Overview of Deep Mixing at Levee LPV 111, New Orleans, LA

Peter Cali[1], PhD, P.E., Bruce Lelong[2], P.E, Donald Bruce[3], PhD, P.E., Stefano Valagussa[4], Jim Beckerle[5], Jim Gardner[6], and George Filz[7], PhD, P.E.

[1] Senior Project Manager, USACE, Contractor - Hurricane Protection Office, 7400 Leake Avenue, New Orleans, LA 70160; peter.r.cali@usace.army.mil
[2] URS-JEG JV Design Team Project Manager, URS Corporation, 3500 North Causeway Blvd., Metairie, LA 70002; Bruce_Lelong@urscorp.com
[3] President, Geosystems, L.P., 161 Bittersweet Circle, P.O. Box 237, Venetia, PA 15367 dabruce@geosystemsbruce.com
[4] President and CEO, TREVIICOS, 38 Third Ave, 3rd floor, Charlestown, MA 02129; SValagussa@treviicos.com
[5] Sr. Project Manager, Alberici Constructors, Inc., 8800 Page Ave., St. Louis, MO 63114 jimbe@alberici.com
Senior Project Manager, Archer Western Contractors (Archer Western Alberici), 2121 Ave J, Suite 103, Arlington, TX 76006; jgardner@walshgroup.com
[6] Senior Project Manager, Archer Western Contractors (Archer Western Alberici), 2121 Ave J, Suite 103, Arlington, TX 76006; jgardner@walshgroup.com
[6] Professor of Civil and Environmental Engineering, Virginia Tech, Blacksburg, VA 24061; filz@vt.edu

ABSTRACT: During the storm surge that accompanies a hurricane, New Orleans, Louisiana, is an island, and owes its very existence to the 563-km (350-mile) long system of hurricane protection levees and walls that surround the city. The Hurricane and Storm Damage Risk Reduction System (HSDRRS) protects the area from storm surge. An 8.9-km (5.5-mile) long levee section of the Lake Pontchartrain and Vicinity (LPV) Hurricane Protection System, located in East New Orleans and called LPV-111, was designed and constructed by the United States Army Corps of Engineers (USACE) using the latest advances in Deep Mixing Methods (DMM) and innovative contracting and construction procedures. In the process, a new DMM Design Guide was created and peer-reviewed; an innovative contract acquisition plan, Early Contractor Involvement (ECI), was employed; and construction time was minimized through a close relationship among the project owner, designer, and contractor. This is the first in a series of five papers describing the technical and contractual advances and challenges overcome during design and construction. In this paper, an overview of the project is presented and general perspectives from the owner, designer, and contractor are presented.

INTRODUCTION

As part of the Lake Pontchartrain and Vicinity Hurricane Protection System, the project identified as LPV-111 presented challenges that required innovative approaches in design, contracting, and construction. LPV-111 extends along the north bank of the Gulf Intracoastal Waterway (GIWW) for approximately 7.2 kilometers (4.5 miles) and then turns north for 1.3

kilometers (0.8 miles) where it terminates at the CSX Railroad Gate (Figure 1). The levee is adjacent to the Bayou Sauvage National Wildlife refuge operated by the U.S. Fish and Wildlife Service (USFWS). Two pump stations are located along the levee, Pump Station 15 near the center of the levee section along the GIWW operated by the New Orleans Sewage and Water Board, and a smaller pump station on the north-south leg of the levee operated by USFWS. The levee is divided into three hydraulic reaches, 11B (north-south leg), and 12A and 12B on the east and west sides of Pump Station 15, respectively. The subsurface conditions and design procedures for each of the three reaches were generally similar.

