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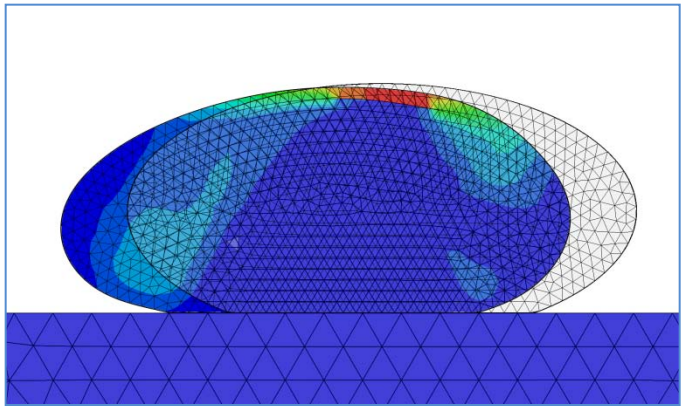
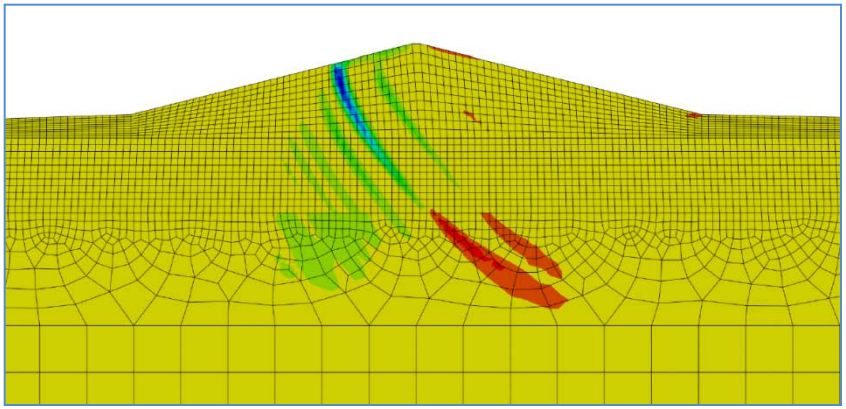
Innovative Component Design and Retrofit of Critical Civil Infrastructure





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DIEM ■ Natural Hazards, Coastal Infrastructure & Emergency Management ■

Based at The University of North Carolina at Chapel Hill

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Project Overview

Geotubes Failure (Galveston, TX)
Photo by Dr. M. Overton

Component Design-Coastal Protective Structures

Need for Innovations:

- Upgrade Engineering Loading Functions
- Address Multimodal Loading Conditions
- Expedite Repair and Rehabilitation of Damaged Infrastructure

Gaps in the literature:

- Wave Action
- Multiple Cycles of Rapid Rise and Fall of Water
- Deformation-Based Limit States for Earth Structures
- Stress History of Engineering Properties of Earth Structures

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Project Relevance to DHS Mission

Research findings support the goal of "DHS Mission 5, Ensuring Resilience to Disaster" by :

- ***Establishing Critical Loading Functions***
- ***Defining Performance Limit States***
- ***Assessing Vulnerability of Protective Earth Structures***
- ***Investigating Retrofit Technologies For Resilience Responses***

State and Federal Government Agencies and Private Consultants Can Utilize Research Findings for :

- ***Upgrade Code for Representative Structural Response***
- ***Mitigate Structural Damage Caused by Severe Storms***
- ***Effectively Distribute Resources***

