

**DESIGN GUIDE  
FOR  
LEEVE AND FLOODWALL STABILITY USING DEEP-MIXED SHEAR WALLS**

**USACE Responses to Independent External Peer Review**

**April 2011**

Deep Mixing Methods (DMM) were used by the Hurricane Protection Office (HPO) to reinforce foundations for several levee and floodwall projects within the Hurricane and Storm Damage Risk Reduction System (HSDRRS). As design progressed, HPO decided that an independently reviewed set of DMM design guidelines should become part of the design documentation. Until this time, DMM design and stability analysis methods had evolved from the Japanese Coastal Development Institute of Technology (CDIT) publication, *The Deep Mixing Method, Principle, Design and Construction* (2002). HPO contracted with Dr. George Filz, Virginia Tech University, and Mr. Eddie Templeton, Burns, Cooley & Dennis, Inc., Ridgeland, Mississippi, to research the literature on the subject and to compile external and internal stability analyses into a unified method that represents the state-of-the-practice in DMM design. The resulting design methodology, universally applicable to any DMM application, was specifically tailored to the reinforcement of embankment foundations using contiguous shear panels. Many of the 13 Independent External Peer Review (IEPR) comments were actually recommendations for improving and expanding the document to address specifications and construction issues, as well as numerical modeling and alternate arrangements of columns. The design guide is intended to be a living document, and it will be expanded as time permits, but the scope of this effort was to obtain an Independent External Peer Review (IEPR) for the DMM design methodology developed for use within the HSDRRS.

**IEPR Comment 2453538, Chapter I: Introduction**

Comment: A complete self contained design and construction Deep Soil Mixing Design Guide for Levees and Floodwalls (DSM Design Guide) would prove invaluable for the NOLA effort. This document has the potential to establish a uniform basis/standard of design and

construction for a great deal of DSM work throughout the NOLA area and in similar applications/ground conditions throughout the world. This uniform basis and standard of design will benefit the client in completing the significant work ahead, within tight cost and schedule constraints, by increasing the design and construction capacity and competitiveness, allowing some flexibility and innovation through a balance between prescriptive and performance specifications, and yet maintain a high uniform standard of design, construction, and performance of the completed projects. Generally, the DSM Design Guide will benefit from expanded sections including: background, geometric considerations, numerical analyses, specifications, and lessons learned, in relation to the specific applications and subsurface conditions posed by NOLA projects. More specifics are identified in subsequent comments.

**This comment is of Low Significance. The recommendations were not adopted.**

**Response: The reviewers recommended expansion of the document beyond its defined scope. While the IEPR recommendations are valid, and hopefully the document will someday be expanded to address DMM design and construction more comprehensively, the intent of this document was to provide a limit equilibrium method for internal and external stability analysis of embankments on soft foundations that are reinforced with DMM shear panels. This had to be accomplished within a tight design schedule and limited task order budget. As such, while the USACE concurred with the IEPR recommendations, the document was not changed, except for minor clarifications noted in the Dr. Checks chain.**

#### **IEPR Comment 2453557, Chapter II: Summary of Recommended Step by Step Design Procedure**

Comment: The summary is an excellent brief overview of the recommended design procedure. In order to give the owner and designer more direction and a greater comfort level with the step by step procedure, this section should be expanded to include a flow chart and alternative decisions/paths.

**This comment is of Low Significance. The recommendations were not adopted.**

**Response: The reviewers recommended expansion of the document beyond its defined scope. While the IEPR recommendations are valid, and hopefully the document will**

someday be expanded to address DMM design and construction more comprehensively, the intent of this document was to provide a limit equilibrium method for internal and external stability analysis of embankments on soft foundations that are reinforced with DMM shear panels. This had to be accomplished within a tight design schedule and limited task order budget. As such, while the USACE concurred with the IEPR recommendations, the document was not changed, except for minor clarifications noted in the Dr. Checks chain.

