Development of a comprehensive engineering design tool to predict and evaluate long term performance of Louisiana coastal restoration and protection projects

Coastal property development, oil and water extraction, global climate change, coastal land subsidence, loss of barrier islands, and other natural and man-made factors have resulted in high rates of wetland loss, water quality degradation, decline in fisheries and reduced storm surge protection in coastal areas in Louisiana and throughout the world. The loss of marshland in Louisiana coastal zones has also exposed significant infrastructure to open water conditions and has degraded the habitat of nearby areas. Published data indicate that coastal Louisiana and the Mississippi river basin have an annual marsh land loss of about 16 square miles. One of the goals towards reestablishing a healthy coastal ecosystem is to rebuild the world's coastal wetlands with river diversion or sediment conveyance projects that will optimally manage and allocate sediments, minimally impact native flora and fauna, and positively affect the water quality. Restoring the marshes through deposition of dredged material from adjoining navigation channels and close by river bed and subsequent reestablishment of emergent wetland vegetation will help to protect the levees and storm protection systems from accumulated damage due to elevated water levels and storm surge forces as well as create a sustainable coastal environment to booster vital economic, social, and recreational opportunities for millions of people. Native or recently deposited in-situ material is mechanically or hydraulically dredged from its location below the mudline in a fresh, brackish, or saltwater environment and transported in pipelines and distributed in the open water areas for marsh renourishment.

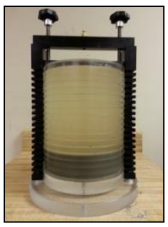
Some of the mathematical models of dredging operation and dredged sediments fate including settlement estimates of the dredged material and foundation soils, that have been designed by U.S. Army Engineer Research and Development Center (ERDC), include (a) Primary Settlement and Desiccation of Dredged Fill (PSDDF), (b) Short-term Fate of Dredged Material Disposed in Open Water (STFATE), and (c) Long term Fate of Dredged Material Disposal in Open Water (LTFATE). Engineering properties and material characteristics of the dredged sediments and foundation soils are input parameters in these mathematical models. Furthermore, current engineering methodologies and mathematical models used to develop the Coastal protection plan, and to predict long term geomorphological characteristics of the fragile eco-system, rely heavily on sediment characteristics obtained from published literature and assumed values from other geographic regions. Although design and construction of several marsh renourishment projects are currently underway in coastal Louisiana, there is a lack of field and laboratory test data evaluating the effects of (a) grain size distribution, (b) salinity, and (c) solid particle concentration on the sedimentation and resuspension characteristics of the dredged sediment material as well as on the time rate of settlement of the suspended solids in the slurry and of the foundation soils in the renourishment areas. Therefore, proper characterization of the dredged sediment is of utmost importance in the correct design of a marsh nourishment project which will contribute to the cost-savings, time-savings, and improved outcomes of any Coastal Restoration project implementation. The proposed research aims at developing a comprehensive engineering design tool to predict and evaluate long term performance of Louisiana coastal restoration and protection projects. This will be accomplished by performing the following tasks:

- **Task #1 – Historical Data Acquisition and Data Gap Analyses**: Existing geotechnical subsurface investigation data and design soil parameters will be gathered from different marsh creation projects. Based on discussion with Mr. Russ Joffrion, P.E. with CPRA, data will be gathered from the following marsh creation projects: PO-33, BA-36, BA-37, BA-39, TE-44, BA-42, BA-43, BA-48, BA-68, PO-04, and TE-72. The data will be used to develop a (a) dredge slurry geotechnical database and (b) foundation soil geotechnical database for sites located throughout the coastal areas of Louisiana. ArcGIS software will be utilized to compile data and analyze the different soil parameters commonly utilized in design of coastal restoration and protection projects.
- **Task #2 – Geotechnical Laboratory Testing on Coastal Sediments:** The proposed research will also study the effects of (a) grain size distribution, (b) salinity, and (c) solid particle concentration on the (i) sedimentation, (ii) re-suspension, and (iii) consolidation characteristics of the dredged material and foundation soils in coastal Louisiana. To perform this study, dredged sediment samples and foundation soil will be collected from different locations throughout south Louisiana during field exploration activities of ongoing projects managed by CPRA. These projects are located in fresh water, salt water, as well as in brackish water environment with different salinity characteristics, an important variable for the study. The dredged sediments and foundation soils obtained from different project locations will be secured properly and transported to the laboratory at the University of New Orleans (UNO) to determine their grain size distribution, water content, specific gravity, and Atterberg Limits. Furthermore, "sedimentation" characteristics of the suspended solids in slurries prepared from the material obtained from the different sources will be determined by performing Column Settling tests in

