Effect of Nonlinear Soil Modeling on Ground Response at Macau

By

ZHOU JIAN MEI

Master of Science in Civil Engineering

August 2010

Faculty of Science and Technology

University of Macau

UNIVERSIDADE DE MACAU
仁義禮知信
澳門大學

Effect of Nonlinear Soil Modeling on Ground Response at Macau

By

Zhou Jianmei

A thesis submitted in partial fulfillment of the
requirements for the degree of

Master of Science in Civil Engineering

Faculty of Science and Technology
University of Macau

2010

Approved by: _____ Date: _____
Thesis Supervisor

Approved by: _____ Date: _____
Thesis Examiner

Approved by: _____ Date: _____
Thesis Examiner

In presenting this thesis in partial fulfillment of the requirements for a Master's degree at the University of Macau, I agree that the Library and the Faculty of Science and Technology shall make its copies freely available for inspection. However, reproduction of this thesis for any purposes or by any means shall not be allowed without my written permission. Authorization is sought by contacting the author at

Address: Macau, P.R. China

Telephone: (853)83974286

Fax: N/A

E-mail: zhoujm0116@163.com

Signature: _____

Date: _____

University of Macau

Abstract

Effect of Nonlinear Soil Modeling on Ground Response at Macau

by Zhou Jianmei

Thesis Supervisor: Dr.Lok Man Hoi

The study is part of a larger project for the investigation of seismic ground response at Macau. Previous tasks including site investigation and measurement of shear wave velocity of local soils were carried out in recent years. A series of ground response analyses consisting thousands of cases using equivalent linear procedure was conducted using the data obtained from the investigation. In particular, the current study is aimed to investigate the effects of nonlinear soil modelling on the seismic ground response at Macau

To obtain linear and nonlinear site response spectra during seismic loading, site response analyses for some representative sites were performed using the one-dimensional equivalent linear (PROSHAKE) and the fully nonlinear (D-MOD2000) seismic site response codes. The model parameters for nonlinear analysis were estimated based on the modulus degradation and damping curves used for the different soils in Macao as input for the equivalent linear method.

V_{s30}, which is defined as the ratio of 30m to the travel time of a vertically propagating shear wave between a depth of 30m and the ground surface, was used in this study for classification. The idealized cases were classified based on this classification into three site classes. The comparisons were made for each site class between linear and nonlinear analysis.

From the comparison of results obtained in this study, the shape of response spectra from both equivalent linear and nonlinear analyses is similar to each other for lower input maximum horizontal acceleration less than 0.3g, while the comparison for input

maximum horizontal acceleration of higher than 0.3g, the shapes of response spectra from linear and nonlinear programs start to deviate from each other. Therefore, the nonlinear analysis is necessary when the input motion holds large magnitude.

The finding also shows that at low to moderate acceleration levels, acceleration at all soil sites are likely to be higher than rock site. However for stiff and soft deposit case, especially at deep stiff and soft deposit soil sites, maximum horizontal acceleration tends to be less than rock site at high level of earthquake, such as a_{max}>0.5g from both linear and nonlinear analysis.

The comparison between GB50011-2001 and calculated response spectra were made and the modification on design response spectra were recommended for local sites.

