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Erosion rate of chemically stabilised soils incorporating tensile stress-deformation behaviour

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EROSION RATE OF CHEMICALLY STABILISED SOILS INCORPORATING TENSILE STRESS - DEFORMATION BEHAVIOUR

A thesis submitted
in fulfilment of the requirements for the Award of the Degree

DOCTOR OF PHILOSOPHY

from

UNIVERSITY OF WOLLONGONG

by

Thevaragavan Muttuvel, BSc Eng (Hons)

School of Civil, Mining and Environmental Engineering
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2008

THESIS CERTIFICATION

I, Thevaragavan Muttuvel, declare that this thesis, submitted in fulfillment of the requirements for the award of Doctor of Philosophy, in the School of Civil, Mining and Environmental Engineering, Faculty of Engineering, University of Wollongong, is wholly my own work unless otherwise referenced or acknowledged. The document has not been submitted for qualification at any other academic institution.

…………………………

Thevaragavan Muttuvel

April 2008

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Finally, the author dedicates this piece of work to his mother and sister because without their support it would have been impossible to achieve this goal.

LIST OF PUBLICATIONS

The following publications were generated during my research period.

Indraratna, B., Thevaragavan, M., Khabbaz, H., and Armstrong, R. (2007). “Predicting the erosion rate of chemically treated soil using a process simulation apparatus for internal crack erosion”, Journal of Geotechnical & Geo-environmental Engineering, ASCE, Accepted for publication.

Indraratna, B., Thevaragavan, M., and Khabbaz, H. (2007). “Modelling the erosion rate of chemically stabilised soil incorporating tensile stress-deformation characteristics”, Canadian Geotechnical Journal, Submitted for publication.

Indraratna, B., Thevaragavan, M., and Khabbaz, H. (2008). “Investigating erosional behaviour of chemically stabilised erodible soils”, Geotechnical special publication 178, Geo-congress 2008, ASCE, 670-677.

ABSTRACT

Problems associated with erodible soils have been reported in Australia and many parts of the world since the early 1970s. Significant soil loss from embankments, internal erosion and piping are some of the problems that practicing engineers face during the construction and maintenance phase of earth structures constructed with erodible soils. It is therefore necessary to identify appropriate stabilisation techniques to control erosion. This study considers chemical stabilisation as an erosion control method and a rigorous testing program has been conducted to investigate how effectively two chemical agents (general purpose Portland cement and lignosulfonate) control the erosion rate of two natural erodible soils (a silty sand and dispersive clay).

In this study, a Process Simulation Apparatus for Internal Crack Erosion (*PSAICE*) has been designed and built to conduct tests on chemically treated and untreated soil samples. The effect of the degree of compaction and moulding water content on erosional behaviour of soils has also been addressed. In addition, the tensile stress-deformation characteristics of chemically treated soil samples have been investigated using a uniaxial tensile testing apparatus, designed and built at University of Wollongong for this current research study.

One of the main objectives was to develop an analytical model for the erosion rate that incorporates the tensile stress-deformation characteristics of the soil. The model has been developed based on the law of the conservation of energy and validated using the results of erosion and uniaxial tensile tests conducted on chemically stabilised soil samples.

The results of the tests indicated that the erosion rate changes linearly with the hydraulic shear stress; slope of the line that represents the coefficient of soil erosion. The coefficient of soil erosion decreases, while the critical shear stress increases with an increasing amount of stabiliser,

irrespective of the soil type. It was also found that the coefficient of soil erosion of chemically treated soil has a strong relationship with its critical shear stress. Uniaxial tensile tests on chemically treated saturated samples showed that both stabilisers increase the tensile strength with a decrease in the displacement at failure.

Model validation demonstrated that only a fraction of flow energy (i.e. efficiency index) is used for the erosion process, and it depends on the hydraulic conditions of flow. Moreover, the proposed model can be used to predict the erosion rate of chemically treated erodible soils, if the tensile stress-deformation characteristics, mean particle diameter, dry density, and mean flow velocity through the crack are known.

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LIST OF SYMBOLS AND ABBREVIATIONS

Symbols	Description
A_s	Cross-sectional area of the soil sample used for tensile test
a, b	Constants
CP	Amount of chemical stabiliser
D	Mean particle diameter of soil
c, d	Constants
e	Void ratio
F	Inter-particle bond strength
F_J	Friction at the joint of tensile testing apparatus
F_T	Tensile force acting on the fracture plane
f	Friction factor
g	Gravitational acceleration
J	Jet index
k	Mean coordination number
k_c	Empirical factor relating turbidity to the soil solids concentrated in the flow
k'	Average number of common contacts (inter-particle bonds) per particle
L	Applied tensile load
l	Length of the sample used for erosion test

M	Total amount of soil eroded during an erosion test
m	Proportionality coefficient used for the prediction of critical shear stress of treated soil
P	Unit stream power
P_c	Critical unit stream power
Q_i	Flow rate of i^{th} time step
R	Mean particle radius
r	Contact radius between particles
S_v	Vane shear strength
s	Hydraulic gradient across the crack
T_i	Effluent turbidity of i^{th} time step
u_*	Shear velocity of the flow
v	Mean velocity of the flow through crack
v_c	Critical mean velocity of the flow through crack
W_A	Weight of the upper part of the tensile testing apparatus
W_S	Weight of the soil in the upper part of the tensile testing apparatus
α	Coefficient of soil erosion
λ, β, γ	Constants
δ_T	Tensile deformation
δ_{Tf}	Failure tensile deformation
χ	Relative roughness
$\dot{\varepsilon}$	Erosion rate

μ	Dynamic viscosity of the eroding fluid
ρ_d	Dry density of the soil
ρ_s	Density of the particle
ρ_w	Density of the eroding fluid
σ_T	Applied tensile stress
σ_{Tf}	Tensile strength of the soil
τ_a	Hydraulic shear stress
τ_c	Critical shear stress
ϕ_i	Soil crack diameter at time t
ω	Efficiency index

Abbreviations

PSAICE	Process Simulation Apparatus for Internal Crack Erosion