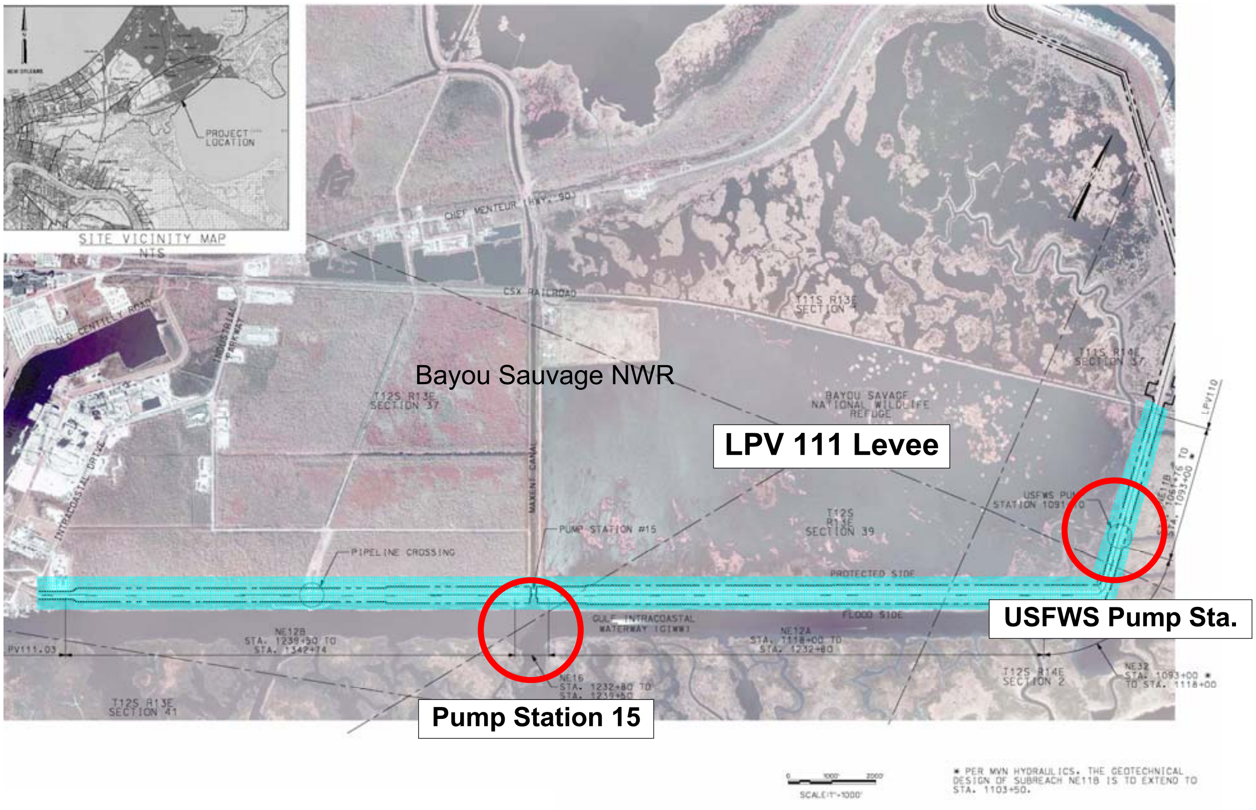

FIGURE 1. LPV 111 Vicinity Map

The levee was originally built to Elevation 2.7 m (9.0 ft) NAVD88 (2004.65) then raised in three stages to El. 5.2 m (17 ft) in the 1970's. During Hurricane Katrina, it was overtopped and severely damaged (see photos below), but was repaired after Katrina and raised to El. 5.5 m (18 ft). The design discussed in this paper required raising the levee to the 100-year level of flood protection, which resulted in about a 3.0 m (10 ft) raise to El. 8.4 m (27.5 ft) (Top of Protection Elevation, or TOP) for a Still Water Elevation (SWE) of El. 6.0 m (19.7 ft).

FIGURE 2. Damage at Pump Station 15 (left) and to LPV 111 levee (right), following Hurricane Katrina

To meet the more stringent design standards of the HSDRRS, Deep Mixing Methods (DMM) were used to buttress the foundation for greater slope stability and to virtually eliminate consolidation settlement. Early Contractor Involvement (ECI) was selected as the acquisition plan for contract award to accelerate construction. This allowed design and construction to partner for the betterment of both. The result was project completion on time, within budget, and to the highest industry standards.