TABLE OF CONTENTS

TABLE OF CONTENTS i

LIST OF TABLES v

LIST OF FIGURES vii

ACKNOELEGMENT xxiv

CHAPTER 1 INTRODUCTION

1.1 Research Statement 1

1.2 Problem Significant 1

1.3 Scope of Study 2

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction 4

2.2 Causes of Earthquakes 4

2.2.1 Interior Structure of Earthquake 4

2.2.2 The Theory of Seafloor Spreading 6

2.2.3 Plate Tectonics 7

2.3 Parameters Used to Describe Ground Motion 8

2.3.1 Earthquake Magnitude 8

2.3.2 Amplitude Parameters 10

2.3.3 Duration Parameters 11

2.4 Response Spectra 12

2.4.1 Introduction 12

2.4.2 Single-Degree-of-Freedom System 12

2.4.3 Equation of Motion for SDOF System 13

2.4.4 Response for Linear SDOF Systems 16

2.4.5 Response for Nonlinear SDOF System 18

2.4.6 Response Spectra 20

2.5 Ground Motion Analysis 21

2.5.1 Linear Approach 21

2.5.2 Nonlinear Approach 22

2.6 Reviews on Previous Study 23

2.6.1 Study by Chang (1996) 23

2.6.2 Study by Sae Teng (2009) 35

2.6.3 Codes for Seismic-resistant Design 41

CHAPTER 3 EQUIVALENT LINEAR AND NONLINEAR METHODS FOR SITE RESPONSE ANALYSIS

3.1 Introduction 46

3.2 Assumptions 46

3.2.1 Reasons for One-Dimensional Analysis 46

3.2.2 Contents of Assumptions 47

3.2.3 Description on Ground Motions 49

3.3 Theories in PROSHAKE and D-MOD2000 50

3.3.1 Theories in PROSHAKE 50

3.3.2 Theories in D-MOD2000 57

3.4 Procedures in PROSHAKE and D-MOD2000 66

3.4.1 Response Calculation Procedure in PROSHAKE 66

3.4.2 Response Calculation procedure in D-MOD2000 69

CHAPTER 4 PARAMETER DETERMINATION IN PROSHAKE AND D-MOD2000

4.1 Parameter Determination in PROSHAKE 70

4.2 Parameter Determination in D-MOD2000 76

4.2.1 Model Parameters in Backbone Curve 76

4.2.2 Comparison of Curve Fitting Methods 79

4.2.3 Specification of Damping in D-MOD2000 95

4.3 Input Motion Specification in D-MOD2000 and PROSHAKE 102

CHAPTER 5 COMPARISON RESULTS BETWEEN D-MOD2000 AND PROSHAKE

5.1 Introduction 115

5.2 Background on Site Classification 116

5.2.1 Classifying Methods on Idealized Cases 116

5.3 Results of Ground Response Analysis for Different Input Motions 119

5.3.1 Introduction 119

5.3.2 Ground Response for Input Motion of *chichi0.05g* 119

5.3.3 Ground Response for Input Motion of *kobe0.05g* 125

5.3.4 Ground Response for Input Motion of *loma0.05g* 130

5.3.5 Ground Response for Input Motion of *chichi0.1g* 135

5.3.6 Ground Response for Input Motion of *kobe0.1g* 140

5.3.7 Ground Response for Input Motion of *loma0.1g* 145

5.3.8 Ground Response for Input Motion of *chichi0.3g* 150

5.3.9 Ground Response for Input Motion of *kobe0.3g* 155

5.3.10 Ground Response for Input Motion of *norb0.3g* 160

5.3.11 Ground Response for Input Motion of *chichi0.5g* 165

5.3.12 Ground Response for Input Motion of *norb0.5g* 170

5.3.13 Ground Response for Input Motion of *kobe0.5g* 175

5.3.14 Ground Response for Input Motion of *chichi0.7g* 180

5.3.15 Ground Response for Input Motion of *loma0.7g* 185

5.3.16 Ground Response for Input Motion of *kobe0.7g* 190

5.4 Discussion 196

5.4.1 Conclusion on Comparison of Site Response 196

5.4.2 Comparison of Nonlinear Ground Response Spectra with Chinese Code 200

CHAPTER 6 CONCLUSIONS AND FUTURE STUDY

6.1 Conclusions 205

6.2 Future Study 208

REFERNCE 209

LIST OF TABLES

Table 2.1	Combination of sites and earthquakes used for deep sites response analysis by Chang (1996)	25
Table 2.2	Scenario earthquakes used for deep stiff soil sites by Chang (1996)	25
Table 2.3	Sites Names and Locations for Testing	36
Table 2.4	Information for Soil properties and relationship of depth and Vs	36
Table 2.5	Proposed Classification of Soil Profile.	40
Table 2.6	Conversion Table for Determination of *Vs*. (GB50011-2001)	42
Table2.7	Site Classification Corresponding to Thickness (m) of Top Stratum.(GB 50011-2001)	43
Table 2.8	Spectrum characteristic period T_g, for the several ground site-class	44
Table 3.1	Summary of the Newmark Method for direct integration	60
Table 4.1	Curve fitting parameters for MR Fitting Method used in different soil	79
Table 4.2	Curve fitting parameters for MRD Fitting Method used in different soils	80
Table 4.3	Pseudo-reference Strain γ_r for MR Fitting Method and MRD Fitting Method	80
Table 4.4	Condition on Shallow Sites	89
Table 4.5	Condition on Medium Depth Sites	89
Table 4.6	Condition on Deep Sites	89

