GSP 300

PanAm Unsaturated Soils 2017

Plenary Papers

Papers from Sessions of the
Second Pan-American Conference
on Unsaturated Soils

Dallas, Texas
November 12–15, 2017

Edited by

Laureano R. Hoyos, Ph.D., P.E.
John S. McCartney, Ph.D., P.E.
Sandra L. Houston, Ph.D., D.GE
William J. Likos, Ph.D.

ASCE

G-I ASCE GEO-INSTITUTE

GEOTECHNICAL SPECIAL PUBLICATION NO. 300

PANAM UNSATURATED SOILS 2017

PLENARY PAPERS

SELECTED PAPERS FROM SESSIONS OF THE SECOND
PAN-AMERICAN CONFERENCE ON UNSATURATED SOILS

November 12–15, 2017
Dallas, Texas

SPONSORED BY
International Society of Soil Mechanics and Geotechnical Engineering
The Geo-Institute of the
American Society of Civil Engineers

EDITED BY
Laureano R. Hoyos, Ph.D., P.E.
John S. McCartney, Ph.D., P.E.
Sandra L. Houston, Ph.D., D.GE
William J. Likos, Ph.D.

Published by the American Society of Civil Engineers

Published by American Society of Civil Engineers
1801 Alexander Bell Drive
Reston, Virginia, 20191-4382
www.asce.org/publications | ascelibrary.org

Any statements expressed in these materials are those of the individual authors and do not necessarily represent the views of ASCE, which takes no responsibility for any statement made herein. No reference made in this publication to any specific method, product, process, or service constitutes or implies an endorsement, recommendation, or warranty thereof by ASCE. The materials are for general information only and do not represent a standard of ASCE, nor are they intended as a reference in purchase specifications, contracts, regulations, statutes, or any other legal document. ASCE makes no representation or warranty of any kind, whether express or implied, concerning the accuracy, completeness, suitability, or utility of any information, apparatus, product, or process discussed in this publication, and assumes no liability therefor. The information contained in these materials should not be used without first securing competent advice with respect to its suitability for any general or specific application. Anyone utilizing such information assumes all liability arising from such use, including but not limited to infringement of any patent or patents.

ASCE and American Society of Civil Engineers—Registered in U.S. Patent and Trademark Office.

Photocopies and permissions. Permission to photocopy or reproduce material from ASCE publications can be requested by sending an e-mail to permissions@asce.org or by locating a title in ASCE's Civil Engineering Database (http://cedb.asce.org) or ASCE Library (http://ascelibrary.org) and using the "Permissions" link.

Errata: **Errata, if any, can be found at https://doi.org/10.1061/9780784481677**

Copyright © 2018 by the American Society of Civil Engineers.
All Rights Reserved.
ISBN 978-0-7844-8167-7 (PDF)
Manufactured in the United States of America.

Preface

The Second Pan-American Conference on Unsaturated Soils (PanAm-UNSAT 2017) was held in Dallas, Texas, November 12-15, 2017, featuring the latest research advances and engineering-practice innovations in the area of Unsaturated Geotechnics, with a focus on characterization, modeling, design, construction, field performance and sustainability.

PanAm-UNSAT 2017 follows a now well-established series of regional and international conferences on Unsaturated Soils, bringing together researchers, practitioners, students and policy makers from around the world, particularly the Americas. The conference built upon the success of PanAm-UNSAT 2013 (First Pan-American Conference on Unsaturated Soils, Cartagena, Colombia), as well as that of previous conferences on unsaturated soils hosted in the United States, including UNSAT 2006 (Fourth International Conference on Unsaturated Soils, Carefree, Arizona) and EXPANSIVE'92 (Seventh International Conference on Expansive Soils, Dallas, Texas, 1992).

Proceedings of PanAm-UNSAT 2017 have been documented in four Geotechnical Special Publications (GSP) of ASCE including Volume 1: Plenary Session Papers; Volume 2: Fundamentals; Volume 3: Applications; and Volume 4: Swell-Shrink and Tropical Soils.

Current Volume 1 (Plenary Session Papers) consists of three sections:

Section I includes 4 papers documenting the invited Keynote Lectures delivered by Profs. Delwyn Fredlund, Ning Lu, Bernardo Caicedo and Tacio de Campos, respectively; and 2 more companion papers documenting the First Distinguished Pan American Lecture on Unsaturated Soils delivered by Prof. Sandra L. Houston.

