Quantifying Geotechnical Properties and Processes in the Fort St. Phillip Crevasse Complex: Implications to Sediment Diversions

BACKGROUND

Louisiana CPRA is in the process to spend several billion dollars designing, constructing, and operating sediment diversions in the Mississippi River as a primary tool for building and sustaining coastal wetlands in the Barataria and Breton Sound basins. The overarching goal of this CSAP proposal is to reduce the uncertainty in the geotechnical processes that will determine the ultimate efficacy of both sediment diversions. Crevassing is the natural process by which the river breaches the natural levee and evolves a subaqueous to subaerial lobate deposit with continued delivery of sediment-laden water that simultaneously progrades seaward and accretes upward (Yuill et al. 2016). Accordingly, the are a natural surrogate to sediment diversions and thus will be used in this research project to address the following research objectives: (1) Develop models to predict the consolidation (compaction) of the sediment and pre-existing marsh and bay bottom substrate; (2) Determine the relationship of soil erodibility and shear strength for sediment remobilization; and (3) Quantify the trajectory of vegetation productivity.

1. The goal of the sediment diversions is to raise the marsh platform elevation, but consolidation will cause a decrease in elevation. How much net elevation gain can we anticipate? Törnqvist et al. (2008) show in a Bayou Lafourche crevasse splay that the magnitude of consolidation (compaction) is linearly correlated with overburden thickness, decreasing moving away from the outfall area. This indicates that consolidation must be accounted in the land building process. However, these observations were formed from cores and radiocarbon dating and did not include quantitative analyses. An objective of this CSAP project is to unravel magnitude and rate of consolidation in a crevasse splay and the covariability with sediment type (clay, silt, sand) and pre-existing geological stratigraphy.
2. In addition to scouring of the outfall area, recently deposited sediment exhibit very low strengths and thus are prone to remobilization and redeposition. A significant uncertainty in sediment transport numerical models is quantifying the critical shear stress for remobilization, which is a completely different focus compared to prior and current CSAP and COE work on erodibility as applied to initial scour hole formation. Erodibility is a function of sediment type and mineralogy, degree of consolidation, organic content, salinity, and bulk density (Grabowski et al. 2011). Similar factors also impact sediment shear strength (Whelan et al. 1975; Briaud 2013; Dejong et al. 2013), providing the impetus to develop a direct correlation of in-situ cone penetrometer shear strength and erodibility from a field-calibrated Delft3D sediment transport model. The advantage of identifying this relationship is that cone penetrometers continuously measure shear strength with depth, limiting the need and expense for many deep cores to perform laboratory erodibility tests. In particular, many cone penetrometer tests were performed for the geotechnical subsurface investigations in the receiving basin of the sediment diversions, which can now also be used to predict scour formation.
3. The success of sediment diversions is predicated on not only land building but also creating healthy wetland habitat. The trajectory of wetland productivity can be measured for fresh to saline vegetation types using cone penetrometer shear strengths (Jafari et al. 2019). The shear strength response of the roots and rhizomes to the input of sediment and nutrients can assist in forecasting performance to the sediment diversion, future hurricanes, and sea level rise. Moreover, quantitative measurements of root strength are important for developing baseline conditions and tracking changes over time, as well as being valuable for the parameterization of Louisiana's Coastal Master Plan (CPRA 2017) and other numerical models used to inform coastal restoration and protection decision making (Jafari et al. 2019).

