BENNETT – RPI
GABR - NCSU
DHS COASTAL RESILIENCE CENTER
RESEARCH PROJECT
YEAR 3 PERFORMANCE REPORT
AND
FINAL PROJECT REPORT

Project Title: Establishment of a Remote Sensing Based Monitoring Program for Performance Health Assessment of the Sacramento Delta

Principal Investigator Name/Institution: Victoria Bennett, Rensselaer Polytechnic Institute

Co-Principal Investigators and Other Partners/Institutions:

- Tarek Abdoun, RPI
- Mourad Zeghal, RPI
- Mohammed Gabr, NCSU
- Brina Montoya, NCSU
- Cathleen Jones, NASA/Jet Propulsion Laboratory
- Joel Dudas, Department of Water Resources, Sacramento, CA
- Mike Sharp, USACE, Vicksburg, MS

Project Start and End Dates: 1/1/2016 – 6/30/2018

Short Project Description ("elevator speech"):

As climate change progresses in the form of continuous land subsidence and rising sea level, the integrity and reliability of flood-control infrastructure have become ever more essential components to homeland security. This project employed a sensor-based (remote sensing with in-ground instrumentation for validation) and model-aided approach to provide engineers and decision makers with systematic tools to assess the health and provide early warning of deteriorating levee systems. The modeling tool integrated the use of measured data with the concept of performance limit states to effectively achieve a performance-based, network-level health assessment of the levee system. An artificial neural network tool, labeled Risk Estimator for Earth Structures (REES), was developed for the transition of the research findings to the end users.

Summary Abstract:

The integrity and reliability of levee systems are essential components of homeland safety and security. The integrity of the levees is not limited to the flood defense aspect, it also contributes to the preservation of water resources, as in the case of the California Delta levees. The distributed levee systems are, however, aging, and their structural health are deteriorating. Assessing the health, predicting the performance, and implementing countermeasures to sustain such performance are challenging tasks for aged civil infrastructure in view of the complexity of the

associated processes of long-term degradation and wear. A validated remote sensing-based approach coupled with analyses to place the monitored data in context of performance parameters is used herein to assess the health of the spatially distributed levee system. This project highlighted the potential of a remote sensing-based monitoring system and health assessment tools that could enable early identification and warning of vulnerable levee or dam sections and enabling prioritized repair work. This project validated the use of satellite imagery to detect rate of deformation of a levee section on Sherman Island, California. Such data were then implemented in a numerical model for estimating the probability of exceeding a performance limit state. This probability provides an indication of the likelihood of damage and the extent of performance failure. The concept of limit state was also used to assess the performance of the Princeville levee, located in the city of Princeville, North Carolina, under the effect of repeated rise and fall of water levels, representing severe storm cycles. Results showed that the increase of storm cycles leads to an increase in probability of exceeding a given performance limit state by several orders of magnitude. While the stability factor of safety obtained from traditional limit equilibrium approach is unaffected by the number of storm cycles. Finally, an artificial neural network tool labeled Risk Estimator for Earth Structures (REES) was developed to facilitate the transition of the research findings to the end users.

REPORT NARRATIVE

1. Research Need:

   Work in this project employed remote sensing (with in-ground instrumentation for validation) and a modeling-aided approach to provide engineers and decision makers with systematic tools to predict performance aspects and assess the health and condition of deteriorating levees. The modeling tool integrated the use of measured data with the concept of performance limit states to effectively achieve a performance-based assessment of the levee system condition and predict future response under severe storm events.

2. Project History:

   The primary objective of this project was to establish a remote sensing-based monitoring program for the performance-based health assessment of a Sacramento Delta levee on Sherman Island. To this end, the satellite images and in-ground GPS sensors were used for displacement measurements of a levee section in the first phase of this project. The study levee section is part of the Whale's Mouth on Sherman Island. This levee was modeled using the large deformation option of the finite element program Plaxis 2D. The model was used to establish the deterministic performance response under maximum water level loading and to investigate the effect of peat decomposition on the deformation response of the levee section. The modeling results were guided and calibrated by the remote sensing data.

   The concept of performance limit states was utilized in the second phase of this project to assess quantitatively the functionality of the levee section under severe storm loading events. The probability of exceeding a prescribed limit state is defined based on the strain or hydraulic gradient levels in potential emerging failure zones. The variation in strength properties and hydraulic conductivity of the levee embankment, as well as the rate of rising water level and duration of flooding, may lead to the progression of the distress state from a low probability of exceeding adequate functionality to the probability of imminent failure. The displacement data collected during these loading and unloading events were used to establish the levee condition assessment on the basis of the performance limit states. An artificial neural network tool labeled Risk Estimator for Earth Structures (REES) was developed for the transition of the research findings to the end users. REES can assess the probability of exceeding a limit state without the need to conduct advanced numerical modeling. It is important to note that the parameter needed for training the REES tool should be the shear strain at key locations within the earth structure (such as the toe of the levee). The scaled conjugate gradient backpropagation training function was implemented in MATLAB to train the REES tool and the modified approach led to lower mean square error.