Section II includes 6 papers documenting the invited Fredlund Symposium Lectures delivered by distinguished scholars in honor to the decades-long contribution of Prof. Delwyn G. Fredlund to the discipline of Unsaturated Geotechnics.

Section III includes 6 more papers documenting the invited State-of-the-Art and State-of-the-Practice Lectures delivered by distinguished researchers and experienced practitioners from the region.

Each paper was subject to rigorous technical review and received a minimum of two positive peer reviews before final acceptance by the conference technical committee.

© ASCE

Acknowledgments

The following individuals deserve special acknowledgment and recognition for their direct involvement and efforts in making this regional conference a success:

PanAm-UNSAT 2017 Program Committee
Conference Chair: Laureano R. Hoyos, Ph.D., P.E., University of Texas at Arlington
Conference Co-Chair: John S. McCartney, Ph.D., P.E., M.ASCE, University of California, San Diego
Technical Program Chair: Sandra L. Houston, Ph.D., D.GE, M.ASCE, Arizona State University
Technical Program Co-Chair: William J. Likos, Ph.D., M.ASCE, University of Wisconsin, Madison
Local Chair: Marcelo J. Sanchez, Ph.D., Aff.M.ASCE, Texas A&M University
Local Co-Chair: Gerald A. Miller, Ph.D., P.E., M.ASCE, University of Oklahoma
Logistics Coordinator: Majid Ghayoomi, Ph.D., A.M.ASCE, University of New Hampshire
Sponsorships/Exhibits Chair & Liaison from the G-I Technical Coordination Council (TCC): Anand J. Puppala, Ph.D., P.E., D.GE, F.ASCE, University of Texas at Arlington

The Geo-Institute (G-I) of the ASCE
Brad Keelor, Director
Helen Cook, Board and Meetings Specialist
Lucy King, Senior Manager, Conferences
Cristina Charron, Manager, Conferences
Drew Caracciolo, Manager, Sponsorships and Exhibits
Rachel Hobbs, Administrator, Conferences

The conference Program Committee would also like to acknowledge the officers of the TC106 Committee on Unsaturated Soils (ISSMGE), and all members of the Technical Advisory and International Technical Committees, who provided guidance and support during the early planning phases of the conference.

TC106 Committee on Unsaturated Soils (ISSMGE)
David Toll, Chair, University of Durham, UK
Bernardo Caicedo, Vice Chair, Universidad de Los Andes, Bogotá, Colombia
Adrian Russell, Secretary, University of New South Wales, Australia

Technical Advisory Committee
Sai Vanapalli, University of Ottawa, Canada
Greg Siemens, Royal Military College, Canada
Kanthasamy (Muralee) Muraleetharan, University of Oklahoma, USA

© ASCE

Xiong Zhang, University of Cincinnati, USA
Ning Lu, Colorado School of Mines, USA
Claudia Zapata, Arizona State University, USA
Jorge Zornberg, University of Texas at Austin, USA
Jorge Abraham Diaz-Rodriguez, UNAM, Mexico
Bernardo Caicedo, Universidad de Los Andes, Bogotá, Colombia
Julio E. Colmenares, Universidad Nacional, Bogotá, Colombia
Orencio Villar, University of São Paulo, São Carlos, Brazil
Tacio de Campos, PUC-Rio, Brazil
Fernando Marinho, University of São Paulo, Brazil
Manoel Porfírio Cordão Neto, Universidade de Brasília, Brazil
Diego Manzanal, University of Buenos Aires, Argentina
Alejo Sfriso, University of Buenos Aires, Argentina

International Technical Committee
David Toll, University of Durham, UK
Adrian Russell, University of New South Wales, Australia
Eduardo Alonso, UPC, Barcelona, Spain
Antonio Gens, UPC, Barcelona, Spain
Lyesse Laloui, EFP Lausanne, Switzerland
J. Carlos Santamarina, KAUST, Saudi Arabia
Charles Ng, HKUST, Hong Kong

PanAm-UNSAT 2017 Session Chairs
The conference Program Committee would also like to acknowledge the conference Session Chairs, who guided authors and reviewers through the draft and final phases of paper submission and review. In most cases, these chairs also served as on-site moderators during the conference itself.

