Subsurface Drainage for Slope Stabilization

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Abstract: This book describes methods of stabilizing slopes by removing groundwater. After reviewing the ways in which groundwater pressure affects stability and the general principles of reducing it by drainage, chapters give details of the mechanics of flow in soil, rock, aggregates, geotextiles, and pipes. The book presents filtration theory and filter design in a geotechnical context, together with the general characteristics of drains and the assessment of their performance. The materials used in drains as well as construction procedures are also described. The book covers trench, blanket, and horizontal drains, and wells. Also included are discussions of field and laboratory investigations, stability computations, and slope instrumentation and its monitoring. The book ends with an account of clogging mechanisms and maintenance procedures, and an appendix of case examples.

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For my parents,
Charles and Annie Forrester,
and
for former colleagues
of the landslides game

Contents

Symbols and Abbreviations

Symbols

A = area (m^2)
a = distance (m)
B = drain spacing (m)
b = thickness (m)
C_u = coefficient of uniformity
c = cohesion (kPa)
D = diameter; pipe internal diameter (m)
d_x = particle size, x% by mass finer than d (mm or μm)
d_x^f = particle size, x% by mass finer than d in filter (mm or μm)
d_x^p = particle size, x% by mass finer than d in protected material (mm or μm)
F = piezometer tip shape factor (m)
g = acceleration due to gravity (9.81 m/s^2)
H = height; depth of trench (m)
h = piezometric head (m)
Δh = drop in water level (m)
i = piezometric or hydraulic gradient; open channel gradient (sine)
K_0 = coefficient of earth pressure at rest
k = coefficient of permeability (m/s)
k_H = seismic coefficient, horizontal
k_g = coefficient of permeability of geotextile (m/s)
L = length (m)
Δl = element of length (m or mm)
m = mass (Mg)
n = Manning roughness coefficient

n_f = number of channels between flow lines
n_e = porosity
p = piezometric pressure (kPa)
p_c = earth pressure due to compaction (kPa)
p_0 = earth pressure at rest (kPa)
Q = volume flow rate (m^3/s)
Q_{50}, Q_{100} = geotextile flow rate under heads of 50 or 100 mm ((m^3/s)/m^2)
q = volume flow rate per unit horizontal width ((m^3/s)/m)
q_0 = volume flow rate per unit horizontal area ((m^3/s)/m^2)
Δq = incremental volume flow rate per unit horizontal width ((m^3/s)/m)
$\mathbf{R}$ = Reynolds number
R = radius of influence (m)
R_h = hydraulic radius (m)
r = radius (m)
$r_{w'}$ = internal radius of a well (m)
r_0 = internal radius of pipe to crest of corrugations (mm)
S = storativity
s_u = total strength (kPa)
T = transmissivity ((m^3/s)/m)
t = time (s)
t_0 = time intercept on zero drawdown axis (s)
t_b = basic time lag (s)
u = pore pressure (kPa)
V' = volume per unit horizontal area (m^3/m^2)
v_d = discharge velocity, =Q/A (m/s)
v_s = seepage velocity (m/s)
w = uniformly distributed line load (kN/m)
x, y, z = Cartesian co-ordinates
z_c = depth to maximum earth pressure due to compaction (m)
α = angle, slope angle
δ = horizontal deflection (mm)
θ = angular tilt from vertical
λ = axial pitch of pipe corrugations (mm)
ρ = density (Mg/m^3)
ϕ = friction angle
ϕ_r = friction angle, residual shear strength
ψ = permittivity (1/s)

Abbreviations

AASHTO American Association of State Highway and Transportation Officials
AE Acoustic emission

AOS	Apparent opening size
ASCE	American Society of Civil Engineers
ASTM	American Society for Testing and Materials
Caltrans	State of California, Department of Transportation
CCTV	Closed circuit television
CDH	California Division of Highways
CRO	Cathode ray oscilloscope
CU	Consolidated-undrained
DMR/RTA	Department of Main Roads/Roads and Traffic Authority, New South Wales, Australia
EDM	Electronic distance measurement
FS	Factor of safety
HDPE	High density polyethylene
ID, OD	Inside, outside diameter
LED	Light-emitting diode
NAVFAC	Naval Facilities Engineering Command, U.S. Navy
pH	Hydrogen potential
PVC	Polyvinyl chloride
RQD	Rock quality designation
SARN	Subaudible rock noise
SPT	Standard penetration test
STP	Special technical publication
TDR	Time domain reflectometry
USBR	United States Bureau of Reclamation
UU	Unconsolidated-undrained
UV	Ultra violet
WAE	Work-as-executed

Introduction

Groundwater and Instability

Groundwater has long been recognized as contributing to distress in various types of structures, and this is certainly true of slopes. A slope is more likely to fail during or after prolonged wet weather, and if the slope fails, the wet condition of the material within the slope is obvious. Several stability analysis methods are available and may be used to assess quantitatively the adverse effect of groundwater.

