

การประยุกต์ใช้วิธีวิเคราะห์คลื่นผิวแบบหลายช่องสัญญาณเพื่อการสำรวจชั้นดิน
ระดับตื้นของประเทศไทย



นาย ชูจน์ เสง

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิศวกรรมศาสตรมหาบัณฑิต
สาขาวิชาวิศวกรรมโยธา ภาควิชาวิศวกรรมโยธา
คณะวิศวกรรมศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย
ปีการศึกษา 2551
ลิขสิทธิ์ของจุฬาลงกรณ์มหาวิทยาลัย

**APPLICATION OF MULTICHANNEL ANALYSIS OF SURFACE WAVE TO
SHALLOW SITE INVESTIGATION FOR SUBSOIL IN THAILAND**

Mr. Sochan Seng

A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Engineering Program in Civil Engineering

Department of Civil Engineering

Faculty of Engineering

Chulalongkorn University

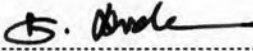
Academic Year 2008

Copyright of Chulalongkorn University

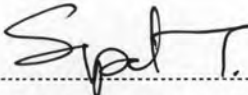
511510

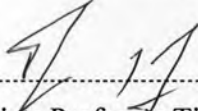
Thesis Title APPLICATION OF MULTICHANNEL ANALYSIS OF
SURFACE WAVE TO SHALLOW SITE INVESTIGATION
FOR SUBSOIL IN THAILAND
By Mr. Sochan Seng
Field of Study Civil Engineering
Thesis Advisor **Associate Professor Tirawat Boonyatee, D. Eng.**
Thesis Co-advisors **Associate Professor Hiroyuki Tanaka, D. Eng.**

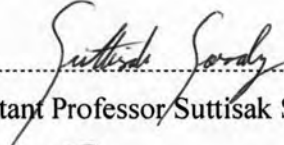
Accepted by the Faculty of Engineering, Chulalongkorn University in
Partial Fulfillment of the Requirements for the Master's Degree

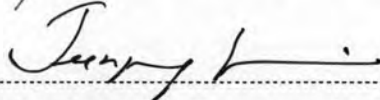
 Dean of the Faculty of Engineering
(Associate Professor Boonsom Lerthirunwong, Dr. Ing.)


THESIS COMMITTEE

 Chairman
(Professor Supot Teachavorasinskun, D. Eng.)

 Thesis Advisor
(Associate Professor Tirawat Boonyatee, D. Eng.)

 External Member
(Assistant Professor Suttisak Soralump, Ph. D.)

 Member
(Associate Professor Teerapong Senjuntichai, Ph. D.)

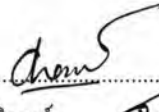
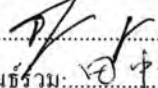
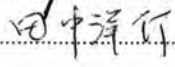
 Member
(Assistant Professor Anat Ruangrassamee, Ph. D.)

การประยุกต์ใช้วิธีวิเคราะห์คลื่นผิวแบบหลายช่องสัญญาณเพื่อการสำรวจชั้นดินระดับตื้น
ของประเทศไทย (APPLICATION OF MULTICHANNEL ANALYSIS OF SURFACE
WAVE TO SHALLOW SITE INVESTIGATION FOR SUBSOIL IN THAILAND) อ.ที่
ปริกษาวิทยานิพนธ์ : รศ.ดร.จิรวัตร์ บุญญะฐิติ, อ.ที่ปริกษาวิทยานิพนธ์ร่วม:
ASSOC.PROF.HIROYUKI TANAKA, D. Eng.

วิธีวิเคราะห์คลื่นผิวแบบหลายช่องสัญญาณเป็นวิธีการสำรวจชั้นดินแบบไม่ทำลายที่ถูก
พัฒนาขึ้นไม่นาน การทดสอบกระทำบนผิวดินโดยไม่ต้องเจาะหลุมสำรวจและได้ผลลัพธ์เป็นค่า
ความเร็วของคลื่นเฉือนซึ่งจำเป็นสำหรับการออกแบบเชิงพลวัต กระบวนการทดสอบประกอบด้วย
3 ขั้นตอนย่อย ได้แก่ การตรวจวัดภาคสนาม การแปลงโดยใช้ผลการแปลงของฟูรีเยร์ในปริภูมิสอง
มิติ และ การคำนวณย้อนกลับเพื่อหาค่าความเร็วของคลื่นเฉือน