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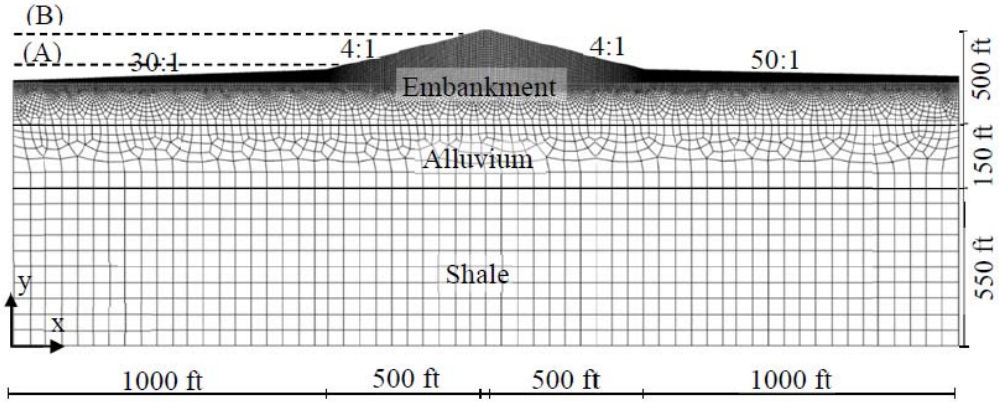
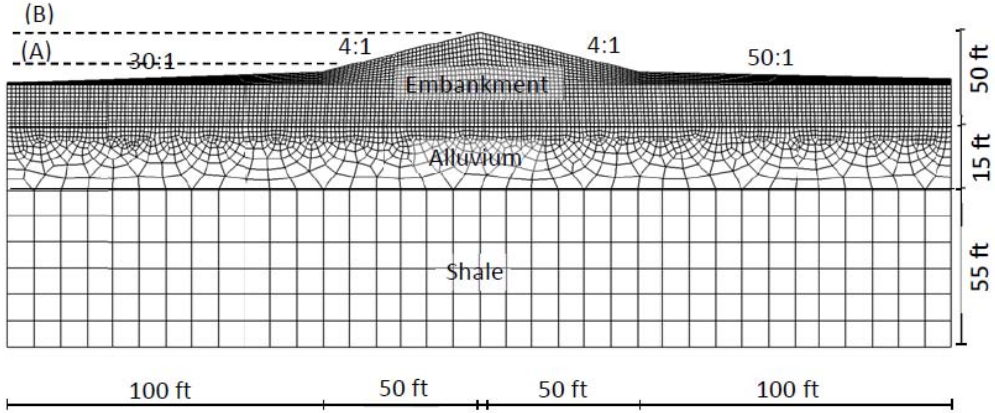
Technical Approach

- ❑ *Finite Element Approach*
- ❑ *Coupled Deformation-Seepage Nonlinear Numerical Model*
- ❑ *Saturated-Unsaturated Initial Conditions*



- ❑ 75,000 Nodes and 24,000 Elements
- ❑ Water Rise= 80 ft
- ❑ 1-2 days Run Time



- ❑ 20,000 Nodes and 6,600 Elements
- ❑ 1/10th Scale of the Original Model
- ❑ Water Rise= 8 ft
- ❑ 6-hr Run Time

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Technical Approach

- ***Definition of Performance Criteria Corresponding to Various Limit States***
  - ***Horizontal Deformation***
  - ***Plastic Zones and Shear Strain***
  - ***Seepage Gradient***
  - ***Water Retention Capacity***
- ***Correlation of Different Performance Criteria to Limit States I , II and III***

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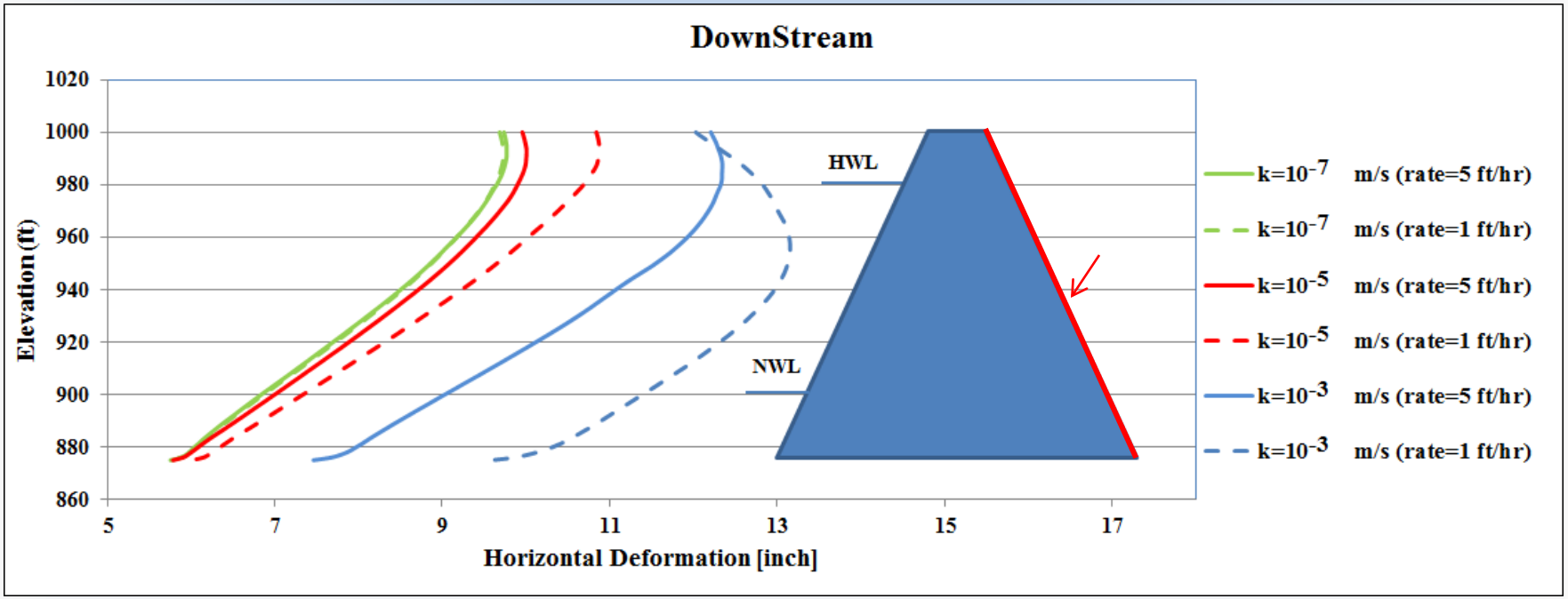
Current Status

