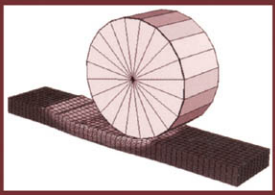
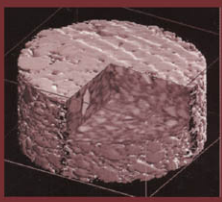
Geotechnical Special Publication No. 176

Analysis of Asphalt Pavement Materials and Systems

EMERGING METHODS





EDITED BY
Linbing Wang and Eyad Masad

ASCE

GEO INSTITUTE

GEOTECHNICAL SPECIAL PUBLICATION NO. 176

ANALYSIS OF ASPHALT PAVEMENT MATERIALS AND SYSTEMS

EMERGING METHODS

PROCEEDINGS OF THE SYMPOSIUM
ON THE MECHANICS OF FLEXIBLE PAVEMENTS

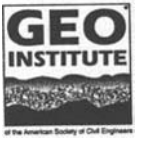
June 25–30, 2006
Boulder, Colorado

SPONSORED BY
Pavements Committee of the Geo-Institute of the American Society of Civil Engineers

The Inelastic Committee and the Granular Materials Committee of the ASCE Mechanics Division

EDITED BY
Linbing Wang
Eyad Masad





Published by the American Society of Civil Engineers

Library of Congress Cataloging-in-Publication Data on file.

American Society of Civil Engineers
1801 Alexander Bell Drive
Reston, Virginia, 20191-4400

www.pubs.asce.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 therefore. This information should not be used without first securing competent advice with respect to its suitability for any general or specific application. Anyone utilizing this 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 reprints.
You can obtain instant permission to photocopy ASCE publications by using ASCE's online permission service (www.pubs.asce.org/authors/RightslinkWelcomePage.html). Requests for 100 copies or more should be submitted to the Reprints Department, Publications Division, ASCE, (address above); email: permissions@asce.org. A reprint order form can be found at www.pubs.asce.org/authors/reprints.html.

Copyright © 2007 by the American Society of Civil Engineers. All Rights Reserved.
ISBN 13: 978-0-7844-0924-4
ISBN 10: 0-7844-0924-2
Manufactured in the United States of America.

14 13 12 11 10 09 08 07 1 2 3 4 5

Preface

This special publication includes 13 papers on characterization, modeling and simulation of asphalt concrete and subgrade, addressing some timely issues in mechanics of flexible pavements. They include four papers on modeling and simulations of asphalt concrete by incorporating the microscopic structures of the material, the interactions between aggregates, mastics and voids, and the use of Finite Element Method (FEM) and Discrete Element Method (DEM); two papers on the continuum approaches including nonlinear viscoelastic analysis and temperature dependency; two papers on laboratory characterization of asphalt concrete; three papers on the characterization of subgrade soil resilient modulus, incorporation of nonlinear soil behavior into pavement analysis, and the evaluation of the effect of using geogrid; and one paper on pavement evaluation.

Each paper published in this GSP was evaluated by peer reviewers and the editors. The review comments were sent to the authors and they have been addressed to the reviewers and the editors' satisfaction. The ASCE Geo-Institute Pavements Committee and the reviewers are sincerely acknowledged for their time and efforts.

The papers in this GSP include eight papers that were presented in the symposium on Mechanics of Flexible Pavements at the 15th U.S. National Congress of Theoretical and Applied Mechanics, held at Boulder, Colorado, June 25-30 2006 and five papers submitted for publication only. The symposium was supported by the Geo-Institute Pavements Committee, the Inelastic Committee and the Granular Materials Committee of the ASCE Mechanics Division.

The editors of this GSP would like to thank the Board of Governors of the Geo Institute for their approving the symposium and the special publication.