New ground was broken on several fronts as part of the innovative DMM design, including development of a comprehensive limit equilibrium design methodology, and preparation of meaningful sampling and testing specifications. At roughly 1.3 million cubic meters (1.7 million cubic yards) of mixed material, LPV 111 is the largest DMM project ever attempted in the United States. Advances in mixes and equipment helped optimize cement usage that averaged over 2,000 tons per day. Re-use of mixed material, termed Recycled Embankment Material (REM), as part of the levee fill was another first use for flood protection embankments.

Advances made and lessons learned during project design and construction are shared in this series of five interconnected technical papers and presentations. The other four papers are:

- Deep Mixing Design for Raising Levee Section, LPV 111, New Orleans, LA (Cooling et al. 2012)
- Construction Operations and Quality Control of Deep Mixing at Levee LPV 111 in New Orleans (Schmutzler et al. 2012)
- Bench-Scale testing and Quality Control/Quality Assurance Testing for Deep Mixing at Levee LPV 111 (Bertero et al. 2012)
- Use of Deep Mixing Return Material for Levee Construction at LPV 111 (Druss et al. 2012)

SELECTION OF THE CONSTRUCTION METHOD

Hydraulic models for more than 152 combinations of hurricane intensity and path were created to estimate the maximum surge that would accompany a hurricane that has 1% probability of occurring in any given year. This is often termed the 100-year event - a misnomer since this hypothetical storm could occur annually or never. From the final models, site specific Still Water Elevations (SWE) and wave loads were established as design criteria for each project in the system. Models also indicated overtopping flow rates for storms exceeding the design hurricane. These flow rates were used to evaluate levee landside slope armoring alternatives.

Preliminary analyses were performed for the higher levee grades and more stringent HSDRRS design criteria as part of the Engineering Alternatives Report (EAR), on which the selection of a construction method was based. An earthen levee without reinforcement was quickly eliminated from consideration after stability berms needed to meet the required slope stability safety factors were found to extend well beyond the existing right-of-way and into the wildlife refuge. From cost, schedule, and environmental constraints, this alternative was unacceptable. The remaining alternatives were then evaluated using the U.S. Army Corps of Engineers (USACE) Alternatives Evaluation Process (AEP), whereby alternatives were assigned weighted numerical scores in six categories by a panel of technical, management, and construction personnel with relevant expertise.

Preliminary studies reduced the number of viable construction alternatives to four, which were more closely evaluated. Only solutions that did not encroach on the wildlife refuge were considered practical due to the lengthy permitting process that would be required for constructing in the protected wetlands.

- Reinforced concrete floodwall (T-Wall)
- Earthen levee with DMM
- Prefabricated Vertical Drains with high strength geotextile
- Lightweight fill, expanded clay-shale

Selection criteria were based on owner concerns and were weighted by relative importance. Then a score was awarded to each alternative to produce weighted ratings. The selection criteria values were:

- Quality - Risk and Reliability - 30%
- Schedule – 100-year protection complete by June 2011 – 15%
- Cost – 25%
- Right-of-Way – 5%
- Environmental impacts – 20%
- Operation and Maintenance – 5%

Earthen levee with DMM ranked as the best alternative, with T-Walls a close second in score. Several factors were considered further. Opinions that DMM was still an emerging technology fostered concerns that equipment availability and production rate and would delay construction. To meet the June 2011 completion deadline, 1.3 million cubic meters (1.7 million cubic yards) of DMM work had to be completed along with the placement of (841,000 cubic meters (1.1 million cubic yards) of clay levee fill.

Although the levee location is adjacent to the GIWW, an easily accessible and navigable waterway, adjacent water access was not available for delivery of construction materials because the property located on the floodside of the levee right-of-way is also part of the environmentally protected area. Water access was available a short distance away, but most construction materials, including clay, were delivered to the levee by truck. From a logistical standpoint, given the limited access, it was important to minimize the quantity of soil delivered to the project.