Coastal Protective Structures:

- ***Establishing the loading condition with storm surge***
- ***For relatively high hydraulic conductivity ($k = 10^{-5}$m/s and higher), water rising rate shows an impact***



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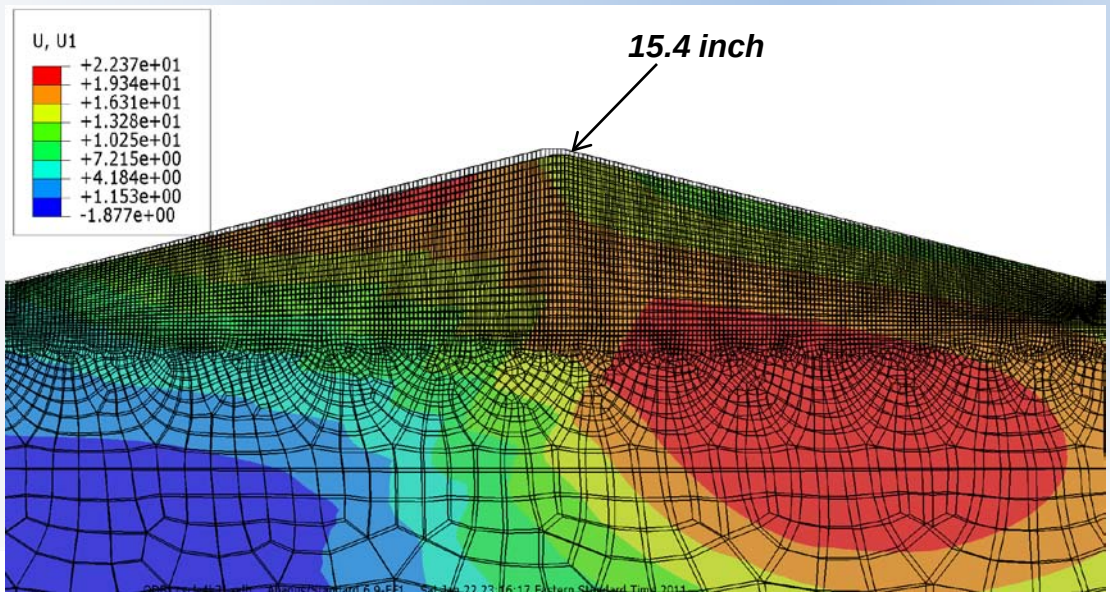
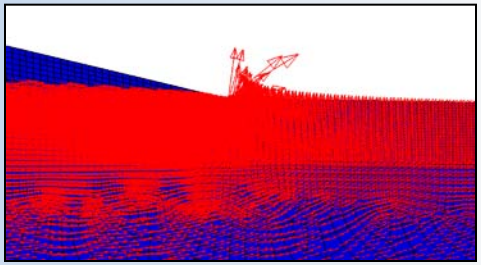
Current Status