general accordance with the procedure outlined in U.S. Army Corps of Engineers (1987) Engineers Manual 1110-2-5027 – Confined Disposal of Dredged Material. The "re-suspension" characteristics of the slurry will be evaluated at UNO using a Lick-Shaker developed by Dr. Wilbur Lick. Total Suspended Solids (TSS) of the slurry will be monitored with time as the Lick shaker equipment generates pulses corresponding to bed shear stress of re-suspension. Additionally, the "self-weight consolidation" characteristics of the sediment slurry will be evaluated using a low-pressure consolidation setup at UNO.

Settling Column at UNO

Lick shaker apparatus at UNO



Self-weight consolidation apparatus at UNO

- **Task #3 – Development of a Geotechnical Design Tool:** A three dimensional numerical model will be developed to evaluate and predict the long term performance of a marsh creation project in Louisiana. This new windows-based software will more accurately plan and design a marsh creation project based on previous project performance, and properties of foundation material and dredged slurry. The model will include important natural processes, which affect long-term service life of dredged material placement, and will incorporate (a) primary consolidation, (b) secondary compression, (c) desiccation, (d) resuspension, (e) sea level rise, and (f) natural regional ground subsidence. The model will also be capable of (i) conducting a comparison of estimated versus measured fill settlement readings, and (ii) evaluating the estimated consolidation settlement curve data, consolidation parameters, and consolidation methodology used for the development of the construction marsh fill elevation design. Input from engineers at CPRA and other engineering companies involved in marsh creation project design will be incorporated in the development of the geotechnical design tool. The results from the laboratory testing, described above, will also be used to validate the three dimensional numerical model. Following are some equations that will be used in this numerical model:

$$\left(\frac{\gamma_S}{\gamma_w}-1\right)\frac{d}{de}\left[\frac{k(e)}{(1+e)}\right]\frac{\partial e}{\partial z}+\frac{\partial}{\partial z}\left[\frac{k(e)}{\gamma_w(1+e)}\frac{\mathrm{d}\sigma'}{\mathrm{de}}\frac{\partial e}{\partial z}\right]+\frac{\partial e}{\partial t}=0$$ --------- Primary consolidation equation

$$t=\frac{T\left(\mathrm{H_{dr}}\right)^2}{c_v}$$ --------- Time rate of consolidation equation

$$S_S=\frac{\mathrm{C}_\alpha}{(1+e_0)}(\mathrm{h})\log\left(\frac{\mathrm{t}}{\mathrm{t_p}}\right)$$ --------- Secondary compression equation

$$\Delta W'=CS-\left[\left(C_E'\right)\mathrm{EP}\right]+\left(1-C_D\right)\mathrm{RF}$$ --------- Empirical dessication equation

$$\mathrm{E_{res}}=\frac{\mathrm{a_c}}{\mathrm{T_{res}}\ \mathrm{T_{con}}^m}\left(\frac{\tau_{bed}}{\tau_{cr}}-1\right)^n$$ --------- Empirical resuspension equation