ในการศึกษานี้ได้ทำการทดสอบด้วยวิธีดังกล่าวพร้อมกับการทดสอบดาวน์โฮลในสถานที่ต่างๆ
ในประเทศไทยจำนวน 7 แห่ง ทั้งนี้มีวัตถุประสงค์ 3 ประการคือ เพื่อตรวจสอบความน่าเชื่อถือของ
วิธีทดสอบ เพื่อหาวิธีประเมินผลที่เหมาะสม และ เพื่อหาเทคนิคการทดสอบที่ให้ผลดี การศึกษา
กระทำโดยการเปรียบเทียบผลการวิเคราะห์ที่ได้กับผลการทดสอบของนักวิชาการอื่นๆ ซึ่ง
ประกอบด้วยผลการทดสอบดาวน์โฮล ผลการเจาะสำรวจดิน และ ผลการทดสอบด้วยกรวยหยั่ง
แบบสั้น (Seismic Cone Penetration Test)

จากการศึกษาพบว่า การคำนวณย้อนกลับด้วยวิธี $\lambda/3$ ให้ผลที่สอดคล้องกับการทดสอบวิธีอื่นๆ
ดังนั้นวิธีวิเคราะห์คลื่นผิวแบบหลายช่องสัญญาณจึงน่าจะเป็นอีกทางเลือกหนึ่งที่ใช้ได้สำหรับการ
สำรวจชั้นดินในประเทศไทย สำหรับการศึกษาด้านเทคนิคการทดสอบพบว่า ชุดอุปกรณ์และ
ลักษณะการจัดวางที่ใช้ในการศึกษานี้สามารถสำรวจได้ลึกที่สุดถึง 20 เมตร โดยควรจัดให้
แหล่งกำเนิดคลื่นห่างจากมาตรวัดสัญญาณตัวแรกเป็นระยะประมาณร้อยละ 20 ถึง 30 ของความยาว
วัดจากมาตรวัดสัญญาณตัวแรกถึงตัวสุดท้าย

ภาควิชา: วิศวกรรมโยธา ลายมือชื่อนิสิต: 
สาขาวิชา: วิศวกรรมโยธา ลายมือชื่อที่ปริกษาวิทยานิพนธ์: 
ปีการศึกษา: 2551 ลายมือชื่ออาจารย์ที่ปริกษาวิทยานิพนธ์ร่วม: 

##4970764221: MAJOR CIVIL ENGINEERING

KEYWORDS : MASWM/TIME-SPACE/2D FFT/FREQUENCY-WAVENUMBER/
INVERSION/DOWNHOLE/SHEAR WAVE VELOCITY

SOCHAN SENG: APPLICATION OF MULTICHANNEL ANALYSIS OF
SURFACE WAVE TO SHALLOW SITE INVESTIGATION FOR SUBSOIL IN
THAILAND. THESIS PRINCIPAL ADVISOR: ASSOC. PROF. TIRAWAT
BOOYATEE, D. Eng. THESIS CO-ADVISOR: ASSOC. PROF. HIROYUKI
TANAKA, D. Eng.

The multichannel analysis of surface wave method (MASWM) is a nondestructive test recently developed for subsoil characterization. By conducting the test on ground surface, the shear wave velocity which is a necessary parameter for dynamic analysis, can be easily attained. In this study, the tests have conducted at seven sites in Thailand along with the seismic downhole test, searching for the validity and proper inversion algorithm as well as the best practice for testing. The process consists of three sequences which are the field data collection, the transformation by the Two Dimensional Fast Fourier Transform (2D FFT), and the inversion to shear wave velocity profile. Afterward, the obtained shear wave velocity profiles are investigated by comparing with the predictions by other methods; namely those from seismic downhole tests, boring reports, and Seismic Cone Penetration Test (SCPT). It is found that the $\lambda/3$ inversion algorithm offers the predictions that are consistent with other methods. Therefore, it is concluded that MASWM is also a valid choice for subsoil exploration in Thailand. For the test configuration, it is recommended that the distance between the seismic source to the first geophone should be around 25 to 30% of the spread length. When using the same equipment and configuration, the investigation depth is limited to 20m. In addition, the sophisticated inversions are recommended for future research.

Department: Civil Engineering

Field of Study: Civil Engineering

Academic Year: 2008

Student's Signature: Chan S

Advisor's Signature: Tirawat

Co-advisor's Signature: 田中洋行

ACKNOWLEDGEMENTS

I would like to express my deepest and sincerest appreciation and gratitude to my generous advisor, Associate Professor Dr. Tirawat Boonyatee and co-advisor, Associate Professor Dr. Hiroyuki Tanaka, for always spending their precious times to show me the valuable instruction, advice, support, and encouragement during my study at Chulalongkorn University. I would like also to take this moment to apologize for all my mistakes that made them disappointed.

I honestly thank to AUN/SEED-Net (JICA) for financially support and officially coordinate for my study and to all the officers and staffs of AUN/SEED-Net for their helpfulness and kind cooperation.

