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**Wave-Wave Interactions and the
Infrasonic Pressure Field
in the Ocean**

A thesis submitted to

The University of Auckland

in partial fulfilment of
the requirements for the degree of

Doctor of Philosophy in Physics

by

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Abstract

Building on Kibblewhite's long term investigations of the nonlinear wave-wave interactions and the infrasonic ocean noise and the microseisms these induce, this thesis further explores the physical nature of these processes. The classical description of this interaction, which takes into account only the homogeneous component of the induced field, has been extended to include the inhomogeneous component. A complete expression for the wave induced noise spectrum is established following a geometrical analysis of the dispersion relations among interacting waves. The relative importance of these two components and their directivity properties are also calculated and discussed. It is shown that while at observation points deeper than 500 meters the effects of the inhomogeneous component can be regarded as negligible, it can cause an increase of noise level of up to 40 *dB* in the region near the surface of the sea. Furthermore, in contrast to the nearly omni-directional distribution of the homogeneous component of the induced acoustic field, there is a tendency for the energy associated with the inhomogeneous component to focus in the wind direction.

Based upon a multilayer analysis of a visco-elastic geoacoustic model, Green's functions and the spectral transfer functions relating the surface source pressure field to the underwater noise and microseism fields are derived for both near and far field cases. A 3-dimensional presentation defined on the dispersion plane (frequency and horizontal wave number) is introduced to describe the sea bottom reflection-loss and Green's functions, and is extended to include the inhomogeneous region for the first time. The characteristics of this 3-D presentation are explained in terms of the geoacoustic parameters.

The influence of the interaction of multiple seas (and swell) on the induced acoustic field are also discussed in this thesis.

All these effects are considered in the calculation of the synthetic spectra of both the noise and microseism field. When compared with measured data excellent agreement is found between the theoretical and experimental results, which provides further confirmation that the nonlinear interaction is the most important source of the infrasonic ocean noise, as well as confirming the basic validity of the procedure introduced by Kibblewhite and Ewans to derive the ocean noise spectra from microseism records.

Acknowledgements

Now I am finally close to the end of the project. I am very excited. Four years ago, attracted by the interesting connection between the ocean wave activities and microseismic noise records reported by Kibblewhite and Ewans I began this study. When I firstly got from Professor Kibblewhite his collection of four fully packed boxes of reference papers I could not keep from being surprised by the complexity and involvement of this subject. So many branches of science: air turbulent motion, ocean wave development, underwater acoustics, and seismic wave propagation are involved and I wondered what I should choose to do first. It was Professor Kibblewhite who had then suggested and encouraged me to focus on the physical nature of the wave interaction process and the energy transfer in real environments. For the last four years I have been kept in going progressively in this direction without straying.

Reviewing the whole process I owe all the progresses in the study to Professor Kibblewhite, my supervisor. His close guidance is vitally important to my studies at each stage. His enthusiasm for exploring unknowns as well as the spirit of devoting to science have greatly influenced me, and most importantly, his deep insight into the subject and rich in experiences of scientific researches have from time to time guided me solving all the problems I met. Infact, what I have done is only small improvements based on his previous wide range investigations. I owe him also most of original ideas and motivations in the development of this study. I got from him all the geoacoustic parameters and experimental data used in the thesis. Besides these, he finantially supported me to cover all the expenses. Without all these it would never be possible for me to finish this study. Another thing which often touched me deeply was the great patience he exercised in correcting my poor English drafts and even rewriting them.

I would also like to address here my warm acknowledgment to Dr.K.C. Ewans. His comprehensive thesis, "Ocean Waves, Microseisms, and Their Interrelations", recorded vast amount of experimental data, from which I learned about the previous investigations as well as the background knowledge about the subject.

I thus always feel it not proper to put only my name as the auther of the thesis. In fact in this long period of study I received also large amount of help, beside those mentioned above, from all my friends and colleagues in the department.