FORT SAINT PHILIP CREVASSE EVOLUTION

Professor Mead Allison (Tulane University) is currently investigating the Fort St. Phillip (FSP) Crevasse splay via a 2020 CSAP project. His proposal highlights how FSP is an excellent analogue for understanding sediment evolution and land growth of the authorized Mid-Breton and Mid-Barataria sediment diversions. In particular, water discharge Ft. St. Phillip (FSP) reaches more than 100,000 cfs during periods when

Bonnet Carre Spillway is open (e.g., 2016, 2018, 2019), which is the same order of magnitude as the proposed Mid-Barataria and Mid-Breton sediment diversions (Suir et al. 2014). Evidence of from a remote sensing study that compared land change through 2017 (Costanza and Frank-Gilchrist 2019) demonstrates that the large sediment flux turned the receiving area into net land gain (1,134 acres since 2008), with additional land gain because of the large floods of 2018 and 2019. He also pinpoints the research questions that still remain unresolved, including the amount of self-weight consolidation (subsidence) of the sediment and pre-existing substrate with splay growth and the rate of mineral trapping (and erosion of the entire marsh substrate in the proximal areas). This CSAP proposal has a companion proposal by Professor Ehab Meselhe (Tulane), with the intent to perform synergistic sediment transport numerical modeling and geotechnical in-situ measurements and laboratory testing. The overarching goal from these two CSAPs will be a comprehensive and integrated investigation of a crevasse splay that accounts for the geomorphology (and sediment budget from Prof. Allison), quantifies the erodibility and consolidation properties of sediments and pre-existing substrates, and develops field-calibrated sediment transport models that ultimately can be used by CPRA to better understand operation strategies for optimizing sediment delivery.

RESEARCH PLAN

This study will involve an integrated field-laboratory-numerical research plan to address the three objectives. The field program will leverage the ongoing field work by Prof. Allison, with joint LSU-Tulane teams. The LSU field plan encompasses spatially distributed cone penetrometer tests to a depth of 2 m (or greater if very soft soils) to map the consolidating sediments and vegetation root strength using the procedure outlined in Jafari et al. (2018). Field visits will occur with the objective to identify the seasonal variation in root strength and degree of consolidation, with targeted field trips before and after flood season. Cores extracted from different ages of splays will be used to measure the low stress compressibility and permeability of sediments, following the test procedure developed by former CSAP student Jack Cadigan. This method combines an instrumented settling column and piezometers with a constant rate of strain device. These properties will serve as inputs into the program PSDDF (primary consolidation, secondary compression, and desiccation of dredged fill). PSDDF uses finite strain consolidation theory to simulate sediment deposition and consolidation. As the sediment settles to form a soil structure, it undergoes self-weight consolidation, which concomitantly loads and consolidates the underlying pre-existing marsh and bay bottom substrate. Model predictions will provide insight into the net gain in elevation from sediment diversions. Cone penetrometer tests will be used to define the root shear strength and hydroperiod relationship (Jafari et al. 2020), stratigraphy (Li et al. 2019), and trajectory of restored wetlands (Harris et al. 2020). The relationship between shear strength and erodibility will be achieved by calibrating cone penetrometer shear strengths with field-validated sediment transport models of an active crevasse splay.

DELIVERABLES AND OUTCOMES

Deliverables include conference presentations, peer-reviewed journal articles, and comprehensive dataset available to scientific communities. A unique dataset of sediment shear strength, compressibility, and permeability relationships will be collected and measured. These data will be used to investigate the erosional processes in multiple sediment diversion receiving basins. Major findings of this project will be presented at the State of the Coast Conference and national/international conferences. At least three peer-reviewed paper will be published based on the research in this project, as evidence by other CSAP students advised by Prof. Jafari (e.g., (Harris et al. 2020); (Harris et al. 2020); (Cadigan et al. 2020)). In 2016, Prof. Jafari received a CPRA CSAP Fellowship to support Brian Harris, who interned with the engineering and operations divisions (interacting with Russ Joffrion, Jas Singh, Greg Mattison, Jacque Boudreaux, and Ignacio Harrouch). Based on his work with CSAP, Brian subsequently received a Department of Defense SMART Scholarship and is now a research scientist in the USACE Coastal Hydraulics Lab at ERDC. His success in bridging coastal geotechnics with wetlands and contacts at CPRA will assist in knowledge transfer between USACE and CPRA. I believe that such kind of successful partnership will continue.

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