#### **IEPR Comment 2453648, Chapter V: Strength Values**

Comment: The DSM Design Guide would benefit from specific guidance on the selection of design strengths including the variability of strengths achieved at the completion of construction for NOLA projects. The variability in strength of the completed in-place deep-mixed ground is key to the project's success. It is not clear if the strength reduction/variability factors recommended in the DSM Design Guide are based only on information obtained from International and other US projects, or if these factors have been confirmed by NOLA field experience. Is "...the reduction factor,  $r_{dm}$ , to account for variability", equivalent to "...the factor for variability,  $f_v$ , to be applied..."? Please check terminology/variable names.

**Response: This comment was a request for clarification. USACE's response was accepted and the comment was closed.**

#### **IEPR Comment 2453662, Chapter VI: External Stability**

It is recommended that the required factors of safety presented in the HSDRRSDG Design Guidelines (Table 3.1) be presented in tabular format in the DSM Design Guide.

**Response: This comment was of Low Significance. It was not adopted. The reviewer concurred after a second look and closed the comment.**

#### **IEPR Comment 2453666, Chapter VII: Internal Stability**

Comment: As presented in Chapter VI: External Stability, the DSM Design Guide would benefit from referencing CDIT (2002) and or other pertinent references as the specific source for the equations.

**Response: This comment was of Low Significance. It was accepted, and changes to the document were made.**

#### **IEPR Comment 2453669, General**

Comment: The terminology in the DSM Design Guide should be revised to include and make consistent with standard USACE terminology.

**Response: This comment was of Low Significance. It was adopted in part. Some changes were made to the document to make terminology compatible with USACE references, but DMM is a specialized technology and technical descriptions must use specialized industry terms that are not used in EM documents, for example. The DMM Design Guide must remain internally consistent, so the comment was only partially adopted.**

#### **IEPR Comment 2453677, Chapter VI: External Stability / Chapter VII: Internal Stability**

Comment: It is recommended that a distinction be made in the DSM Design Guide between a sliding surface passing through the deep-mixed zone and the adjacent soil on either side, (the former, total stress analyses recommended) versus a potential failure surface passing entirely above or entirely below the deep-mixed zone (the later, total or effective stress analyses). Further discussion is required to clarify the use of total stress (Chapter V: Strength Values) versus equations for both total stress and effective stress (Chapter VI: External Stability) for the calculating soil strength beneath the DSM ground / shear walls.

**Response: This comment was of Low Significance. This section of the report was misunderstood by the reviewer. The USACE response, which included an agreement to add some clarifying language, was accepted by the reviewer and the comment was closed.**

## **IEPR Comment 2453686, Chapter IX: Numerical Analysis of Stability**

Comment: The DSM Design Guide would benefit from references and examples where deep mixing is applied in unusual geometries, adjacent to structures, for complex conditions, and or with isolated columns, for which numerical analyses may be recommended or warranted. The references and examples are necessary to give the designer a basis for assessing the need for alternative / numerical analyses.

**This comment is of Low Significance. The recommendations were not adopted.**

**Response: In this comment, the reviewers recommended expansion of the document beyond its defined scope. While the IEPR recommendations are valid, and hopefully the document will someday be expanded to address DMM design and construction more comprehensively, the intent of this document was to provide a limit equilibrium method for internal and external stability analysis of embankments on soft foundations that are reinforced with DMM shear panels. This had to be accomplished within a tight design schedule and limited task order budget. As such, while the USACE concurred with the IEPR recommendations, the document was not changed, except for minor clarifications noted in the Dr. Checks chain.**

## **IEPR Comment 2453706, Lessons Learned for the Designer**

Comment: Possibly re-title this section to include instructions to both design engineers ("Engineering Considerations and Instructions for the Design Engineer") and field personnel (Engineering Considerations and Instructions for Field Personal). This is particularly useful where the Design Documentation Report (DDR) is prepared by someone other than the design engineer/engineer of record, or in the case of a program manager completing a design basis, conceptual or preliminary design for a large project, where many smaller project segments are designed by others, ideally to the same or similar design basis. This will benefit the client, design engineer, and field personal in completing the significant work ahead, within tight cost and schedule constraints, and maintain a high uniform standard of design, construction, and performance of the completed projects.