Table 4.7	Representative strong motions.(Sae,Teng.2009)	114
Table 5.1	Predominant Period for Each Input Motion	115
Table 5.2	Site Classification	116
Table 5.3	Idealized Site Condition	117
Table 5.4	Classification of Idealized Site Conditions	118

LIST OF FIGURES

Figure 2.1	The interior structure of earth	5
Figure 2.2	Convection currents in mantle. (After Noson et al., 1988)	7
Figure 2.3	Damped SDOF system subjected to an external dynamic load Q(t)	13
Figure 2.4	Dynamic force acting on mass from figure 2.2(Kramer, 1996)	14
Figure 2.5	Damped SDOF system subject to base shaking (Kramer, 1996)	16
Figure 2.6	SDOF system with nonlinear damping and spring force(Kramer, 1996)	19
Figure 2.7	Response spectrum (Kramer, 1996)	21
Figure 2.8	Generalized “calculated” deep stiff soil profile of Oakland Area Sites used in dynamic response analyses (Chang, 1996)	29
Figure 2.9	Idealized soil profile for the Sylmar-County Hospital Parking Lot Site (Chang, 1996)	30
Figure 2.10	Soil profile for the LA Hollywood Storage Building Grounds modified (Chang,1996)	31
Figure 2.11:	Soil profile for Santa Monica City Hall Parking Lot Grounds. (Chang, 1996)	32
Figure 2.12:	Average of normalized response spectra from Oakland and Los Angeles sites; recommended design spectrum for deep stiff soil sites. (Chang, 1996)	33

Figure 2.13:	Recommended relationship for MHA on rock vs. MHA on soil for deep stiff soil sites and range of MHA on rock vs. MHA on soil from analytical and recorded data. (Chang, 1996)	34
Figure 2.14	Site Profile for Campus	37
Figure 2.15	Site Profile for Chun Su Mei	37
Figure 2.16	Site Profile for Ocean World	38
Figure 2.17	Site Profile for Vehicle Detention Center	38
Figure 2.18	Site Profile for Oriental Golf Course	39
Figure 2.19	Idealized site conditions Modeled (Sae Teng, 2009)	39
Figure 2.20	Mean peak ground acceleration versus maximum acceleration on rock for defined sites. (Sae Teng, 2009)	40
Figure 2.21	Proposed site-dependent response spectra. (5% damping) (Sae Teng, 2009)	41
Figure 2.22	The response spectrum with structure damping equal to 5%. (GB50011-2001)	44
Figure 3.1	Schematic representation of the seismic response problem and the basic definitions (Matasovic, 1993)	48
Figure 3.2	Ground response nomenclature(a) soil overlying bedrock; (b) no soil overlying bedrock. Vertical scale is exaggerated (Kramer, 1996)	49
Figure 3.3	Relationship between hysteresis loop and damping ratio. (Kramer, 1996)	51
Figure 3.4	Linear elastic soil deposit of thickness H overlying on elastic rock	52

Figure 3.5	Nomenclature for layered soil deposit on elastic bedrock (Kramer,1996)	55
Figure 3.6	Average “shear modulus Gsec	56
Figure 3.7	General model for the dynamic representation of the horizontal layered soil deposit shaking at its base (after Lee and Finn, 1978; Matasovic, 1993)	58
Figure 3.8	State of stresses in a representative soil element: (a) Before shaking;(b) During shaking (Matasovic, 1993)	61
Figure 3.9	Full nonlinear degrading stress-strain model incorporated in D-MOD2000	63
Figure 3.10	Masing rules and extended Masing rules from Vucetic (1990)	65
Figure 3.11	Procedure outlines in PROSHAKE	68
Figure 3.12	Procedure outlines in D-MOD2000	69
Figure 4.1(a)	Modulus degradation curves for gravel (Seed et al,1986)	72
Figure 4.1(b)	Damping curves for gravel (Seed et al 1986)	72
Figure 4.2(a)	Modulus degradation curves for sandy soils (Seed &Idriss, 1970)	73
Figure 4.2(b)	Damping curves for sandy soil (Seed &Idriss,1970)	73
Figure 4.3(a)	Modulus degradation curves for marine clay (Vucetic & Dobry,1991)	74
Figure 4.3(b)	Damping curves for marine clay (Vucetic & Dobry,1991)	74