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Contents

CHAPTER 1	Introduction	1
	References	4
CHAPTER 2	The Generation of Infrasonic Ambient Noise in the Ocean by Nonlinear Interactions of Ocean Surface Waves	6
	2.1 Introduction	
	2.2 Non-Linear Interaction Between Plane Surface Wave Trains and the Resulting Source Pressure Field	7
	2.3 Response of a Liquid Layer Overlying a Solid Half-Space to a Plane-Wave Pressure-Field	13
	2.4 The Underwater Infrasonic Noise Field Induced by Nonlinear Interactions in Surface Wind Waves	15
	2.5 The Spectral Transfer Functions and Their Approximations	19
	2.6 The Shear-Wave Contribution	22
	2.7 Summary	28
	References	30
	Appendix	32
CHAPTER 3	The Relative Levels of the Homogeneous and Inhomogeneous Components of the Acoustic Pressure Field	65
	3.1 Introduction	
	3.2 Geometrical Description of Wave-Wave Interactions	66
	3.3 Wave Number-Frequency Spectrum of the Pressure Field	70
	3.4 Homogeneous and Inhomogeneous Components of the Pressure Field	71
	3.5 General Expressions for the Wave-Induced Underwater Pressure Field and Microseisms	73
	3.6 Space-Time Covariance and an Equivalent Source Level of the Noise Pressure-Field	76
	3.6.1 An analysis based on the plane-wave reflection coefficient	76
	3.6.2 An analysis based on the Green's function	77
	3.6.3 Comparison of the two approaches	78
	3.6.4 Ocean surface-noise source level	81

	3.7	Summary	83
		References	85
		Appendix	87
CHAPTER 4		Directivity of the Underwater Acoustic Field Induced by Nonlinear Interaction of Ocean Surface Gravity Waves	94
	4.1	Introduction	
	4.2	Nonlinear Coupling of Interacting Surface Waves And the Induced Acoustic Wave Field	95
	4.3	Angular Distribution Function of the Homogeneous Component	97
	4.4	Angular Distribution Function of the Inhomogeneous Component	101
	4.5	Numerical Examples	102
	4.6	Summary	104
		References	105
		Appendix	107
CHAPTER 5		A Reexamination of the Role of Wave-Wave Interactions in Ocean Noise Generation	109
	5.1	Introduction	
	5.2	Basic Theoretical Predictions	110
	5.3	The Ocean-Wave Spectra	112
	5.4	The Influence of the Spreading Coefficient on the Pressure Field	113
	5.5	The Transfer Function	116
	5.6	The Event of 16-24 October 1981	117
	5.7	The Case of Multiple Seas	119
	5.8	The Sediment - Velocity Structure	122
	5.9	The Shear-Wave Contribution	123
	5.10	The Theoretical and Revised Experimental Curves	124
	5.11	Frequency Dependence of the Noise Fields	125
	5.12	Conclusions	127
		References	129
		Appendix	131
CHAPTER 6		The Plane-Wave Reflection Coefficient for a Multi-Layered Visco-Elastic Seabed	132

6.1	Introduction	
6.2	Plane-Wave Reflection From a Layered Half-Space	135
6.2.1	Propagator Matrix	137
6.2.2	Reflection From Solid Layers	139
6.2.3	Reflection from liquid layers	142
6.3	Examination of the Frequency-Wave Number Spectrum of the Bottom Reflection-Loss	142
6.3.1	Preamble	142
6.3.2	Reflection loss for the K model	143
6.3.3	The case of two contacting half-spaces	145
6.3.4	The three layer model	147
6.4	Summary	152
	References	153
CHAPTER 7	Spectral Transfer Functions and Green's Functions for a Multilayered Seabed	156
7.1	Introduction	
7.2	The Integral Solution of the Wave-Induced Underwater Pressure and Microseismic Fields	157
7.3	Far and Near-Field Approximations	162
7.4	Spectral Transfer Function	164
7.5	On-Shore Microseism Response	168
7.6	The Green's Function in its Three Dimensional Form	170
7.6.1	Two-layered model involving the water layer and a "hard" seabed	171
7.6.2	Three layer models	173
7.6.3	The K -model	174
7.7	Summary	174
	References	176
	Appendix	177
CHAPTER 8	Spectral Characteristics Of The Wave-Induced Pressure-Field	184
8.1	Introduction	
8.2	The Influence of Water Depth	185
8.3	The $ E ^2$ Functions for the MK -Model	186
8.4	The Effect of the Unconsolidated Sediment Layer	188
8.5	The Effects of the Low Shear-Velocity Layer ($LSVL$)	189

8.6	Comparison with the Kibblewhite-Ewan's (KE) Spectra	189
8.7	Comparison with the Webb and Cox Experiment	192
8.8	Comparison of Synthetic Microseismic Spectra with the Measured Data	194
8.9	Summary	195
	References	197
	Appendix - Analysis of the $ E ^2$ Functions in the δ - f Plane	199
A.1	The Case of a Water Layer Overlying a Solid Half-Space	199
A.2	The Multilayered Case	201
CHAPTER 9	Conclusions	204