fills directly in place, not the "lift and re-shape" construction with fat clays employed by the New Orleans district in the Atachafalaya basin, along MRGO, and elsewhere. The specific method of construction, relevant here for construction on and using very soft and compressible soils, is unique to the New Orleans district and hence did not find its way into the EM generally intended for Corps-wide applicability.

April 1978, First Enlargement, B/L (Base Line) Sta. 708+95 to B/L Sta. 945+85

This contract provided for reshaping the first lift materials, placed eight years earlier, southeast of Bayou Dupre. These materials originally reached top elevations of +13 to +17 ft. The 1976 profiles shown on these construction drawings provide top elevations primarily in the range +11 to +13 ft., indicating settlement on the order of 3 ft. since placement. Borrow was to be obtained from a very wide (315 ft.) landside borrow area, excavating a very shallow cut down to elevation +4 ft. Borings show the borrow materials to be primarily soft to very soft fat clays (CH). The raised levee was to have a top elevation of +18 ft. with 1V on 5H side slopes. Fill was shown as uncompacted fill except for short reaches of semicompacted fill.

A few deep soil borings show no evidence of significant pervious substrata underlying thin semipervious top strata that would suggest the need for underseepage analysis.

The August, 1979 narrative completion report mentions "Manitowoc 4600s," suggesting that a dragline was used to move materials. Dozers also are mentioned, apparently for final shaping.

Opinion: I conclude that the method of construction was appropriate for the specific conditions and purposes and was consistent with the then generally-accepted engineering practices for constructing a levee that would not be destabilized by through or underseepage during short-term loading such as would exist during hurricanes.

July 1980, First Enlargement, Sta. 360+70 to Sta. 699+00

This contract provided for reshaping the first lift materials placed eight years earlier, generally from Bayou Bienvenue to Bayou Dupre. Levee centerline profiles showed top elevations typically between elevations +11 and +14 ft., indicating settlement on the order of 4 ft. since placement of the first lift. Borrow materials were to be obtained from both landside and waterside borrow areas, by land-based equipment, with the borrow excavations down to elevations -4 to -5 ft. Soil borings in the borrow areas indicate clays (CH and CL), silts (ML) and silty sands (SM**)**. Under this contract, the levee was raised to elevation +18 ft. Fills were shown as "uncompacted" with the exception of an area of semicompacted fill adjacent to the Bayou Bienvenue closure structure.

A few deep soil borings show no evidence of significant pervious substrata underlying the thin semipervious top strata that would create an expectation of likely underseepage or suggest the need for underseepage analysis.

A narrative completion report prepared on June 15, 1981, mentions a delay due to the government providing a landside borrow pit after hauling waterside borrow significant distances was found to be impractical. Draglines were used to move material to the levee and place uncompacted fill. A sudden sinking of the levee by three feet in April 1981 suggested a localized slope stability failure, which was repaired and again failed shortly thereafter. After this second failure, work on that section was deferred. The small area of semicompacted fill was placed using a backhoe and dump trucks.

November 1982, Bayou Bienvenue to Bayou Dupre Levee Closure

This contract provided for closing of the natural channels of Bayous Bienvenue, Villere and Dupre, and closing a previous open area at the Southern Pipeline crossings. These closures were made with hydraulic fill obtained from a borrow area in the MRGO channel extending down to elevation -8 ft. The contract does not provide soils information for these deep channel borrow areas. Closures were to be constructed to top elevations varying from +13 to +15 ft. Retaining dikes for the hydraulic fills were to be made with surface borrow materials located within the limits of the new fills.

March 1983, Second Enlargement, B/L Sta. 708+68 to B/L Sta. 945+87

This contract consisted of a second reshaping of materials southeast of Bayou Dupre. The first enlargement (reshaping) had been done some five years earlier. Borrow was obtained waterside of the levee. August 1981 surveys showed the existing levee grade to be typically at elevation +16 to +18 ft., suggesting that settlement since the first enlargement had been approximately 1 ft. The contract provided for raising the levee to elevation 20 ft. with uncompacted fill except for small reaches of semicompacted fill near transitions to floodwall structures. Soil boring logs are provided for four deep borings, but none of these borings were located in the borrow areas.

A soils report dated November 1982 was available and apparently accompanied the plans and specifications. This report recorded four deep soil borings and related testing, which were used for stability analyses to verify that the design section had a minimum factor of safety of 1.3. A settlement analysis that determined a gross grade of +20 ft. NGVD was needed to yield a net grade of +17.5 ft.

A narrative completion report filed in February 1984, stated that the uncompacted fill was placed with a dragline, and the small amount of semicompacted fill was placed with a D-6 dozer.

Opinion: As no soil boring data for the borrow areas are presented in the specification drawings, it is assumed that contractors bidding the work were likely familiar with soil conditions in the area from previous construction work. Furthermore, whether these materials were clays, silts or silty sands, the same types of hauling equipment could be used, and the use of uncompacted fill likewise reduced the need for the contractor to have more specific information about the soils.

May 1985, Second Enlargement, MRGO B/L Sta. 380+50 to Sta. 692+50

This contract provided for reshaping of the second lift materials placed five years earlier, generally from Bayou Bienvenue to Bayou Dupre. Levee centerline profiles showed top elevations typically between elevations +15 and +17 ft., indicating settlements of approximately 4 ft. since placement of the first lift. In this contract, the levee was to be raised to elevation +20.5 ft., with side slopes of 1V on 3.5H. Borrow materials were to be obtained from both landside and waterside borrow areas, by land-based equipment. The degree of compaction was not noted on the drawings and presumably was in the written specifications.

August 1985 NOD Decision on Benchmarks

In 1984 and 1985, the NOD and the LMVD confronted the issue that significant subsidence was occurring in the region, and that the design levee grades may not be sufficiently high to protect against the intended SPH. A summary follows:

- On 11/2/1984, Fred Chatry, NOD Chief of Engineering, wrote to LMVD informing that the 1983 benchmark adjustments by the National Geodetic Survey (NGS) had been finalized. He refered to previous discussions on 4/10/84 and 10/24/84, and noted that there may be significant implications to these revised elevations. He enclosed some plots and recommended a meeting.

- On 3/5/1985, Rod Resta, Chief of Engineering at LMVD, wrote to Rear Admiral Bossler, Director of Charting and Geodetic Services, NOAA. He stated that surveys by the NOD using the new data indicated that some levees could be more than one foot lower than intended in less than 20 years. He requested input from NOAA / NGS regarding these adjusted elevations.

- On 3/29/1985, R.A. Bossler responded to Mr. Resta stating a very high level of confidence in the 1983 adjustments, and forwarded two publications. Bossler mentioned a subsidence measuring plan, termed the Geocadastre, on which they briefed NOD in November 1984. Bossler also provided contact information for staff available to meet.

- On 4/12/1985, Bob Kaufman, Acting Chief of Engineering at LMVD, forwarded the 3/29/1985 R.A. Bossler letter to NOD.

- On 5/1/1985, Bob Kaufman wrote to NOD, requesting: a review of the situation, consultation with NOAA staff as necessary, and a proposed course of action by 5/31/1985.

- On 5/24/1985, Fred Chatry of NOD replied to LMVD that NOD and the Regional Planning Commission representing Jefferson, Orleans, St. Bernard and St. Tammany Parishes had met with NOAA and that there would be another meeting on 6/12/1985.

- On 8/7/1985, Chatry provided a detailed letter to LMVD. The district concurred that the new 1983 benchmark elevations were correct, and outlined a broad range of concern

areas, such as the effects on river and stream gauges, river levees, dredging projects and hurricane protection levees. For hurricane protection levees, the letter states:

> *Hurricane protection projects which are partially complete will use the NGS benchmarks current at the time of construction of the first increment of the project. To shift to the later NGS data without altering the heights of previously constructed portions would make "fuseplugs" of those portions and thus impose a gratuitous servitude on the lands and facilities they protect. And altering previously constructed works would not be practicable.*
>
> *New hurricane protection projects will be constructed using the latest available NGS benchmark data.*

- On 9/19/1985, in the first indorsement to the above letter, the LMVD states that
  - It agrees in general with the position of NOD.
  - NOD should conscientiously review flood control works to ensure there are no exceptions that should be individually analyzed based on specifics.
  - "Consideration should be given to reanalyzing and modifying (if needed) hurricane protection work in high density urban areas where the datum changes will drastically reduce the level of protection."

Opinion: The 1985 decision by NOD clearly led to levees with lower elevations than would have resulted from an alternate decision. The comments provided with the LMVD approval permit the NOD to make exceptions, at NOD's discretion. The rationale for the decision is stated fairly clearly in the NOD letter. Based on having worked in the St. Louis District (also in the LMVD) for 15 years prior to this letter, having performed work for NOD, having been in review meetings with LMVD during that time, and having reviewed other documents, I conclude the following:

- The SPH, as well as the Standard Project Flood (SPF) on the Mississippi River were generally viewed as "limiting cases" that engineers could expect to see once in 200 years.
- Seeking new authorizations or post-authorization changes to accommodate elevation changes due to subsidence would 1) radically delay the project, and 2) could result in the possibility that the project would be suspended or delayed indefinitely. (Both the Carter and Reagan administrations saw significant reductions in funding for Corps' projects).
- Both the local interests and Corps' officials, many of whom owned homes protected by the levees, may have seen a "good and consistent" level of protection as a preferred alternative to not completing the project.

January 1987, Levee Closures, B/L Sta. 367+60 to 1005+49

This contract involved the raising of Bayou closure sections constructed earlier in 1982. At Bayou Bienvenue, the closure section was raised from about elevation +12-13 to +15 ft. At Bayou Vilere, the raise was to elevation +20.5 ft.; at the Southern pipeline, +15 ft.; and at Bayou Dupre, +20.5 ft. Borrow was taken from both waterside and landside borrow areas adjacent to the levees. Fill was specified as uncompacted. Soil boring logs are provided for areas on the

levee centerline, at the levee toe, and in the borrow areas. Levee soil boring logs show soft clays (CH and CL) and some silty sands (SM). Borrow area soil boring logs show similar materials, plus some silts (ML).

A narrative completion report written in April 1988, shows that soils were cast by dragline and shaped and dressed by dozers. The last section of this report refers to sufficient subsidence in borrow areas between the time of design and construction leading to shortages of sufficient material for construction.

May 1992, Levee Closures, Sta. 366+00 C/L to Sta. 1007+91 C/L

This contract provided for placement of semi-compacted fill and sheet piling to elevation +18.5 ft. at a number of locations, generally adjacent to the closure structures and pipeline crossings mentioned above. The drawings include both levee and borrow area borings that show clays (CL and CH) and silty sands (SM) near the top of the levee and in the borrow materials.

A narrative completion report written in January 1994, shows that materials were moved from the borrow areas to the levee with dump trucks and compacted with dozers. Sheet pile apparently were driven without any difficulty.

April 2000 EM 1110-2-1913, Design and Construction of Levees

The 1978 EM on design and construction of levees was revised in 2000.

Engineer Manual Provides Basic Principles and Guidance. The transmittal letter, signed by General Fuhrman, provides wording that is identical to the March 1978 transmittal previously discussed.

Opinion: This 2000 revision of the EM for Design and Construction of Levees reaffirms the Corps' continuing policy that EMs provide basic guidance, but specific design issues are addressed on a project-by-project basis. That project-by-project review continues to be performed through the multi-level design review.

Erosion Protection. The wording of the 2000 EM on this subject (paragraph 7-6) is essentially unchanged from the 1978 wording, especially regarding short duration loadings and fat clays (CH) having the best erosion resistance.

Opinion: This reflects that, in the 22-year period between the two manuals, nothing "quantitative" regarding design for erosion protection came about for which the Corps had enough confidence in the methodology to include it in the revised EM. It also may reflect that the manual in large part was written for river levees for which it was considered adequate. Hurricane levees were addressed on a case by case basis by the District and Division. The judgment of the District and Division correctly remained that because of only short duration of exposure to waves, and the levee composition of primarily fat clays, the existing levee design was adequate.

Overtopping Considerations. The 2000 EM does introduce, in section 6.3.b, a caution against using hydraulic fill construction as it would quickly erode if overtopped.

Opinion: So far as I can determine, this is the first instance in Corps guidance where erosion resistance during overtopping is addressed in any fashion, and it was published some 33 years after the design approved in GDM No. 3. I conclude that this guidance is likely written in the context of hydraulic sand fill levees such as those on the Illinois River, where many agricultural levees are built to 50 year protection. In the five years before Katrina, however, it would not have been feasible to rebuild every levee in the system that had been constructed using hydraulic fill. In my opinion, the 2000 revision confirms that the LPVHPP Reach 2 levees were designed and constructed in keeping with the then-prevailing engineering standards for such structures.

Levee Materials. The text previously cited in section 4-2.a appears to be unchanged from the 1978 edition, as is 6-1.a(1). The wording in 6-3.b.(3), again apparently the same, again presumes sand hydraulic fills and not the predominately fat clay materials or the lift and reshape construction used at MRGO.

2001 Geotechnical Investigation, Chalmette Area Plan, Bayou Bienvenue to Bayou Dupre

This design document summarizes geotechnical design studies performed in connection with a proposed levee lift between the two bayou closure structures. The study included four new soil borings and three older borings on the levee centerline, plus a number of other borings. The proposed work was intended to raise the levee to elevation +20 ft., and the report notes that the SPH grade was intended to be +17.5 ft..

The proposed design included raising the levee centerline and placing compacted clay fill. The report made reference to both compacted clay and compacted earth fill, but then indicated that permissible fills could be either CL, CH, or ML, with ML in fact referring to silt. Most significantly, the design intent referred to a quantitative degree of compaction rather than using the previous terms “semicompacted” or “uncompacted.” Rather than defining compaction by equipment operation and passes, the design called for soils to be compacted to 90% of maximum dry density as defined by ASTM D 698. “Fully compacted” would be specified as 95%, and can be difficult to obtain with wet borrow materials. This level of compaction and type of specification reflects a shift in the Corps’ approach to compaction specifications, but still is consistent in design intent with “semicompacted.”