In the third phase of the project, the concept of limit states was applied to assess the performance of the Princeville levee under the effect of repeated rise and fall of water levels, representing severe storm cycles. These storms were the representative hurricanes Floyd and Matthew. The Princeville levee system is located on the western, southwestern, and northern sides of the Town of Princeville, North Carolina. Results showed that the increase of storm cycles leads to an increase in the probability of exceeding a given limit state by several orders of magnitude. While the stability factor of safety obtained from the conventional limit equilibrium approach is unaffected by the number of storm cycles. The application of the proposed approach to the Princeville levee demonstrated its usefulness for predicting the levee performance under future severe storms.

3. Results:

The work conducted in this project includes the integration of a remote-sensing monitoring program and numerical modeling for the development of a protocol for assessing the integrity of levees. The Sherman Island levee section, within the California Delta region, is used as a catalyst for the development of the proposed technology. Data (from literature and discussion with end users) show the Sherman Island site to be underlain by highly fibrous peat. As shown in Figure 1, satellite images and in-ground GPS sensors were used to collect displacement measurements at the study levee section. These measurements were used for the calibration of a numerical model, using the finite element program Plaxis 2D, with large deformation mesh updating. A fine 15-nodal element was used with the domain having 1961 elements and 15,975 nodes. The locations of three Global Navigation Satellite System (GNSS) in situ stations (GNSS-1, 2 and 3) are shown in Figure 1. Points A and B along the levee landslide side slope are used to compare the data from the numerical model with monitored GNSS records. Flow and deformations boundary conditions were assigned appropriately.

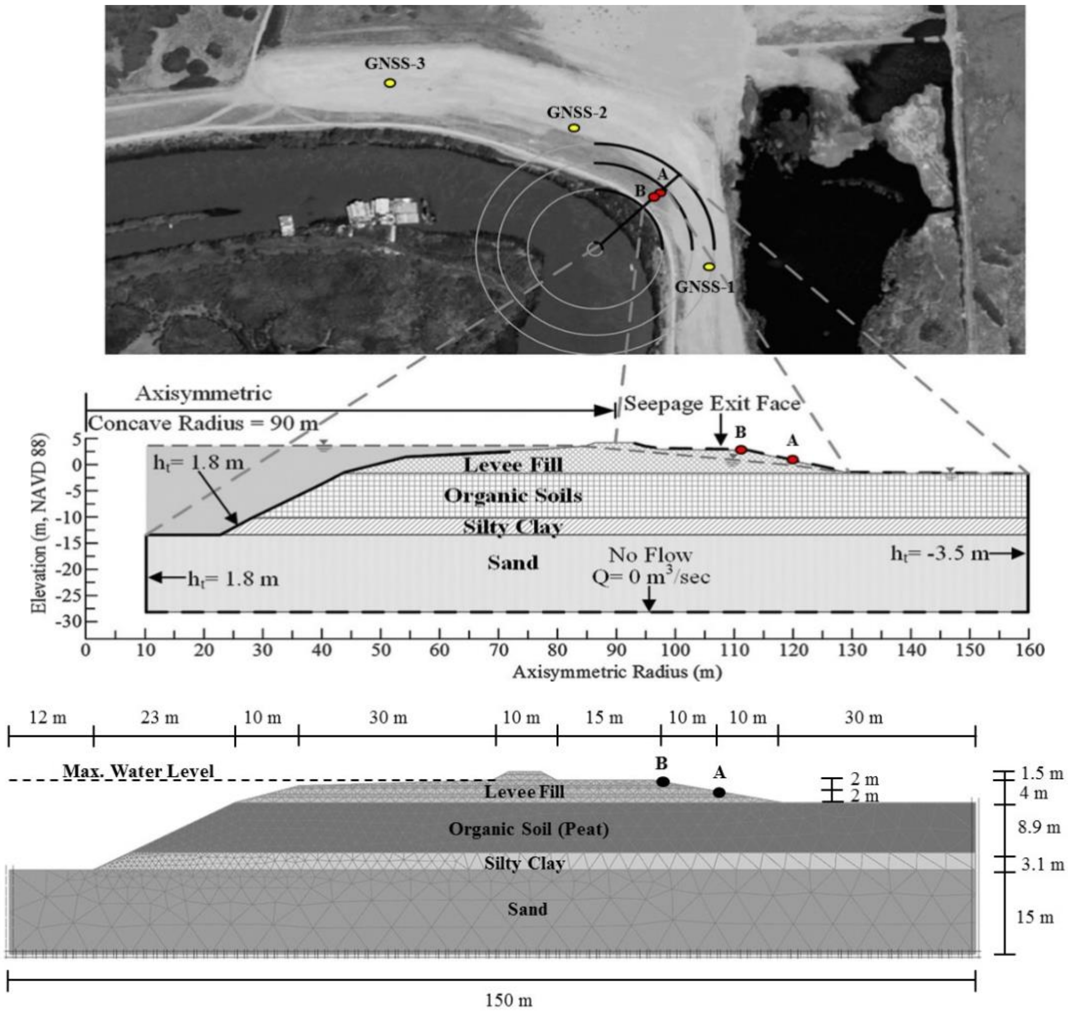

Figure 1. Finite element Plaxis 2D levee mesh and boundary conditions.