- **Task #4 – Geotechnical Instrumentation of marsh creation area:** The research will also develop comprehensive geotechnical instrumentation plans for ongoing and upcoming marsh creation projects overseen by CPRA. The marsh fill component of a marsh creation project accounts for approximately 70% of the total project cost. The marsh creation fill volume is computed by determining the Construction Marsh Fill Elevation (CMFE) for the proposed marsh fill area. This is the constructed elevation of the dredged slurry material as determined from the geotechnical engineering consolidation estimation based on the geotechnical parameters of the dredge and the underlying soils. However, the current methodology for this total consolidation estimation has not been validated because of the lack of an in-situ geotechnical engineering instrumentation plan. With assistance from Geokon, an instrumentation company, this research will install geotechnical instruments at multiple ongoing marsh creation projects to monitor engineering parameters that influence (i) construction fill elevation and (ii) final fill elevation after multiple years. The parameters that will be captured using this instrumentation plan includes (a) settlement of foundation soil layers, (b) self-weight consolidation settlement of the dredged slurry, (c) initial increase and subsequent dissipation of pore water pressure, (d) changes in stresses within the soil mass, and (e) lateral deformation of the containment dikes or slopes. The data collected from actual marsh creation projects will also be used to validate the three dimensional numerical model. Furthermore, the instrumentation data will be used to calibrate the geotechnical tool and improve the numerical model.

Project Significance and Applicability to CPRA and Coastal Master Plan

The Louisiana Coastal Master Plan objectives reflect the key issues affecting people in and around Louisiana's coast and define what the plan aims to achieve as whole. The objectives seek to improve flood protection for families and businesses, recreate the natural processes that built Louisiana's delta, and ensure that our coast continues to be both a Sportsman's Paradise and a hub for commerce and industry.

The proposed research aims at developing a comprehensive engineering design tool to predict and evaluate long term performance of Louisiana coastal restoration and protection projects. The research project will (a) compile historical geotechnical data and perform Data Gap Analyses of the different soil parameters commonly utilized in design of coastal restoration and protection projects, (b) develop a GIS based database of foundation soil and dredged sediments for use by coastal and geotechnical engineers, (c) perform laboratory testing on new coastal sediments, (d) develop a geotechnical design tool, and (e) develop a geotechnical instrumentation plan for current and future marsh creation projects. The proposed research will offer the following significant contributions to the advancement of coastal science and engineering in Louisiana:

- Improved outcomes: the use of measured and applied consolidation data will allow for more accurate total consolidation settlement estimates for the marsh creation fill areas.
- Reduced time: the design tool will use properties of local Louisiana soils obtained from field exploration and laboratory testing. This will make the design more efficient based on local knowledge and lessons learned from similar projects in Louisiana.
- Lowered costs: marsh creation fill area volumes account for 70% of the total construction cost for marsh creation projects in Louisiana. The geotechnical design tool suggested in this proposal aims at reducing design uncertainty of the total marsh fill area volume. This would potentially result in lower estimated volumes and therefore lower construction costs.

Implementation of the research technology

A potential impact of the proposed research is enhancement of fundamental knowledge and better understanding of physiochemical and hydrodynamic processes occurring in the coastal environment and their long term socio-economic impacts on the coastal infrastructure. If implemented, the research findings will fit within the 2012 CPRA Coastal Master Plan by

- Improvement of Existing Methods and Technologies: The marsh fill component of a marsh creation project accounts for approximately 70% of the total project cost. The marsh creation fill volume is computed by determining the Construction Marsh Fill Elevation (CMFE) for the proposed marsh fill area. This is the constructed elevation of the dredged slurry material as determined from the geotechnical engineering consolidation estimation based on the geotechnical parameters of the dredge and the underlying soils. However, the current methodology for this total consolidation estimation has not been validated based on the lack of an in-situ geotechnical engineering instrumentation plan. However, settlement plates have been authorized during construction.
- Improvement of Project Implementation: This applied geotechnical engineering technology will enable design engineers to more accurately and efficiently determine the required marsh fill area volumes, thus reducing the design engineering task time and contractor risk.

