Hydro-Geotechnical Behaviour of Porous Coastal Structures

A H R Ratnasooriya

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A H R Ratnasooriya

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Professor S S L Hettiarachchi

Supervisor

ABSTRACT

Theoretical modeling of the flow field in the vicinity of a porous coastal structure was carried out to investigate the hydro-geotechnical behaviour of such a structure. The area of interest consists of the regions in front of and within the structure and in the sub soil below the sea bed, resulting in three inter-related flow models, External Flow, Internal Flow and the Pore Pressure Response Models.

In the External Flow Model, the governing equations are based on the principles of conservation of mass and momentum and were solved numerically by an explicit finite difference method. The model was shown to yield the flow characteristics and the computed wave run-up, run-down and reflection coefficient were shown to be in qualitative agreement with the available empirical formulae.

The governing equations in the Internal Flow Model are also based on the principles of conservation of mass and momentum and were solved by a mixed numerical technique involving a combined finite difference-method of characteristic scheme and a finite element method. The model was shown to represent the two dimensional nature of flow and yield satisfactory agreement with the experimental data for the position of the phreatic surface.

In the Pore Pressure Response Model, the governing equation for the flow in the soil is based on the principle of conservation of mass with the generation of pore pressure represented by an empirical expression. An explicit finite difference method was used to solve it and the solution provides the complete time history of pore water pressure response due to cyclic wave loading.

With the flow models shown to be capable of simulating the flow field in the vicinity of a porous coastal structure, this study forms a basis for further studies aiming at supplementing the design practices of such structures presently based on physical modeling and empirical formulations.

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LIST OF SYMBOLS

The important symbols used in the text are listed below. The symbols that have been used locally are not listed, but defined in the text. Some symbols have more than one meaning and it is evident from the text which meaning is intended. External Flow Model, Internal Flow Model and the Pore Pressure Response Model are abbreviated by EFM, IFM and PPRM respectively in the description of symbols. Still water level is abbreviated by SWL.

a	Non Darcy flow: laminar flow coefficient
a	Empirical constant: PPRM
A_{aw}	Area of unsaturated flow: IFM
A_0	Reference area for unsaturated flow region: IFM
b	Non Darcy flow: turbulent flow coefficient
b	Empirical constant: PPRM
c	Normalised wave celerity: EFM
c'	Wave celerity
C_{am}	Inertial coefficient associated with added mass: IFM
c_m	Maximum value of c: EFM
C_p	Pressure distribution correction factor: IFM
C_{vm}	Virtual mass coefficient: IFM
D'_{10}	Effective size in mm for sands: PPRM
D'_{15}	15% finer diameter from sieve analysis: EFM
D'_{85}	85% finer diameter from sieve analysis: EFM
D'_p	Representative armour diameter: EFM
Dr	Relative density of soil
d'	Depth of water below SWL: PPRM
d'_{50}	Nominal diameter of particles in the permeable layer: EFM
d'_p	Representative diameter of particles in the permeable layer: EFM

d_t	Normalised depth of water below the SWL at the toe of the slope: EFM
d'_t	Depth of water below the SWL at the toe of the slope: EFM
e	Void ratio
e_{max}	Maximum void ratio
e_{min}	Minimum void ratio
f	Normalised friction factor associated with the slope: EFM
f'	Friction factor associated with the slope: EFM
g	Acceleration due to gravity
H'	Wave height
H'	Piezometric head
H'_{eq}	Equivalent wave height: PPRM
H'_i	Incident wave height: IFM
H'_0	Still water depth: IFM
H'_m	Height of m^{th} wave component of storm: PPRM
H'_s	Significant wave height
h	Normalised depth of water above the slope: EFM
h'	Depth of water above the slope: EFM
h'_c	Characteristic thickness of the permeable layer: EFM
h_p	Normalised vertical thickness of the permeable layer: EFM
h'_p	Vertical thickness of the permeable layer: EFM
i	Hydraulic gradient
i_L	Non Darcy flow: laminar hydraulic gradient
i_T	Non Darcy flow: turbulent hydraulic gradient
K_D	Stability coefficient
$K(\nabla\phi')$	Non linear hydraulic conductivity: IFM
k'	Coefficient of permeability
$k'_{x'}$	Coefficient of permeability in x' direction: PPRM
$k'_{z'}$	Coefficient of permeability in z' direction: PPRM

k_r	Reflection coefficient: PPRM
L	Normalised wave length: EFM
L'	Wave length
L'_0	Deep water wave length
L'_m	Length of m^{th} wave component of storm: PPRM
M	Number of different wave components of the storm: PPRM
m	Normalised volume flux per unit width: EFM
m'_v	Coefficient of volume compressibility of soil: PPRM
m'_{v0}	Coefficient of volume compressibility of soil when the pore water pressure is zero: PPRM
N	Number of stress cycles: PPRM
N_{eq}	Equivalent number of uniform stress cycles: PPRM
N_L	Number of stress cycles to cause initial liquefaction: PPRM
N_m	Number of waves for m^{th} wave component of the storm: PPRM
n_p	Porosity
p	Dimensionless parameter expressing the degree of permeability effects on the flow over the rough permeable slope: EFM
p	Pore water pressure ratio
p'	Pore water pressure: PPRM
p_u	Dimensionless parameter: EFM
p'_0	Wave induced cyclic pressure on the sea bed: PPRM
p_0	Amplitude of wave induced cyclic pressure on the sea bed: PPRM
$(p)_{Rs}$	Residual pore water pressure ratio
p'_{Rs}	Residual pore water pressure
q_b	Normalised volumetric flow rate per unit horizontal area into the permeable layer: EFM
q'_b	Volumetric flow rate per unit horizontal area into the permeable layer: EFM
R_d	Normalised wave run down