Coastal Protective Structures:

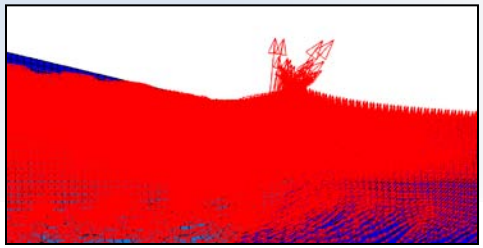
- ❑ ***Development of Conceptual Mechanistic Failure Modes***
  - ❑ ***Structure's water retention capacity is impacted by the level of deformation.***
  - ❑ ***Defined three limit states describing performance levels to quantify such a response***



Water Level=940 ft



Water Level=980 ft



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Current Status

Coastal Protective Structures:

- ***Coupled Deformation-Seepage Analysis with Initial Unsaturated Conditions***

- ***As water rises in a reservoir, horizontal deformation increases***

- ***Water impounding capacity then changes with the embankment deformation level***

- ***Structure can be at Limit State I or II or III based on initial water level, rate of water level rise, and past history of the structure (Cycles)***

- ***Probability of exceeding each limit state based on uncertainties of soil parameters is estimated from a modified risk-based analysis***

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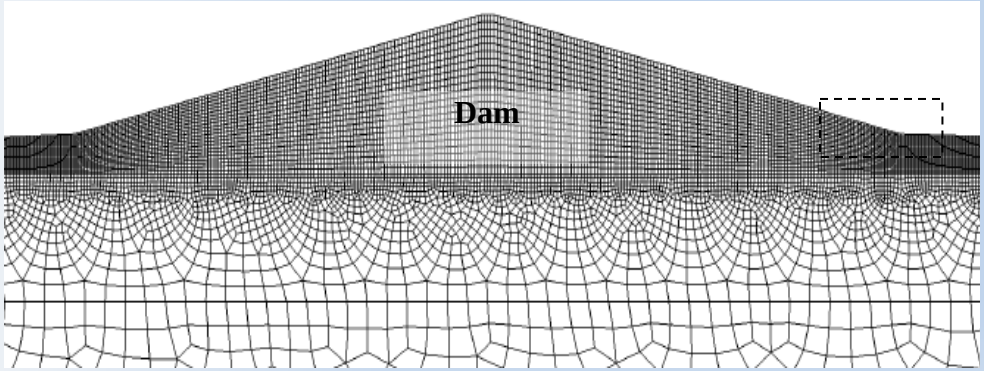
Current Status

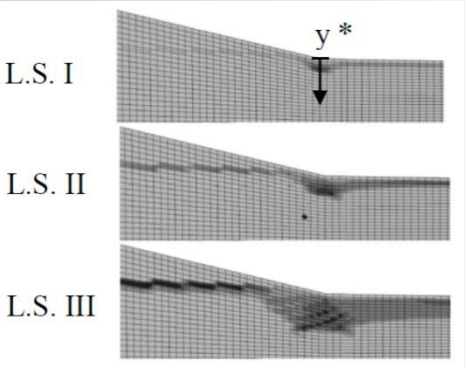
Progression of Plastic Zone with Rising Pool Water Level ⬇

Pore Pressure Distribution with Rising Pool Water Level ⬆

Current Status

- *Three limit states:*
  - *Limit State I: Structure fully maintains its functionality;*
  - *Limit State II: Onset of development of plastic shear zone and expansion of high seepage gradient zones*
  - *Limit State III: Shear bands are fully developed with a high seepage gradients*





- *Zones of high gradients progressively increase at the toe with transition to a higher limit state.*

- *Based on the deformation levels, the probability of exceeding a given limit state is estimated, and a simplified probabilistic approach is implemented.*

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Technical Approach

❑Probability of Exceeding each Limit State

Calculating Probability of Exceeding Limit States [1 pcf=16 kg/m^3]