Results for vertical displacement (negative sign means settlement downwards) versus time for fibrous peat are shown in Figure 2 for locations A and B on the levee section (designated on Figure 1). These locations were chosen to allow for the model calibration with the available GNSS-1 and GNSS-2 remote sensing records for the Sherman Island levee. These GNSS data were for a one-year period from 4/1/2015 up to 4/1/2016. In this case, the rate of deformation with time show a relatively close trend as the model results falls between the range of measured deformation at points A and B. The GNSS data showed an average of 0.13 m of deformation per year compared to the computed 0.095 per year computed for location A. The rates between the model results and location B were not in agreement but the monitored points are located on the landside side slope; a location consistent with "point A."

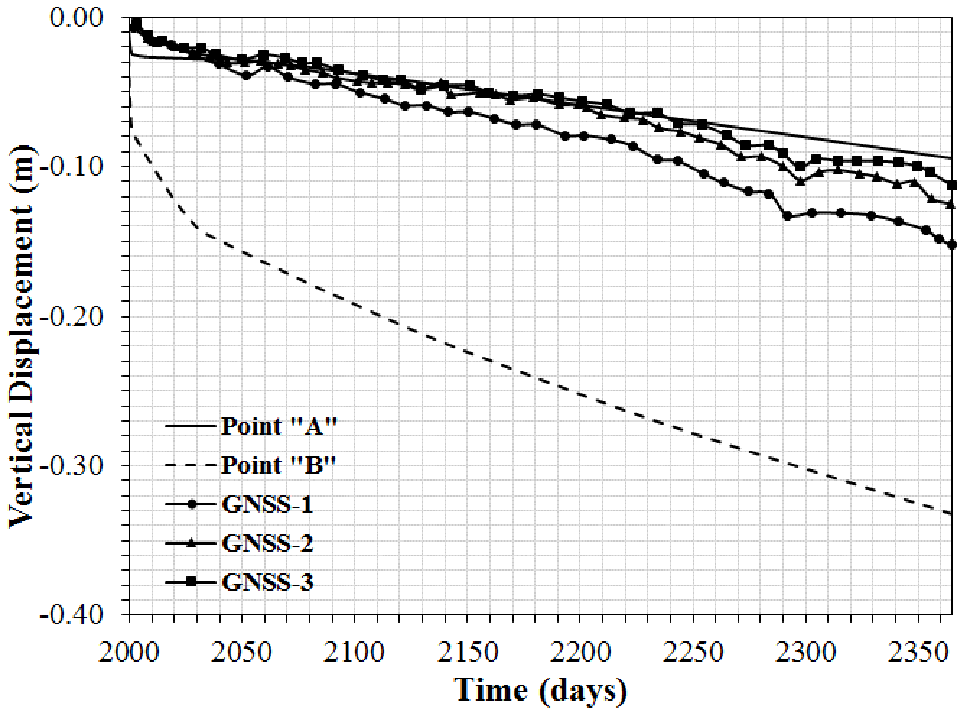

Figure 2. Displacement with time for fibrous peat versus measured data.

The data from the numerical model were used to establish fragility curves providing the probability of exceeding performance limit states including the influence of the peat layer decomposition/aging with time. Peats with three degrees of decomposition, from fibrous (H1-H3) to hemic (H4-H7) to amorphous (H8-H10), were modeled and the corresponding deformation aspects are shown in Figure 3 at 10,000 days for the presumed three-peat decomposition ranges. It is important to note that the Sherman Island levees have been constructed around 1870's. This implies around 147 years of peat layer decomposition for these levees (~50,000 days). Figure 3 shows higher deformation especially at toe location for fibrous (H1-H3) peat compared to H4-H7 and H8-H10 peats. As the peat decomposition level increases, the deformation values decrease as the peat layer experiences less compression with time. Figure 4 shows the fragility curves for the three modeled peat decomposition ranges. In this case, fragility is defined as the probability of exceeding a given limit state, given the decomposition rate of the peat layer with time. It should be noted that LS3 is corresponding to the critical condition, defined as exceeding shear strain of 5% or higher at the landside toe area; an indication of excessive deformation and potentially failure.

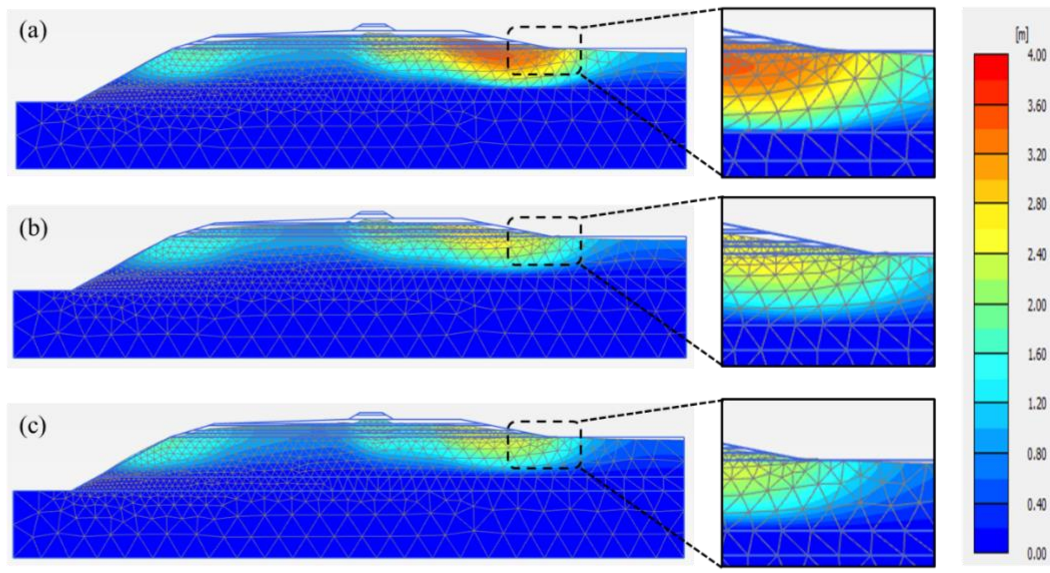

Figure 3. Deformation of levee for a) H1-H3 peat b) H4-H7 peat c) H8-H10 peat at 10,000 days.