01/ Dynamic Behavior of Unsaturated Soils, part I
Majid Ghayoomi, Ph.D., A.M.ASCE, University of New Hampshire

02/ Dynamic Behavior of Unsaturated Soils, part II
Nadarajah Ravichandran, Ph.D., M.ASCE, Clemson University
Laureano R. Hoyos, Ph.D., P.E., M.G-I, University of Texas at Arlington

03/ Expansive Soils and Volume Change, Part I
Rifat Bulut, Ph.D., M.ASCE, Oklahoma State University

04/ Expansive Soils and Volume Change, Part II
Jairo E. Yepes, Ph.D., Universidad Santo Tomás, Bogotá, Colombia
Ujwalkumar D. Patil, Ph.D., P.E., M.ASCE, University of Guam
Liangbo Hu, Ph.D., A.M.ASCE, University of Toledo

© ASCE

05/ Expansive Soils and Volume Change, Part III
Iraj Noorany, Ph.D., P.E., G.E., F.ASCE, Noorany Geotechnical

06/ Pore Fluid Retention Behavior, Part I
William J. Likos, Ph.D., M.ASCE, University of Wisconsin, Madison
Idil Deniz Akin, Ph.D., A.M.ASCE, Washington State University

07/ Pore Fluid Retention Behavior, Part II
Corrie Walton-Macaulay, Ph.D., P.E., M.ASCE, Bucknell University

08/ Hydraulic Behavior, Part I
Leonardo D. Rivera, METER Group

09/ Hydraulic Behavior, Part II
Leonardo D. Rivera, METER Group

10/ Shear Strength Behavior
Ali Khosravi, Ph.D., Aff.M.ASCE, Sharif University of Technology

11/ Innovations in Testing, Part I
Morteza Khorshidi, Ph.D., Aff.M.ASCE, Geosyntec Consultants
Xin Kang, Ph.D., ACI, ASTM, A.M.ASCE, Hunan University

12/ Innovations in Testing, Part II
Morteza Khorshidi, Ph.D., Aff.M.ASCE, Geosyntec Consultants
Xin Kang, Ph.D., ACI, ASTM, A.M.ASCE, Hunan University

13/ Innovations in Testing, Part III
Morteza Khorshidi, Ph.D., Aff.M.ASCE, Geosyntec Consultants
Xin Kang, Ph.D., ACI, ASTM, A.M.ASCE, Hunan University

14/ Field Applications of Unsaturated Soils
Gerald A. Miller, Ph.D., P.E., M.ASCE, University of Oklahoma

15/ Stability of Unsaturated Slopes, Part I
Navid H. Jafari, Ph.D., A.M.ASCE, Louisiana State University

16/ Stability of Unsaturated Slopes, Part II
Soonkie Nam, Ph.D., EIT, A.M.ASCE, Georgia Southern University

17/ Numerical Modeling: Flow and Deformation, Part I
Zhen Liu, Ph.D., P.E., M.ASCE, Michigan Technological University

© ASCE

18/ Numerical Modeling: Flow and Deformation, Part II
Xiaoyu Song, Ph.D., A.M.ASCE, University of Florida

19/ Numerical Modeling: Coupled Processes
Giuseppe Buscarnera, Ph.D., Aff.M.ASCE, Northwestern University

20/ Foundations on Expansive Soils
Xiong Zhang, Ph.D., P.E. A.M.ASCE, Missouri University of Science and Technology

21/ Expansive Soils: Mitigation
Bhaskar C.S. Chittoori, Ph.D., P.E., M.ASCE, Boise State University

22/ Expansive Soils: Modeling
Xinbao Yu, Ph.D., P.E., M.ASCE, University of Texas-Arlington

23/ Pipeline and Transportation Structures in Unsaturated Soils
Claudia E. Zapata, Ph.D., A.M.ASCE, Arizona State University
Mohammad Sadik Khan, Ph.D., P.E., M.ASCE, Jackson State University

24/ Modeling of Cracked Soils and Effects of Cracking
Marcelo J. Sanchez, Ph.D., Aff.M.ASCE, Texas A&M University

25/ Constitutive Modeling: Micro to Macro
Kalehiwot N. Manahiloh, Ph.D., P.E., M.ASCE, University of Delaware

26/ Climate Effects and Permafrost
Farshid Vahedifard, Ph.D., P.E., M.ASCE, Mississippi State University

27/ Energy Geotechnics, Bio-Geo, and Sustainability
John S. McCartney, Ph.D., P.E., M.ASCE, University of California, San Diego

PanAm-UNSAT 2017 Draft Paper Reviewers

Finally, the Program Committee would also like to acknowledge those who contributed to the conference by serving as the primary reviewers of draft papers. Their efforts in providing careful, thorough reviews of each submission form the backbone of quality assurance, providing organizers the confidence that conference content would represent the best of current thinking in the field, and allowing these Proceedings to be published as a multi-volume Geotechnical Special Publication (GSP).