Anticipated Curriculum for the student

The Master of Science in Engineering degree in the department of Civil and Environmental Engineering at the University of New Orleans has the following requirements. To graduate with a Master of Science in Engineering degree students can select between two options: (a) Thesis (Research) option and (b) Non-thesis option. However, for the proposed Sea Grant project, the student will be required to choose the Thesis (Research) option. Applicants should have received a Bachelor's degree in a field of engineering from an ABET accredited engineering program. Applicants for admission to the Graduate School in a master's degree program in engineering are expected to have a grade point average (GPA) of 3.0 for undergraduate work and for all graduate and post-bachelor work. Students applying for admission to the UNO Graduate Program in Engineering will have to submit the scores for the Graduate Record Examination (GRE) prior to being allowed to register for graduate courses in a degree program.

Coursework: For the thesis option, the graduate students must complete 30 hours of graduate work, including at least 15 hours of 6000 level courses and six (6) hours of thesis research credit at the 7000 level. Students will have to complete a maximum of 15 credit hours at the level of 6000. Furthermore, the students are required to take at least 18 semester hours in engineering subjects (excluding thesis research) and the remaining hours may be selected from Engineering, Mathematics, Physics, Business Administration, Biological or Earth Sciences or other specific graduate fields approved by the student's graduate advisor and the College of Engineering. These courses must be at the 4000 level or higher. A list of available (and proposed) courses for the applicant are as follows:

- Coastal Geotechnics
- Sediment Transport and Dredging
- Design of Coastal and Hydraulic Structures
- Coastal processes
- Coastal Geomorphology
- Ocean and Coastal Engineering
- Coastal Restoration and Management
- Advanced Hydrology
- Environmental Geology

The graduate student's advisor will provide counseling on graduate courses, transfer credits, thesis requirements, research topics and elective subjects and serves as the chairman of the committee to conduct the final examination of the candidate for the graduate degree.

Furthermore, to fulfill the requirements of the award, the student will complete an internship of 240 hours at a CPRA office during the period of the CSAP funding.

Current and anticipated funding sources

The proposed research will consist of (a) obtaining dredged material samples from multiple locations throughout Louisiana, (b) transporting the samples to the Soil Mechanics laboratory at UNO, and (b) performing a series of laboratory tests to characterize and evaluate the (i) sedimentation, (ii) re-suspension, and (iii) self-weight consolidation characteristics of the dredged and diverted sediments.

The first and second tasks will be conducted in conjunction with field activities for ongoing projects managed by Dr. Ioannis Georgiou, Associate Professor in the Department of Earth and Environmental Sciences at UNO. The graduate student will visit the different project sites with Dr. Georgiou's students to collect representative dredging material and water and transport them back to the Soil mechanics laboratory at UNO in secured containers. The latitude and longitude of the location from where the samples are being collected will be noted using a hand held GPS unit. Furthermore, the graduate student will accompany PSI's field crew to obtain additional dredged material samples for this project.

The graduate student will use existing equipment in the Soil mechanics laboratory at UNO to conduct a series of tests to (a) comprehensively characterize the dredged material and (b) evaluate the effects of grain size distribution, salinity, and particle concentration on the sedimentation characteristics of the dredged material slurry. Specifically, the following laboratory tests will be performed on the dredged material to complete the above referenced tasks:

1) Natural moisture content determination
2) Specific Gravity
3) Grain size distribution including hydrometer analysis
4) Density of the material
5) Atterberg Limits determination
6) Total solids concentration
7) pH
8) Column settling test (sedimentation of dredged slurry)
9) Re-suspension characteristics (critical bed shear stress determination)
10) Self-weight consolidation tests

It should be noted that the laboratory tests will be performed in general accordance with either ASTM Standard Procedures or US Army Corps of Engineers manual, as appropriate. The department will provide a desktop computer to the graduate student to complete his Masters degree. Therefore, no additional funding will be required to complete the student's research goals. However, if additional funding is required during the student's research program at UNO, I will apply for research grants (in advance) to UNO's Office of Research and Sponsored Programs, Louisiana Board of Regents, or National Science Foundation.