As shown in Figure 4, for fibrous (H1-H3) peat, shear strain exceeds a value of 1% (corresponding to LS1) at approximately 270 days. Probability of exceeding LS2 increases around 9100 days when shear strain reaches 2.6% and the probability of exceedance keeps increasing to reach 95% at 50,000 days. For (H4-H7), it takes 10,000 days to reach 100% probability of exceeding LS1 as the shear strain trend for this case does not exceed the 1% value until 1800 days. The assumption of amorphous peat (H8-H10) properties leads to more time (around 300,000 days) to yield an indication of 100% probability of exceedance. The probability of exceeding LS2 for both H4-H7 and H8-H10 peat is very low as the shear strain values are below 3% (LS2) by 50,000 days. Within the context of the modeling, the use of H1-H3 peat (Fibrous) yielded a shear strain value around 3.2% at 50,000 days which corresponds to the lifetime of the Sherman Island levee (Figure 4). This value of shear strain corresponds to 100% probability of exceeding LS1. As peat ages with time, more shear strain will be developed causing the probability of exceeding LS2 to increase as well and therefore increases the vulnerability of the levee and its susceptibility to failure (reaching LS3) under extreme flood events. It is important however to mention that several factors still need to be investigated for more detailed analyses and representative results. These include the time needed in the field for peat to decompose, as the decomposition rate is influenced by temperature, aerobic and anaerobic activity, pH, etc. These analyses nonetheless demonstrate the value of condition assessment of levee health to place its vitality in the context of potential damage to be caused by impending severe weather events.

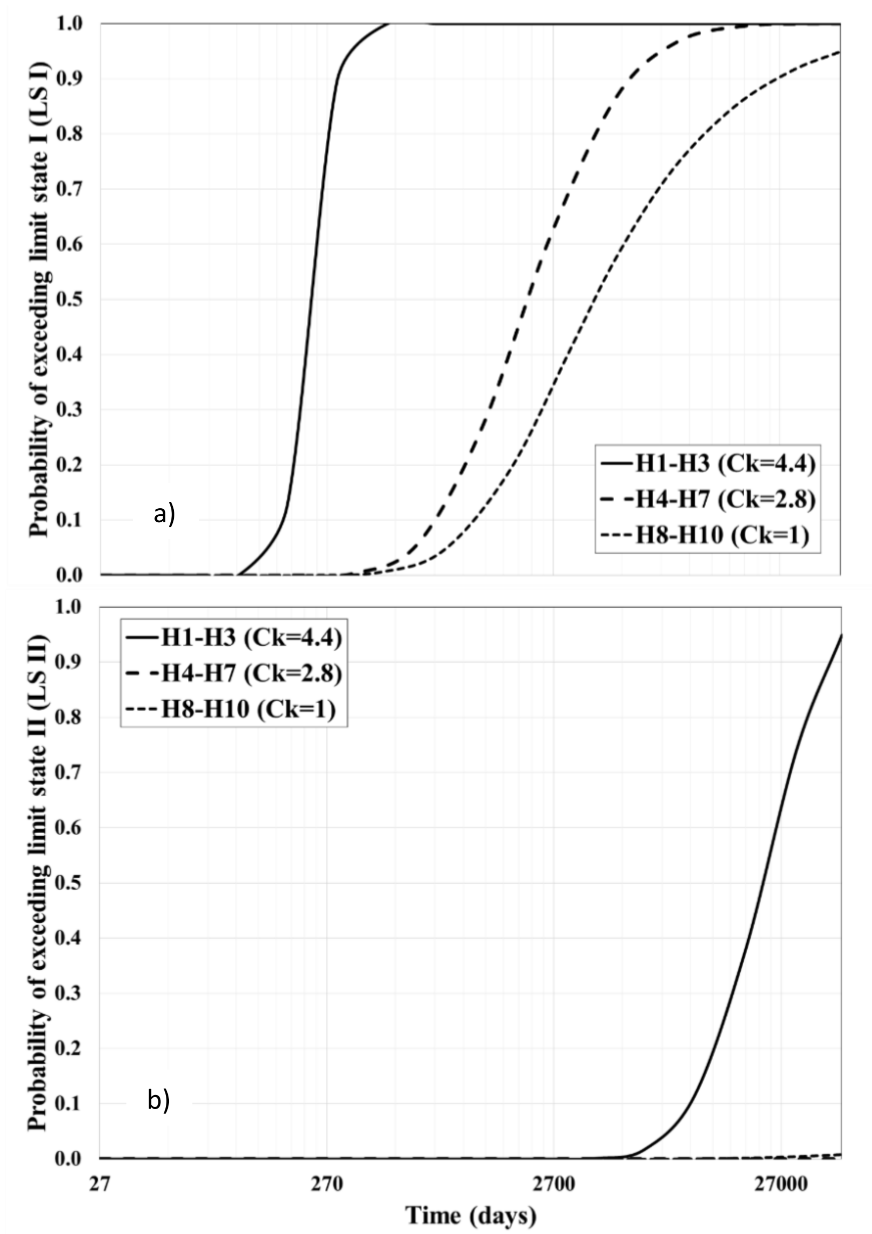

Figure 4. Probability of exceedance: a) LS1 and b) LS2 for shear strain for peat with different degrees of decomposition.

