Development of design criteria for the use of articulating concrete mats and geosynthetic separator fabric as protective features for earthen containment dikes exposed to localized wave forces

Introduction

The coastal wetland loss in Louisiana is a very complex issue. A wide spectrum of solutions or approaches aiming at alleviating, neutralizing, reversing the losses are being implemented or proposed by CPRA. General techniques include restoration of both structural and habitat function, Construction of containment dikes from in-situ soils, sheet-pile weir or rock revetments, re-creation of new marshland by hydraulically dredging riverine sediments and pumping via pipeline for transportation, and reduction of tidal exchange in marshes, etc. Low containment dikes were constructed from in-situ soils along a portion of the project area to create a full perimeter containment, as shown in Fig. 1(a).

Along the shoreline, earthen dikes are usually built on the soft clay, silts or fine sands. An earthen dike reinforced using articulating concrete mats and geosynthetic separator fabric consists of planar reinforcements arranged in nearly horizontal planes in the reinforced fill to resist outward movement of the reinforced fill mass. Facing treatments ranging from vegetation to flexible armor systems are applied to prevent unraveling and sloughing of the face. These dikes are different from regular levees or embankments, and they are subjected to high current and wave pressure, and pore water pressure conditions. Special design criteria should be developed by considering all the special factors.

The design of reinforcement for a safe dike requires a rigorous analysis. The design of reinforcement for this application is critical, as failure of the reinforcement would result in failure of the dike. The overall design requirements for a reinforced dike should follow those for an unreinforced slope: A limit equilibrium analysis-based, allowable stress approach is used and the factor of safety must be adequate for both the short-term and long-term conditions and for all possible modes of failure. However, those forces from localized waves, currents and tides must be fully considered in determining the reinforcement spacing, length, etc. Soil erosion is a critically important factor in the design of earthen containment dikes. An effective method to analyze the stability should be developed. As illustrated in Fig. 1(b), there are three failure modes for reinforced dikes.

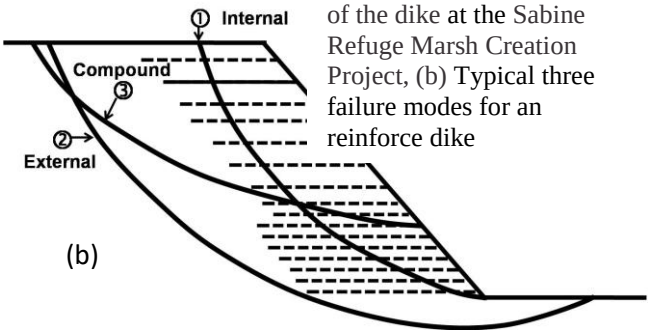

Figure 1. (a) construction of the dike at the Sabine Refuge Marsh Creation Project, (b) Typical three failure modes for an reinforce dike

How this research is of interest to the Coastal Protection and Restoration Authority (CPRA) and how it fits within the CPRA Master Plan?

The proposed research is aimed to develop criteria to design earthen containment dikes for coastal marsh creation projects. Field investigation, soil sampling work, and research process will be guided by officials at CPRA/Office of Coastal Protection and Restoration.

Objectives of the research

Design criteria and step-by-step procedures will be developed for the design of reinforced earthen dikes with geosynthetic or concrete mats. Recommendations for deep seated failure using a computer program, such as Slope/W, will be suggested. Proposed research is briefly described as follows:

- Collect and analyze data and reports of dredged fill dikes from CPRA offices and USACE websites, with special attention to the records of hurricane wave and current heights in the marsh creation coastal areas to find an accurate method to estimate the localized wave forces.

- Review EM 1110-2-5027 “Confined Disposal of Dredged Material”, with attention to be focused on Chapter Six “Design and Construction of Dikes for Containment of Dredged Material”.
- Review design manual “Design and Construction of Mechanically Stabilized Earth Walls and Reinforced Soil Slopes – Vols. I & II”, recommended by Federal Highway Administration for the regular criteria to design a regular reinforced soil embankment.
- Contact CPRA personnel, and relevant contractors to gather fundamental data for dike design, wave and current load, etc. to establish the geometric, loading, and performance requirements for design for a typical dike and reinforcement materials.
- Investigate and find an effective way to determine the engineering properties of the in-situ dike (sea bed) soils., and to evaluate design parameters for the reinforcement.
- Develop the design details of an earthen dike taking the articulating concrete mats and geosynthetic separator fabric as reinforcements of dike fills or protective features.
    i. Determine an effective way to perform stability analyses to find the safety factors for potential failure (slip) surfaces by considering the reinforcement and drainage functions of the concrete mats and geosynthetic separator fabric.
    ii. Determine the size of the critical zone of the dike to be reinforced.
    iii. Find an effective way to calculate the total reinforcement tension per unit width of dike.
    iv. Determine the distribution of geosynthetic reinforcement.
    v. Determine the vertical spacing or the maximum design tension requirements for each reinforcement layer (concrete mats or geosynthetic fabric).
    vi. Determine the required reinforcement lengths.
    vii. Determine the strength reduction factors for installation damage, creep, and biological and chemical degradations, respectively, under the special working environment.
    viii. Determine the factor of safety against sliding, and deep-seated global stability of the dike.
    ix. Establish a method to check local bearing failure at the toe of dike.
    x. Find an efficient way to calculate foundation settlement of dike.
    xi. Determined a factor of safety required for the earthen containment dikes of this kind.
- Conduct experimental studies on interactions between dike soils and reinforcements.

Figure 2 (left) The large-scale direct shear test machine, (right) the 12 in ×12 in shear box after a test was completed

Large-scale direct shear tests will be conducted for the enhanced shear strength of the geosynthetic or concrete mat-reinforced dike soils. In the 300 mm by 300 mm and height of 150 – 300 mm shear box as shown in Fig. 2, the reinforced dike soils are sheared to failure, and the shear strength parameters (cohesion and friction angle) are measured, which are required in the dike design and analyses.

Deliverable

Design criteria will be proposed for the use of articulating concrete mats and geosynthetic separator fabric as protective features for earthen containment dikes. Detailed step-by-step design procedures will be provided.

Expertise

Dr. Wang is a professor at Louisiana Tech. He is a Louisiana registered civil engineer with more than 30-year extensive experiences in soils, slope stability and foundation engineering. Since year 2010, Dr. Wang has been working on a series of research projects funded by CPRA on the marsh creation projects. In the last five years, Dr. Wang and three graduate students have been working on research projects of development of a mechanistic-based design method for geosynthetics-reinforced pavement on expansive soils, which were funded by the University Transportation Center in District Five called South Plains Transportation Center.