A SPECTRAL APPROACH TO THE TRANSIENT ANALYSIS OF WAVE-FORMED SEDIMENT RIPPLES

by Joseph P. Davis

Submitted in fulfilment of the requirements for the degree of
DOCTOR OF PHILOSOPHY

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FACULTY OF ENGINEERING, COMPUTER AND MATHEMATICAL SCIENCES

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THE UNIVERSITY
OF ADELAIDE
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Abstract

Wave-formed rippled sediment beds are extremely important to the processes that act on or across the sediment-water interface. Ripples increase the exchange of materials between the sediment and the water column, enhance sediment transport rates, and act to increase the dissipation of waves by increasing the hydraulic roughness of the seafloor. Previous research has, however, failed to take into account the substantial spatial and temporal variation rippled beds display when formed under real sea conditions. Based on a set of laboratory experiments a spectral method to predict and model rippled beds has been developed. Through the use of the rippled surface's spectral density function the spatial and temporal variability of the rippled surface can be taken into account with greater efficiency.

A prediction method for the equilibrium ripple spectrum was developed based on a non-dimensional spectral form, which utilised the peak orbital excursion diameter and the 50th percentile grain size diameter of the sediment bed. The method provided an effective technique to predict ripple parameters with the same degree of accuracy achievable at small scale as more accepted ripple prediction methods.

A new method was derived to model the changes a rippled bed undergoes as it actively evolves between two given equilibrium states due to a change in surface wave conditions. The evolution of a rippled bed can be described mathematically in exactly the same way as a rippled bed growing from a flat bed condition. The method allows any bed to be modelled through time if the flow conditions and sediment properties are known.

There is little advantage in using the spectral method to predict rippled beds when they *are in equilibrium with the flow conditions. The main benefit of the spectral method comes when attempting to model rippled beds evolving under changed flow conditions. In the same way as the parameterisation of surface waves in terms of their spectral density function has increased the ability to model wind generated wave fields, studies of rippled beds would benefit from the increased detail and ease the spectral method brings.*

Statement of Originality

I Joseph P. Davis hereby declare that this work contains no material that has been accepted for the award of any other degree or diploma in any university or other tertiary institution. To the best of my knowledge and belief, it contains no material previously published or written by any other person, except where due reference is made in the text.

I give consent to this copy of my thesis, when deposited in the University Library, being available for loan and photocopying.

SIGNED: . . . . *DATE:* . . . .

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List of Symbols

Symbol	**Quantity**	**SI Unit**
a_0	polynomial fitting parameters	–
a_1	polynomial fitting parameters	–
a_2	polynomial fitting parameters	–
C_u	coefficient of uniformity	–
C_v	coefficient of variation	–
D	generic sediment grain diameter	m
d	general orbital excursion diameter	m
D_{30}	30 percentile grain size diameter	m
D_{50}	50 percentile grain size diameter	m
D_{60}	60 percentile grain size diameter	m
d_m	maximum orbital excursion diameter	m
d_o	orbital excursion diameter from linear theory	m
d_{op}	peak orbital excursion diameter	m
E	non-dimensional spectral energy	–
$\bar{E}$	total average energy of the wave profile	$kg.s^{-2}$
E_f	final non-dimensional spectral energy	–
E_o	initial non-dimensional spectral energy	–
F	general wavenumber spectrum	–
f_p	peak surface wave frequency	Hz
F_s	sample frequency	Hz
f_s	spatial frequency	m^{-1}
f_s'	non-dimensional spatial frequency	–
f_{s1}	lower banding spatial frequency	m^{-1}
f_{s2}	upper banding spatial frequency	m^{-1}
f_{sp}	peak spatial frequency	m^{-1}
f_w	wave friction factor	–
g	gravity constant	$m.s^{-2}$
$G(f_s)$	Fourier transform of g(x)	–

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Symbol	Quantity	SI Unit
$g(x)$	general sediment surface function	–
h	distance from bed	m
h	water depth	m
H_s	significant wave height	m
K	*Tsujimoto and Nakagawa* [1983] coefficient	–
k	wavenumber	$rad.m^{-1}$
k_f	bed form roughness	m
k_g	grain roughness	m
K_N	effective sand grain roughness	m
l	correlation length	m
m_n	the nth moment of the spectral density	$m^2.s^{-n}$
n	spectral function fitting parameter	–
n	number of data points	–
N_R	normalised residual error	–
P	general power spectrum	m^2
p_e	equilibrium value of ripple parameter (ripple height or length)	m
p_e	estimated ripple parameter (ripple height or length)	m
p_m	measured ripple parameter (ripple height or length)	m
p_o	generic ripple parameter (ripple height or length)	m
Q	*Pouliquen et al.* [2000] joint probability distribution function	–
Q	spectral peakedness parameter	–
Q_w	surface wave wavenumber spectrum	$m3^3.rad^{-1}$
$\Re$	Reynolds number	–
R^2	linear correlation coefficient	–
$\Re_d$	sediment Reynolds number	–
S	general spectral function	–
S	general variance spectrum	$m^2.s$
S_I	incident wave spectrum	m^2/Hz
S_R	reflected wave spectrum	m^2/Hz
s	relative sediment density (rs/rw)	–
S'	non-dimensional ripple spectrum	–
S_*	non-dimensional sediment parameter	–
S_r	ripple variance spectrum	m^3
S_u	bottom velocity variance spectrum	$m^2.s^{-1}$
S_{vp}	peak spectral density	m^3
S_w	surface wave variance spectrum	$m^2.s$

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Symbol	Quantity	SI Unit
T	wave period	s
t	time	s
t_e	equilibrium time	s
T_e	time to reach equilibrium	s
U_o	orbital velocity from linear theory	$m.s^{-1}$
U_p	peak bottom orbital velocity	$m.s^{-1}$
U_{rms}	root mean squared velocity	$m.s^{-1}$
V	voltage output	V
W	*Pouliquen et al.* [2000] gaussian seafloor function	$m^3.rad^{-1}$
W_g	*Lyons et al.* [2002] seafloor function	$m^3.rad^{-1}$
α	form roughness proportionality coefficient	–
α	evolution rate	s^{-1}
α	*Grinvald and Nikora* [1988] scaling exponent	–
α	spectral function fitting parameter	–
α	*Hino* [1968] power law constant	–
β	spectral function fitting parameter	–
γ	*Shuliak* [1971] coefficient	–
γ	spectral function fitting parameter	–
γ	*Hino* [1968] power law exponent	–
γ	JONSWAP shape coefficient	–
δ	*Pouliquen et al.* [2000] correction factor	–
η	ripple height	m
η_c	characteristic ripple height	m
Θ	spectral function fitting parameter	–
ϑ	Shields number	–
ϑ_c	critical Shields number	–
λ	ripple length	m
λ_c	characteristic ripple length	m
μ	mean of the record	m
π	pi constant	–
ρ_s	sediment density	$kg.m^{-3}$
ρ_w	water density	$kg.m^{-3}$
σ	standard deviation of the record	m
υ	kinematic viscosity	$m^2.s^{-1}$
υ	spectral width factor	–

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Symbol	**Quantity**	**SI Unit**
Φ_r	wave reflection coefficient	–
ϕ_{50}	phi sediment size based on the D_{50} of the sediment	–
χ	period parameter	–
ψ	mobility number	–
ω	radian or angular frequency	$rad.s^{-1}$