Murad Abu Farsakh	Asif Ahmed	Idil Akin
Raju Acharya	Beena Ajmera	Miguel Alfaro
Marshall Addison	Amir Akbari Garakani	Saumya Amarasiri

© ASCE

Omar Amer
Ron Andrus
Mohamed Arab
Andrew Assadollahi
Guillermo Avila
Kleio Avrithi
Muwafaq Awad
Ramdane Bahar
Aritra Banerjee
Tugce Baser
Munwar Basha
Bate Bate
Melissa Beauregard
Craig Benson
Riad Beshoy
Tejovikash Bheemasetti
Katia Bicalho
Mahnoosh Biglari
Hemanta Bista
Amin Borghei
Tommy Bounds
Rifat Bulut
Giuseppe Buscarnera
Jack Cadigan
Donald Cameron
Gaylon Campbell
Junnan Cao
Amy Cerato
Uma Chaduvula
Lizhou Chen
Can Chen
Bhaskar Chittoori
Mehmet Cil
Rodney Collins
Jose Andres Cruz
Sheng Dai
Arghya Das
Abhijit Deka
Ludmilla Derk
Yi Dong
Ghada Ellithy
David Elwood
Matt Evans
Arvin Farid
Ashok Gaire
Fernando Garcia
Lucas Garino
Kevin Gaspard
Antonio Gens
Hande Gerkus
Omid Ghasemi-Fare
Saswati Ghatak
Majid Ghayoomi
Amin Gheibi
Michael Gomez
James Graham
Xiangfeng Guo
Marte Gutierrez
Jumanah Hajjat
MD Haque
Arash Hassanikhah
Kianoosh Hatami
Carol Hawk
Nathan Hayman
Arash Hosseini
Sandra Houston
Laureano Hoyos
Nejan Huvaj
Tatsuya Ishikawa
Navid Jafari
Pegah Jarast
Jay Jayatilaka
Mohammad Sadik Kahn
Edward Kavazanjian
Mohammadreza Keshavarz
Sadik Khan
Morteza Khorshidi
Arman Khoshghalb
Mohammad Khosravi
Ali Khosravi
Naji Khoury
Charbel Khoury
Golam Kibria
Wansoo Kim
Sihyun Kim
S. Sonny Kim
Alan Kropp
M. R. (Kantha) Lakshmikantha
Eng Choon Leong
Lin Li
Jie Li
William Likos
Chuang Lin
Zhen (Leo) Liu
Jose Lizarraga
Naresh M
Michael Maedo
Nariman Mahabadi
Emad Maleksaeedi
Kalehiwot Manahiloh
Ferdinando Marinelli
Alejandro Martinez
David Mathon
John McCartney
Marta Miletic
Gerald Miller
Morteza Mirshekari
Debakanta Mishra
Shannon Mitchell
Rigoberto Moncado Lopez
M. Azizul Moqsud
Ali Moradi
Derek Morris
Kimia Mortezaei
Hamed Mousavi
Masoud Mousavi
Sayed Masoud Mousavi
Balasingham Muhunthan
Kanthasamy Muraleetharan
Boo Hyun Nam
Soonkie Nam
James Nevels
Thai Nguyen
Wen-Jie Niu

