Numerical Simulation of Performance of Pavement Structures with and without Wicking Geotextile

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INTRODUCTION

Excess water within pavement structures is the major cause of deteriorations. The existing subsurface drainage systems can only drain "free" water, but not capillary water. Conventional treatments are not effective in dealing with excess water induced deteriorations. A new wicking geotextile has the potential to dehydrate the road embankment and improve the long-term performance of the pavement system. This research aims at exploring the working mechanism of the wicking geotextile, quantifying the benefits of via numerical simulations, and incorporating the benefits into the existing pavement design.

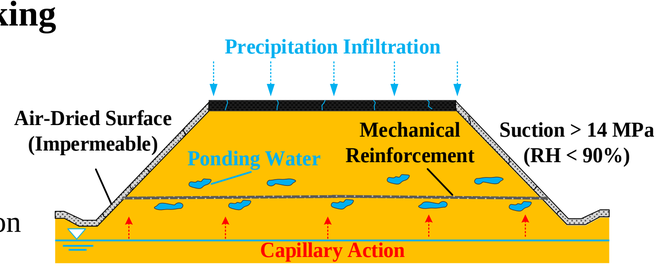
PROBLEM STATEMENT

Adverse Effect of Water

- Pothole
- Land Dropoff
- Frost Heave

Conventional Treatments NOT Working

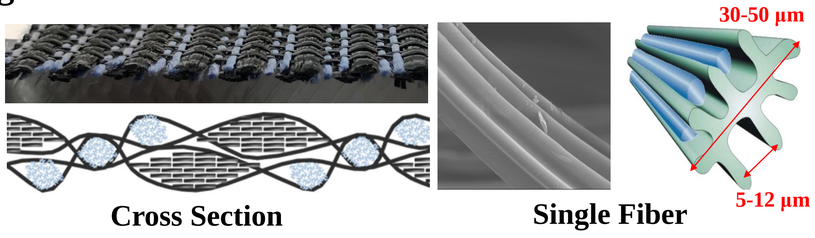
- Good-Quality Material:
  - ✓ Expensive and not readily available
- Mechanical Reinforcement
  - ✓ Benefits devastate under unsat. condition
  - ✓ Excess water accumulation



Capillary Break Effect

Proposed Solution: Wicking Geotextile

- Dual-Function Geotextile
  - ✓ PE fiber: reinforcement
  - ✓ 4DG nylon fiber: drainage
- Drain Both "Free" Water and Capillary Water
- Subsurface Drainage Design
  - ✓ Sustainable
  - ✓ Cost-effective

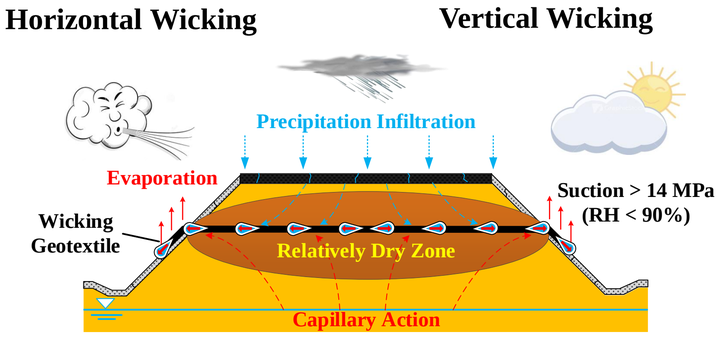


Cross Section Single Fiber

Horizontal Wicking Vertical Wicking

Objectives:

- Understand Working Mechanism
- Quantify Engineering Benefits
- Incorporate into existing design methods



Subsurface Drainage with Wicking Geotextile

MATERIAL CHARACTERIZATIONS

Summary of Material Characterizations

		Soil		Wicking Geotextile		Interactions
Mechanical Properties		Resilient Modulus Test		Wide-Width Tensile Strength Test (from Specification)		Large-Scale Direct Shear Test
Hydraulic Properties	Hold Water	SWCC	Pressure Plate	GWCC	Capillary Rise test	Suction Controlled Oedometer Test (AEV)
					Pressure Plate Test	
			Salt Concentration		Salt Concentration Test	
	Trans. Water	Constant Head Test		Constant Head Test		Water Vapor Transmission (WVT)