The proposed design criteria for I-walls included factors of safety of 1 to 1.5, depending on loading. A safety factor of 1.0 was for an “overload” condition with water at 2.0 ft above the design static water level. Levees were designed for a minimum factor of safety of 1.3 except at pipeline crossings, where 1.5 was used. Stability analyses were performed using the LMVD methods of planes. The “method of planes” is a simple method of slope stability analysis that is easily programmed for computers, and easy to hand check. Its results generally compare well with more complex and more rigorous methods. The design provided for a “wave berm” 120 ft wide on the water side of the levee. Soil boring logs show the levee materials to be predominately clays (CH and CL).

Opinion: This design document clearly shows the Corps' intent for the finished levee surface to be comprised of compacted impervious materials that would provide a degree of erosion resistance and support vegetation. I have not found any evidence that this work was actually constructed.

DESIGN AND CONSTRUCTION OF THE BAYOU BIENVENUE AND BAYOU DUPRE CONTROL STRUCTURES

The Bayou Bienvenue and Bayou Dupre control structures each have a set of sector gates that are normally kept open to permit water to enter the bayous, but can be closed in very high tides or for approaching hurricanes. The structures were both completed in 1974. General design of the structures is documented in the 1966 GDM No. 3 and detailed design of the structures is documented in the March 1968 DDM No. 5.

I do not have the original construction drawings for the structures. Some of these drawings, however, are reproduced in the 2002 Periodic Inspection Report for Bayou Dupre, and the 2004 report for Bayou Bienvenue, along with additional information about the structures.

The connections of the adjacent levees to the structures occurred in three separate construction contracts, previously mentioned, in 1982, 1987 and 1992.

During Katrina, at Bayou Bienvenue, a steel sheet pile connecting a section of concrete T-wall to the earth embankment southeast of the structure failed, leaving a breached area. This breach area coincided with the old channel closure section. At Bayou Dupre, a concrete sheet pile I-wall northwest of the structure failed, leaving a breached area which also coincided with the old channel closure section.

The structures themselves, and adjacent T-walls, were pile founded (piles driven into the soil) and remained intact. A point of discussion in the present legal case is the use of lightweight shell fill as a construction material, and how that may have contributed to the failure. Some of this shell material could be observed around the breach sites after the hurricane.

Channels were to be filled with shell materials and then capped with impervious clay. A general cross section is provided in GDM No. 3 and detailed cross sections across several lifts and enlargements are provided in DDM No. 5. The shell fill was used because it could reliably be placed underwater, and was apparently lighter than the hydraulic fill, minimizing settlement. The sections show the shell fill extending down to the channel bottom at elevation -14 ft., and upward to elevation +12.5 ft. A five feet thick impervious clay (CH) cap was intended to bring the levee up to a grade of +17.5 ft. Hydraulic fill on either side of the shell fill would have the effect of isolating the pervious shell fill materials with impervious materials in all directions: foundation soils below, hydraulic fill to either side, and impervious clay (CH) above.

Although GDM No. 3 and GDM No. 5 do not show sheet piling in the closure sections, piling was installed in 1992 to bring the line of protection up to +18.5 ft. Plan drawings show these to be driven through "shell core," with a tip elevation of +5.0 ft.

Opinion. The designers chose the shell fill in order to provide a working base for subsequent construction that could easily and rapidly be placed under water, and would not require compaction under water. The pervious nature of the shell fill was accounted for in the design by placing clay materials around and above it, isolating it from access to seepage. I conclude that the designs of these control structures were in accordance with the best practices at the time and that the breaches did not result from seepage or instability attributable to a negligent design.

MRGO BANK EROSION (LEVEE FORESHORE EROSION) ISSUES

Over the years, bank erosion of the MRGO has caused the channel to widen significantly. The widening of the channel could be perceived to have at least two adverse effects:

- Could the larger channel area have increased the storm surge in the MRGO, loading the levees more than would otherwise have occurred? This is outside this writer's area of expertise and will be addressed by others.

- Could loss of foreshore waterside of the levees aggravate stability or seepage considerations?

Regarding stability and seepage concerns:

- The 1958 design of the MRGO (DM-1B, p. 5, previously discussed) anticipated such erosion would occur, and would be handled by local interests acquiring additional right-of-way as needed.

- The 1966 GDM No. 3 proposed construction of a riprap stabilization dike on the face of the spoil area retaining dike, between elevations -2 and +5 ft.

- In the sixth indorsement to the GDM, the NOD agreed to perform stability analyses with the assumption that the entire foreshore is eroded away. In any case, there was no evidence of slope stability problems prior to Katrina.

- As previously noted, seepage was not a concern due to the predominance of impervious materials and short duration of hurricane loading. The only potential concern was for stability, analyses were performed to check this concern, and no stability problems have been observed.

SUMMARY OPINIONS ON THE CORPS' DESIGN OF THE MRGO LEVEES

Based on my review of the system as shown in the previous section of this report on design and construction of the MRGO levees, I conclude that the Corps designed the levees, including considerations of needed compaction, stability, seepage and erosion resistance, based on the "best" information at the time. In the United States, there essentially was and still is no "external" expertise in levee design, as no other entity designed or constructed these types of structures of this size and quality. Design quality was ensured by having two separate levels of

review, one in Vicksburg, MS and one in Washington, DC. Some of the reviewers at each level were also in fact published researchers in the field whose work had been peer reviewed.

Beyond the United States (e.g. Netherlands, Czechoslovakia), there were other engineers designing public levees, but there was little interaction with these entities. These countries were not part of the community of practice for the design and construction of levees in the United States during the course of the LPVHPP.

MRGO LEVEES AT THE TIME OF KATRINA

Soil Borings

The large majority of soil borings taken during design and construction show the levees to be predominately fat clays (CH), with a few borings showing silts (ML) and silty sands (SM). Even where silty sands are present, based on soil borings or surface observations after Katrina, I found no indication of any locations where enough of the levee section was comprised of erodible materials that would suggest it was capable of erosion-induced breaching before overtopping.

Completion Reports

The construction project completion reports provide little additional information. Most of the fill was specified to be "uncompacted," and expected to consolidate under its own weight and under additional lifts. There were no Corps EMs or Engineering Regulations (ER) requiring the performance of density testing.

November 2005 ASCE-UCB- NSF Report (Seed, et. al, November 2005)

A preliminary report was issued jointly by an early ASCE reconnaissance team and persons affiliated with the University of California at Berkeley (partially funded by NSF) that later led to the "Independent Levee Litigation Team" (ILIT). The report has over 20 co-authors including myself and plaintiffs' expert Dr. Robert Bea. As this team was formed after Katrina, our only ability to observe the condition of the levees was to view the remants. Section 4.5 of the report describes post Katrina observations of the MRGO levees and provides the following:

- Discussion is centered on overtopping, which occurred from +0.5 to +7.5 ft. There is no discussion and no evidence was found upon which to base a determination that breaching occurred before overtopping.
- There is a discussion of sandy materials in the levee soils at the eroded sites. But even this discussion is connected to the levees' inability to resist overtopping, rather than breaching before overstopping.

IPET Report

The Interagency Personnel Evaluation Team (IPET) was a large team of engineers in government (Corps and elsewhere), academia and private practice that issued a voluminous report in June 2006 on the causes and lessons learned from Katrina's flooding. I was not a

member of the primary team, but assisted the IPET in the internal review of the report just prior to publication. The ASCE provided an external review of the IPET analyses and conclusions through a group titled the External Review Panel (ERP).

The IPET report considers the failures along MRGO to be the result of overtopping, and found no evidence supporting a conclusion that erosion-induced breaching occurred before overtopping.

Page V-91 of the report provides a photo and discussion of "minor front side erosion from wave action." The report further provides a much more detailed explanation as to how backside erosion after overtopping can work back to create loss of crest elevation and ultimately cause a complete breach.

Page V-104 of the report discusses the role of soil types in the progression of erosion, but again only from the perspective of overtopping. This and the succeeding page note that "characterizing soil erodibility is a complicated matter due to spatial non-homogeneity and variability in soil types, difficulty in selecting accurate engineering properties …." The report provides an extensive list of relevant factors.

Significantly, page V-105 states that soil types present and construction methods (hydraulic fill) relate to observed erosion, but the context remains that of overtopping:

> *The levees along the MRGO on the northeast side of St. Bernard Parish and the New Orleans East back levee, which fronts Lake Borgne, had numerous breaches and were washed out over considerable lengths. These levees were constructed using hydraulic fill that contains significant silt and sand, and they were subjected to large waves and significant depths of overtopping.*
>
> *The New Orleans East back levee suffered considerable erosion. Figure 84 shows the major levee segments. The locations of the levee breaches caused by erosion are shown in Figure 85 and the hydraulic fill and hauled fill segments are indicated in Figure 86. It can be noted that the breaches are located in sections that were constructed of hydraulic fill. However, this is not an exact correlation, and other factors need to be considered. Figure 87 shows locations where the surge and wave hydrographs have been determined from calculations and high-water marks. Figure 88 shows a plot of pre-Katrina levee elevations and the surge height plus the peak wave height at these locations. It can be seen that the greatest erosion of the hydraulically filled levees occurs when the surge height plus the peak wave height had the greatest level above the crest of the levee. Examination of this information has shown that the peak wave height is the most important component of the surge. The figure also shows that levees constructed of rolled fill had equal to or greater surge plus the peak wave height over their crest, yet did not breach. Therefore, it is concluded that the combination of hydraulically filled levees and high surge and wave action leads to breaches by erosion.*

Pages 115 and following address a significant number of locations along the MRGO levees where samples were erosion tested by the Engineer Research and Development Center (ERDC), which concludes (on page 121):

> *The soil type, scour depth, and hydraulic loading data from the above figures (Figures 100 through 108) are generalized in Table 4. The levee crown surface soil types and consistencies (strengths) are shown with approximate scour depths and approximate surge plus wave heights. Figure 109 is a plot of the Table 4 data and shows the relations between soil type, soil strength, hydraulic loading, and erosion depths at selected points along the levee crown. Note that no strong correlation between erosion depth and hydraulic loading was observed. From these selected points (Table 4), it appears that soil consistency (strength) and soil type correlate with erosion depth and hydraulic loading. The soil consistency is correlated in that soft fat clays performed poorly (i.e., had deeper erosion) compared to medium fat clays, and the medium fat clays performed better than the medium lean clays. The soil strengths (consistencies) are directly comparable to the construction compaction effort. For example, a compacted clayey soil will have higher density and strength than an uncompacted clayey soil at the same water content.*

While these conclusions about soil strength (as reflected in consistency and correlated to density and degree of compaction) may sound intuitive, there is no mention of strength or density in any of the Corps' guidance or the documented design review during the time of design or construction. Designers and reviewers viewed the predominately CH materials as having adequate erosion resistance prior to overtopping, and overtopping itself was beyond the intent of the project.

Pages V-123 and 124 summarize the IPET findings and lessons learned. They include the following:

> *No levee breaches occurred without overtopping. The degree of erosion and breaching of overtopped levees was directly related to the character of the in-place levee materials and the severity of the surge and wave action. Hydraulically filled levees with higher silt and sand content in the embankment material that were subjected to high overtopping surge and wave action suffered the most severe damage. Rolled clay levees performed well, even when overtopped.*
>
> *Rolled clay-fill embankments are generally able to withstand overtopping without erosion for many hours and should be used to construct levees wherever possible. Armoring can augment existing levee materials to provide improved erosion resilience.*

These statements are categorized under findings and lessons learned, implying that these are additions to the professional knowledge base.

Page V-127 provides a comparison between the IPET conclusions and the University of California at Berkeley (UCB), ILIT, conclusions:

The second area of significant difference dealt with the performance of the levees, specifically along the MRGO. The UCB report and numerous media accounts attributed to these teams hypothesized that these levees "crumbled" prior to water levels reaching the crest of the levees. There was also stipulation of wave action causing high pore pressures within the levee materials leading to deterioration by slumping and seepage-induced erosion. An analytical basis for these hypotheses has not been presented to date by the UCB Team. The IPET investigation has shown that even if the levees along MRGO were totally constructed of a clean sand, which they were not, the time that the water remained on the unprotected side of the levees due to the Hurricane Katrina surge before it overtopped the levees was not sufficient to establish through seepage and cause erosion of the levees (Appendix 17).

It is true that the relatively permeable and erodible materials of the levees constructed by hydraulic fill did contribute to their ultimate breaching. However, analysis and field observations demonstrate that the UCB/LSU hypothesis was not the systemic process leading to breaching. IPET's analysis of this phenomenon included regional analysis of the surge and wave hydrographs along the levee sections, detailed modeling of wave action and currents in proximity to the levees, and analysis of the erosion process for the materials comprising the levees. The IPET analysis and physical evidence at the sites show that the systemic issue for levee performance was overtopping, and the subsequent erosion from waves and ultimately surge. Where waves were incident perpendicular to the levees, the overtopping waves created velocities on the protected side of the levees up to three times those experienced on the front (water) exposed sides. This created a potential for erosion 27 times more severe on the crest and protected sides of the levees. In addition, claims of wave action increasing pore pressures within the relatively permeable materials of the interior of the levees leading to seepage-induced erosion do not stand the "test of time." The permeability of the materials was not sufficient to allow this process to take place in the time frame of exposure to high waves and surge.

Appendix V-18 of the IPET report provides more detail in support of the remarks in the main report.

Opinion:

- As noted in the IPET report, characterizing soil erodibility for a large earth structure such as the MRGO levees is nearly impossible, due to significant spatial variability. Soil composition, density, strength, cover, exposure and other variables can vary significantly from point to point, as can the characteristics of the attacking water.

