## Soil Strength and Slope Stability

J. Michael Duncan Stephen G. Wright



This book is printed on acid-free paper. @

Copyright © 2005 by John Wiley & Sons, Inc. All rights reserved

Published by John Wiley & Sons, Inc., Hoboken, New Jersey Published simultaneously in Canada

No part of this publication may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, photocopying, recording, scanning, or otherwise, except as permitted under Section 107 or 108 of the 1976 United States Copyright Act, without either the prior written permission of the Publisher, or authorization through payment of the appropriate per-copy fee to the Copyright Clearance Center, Inc., 222 Rosewood Drive, Danvers, MA 01923, (978) 750-8400, fax (978) 750-4470, or on the web at www.copyright.com. Requests to the Publisher for permission should be addressed to the Permissions Department, John Wiley & Sons, Inc., 111 River Street, Hoboken, NJ 07030, (201) 748-6011, fax (201) 748-6008, e-mail: permcoordinator@wiley.com.

nit of Liability/Disclaimer of Warranty: While the publisher and or have used their best efforts in preparing this book, they no representations or warranties with respect to the accuracy npleteness of the contents of this book and specifically aim any implied warranties of merchantability or fitness for a cular purpose. No warranty may be created or extended by representatives or written sales materials. The advice and gies contained herein may not be suitable for your situation. should consult with a professional where appropriate. Neither ublisher nor author shall be liable for any loss of profit or any commercial damages, including but not limited to special, antal, consequential, or other damages.

eneral information on our other products and services or for ical support, please contact our Customer Care Department .n the United States at (800) 762-2974, outside the United .es at (317) 572-3993 or fax (317) 572-4002.

Wiley also publishes its books in a variety of electronic formats. Some content that appears in print may not be available in electronic books. For more information about Wiley products, visit our web site at www.wiley.com.

## Library of Congress Cataloging-in-Publication Data:

Duncan, J. M. (James Michael)

Soil strength and slope stability / J. Michael Duncan, Stephen G. Wright.

p. cm.

Includes index.

ISBN 0-471-69163-1 (cloth: alk. paper)

Slopes (Soil mechanics) I. Wright, Stephen G. (Stephen Gailord), 1943 Title.

TA710.D868 2005 624.1'51363--dc22

2004019535

Printed in the United States of America

1098765432

## CONTENTS

CHAPTER I INTRODUCTION	1
CHAPTER 2 EXAMPLES AND CAUSES OF SLOPE FAILURE	5
Examples of Slope Failure Causes of Slope Failure Summary	5 14 17
CHAPTER 3 SOIL MECHANICS PRINCIPLES	19
Drained and Undrained Conditions Total and Effective Stresses Drained and Undrained Shear Strengths Basic Requirements for Slope Stability Analyses	19 21 22 26
CHAPTER 4 STABILITY CONDITIONS FOR ANALYSES	31
End-of-Construction Stability Long-Term Stability Rapid (Sudden) Drawdown Earthquake Partial Consolidation and Staged Construction Other Loading Conditions	31 32 32 33 33 33
CHAPTER 5 SHEAR STRENGTHS OF SOIL AND MUNICIPAL SOLID WASTE	35
Granular Materials Silts Clays Municipal Solid Waste	35 40 44 54
CHAPTER 6 MECHANICS OF LIMIT EQUILIBRIUM PROCEDURES	55
Definition of the Factor of Safety Equilibrium Conditions Single Free-Body Procedures Procedures of Slices: General	55 56 57