Laboratory Characterizations of Soil, Geotextile, and Their Interactions

NUMERICAL MODEL

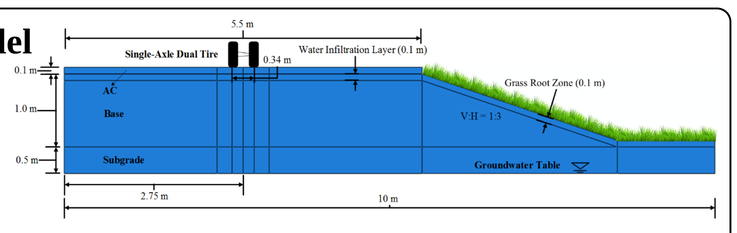
Coupled Hydro-Mechanical Model

$$(\lambda+G)\frac{\partial \varepsilon_v}{\partial x}+G\nabla^2 u-(3\lambda+2G)\alpha\frac{\partial(-u_w)}{\partial x}+X=0$$

$$(\lambda+G)\frac{\partial \varepsilon_v}{\partial y}+G\nabla^2 v-(3\lambda+2G)\alpha\frac{\partial(-u_w)}{\partial y}+Y=0$$

$$(\lambda+G)\frac{\partial \varepsilon_v}{\partial z}+G\nabla^2 w-(3\lambda+2G)\alpha\frac{\partial(-u_w)}{\partial z}+Z=0$$

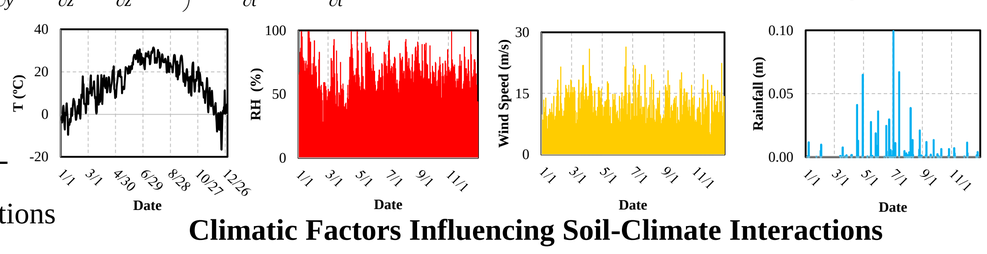
$$\frac{1}{\gamma_w}\left(\frac{\partial}{\partial x}(k\frac{\partial(-u_w)}{\partial x})+\frac{\partial}{\partial y}(k\frac{\partial(-u_w)}{\partial y})+\frac{\partial}{\partial z}(k\frac{\partial(-u_w)}{\partial z}+1)\right)=m_1^w\frac{\partial\sigma_m}{\partial t}+m_2^w\frac{\partial(-u_w)}{\partial t}+S$$



Numerical Model Geometry

Challenges

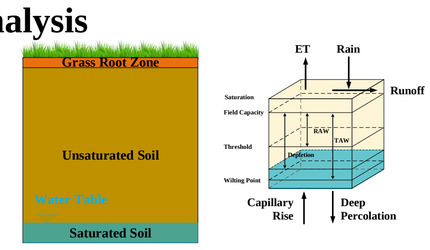
- Nonlinearity
- Soil-Vegetation-Climate Interactions

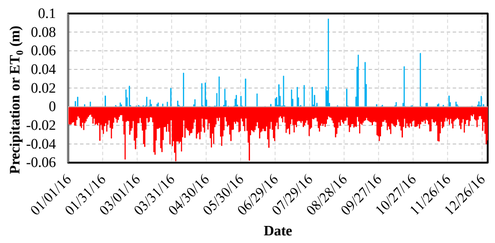


Climatic Factors Influencing Soil-Climate Interactions

Water Balance Analysis

- BC at grass layer
- Control amount of water in/out of soil

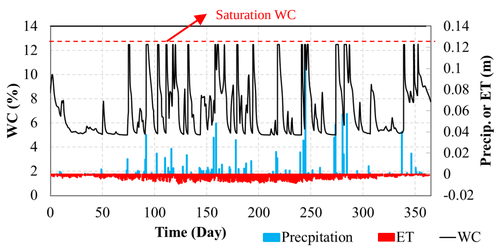




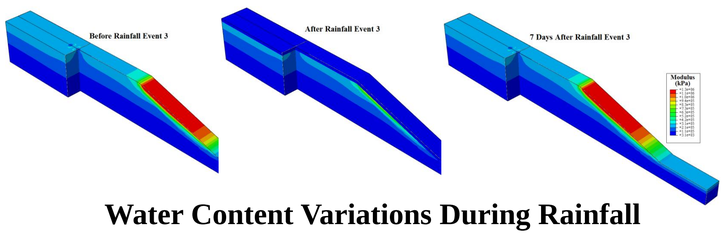
Water Balance Analysis Considering Climate Effect