- The IPET report considers all of the breaching of the MRGO levees to be the result of overtopping, and there is no evidence to support breaching prior to overtopping. It is recognized that if there were such evidence it would likely have been destroyed due to the overtopping, but nevertheless, there is no evidence, not even a "near miss" on some other levee in the region.

- The report identifies that soil strength, as inferred by density and consistency (very soft, soft, medium) is a factor that affects the erodibility of fat clays (CH). Despite being consistent with a geotechnical engineers' intuition, there was never any differentiation on clay consistency in Corps' levee guidance or the design documents, including reviews. The design engineers perceived that the CH materials were sufficiently erosion resistant in light of the short times of loading and would perform adequately up to overtopping. This judgment is confirmed by the evidence and through the analysis and conclusions of IPET.

ILIT Report

In July 2006, a number of authors, led by researchers at the University of California at Berkeley and commonly known as the Independent Levee Investigation Team (ILIT) also published a post-Katrina levee investigation report. Their studies of St. Bernard Parish are in Chapter 6 of the report.

On page 6-3, the report states that the levees along MRGO were "sand core levees," however that does not agree with the numerous soil boring logs included in the construction documents, which show that the levee materials are predominately fat clays (CH). Nor does it agree with the previous paragraph of the ILIT report, which discusses the time dependent "dissipation of pore pressures (which results in progressive strength and stiffness gain in both the levee fill and the underlying foundation soils….)" Had the levees been primarily sands, they would have no excess pore pressures due to construction and strength gain would not be time-dependent.

At the top of page 6-4, after stating that the various investigations do not agree on the exact nature of erosion and breaching, the ILIT authors state that "sections of this levee frontage appear to have been eroded and begun to be breached prior to the storm surge reaching its full height." The report then discusses the possibility of scalloped-shaped water side erosion creating notches at the crest.

On page 6-5, they state that

> *Methods and procedures for calculation of rates of likely erosion due to the various erosive mechanisms … are not well established, and there is little agreement within the profession as to how the erodibility of the various materials present…" (sentence is not complete).*

The ILIT report (p. 6-5) does, however, indicate that a number of their team members made their own estimates of the likely erosion rate of the levee materials and all indicated a high likelihood of initial breaching prior to overtopping. The considerable variability of these estimates is illustrative of the lack of a well-established and reliable methodology for calculating levee erosion to a reasonable degree of scientific certainty, especially for wave-induced front side erosion. Additionally, their analyses do not address the evidence that demonstrates that it is more probable that overtopping, rather than wave-induced front side erosion, caused the breaches.

Opinion:

- The ILIT report gives the reader the impression that the MRGO levees were "sand core." This is at odds with the soil borings taken through the levees over the years, and is at odds with the ILIT authors own discussion of the dissipation of pore pressures and strength and stiffness gain of the levee soils over the years.

- The ILIT authors take a position contrary to the IPET report and to the external peer reviewers of the IPET report (see ASCE ERP) contending that some breaching of the MRGO levees began prior to overtopping. The ILIT authors base this on highly variable personal, judgmental estimates (all of which conclude breaching). Nevertheless, they concede that there are no well established methods to calculate rates of erosion, nor is there much agreement within the profession on erosion rate calculations.

ASCE External Review Panel (ERP)

The ASCE ERP prepared a number of letters documenting its review of the IPET report. The most recent and final, dated September 3, 2008 and addressed to L.G. Van Antwerp, Chief of Engineers, supports the IPET finding that MRGO levees breached after overtopping in the following text on page 2:

> *The description of levee failures by overtopping states that "…the structures that ultimately breached performed as designed, providing protection until overtopping occurred and then becoming vulnerable to catastrophic breaching." While accurate per se, this statement does not make the more significant and compelling assertion, which is that consideration of overtopping was not included in the design….*

Near its conclusion, the ASCE ERP letter states:

> *Overall, we believe that the IPET used sound methods of analysis and investigation, and that its conclusions represent logical and appropriate findings from the data collected. In several areas, the IPET's work has advanced the state-of-the-art for analysis of hurricanes and the design of hurricane protection systems.*

EROSION TESTING AND MODELING

Erosion testing by The Interagency Project Evaluation Team (IPET)

The IPET team performed a series of erosion tests and analyses which are documented in Attachment A to Volume V, Appendix 18 of the IPET report. While the report does show some evidence of waterside erosion without breaching, the report concludes, based on the evidence, that overtopping-induced landside erosion followed by breaching occurred. The report also discusses the mechanisms that occur between overtopping and full breaching. The IPET report does not conclude that there was any levee breaching prior to overtopping.

To investigate the erodibility of the levee soils, the Engineer Research and Development Center (ERDC) in Vicksburg, MS borrowed a Jet Index testing apparatus from the U.S. Department of Agriculture's Research Center at Oxford, MS. This is an in-situ test that does not require soils to be sampled, handled in a laboratory or recompacted to a desired density. Per the Attachment A:

> *The Jet Index test consists of placing the testing device on the soil surface and allowing a submerged water jet to impinge on and scour the surface. The scoured hole depth is then measured, and analytical procedures determine the soil erodibility parameters. The test method and apparatus were developed by the U.S. Department of Agriculture as a means to predict the erodibility of cohesive bank materials (Hanson, et. al. 2002). Hanson (1991) developed a soil-dependent "jet index" based on the change in maximum scour depth caused by an impinging jet versus time. The test method and apparatus are described in ASTM Standard D5852-00.*

ERDC performed jet erosion tests at fifteen sites in the Greater New Orleans area, including four sites along Reach 2 of the MRGO (M1, M2-1, M2-2, and M-3), with six tests at each site. At each site, two concurrent tests were performed at three locations, starting at the water side toe and progressing up the slope. Three of the MRGO sites were levees being reconstructed, and the fourth (M3) was a site that had been overtopped but not eroded. Using the erosion parameters obtained from the test, the authors of Attachment A plot an erosion index K_d against critical shear stress τ to locate test results in chart regions corresponding to varying degrees of erodibility. As is the case for the EFA testing by Briaud, et. al., (2008) described next, the MRGO levee soils are found to exhibit a wide range of erodibility values, from very erodible to very resistant.

The IPET report focuses on characterizing in-situ soils (both those that withstood overtopping and those in repair areas) from very erodible to very resistant based on the Jet Index test, and using the results to assess the resistance of existing levees and those under reconstruction. No attempt is made to use the quantitative erosion resistance parameters for any purpose beyond categorization, such as predicting time rate of failure for levees under wave attack, or even for overtopping.

Erosion testing by Briaud, et. al.

Briaud, et. al., (2008) published a refereed journal paper about overtopping erosion of the MRGO levees in the May 2008 volume of the ASCE Journal of Geotechnical and Geoenvironmental Engineering. The fourth co-author of the paper is Mr. Rune Storesund, who has also contributed to reports filed by the Plaintiffs' experts. In the introduction to the paper, the writers note that the paper only addresses overtopping by sheet flow, and "possible erosion of the levees by wave attack prior to overtopping sheet flow was not studied in this work."

The paper documented the development of a soil erodibility classification chart, where erodibility was defined as "the relationship between the velocity of the water flowing over the soil and the corresponding erosion rate experienced by the soil." A previous work (Briaud, et. al., 2001) defined the concept of an erosion function, and documented the development of an erosion

function apparatus (EFA) that could test soils to determine the parameters of the erosion function. Per Briaud, et. al. (2008):

> *The EFA test consists of eroding a soil sample by pushing it out of a thin wall steel tube and recording the erosion rate for a given velocity of the water flowing over it. Several velocities are used and the erosion function is defined.*

In the 2001 paper, Briaud, et. al. state that

> *… the EFA (Erosion Function Apparatus) was developed to quantify the rate at which fine grained soils erode. The EFA can also be used to quantify the erosion rate of any soil that can be sampled in a Shelby tube.*

In the 2008 paper, Briaud, et. al., describe erosion testing of samples taken from 11 locations in and around New Orleans, with four of the locations (S-3 through S-6) taken in Reach 2 of the MRGO. Of these four sites, undisturbed Shelby tube samples could only be obtained at location S-3. Samples from sites S-4 through S-6 were taken by shovel, placed in plastic bags, and reconstituted for erosion testing. This methods of sampling was used as access by a drill rig was not feasible; the MRGO levees were reached by boat. Per the expert report of Robert Bea, July 14, 2008, p. 26, these shovel samples were taken by Bea and shipped to Dr. Briaud at Texas A&M.

In reconstituting the samples, Briaud, et. al. (2008) noted:

> *The same process as the one used to prepare a sample for a Proctor compaction test was used. Since it was not known what the compaction level was in the field, two extreme levels of compaction energy were used to recompact the samples. The goal was to bracket the erosion response of the intact soil. The high compaction effort corresponded to 100% of ASTM modified Proctor compaction effort, while the low compaction effort corresponded to 1.63% of ASTM modified Proctor compaction effort.*

Results from samples S-3 through S-6 are summarized in Table 2 below.

Table 2. Erosion Test Results from MRGO Reach 2
(from Briaud, et. al., 2001; all tested using sea water)

Sample	Depth	Soil	Total unit weight kN/m^3 / lb/ft^3	Dry unit weight kN/m^3 / lb/ft^3	Water content, %	Erodibility
S3-B1	2 – 4 ft	Clay, CL-CH [(1)]	17.60 / 112.0	13.60 / 86.5	27.00	Medium (III) – Low (IV)
S3-B2	0 - 2 ft	Clay with some sand, CH	20.20 / 128.5	17.26 / 109.8	31.66	Medium (III)

S3-B3	0 – 1 ft	Clay, CL-CH[(2)]	17.16 / 109.2	13.95 / 88.7	23.00	Low (IV)
S-4 light compaction	0 – 0.5 ft	Clay with some sand[(3)]	13.87 / 88.2	10.42 / 66.28	33.14	Very high (I)
S-4 heavy compaction	0 – 0.5 ft	Clay with some sand	17.69 / 112.5	13.23 / 84.2	33.14	Medium (III) – Low (IV)
S-5 light tamping	0 – 0.5 ft	Silt-clay	21.85 / 139.0	18.15 / 115.4	20.40	High (II)
S-6 light compaction	0 – 0.5 ft	Sand with some clay, SP[(4)]	13.45 / 85.6	12.79 / 81.4	5.21	Very high (I) – High (II)

Opinion: Based on quantitative data presented in the paper, soil classifications in Table 2 should be as noted below.

(1) For LL= 48, PI = 31 shown in paper, correct soil classification is CL, but LL=50 would make it a CH.
(2) For LL=32, PI=17 shown in paper, correct soil classification is CL.
(3) For LL=60, PI=30 shown in paper, classification is CH.
(4) For 8.9% fines shown in paper, correct classification is SP-SC.

The two levels of compaction effort described above would likely produce soil densities that widely bracket the actual density. It is unusual that modified Proctor effort was used at all; this is a high level of compaction effort that the Corps of Engineers primarily uses for soils under pavements and other highly-loaded structures. Well-constructed Corps dams are typically compacted to at least 95% of *standard* Proctor compaction effort, where standard effort would correspond to about 22% of modified effort. Compacting dams to a minimum of 95% of this value would correspond to about 21% of modified effort. “Semicompacted” levee fill is often assumed to attain about 90% of standard Proctor effort, which would be about 20% of modified Proctor effort. An effort of only 1.63% likely reflects simply pushing the soil into the tube with a few drops of the hammer. In my opinion, the density of the uncompacted MRGO levees would be something greater than would be obtained from the 1.63% of modified Proctor effort, but smaller than for standard effort. Using standard effort for the higher level of compaction would have better replicated the field conditions.

Unlike the IPET report, Briaud, et. al. (2008) provide results of numerical analyses to show that the erosion rates developed from their testing at overtopping locations are consistent with the levee breaching from overtopping in less than an hour. However, the analyses are restricted to analysis of overtopping flow, where water velocities parallel to the levee crest would be relatively consistent, as they are in the EFA test.

Briaud's work and apparatus was originally funded by the Federal Highway Administration (FHWA) to evaluate erosion resistance of bridge foundations against flows in rivers. In both the 2001 paper and the 2008 paper, the authors note that the EFA test and the related mathematical models assume that the force exerted by the water on the soil is a shear force parallel to the eroding surface. In the conclusion of the paper, the authors reiterate that "possible erosion of the levees by wave attack prior to overtopping sheet flow was not studied in this work."

I am not aware of any published literature where the results of EFA testing have been related to erosion by means other than constant flow parallel to the soil surface. Whether this approach is relevant to wave attack remains an open question. The analyses must consider waves climbing the unprotected levee slope, crossing over the levee crest, and then descending down the levee protected side. For such a complex analysis to be useful, it must be proven accurate and peer-reviewed.

Dr. Bea's Analysis of, and Conclusions Regarding, Pre-Overtopping Breaching by Erosion

In his Declaration No. 1 of July 2008, pp. 31 and following, Dr. Bea presents his study of wave-induced levee erosion at a site south of Bayou Bienvenue in MRGO Reach 2.

Beginning on page 87, he describes how wave runup on the levees was modeled using LS-DYNA, a dynamic finite-element modeling program. On page 89, he describes using results from the EFA tests performed on samples S-3 through S-6:

> *The fluid-soil EBSB interaction shear velocities calculated by the LS-DYNA numerical simulation were compared against the erosion/scour soil limits (capacity) as estimated based on the Erodibility Function Apparatus and EBSB soil composition. Soil samples collected from the EBSBs south of Bayou Bienvenue and north of Bayou Dupre were found to be generally "very high" to "high" erodibility materials (hydraulic fill from the MR-GO navigation channel).*
>
> *The analyses were oriented to determining the likelihood of EBSB breaching primarily due to wave impact prior to EBSB overtopping. As a result, the analysis time frame was limited to the time before the storm surge overtopped the EBSB. …*

The wave action modeled by LS-DYNA involves water that travels up the water side slope of the levee, stops, and runs back down. This is illustrated in Figure 76 of Bea's declaration 1, page 92. Such wave action involves a constantly changing velocity, including a direction change. This is illustrated in Figure 78 of Bea's declaration 1, page 94, where the velocity and direction are shown to vary through an entire cycle about every four seconds.