Figure 4.4(a)	Modulus degradation curves for Rock (Idriss, 1992)	75
Figure 4.4(b)	Damping curves for rock (Idriss, 1992)	75
Figure 4.5	Schematic illustration of MKZ constitutive model showing stress-strain behavior in first cycle (at time t=0) and subsequent cycle (at time t) (Stewart et al. 2008)	77
Figure 4.6	Schematic illustration of backbone curve used for nonlinear ground response analyses (Stewart et al. 2008)	77
Figure 4.7(a)	Measured and MKZ modeled modulus curves for fill based on MD Fitting Method	80
Figure 4.7(b)	Measured and MKZ modeled damping curves for fill based on MD Fitting Method	81
Figure 4.7(c)	Measured and MKZ modeled modulus curves for marine based on MD Fitting Method	81
Figure 4.7(d)	Measured and MKZ modeled damping curves for marine based on MD Fitting Method	82
Figure 4.7(e)	Measured and MKZ modeled modulus curves for alluvium based on MD Fitting Method	82
Figure 4.7(f)	Measured and MKZ modeled damping curves for alluvium based on MD Fitting Method	83
Figure 4.7(g)	Measured and MKZ modeled modulus curves for CDG based on MD Fitting Method	83
Figure 4.7(h)	Measured and MKZ modeled damping curves for CDG based on MD Fitting Method	84
Figure 4.8(a)	Measured and MKZ modeled modulus curves for fill based on MRD Fitting Method	84
Figure 4.8(b)	Measured and MKZ damping curves for fill based on MRD Fitting Method	85
Figure 4.8(c)	Measured and MKZ modeled modulus curves for marine based on MRD Fitting Method	85

Figure 4.8(d)	Measured and MKZ damping curves for marine based on MRD Fitting Method	86
Figure 4.8(e)	Measured and MKZ modeled modulus curves for alluvium based on MRD Fitting Method	86
Figure 4.8(f)	Measured and MKZ damping curves for alluvium based on MRD Fitting Method	87
Figure 4.8(g)	Measured and MKZ modeled modulus curves for CDG based on MRD Fitting Method	87
Figure 4.8(h)	Measured and MKZ damping curves for CDG based on MRD Fitting Method	88
Figure 4.9(a)	Comparison results on shallow site at depth =5m	90
Figure 4.9(b)	Comparison results on shallow site at depth =15m	90
Figure 4.9(c)	Comparison results on shallow site at depth =20m	91
Figure 4.10(a)	Comparison results on medium depth site at depth =30m	92
Figure 4.10(b)	Comparison results on medium depth site at depth =35m	92
Figure 4.10(c)	Comparison results on medium depth site at depth =40m	93
Figure 4.11(a)	Comparison results on deep depth site at depth =70m	94
Figure 4.11(b)	Comparison results on deep depth site at depth =75m	94
Figure 4.11(c)	Comparison results on deep depth site at depth =90m	95
Figure 4.12	ξ in D-MOD2000 is 0.5% for Shallow stiff site	98

Figure 4.13	ξ in D-MOD2000 is 5% for shallow stiff site	99
Figure 4.14	ξ in D-MOD2000 is 0.5% for soft clay site	99
Figure 4.15	ξ in D-MOD2000 is 5% for soft clay site	100
Figure 4.16	ξ in D-MOD2000 is 0.5% for deep soil site	100
Figure 4.17	ξ in D-MOD2000 is 5% for deep soil site	101
Figure 4.18(a)	Strong motion record of Chichi Earthquake (0.05g).	104
Figure 4.18(b)	Strong motion record of Kobe Earthquake (0.05g).	104
Figure 4.18(c)	Strong motion record of Loma Prieta Earthquake (0.05g).	104
Figure 4.18(d)	Strong motion record of Chichi Earthquake (0.1g).	105
Figure 4.18(e)	Strong motion record of Kobe Earthquake (0.1g).	105
Figure 4.18(f)	Strong motion record of Loma Prieta Earthquake (0.1g).	105
Figure 4.18(g)	Strong motion record of Chichi Earthquake (0.3g).	106
Figure 4.18(h)	Strong motion record of Kobe Earthquake (0.3g).	106
Figure 4.18(i)	Strong motion record of Northridge Earthquake (0.3g).	106
Figure 4.18(j)	Strong motion record of Chichi Earthquake (0.5g).	107

