

Selected Papers from the Proceedings of the
Fourth Geo-China International Conference

Geotechnical Special
Publication No. 261



Geosynthetic Civil Infrastructure, Disaster Monitoring, and Environmental Geotechnics

Edited by

Sao-Jeng Chao, Ph.D.

Xin Zhuang Cui, Ph.D.

Kwok-Leung Pun, Ph.D.



This is a preview. [Click here to purchase the full publication.](#)

GEOTECHNICAL SPECIAL PUBLICATION NO. 261

GEO-CHINA 2016

*GEOSYNTHETIC CIVIL INFRASTRUCTURE, DISASTER
MONITORING, AND ENVIRONMENTAL GEOTECHNICS*

SELECTED PAPERS FROM THE PROCEEDINGS OF THE FOURTH
GEO-CHINA INTERNATIONAL CONFERENCE

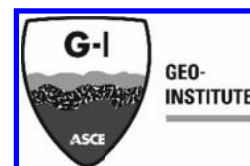
July 25–27, 2016
Shandong, China

SPONSORED BY

Shandong University
Shandong Department of Transportation
University of Oklahoma
Chinese National Science Foundation
Geo-Institute of the American Society of Civil Engineers

EDITED BY

Sao-Jeng Chao, Ph.D.
Xin Zhuang Cui, Ph.D.
Kwok-Leung Pun, Ph.D.



Published by the American Society of Civil Engineers

This is a preview. [Click here to purchase the full publication.](#)

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 <http://dx.doi.org/10.1061/9780784480045>

Copyright © 2016 by the American Society of Civil Engineers.
All Rights Reserved.
ISBN 978-0-7844-8004-5 (PDF)
Manufactured in the United States of America.

Preface

This Geotechnical Special Publication (GSP) contains 20 papers presented at the 4th GeoChina International Conference held in Shandong, China from July 25 to 27, 2016. The conference is endorsed by a number of leading international professional organizations. The technical programs for the 4th GeoChina International Conference came into contact with a balance between the fundamental theories and field applications. The papers in this GSP address a mixture of current issues in the Advances in Unsaturated Soil, Seepage, and Environmental Geotechnics, Natural Hazard and Disaster Monitoring, and Geosynthetic Reinforced Soil Retaining Structure. Furthermore, this GSP includes investigations and solutions from numerous countries, and it expands ranges of tools that are available to engineers and scientists.

Acknowledgments

The following individuals have assisted on preparing the GSP and reviewing the papers: Howard Hwang, Hui-Mi Hsu, An Cheng, Wei-Ting Lin, Jiong Zhang, and Yingjie Zheng.

Contents

Consolidation-Induced Contaminant Transport in Multi-Layer Soils.....	1
Hefu Pu and Patrick J. Fox	
Design of Shallow Square Foundations Using Saturated and Unsaturated Soil Parameters.....	9
Feyzullah Gulsen and Aykut Senol	
Hydro-Mechanical Properties of Some Potential Clay Liner Materials in Southwestern Nigeria	18
Oluwapelumi O. Ojuri and Micheal A. Uduebor	
Hydraulic Conductivity of Partially Saturated Semi-Arid Tropical Black Clay from Consolidation Tests	26
Joseph B. Adeyeri, Oluwapelumi O. Ojuri, and Micheal A. Uduebor	
Design of Sand-Based Landfill Liners as Waste Containment Barriers in Coastal Areas	34
Oluwapelumi O. Ojuri and Jude E. Ojemen	
Efficacy of Lime Treatment on the Mercury Retention Characteristics of Semi Arid Soils.....	41
Arif Ali Baig Moghal, Krishna R. Reddy, Abu Syed Mohammed, Mosleh Ali Al Shamrani, and Waleed M. Zahid	
Role of Different Leaching Methods to Arrest the Transport of Ni²⁺ in Soil and Soil Amended with Nano Calcium Silicate	49
S. A. S. Mohammed, P. F. Sanaulla, A. M. Alnuaim, and Arif Ali Baig Moghal	
Monitoring Landslide Phenomena along Li-Shing Estate Road in Nantou County of Central Taiwan by Applying an Object-Oriented Segmentation Approach	57
Chenyuan Chiu, Chih-Ping Peng, Yishuo Huang, and Chi-Ping Wang	
Using PIV to Analyze Landslide Movement on a Large Landslide	65
Tai Seong Quah, Sung-Chi Hsu, Ya Suan Huang, Y. J. Ye, Chih-Hung Chiang, and Tao-Min Cheng	
Evaluation of the Impact of Land Use Change and Climate Change on Watershed Ecosystem Services in the Chenyulan Watershed.....	73
Li-Chi Chiang and Yi-Ting Chuang	