The EFA test was developed for the purpose of quantifying soil erosion due to constant velocity water flow parallel to a soil face. In the EFA test, the flow velocity is held constant for a period of one hour, or until the soil face erodes 1 mm, whichever comes first.

I am not aware of any work prior to Dr. Bea's declaration where EFA results were used for analysis of erosion under rapidly changing velocities, or for wave action in general, where the soil is alternately submerged and exposed to the air; nor am I aware of any research done as to how properly to select erosion rates for such rapidly changing velocities. The multiple variables concerned make suspect any results obtained from such exercises.

Starting on page 107 of Bea's Declaration 1, Bea describes his analysis of levee erosion. This involved three steps:

- Developing velocity profiles using LS-DYNA.
- Determining time to loss of grass cover (critiqued elsewhere in this report).
- Estimating the magnitude of lateral erosion using soil erodibility characteristics from the EFA test in combination with the estimated wave-induced water velocities on the water side of the levee.

Regarding the third point above, on page 109 Dr. Bea indicates that the cumulative erosion was calculated using an integrated time-step function based on the erodibility of the levee soil, at the time step being evaluated, where the erodibility of the time step is determined by the time-average shear velocities calculated at the defined storm surge elevations. Hence, at each of many short time increments (fractions of a second), for which the water has a different velocity in each increment, the erodibility is assumed to be equal to that found in the EFA over a period of one hour or over the period required for one mm of erosion (whichever comes first).

Again, the use of the EFA results for water flow that is rapidly varying in velocity and direction, to my knowledge, is unprecedented and unverified. Even the developer of the test, Briaud, limits his published analysis to overtopping sheet flow, and that work was published some two and a half years after Katrina and seven years after his development of the EFA test.

Opinion: In summary, Dr. Bea's analyses do not prove that breaching occurred prior to overtopping. They indicate only that breaching *may* have occurred before overtopping:

- *if* LS-DYNA properly predicts wave velocities versus time on the water side, and
- *if* the grass lift-off model properly predicts the time of grass lift-off (which would in fact likely vary significantly from point to point), and
- *if* the results of the EFA test can be used directly for rapidly varying velocities and flow directions.

The certainty of pre-overtopping breaching is also clouded by Dr. Bea's statement on page 122 of his Declaration 1, where he states that "the 'evidence' for front side oriented erosion scarps was erased and replaced with backside erosion scarps." None of the post-Katrina investigations found conclusive evidence of pre-overtopping breaching due to water side wave attack. Finally, due to the remoteness of the MRGO Reach 2 and the weather conditions during Katrina, there was no eyewitness evidence of such events.

Grass Lift-off Under Wave Attack

In Dr. Bea's declaration of July 2008, beginning on page 74, he notes that grass cover on levees provides some level of erosion protection. He then develops a model to predict a time of grass lift off (removal of grass exposing underlying soil). Using the LS-DYNA model to represent wave action, the soil erosion model is not invoked until such time as the grass lift-off model indicates that the soil has been exposed.

On page 74, sixteen references are cited related to grass lift-off under wave attack. However, all but two are dated 1994 or later, and at least four refer to post-Katrina forensic evaluations. The references cited would not have been of any benefit to the designers of the MRGO levees, who at that time of design could only assume that the combination of a grass cover and the short duration of hurricane loading would provide sufficient erosion resistance at least until overtopping.

In one of the publications on grass lift-off most cited in the Dr. Bea declaration (Verheij, et. al., 1997), a manual published by the Technical Advisory Committee for Flood Defences in the Netherlands, the authors state in their Introduction

> *…This report concerns the stability of grass coverings against the erosion caused by the loading put on them by waves. Until 1990, there was almost nothing known about this subject. Six years later, there is more to say about design, maintenance and testing of grass mats and the first attempt at a model has been made.*

This quote confirms that designers of the MRGO levees had no basis for better assumptions about erosion resistance than are stated above. Figures 60 through 63 in the Dr. Bea Declaration of July 2008 are all taken from this reference.

The primary source of Bea's grass lift-off analysis is from a number of papers developed by Verheij and colleagues in the Netherlands between 1995 and 1998, including the manual mentioned above. Working from these, Dr. Bea presents a plot of grass lift-off time as a function of significant wave height in figure 70 on page 84. For wave heights as small as 2 ft, grass lift off times vary from less than one hour (for poor grass density) to less than two hours (for good grass density). As the intensity of the wave action varies with time, Dr. Bea then introduces a fatigue damage accumulation model (p. 85) where the varying wave heights over time are input and grass lift-off is assumed to occur when a parameter D (damage) reaches a value of 1.0. The damage accumulation model is stated to be robust and used for a number of failure phenomena, but apparently has not previously been used in relation to any of the Dutch work or other grass-lift off research cited. Again, this work is unsubstantiated by industry practice and has not been peer reviewed.

Verheij, et. al (1997) at p. 35, exercise caution in the presentation of their model (see Dr. Bea declaration figures 64, 66):

In summary, it has been established that the empirical model still contains some uncertainties concerning application area and accuracy, which means it cannot yet be used in practical design work.

Opinion: The grass lift-off model, as applied by Dr. Bea, and reported in his declaration, is another case of the work not proving that something did happen, but only showing that the scenario is a possible one:

- *if* the soils and grasses at the MRGO levees behave similarly to those tested by the Dutch, and
- *if* the fatigue damage accumulation model proposed to deal with time-varying wave action is appropriate for the modeling of grass liftoff (which has not been shown by any experiments), and
- *if* all the inherent parameter values have been properly matched up between prototype and model.

Calibrating Numerical Models in Engineering

Numerical models are mathematical abstractions of real physical phenomena. If numerical models include equations or relationships that properly represent physical behavior and if values of the input parameters properly correspond to the physical properties of the materials, numerical models can reasonably predict actual physical behavior of the prototype. To use a numerical model with confidence in engineering decision-making, it must be determined that the model and the parameter values do in fact predict the physical behavior of the prototype system. This determination can be thought of as *verification*, *validation*, *calibration* or *confirmation*. A 1994 paper in *Science* by Oreskes, et. al., discusses the nuances of these four terms. For the purposes of this report, regardless of the term used, the central concept is that of ensuring that the numerical model in fact corresponds with actual physical behavior.

A very powerful numerical model used in Dr. Bea's work is LS-DYNA, a dynamic simulation model available from Livermore Software (LS). A visit to the provider's web site http://www.lstc.com/lsdyna.htm or a Wikipedia search of LS-DYNA will show the very wide variety of problems that LS-DYNA has been used to model, including automobile crash behavior, metal forming behavior, explosion or blast behavior, and many more. To describe the process of calibration, we will use an example of automobile crash testing.

Before the development of sophisticated numerical models, a significantly larger number of full-size automobiles had to be physically crash-tested to obtain the same level of information about crash performance as can now be obtained with a mix of physical tests and numerical modeling. Using LS-DYNA, a more limited number of prototype crash tests can be performed. To calibrate the numerical model, actual observed crash tests are simulated in the numerical model, with parameter values and constitutive models (equations and relationships) iteratively adjusted until the predicted behavior of the numerical model matches the observed behavior of the prototype. Once calibrated, the numerical model can be used with some confidence to model other conditions for which additional prototype crash tests would increase costs and design time (e.g.

differing speeds, loadings, geometry, etc.). In effect, the numerical model can be used to simulate physical crash tests for additional conditions or characteristics, "filling in gaps" between the results of physical crash tests.

Similar calibration is commonplace for all applications of LS-DYNA. At the LS software's repository of conference papers (www.dynalook.com), a search of "calibration" led to 56 hits among more than 780 papers. A Google search of "LS-DYNA calibrate" gives over 7,000 hits. It is clearly commonplace to expect that one does not put faith in the results of numerical modeling until the model has been demonstrated to match prototypical behavior for at least a number of observed cases similar to the case at issue.

Opinion: In Dr. Bea's numerical modeling of hypothesized levee breaching by water side wave attack, there is a significant number of instances where absolutely no calibration has been done, or could even be possible:

- LS-DYNA is used to model the wave action on the levee, including runup and rundown. However, there is no real record of actual wave behavior (magnitude, velocity, etc., as a function of time that can be used to verify or confirm that the underlying assumptions are correct).

- Relationships developed by Verheij, et. al., are used to relate grass lift-off time to significant wave height. As these relationships are based on direct observations, there may be more credibility here than for some other elements (e.g., soil erosion). However, questions remain regarding how the grasses and soils tested compare to the grasses and soils at the MRGO. Further, Verheij, et. al. concede that their model includes remaining uncertainties and may not be ready for practical use.

- The work by Dr. Bea uses a fatigue-damage accumulation model to handle the discrepancy between the Dutch grass lift-off (constant wave height) and the Katrina event (time-varying wave height). No indication of validation or verification of this approach is presented.

- Following grass-lift off, Bea's work uses quantitative data from Briaud's EFA test to predict the time of lateral levee erosion. Briaud's test is based on constant velocity water flow parallel to the soil for an extended period of time. Dr. Bea's modeling uses numerical integration to accumulate soil erosion calculations for a series of very small time increments over which velocities rapidly change. Again, no calibration or verification of this approach has been made. If one were to control the velocities and flow directions in the EFA test to match these rapid changes, would the physical test match Dr. Bea's model? No one knows, as this has not been done.

- The erosion modeling presented in the Dr. Bea declaration is a chain of a number of inferences, none of which have been "calibrated" to prototype behavior, as is the

common standard when engineering decisions or designs are made using numerical models. Further, none of these non starndard uses of the models have been peer reviewed.

In the widely-cited (894 citations per Google Scholar) paper previously noted by Oreskes, et. al. (1994), the authors set out to show:

> *Verification and validation of numerical models of natural systems is impossible. This is because natural systems are never closed and because model results are always non-unique…. Models can be confirmed by the demonstration of agreement between observation and prediction, but confirmation is inherently partial…. Models can only be evaluated in relative terms, and their predictive value is always open to question. The primary value of models is heuristic.*

The above quotation is from the paper abstract. Note that the model presented by plaintiffs' experts has not been "confirmed" in the language of the authors.

Near the end of their paper, Oreskes, et. al., question "Then What Good are Models?" and reply with the following:

> *Models can corroborate a hypothesis by offering evidence to strengthen what may be already partially established by other means. Models can elucidate discrepancies in other models. Models can also be used for sensitivity analysis–for exploring "what if" questions—thereby illuminating which aspects of the system are most in need of further study, and where more empirical data are most needed. Thus, the primary value of models is heuristic: Models are representations, useful for guiding further study but not susceptible to proof.*

Applying the above to the problem at hand, Dr. Bea's application of the erosion model(s) presented in his declaration fails on the first count above. Rather than strengthening what is already partially established, it appears to be used as a vehicle to in fact partially establish. His efforts may relate to the exploration of "what if," but his work is overly replete with "ifs." Most importantly, models of natural systems are not susceptible to proof, and certainly Dr. Bea's application of the ones presented in his declaration do not prove anything.

PART II:
IHNC FLOODWALL PERFORMANCE

The Inner Harbor Navigation Canal (IHNC), sometimes called the Industrial Canal, runs generally north-south, connecting Lake Pontchartrain at its north end to the Mississippi River at its south end. The western end of the MRGO (the GIWW) connects to the IHNC and the two form a T-shaped connection. During Hurricane Katrina, two major breaches occurred at I-type floodwalls on the east side of the INHC and south of the MRGO, between the Claiborne Avenue bridge and the Florida Avenue bridge.

IPET Findings

Per the IPET report, the peak storm surge elevation in the INHC was +14.2 ft at 9:00 a.m., August 29, 2005 some 1.7 ft. above the top of the floodwalls. All post-Katrina studies agree that the floodwalls were overtopped.

Stability analyses conducted by the IPET concluded that foundation instability occurred at the north breach before overtopping, but the south breach was stable until overtopping, when landside scour eroded the levee and the floodwall foundation. For the north breach, a design factor of safety of 1.0 had been calculated for a water elevation of +11.2 ft. This would correspond to water levels reached between 6:00 and 7:00 a.m., which is reasonably consistent with the conclusion of a failure prior to overtopping, considering the uncertainties involved.

IPET reports that stability analyses of the south breach showed the factor of safety remaining above 1.0 even for water at the top of the wall and assumption of the well-known "gap" between the wall and the embedment soil, leading to the conclusion that the failure was due to overtopping scour only.

I concur in the IPET findings that the north breach occurred before overtopping and the south breach occurred due to overtopping.

ILIT Findings

The Independent Levee Investigation Team (ILIT) report describes its investigation of the same failures on the east bank of the INHC. The introduction to the relevant section of the report (p. 6-6), states that failure occurred between 7:30 and 7:45 a.m., at an INHC water level of approximately +14 to 14.5 ft (MSL). This value can be read from the same hydrograph common to both reports. Note, however, that ILIT concludes the timing of the failures was essentially concurrent with overtopping, which is about 2.5 hours later than the eyewitness accounts cited in the IPET report.

The ILIT report (plaintiffs' expert Dr. Bea is a co-author) performs finite element analyses of the south breach, including modeling of transient seepage conditions as floodwaters rose. From these analyses, the writers conclude that instability occurred at a water level of approximately +12 to +13 ft., essentially concurrent with overtopping of the floodwall, where elevation was about +12.5 ft. ILIT attributes instability to one of three factors:

- Seepage erosion and piping at the inboard toe.
- Hydraulic uplift or "blowout" at the inboard toe.
- Translational stability failure, as a result of reduction in foundation strength due to underseepage-induced pore pressure failures.