Linbing Wang, Virginia Tech
Eyad Masad, Texas A & M University

January 10, 2007

Geotechnical Special Publications

1 *Terzaghi Lectures*
2 *Geotechnical Aspects of Stiff and Hard Clays*
3 *Landslide Dams: Processes, Risk, and Mitigation*
7 *Timber Bulkheads*
9 *Foundations & Excavations in Decomposed Rock of the Piedmont Province*
11 *Dynamic Response of Pile Foundations - Experiment, Analysis and Observation*
14 *Geotechnical Aspects of Karst Terrains*
15 *Measured Performance Shallow Foundations*
16 *Special Topics in Foundations*
17 *Soil Properties Evaluation from Centrifugal Models*
18 *Geosynthetics for Soil Improvement*
19 *Mine Induced Subsidence: Effects on Engineered Structures*
21 *Hydraulic Fill Structures*
22 *Foundation Engineering*
23 *Predicted and Observed Axial Behavior of Piles*
24 *Resilient Moduli of Soils: Laboratory Conditions*
25 *Design and Performance of Earth Retaining Structures*
27 *Geotechnical Engineering Congress*
28 *Detection of and Construction at the Soil/Rock Interface*
29 *Recent Advances in Instrumentation, Data Acquisition and Testing in Soil Dynamics*
32 *Embankment of Dams - James L. Sherard Contributions*
33 *Excavation and Support for the Urban Infrastructure*
34 *Piles Under Dynamic Loads*
35 *Geotechnical Practice in Dam Rehabilitation*
37 *Advances in Site Characterization: Data Acquisition, Data Management and Data Interpretation*
39 *Unsaturated Soils*
40 *Vertical and Horizontal Deformations of Foundations and Embankments*
41 *Predicted and Measured Behavior of Five Spread Footings on Sand*
42 *Serviceability of Earth Retaining Structures*
43 *Fracture Mechanics Applied to Geotechnical Engineering*
44 *Ground Failures Under Seismic Conditions*
45 *In Situ Deep Soil Improvement*
46 *Geoenvironment 2000*
47 *Geo-Environmental Issues Facing the Americas*
48 *Soil Suction Applications in Geotechnical Engineering*
49 *Soil Improvement for Earthquake Hazard Mitigation*
50 *Foundation Upgrading and Repair for Infrastructure Improvement*
51 *Performance of Deep Foundations Under Seismic Loading*
52 *Landslides Under Static and Dynamic Conditions - Analysis, Monitoring, and Mitigation*
53 *Landfill Closures - Environmental Protection and Land Recovery*
54 *Earthquake Design and Performance of Solid Waste Landfills*
55 *Earthquake-Induced Movements and Seismic Remediation of Existing Foundations and Abutments*
56 *Static and Dynamic Properties of Gravelly Soils*
57 *Verification of Geotechnical Grouting*
58 *Uncertainty in the Geologic Environment*
59 *Engineered Contaminated Soils and Interaction of Soil Geomembranes*
60 *Analysis and Design of Retaining Structures Against Earthquakes*
61 *Measuring and Modeling Time Dependent Soil Behavior*
62 *Case Histories of Geophysics Applied to Civil Engineering and Public Policy*
63 *Design with Residual Materials: Geotechnical and Construction Considerations*
64 *Observation and Modeling in Numerical Analysis and Model Tests in Dynamic Soil-Structure Interaction Problems*
65 *Dredging and Management of Dredged Material*
66 *Grouting: Compaction, Remediation and Testing*
67 *Spatial Analysis in Soil Dynamics and Earthquake Engineering*
68 *Unsaturated Soil Engineering Practice*
69 *Ground Improvement, Ground Reinforcement, Ground Treatment: Developments 1987-1997*
70 *Seismic Analysis and Design for Soil-Pile-Structure Interactions*
71 *In Situ Remediation of the Geoenvironment*
72 *Degradation of Natural Building Stone*
73 *Innovative Design and Construction for Foundations and Substructures Subject to Freezing and Frost*