The performance limit state or strain-based approach was also used to assess the probability of exceeding performance limit states of the Princeville levee, North Carolina, due to the effect of repeated rise and fall of water levels, representing severe storm cycles. The Princeville levee system is located on the western, southwestern, and northern sides of the Town of Princeville, North Carolina. The levee was constructed as a flood defense structure for the town which was established in 1865 by freed slaves (and originally named Freedom Hill). The geometry, soil layers, and finite-element mesh of the analyzed Princeville levee section are shown in Figure

5. In a feasibility study, the US Army Corps of Engineers identified the levee section at Station 32+00 as a “critical” since it was overtopped by flooding associated with Hurricane Floyd in 1999 (USACE, 2015). Another major flood event following Hurricane Matthew in 2016 occurred at this levee. Although this time the levee was not overtopped, as was the case following Hurricane Floyd, the town was flooded with 10 ft of water primarily from the ends of the levee system and from an un-gated culvert running underneath the embankment.

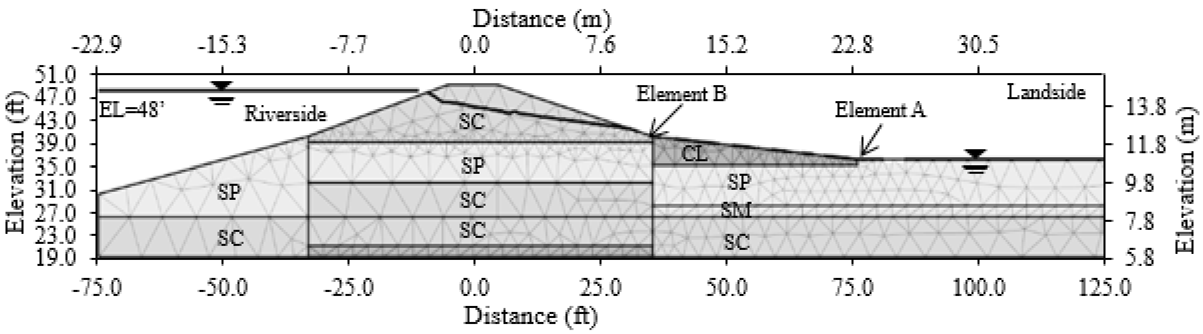

Figure 5. Princeville levee: geometry and discretized mesh.

The Princeville levee was analyzed using a strain-based approach through numerical analyses, strength reduction method (SRM), and the traditional limit equilibrium method (LEM). Four cycles of water level rise and fall, representative of hydrographs observed during Hurricane Floyd and Hurricane Matthew were applied to the levee. The strain-based approach considered the uncertainty of the permeability of the foundation layer and considered the permeability as random variable. The probability of exceeding a given limit state was determined considering 1 and 2 standard deviations (SD) and is presented in Figure 6 as a function of the number of loading cycles. Approximately 68.2% of a given property values are within +/- one SD of the mean and 95.4% are within +/- two SD of the mean value. The probability of exceeding LS1 was near unity in all cases, and therefore is not shown here. The probability of exceeding limit state value is very small after 1 cycle for 1 SD variation, and is not shown in Figure . The FS obtained from the LEM and SRM for the design flood scenario after each storm cycle is shown in Figure . Results indicated that the probability of exceeding a given limit state is increased by 1 to 3 orders of magnitude as the number of storm cycles is increased from 1 to 4 due to the accumulation of shear strain after each storm cycle. The increase in the degree of uncertainty (represented by assuming 1SD versus 2SD in the distribution of the foundation layer permeability) related to permeability of the SP soil layer (Figure 5) also leads to an increase in probability of exceeding a given limit state by 1 to 8 orders of magnitude, depending on the number of storm cycles. If both the loading history and the degree of uncertainty in permeability are considered, this increase would be more significant. For instance, the probability of exceeding LS3 is 1 in 10,000,000 after 4 storm cycles considering 1 SD variability in SP layer permeability. This value is increased to 1 in 20 considering 2 SD variability in SP layer permeability. The deterministic FS remains as 1.61 from the LEM in this case. In parallel, the FS obtained from SRM remains unchanged after 2 cycles. However, it drops from 1.60 to 1.51 after 3 storm cycles (corresponding to a 5.6% decrease) due to the change in the location of the critical slip surface after 2 storm cycles.