Furthermore, the authors state that the third mechanism likely "won the race," but it is possible that all three mechanisms contributed at least in part.

The writers note that this conclusion contradicts that of the IPET report, and notes that "while overtopping and trenching were in fact occurring, it was underseepage-induced instability that actually developed the more critical mechanism that led to failure at this site."

For the north breach, the ILIT team performed similar coupled seepage and stability analyses, and again attribute failure concurrent with overtopping to one or more of the three seepage-related causes noted above.

A major difference among the writers of the ILIT report and the IPET report involves the permeability (more properly termed hydraulic conductivity) of a "marsh" layer underlying the levee system. The ILIT team assigned significantly higher permeability values that would make this layer a significant conductor of seepage. The ILIT team's horizontal permeability factor was 28.3 ft/day for the marsh layer, which is equivalent to 10^{-2} cm/sec or 100 x 10^{-4} cm/sec when written in notation commonly used in Corps' seepage analysis. For Mississippi River alluvial soils, this value would correspond to the permeability of a silty sand. The analyses also assume that this marsh layer is openly exposed to the waters of the INHC, without even a thin overlying layer of silt. However, in seepage analyses, a small amount of siltation on the canal slope may significantly affect permeability calculation results.

Experienced-based practice in the Corps of Engineers would put the permeability of the marsh deposits much lower. Textbook values for the permeability or hydraulic conductivity of peat vary widely, likely because the materials themselves vary widely, and permeability can decrease by orders of magnitude as marsh or peat deposits consolidate under the weight of overlying soils. A widely-reproduced table by Bear, included in the Wikipedia entry on "hydraulic conductivity," puts typical values for peat in the range $10^{-2} – 10^{-3}$, which would put the ILIT value on the high end of "typical." At the same time, *Theory of Groundwater Flow* by Verrujit (1970) puts typical values three orders of magnitude lower at 10^{-5} to 10^{-7} cm/sec.

The lower the permeability of the marsh deposit, the lower the potential for failure due to underseepage. It is my opinion that the IPET analysis is based on more reasonable permeability factors for this area and is more supported by the evidence than the analysis provided by ILIT.

Bea Declaration II of July, 2008

Bea Declaration No. 2 of July 2008, prepared for this litigation, also presents studies regarding failure of the IHNC levees and I-walls. Unlike the ILIT report, Dr. Bea (para. 26) concurs with the IPET finding that the Ninth Ward flooding began at about 5:00 a.m., becoming fully developed between 6:00 and 7:00 a.m.

Paragraph 32 of the declaration states that the north breach occurred before the wall was overtopped, similar to the finding of the IPET report. Paragraph 33 of the declaration states that the south breach was a translational stability failure related to loss of lateral support due to the presence of a scour trench. Interestingly, that is contrary to the ILIT report, which points to seepage-induced development of excess porewater pressures. The ILIT report does not provide any dissenting opinion by Dr. Bea who participated in its findings and conclusions.

In his analysis of the north breach, Dr. Bea brackets the permeability of the marsh deposit between 10^{-2} and 10^{-6} cm/sec, which is more typical of the possible range as noted earlier. Including the "gap" on the water side and a water side excavated area, the declaration indicates initiation of uplift at about 6:00 a.m. The seepage analyses are found to be insensitive to the marsh permeability, but the model assumes a large excavation water side of the levee has been backfilled with a coarse sand with a permeability value of 10^{-1} cm/sec, creating a very direct connection to the foundation soils. A comparison assuming a clay-filled excavation shows much lower pore pressure developing.

Results of the seepage analysis are subsequently used by Dr. Bea in a stability analysis. Despite the description of transient seepage developing in the marsh materials, "undrained" soil strength parameters are assigned to the marsh materials. Undrained strengths are used in soil mechanics where low permeabilities are present such that soils do not have sufficient time to change water content when subjected to shearing forces. This is a departure from the ILIT report where the term "undrained" is used for the marsh in the finite-element analyses, but the strength shown (c = 0) clearly is indicative of the assumption of drained conditions. If the marsh is considered highly permeable (ILIT assumption), drained conditions should be assumed. If the marsh is considered to have low permeability, undrained conditions should be assumed.

Beginning in paragraph 79, Dr. Bea's declaration presents seepage and stability analyses of the south breach, that are based on similar assumptions. Again, the declaration finds (Figure 60), that for certain assumptions, stability failure would occur at water levels between +12 and +14 ft. With the top of the wall at +12 ft. this would indicate that the suggested failure mode may have occurred at the same time as the wall height became insufficient to serve its intended function which is to prevent overtopping.

Additional uncertainty exists regarding the validity of the assumptions in the declaration regarding the character of excavation backfill materials, and the use of undrained strengths to model the marsh materials for the cases where it has been assigned a high permeability. As has been stated in the earlier section on erosion resistance of MRGO levee soils, and in the section of numerical modeling, it is not apparent that the analyses in the declaration prove anything, but merely illustrate that certain things *could* have occurred *if* all the various assumptions made are in fact correct.

CLOSING

I have not had the benefit of plaintiffs' experts' final depositions before trial. I will be prepared to address anything raised by those depositions or at trial within my areas of expertise.

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Oklahoma State University, August 1974
Major Professor: T. A. Halliburton
Report Title: *Performance of Underseepage Controls during the 1973 Mississippi River Flood*

Ph.D., Civil Engineering (Geotechnical)
Purdue University, May, 1985
Major Professor: M. E. Harr.
Thesis Title: *Analysis and Design of Embankment Dam Slopes: A Probabilistic Approach*

MAJOR AREAS OF RESEARCH AND PRACTICE

- Reliability Analysis in Civil Engineering
- Probabilistic Methods in Geotechnical Engineering
- Dams, Levees, and Hydraulic Structures
- Seepage and Dewatering
- Foundations and Retaining Structures
- Computer-Aided Design and Numerical Methods in Geotechnical Engineering
- Engineering Education

EMPLOYMENT

Michigan State University, East Lansing, MI
- Associate Dean for Undergraduate Studies, August 1998–Present
- Associate Professor of Civil Engineering , 1991–Present
- Assistant Professor of Civil Engineering, 1986–1991

Washington University, Saint Louis, MO
- Affiliate Professor of Civil Engineering , 1984–1985

Geotechnical Engineering Consultant, 1986–Present

U.S. Army Corps of Engineers, Saint Louis District
- Geotechnical Engineer, 1970–1985
- Student Engineering Aide, 1967–1970

REGISTRATION

- Registered Professional Engineer, Missouri, since 1975.

PROFESSIONAL SOCIETY MEMBERSHIPS

- American Society of Civil Engineers (ASCE), Member
- Member, ASCE Geo-Institute Committee on Reliability and Safety
- American Society for Engineering Education (ASEE)
- Women in Engineering Program Advocates Network (WEPAN)
- National Association of Minority Engineering Program Administrators (NAMEPA)

GEOTECHNICAL ENGINEERING EXPERIENCE AND RESEARCH

Corps of Engineers, 1970 - 1985

Fifteen years of successively increasing responsibility for geotechnical aspects of water resource projects.

Served on U.S. Army Corps of Engineers' GCASE (Geotechnical aspects of Computer Aided Structural Engineering) Committee (1980–1985), which provided opinions and advice on computer program development.

Served on U.S. Army Corps of Engineers' CASE (Computer Aided Structural Engineering) Committee task group on retaining walls and flood walls, which provided opinions and advice on program development and methods of analysis.

Served on U.S. Army Corps of Engineers' CAGE (Computer Aided Geotechnical Engineering) Committee task group on slope stability, which oversaw development of program UTEXAS2.

Project Geotechnical Engineer, Melvin Price Lock and Dam, Mississippi River, Alton, IL. Performed and oversaw analysis and design of foundations and earth structures, including specifications and performance evaluation for two dewatering systems in excess of 100,000 gallons per minute, pile load test program, overwater exploration program, concept development for $1 million research program on instrumented cofferdam cell, concept development for $15 million research program to determine the effects of pile driving adjacent to grouted and ungrouted foundations, technical evaluation of major contract claims, and hydrogeologic analysis to predict change in regional groundwater levels.

Project Geotechnical Engineer, Lock and Dam No. 3, Red River Waterway, Louisiana; engineering analysis and design for semi-gravity dam on Tertiary claystone and sand-founded navigation lock.

Served as team leader, team geotechnical engineer, peer reviewer for numerous inspections of non-federal dams under Corps of Engineers' dam inspection program. Field staff engineer on construction of Rend Lake Dam, Benton, IL.

Performed miscellaneous engineeering analysis and design tasks for many water resources projects**,** including the Alton-to-Gale, IL levees system, Carlyle Dam, Shelbyville Dam, Clarence Cannon Dam, and Kaskaskia Lock & Dam and Navigation Project.

Funded Civil Engineering Research (MSU)

Research Engineer under Interagency Personnel Agreement with U.S. Army Engineer Waterways Experiment Station, Vicksburg MS (April 1986 – January 1987, $21,914). Drafted chapters and sections of Corps of Engineers' Engineering Manual on design of retaining walls and flood walls, and Engineering Manual on slope stability. Reviewed Corps' design procedures for levee underseepage controls.

Principal Investigator, *Uncertainty, Judgment, and Decision in Foundation Design, an Integrated Study*, funded by Michigan State University, Jan. – Dec. 1987 $6,575

Principal Investigator, *Levee Underseepage Analysis for Special Foundation Conditions*, sponsored by U.S. Army Engineer Waterways Experiment Station, Mar. – Sep. 1987. $40,712.

Principal Investigator, *Improvements to Underseepage Analysis for Special Foundation Conditions*, sponsored by U.S. Army Engineer Waterways Experiment Station, August 1988 – May 1989. Includes development of program LEVEEMSU. $24,729.

Principal Investigator, *Finite Element Verification of Underseepage Analysis Procedures*, sponsored by U.S. Army Engineer Waterways Experiment Station, May – September 1989. $9,021.

Principal Investigator, *Interference Assessment for Pile Groups Using Probabilistic Methods,* sponsored by U.S. Army Engineer Waterways Experiment Station, May 1989 - April 1990. $21,122.

Principal Investigator, *Design Guidance for Pile Interference Assessment*, sponsored by U.S. Army Engineer Waterways Experiment Station, June – September 1990. $16,045.

Principal Investigator, *Engineering Reliability Assessment of Navigation Systems*, sponsored by U.S. Army Waterways Experiment Station, April – September 1991. $73,493.

Principal Investigator, *Engineering Reliability Assessment of Navigation Systems (Part II)*, sponsored by U.S. Army Waterways Experiment Station, January – March 1992, $11,844.

Principal Investigator, *Probabilistic Assessment of Pile Interference*, sponsored by U.S. Army Waterways Experiment Station, July 1993 – June 1994, $44,359

Principal Investigator, *Reliability of Existing Levees*, sponsored by U.S. Army Waterways Experiment Station, May – September 1994, $19,854.

Principal Investigator, *Geotechnical Reliability of Dam and Levee Embankments*, sponsored by U.S. Army Waterways Experiment Station, May – September 1995, $40,000.

Co-Principal Investigator, *Test Method to Determine the Existence of Segregation in Bituminous Mixtures*, with Dr. G. Y. Baladi, sponsored by Michigan Department of Transportation, September 1995 - September 1997, $120,000.

Co-Principal Investigator, *Engineering Characteristics and Maintenance of Golf Putting Greens*, with Dr. J. Crum, sponsored by United States Golf Association, May 1996 - May 1998, $40,000 (engineering portion).

Co-Prinicpal Investigator, *Detecting and Quantifying Segregation in Bituminous Pavement and Predicting its Effect on Performance*, with Dr. G.Y. Baladi, sponsored by Michigan Department of Transportation, September 1997 - September 1999, $200,328.

Co-Principal Investigator, *Engineering Characteristics and Maintenance of Golf Putting Greens*, with Dr. J. Crum and others, sponsored by United States Golf Association, May 1998 - May 2001, $75,000.

PROFESSIONAL ACTIVITIES IN ENGINEERING EDUCATION

Associate Dean for Undergraduate Studies
College of Engineering, Michigan State University

Oversight of 28 permanent employees and over 100 student employees and graduate assistants involved in undergraduate engineering recruiting and scholarships, undergraduate academic advising, enrollment management, undergraduate academic records and actions, freshman residential living-learning program, Cornerstone (first-year) Engineering Curriculum, Office of Experiential Education and Employer Relations, Engineering Diversity Programs Office, Engineering Study Abroad Office, K-12 outreach, liaison to engineering student organizations and student machine shops. Advise Dean of Engineering on undergraduate education matters, and serve as Acting Dean of the College in his absence.

Special assignments and initiatives have included playing lead roles in initiatives in earlier admission to the College, first-year engineering design, expanded residential program, and the launch of an MSU instructional site in Dubai.

Funded Grants in Engineering Education

Michigan Louis Stokes Alliance for Minority Participation (MI-LSAMP). Joint NSF-funded project with University of Michigan (lead), Western Michigan, and Wayne State University. Lead co-PI for Michigan State University. $2,580,680 over five years; MSU allocation $544, 511 October 2005-2010.

CPATH CB: Computing and Undergraduate Engineering: A collaborative Process to Align Computing Eduction with Engineering Workforce Needs, with Jon Sticklen, Daina Briedis, Neeraj Buch, Mark Urban-Lurain, and Louise Paquette. Funded by NSF for $449,859, September 1, 2007 – August 31, 2009. Project includes Lansing Community College and The Corporation for a Skilled Workforce.