Friction Angle					L.S.I (S_1=2.5 in)		L.S.II (S_2=5 in)		L.S.III (S_3=10 in)	
Soil Type	μ	σ	μ+/-σ	S (in)	N=S_1/S	ΔN	N=S_2/S	ΔN	N=S_3/S	ΔN
Embankment	27.1	2.56	29.66	10.0	0.2500	0.0119	0.5000	0.0238	1.0000	0.0476
			24.54	10.5	0.2381		0.4762		0.9524	
Alluvium	18.0	3.93	21.92	10.5	0.2381	-0.0046	0.4762	-0.0092	0.9524	-0.0185
			14.08	10.3	0.2427		0.4854		0.9709	
Shale	20.8	5.57	26.37	10.3	0.2427	0.0023	0.4854	0.0047	0.9709	0.0093
			15.23	10.4	0.2404		0.4808		0.9615	

	L.S. I	L.S. II	L.S. III
Standard Deviation	0.0065	0.0130	0.0260
Mean	0.2420	0.4840	0.9680
C.O.V.	0.0268	0. 0268	0. 0268
β	-34.874	-17.841	-0.8078
R=Φ(β)	0.000	0.000	0.210
P(E.L.)=1- R	1.000	1.000	0.790

Notations:
μ=Expected value of friction angle/unit weight
σ=STANDARD deviation of friction angle//unit weight
L.S. i=Limit State i
S=Horizontal deformation
N=Normalized deformation
R=Reliability
C.O.V=Coefficient of Variation
β=Reliability index
P(E.L.)=Probability of exceeding the limit state

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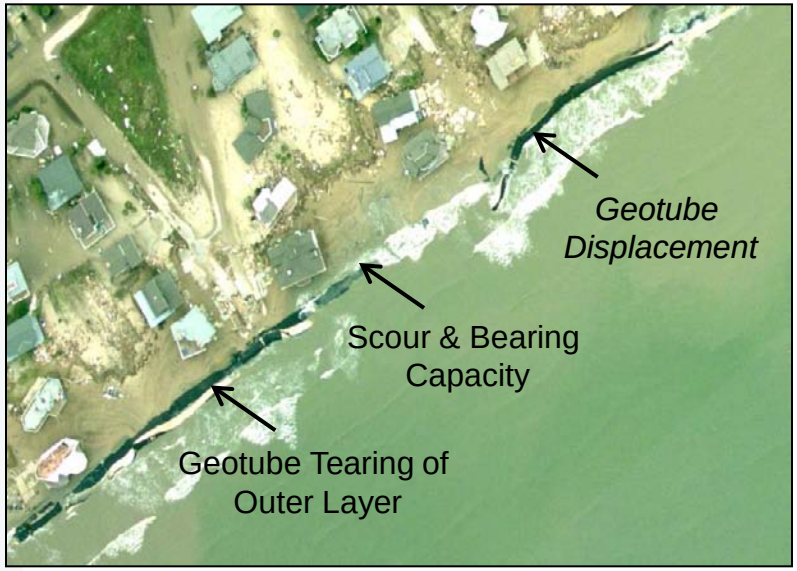
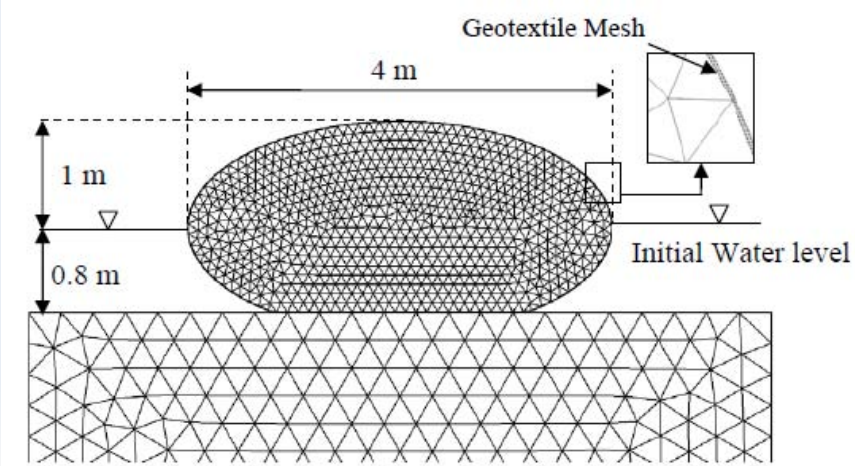
Current Status

Geotube Failure Under Wave Loading:

- ❑ *External and Internal Stability*
- ❑ *Limit Equilibrium versus Deformation-Based Approach*
- ❑ *Effect of Material Properties on:*
  - ❑ *Limit Equilibrium Stability*
  - ❑ *Deformation Stability*
  - ❑ *Mobilized Tension in Geotextile*