Figure 4.18(k)	Strong motion record of Kobe Earthquake (0.5g).	107
Figure 4.18(l)	Strong motion record of Northridge Earthquake (0.5g).	107
Figure 4.18(m)	Strong motion record of Chichi Earthquake (0.7g).	108
Figure 4.18(n)	Strong motion record of Kobe Earthquake (0.7g).	108
Figure 4.18(o)	Strong motion record of Loma Prieta Earthquake (0.7g).	108
Figure4.19 (a)	Response spectrum of Chichi Earthquake (0.05g).	109
Figure 4.19(b)	Response spectrum of Kobe Earthquake (0.05g).	109
Figure 4.19(c)	Response spectrum of Loma Prieta Earthquake (0.05g).	109
Figure 4.19(d)	Response spectrum of Chichi Earthquake (0.1g).	110
Figure 4.19(e)	Response spectrum of Kobe Earthquake (0.1g).	110
Figure 4.19(f)	Response spectrum of Loma Prieta Earthquake (0.1g).	110
Figure 4.19(g)	Response spectrum of Chichi Earthquake (0.3g).	111
Figure 4.19(h)	Response spectrum of Kobe Earthquake (0.3g).	111
Figure 4.19(i)	Response spectrum of Northridge Earthquake (0.3g).	111
Figure 4.19(j)	Response spectrum of Chichi Earthquake (0.5g).	112

Figure 4.19(k)	Response spectrum of Kobe Earthquake (0.5g).	112
Figure 4.19(l)	Response spectrum of Northridge Earthquake (0.5g).	112
Figure 4.19(m)	Response spectrum of Chichi Earthquake (0.7g).	113
Figure 4.19(n)	Response spectrum of Kobe Earthquake (0.7g).	113
Figure 4.19(o)	Response spectrum of Loma Prieta Earthquake (0.7g).	113
Figure 5.1	Response spectra and mean response spectrum for site class A with *chichi0.05g* from PROSHAKE	120
Figure 5.2	Response spectra and mean response spectrum for site class A with *chichi0.05g* from D-MOD2000	121
Figure 5.3	Comparison of mean acceleration response spectra for site class A between D-MOD2000 and PROSHAKE with *chichi0.05g*	121
Figure 5.4	Response spectra and mean response spectrum for site class B with *chichi0.05g* from PROSHAKE	122
Figure 5.5	Response spectra and mean response spectrum for site class B with *chichi0.05g* from D-MOD2000	122
Figure 5.6	Comparison of mean acceleration response spectra for site class B between D-MOD2000 and PROSHAKE with *chichi0.05g*	123
Figure 5.7	Response spectra and mean response spectrum for site class C with *chichi0.05g* in PROSHAKE	123
Figure 5.8	Response spectra and mean response spectrum for site class C with *chichi0.05g* from D-MOD2000	124
Figure 5.9	Comparison of mean acceleration response spectra for site class C between D-MOD2000 and PROSHAKE with *chichi0.05g*	124
Figure 5.10	Response spectra and mean response spectrum for site class A with *kobe0.05g* from PROSHAKE	126