Curriculum Vitae

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Education and Research

- *Post-Doctoral Research Associate, February 2001 -- December 2001*
  Microscale Physiochemical Engineering Center, The University of Akron, Ohio, USA
- *Ph.D., Civil (Geotechnical & Geo-Environmental) Engineering, May 2001.*
  Kansas State University, Kansas, USA
- *M. Tech., Civil (Geotechnical) Engineering, July 1998.*
  Indian Institute of Technology (I.I.T.), Kharagpur, INDIA
- *B.E., Civil Engineering, August 1996.*
  University of North Bengal, INDIA

Professional Experience

- *Assistant Professor in Geotechnical Engineering – Department of Civil and Environmental Engineering, University of New Orleans, New Orleans, Louisiana, August 2011 to Present*
- *Department manager and Regional Geotechnical Engineer, Professional Service Industries (PSI), Inc., New Orleans, Louisiana, October 2003 to December 2011*
- *Geotechnical Project Manager, Geotech Engineering and Testing, Houston, TX, USA, Jan 2002 to Oct 2003*

Research Interests

- Coastal restoration and shoreline stabilization
- Geotechnical and Geo-environmental Engineering
- In-situ and laboratory characterization of coastal deposits
- Coastal infrastructure (levees and floodwalls)
- Soil-Structure Interaction

Engineering Experience related to this Proposal

- **Barataria shoreline restoration project, Port Fourchon, Louisiana**
  (Project geotechnical engineer: responsibilities included characterization of dredged material, slope stability analysis of containment dikes, settlement estimates of containment dikes, settlement estimates of dredged fill and foundation soil using USACE PSDDF software, estimation of cut-fill ratio)
- **Fringe Marsh restoration project, Plaquemines Parish, Louisiana**
  (Project geotechnical engineer: responsibilities included characterization of dredged material, slope stability analysis of containment dikes, settlement estimates of containment dikes, settlement estimates of dredged fill and foundation soil using USACE PSDDF software, estimation of cut-fill ratio)

Awards, Honors, and Fellowships

- 2015 Louisiana Discovery, Integration, and Application (LaDIA) Fellow, Louisiana Sea Grant
- 2014 University of New Orleans Early Career Research Award
- 2014 ASCE ExCEEd New Faculty Excellence in Teaching award
- 2014 ASEE-GSW conference Faculty paper award, "Project-based Education on Sustainability Principles for Engineers," ASEE-GSW annual conference, New Orleans, Louisiana, April 2-4, 2014.
- 2014 ASCE Louisiana section Educator of the Year award
- American Society of Civil Engineers (ASCE) -- Excellence in Civil Engineering Education (ExCEEd) Fellow for 2012

Professional Registration

Registered Professional Engineer (P.E.) – Louisiana, Mississippi, Arkansas, Minnesota, Colorado

Synergistic Activities

- Designated speaker for Louisiana Board of Regents' Speaking of Science (SOS) program for Kindergarten to 12th grade students, K-12 parents and educators, College undergraduate and faculty members.

- Past President, American Society of Civil Engineers – New Orleans branch (2011-2012)
- Chair – Academic committee: Institute for Sustainable Infrastructure (ISI). (2012 to present)
- Member, Engineering Geology and Site Characterization committee, ASCE's Geo Institute –(2011 to present)
- Member, Driven Pile committee, Deep Foundation Institute (DFI) – (2013 to present)
- Participating committee member: ASCE Report Card for Louisiana – Levee Committee
- Participating Member, Engineers without Borders (EWB) – New Orleans Branch.