Sensitivity and Uncertainty Analyses of the Translational Slide at the Cidu Section, 3.1k of the Taiwan Formosan Freeway.....	81
Shong-Loong Chen, Chia-Pang Cheng, and Meen-Wah Gui	
Seismic Response of a Geosynthetic-Reinforced Slope in Northeastern Taiwan	90
Hui-Mi Hsu, Lih-Chuan Hwang, An Cheng, Tsan-Hsuan Yu, and Jason Chao	
Examination of the Design Procedures and Case Studies for Polyester Strip Reinforced MSE Retaining Structures in Non-Standard Soil.....	98
Giulia Lugli, Funding Xu, and Moreno Scotto	
The Performance of Strip Footing Resting on Geogrid-Reinforced Dune Sand.....	106
Yahia E.-A. Mohamedzein and Mohammed Y. Al-Aghbari	
Application and Advantages of Lime Stabilized Backfill MSE Retaining Structures	114
Giulia Lugli, Giuseppe Lembo, and Fuding Xu	
Evaluating the Performance of Geotextile Wrapped/Layered Soil: A Comparative Study Using the DEM.....	122
Hongyang Cheng and Haruyuki Yamamoto	
EPS Resistance Factors and Applications on Flexible Walls.....	131
Sherif S. AbdelSalam and Salem A. Azzam	
Laboratory Testing of Enhancing the Bearing Capacity of Strip Footing with Woven Geotextiles	139
Shengmin Wu, Jiunnren Lai, Chiung-Fen Cheng, Guo-Hao Lai, and Chun-Jung Wei	
Study on Calculation Methods for Reinforced Earth	146
Baotong Shi and Xiangxing Kong	
Study on the Vegetation Restoration Method to Reinforce Slope.....	152
Baotong Shi and Xiangxing Kong	

Consolidation-Induced Contaminant Transport in Multi-Layer Soils

Hefu Pu, A.M.ASCE¹; and Patrick J. Fox, F.ASCE²

¹Professor, School of Civil Engineering and Mechanics, Huazhong Univ. of Science and Technology, Wuhan, Hubei 430074 China. E-mail: hefupu85@gmail.com

²Shaw Professor and Head, Dept. of Civil and Environmental Engineering, Pennsylvania State Univ., University Park, PA 16802. E-mail: pjfox@engr.psu.edu

Abstract: This paper presents a numerical investigation of the effects of large strain consolidation on contaminant transport in multi-layer soils. Numerical simulations were conducted using the CST3 model, which accounts for one-dimensional coupled large strain consolidation and contaminant transport in saturated multi-layer porous media. The consolidation algorithm accounts for vertical strain, soil self-weight, general constitutive relationships, relative velocity of fluid and solid phases, changing compressibility and hydraulic conductivity during consolidation, unload/reload, time-dependent loading, time-dependent boundary conditions, external hydraulic gradient, variable preconsolidation stress profiles, and multiple soil layers with different material properties. The contaminant transport algorithm accounts for advection, diffusion, mechanical dispersion, linear and nonlinear sorption, equilibrium and nonequilibrium sorption, porosity-dependent effective diffusion coefficient, and first-order decay reactions. Simulation results indicate that layered soil heterogeneity can have significant effects on both consolidation behavior and contaminant transport behavior. Characterization of a multi-layer soil stratum as a homogeneous single layer with average properties may result in significant errors in the analysis of consolidation-induced contaminant transport in multi-layer soils.

INTRODUCTION

The phenomenon of consolidation-induced contaminant transport is observed in a variety of geoenvironmental engineering applications, including contaminant transport through landfill bottom liner systems during waste placement operations, confined disposal of dredged contaminated sediments, and subaqueous capping of contaminated sediments (Fox and Shackelford 2010). For these applications, contaminant transport processes involve advection, dispersion, and sorption, which is

similar to the transport in rigid porous media as described by classical transport theory. In addition, consolidation-induced contaminant transport processes also involve transient advective flows and changes in transport properties such as porosity and effective diffusion coefficient, which further complicate the modeling of such transport processes.

Over the last two decades, several research groups have utilized different methods to consider consolidation-induced contaminant transport in porous media, such as the work by Potter et al. (1994), Smith (2000), Peters and Smith (2002), Fox (2007a, 2007b), Fox and Lee (2008), Pu and Fox (2015a), Fox and Pu (2015), and Pu et al. (2015). All of these studies assume that the porous medium is homogeneous and thus layered soil heterogeneity, which is more common in reality, is neglected. Although many solutions are available for the contaminant transport in rigid multi-layer porous media (e.g., Leij and van Genuchten 1995; Li and Cleall 2011), very limited progress has been made in the area of coupled consolidation and contaminant transport in multi-layer soils. Recently, Pu and Fox (2015b) developed a piecewise-linear numerical model, called CST3, to model such problem.