© ASCE

Iraj Noorany
Hyunjun Oh
Olurotimi Victor Ojekunle
Austin Olaiz
Orlando Oliveira
Fatih Oncul
Mandeep Pandey
Youngjin Park
Ujwalkumar Patil
Meghdad Payan
Aravind Pedarla
James Phipps
Hariprasad Ponnapu
Allison Quiroga
Harianto Rahardjo
Mehrzad Rahimi
Nadarajah Ravichandran
Ronald Reed
Leonardo Rivera
Nick Rocco
Breno Rocha
Ivo Rosa Montenegro
Hakan Sahin
Sonia Samir
Marcelo Sanchez
Sireesh Saride
Rajesh Sathiyamoorthy
Gokhan Saygili
Sreedeep Sekharan
Charles Shackelford
Babak Shahbodaghkhan
Mohammadreza Shakeri
Longtan Shao
Sunil Sharma
Ajay Shastri
Zhenhao Shi
Jimmy Si
John Siekmeier
Greg Siemens
Pawan Sigdel
Behzad Soltanbeigi
Chung Song
Xiaoyu Song
Timothy Stark
Melissa Stewart
Richard Sullivan
HeMei Sun
Amirata Taghavi
Nagasreenivasu Talluri
Rupert Tart, Jr.
Oliver-Denzil Taylor
Faraz Tehrani
Colby Thrash
Martin Tjioe
Kala Venkata Uday
Florian Unold
Farshid Vahedifard
Julio Valdes
Sai Vanapalli
B.V.S. Viswanadham
Divya Viswanath
Kenneth Walsh
Hanlin Wang
Kaiqi Wang
Shaun Weldon
Joshua White
Xialong Xia
Sudheer Yamsani
Xiaoming Yang
Yaolin Yi
Xinbao Yu
Atefeh Zamani
Siavash Zamiran
Bo Zhang
Yida Zhang
YouHu Zhang
Chao Zhang
Xiong Zhang
Honghua Zhao
Bohan Zhou
Yang Zhou

© ASCE

Contents

Keynote Lectures and First Distinguished Pan American Lecture

Effect of Initial Conditions on the Interpretation of Soil-Water Characteristic Curves (SWCCs) in Geotechnical Engineering 1
Delwyn G. Fredlund and Feixia (Cherry) Zhang

Generalized Elastic Modulus Equation for Unsaturated Soil 32
Ning Lu

A Mechanical Framework for Modelling Soil Compaction.....49
Bernardo Caicedo

Failure Mechanisms of Unsaturated Soil Slopes under Rainstorms in Rio de Janeiro, Brazil: An Overview 69
Tácio M. P. de Campos, Mariana F. B. Motta, Thiago S. Carnavalle, Eurípedes do A. Vargas Jr., and Antônio R. M. B. de Oliveira

Suction-Oedometer Method for Computation of Heave and Remaining Heave.....93
Sandra L. Houston and William N. Houston

Use of the Net Partial Wetting Factor (NPWF) Method of Computation of Remaining Heave: A Forensic Study 117
Sandra L. Houston, Peter A. Stauffer, Michael W. West, Emma L. Bradford, and William N. Houston

Delwyn G. Fredlund Symposium Lectures

Numerical Analyses for Assessment of Geobarrier System Performance 132
H. Rahardjo, Q. Zhai, A. Satyanaga, E. C. Leong, C. -L. Wang, and Johnny L. -H. Wong

Empirical Approach for the Use of Unsaturated Soil Mechanics in Pavement Design.....149
Claudia E. Zapata

Spatial Resolution of Degree of Saturation Measurements in Unsaturated Transparent Soil Experiments.....174
G. A. Siemens and R. A. Beddoe

© ASCE

Microstructure and Shear Strength of Widely Graded Soils during Desaturation 185
Hongfen Zhao and Limin Zhang

Fundamentals of Soil Shrinkage.....198
F. A. M. Marinho

Simple Approaches for the Application of the Mechanics of Unsaturated Soils into Conventional Geotechnical Engineering Practice.....223
Sai K. Vanapalli and Zhong Han

State-of-the-Art and State-of-the-Practice Lectures

Desaturation via Biogenic Gas Formation as a Ground Improvement Technique 244
Leon A. van Paassen, Vinh Pham, Nariman Mahabadi, Caitlyn Hall, Elizabeth Stallings, and Edward Kavazanjian Jr.

Unsaturated Soil Mechanics in Mining.....257
L. A. Oldecop and G. Rodari

Soil-Atmosphere Interaction in Unsaturated Soils Problem Solving.....281
G. F. N. Gitirana Jr.

Using Principles of Unsaturated Soil Behavior to Design Water Balance Covers for Waste Containment: Case Study.....306
Craig H. Benson

Compaction and Volume Change Behavior of Embankment Soil.....325
Gerald A. Miller

State of the Practice in Mexico and Minnesota to Estimate the Effect of Water Content/Suction in Subgrade Soils and Granular Materials.....344
P. Garnica, N. Perez, J. Siekmeier, R. Roberson, and B. Tanquist

© ASCE