Figure 5.11	Response spectra and mean response spectrum for site class A with *kobe0.05g* from D-MOD2000	126
Figure 5.12	Comparison of mean acceleration response spectra for site class A between D-MOD2000 and PROSHAKE with *kobe0.05g*	127
Figure 5.13	Response spectra and mean response spectrum for site class B with *kobe0.05g* from PROSHAKE	127
Figure 5.14	Response spectra and mean response spectrum for site class B with *kobe0.05g* from D-MOD2000	128
Figure 5.15	Comparison of mean acceleration response spectra for site class B between D-MOD2000 and PROSHAKE with *kobe0.005g*	128
Figure 5.16	Response spectra and mean response spectrum for site class C with *kobe0.05g* from PROSHAKE	129
Figure 5.17	Response spectra and mean response spectrum for site class C with *kobe0.05g* from D-MOD2000	129
Figure 5.18	Comparison of mean acceleration response spectra for site class C between D-MOD2000 and PROSHAKE with *kobe0.05g*	130
Figure 5.19	Response spectra and mean response spectrum for site class A with *loma0.05g* from PROSHAKE	131
Figure 5.20	Response spectra and mean response spectrum for site class A with *loma0.05g* from D-MOD2000	131
Figure 5.21	Comparison of mean acceleration response spectra for site class A between D-MOD2000 and PROSHAKE with *loma0.05g*	132
Figure 5.22	Response spectra and mean response spectrum for site class A with *loma0.05g* from PROSHAKE	132
Figure 5.23	Response spectra and mean response spectrum for site class B with *loma0.05g* from D-MOD2000	133
Figure 5.24	Comparison of mean acceleration response spectra for site class B between D-MOD2000 and PROSHAKE with *loma0.05g*	133
Figure 5.25	Response spectra and mean response spectrum for site class C with *loma0.05g* from PROSHAKE	134

Figure 5.26	Response spectra and mean response spectrum for site class C with *loma0.05g* from D-MOD2000	134
Figure 5.27	Comparison of mean acceleration response spectra for site class C between D-MOD2000 and PROSHAKE with *loma0.05g*	135
Figure 5.28	Response spectra and mean response spectrum for site class A with *chichi0.1g* from PROSHAKE	136
Figure 5.29	Response spectra and mean response spectrum for site class A with *chichi0.1g* from D-MOD2000	136
Figure 5.30	Comparison of mean acceleration response spectra for site class A between D-MOD2000 and PROSHAKE with *chichi0.1g*	137
Figure 5.31	Response spectra and mean response spectrum for site class B with *chichi0.1g* from PROSHAKE	137
Figure 5.32	Response spectra and mean response spectrum for site class B with *chichi0.1g* from D-MOD2000	138
Figure 5.33	Comparison of mean acceleration response spectra for site class B between D-MOD2000 and PROSHAKE with *chichi0.1g*	138
Figure 5.34	Response spectra and mean response spectrum for site class C with *chichi0.1g* from PROSHAKE	139
Figure 5.35	Response spectra and mean response spectrum for site class C with *chichi0.1g* from D-MOD2000	139
Figure 5.36	Comparison of mean acceleration response spectra for site class C between D-MOD2000 and PROSHAKE with *chichi0.1g*	140
Figure 5.37	Response spectra and mean response spectrum for site class A with *kobe0.1g* from PROSHAKE	141
Figure 5.38	Response spectra and mean response spectrum for site class A with *kobe0.1g* from D-MOD2000	141
Figure 5.39	Comparison of mean acceleration response spectra for site class A between D-MOD2000 and PROSHAKE with *kobe0.1g*	142
Figure 5.40	Response spectra and mean response spectrum for site class B with *kobe0.1g* from PROSHAKE	142

Figure 5.41	Response spectra and mean response spectrum for site class B with *kobe0.1g* from D-MOD2000	143
Figure 5.42	Comparison of mean acceleration response spectra for site class B between D-MOD2000 and PROSHAKE with *kobe0.1g*	143
Figure 5.43	Response spectra and mean response spectrum for site class C with *kobe0.1g* from PROSHAKE	144
Figure 5.44	Response spectra and mean response spectrum for site class C with *kobe0.1g* from D-MOD2000	144
Figure 5.45	Comparison of mean acceleration response spectra for site class C between D-MOD2000 and PROSHAKE with *kobe0.1g*	145
Figure 5.46	Response spectra and mean response spectrum for site class A with *loma0.1g* from PROSHAKE	146
Figure 5.47	Response spectra and mean response spectrum for site class A with *loma0.1g* from D-MOD2000	146
Figure 5.48	Comparison of mean acceleration response spectra for site class A between D-MOD2000 and PROSHAKE with *loma0.1g*	147
Figure 5.49	Response spectra and mean response spectrum for site class B with *loma0.1g* from PROSHAKE	147
Figure 5.50	Response spectra and mean response spectrum for site class B with *loma0.1g* from D-MOD2000	148
Figure 5.51	Comparison of mean acceleration response spectra for site class B between D-MOD2000 and PROSHAKE with *loma0.1g*	148
Figure 5.52	Response spectra and mean response spectrum for site class C with *loma0.1g* from PROSHAKE	149
Figure 5.53	Response spectra and mean response spectrum for site class C with *loma0.1g* in D-MOD2000	149
Figure 5.54	Comparison of mean acceleration response spectra for site class C between D-MOD2000 and PROSHAKE with *loma0.1g*	150
Figure 5.55	Response spectra and mean response spectrum for site class A with *chichi0.3g* from PROSHAKE	151