Simulation Results

- Water content variations

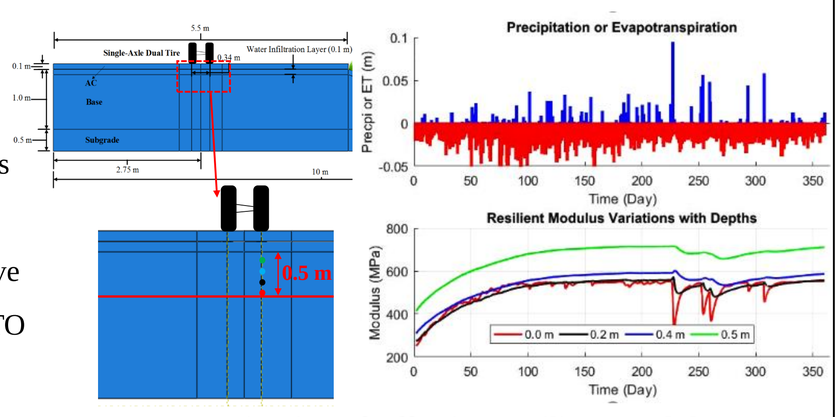


- Water content contours



Water Content Variations During Rainfall

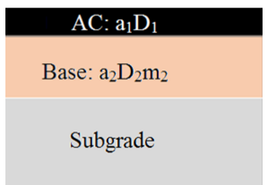
- Resilient modulus variations
  - ✓ Daily resilient modulus
  - ✓ Effective resilient modulus throughout the year
  - ✓ Accurate and representative
  - ✓ Critical inputs for AASHTO 1993 design guideline



Determination of Effective Resilient Modulus

INCORPORATION INTO EXISTING DESIGN METHODS

AASHTO 1993 Design Guideline



$$\log_{10}(W_{18})=Z_r\times S_0+9.36\times\log_{10}(SN+1)-0.2+\frac{\log_{10}\left(\frac{\Delta PSI}{4.2+1.5}\right)}{0.4+\frac{1094}{(SN+1)^{5.19}}}+2.32\times\log_{10}(M_R)-8.07$$

Design Volume Reliability Pavement Structure Performance Evaluation Subgrade Condition

- Calculated E_2 as input
- Determine a_2
- Determine layer thickness D_2

$SN = a_1 D_1 + a_2 D_2 m_2$

SN = structural number
a_i = layer coefficient (stiffness)
D_i = thickness of layer
m_i = drainage coefficient

For Base Course:

$$a_2 = 0.249\log_{10}(E_2) - 0.977$$

Effective Resilient Modulus from Simulation Result

Case Studies

Cases	Effective M_R (MPa)	Change (%)	Layer Coefficient, a_2	Base Thickness D_2 (in)	Thickness Reduction (m)
Designed (WC=8.5%)	293	-	0.175	17 in	-
No Wicking Geotextile	226	↑25.60	0.147	21 in	6 in
With Wicking Geotextile	368	↓61.33	0.200	15 in	

Field Observations

May 12, 2010 May 24, 2011 Beaver Slide, Alaska

Dalton Highway 197-209

July 20, 2016 July 20, 2017 Parks Highway, Alaska

CONCLUSIONS

This research studies the possibility of using a wicking geotextile to dehydrate road embankment using numerical simulations. Laboratory tests were performed to characterize the mechanical and hydraulic properties of soil, geotextile, and their interactions. Then, a coupled hydro-mechanical model was proposed to simulate the soil-vegetation-climate interactions. The pavement performances with and without the wicking geotextile were evaluated. A more accurate and representative effective resilient modulus value could be determined, which could be used as a critical material input in the AASHTO 1993 design guidelines. Base on the case studies, by using the wicking geotextile, the resilient modulus increased by 87% and the base course thickness can be reduced from 21 in to 15 in.

ACKNOWLEDGEMENTS

Missouri S&T

GRI GEI GSI GII GAI GCI Geosynthetic Institute

TenCate materials that make a difference