Special thanks to my thesis committees: Professor Dr. Supot Teachavorasinskun, Associate Professor Dr. Teerapong Senjuntichai, Assistant Professor Dr. Anat Ruangrassamee, and Assistant Professor Dr. Suttisak Soralump, for their extensive comments and constructive discussion on my thesis. Again, I would like to extend my gratitude to Assistant Professor Dr. Anat Ruangrassamee for providing me the financial support and opportunities to join his team in conducting the research at different places.

I would appreciate to all the lecturers and professors at the Department of Civil Engineering, Chulalongkorn University, for their prolific sources of knowledge, and wisdoms.

I am definitely grateful to all my generous friends and especially Mr. Opart Petset who have been working hard to help me in conducting the in situ testing and also to Mr. Chitti P. who offers me the data of seismic downhole tests for my research.

Last but not least, I would show my profoundly gratitude and love to my family who always taking care, giving love and encouragement. They never let me down. Without them this thesis can not be achieved.

CONTENTS

	Page
Abstract (Thai)	iv
Abstract (English)	v
Acknowledgements	vi
Contents	vii
Table of Tables	ix
Table of Figures	x
CHAPTER I INTRODUCTION	1
1.1 Research Motivation	1
1.2 Research Objectives.....	2
1.3 Scope of Study	2
1.4 Research Outcome	3
CHAPTER II LITERATURE REVIEW	4
2.1 Overview.....	4
2.2 Steady State Rayleigh Method (SSRM)	5
2.3 Spectral Analysis of Surface Wave Method (SASWM).....	7
2.3.1 Field Configuration.....	7
2.3.2 Signal Processing and Dispersion Curve Construction	10
2.3.3 Normally and Inversely Dispersive Systems	13
CHAPTER III THEORETICAL BASIS OF MASWM	16
3.1 Overview.....	16
3.2 Notation of Useful Relationship	16
3.3 Spatial Sampling Rate for MASWM Test	17
3.4 Temporal Sampling Rate for MASWM test.....	18
3.5 Two Dimensional Fast Fourier Transform (2D FFT).....	19
3.6 Body Wave and Surface Wave	19
3.7 Rayleigh Waves in an Infinite Homogeneous Half-Space	20
3.8 Rayleigh Wave in an Heterogeneous Media	24

	Page
3.9 Near-Field and Far-Field Effects	25
CHAPTER IV RESEARCH METHODOLOGY	26
4.1 Overview.....	26
4.2 Research Framework	27
4.3 Research Assumption	28
4.4 Data Collection	28
4.4.1 Field Equipment.....	28
4.4.2 Test Setup.....	30
4.4.3 Raw Data.....	32
4.5 Data Processing	36
4.6 Data Inversion.....	44
CHAPTER V RESULTS AND INTERPRETATIONS	46
5.1 Overview.....	46
5.2 Results from Downhole Test and Boring Reports.....	46
5.3 Extra References from Downhole Test and SCPT	47
5.4 Data Comparison and Interpretation.....	48
CHAPTER VI CONCLUSIONS AND RECOMMENDATIONS.....	58
6.1 Conclusions.....	58
6.2 Recommendations.....	59
References	60
Appendices	63
Appendix A Shear wave velocities from MASWM	64
Appendix B Downhole test and Boring log results	65
Appendix C Comparison Computation	71
Biography	82

LIST OF TABLES

		Page
Table 4-1	Active Source Acquisition Parameters	31
Table 4-2	the Nyquist frequencies and wavenumbers of seven sites	40
Table 5-1	Shear wave velocity from Downhole test and SCPT	47
Table A-1	Shear wave velocities from MASWM	64
Table B-1	Shear wave velocities from downhole test at seven sites	67
Table B-2	Boring log reports at seven sites	68
Table B-3	Shear wave velocities from boring log at seven sites	70
Table C-1	Shear wave velocity comparison at Chula	71
Table C-2	Shear wave velocity comparison at TMD Bangkok	73
Table C-3	Shear wave velocity comparison at AIT	75
Table C-4	Shear wave velocity profiles at Kirdkao Observatory	77
Table C-5	Shear wave velocity comparison at TMD Kanchanaburi	78
Table C-6	Shear wave velocity comparison at ChiangMai University	79
Table C-7	Shear wave velocity comparison at Wat Chediluang, ChiangMai	81