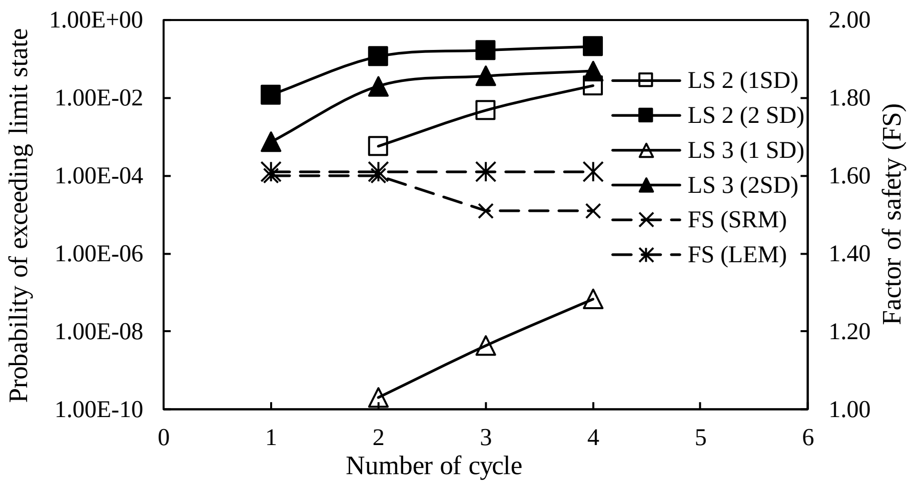

Figure 6. Variation of probability of exceeding limit state and factor of safety with number of storm cycle.

The flood event related to Hurricane Floyd caused more than $6 million in property damage. The Federal Emergency Management Agency (FEMA) allocated $26 million to the town to rebuild after Floyd's floodwaters receded. Figure 7 shows the probability of exceeding LS3 for the Princeville levee, plotted against risk criteria for traditional civil facilities; the risk criteria were presented by Baecher and Christian (2003). A value for 2 SD variation in the permeability of the SP layer was assumed. The probability of exceedance was plotted against the property damage value ($6 million) as a consequence, as was the case following Hurricane Floyd. Figure shows the probability of exceeding LS3 transitioning from ‘acceptable’ region after 1 storm cycle into the ‘unacceptable’ region after 4 cycles. Thus, using the proposed approach developed herein, the characterization of the damage level and the associated probability of occurrence allow for forecasting the consequences of future damage and therefore assist in informing decisions regarding rehabilitation and retrofitting expenditures for mitigating future risk.

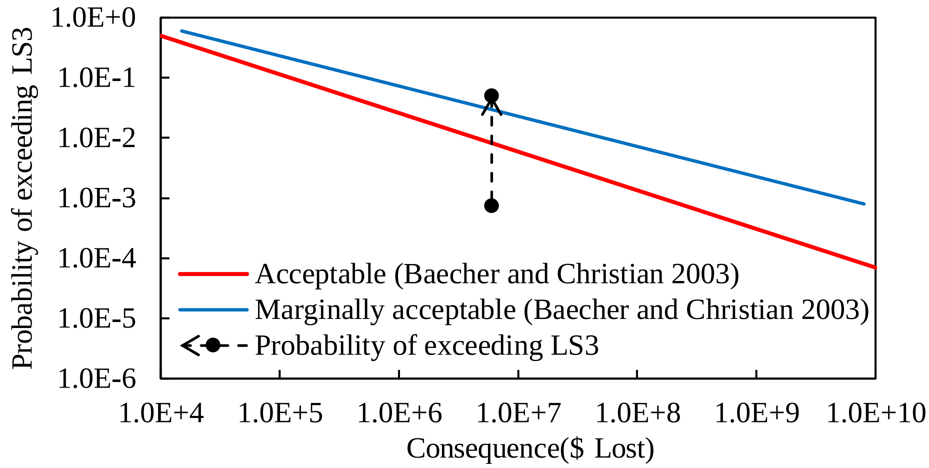

Figure 7. Probability of exceeding LS3 versus consequence curve showing the effect of load history on risk evaluation associated with slope failure.

Risk Estimator for Embankment Structures "REES" tool development

REES was developed based on the Artificial Neural Network (ANN) platform to assess the probability of exceeding a limit state without the need to conduct advanced numerical modeling. A graphical user interface (GUI) tool was developed to implement the ANN model and allows for a user friendly approach for estimating the probabilities of exceeding a given limit states. ***REES*** provides the probability of exceeding the three predefined limit states. Using the probability of exceeding LS III (the ultimate limit state) risk in terms of failure consequence as a function of fatality rates with distance away from the embankment structure is estimated using peak breach discharge (cfs) and 10-year discharge (cfs) values from the FEMA loss of life risk sheet (FEMA risk tool, 2008). However, the risk can be estimated in terms of economics and loss of functionality of critical infrastructure if the "impact" data downstream are available. A user manual was developed to guide the user through operating the tool with examples.

4. <u>End Users and Transition Partners:</u>

The work in this project was focused on developing an innovative platform for monitoring and condition assessment of the California Delta levees. A levee on Sherman Island was used for this purpose. The proposed approach couples the concept of strain-based limit states (LS) with data collection from remote sensing efforts to identify the levees' weak sections and possible impending failure modes. The modeling of the levee sections provide condition assessment of their current state and provide the context through which the monitoring data are viewed to discern gradual and abrupt condition changes. The end users include the following:

i. California's Department of Water Resources (DWR);
ii. US Army Corps of Engineers (USACE);
iii. Federal Emergency Management Agency (FEMA);
iv. US Bureau of Reclamation (USBR); and
v. Levee Safety Boards.