74 *Guidelines of Engineering Practice for Braced and Tied-Back Excavations*
75 *Geotechnical Earthquake Engineering and Soil Dynamics III*
76 *Geosynthetics in Foundation Reinforcement and Erosion Control Systems*
77 *Stability of Natural Slopes in the Coastal Plain*
78 *Filtration and Drainage in Geotechnical/Geoenvironmental Engineering*
79 *Recycled Materials in Geotechnical Applications*
80 *Grouts and Grouting: A Potpourri of Projects*
81 *Soil Improvement for Big Digs*
82 *Risk-Based Corrective Action and Brownfields Restorations*
83 *Design and Construction of Earth Retaining Systems*
84 *Effects of Construction on Structures*
85 *Application of Geotechnical Principles in Pavement Engineering*
86 *Big Digs Around the World*
87 *Jacked Tunnel Design and Construction*
88 *Analysis, Design, Construction, and Testing of Deep Foundations*
89 *Recent Advances in the Characterization of Transportation Geo-Materials*
90 *Geo-Engineering for Underground Facilities*
91 *Special Geotechnical Testing: Central Artery/Tunnel Project in Boston, Massachusetts*
94 *Performance Confirmation of Constructed Geotechnical Facilities*
95 *Soil-Cement and Other Construction Practices in Geotechnical Engineering*
96 *Numerical Methods in Geotechnical Engineering: Recent Developments*
97 *Innovations and Applications in Geotechnical Site Characterization*
98 *Pavement Subgrade, Unbound Materials, and Nondestructive Testing*
99 *Advances in Unsaturated Geotechnics*
100 *New Technological and Design Developments in Deep Foundations*
101 *Slope Stability 2000*
102 *Trends in Rock Mechanics*
103 *Advances in Transportation and Geoenvironmental Systems Using Geosynthetics*
104 *Advances in Grouting and Ground Modification*
105 *Environmental Geotechnics*
106 *Geotechnical Measurements: Lab & Field*
107 *Soil Dynamics and Liquefaction 2000*
108 *Use of Geophysical Methods in Construction*
109 *Educational Issues in Geotechnical Engineering*
110 *Computer Simulation of Earthquake Effects*
111 *Judgment and Innovation: The Heritage and Future of the Geotechnical Engineering Profession*
112 *Soft Ground Technology*
114 *Soils Magic*
115 *Expansive Clay Soils and Vegetative Influence on Shallow Foundations*
116 *Deep Foundations 2002: An International Perspective on Theory, Design, Construction, and Performance*
117 *Discrete Element Methods: Numerical Modeling of Discontinua*
118 *A History of Progress: Selected U.S. Papers in Geotechnical Engineering*
119 *Soil Behavior and Soft Ground Construction*
120 *Grouting and Ground Treatment*
121 *Probabilistic Site Characterization at the National Geotechnical Experimentation Sites*
122 *Sinkholes and the Engineering and Environmental Impacts of Karst*
123 *Recent Advances in Materials Characterization and Modeling of Pavement Systems*
124 *GeoSupport 2004: Drilled Shafts, Micropiling, Deep Mixing, Remedial and Specialty Foundation Systems*
125 *Current Practices and Future Trends in Deep Foundations*
126 *Geotechnical Engineering for Transportation Projects*
127 *Recycled Materials in Geotechnics*
128 *Soil Constitutive Models: Evaluation, Selection, and Calibration*
129 *Advances in Designing and Testing Deep Foundations*
130 *Advances in Pavement Engineering*
131 *Contemporary Issues in Foundation Engineering*
132 *Advances in Deep Foundations: In Memory of Michael W. O'Neill*
133 *Earthquake Engineering and Soil Dynamics*
134 *Soil Dynamics Symposium in Honor of Professor Richard D. Woods*
135 *Erosion of Soils and Scour of Foundations*
136 *Innovations in Grouting and Soil Improvement*