EEES: Engaging Early Engineering Students to Expand Numbers of Degree Recipients, with Jon Sticklen, Daina Briedis, Mark Urban-Lurain, Neeraj Buch, and others from MSU and Lansing Community College. NSF Award Number 0757020, $2.5 million over five years. (Initial award $1,427,298, July 1, 2008 – June 30, 2011).

Teaching – Michigan State University

- CE 271 - Introduction to Civil Engineering (surveying component)
- CE 312 - Soil Mechanics
- CE 390 - Civil Engineering Analysis (Numerical Methods)
- CE 418 - Geotechnical Engineering Design
- CE 419 - Stability of Earth Masses (now combined with CE 418)
- CE 490 - Supervised Independent Study
- CE 810 - Reliability-Based Design in Civil Engineering
- CE 812 - Mechanical Properties of Soils
- CE 815 - Special Topics in Geotechnical Engineering (Earth Structures)
- CE 818 - Advanced Geotechnical Design
- CE 890 - Supervised Independent study

- EGR 100 – Introduction to Engineering Design (instructional team)
- EGR 291- Seminar for freshmen in the Residential Option for Science and Engineering Students

Teaching --Washington University (St. Louis), 1984-85:

- Foundations (undergraduate)
- Advanced Topics in Geotechnical Engineering (graduate)

Teaching Awards

- Three-time recipient of the Withrow Teaching Excellence Award in the Department of Civil and Environmental Engineering, 1992, 1993, and 1998.
- Recipient of the 1993 Chi Epsilon, Great Lakes Region, James H. Robbins Award for Excellence in Teaching.

Ph.D. Students Graduated and Dissertation Topics

- Magdal N. Haji, 1990, *A Mathematical Algorithm for Selection of SPT Resistance Value in Foundation Design*.
- Nasrullah Abeer, 1991, *An Expert System for the Preliminary Design of Cantilever Retaining Walls*
- Rosely AbMalik, 1992, *Pile Foundation Design: Interrelation of Safety Measures from Deterministic and Reliability-Based Methods*.
- Weijun Wang, 1992, *Probabilistic Reliability Evaluation of Navigation Structures*
- Mostafa K. Ashoor, 1994, *Applications of Geostatistics to Settlement Problems*
- Ahmed M. Hassan, 1998, *A Practical Approach to Combined Probabilistic Analysis of Slope Stability and Seepage Problems*
- Chieh-Min Chang, 2000, *Detecting Segregation in Bituminous Pavements and Relating its Effect to Performance*, (co-advisor with G.Y. Baladi).

PUBLICATIONS – BOOKS

- Wolff, T. F. (1995), *Spreadsheet Applications in Geotechnical Engineering*, PWS-Kent, Boston, 1995

PUBLICATIONS - BOOK CHAPTERS

- Wolff, T. F.(1994), "Soil Mechanics," and "Foundations and Retaining Structures," in *Principles and Practice of Civil Engineering—PE Exam Review Manual,* Merle Potter, ed., Great Lakes Press, 1994, 1996.
- Wolff, T. F.(1995, 2002), "Soil Relationships and Classification," in *The Civil Engineering Handbook,* CRC Press, Inc., 1995. Second edition, 2002.
- Wolff, T. F.(1996), "Geotechnical Engineering," in *Fundamentals of Engineering, Discipline-Specific FE/EIT Exam Review*, Merle Potter, ed., Great Lakes Press, 1996 Nine editions through 2000.

- Wolff, T.F. (2008), "Reliability of Levee Systems," chapter 12 of *Reliability-Based Design in Geotechnical Engineering*, *Computations and Applications,* K.K. Phoon, ed., Taylor and Francis.

PUBLICATIONS - SPECIAL REPORTS

- Seed, R.B., Nicholson, P.G., ... Wolff, T.F., (22 authors) (2005), *Preliminary Report on the Performance of the New Orleans Levee Systems in Hurricane Katrina on August 29, 2005.* Joint report of teams from ASCE and the University of California Berkeley. Berkeley report No. UCB/CITRIS – 05/01, November 17, 2005. Report was submitted to the U.S. Senate Committee on Homeland Security and Committee on Environment and Public Works.

PUBLICATIONS – PERIODICALS

- Crum, J. R., Wolff, T.F., and Rogers, J.N. III (2004), "Agronomic and Engineering Properties of USGA Putting Greens, USGA Green Section Record, Vol. 42, No. 2, March-April 2004, pp. 11-14. http://www.usga.org/turf/green_section_record/2004/march_april/agronomic.html Also in USGA's Turfgrass and Environmental Research Online, http://usgatero.msu.edu, article http://turf.lib.msu.edu/tero/v02/n15.pdf

PUBLICATIONS - JOURNALS

- Klostermann, M.J., Wolff, T.F., and Jahren, N.G. (1982), "Quantitative Relationship of Grouting to the Reduction of Groundwater Flow through Rock Foundations," *Bulletin of the Association of Engineering Geologists*, Vol. XIX, No. 1, 1982, pp. 15-24.
- Wolff, T. F., (1991), "Embankment Reliability versus Factor of Safety: Before and After Slide Repair," *International Journal for Numerical and Analytical Methods in Geomechanics*, Volume 15, Issue No.1, January 1991.
- Wolff, T. F., (1993), "Probabilistic Assessment of Pile Interference," *Journal of Geotechnical Engineering,* ASCE, Vol. 119, No. 3, March 1993, pp. 525-542.
- Gabr, M.A., Wolff, T.F., Brizendine, A. L., and Taylor, H.M. (1996), "Underseepage Analysis of Levees on Two-Layer and Three-Layer Foundation," *Computers and Geotechnics*, Vol. 18, No. 2, pp. 88-107, 1996.
- Hassan, A. M., and Wolff, T.F., (1999), "Search Algorithm for Minimum Reliability Index of Earth Slopes," *Journal of Geotechnical and Geoenvironmental Engineering, ASCE,* Vol. 124, No. 4, April 1999, pp. 301-308.
- Buch, N., and Wolff, T.F. (2000), "Classroom Teaching through Inquiry," *ASCE Journal of Professional Issues in Engineering ,*July, 2000*.*
- Chang, C.-M., Baladi, G. Y., and Wolff, T.F. (2001), "Using Pavement Distress Data to Assess Impact of Construction on Pavement Performance," *Transportation Research Record,* Volume 1761, pp. 15-25, Transportation Research Board of the National Academies, Washington, D.C., 2001
- Chang, C.-M., Baladi, G. Y., and Wolff, T.F. (2002), "Detecting Segregation in Bituminous Pavements," *Transportation Research Record,* Volume 1813, pp. 77-

86, Transportation Research Board of the National Academies, Washington, D.C., January 2002.

- Henderson, J.J. Crum, J.R., Wolff, T.F., and Rogers, III, J.N.. (2005) "Effects of Particle Size Distribution and Water Content at Compaction on Saturated Hydraulic Conductivity and Strength of High Sand Content Root Zone Materials. *Soil Science,* 170(5):315-324, May 2005

PUBLICATIONS - JOURNAL DISCUSSIONS

- Wolff, T. F., and Conroy, P. J., (1992), discussion of "Improved Design Procedures for Vertically Loaded H-Piles in Sand," by H.M. Coyle and R. Ungaro, *Journal of Geotechnical Engineering*, ASCE, Vol 118, No. 7, July 1992.
- Duncan, M.J., Navin, M., and Wolff, T.F. (2003) discussion of "Probabilistic Slope Stability for Practice," by H. El-Ramly, N.R. Morgenstern and D.M. Cruden, Canadian Geotechnical Journal, vol. 39, pp. 665-683, 2002

PUBLICATIONS – CONFERENCES

- Wolff, T. F., and Harr, M.E., (1987), "Slope Design for Earth Dams," in *Reliability and Risk Analysis in Civil Engineering 2*, Proceedings of the Fifth International Conference on Applications of Statistics and Probability in Soil and Structural Engineering, Vancouver, BC, Canada, May, 1987, pp. 725 - 732 (refereed).
- Wolff, T. F., Hempen, G. L., Dirnberger, M. M., and Moore, B. H., (1988), "Probabilistic Analysis of Earthquake-Induced Pool Release," *Second International Conference on Case Histories in Geotechnical Engineering*, University of Missouri - Rolla, June 1988, pp. 787-794. (refereed)
- Wolff, T. F. (1989), "Geotechnical Judgment in Foundation Design," in *Foundation Engineering: Current Principles and Practices*, Proceedings of the 1989 ASCE Foundation Engineering Congress, Evanston, IL, June, 1989, F.H. Kulhawy, ed., pp. 903-917. (refereed)
- Wolff, T. F. (1989), "Pile Capacity Prediction Using Parameter Functions," in *Predicted and Observed Axial Behavior of Piles, Results of a Pile Prediction Symposium* sponsored by the Geotechnical Engineering Division, ASCE, Evanston, IL, June, 1989, ASCE Geotechnical Special Publication No. 23, pp. 96 - 106.
- Wolff, T.F., and Lamrouex, R. L. (1989), "Microcomputer Simulation and Animation of the Consolidation Test," *Proceedings, 7th National Conference on Microcomputers in Civil Engineering,* W. E. Carroll and D.S. Leftwich, eds., University of Central Florida, Orlando, FL, November, 1989, pp. 102-105.
- Wolff, T.F., and Tipton, R.W. (1989), "Spreadsheet Design of Anchored Sheetpiles," *Proceedings, 7th National Conference on Microcomputers in Civil Engineering*, W. E. Carroll and D.S. Leftwich, eds., University of Central Florida, Orlando, FL, November, 1989, pp. 78-82.

- Wolff, T. F., (1990), "Spreadsheets in Geotechnical Engineering," in *Proceedings of ASCE 1990 National Forum on Education and Continuing Development for the Civil Engineer*, Las Vegas, NV, April, 1990
- Wolff, T. F., and Wang, W. (1993), "Reliability Analysis of Navigation Structures," in *Geotechnical Practice in Dam Rehabilitation,* Proceedings of the specialty conference sponsored by the Geotechnical Engineering Division, ASCE, North Carolina State University, Raleigh, North Carolina, April 25-28, 1993, ASCE Geotechnical Specialty Publication No. 35, pp. 159-173.
- Dias, M. S., Pierce, F. J., and Wolff, T. F., (1993), "Soil Compressibility of Three Glacial Soils Relative to Tillage System and Wheel Traffic," Annual Meetings, American Society of Agronomy - Crop Science Society of America - Soil Science Society of America, Cincinnati, OH, November 7-12, 1993
- AbMalik, R., and Wolff, T. F., (1994), "Correlation of Safety Measures from Deterministic and Reliability-Based Approaches for Pile Foundation Design," DFI - 94, Fifth International Conference of the Deep Foundations Institute, Brussels, Belgium, June 13-15, 1994.
- Wolff, T. F., and AbMalik, R. B., (1994), "Pile Foundation Design: Correlation of Safety Measures from Deterministic and Reliability-Based Approaches Using Spreadsheet Program, *First Congress on Computing in Civil Engineering*, ASCE, Washington, D.C., June 20-22, 1994.
- Wolff, T. F. (1996), "Probabilistic Slope Stability in Theory and Practice," in *Uncertainty in the Geologic Environment: From Theory to Practice*, Proceedings of Uncertainty '96, ASCE Geotechnical Special Publication No. 58, C.D. Shackelford, P. P. Nelson, and M.J.S. Roth, eds., pp. 419-433 (invited paper, refereed).
- Wolff, T. F., Demsky, E.C., Schauer, J., and Perry, E. (1996), "Reliability Assessment of Dike and Levee Embankments, in *Uncertainty in the Geologic Environment: From Theory to Practice*, Proceedings of Uncertainty '96, ASCE Geotechnical Special Publication No. 58, C.D. Shackelford, P. P. Nelson, and M.J.S. Roth, eds., pp. 636-650 (refereed).
- Abeer, N. and Wolff, T. F., (1997), "Development of Knowledge-Based System for the Preliminary Design of Cantilever Retaining Walls," XIV International Conference on Soil Mechanics and Foundation Engineering, Hamburg, Germany, 1997.
- Abeer, N. and Wolff, T. F., (1997), "Effect of Earth Pressure Assumptions on the Design of Cantilever Retaining Walls," 37th Annual Convention, the Institution of Engineers, Pakistan, Lahore, April 1997.
- Wolff, T.F. (1997), Geotechnical Reliability of Levees, paper 6, Hydrology and Hydraulics Workshop on Risk-Based Analysis for Flood Damage Reduction Studies, U.S. Army Corps of Engineers, Hydrologic Engineering Center,
- Crum, J. R., Wolff, T. F., Freeborn, R. A., and Miller, M. (1997), " Engineering Properties of High Sand Content Soils Used in Golf Putting Greens and Sports Fields*," 67th Annual Michigan Turfgrass Conference Proceedings*, Volume 26, January 20-24, 1997, Lansing, MI, Michigan State University Extension, pp. 73-82.
- Hassan, A.M., and Wolff, T.F. (2000), "Effect of Deterministic and Probabilistic Models on Slope Reliability," *GeoDenver 2000*, ASCE, Denver, CO, August 2000. (referreed).