Given the degree of uncertainty of this preliminary design, the slightly lower cost of the levee with DMM compared to the more conventional T-Wall could easily be offset by increased construction time. Nevertheless, the lower cost levee with DMM was ultimately selected. This proved to be a good decision because the ancillary benefits that DMM provided, including reduced settlement of the levee and reduced costs associated with used of DMM spoils, which were referred to as Recycled Embankment Material on this project. Based on DMM production from other projects, it was estimated that the work could be completed in less than 10 months using 10 DMM rigs. This proved to be a reasonable estimate. The DMM work was actually completed in 14 months using eight rigs.

DMM had been used on many projects in the New Orleans area since the requirements of Task Force Guardian in early 2006 (Bruce et al., 2012). There was therefore considerable knowledge within the local engineering community, and the specialty contractors, about the benefits — and challenges — of implementing the technique in the prevailing soil conditions. As detailed in the companion papers, and especially by Schmutzler et al., and Bertero et al., the whole approach to the project followed closely that advocated by the U.S. Federal Highway Administration (FHWA) (2000a, 2000b and 2001). Thus, an initial desk study was conducted by the contractors' consultants to provide guidance on the range of mix designs which had been previously used on local projects, and the resultant deep mixed material properties. This was followed by an intense program of laboratory ("benchscale") tests to refine further mix designs, given the DMM contractors' foreseen particular technique. This program was conducted in several phases to optimize the process. Thereafter, and prior to full-scale production, extensive full-scale field testing was conducted, wherein means, methods and materials were systematically varied in order to identify the particular combinations of variables which would reliably and uniformly satisfy the design requirements placed on the treated soil.

Each specialty contractor tends to have his own unique blend of variables, and this is illustrated in the fact that one used a WJE method, and the other a somewhat modified WRE method (See Figure 3 for description of these methods), with each producing a comparable product in-situ.

LEVEE AND DMM DESIGN

It was clear from the earliest results of hydraulic modeling in 2007 that conventional all-earth levee construction would not be a viable solution. Part of the DMM experience of the New Orleans District of USACE had been gained during the levee reinforcement of Item P-24 (Adams et al. 2008a), which was similar to LPV-111 but on a smaller scale. Responding to the scale of the DMM effort that would be needed for LPV-111, the Hurricane Protection Office (HPO) convened an Industry Forum in August 2007 to brief DMM contractors, cement suppliers, earthwork contractors, designers, and local sponsors about the scale and schedule of the LPV 111 project and to solicit advice from the industry.

Project design was largely in the hands of the Designer of Record, URS Corporation, with input and approval from USACE. Several projects had been designed and built using DMM reinforcement to improve levee and floodwall stability (Adams et al. 2008a,b, Filz et al. 2010), but a universally accepted design methodology did not exist. To analyze the numerous and complex slope stability design cases for LPV 111 that were required to comply with more