No. of Elements: 6200
No. Nodes: 5200
Runtime: approximately 10 hrs





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Current Status

Limit Equilibrium:

- ❑ ***Sliding***
- ❑ ***Overturning***

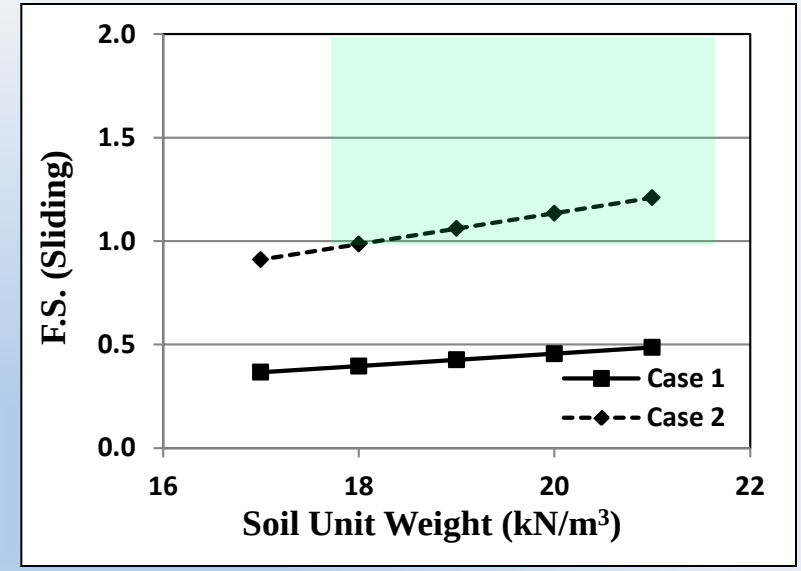
❑***Numerical Model:***

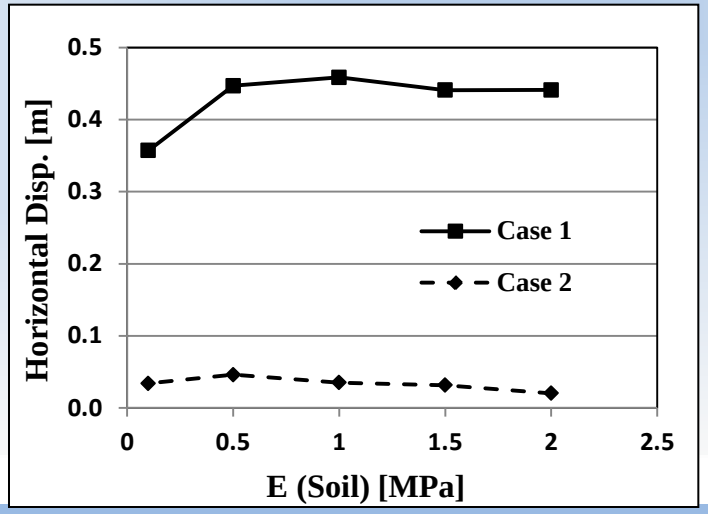
❑***Soil Elasticity Modulus***

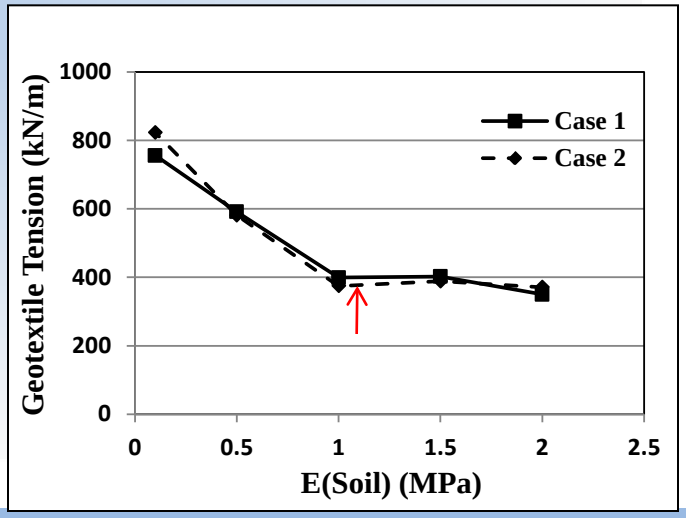
❑***Soil Unit Weight***

❑***Geotextile Elasticity Modulus***

❑***Interface Friction***







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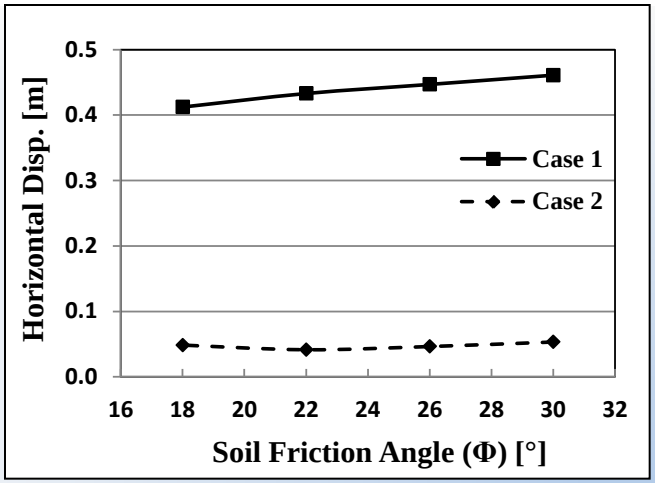
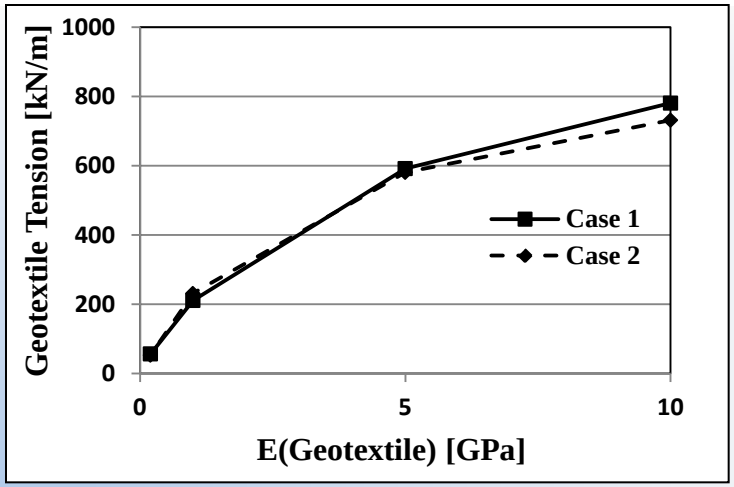
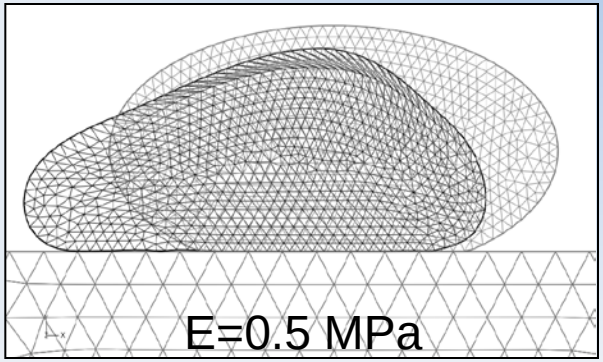
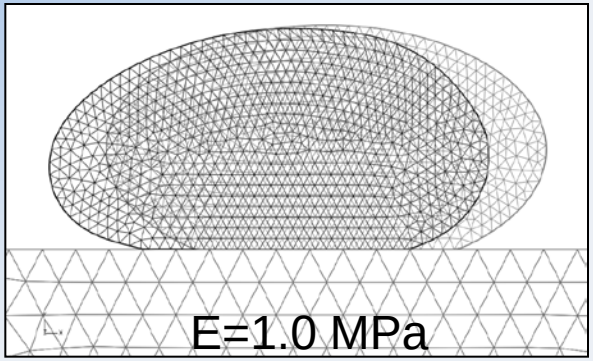
Current Status





- ***Effect of Soil Friction Angle***
- ***Effect of Geotextile Elasticity Modulus***





- ***Increasing contact Length***

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Next Steps

Proposed Tasks :

Establishment of status of the earth structure subjected to series of storm loading as opposed to a single event

Extending the limit state concept to correlate internal behavior of embankment dams to observable matrics that can serve as a warning sign

Incorporating of advanced materials to minimize damage, possibly alter failure mode for a sustainable functionality