- Henderson, J.J., Crum, J.R., Wolff, T. F., and Rogers, J.N. (2000). "The Effects of Adding Silt and Clay on the Agronomic and Engineering Properties of a Sand Textured Root Zone Material," *70th Annual Michigan Turfgrass Conference Proceedings,* vol 29, pp. 164-167.
- Chang, C.-M., Baladi, G. Y., and Wolff, T.F. (2001), "Using Pavement Distress Data to Assess the Impact of Construction on Pavement Performance," *Transportation Research Record, Journal of the Transportation Research Board*, No. 1761, pp. 15-25. Also presented at, and in proceedings of, 80th Transportation Research Board Annual Meeting, Washington, D.C., January 2001. (referreed).
- Zmich, R., and Wolff, T. F. (2001) "The ROSES Program at Michigan State University: History and Assessment," American Society for Engineering Education, Annual Meeting, Albuquerque, NM, June 2001. (referreed).
- Henderson, J.J., Crum, J.R., Wolff, T. F., and Rogers, J.N. (2001). "Athletic Field Root Zone Mixes: What's the Best Mix for Your Field?" *71st Annual Michigan Turfgrass Conference Proceedings,* vol 30, pp. 96-99. http://www.lib.msu.edu/turf/mtc2001/96.pdf
- Chang, C.-M., Baladi, G. Y., and Wolff, T.F. (2000), "Detecting Segregation in Bituminous Pavements and Relating its Effects to Conditon," *79th Transportation Research Board Annual Meeting*, Washington, D.C., January 2000. (referreed).
- Henderson, J.J., Crum, J.R., Wolff, T. F., and Rogers, J.N. (2002). "Athletic Field Systems Study," *72nd Annual Michigan Turfgrass Conference Proceedings,* vol 31, pp. 14-17. http://www.lib.msu.edu/tic/mtc2002/2002mtcproc.pdf
- Henderson, J.J., Crum, J.R., Wolff, T. F., and Rogers, J.N. (2003). "Athletic Field Systems Research," *73rd Annual Michigan Turfgrass Conference Proceedings,* vol 32, pp. 158-161.
- Vergara, C.E., Urban-Lurain, M., Briedis, D., Buch, N. LaPrad, J., Paquette, L., Sticklen, J., and Wolff, T.F. (2008), "Work in Progress – Computing and Undergraduate Engineering: A Collaborative Process to Align Computing Education with Engineering Workforce Needs (CPACE), *38th ASEE/IEEE Frontiers in Education Conference, Session S1E,* October 22-25, 2008, Saratoga Springs, NY,

CONFERENCE PRESENTATIONS

- Wolff, T.F. (1998), "Modeling Real World Design, *American Concrete Institute National Convention*, Session on "Bring Your Course to Life, Los Angeles, CA, October 1998.
- Wolff, T. F. (1999), "Preparation for EC 2000," *American Society for Engineering Education National Conference*, Associate Deans Workshop, Charlotte, NC, June 20-22, 1999.
- Chang, C.-M., Wolff, T.F., and Baladi, G.Y. (2000) "Detecting and Quantifying Segregation in Bituminous Pavements and Relating its Effect to Condition," *79th Transportation Research Board Annual Meeting*, Washington, D.C., January 9-13, 2000.
- Wolff, T.F. (2000), "Enrollment Management in a Limited Enrollment Program," *American Society for Engineering Education National Conference*, Associate Deans Workshop, St. Louis, MO, June 2000.

- Panel Presentation, "Experiences with EC 2000, Big Ten Plus Associate Deans," *American Society for Engineering Education National Conference*, Associate Deans Workshop, St. Louis, MO, June 2000.
- Henderson, J.J., Crum, J.R., Wolff, T. F., Rogers, J.N. III (2001), "The Effects of Adding Silt and Clay on the Agronomic and Engineering Properties of a Sand," *2001 Annual Meeting, American Society of Agronomy, Crop Science Society of America, Soil Science Society of America,* Charlotte, NC, October 2001.

TECHNICAL REPORTS

- U.S. Army Engineer District, St. Louis (USAEDSTL), (1976), "Re-Evaluation of Underseepage Controls, Mississippi River Levees, Alton to Gale, IL, Phase I: Performance of Underseepage Controls During the 1973 Flood."
- Pace, M.E., Mosher, R., Williams, D. R., and Wolff, T. F. (1984), "Seepage Analysis of Confined Flow Problems by the Method of Fragments." *Instructional Report No. K-84-8*, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, September, 1984
- Wolff, T. F., (1987), "Levee Underseepage Analysis for Special Foundation Conditions," research report prepared for U. S. Army Engineer Waterways Experiment Station, Geotechnical Laboratory. Michigan State University, Division of Engineering Research, September, 1987.
- Wolff, T. F., (1988), "Lecture Notes on Retaining Wall Design–Geotechnical Aspects," prepared for Structural Design Criteria Course, U.S. Army Engineer Waterways Experiment Station, 19-23 May 1986; revised June 1988.
- Wolff, T. F., (1988), "Geotechnical Judgment in Foundation Design," Department of Civil Engineering and Division of Engineering Research, Michigan State University, East Lansing, MI, 48824, May 1988.
- Wolff, T. F., (1989), "LEVEEMSU: A Software Package Designed for Levee Underseepage Analysis," research report prepared for U.S. Army Engineer Waterways Experiment Station, Geotechnical Laboratory, May 1989.
- Wolff, T. F., (1989), "Finite Element Verification of Underseepage Analysis Software," research report prepared for U.S. Army Engineer Waterways Experiment Station, Geotechnical Laboratory, Vicksburg, MS, September, 1989.
- Wolff, T. F. (1989), "Levee Underseepage Analysis for Special Foundation Conditions," *Technical Report REMR-GT-11*, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, September, 1989, 91 pp.
- Wolff, T. F. (1989), "LEVEEMSU: A Software Package Designed for Levee Underseepage Analysis," *Technical Report GL-89-13*, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, September, 1989, 74 pp.
- Wolff, T. F., (1990), "PILINT: A Software Package Designed for Pile Interference Analysis," prepared for U.S. Army Engineer Waterways Experiment Station, Information Technology Laboratory, Vicksburg, MS, April, 1990. (currently in publication by Corps).
- Wolff, T. F., and Soehnlen, G., (1991), "Seepage Analysis of Levees on Three-Layer Irregular Foundations," prepared for Geotechnical Laboratory, U.S. Army Engineer Waterways Experiment Station, August, 1991.

- Wolff, T. F., (1991), "Modeling Relief Wells in Program LEVEEMSU," prepared for Geotechnical Laboratory, U.S. Army Engineer Waterways Experiment Station, October, 1991.
- Wolff, T. F., and Wang, W., (1992), "Engineering Reliability of Navigation Structures," research report, Michigan State University, for U.S. Army Corps of Engineers, January 1992.
- Wolff, T. F., and Wang, W., (1992), "Engineering Reliability of Navigation Structures, Supplement No. 1" research report, Michigan State University, for U.S. Army Corps of Engineers, December 1992.

- U.S. Army Corps of Engineers, (1992), "Pile Layout to Minimize Interference," Engineer Technical Letter ETL 1110-8-17(FR), Department of the Army, US Army Corps of Engineers, Washington, DC, 20314-1000.
- Wolff, T. F., (1992), "Recommended Procedures for Reliability Analyses: Locks and Dam No. 25," prepared for Geotechnical Branch, St. Louis District, U.S. Army Corps of Engineers, February, 1992.
- Wolff, T. F., (1992) "Slope Stability Analysis Using Microcomputers," course notes for ASDSO short course, Lansing, MI, June 1992.
- Wolff, T. F., (1993), "Report on Probabilistic Models for Lock and Dam No. 24," prepared for Geotechnical Branch, St. Louis District, U.S. Army Corps of Engineers, January, 1993.
- Shannon and Wilson, Inc., and Thomas F. Wolff, Ph.D., P.E., (1994), "Probability Models for Geotechnical Aspects of Navigation Structures," prepared for St. Louis District, U.S. Army Corps of Engineers, in connection with the Upper Mississippi River Study, January, 1994.
- Wolff, T. F., and Ramon, C., (1994), "CPGP2: A New Program for Pile Interference Assessment," prepared for U.S. Army Engineer Waterways Experiment Station, Information Technology Laboratory, Vicksburg, MS, June 1994.
- Wolff, T. F., (1994), "Evaluating the Reliability of Existing Levees," prepared for U.S. Army Engineer Waterways Experiment Station, Geotechnical Laboratory, Vicksburg, MS, September 1994. This is also Appendix B to U.S. Army Corps of Engineers ETL 1110-2-556, Risk-Based Analysis in Geotechnical Engineering for Support of Planning Studies, 28 May 1999.
- Wolff, T. F. (1996) "Application of Time-Based Reliability Analysis to Corps of Engineers' Geotechnical Engineering Problems," report prepared for St. Louis District, U.S. Army Corps of Engineers, under subcontract to Shannon and Wilson, Inc., St. Louis, MO, November 1996.
- Wolff, T. F. (1996) "Application of Spatial Averaging and Spatial Correlation to Corps of Engineers' Geotechnical Engineering Problems," report prepared for St. Louis District, U.S. Army Corps of Engineers, under subcontract to Shannon and Wilson, Inc., St. Louis, MO, December 1996.
- Wolff, T. F., Baladi, G. Y., and Chang, C.-M. (1997), "Test Method to Determine the Existence of Segregation in Bituminous Mixtures," for Michigan Department of Transportation, MSU Pavement Research Center of Excellence report, September 1997.

- Wolff, T. F. (1998), "Assessment of Geotechnical Reliability," report prepared for St. Louis District, U.S. Army Corps of Engineers, under subcontract to URS-Greiner Woodward-Clyde Consultants, St. Louis, MO, September 1998.
- U.S. Army Corps of Engineers, (1999) ETL 1110-2-556, Risk-Based Analysis in Geotechnical Engineering for Support of Planning Studies, 28 May, 1999, with two appendices. Appendix A, An Overview of Probabilistic Analysis for Geotechnical Engineering Problems. Appendix B: Evaluating the Reliability of Existing Levees.
- Wolff, T. F., Baladi, G. Y., and Chang, C.-M. (2000), "Detecting and Quantifying Segregation in Bituminous Mixtures and Relating its Effect to Condition," for Michigan Department of Transportation, MSU Pavement Research Center of Excellence report, March 2000.
- Wolff, T. F., (2002), "Design and Performance of Underseepage Controls: A Critical Review, " U.S. Army Corps of Engineers, Engineer Research and Development Center, Vicksburg, MS, report ERDC/GSL TR-02-19. Originally written in 1986, formally published in September, 2002.
- Wolff, T. F., Hassan, A., Khan, R., Ur-Rasul, I., and Miller, M. (2004), "Geotechnical Reliability of Dam and Levee Embankments," Report ERDC/GSL CR-04-1, U.S. Army Engineer Research and Development Center, Vicksburg, MS, September 2004. (Originally written in 1995, formally published in 2004).

INVITED LECTURES, PRESENTATIONS and SHORT COURSES

- *Performance of Relief Wells*, for Corps of Engineers' short courses on seepage control, 1978–89.
- *Methods of Slope Stability Analysis*, for Corps of Engineers' short course on Computer - Aided Foundation Engineering, 1985.
- *Seepage Analysis Using Computers*, INFOCORP conference, 1985.
- *Geotechnical Aspects of Retaining Wall Design*, for Corps of Engineers' short courses on Structural Design Criteria and Computer-Aided Design of Retaining Walls, annually, 1986–89.
- *Planning, Constructing, and Operating Cellular Cofferdams*, for North Pacific Division, Corps of Engineers, Portland, OR, 1987.
- *Geotechnical Engineering*, for Professional Engineer Exam review course for Michigan Department of Transportation, 1987.
- Short course on *Soil Mechanics and Foundations* for Pakistan Military College of Engineering, Rawalpindi, Pakistan, 1990 (two weeks).
- *Reliability Analysis of Gravity Monolith Structures*, for Corps of Engineers Short Course on Reliability Analysis of Navigation Structures, Rock Island, IL, December 1991; Vicksburg, MS, June and July 1992; June, August, and September 1993.
- *Reliability Analysis of Navigation Structures*, for Lansing-Jackson Branch, American Society of Civil Engineers, January, 1992.
- *Slope Stability Using Microcomputers*. Regional Seminar for the Association of State Dam Safety Officials (ASDSO), Lansing, MI, June 22-23, 1992
- *Probabilistic Methods in Engineering Analysis and Design*, for St. Louis District, U.S. Army Corps of Engineers, August 4-8, 1992

- *Numerical Techniques for Seepage Analysis*, for Corps of Engineers' short course in Design, Installation and Maintenance of Relief Well Systems, Columbus, OH, September, 1993.
- *Aspectos Hidrogeologicos en la Investigacion de Presas* (a course on seepage analysis of dams), with M.E. Harr and W. Sherman, for Instituto Costarricense de Electricidad (Costa Rican Electric Institute), November 28 – December 2, 1994, San Jose, Costa Rica
- *Probabilistic Methods in Engineering Analysis and Design*, short course for Jacksonville District, U.S. Army Corps of Engineers, March 6-10, 1995.
- *Probabilistic Stability Analysis in Theory and Practice*, Michigan Dam Safety Workshop, sponsored by Michigan Department of Environmental Quality, May, 1996.
- *Probabilistic Methods in Geotechnical Engineering: Some Comments on the Art and Practice*, at *Use of Probability for Geotechnical Aspects of Dams and Waterways*, workshop at Virginia Tech, March 20, 1997.
- *Segregation Evaluation of Bituminous Pavements*, to Michigan Department of Transportation Resident Engineers Conference, March, 1997.
- *Case Histories of Geotechnical Reliability Analysis*, for short course at U.S. Army Engineer Waterways Experiment Station, May 1998.
- *Slope Stability Analysis*, to Michigan Department of Environmental Quality, July 1998.
- *Workshop on Risk Assessment for Seepage and Piping in Dams and Foundations*, invited panelist, Virginia Tech for U.S. Army Corps of Engineers, March 2000.
- *Experience with Engineering Criteria 2000*, to Forum on Lower Division Engineering Education, NSF-sponsored workshop at State University of New York -- Binghamton, NY, August 24-25, 2000.
- *Reliability Analysis for Dams and Levees*, to Grand Rapids Branch, Michigan Section, ASCE, Sep 2002.
- *Civil Engineering Senior Seminar,* University of Missouri - Rolla, October 30, 2003
- *Engineering Today and Tomorrow, ... at MSU, in Michigan and Beyond,* MSPE-ASCE joint annual meeting, Feb 2004.
- *MSU Preparataion for ABET Accreditation*, for University of Michigan, College of Engneering, Dec 2004 and Jan 2005.
- *The Challenges of a Large Study Abroad Program: Taking MSU to Russia,* ASEE Engineering Deans' Institute, Tucson, AZ, Apr 05.
- *Levee Engineering at "A City at the End of the River,"* MSU forum on Hurricane Katrina, October 2005.
- *New Orleans Levees in Hurricane Katrina,* to
    - ASCE. MSU student chapter, Nov 15, 2005
    - ASCE Lansing-Jackson branch, Jan 19, 2006
    - MSU EGR 150, "Engineers and the Engineering Profession," Jan 2006, 2007, and 2008.
    - MSU Engineering faculty brown bag seminar, Feb 14, 2006
    - ASCE, Detroit branch student night, Feb 21, 2006
    - McMaster's University, College of Engineering, Hamilton, ON, March 9, 2006
    - SWE, MSU student chapter, March 22, 2006
    - Purdue Geotechnical Society, West Lafayette, IN Mar 31, 2006