Joel Dudas, Senior Engineer with California's DWR FloodSAFE Environmental Stewardship and Statewide Resources Office, Technical Director of USACE Engineer Research and Development Center (ERDC), and Senior Program Manager at USACE – Risk Management Center, consult with the research team throughout the project and serve as ambassadors for the transition to practice. Joel Dudas is also an incident responder with DWR. Joel McElroy, Superintendent with Reclamation District #341, is responsible for bimonthly levee inspections and is a first responder for levee breaches on Sherman Island. John Paasch, Program Manager for the Delta Flood Emergency Preparedness, Response and Recovery Program, will link our project to others in DWR Emergency Management and California Emergency Management Agency (CalEMA) (http://www.water.ca.gov/floodmgmt/hafoo/fob/dfeprrp/). Head of Levee Condition Assessment Division of Risk Assessment, Mapping and Planning Partners (RAMPP), will help bring the project outcomes from FEMA Region IX to other critical coastal areas such as Louisiana (Region VI) and New York / New Jersey (Region II).

5. Project Impact:

Flood protection infrastructure, such as earthen levees and dams, play a significant role of protecting critical infrastructure during extreme flood events. These levees and dams experience large and rapid fluctuations of water level during extreme flood events. Such events cause major distress to these earth structures and may lead to breaching failure. The failure of such systems can have monumental repercussions, sometimes with dramatic consequences on human life, property and the country's economy. The failure of levees during Hurricane Katrina in 2005 is a highly illustrative example of the criticality of these systems. But this distributed system of national flood-control infrastructure is aging, and its structural health is deteriorating. Assessing the health, predicting the failure, and implementing countermeasures are challenging tasks for any civil infrastructure in view of the complexity of the associated processes of long-term environmental degradation and wear. To efficiently maintain this infrastructure, managing engineers should have access to fully automated programs to continuously monitor, assess the health, and adaptively upgrade these systems. A validated remote sensing-based (i.e., satellite or airborne radar) approach coupled with analyses to place the monitored data in context of performance parameters provides significant impact to sustain the functionality of such a spatially distributed system. This innovative approach serves to identify weak sections and impending failures and can be used as a tool to prioritize maintenance and upgrade efforts on a system level rather than manual inspection of each levee. This project demonstrated the coupling of remote sensing-based monitoring data with analyses and modeling to develop health assessment tools that can enable early identification and warning of vulnerable levee or dam sections enabling prioritized repair work. The advantages of using the concept of performance limit states are demonstrated to quantitatively assess the damage level that a levee system experiences under severe storm loading events. The characterization of the damage level and the associated probability of occurrence allow for the performance of the risk assessment in which the consequences of the damage on the protected assets can be included in the analyses. As such, an informed decision regarding rehabilitation and retrofitting expenditures can be made. An artificial neural network tool labeled Risk Estimator for Earth Structures (REES) was developed as a part of this project which presents a robust and user-friendly way for geotechnical engineers to estimate probabilities of exceeding performance limit states for embankment structures.

6. Student involvement and activities:

- Students involved in research:
    - Amr Helal, Ph.D.-Level Research Assistant, NCSU
    - Rowshon Jadid, Ph.D.-Level Research Assistant, NSCU
    - Chung Nguyen, Ph.D.-Level Research Assistant, RPI

- Degrees attained:
    - Amr Helal, PhD, Civil Engineering (Geotechnical), NCSU - Degree Awarded December 2017
    - Chung Nguyen, PhD, Civil Engineering (Geotechnical), RPI – Degree Awarded August 2018

- Awards:
    - Rowshon Jadid, ***Student Paper Competition Winner***, Dam Safety 2018, Seattle, Washington.
    - Rowshon Jadid, ***Best Oral Presentation,*** 4th Annual Symposium on Geotechnical Engineering by G-I GSO at NCSU 2018.

- Publications:

"***Monitoring and Modeling of Peat Decomposition in Sacramento Delta Levees***" Amr Helal, Victoria Bennett, Mo Gabr, Roy Borden and Tarek Abdoun. Geotechnical Frontiers 2017, Orlando, Florida.

"Deformation Monitoring for the Assessment of Sacramento Delta Levee Performance" Victoria Bennett, Cathleen Jones, David Bekaert, Jason Bond, Amr Helal, Joel Dudas, Mohammed Gabr, Tarek Abdoun. Geo-Risk 2017 (Geotechnical risk from theory to practice), Denver, Colorado.

"Use of remote-sensing deformation monitoring for the assessment of levee section performance limit state" Victoria Bennett, Chung Nguyen, Tarek Abdoun, Amr Helal, Mohammed Gabr, Cathleen Jones, David Bekaert, Joel Dudas. Proceedings of the 19th International Conference on Soil Mechanics and Geotechnical Engineering, Seoul 2017.

"Analysis of Earth Embankment Structures using Performance-based Probabilistic Approach including the Development of Artificial Neural Network Tool" Amr Helal. PhD dissertation, Civil Engineering Department, North Carolina State University, June 2017.

"Deformation-based versus Limit Equilibrium Analyses to Assess the Effect of Repeated Rise and Fall of Water Level on the Stability of Princeville Levee" Rowshon Jadid, Brina Montoya, Victoria Bennett, and Mo Gabr. Dam Safety 2018, Seattle, Washington.