LIST OF FIGURES

	Page
Figure 2-1 Field Procedure for Steady State Rayleigh Method (After Rix 1988).....	5
Figure 2-2 Determination of Average Wavelength of Rayleigh Waves by SSRM (from Richart et al. 1970).....	6
Figure 2-3 SASWM field configuration (Stokoe et al., 1994)	8
Figure 2-4 Common Receiver midpoint array with source position reversing (Foti, 2000)	9
Figure 2-5 Common Source array (Foti, 2000)	9
Figure 2-6 Example of SASW signals: (a) whole signals; (b) wave-train arrivals. (site: ENEA; source: 6kg hammer; d=2m) (Foti, 2000)	10
Figure 2-7 Spectral quantities evaluated from the signals of Figure 2.6 : (a) Phase of the cross-power spectrum; (b) Coherence function; (c) Auto-power spectrum (first receiver); (d) Auto-power spectrum (second receiver) (Foti, 2000).....	12
Figure 2-8 Normal and Inverse Dispersion Phenomenon (Roma, 2001)	14
Figure 2-9 a, b: Normally and Inversely Dispersive layered half-spaces (Foti, 2000)	15
Figure 3-1 Relation between Poisson's ratio and velocity of propagation of compression (P), shear (S) and Rayleigh (R) waves in a linear elastic homogeneous half-space (Foti, 2000).....	22
Figure 3-2 Rayleigh disturbance on the free surface of a homogeneous half- space.....	23
Figure 3-3 Amplitude ratio vs. dimensionless depth for Rayleigh wave in a homogenous half-space (Foti, 2000).....	23
Figure 3-4 The geometrical dispersion in a layered medium (Rix, 1988).....	24
Figure 4-1 Flow chart of research framework	27
Figure 4-2 A 10 lb sledge hammer and a plate steel used as seismic source	29
Figure 4-3 Data acquisition board, NR-2000	29
Figure 4-4 (a) Low frequency geophone (HS-1-LT 2.0Hz-3810 Ω) (b) geophone attached with 9cm spike.....	29
Figure 4-5 Seismic detector response curve output vs. Frequency	30

	Page
Figure 4-6 Scheme of field setup for data acquisition.....	31
Figure 4-7 Seismic data in the space-time domain with geophone interval 4m and record time 1.6s gathered at Chulalongkorn University.	32
Figure 4-8 Seismic data in the space-time domain with geophone interval 2m and record time 1s gathered at TMD, Bangkok.....	33
Figure 4-9 Seismic data in the space-time domain with geophone interval 2m and record time 1.6s gathered at AIT.....	33
Figure 4-10 Seismic data in the space-time domain with geophone interval 1m and record time 1s gathered at Kirdkao Observatory, Kanchanaburi.	34
Figure 4-11 Seismic data in the space-time domain with geophone interval 2m and record time 1s gathered at TMD, Kanchanaburi.	34
Figure 4-12 Seismic data in the space-time domain with geophone interval 2m and record time 1.6s gathered at Chiang Mai University.	35
Figure 4-13 Seismic data in the space-time domain with geophone interval 2m and record time 1s gathered at Wat Chediluang, Chiang Mai.	35
Figure 4-14 Frequency wavenumber domain for Chulalongkorn University	37
Figure 4-15 Frequency wavenumber domain for TMD, Bangkok	37
Figure 4-16 Frequency wavenumber domain for AIT.....	38
Figure 4-17 Frequency wavenumber domain for Kirdkao Observatory, Kanchanaburi	38
Figure 4-18 Frequency wavenumber domain for TMD, Kanchanaburi	39
Figure 4-19 Frequency wavenumber domain for Chiang Mai University	39
Figure 4-20 Frequency wavenumber domain for Wat Chediluang, Chiang Mai	40
Figure 4-21 The dispersion curve of subsoil at Chulalongkorn University.....	41
Figure 4-22 The dispersion curve of subsoil at TMD Bangkok	41
Figure 4-23 The dispersion curve of subsoil at AIT	42
Figure 4-24 The dispersion curve of subsoil at Kirdkao Observatory, Kanchanaburi	42
Figure 4-25 The dispersion curve of subsoil at TMD Kanchanaburi	43
Figure 4-26 The dispersion curve of subsoil at Chiang Mai University.....	43
Figure 4-27 The dispersion curve of subsoil at Wat Chediluang, Chiang Mai	44
Figure 4-28 The simplified inversion process	44

Figure 5-1	Shear wave velocity profiles from various sources of in situ testing at Chula	51
Figure 5-2	Shear wave velocity profiles from various sources of in situ testing at TMD Bangkok	52
Figure 5-3	Shear wave velocity profiles from various sources of in situ testing at AIT	53
Figure 5-4	Shear wave velocity profiles from various sources of in situ testing at Kirdkao Observatory, Kanchanaburi	54
Figure 5-5	Shear wave velocity profiles from various sources of in situ testing at TMD Kanchanburi	55
Figure 5-6	Shear wave velocity profiles from various sources of in situ testing at Chiang Mai University, Chiang Mai.....	56
Figure 5-7	Shear wave velocity profiles from various sources of in situ testing at Wat Chediluang, Chiang Mai.....	57