Selected Recent Publications

- Ghose Hajra, M., Mebust, C., and Mattson, G. (2015). "Settling Characteristics of fine-grained Dredged Sediments used in Louisiana Coastal Restoration and Land Building projects," Proceedings, 2015 International Foundations Congress & Equipment Exposition (IFCEE 2015), March 17-21, 2015, San Antonio, TX
- Ghose Hajra, M., Mebust, C. (2015). "Settling characteristics of fine-grained sediments used in Louisiana coastal land building and restoration projects," Proceedings of the Coastal Sediments 2015 conference, May 11-15, 2015, San Diego, CA
- Ghose Hajra, M., Jensen, R., and Hulliger, L. (2015). "Pile setup and axial capacity gain for driven piles installed using impact hammer versus vibratory system," Proceedings of The 2015 International Foundations Congress & Equipment Exposition (IFCEE 2015), March 17-21, 2015, San Antonio, TX
- Ghose Hajra, M. and Mattson, G. (2014). "Characterization of coastal dredged sediments used in land restoration projects." *Proceedings of 2014 Geo-Congress*: *Geo-Characterization and Modeling for Sustainability*, Feb 23-16, 2014, Atlanta, GA.
- Ghose Hajra, M. and Koob, T. (2014). "Geo characterization and sustainable erosion remediation and restoration measures in south Louisiana navigation channels." *Proceedings of 2014 Geo-Congress*: *Geo-Characterization and Modeling for Sustainability*, Feb 23-16, 2014, Atlanta, GA.
- Ghose Hajra, M. and Scairono, A.J. (2014). "Geo-characterization for design and construction of Gulf Intercoastal waterway – West Closure complex in New Orleans, Louisiana." *Proceedings of 2014 Geo-Congress*: *Geo-Characterization and Modeling for Sustainability*, Feb 23-16, 2014, Atlanta, GA
- Ghose Hajra, M., McCorquodale, A., Mattson, G., Jerolleman, D., and Filostrat, J. (2014). "Effects of salinity and particle concentration on sediment hydrodynamics and critical bed-shear-stress for erosion of fine grained sediments used in wetland restoration projects," Proceedings, Sediment Dynamics from the Summit to the Sea, ICCE/IAHS International Symposium, December 11-14, 2014, New Orleans, LA
- Ghose Hajra, M., and McFadden, D. (2014). "Use of CPT for stability and performance evaluation of Mississippi River Revetment slope in New Orleans" Proceedings of 3rd International Symposium on Cone Penetration Testing, May 12-14, 2014, Las Vegas, NV
- Ghose Hajra, M. and Mattson, G. (2013). "Characterization of Dredged Sediment used in Land Restoration Projects within the Lake Pontchartrain Basin" *Proceedings of 2013 Basics of the Basin*, October 24-26, 2013, New Orleans, LA
- Foust, H. and Ghose Hajra, M. (2010). "Sizing an ultrafiltration process that will treat radioactive waste" Separation Science and Technology Journal, Vol. 45, No. 8, pp. 1025-1032.
- Reddi, L. N., Xiao, M. Ghose Hajra, M., and In Mo Lee (2005). "Physical clogging of soil filters under constant flow rate vs. constant head conditions", Canadian Geotechnical Journal, Vol. 42, No. 3, pp. 804-811.
- Ghose Hajra, M., Mehta, K., and Chase, G.G. (2003). "Effects of humidity, temperature, and nanofibers on drop coalescence in glass fiber media," Separation and Purification Technology Journal, Volume 30, pp. 79-88.
- Ghose Hajra, M., Reddi, L.N., Glasgow, L. A. Glasgow, and Xiao, M. (2002),"Effects of ionic strength on fine particle clogging of soil filters," ASCE Journal of Geotechnical and geoenvironmental Engineering, Vol. 128, No. 8, pp. 631-639.

Outreach (K-12 and STEM Education) Activities:

- Designated speaker for Louisiana Board of Regents' Speaking of Science (SOS) program for Kindergarten to 12th grade students, K-12 parents and educators, College undergraduate and faculty members. Topics include: (1) What does a civil engineer do?, (2) Historic Civil Engineering structures in Louisiana, (3) Restoring Coastal Louisiana – Benefits and Challenges, and (4) Reduce, Reuse, and Recycle towards a Sustainable Future.
- Organizer, Technology Student Association (TSA) sponsored TEAMS (Tests of Engineering Aptitude, Mathematics and Science) Competition – University of New Orleans.
- Committee member, Greenbuild 2014 Tours and Education subcommittee.