Diverting surface water over or around a slope is helpful. In particular, any ponds that form on or near an unstable area should be breached. However, a more effective way of dealing with the problem of groundwater as a cause of instability is to extract the water from within the slope, i.e., install some form of subsurface drainage system.

Groundwater naturally seeps out of all slopes to some extent, and causes failure only when the rate of discharge is inadequate, allowing excessive water pressure to build up. Subsurface drainage gives nature a helping hand by, for example, facilitating the movement of groundwater from the rock structure in a cutting, or allowing rapid discharge from an aquifer that has an artificially obstructed outlet.

Cedergren's Textbook

Seepage, Drainage and Flow Nets (Cedergren 1989) is probably the best known and most frequently quoted text on subsurface drainage. Since the first edition in 1967, the book has been useful to those involved with subsurface drainage.

Because Cedergren's book covers the whole range of subsurface drainage applications, some information is given brief treatment or is omitted altogether, leaving to the reader the task of seeking further details elsewhere. This is certainly apparent in the chapter that deals with slope drainage. Cedergren appears to have acknowledged this shortcoming with the publication of a separate book that dealt solely and extensively with the subsurface drainage of pavements (Cedergren 1974).

This Book

The intent here, then, is to try to do for slopes what Cedergren did for pavements. This book may be regarded as the continuation of *Seepage, Drainage and Flow Nets* within the limits of slope control technology. Matters that Cedergren developed will only be referred to, or at most quoted in outline for continuity of the argument. Readers are also urged to be familiar with Transportation Research Board's Special Report 247: *Landslides. Investigation and Mitigation* (1996), which addresses slope stability.

Although the chosen scope appears at first to be narrow, a slope stabilization project often involves a range of different skills. Most projects require the cooperation of geologists and engineers: the geologists to explore the site and provide a geotechnical model of it, and the engineers to devise an appropriate means of stabilization. One group often overlooked in professional writing is the drilling crew, even though their competence is vital to the successful completion of any geotechnical project. If drainage is involved, a groundwater hydrologist and/or a water chemist may also be needed. Each of these disciplines has a substantial body of background knowledge, and it is impossible to give detailed coverage of them within limited space. This book is intended primarily for engineers, and is written from an engineer's viewpoint. The other aspects, including structural geology, will be touched on only to the extent necessary for engineers to appreciate their relevance.

Even with this restriction, the field is still wide. Some areas such as slope stability analysis methods and pumping technology have become specialties in their own right. To keep the size of this book within reasonable limits, subjects such as these will also be given briefer treatment than their importance warrants, even though they are rightly within the province of engineers. In such cases, references are provided for more detailed reading.

Some of the information presented here was gathered from published literature, and some originates from work carried out by the Department of Main Roads (DMR). The DMR was the state highway authority for New South Wales, Australia, and was recently renamed Roads and Traffic Authority (RTA). The information is thus biased toward problems encountered in road work in general, and toward practices developed in DMR/RTA in particular.

General Comments

Système International (SI) units, i.e., meter/kilogram/second, are used throughout this book, with units derived from them, such as kilopascals (kPa). Exceptions are liters per hour (L/hr), the unit commonly used for the monitored rate of flow from a subsurface drain, and meters per minute (m/min), applied to the rate of movement of a jet cleaning nozzle. Large masses are quoted in megagrams (Mg). This is the unit preferred by ASTM E 380, in place of the identical units tonne and metric ton. Where referenced quantities have been originally quoted in foot-pound or cgs units, they will be converted here to SI, with rounding off as appropriate.

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This book is one of the results of this development. I acknowledge permission by Roads and Traffic Authority of New South Wales to use DMR/RTA material, including reproduction of the following figures from manuals and internal documents: 2.1–2.3, 2.5, 4.1, 4.2, 4.4, 5.5, 7.2, 7.3, 7.8, 7.12, 12.2, 13.10, 14.3–14.8, 14.20, 15.2, 15.7, 18.1, 19.3, and 19.4.