"Effects of Load History on Seepage-Induced Deformation and Associated Performance in Terms of Probability of Exceeding Limit States - Case Study of Princeville Levee" Rowshon Jadid, Brina Montoya, Victoria Bennett, and Mo Gabr. Geo-Congress 2019, Philadelphia, Pennsylvania. (under review)

- Poster:

"Strain-Based Approach versus Limit Equilibrium Analyses: Assessing the Effect of Hydraulic Loading History on the Stability of Princeville Levee" Rowshon Jadid. DHS COE Summit 2018, Arlington, Virginia.

7. Interactions with education projects: Not applicable to this project since the limited budget did not include allowance for a meaningful interaction.

8. Publications

"***Monitoring and Modeling of Peat Decomposition in Sacramento Delta Levees***" Amr Helal, Victoria Bennett, Mo Gabr, Roy Borden and Tarek Abdoun. Geotechnical Frontiers 2017, Orlando, Florida.

"Deformation Monitoring for the Assessment of Sacramento Delta Levee Performance" Victoria Bennett, Cathleen Jones, David Bekaert, Jason Bond, Amr Helal, Joel Dudas, Mohammed Gabr, Tarek Abdoun. Geo-Risk 2017 (Geotechnical risk from theory to practice), Denver, Colorado.

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"Effects of Load History on Seepage-Induced Deformation and Associated Performance in Terms of Probability of Exceeding Limit States - Case Study of Princeville Levee" Rowshon Jadid, Brina Montoya, Victoria Bennett, and Mo Gabr. Geo-Congress 2019, Philadelphia, Pennsylvania. (under review)

9. Tables:

Table 1: Documenting CRC Research Project Product Delivery

Product Name	**Product Type** (e.g., software, guidance document)	**Delivery Date**	**Recipient or End User**
REES "Risk Estimator for Embankment Structures"	Software	June 2018	Federal Agencies looking for an expedient means to assess performance of levees and earth dams

Table 2A: Documenting External Funding

Title	**PI**	**Total Amount**	**Source**
Establishment of Sensor Driven and Model Based Health Assessment for Flood Control Systems	Tarek Abdoun	$61,595	US Army Engineer Research Development Center
New Faculty Startup Funds	Victoria Bennett	$241,500	Rensselaer Polytechnic Institute
10% of annual year salary and associated fringe benefits	Victoria Bennett	$11,780	Rensselaer Polytechnic Institute

Table 2B: Documenting Leveraged Support

Description	**Estimated Total Value**
Spare GPS equipment available from JPL to maintain instrumentation installed in Sherman Island setback levee.	$34,500
Field instrumentation recovered from V-Line Levee site in New Orleans	$25,000

Table 3: Performance Metrics:

BENNETT-GABR PERFORMANCE METRICS

Metric	Year 1 (1/1/16 – 6/30/16)	Year 2 (7/1/16 – 6/30/17)	Year 3 (7/1/17- 6/30/18)
HS-related internships (number)			
Undergraduates provided tuition/fee support (number)			
Undergraduate students provided stipends (number)			
Graduate students provided tuition/fee support (number)	2	3	
Graduate students provided stipends (number)	2	3	
Undergraduates who received HS-related degrees (number)			
Graduate students who received HS-related degrees (number)		2	
Graduates who obtained HS-related employment (number)			
SUMREX program students hosted (number)			
Lectures/presentations/seminars at Center partners (number)	1	1	2
DHS MSI Summer Research Teams hosted (number)			
Journal articles submitted (number)		0	
Journal articles published (number)			
Conference presentations made (number)	2	3	2
Other presentations, interviews, etc. (number)	1	3	
Patent applications filed (number)			
Patents awarded (number)			
Trademarks/copyrights filed (number)			
Requests for assistance/advice from DHS agencies (number)			
Requests for assistance/advice from other agencies or governments (number)	4	2	2
Total milestones for reporting period (number)	3	3	3
Accomplished fully (number)	3	2 (REES being updated)	3
Accomplished partially (number)		1	
Not Accomplished (number)	0	0	0

10. Year 3 Research Activity and Milestone Achievement:

Research Activities and Milestones: Final Status as of 2018
Reporting Period 7/1/2017 – 6/30/2018

Research Activities	Proposed Completion Date	% Completed	Explanation of why activity/ milestone was not reached
Task d. Probability of Exceeding Limit State and Uncertainty	6/30/2017	100%	
Task e. Field Comparison	12/31/2017	100%	
Research Milestones			
Establishment of Levee Section fragility in terms of probability of exceedance versus flood cycle and level	6/30/2017	100%	
Establish the coupled model-monitored data approach as a means to identify vulnerabilities of the levee section studied herein.	12/31/2017	100%	

11. Year 3 Transition Activity and Milestone Status:

Transition Activities and Milestones: Final Status as of 2018
Reporting Period 7/1/2017 – 6/30/2018

Transition Activities	Proposed completion date	% completed	Explanation of why activity / milestone was not reached
Submit a Journal paper documenting the findings of the 2-year study	12/31/2017	50%	Delay in calibrated model of levee section with accurate numerical description of section response shifted timeline in paper submission
Transition Milestones			
Successful demonstration of the coupled model-monitored data for identifying vulnerabilities of the levee section with variation in reservoir level and number of flood cycles	12/31/2017	100%	