R'_d	Wave run down
R_u	Normalised wave run up
R'_u	Wave run up
Re	Reynolds number
s	Relative density of armour unit
s	Relative density of soil particles
s	Wet node next to instantaneous waterline : EFM
t	Normalised time
T'	Wave period
T'_m	Period of m^{th} wave component of storm: PPRM
T'_m	Average period of zero up crossings of waves: EFM
t'	Time
T'_D	Duration of storm
u	Normalised depth averaged horizontal velocity above the slope: EFM
u'	Depth averaged horizontal velocity above the slope: EFM
u'	Depth averaged flow velocity: IFM
u_b	Normalised horizontal flow velocity into the permeable layer: EFM
u'_b	Horizontal flow velocity into the permeable layer: EFM
u_i	Normalised horizontal velocity due to incident wave: EFM
u_m	Maximum value of u: EFM
u_p	Normalised vertically averaged horizontal flow velocity in the permeable layer: EFM
u'_p	Vertically averaged horizontal flow velocity in the permeable layer: EFM
u_r	Normalised horizontal velocity due to reflected wave: EFM
U_r	Ursell parameter
$u'_{x'}$	Flow velocity in x' direction: PPRM
$u'_{z'}$	Flow velocity in z' direction: PPRM
v'	Flow velocity
v'_p	Mean flow velocity of pore fluid

V_{max}	Maximum run up velocity: IFM
V_r	Run up velocity: IFM
W'	Weight of armour unit
x	Normalised horizontal coordinate
x'	Horizontal coordinate
x_{max}	Normalised half width of the soil deposit: PPRM
x_s	Normalised horizontal coordinate of the moving waterline: EFM
z	Normalised vertical coordinate
z'	Vertical coordinate
z_{max}	Normalised thickness of the soil deposit: PPRM
z'_{max}	Thickness of the soil deposit: PPRM
α	Landward advancing characteristic: EFM
α	Characteristic direction: IFM
α'	Non Darcy flow: laminar flow coefficient: EFM
α_0	Dimensionless constant: non Darcy flow
β	Seaward advancing characteristic: EFM
β	Characteristic direction: IFM
β'	Non Darcy flow: turbulent flow coefficient: EFM
β_0	Dimensionless constant: non Darcy flow
γ	Unit weight of armour unit
γ'	Submerged unit weight of soil: PPRM
γ_{sat}	Saturated unit weight of soil
γ_w	Unit weight of water
δ	Normalised water depth specified at the moving waterline : EFM
δ'	Water depth specified at the moving waterline : EFM
$\Delta p'$	Net change in pore water pressure: PPRM
$\Delta p'_d$	Pore water pressure dissipated: PPRM
$\Delta p'_g$	Pore water pressure generated: PPRM

$(\Delta p'_g)_{Rs}$	Residual pore water pressure generated: PPRM
$(\Delta p'_g)_{Tr}$	Transient pore water pressure generated: PPRM
Δt	Normalised temporal increment of numerical computation
$\Delta t'$	Temporal increment of numerical computation
$\Delta t'_{max}$	Maximum temporal increment of numerical computation
Δx	Normalised horizontal spatial increment of numerical computation
$\Delta x'$	Horizontal spatial increment of numerical computation
Δz	Normalised vertical spatial increment of numerical computation
$\Delta z'$	Vertical spatial increment of numerical computation
$\Delta \sigma$	Change in mean total stress: PPRM
$\Delta \sigma'$	Change in effective stress: PPRM
$\varepsilon_{x'}$	Normal strain in x' direction: PPRM
$\epsilon_{z'}$	Normal strain in z' direction: PPRM
η	Normalised free surface elevation above SWL: EFM
η'	Free surface elevation above SWL: EFM, IFM, PPRM
η_i	Normalised free surface elevation of the incident wave above SWL: EFM
η_r	Normalised free surface elevation of the reflected wave above SWL: EFM
θ	Normalised angle of the structural slope: EFM
θ	Empirical constant related to pore water pressure generation: PPRM
θ'	Angle of the structural slope
λ	Friction factor
μ	Dimensionless parameter expressing the order of magnitude of the laminar flow resistance as compared to turbulent flow resistance: EFM
ξ	Surf similarity parameter
ρ	Density of fluid
σ	Mean normal total stress in the soil deposit: PPRM
σ'	Infiltration per unit horizontal length: IFM
σ_h	Horizontal normal total stress in the soil deposit: PPRM

σ_v	Vertical normal total stress in the soil deposit: PPRM
σ'_{v0}	Initial vertical effective stress in soil when the pore water pressure is zero: PPRM
τ'_b	Shear stress related to the roughness of the slope: EFM
τ_{vh}	Shear stress in the soil deposit: PPRM
ν	Coefficient of kinematic viscosity
ϕ	Normalised piezomeric head: IFM
ϕ'	Piezomeric head: IFM
ψ'	Function giving pore water pressure generation under undrained conditions: PPRM

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