		Procedures of Slices: Circular Slip Surfaces	63
		Procedures of Slices: Noncircular Slip Surfaces	71
		Assumptions, Equilibrium Equations, and Unknowns	83
		Representation of Interslice Forces (Side Forces)	83
		Computations with Anisotropic Shear Strengths	90
		Computations with Curved Failure Envelopes and Anisotropic Shear Strengths	90
		Alternative Definitions of the Factor of Safety	91
		Pore Water Pressure Representation	95
CHAPTER	7	METHODS OF ANALYZING SLOPE STABILITY	103
		Simple Methods of Analysis	103
		Slope Stability Charts	105
		Spreadsheet Software	107
		Computer Programs	107
		Verification of Analyses	111
		Examples for Verification of Stability Computations	112
CHAPTER	8	REINFORCED SLOPES AND EMBANKMENTS	137
		Limit Equilibrium Analyses with Reinforcing Forces	137
		Factors of Safety for Reinforcing Forces and Soil Strengths	137
		Types of Reinforcement	139
		Reinforcement Forces	139
		Allowable Reinforcement Forces and Factors of Safety	141
		Orientation of Reinforcement Forces	142
		Reinforced Slopes on Firm Foundations	142
		Embankments on Weak Foundations	145
CHAPTER	9	ANALYSES FOR RAPID DRAWDOWN	151
		Drawdown during and at the End of Construction	151
		Drawdown for Long-Term Conditions	151
		Partial Drainage	160
			.00
CHAPTER	10	SEISMIC SLOPE STABILITY	161
		Analysis Procedures	161
		Pseudostatic Screening Analyses	164
		Determining Peak Accelerations	165
		Shear Strength for Pseudostatic Analyses	166
		Postearthquake Stability Analyses	169
CHAPTER	11	ANALYSES OF EMBANKMENTS WITH PARTIAL	
		CONSOLIDATION OF WEAK FOUNDATIONS	175
		Consolidation during Construction	175
		Analyses of Stability with Partial Consolidation	176

		CONTENTS	vii
		Observed Behavior of an Embankment Constructed in Stages Discussion	178 179
CHAPTER	12	ANALYSES TO BACK-CALCULATE STRENGTHS	183
		Back-Calculating Average Shear Strength Back-Calculating Shear Strength Parameters Based on Slip Surface Geometry	183 185
		Examples of Back-Analyses of Failed Slopes Practical Problems and Limitation of Back-Analyses Other Uncertainties	187 195 197
CHAPTER	13	FACTORS OF SAFETY AND RELIABILITY	199
		Definitions of Factor of Safety Factor of Safety Criteria Reliability and Probability of Failure Standard Deviations and Coefficients of Variation Coefficient of Variation of Factor of Safety Reliability Index Probability of Failure	199 200 200 202 205 206 206
CHAPTER	14	IMPORTANT DETAILS OF STABILITY ANALYSES	213
		Location of Critical Slip Surfaces Examination of Noncritical Shear Surfaces Tension in the Active Zone Inappropriate Forces in the Passive Zone Other Details Verification of Calculations Three-Dimensional Effects	213 219 221 224 228 232 233
CHAPTER	15	PRESENTING RESULTS OF STABILITY EVALUATIONS	237
		Site Characterization and Representation Soil Property Evaluation Pore Water Pressures Special Features Calculation Procedure Analysis Summary Figure Parametric Studies Detailed Input Data Table of Contents	237 238 238 238 239 239 241 243 243
CHAPTER	16	SLOPE STABILIZATION AND REPAIR	247
		Use of Back-Analysis Factors Governing Selection of Method of Stabilization	247 247

	Drainage	248
	Excavations and Buttress Fills	253
	Retaining Structures	254
	Reinforcing Piles and Drilled Shafts	256
	Injection Methods	260
	Vegetation	261
	Thermal Treatment	261
	Bridging	262
	Removal and Replacement of the Sliding Mass	263
APPENDIX	SLOPE STABILITY CHARTS	265
	Use and Applicability of Charts for Analysis of Slope Stability	265
	Averaging Slope Inclinations, Unit Weights, and Shear Strengths	265
	Soils with $\phi = 0$	266
	Soils with $\phi > 0$	270
	Infinite Slope Charts	272
	Soils with $\phi = 0$ and Strength Increasing with Depth	274
	Examples	274
	References	281
	Index	295