  - MSU EGR 110, Oct 23 and 25, 2007
- *Media Interviews regarding Hurricane Katrina* to New York Times, Christian Science Monitor, MSU State News, New Orleans Times-Picayune, NPR, Fox News Network (national television live) WJR radio (Detroit, live) WWL radio (New Orleans, two call-in shows), Impact radio (campus, live), and other outlets, Fall 2005.
- *Research Needs in Disaster Engineering: Hurricane Protection,* ASCE Annual Department Chairpersons Meeting, presentation and panel, Mar 6, 2006
- *Engineers Helping Society Address Risk,* ASFE Annual Meeting, Chicago, IL, Oct 7, 2006
- *Engineering Enrollment Trends and Interest in Engineering,* Big Ten Plus Associate Deans Meeting, University of Minnesota, St. Paul, MN, 3/26/07.
- *Success Beyond College*, invited speaker to Tau Beta Pi Banquet, Michigan Alpha Chapter, Michigan State University, April 22, 2007.
- *Building a K-16 Bridge*, to Magnet Schools of America's Summer Magnet and Related Training (SMART) Conference, by invitation of Lansing Public Schools, Michigan State University, East Lansing, MI, July 16, 2007.
- Workshop session organizer for K-12 education unit for conference *The Role of Engaged Universities in Economic Transformation: A Regional Conference inspired by the National Academies Study, Rising Against the Gathering Storm,* University of Michigan, Ann Arbor, MI, October 15-16, 2007.
- *Preparing Poster Presentations for Undergraduate Research*, Michigan State University, April 4, 2008.
- *Spartan Engineering,* podcast for Impact 89 Radio, Michigan State University, September 2008.

INSTITUTIONAL SERVICE

- Undergraduate Curriculum Committee, MSU Department of Civil and Environmental Engineering, 1986-92, 1995-98.
- Faculty Advisor, Chi Epsilon Civil Engineering Honor Society, 1987 - 1998.
- Curriculum Committee (Engineering Undergraduate Studies Committee, College of Engineering, 1987-92, 1996-98; Chairperson, 1989-92, and 1996-98; Secretary, 1998-present. Included conversion of calendar and curricula from quarters to semesters, 1989-1992.
- MSU Department of Civil Engineering Advisory Committee, 1990 - 1994.
- Faculty Advisor and co-advisor, Michigan State University Student Engineering Council, 1998-present.
- Faculty Co-advisor, Tau Beta Pi Engineering Honor Society, 2000-present.
- University Academic Council, alternate for Dean, 1998-present
- University Teacher Education Committee, 1998-present
- University Commencement Committee, 2000-present
- University Curriculum Committee, 2002-03.
- University ad-hoc committee on MSU Response to Hurricane Katrina, and Hurricane Katrina Seminar Series, 2005
- MSU Study Abroad Task Force, 2007-08.
- MSU Dubai instructional site Central Planning Group, 2007-08

- Mentor for cognitively disabled graduate student, MSU Resource Center for Persons with Disabilities, 2008.
- MSU Provost's ad hoc committee on improved collaboration between academic affairs and student affairs, 2008.

PROFESSIONAL SERVICE

- Advisory Committee on Academic Credentials to Michigan Professional Engineering Board, 1987-1998.
- Organizer, ASEE Associate Dean's Forum at ASEE National Convention-- 2003-06
- Curriculum consulting and outreach support for Woodcreek Science and Engineering Magnet Elementary School, Lansing Public Schools, 2003-present.
- ASCE Committee on Geotechnical Reliability
- ASCE Levee Assessment Team. In October, 2005, spent one week in New Orleans with ASCE, an NSF-sponsored team, and a Corps of Engineers' team preparing a preliminary assessment of levee performance and failures. 22 person team provided a preliminary report which was furnished to the U.S. Senate Committee on Homeland Security on November 1, 2005 (see publications section)
- Session Chair, ASCE Geo-Denver conference, February 2007.
- Proposal review for Southeast Region Research Inititiative, Oak Ridge National Laboratory, Oak Ridge, TN, July 2007. Proposals related to levee safety.
- Workshop session organizer for K-12 education unit for conference *The Role of Engaged Universities in Economic Transformation: A Regional Conference inspired by the National Academies Study, Rising Against the Gathering Storm,* University of Michigan, Ann Arbor, MI, October 15-16, 2007.
- Reviewer of proposals, books and journal articles for
    - ASCE Journal of Geotechnical and Geoenvironmental Engineering (numerous)
    - ASCE Journal of Transportation Engineering
    - ASEE Journal of Engineering Education (2006-2007)
    - Computers and Geotechnics (2005)
    - Great Lakes Press (2007)
    - John Wiley and Sons (2005)
    - Marcel Dekker (2004)
    - Prentice Hall (2005)
    - U.S. Civilian Research and Development Foundation for the Independent States of the Former Soviet Union (2001).

AWARDS for SERVICE

Department of the Army, Corps of Engineers, Commander's Award for Public Service (civilian medal). Awarded by Major General Don T. Riley, 15 August 2007 for service to the Interagency Performance Evaluation Task Force (IPET) for independent technical review of the the nine-volume report on performance of the Southeast Louisiana Hurricane Protection Project following the aftermath of Hurricanes Katrina and Rita.

CONSULTING - CLIENTS AND SERVICES

- Dr. G. A. Leonards, West Lafayette, IN. Assisted in analysis of hotel collapse during earthquake, Loutraki, Greece, 1982
- Geotechnology, Inc., St. Louis, MO. Performance analysis of dewatering system, Melvin Price Lock and Dam, for U. S. Army Engineer District, St. Louis, 1986–87.
- NTH Consultants, Farmington Hills, MI. Advice on application of probabilistic methods for evaluating waste containment alternatives, 1987.
- U.S. Army Engineer Waterways Experiment Station, Geotechnical Laboratory, Vicksburg, MS. Panel member for development of expert system on seepage control for dams, assisting Agapito and Associates, 1987.
- Timothy Mrozowski, Architect, East Lansing, MI. Preliminary foundation requirements for office building on peat, 1988–89.
- Geotechnology, Inc., St. Louis, MO. Investigation of dewatering system performance and cofferdam slope failure, Melvin Price Lock and Dam, for U.S. Army Engineer District, St. Louis, 1988.
- B. Dalimonte, Attorney, Lansing, MI. Expert witness on foundation performance of mobile home, 1989.
- U.S. Army Corps of Engineers, St. Louis District. Preparation of technical report, expert testimony, and review of post-trial briefs for $4 million dollar claim regarding construction dewatering at Melvin Price Lock and Dam, 1989-90.
- E. Czuprynski, Attorney, Bay City, MI. Expert witness on drowning below hydropower dam, 1989-92.
- Geotechnology, Inc., St. Louis, MO. Independent peer review and value engineering study for design of Mozingo Creek Dam, Maryville, MO, a 70 ft high USDA Soil Conservation Service dam on soft alluvium, 1990.
- UAW Legal Services, Detroit, MI. Review of settlement problem at residence, 1991
- U.S. Army Engineer Waterways Experiment Station, Geotechnical Laboratory, Vicksburg, MS. Extension of computer program LEVEEMSU for analysis of three-layer foundation systems, for Geotechnical Laboratory, 1991.
- U.S. Army Engineer Waterways Experiment Station, Geotechnical Laboratory, Vicksburg, MS. Recommendations for improved numerical modeling of relief wells, 1991.
- New Horizons, Inc., Jackson, MI. Advice on slope stability analysis for ash ponds, 1992
- U.S. Army Corps of Engineers, St. Louis District. Application of reliability analysis to Lock and Dam No. 25, Mississippi River, Winfield, MO, 1992.
- Kenneth Tableman, Attorney, Lansing, MI. Expert witness in lawsuit regarding construction payment quantities, 1992.
- Kurt D. Yockey, Attorney, Detroit, MI. Review of lawsuit involving trench cave-in, June 1992.
- John Berlin, Attorney, Cadillac, MI. Expert witness regarding groundwater rise and basement flooding due to ditch construction, 1992–1993.
- Consumer's Energy Company, Jackson, MI. Design review of subdrainage system for power plant ash pond extension, 1993.
- Fraser, Trebilcock, Davis and Foster, P.C., Ron Pentecost, Attorney, Expert advice on lawsuits regarding excessive settlement of foundations, 1993.

- David Landry, Attorney, Farmington MI. Expert witness on drowning below hydropower dam, 1993.
- STS Consultants, Lansing, MI. Advice on finite element modeling of ash pond seepage, 1993
- U.S. Army Corps of Engineers, St. Louis District. Application of reliability analysis to Lock and Dam No. 24, Mississippi River, Clarksville, MO, 1993
- Shannon and Wilson, Inc., St. Louis, MO. Comprehensive study and report on *Probability Models for Geotechnical Aspects of Navigation Structures* prepared for St. Louis District, Corps of Engineers, 1993-94.
- Shannon and Wilson, Inc., St. Louis, MO. Advice on interpretation of piezometer and well flow data for Mississippi River levees in 1993 flood, 1994.
- Knaggs, Harter, King, and O'Malley, Clifford Knaggs, Attorney,, Lansing, MI. Expert witness for lawsuit regarding method of payment for hauling hazardous waste contaminated soil, 1994.
- U.S. Army Corps of Engineers, Jacksonville District. Application of reliability analysis to Herbert Hoover Dike, Lake Okechobee, FL, 1994 - 1997, several contracts.
- U.S. Army Engineer Waterways Experiment Station, Geotechnical Laboratory, Vicksburg, MS. Member of expert panel (with M.E. Harr and J.M. Duncan) to review geotechnical time-reliability model for Upper Mississippi River Navigation Planning Study, 1995
- Ruman, Clements, Tobin and Holub, P.C., David Holub, Attorney, Hammond, IN. Expert witness on flooding due to breaching of embankment, Little Calumet River, Highland IN, 1995.
- U.S. Army Corps of Engineers, New England Division. Consulting and report review for Reliability Analysis of Hodges Village Dam, Massachusetts, 1995.
- Sinas, Dramis, Brake, Boughton, McIntyre, and Reisig, P.C, Attorneys, Lansing, MI. Expert witness in lawsuit regarding personal injury at dam spillway, 1995-1996
- Shannon and Wilson, Inc., St. Louis, MO. Two reports on application of probabilistic methods to geotechnical engineering problems (lifetime models and spatial correlation), prepared for St. Louis District, Corps of Engineers, 1996.
- U.S. Army Corps of Engineers, Mobile District. Application of reliability analysis for Major Rehabilitation Report for Walter F. George Dam, Georgia, 1996-97.
- Shannon and Wilson, Inc., St. Louis, MO. Preparation of Engineering Circular on Geotechnical Reliability Analysis, for Office, Chief of Engineers, U.S. Army, 1997.
- Smith, Haughey, Rice and Roegge, Jennifer Jordan, Attorney, Grand Rapids, MI. Expert witness for lawsuit involving soil and drainage conditions near residence, 1997.
- URS Greiner – Woodward-Clyde Consultants. Development of Corps of Engineers' Guidelines for Geotechnical Reliability Analysis, 1998. ETL 1110-2-556
- URS Greiner – Woodward-Clyde Consultants. Board of Expert Consultants to Jacksonville District, U.S. Army Corps of Engineers, for Review of Seepage Stability of Herbert Hoover Dike, 1998.
- U.S. Army Corps of Engineers, member of expert panel for *Workshop on Risk Assessment for Seepage and Piping in Dams and Foundations* at Virginia Tech, March, 2000

- U.S. Army Engineer Waterways Experiment Station, Geotechnical Laboratory, Vicksburg, MS. Lecture at Levee Reliability Workshop, 2001
- Chesterfield-Monarch Levee District, St. Louis, MO**,** policy and criteria review regarding seepage berms design, 2001
- Sinas, Dramis, Brake, Boughton, McIntyre, and Reisig, P.C, Attorneys, Lansing, MI. Review of other cases regarding dams, 2001
- G2 Consulting Group, Troy, MI. Advice on design of riverfront retaining structures, 2002.
- U.S. Army Corps of Engineers, St. Louis District. Review of Draft Appendix Engineering Circular (Reliability Analysis), 2002-03
- U.S. Army Corps of Engineers, Sacramento District. Independent Technical Reviewer for expert panel regarding seepage control and berm criteria for California levees, 2003.
- U.S. Army Corps of Engineers, St. Louis District. Review of methodology for Reliability Analysis, 2003-05.
- U.S. Army Corps of Engineers, Interagency Project Review Team (IPET), internal review of draft report on Hurricane Katrina and New Orleans Levee Failures, 2006-07.
- U.S. Department of Justice. Expert witness for U.S. Governments defense of flooding claims related to Hurricane Katrina. 2008.