This paper provides an overview of the capabilities of the CST3 model. Then, numerical simulations were performed using CST3 to illustrate the effects of layered soil heterogeneity on the consolidation results and associated contaminant transport results. The errors for modeling multi-layer soils as a homogeneous single layer were discussed for the analysis of consolidation-induced contaminant transport in multi-layer soils.

MODEL DESCRIPTION

CST3 was developed on the basis of the CS2, CS3 and CST2 models and follows similar procedures with regard to geometry, effective stress, fluid flow, settlement, and contaminant transport. The CST3 model and its predecessors have undergone extensive validation, including comparisons with experimental data (e.g., Fox and Berles 1997; Fox 2007b; Fox and Lee 2008; Lee and Fox 2009; Pu and Fox 2015b). Only a brief summary is provided below.

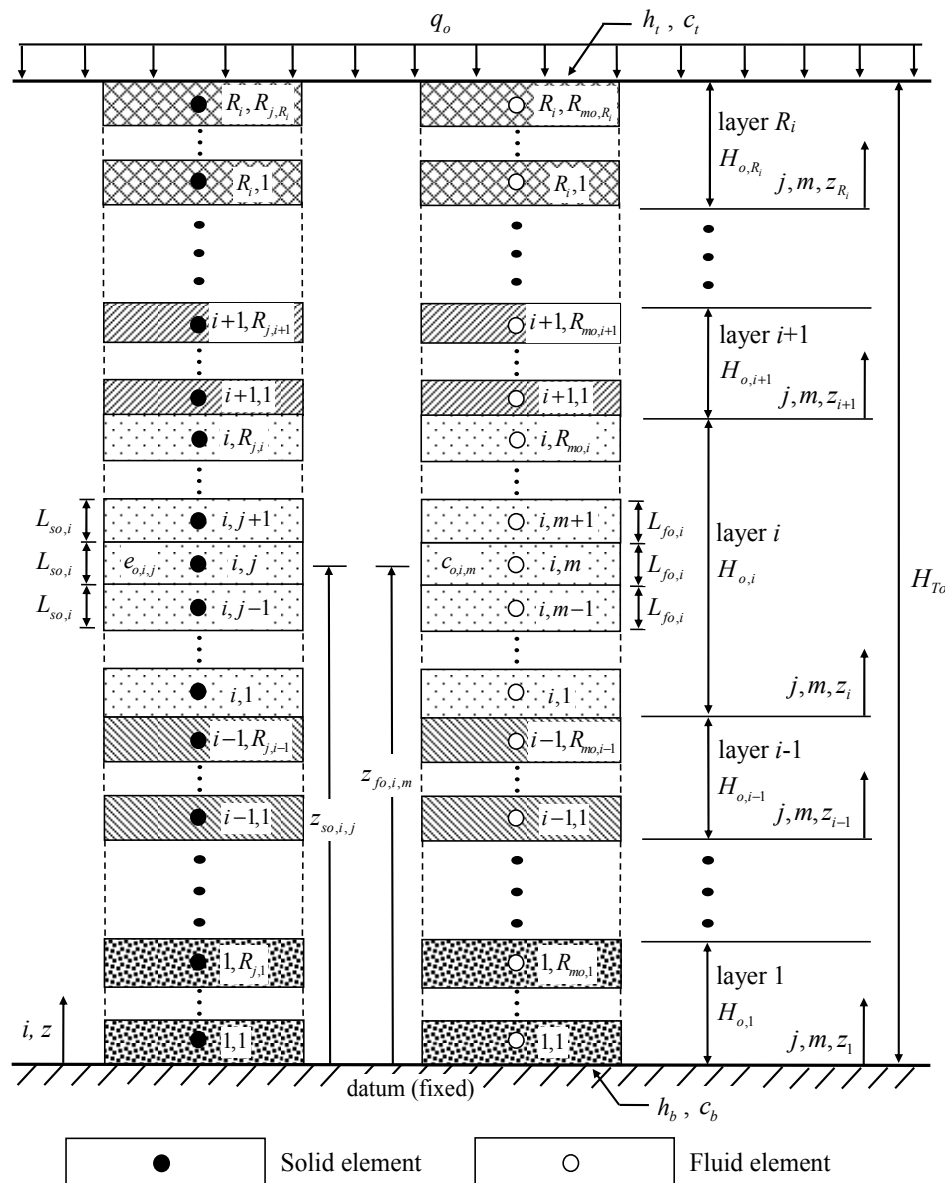
A saturated compressible soil stratum has initial height H_{To} , contains R_i horizontal layers, and is treated as an idealized two-phase material in which the solid particles and pore fluid are incompressible. The initial geometry, prior to application of surcharge load at time $t = 0$, is shown in Fig. 1. The stratum is sufficiently wide such that all quantities vary only in the vertical direction and consolidation can be treated as one-dimensional. Vertical coordinate z and layer coordinate i are defined as positive upward from a fixed datum at the bottom of the stratum. Each layer i has initial height $H_{o,i}$ and the solid phase of layer i is represented as a column of $R_{j,i}$ vertical solid elements, and thus the total number of solid elements for the stratum is $R_{Ts} \left(= \sum_{i=1}^{R_i} R_{j,i} \right)$. Layer elevation coordinate z_i and layer solid element coordinate j are defined as positive upward from the base of each layer. Each solid element j of layer i has unit cross-sectional area (plan view), initial height $L_{so,i}$, a central node at initial elevation $z_{so,i,j}$, and initial void ratio $e_{o,i,j}$. Nodes translate vertically and