Figure 5.56	Response spectra and mean response spectrum for site class A with *chichi0.3g* from D-MOD2000	151
Figure 5.57	Comparison of mean acceleration response spectra for site class A between D-MOD2000 and PROSHAKE with *chichi0.3g*	152
Figure 5.58	Response spectra and mean response spectrum for site class B with *chichi0.3g* from PROSHAKE	152
Figure 5.59	Response spectra and mean response spectrum for site class B with *chichi0.3g* from D-MOD2000	153
Figure 5.60	Comparison of mean acceleration response spectra for site class B between D-MOD2000 and PROSHAKE with *chichi0.3g*	153
Figure 5.61	Response spectra and mean response spectrum for site class C with *chichi0.3g* from PROSHAKE	154
Figure5.62	Response spectra and mean response spectrum for site class C with *chichi0.3g* from D-MOD2000	154
Figure 5.63	Comparison of mean acceleration response spectra for site class C between D-MOD2000 and PROSHAKE with *chichi0.3g*	155
Figure 5.64	Response spectra and mean response spectrum for site class A with *kobe0.3g* form PROSHAKE	156
Figure 5.65	Response spectra and mean response spectrum for site class A with *kobe0.3g* from D-MOD2000	156
Figure 5.66	Comparison of mean acceleration response spectra for site class A between D-MOD2000 and PROSHAKE with *kobe0.3g*	157
Figure 5.67	Response spectra and mean response spectrum for site class B with *kobe0.3g* from PROSHAKE	157
Figure 5.68	Response spectra and mean response spectrum for site class B with *kobe0.3g* from D-MOD2000	158
Figure 5.69	Comparison of mean acceleration response spectra for site class B between D-MOD2000 and PROSHAKE with *kobe0.3g*	158
Figure 5.70	Response spectra and mean response spectrum for site class C with *kobe0.3g* from PROSHAKE	159

Figure 5.71	Response spectra and mean response spectrum for site class C with *kobe0.3g* from D-MOD2000	159
Figure 5.72	Comparison of mean acceleration response spectra for site class C between D-MOD2000 and PROSHAKE with *kobe0.3g*	160
Figure 5.73	Response spectra and mean response spectrum for site class A with *norb0.3g* from PROSHAKE	161
Figure 5.74	Response spectra and mean response spectrum for site class A with *norb0.3g* from D-MOD2000	161
Figure 5.75	Comparison of mean acceleration response spectra for site class A between D-MOD2000 and PROSHAKE with *norb0.3g*	162
Figure 5.76	Response spectra and mean response spectrum for site class B with *norb0.3g* from PROSHAKE	162
Figure 5.77	Response spectra and mean response spectrum for site class B with *norb0.3g* from D-MOD2000	163
Figure 5.78	Comparison of mean acceleration response spectra for site class B between D-MOD2000 and PROSHAKE with *norb0.3g*	163
Figure 5.79	Response spectra and mean response spectrum for site class C with *norb0.3g* from PROSHAKE	164
Figure 5.80	Response spectra and mean response spectrum for site class C with *norb0.3g* from D-MOD2000	164
Figure 5.81	Comparison of mean acceleration response spectra for site class C between D-MOD2000 and PROSHAKE with *norb0.3g*	165
Figure 5.82	Response spectra and mean response spectrum for site class A with *chichi0.5g* from PROSHAKE	166
Figure 5.83	Response spectra and mean response spectrum for site class A with *chichi0.5g* from D-MOD2000	166
Figure 5.84	Comparison of mean acceleration response spectra for site class A between D-MOD2000 and PROSHAKE with *chichi0.5g*	167
Figure 5.85	Response spectra and mean response spectrum for site class B with *chichi0.5g* from PROSHAKE	167