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Expected Products

Publications :

- *Khalilzad, M. and Gabr M. A., "Deformation-Based Limit States for Earth Embankments", Paper accepted to Geo-Frontiers 2011. Dallas, Texas, USA March 13 - March 16, 2011*
- *Gabr, M. A., Brizendine , A. L. and Khalilzad, M., "Effect of roots on the Soil Hydraulic Conductivity at Four Levee Sites," Paper prepared for submission to the ASCE Journal of Geotechnical and Geoenvironmental Engineering.*
- *Khalilzad, M. and Gabr M. A. "A numerical Study on Geotubes Behavior Under Strom Loading," Paper prepared for Geo-Risk 2011 Atlanta, Georgia, USA June 26 - 28, 2011*

Presentations:

- *Presentation at Second Annual Meeting for Natural Disasters, Coastal Infrastructure and Emergency Management (DIEM), Chapel Hill, North Carolina, February 17th, 18th 2010*
- *Poster Presentation: "Geotubes Behavior in Galveston during Hurricane IKE," Water Resources and Environmental Engineering Spring Symposium, March 13th, 2009, North Carolina State University."*
- *Poster Presentation " Performance Levels of Earth Embankments," The Third Annual DHS University Network Summit, March 2011, Washington DC*
- *Invited Presentation "Stability of Geotubes and Research Needs" the 2008 Geotextile Tubes Workshop, Starkville, MS. This presentation was sponsored by Southeast Regional Research Initiative (SERRI).*

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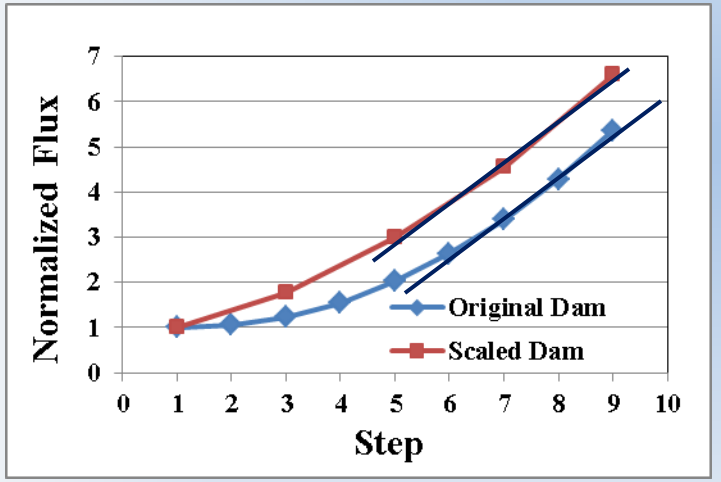
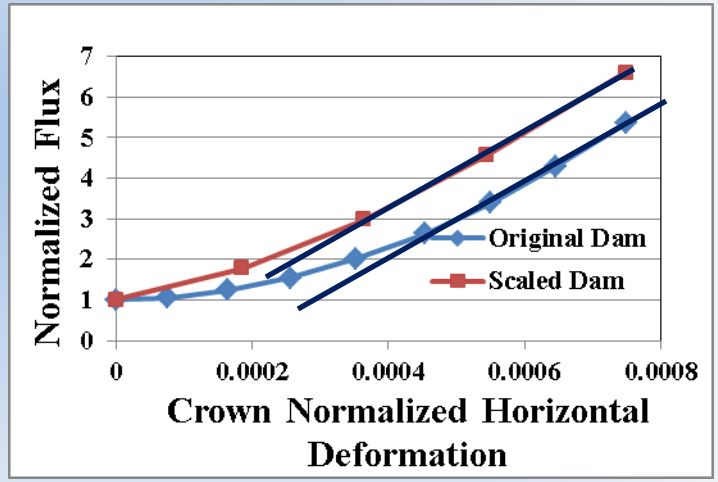
Current Status

- ***Generalizing Limit States:***
  - ***Similar trends have been observed for the dam in original size and the scaled dam.***
  - ***Current effort is focused on more ABAQUS runs to correlate these trends.***



Y axis: Flux normalized to flux at step 1,
X axis: Increase of water elevation normalized to final increase in water elevation.



Y axis: Flux normalized to flux at step 1,
X axis: Horizontal Deformation of the crown normalized to squared of dam height

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Thank you

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