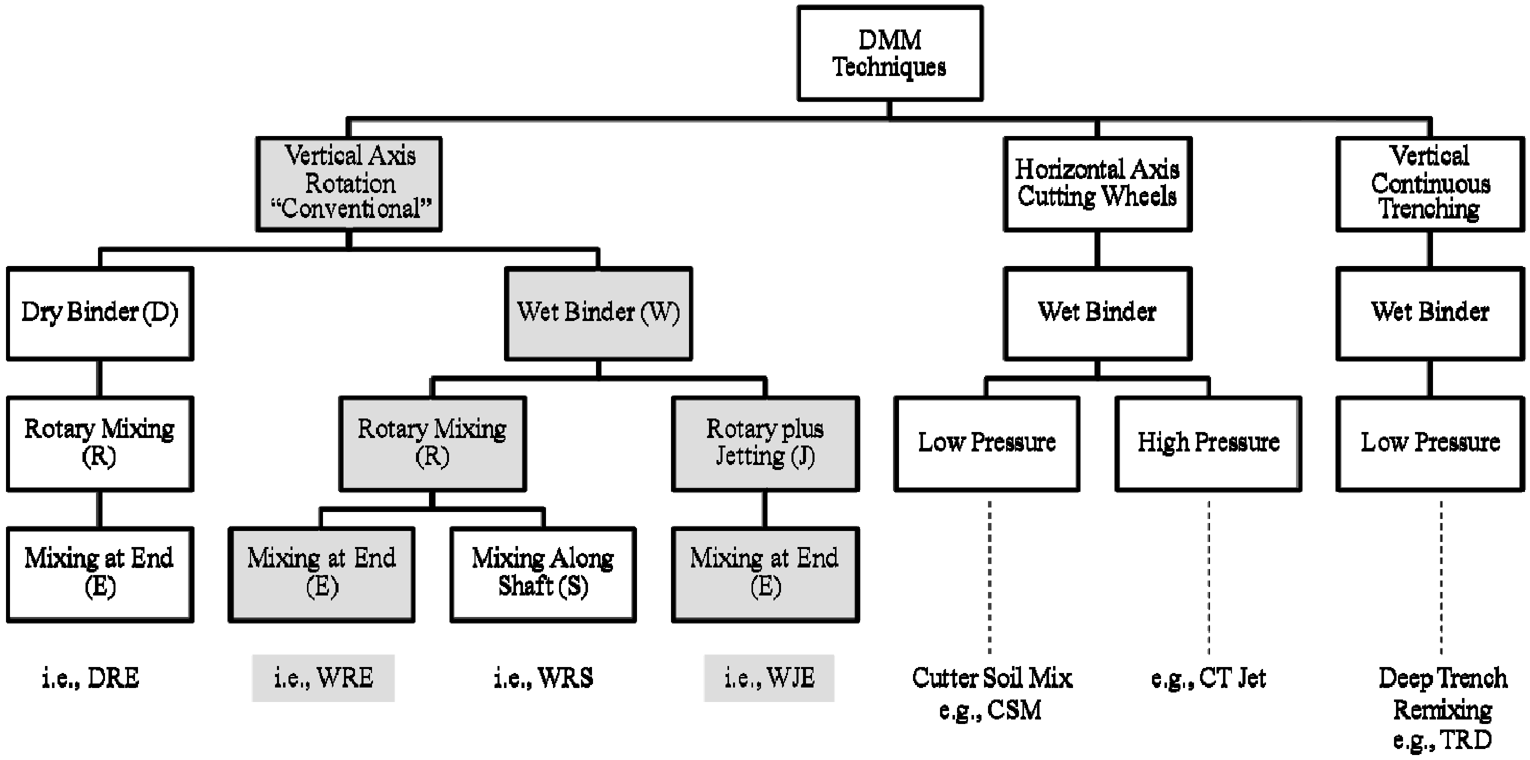

Figure 3. Classification of DMM technologies (after FHWA, 2000).

This is based progressively on: the basic operating principle (i.e., vertical axis rotation; cutting wheels; trenching); the type of binder (Wet or Dry); the penetration/mixing principle (Rotary with low pressure binder or Rotary with high pressure Jetting); and the location of the mixing action (i.e., all along the Shaft of the axis, or only near the End).

stringent criteria adopted by the USACE after Hurricane Katrina, the USACE commissioned Dr. George Filz, Virginia Tech University, and Mr. Eddie Templeton, of Burns, Cooley, Dennis, Inc., to compile a new DMM Design Guide based on accepted design methods being used in Japan, Europe, and in the US. The DMM Design Guide was subjected to Independent Technical Review by reviewers selected by Battelle International, Seattle, Washington, who had no affiliation with the USACE or with designs being performed for the HSDRRS. The result of applying this DMM design methodology to LPV 111, as well as many other equally important standard and unique design analyses and considerations, are described by Cooling et al. (2012).

EARLY CONTRACTOR INVOLVEMENT

HPO used Early Contractor Involvement (ECI) for contract acquisition. This was a radical change from the conventional "Design-Bid-Build" process commonly used by the USACE. ECI permitted design innovation during construction and was a key element in the project's success. With ECI, prospective contractors bid on the project based on 10% design completion. The contract was awarded to the bidder offering the lowest projected cost and best plan for on-time completion. After a contractor was selected, the designer, owner, and contractor co-located as a team and pooled their experience and expertise to optimize the design. ECI not only allowed for contractor input on constructability, including review of plans and specifications, it also enhanced communication among all parties, and it enabled the contractor to obtain a thorough understanding of the design intent and to work directly towards achieving the design intent, with consequential benefits on construction quality and reduced potential for disputes. Once the design was completed and 100% construction plans and specifications were approved, the contractor submitted a Firm Fixed Price to complete the construction on schedule. Significant ECI design innovations that are described in the accompanying papers include:

- Use of Recycled Embankment Material as levee fill (Cooling et al. 2012, Druss et al. 2012).
- Configuration of the column diameter and panel spacing to match the contractor's equipment (Cooling et al. 2012).
- Development of appropriate design details to protect against differential settlement (Cooling et al. 2012).
- Accommodation of construction logistics in the design (Cooling et al. 2012, Schmutzler et al. 2012).
- Reduction of specified column strength and refinement of other details of the DMM acceptance criteria based on Quality Control and Quality Assurance observations and statistical analyses of the data (Schmutzler et al. 2012, Betero et al. 2012).
- Increase of the maximum allowable moisture content for compaction of clay material.
- Reduction in the thickness of the clay cover on the protected side slope (Druss et al. 2012).

With construction scheduled for completion by June 2011, the ECI design and construction period was compressed to only 23 months after contract award in July 2009. While the design was being refined, notice to proceed for construction was not issued until September 2009, leaving only 20 months to achieve 100-year flood protection. However, construction was allowed to begin using separate work packages, mini-contracts of a sort, for mobilization and staging area preparation, construction of access roads, and other construction features that would not be impacted by design changes. Additional subsurface investigation was performed to better define peat thickness, delineate the Pleistocene horizon, and obtain samples for bench-scale testing. Bench-scale testing was begun as soon as samples were obtained, and design mixes were optimized almost continuously throughout the project (Bertero et al. 2012).

CONCLUSIONS

The LPV 111 project is the largest deep mixing project completed to date in the US, and one of the largest in the world. The project has been successful due to the collaborative efforts of the Owner, Designer, and Contractor. Because the project was unique in terms of size, contracting method, and schedule, several important lessons were learned during the course of the work:

- In Design-Bid-Build contracts, the Designer of Record performs Engineering during Construction to insure that construction is executed in accordance with the design, while in ECI the Designer is embedded with the Construction Contractor and Owner during all phases of construction. Therefore, the DOR must be engaged throughout the construction process to reap full benefits of the Design-during-Construction approach. This is more effort than afforded a typical Engineering during Engineering-during-Construction approach since the design evolves throughout construction.
- Co-location of the Owner, Designer, and Contractor is critical to establish the teamwork and trust necessary to successfully execute an ECI project. Important benefits are that the Designer fully understands the needs of construction, and the Contractor fully understands the design intent. The outcome is that the Designer's plans and specifications are consistent with construction means and methods, and the Contractor is engaged from the beginning in producing a facility that meets the Owner's needs.
- As long as the end product meets the design requirements, design should be modified to best facilitate construction. This requires three things on the part of the Owner and Designer: (1) flexibility to consider contractor suggestions, (2) careful review to verify that the design intent is still being met, and (3) an appropriate design budget to permit such review. On the Contractor's part, this requires the ability to rapidly adapt to design changes.
- Accurate As-Built drawings and records are particularly important for ECI construction.
- Because of the nature of an evolving design, Design Documentation Reports should be updated post-construction.
- Relatively inexpensive subsurface investigations using CPT or disturbed drilling techniques to better define problem strata can save mixing time and cement usage, more than offsetting the cost for investigation. A specific application of this at LPV 111 was to perform additional borings to define the extent of the marsh/peat deposits to permit a more realistic estimate of their vertical extent along the project alignment, and thereby reduce the conservatism that would otherwise be necessary to ensure adequate treatment of these materials, which require more binder than other soil types.
- When a large DMM project is anticipated, a pre-design Industry Forum can help the designer and the industry anticipate and overcome design and construction challenges.

- When comparing the cost of construction alternatives, all ancillary benefits of DMM should be considered. These include settlement minimization, lesser need for quality imported earth fill, and re-use of REM as a construction material.

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