remain at the center of their respective elements throughout the consolidation process. The distribution of void ratio is assumed to be uniform within each solid element and varies vertically among solid elements depending on the initial vertical effective stress at the top of the stratum q_o , the compressibility and self-weight of the soil, and any vertical seepage forces due to an external hydraulic gradient acting across the stratum (Fox 2007a).

The pore fluid of each layer i is also represented as a column of elements, with $R_{mo,i}$ fluid elements initially in the column, and thus the initial total number of fluid elements for the stratum is $R_{Tf} \left(= \sum_{i=1}^{R_i} R_{mo,i} \right)$. Fluid elements are defined by vertical element coordinate m upward from the base of each layer. Each m^{th} fluid element of layer i has initial height $L_{fo,i}$, unit cross-sectional area (plan view), and a central node located at initial elevation $z_{fo,i,m}$. Each m^{th} fluid element of layer i has initial solute (i.e., dissolved) concentration $c_{o,i,m}$ [mass solute/volume fluid] and initial solute mass $C_{fo,i,m} = c_{o,i,m} V_{fo,i,m}$, where $V_{fo,i,m} = L_{fo,i} e_{o,i,j} / (1 + e_{o,i,j})$ is the initial volume of fluid in the element and $e_{o,i,j}$ is the initial void ratio of the solid element at the same elevation. The initial sorbed concentration for each solid element $s_{o,i,j}$ [mass contaminant/mass solid] is assumed to be in equilibrium with the local solute concentration.

Constitutive relationships are defined using conventional log-linear parameters for each layer. Each solid element is characterized as normally consolidated (NC) or overconsolidated (OC). If OC, the compressibility relationship is defined by $(\hat{e}_i, \hat{\sigma}'_i)$, recompression index $C_{r,i}$, preconsolidation stress $\sigma'_{p,i,j}$, and compression index $C_{c,i}$, where $(\hat{e}_i, \hat{\sigma}'_i)$ is a known point on the compressibility curve. Vertical hydraulic conductivity k for each solid element is defined by a log-linear relationship $k_{i,j} = k_{o,i,j} \exp[(e_{i,j} - e_{o,i,j}) C'_{k,i} \ln 10]$, where $k_{o,i,j}$ is the vertical hydraulic conductivity at $e_{o,i,j}$, and $C'_{k,i}$ is the reciprocal of hydraulic conductivity change index $= \Delta \log k / \Delta e$. Aside from unload/reload effects, a one-to-one correspondence is assumed for each constitutive relationship. Thus, CST3 does not account for the effects of strain rate, secondary compression, or aging on the compressibility or hydraulic conductivity of the soil. Furthermore, the solute is assumed to be sufficiently dilute so as to not alter the constitutive relationships of the soil.

Top and bottom boundaries of the stratum can be specified as drained or undrained and, if drained, are assigned individual total hydraulic head values, h_t and h_b , taken with respect to the datum (Fig. 1). Transport conditions for the top and bottom boundaries can be specified as prescribed concentration (Type I), prescribed concentration gradient (Type II), or prescribed solute mass flux (Type III). CST3 can also consider a reservoir boundary condition, which represents the time-varying concentration of an accumulating well-mixed aqueous reservoir formed above the soil stratum from fluid outflow at the top boundary (Fox and Lee 2008).



Surcharge load is applied to the soil stratum beginning at $t = 0$. The vertical effective stress at the top boundary at time t is equal to $q_o + \Delta q'$, where effective stress increment $\Delta q'$ is constant with depth but can change with time. In response to surcharge loading, excess pore pressures generated within the layer cause fluid flow to all drainage boundaries. Soil deformation is one-dimensional and occurs in response to the net fluid outflow from each element. In a deforming soil stratum, contaminant transport occurs by transient advection and dispersion in the fluid phase and sorption onto moving solid elements. The sorption can be considered as linear or nonlinear (Freundlich isotherm), equilibrium or nonequilibrium (i.e., kinetic). An effective diffusion coefficient that changes with soil porosity during consolidation can