**This comment was of Low Significance. It was accepted and changes to the document were made.**

### **IEPR Comment 2453714, Chapter I: Introduction**

Comment: The DSM Design Guide, which addresses forces, stresses, and factors of safety, should also address settlement and lateral deflection, as failure or overtopping could occur if these issues are not considered during the design phase. These are very important considerations when constructing on very soft soils. If the shear walls are not founded on a competent soil stratum, then settlement may be significant. Lateral deflections may also be a major concern, especially for I-wall shear walls. Relying on the factor of safety for internal and external stability checks is not sufficient to ensure settlement and/or lateral deflections will be within acceptable tolerances. Unchecked settlement and/or lateral deflections could lead to overtopping of levees.

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**Response: In this comment, the reviewers recommended expansion of the document beyond its defined scope. While the IEPR recommendations are valid, and hopefully the document will someday be expanded to address DMM design and construction more comprehensively, the intent of this document was to provide a limit equilibrium method for internal and external stability analysis of embankments on soft foundations that are reinforced with DMM shear panels. This had to be accomplished within a tight design schedule and limited task order budget. As such, while the USACE concurred with the IEPR recommendations, the document was not changed, except for minor clarifications noted in the Dr. Checks chain.**

### **IEPR Comment 2453719, Chapter VII: Internal Stability**

Comment: The spacing of the shear walls should not be determined based on a single specific geometry (Table 3, Section IV.3). This is only one of innumerable possibilities. The DSM Design Guide is too geometry specific; if other geometries are used, need for a different analysis. The shear wall spacing will be controlled, to some extent, by extrusion of the soft ground between shear walls as provided in Section VII.4. With soft ground conditions, extrusion between shear walls may be controlling factor for internal stability.

**This comment is of Low Significance. The recommendations were not adopted.**

**Response:** In this comment, the reviewers recommended expansion of the document beyond its defined scope. While the IEPR recommendations are valid, and hopefully the document will someday be expanded to address DMM design and construction more comprehensively, the intent of this document was to provide a limit equilibrium method for internal and external stability analysis of embankments on soft foundations that are reinforced with DMM shear panels. This had to be accomplished within a tight design schedule and limited task order budget. As such, while the USACE concurred with the IEPR recommendations, the document was not changed, except for minor clarifications noted in the Dr. Checks chain.

**IEPR Comment 2453629, Background Information / Chapter IV: Geometric Considerations**

Comment: This section could be improved with a summary of deep soil mixing methods, including wet vs. dry, rotary versus jet, and shaft versus end, including the advantages and disadvantages in subsurface conditions similar to those for NOLA. One single arrangement/geometry (single row of columns forming shear wall perpendicular to slope) is shown. It is suggested that the DSM Design Guide would benefit from a discussion of alternate arrangements and their respective geometric equations.

**This comment is of Low Significance. The recommendations were not adopted.**

**Response:** In this comment, the reviewers recommended expansion of the document beyond its defined scope. While the IEPR recommendations are valid, and hopefully the document will someday be expanded to address DMM design and construction more comprehensively, the intent of this document was to provide a limit equilibrium method for internal and external stability analysis of embankments on soft foundations that are reinforced with DMM shear panels. This had to be accomplished within a tight design schedule and limited task order budget. As such, while the USACE concurred with the IEPR recommendations, the document was not changed, except for minor clarifications noted in the Dr. Checks chain.

## **IEPR Comment 2453690, Chapter X: Specifications for Construction**

Comment: The Specifications for Construction section should be expanded and sample specifications developed to include recommended QA/QC with: roles, responsibilities and different types of QA/QC testing such as: soil borings (SPT), cone penetration test soundings (CPT), and geophysical methods (cross hole). Other QA/QC test methods may be applicable depending upon the soil type /characteristics and strength achieved. The prescriptive versus performance specifications should be addressed, and the inherent differences and benefits/limitations of each described.

**This comment is of Low Significance. The recommendations were not adopted.**

**Response: In this comment, the reviewers recommended expansion of the document beyond its defined scope. While the IEPR recommendations are valid, and hopefully the document will someday be expanded to address DMM design and construction more comprehensively, the intent of this document was to provide a limit equilibrium method for internal and external stability analysis of embankments on soft foundations that are reinforced with DMM shear panels. This had to be accomplished within a tight design schedule and limited task order budget. As such, while the USACE concurred with the IEPR recommendations, the document was not changed, except for minor clarifications noted in the Dr. Checks chain.**