137 *Legal and Liability Issues in Geotechnical Engineering*
138 *Site Characterization and Modeling*
139 *Calibration of Constitutive Models*
140 *Slopes and Retaining Structures Under Seismic and Static Conditions*
141 *International Perspectives on Soil Reinforcement Applications*
142 *Waste Containment and Remediation*
143 *Geomechanics: Testing, Modeling, and Simulation*
144 *Sinkholes and the Engineering and Environmental Impacts of Karst*
145 *Seismic Performance and Simulation of Pile Foundations in Liquefied and Laterally Spreading Ground*
146 *Asphalt Concrete: Simulation, Modeling and Experimental Characterization*
147 *Unsaturated Soils 2006*
148 *Advances in Unsaturated Soil, Seepage, and Environmental Geotechnics*
149 *Site and Geomaterial Characterization*
150 *Soil and Rock Behavior and Modeling*
151 *Advances in Earth Structures: Research to Practice*
152 *Ground Modification and Seismic Mitigation*
153 *Foundation Analysis and Design: Innovative Methods*
154 *Pavement Mechanics and Performance*
155 *Underground Construction and Ground Movement*
156 *Geomechanics II: Testing, Modeling, and Simulation*
157 *Computer Applications in Geotechnical Engineering*
158 *Contemporary Issues in Deep Foundations*
159 *Case Studies in Earth Retaining Structures*
160 *Dynamic Response and Soil Properties*
161 *Embankments, Dams, and Slopes: Lessons from the New Orleans Levee Failures and Other Issues*
162 *Problematic Soils and Rocks and In Situ Characterization*
163 *Geoenvironmental Engineering*
164 *Innovative Applications of Geophysics in Civil Engineering*
165 *Geosynthetics in Reinforcement and Hydraulic Applications*
166 *Educational Activities in Geotechnical Engineering*
167 *Geotechnics of Soil Erosion*
168 *Grouting for Ground Improvement: Innovative Concepts and Applications*
169 *Soil and Material Inputs for Mechanistic-Empirical Pavement Design*
170 *Probabilistic Applications in Geotechnical Engineering*
171 *Advances in Shallow Foundations*
172 *Soil Improvement*
173 *Advances in Measurement and Modeling of Soil Behavior*
174 *Designing Our Underground Space*
175 *Field Measurements in Geomechanics 2007*

Contents

Stress Concentration Factor as a Performance Indicator for Asphalt Mixes 1
Linbing Wang, Yongping Wang, Qingbin Li, and Gerardo Flintsch

Aggregate Effect on Asphalt Mixture Properties by Modeling Particle-to-Particle Interaction 14
Zhanping You, William G. Buttlar, and Qingli Dai

Investigation of Linear and Damage-Coupled Viscoelastic Properties of Sustainable Asphalt Mixture Using a Micromechanical Finite Element Approach 22
Qingli Dai and Zhanping You

Estimation of the Stiffness of Asphalt Mastics Using Hirsch Model 33
Cristian Druta, Linbing Wang, George Z. Voyiadjis, and Chris Abadie

Fundamental Mechanics of Asphalt Compaction through FEM and DEM Modeling 45
Linbing Wang, Bing Zhang, Dong Wang, and Zhongqi Yue

Analysis of Nonlinear Viscoelastic Properties of Asphalt Mixtures 64
Chien-Wei Huang, Eyad Masad, Anastasia H. Muliana, and Hussain Bahia

The Temperature Dependent Generalized Kuhn Model for Asphalt Concrete 73
Vassilis P. Panoskaltsis

Laboratory Validation of Viscoelastic Interconversion for Hot Mix Asphalt 87
Myung Goo Jeong, Amara Loulizi, and Gerardo W. Flintsch

A Laboratory Study on Cracking Potential of Binder Course Asphalt Mixtures Used in Semi-Rigid Pavements 102
Fujian Ni, Zhong Wu, Rongsheng Chen, Xingyu Gu, and Qiao Dong

Effect of the Relative Root-Mean-Square Error on Pavement Response 117
Wael Alkasawneh, Ernie Pan, and Roger Green

Considerations for Nonlinear Analyses of Pavement Foundation Geomaterials in the Finite Element Modeling of Flexible Pavements 133
Erol Tutumluer and Minkwan Kim

Evaluation of Geogrid Benefits Using Monotonic and Repeated Load Triaxial Tests 145
Munir D. Nazzal, Murad Abu-Farsakh, and Louay N. Mohammad

Permanent Deformation of Subgrade Soils 156
Zhong-yin Guo, Hong-liang Zhang, Lin Cong, and Qi-ju Gao

Subject Index 171

Author Index 173