Figure 5.86	Response spectra and mean response spectrum for site class B with *chichi0.5g* from D-MOD2000	168
Figure 5.87	Comparison of mean acceleration response spectra for site class B between D-MOD2000 and PROSHAKE with *chichi0.5g*	168
Figure 5.88	Response spectra and mean response spectrum for site class C with *chichi0.5g* from PROSHAKE	169
Figure 5.89	Response spectra and mean response spectrum for site class C with *chichi0.5g* from D-MOD2000	169
Figure 5.90	Comparison of mean acceleration response spectra for site class C between D-MOD2000 and PROSHAKE with *chichi0.5g*	170
Figure 5.91	Response spectra and mean response spectrum for site class A with *norb0.5g* from PROSHAKE	171
Figure 5.92	Response spectra and mean response spectrum for site class A with *norb0.5g* from D-MOD2000	171
Figure 5.93	Comparison of mean acceleration response spectra for site class A between D-MOD2000 and PROSHAKE with *norb0.5g*	172
Figure 5.94	Response spectra and mean response spectrum for site class B with *norb0.5g* from PROSHAKE	172
Figure 5.95	Response spectra and mean response spectrum for site class B with *norb0.5g* from D-MOD2000	173
Figure 5.96	Comparison of mean acceleration response spectra for site class B between D-MOD2000 and PROSHAKE with *norb0.5g*	173
Figure 5.97	Response spectra and mean response spectrum for site class C with *norb0.5g* from PROSHAKE	174
Figure 5.98	Response spectra and mean response spectrum for site class C with *norb0.5g* from D-MOD2000	174
Figure 5.99	Comparison of mean acceleration response spectra for site class C between D-MOD2000 and PROSHAKE with *norb0.5g*	175
Figure 5.100	Response spectra and mean response spectrum for site class A with *kobe0.5g* from PROSHAKE	176

Figure 5.101	Response spectra and mean response spectrum for site class A with *kobe0.5g* from D-MOD2000	176
Figure 5.102	Comparison of mean acceleration response spectra for site class A between D-MOD2000 and PROSHAKE with *kobe0.5g*	177
Figure 5.103	Response spectra and mean response spectrum for site class B with *kobe0.5g* from PROSHAKE	177
Figure 5.104	Response spectra and mean response spectrum for site class B with *kobe0.5g* from D-MOD2000	178
Figure 5.105	Comparison of mean acceleration response spectra for site class B between D-MOD2000 and PROSHAKE with *kobe0.5g*	178
Figure 5.106	Response spectra and mean response spectrum for site class C with *kobe0.5g* from PROSHAKE	179
Figure 5.107	Response spectra and mean response spectrum for site class C with *kobe0.5g* from D-MOD2000	179
Figure 5.108	Comparison of mean acceleration response spectra for site class C between D-MOD2000 and PROSHAKE with *kobe0.5*	180
Figure 5.109	Response spectra and mean response spectrum for site class A with *chichi0.7g* from PROSHAKE	181
Figure5.110	Response spectra and mean response spectrum for site class A with *chichi0.7g* from D-MOD2000	181
Figure 5.111	Comparison of mean acceleration response spectra for site class A between D-MOD2000 and PROSHAKE with *chichi0.7g*	182
Figure 5.112	Response spectra and mean response spectrum for site class B with *chichi0.7g* from PROSHAKE	182
Figure 5.113	Response spectra and mean response spectrum for site class B with *chichi0.7g* from D-MOD2000	183
Figure 5.114	Comparison of mean acceleration response spectra for site class B between D-MOD2000 and PROSHAKE with *chichi0.7g*	183
Figure 5.115	Response spectra and mean response spectrum for site class C with *chichi0.7g* from PROSHAKE	184

Figure 5.116	Response spectra and mean response spectrum for site class C with *chichi0.7g* from D-MOD2000	184
Figure 5.117	Comparison of mean acceleration response spectra for site class C between D-MOD2000 and PROSHAKE with *chichi0.7g*	185
Figure 5.118	Response spectra and mean response spectrum for site class A with *loma0.7g* from PROSHAKE	186
Figure 5.119	Response spectra and mean response spectrum for site class A with *loma0.7g* from D-MOD2000	186
Figure 5.120	Comparison of mean acceleration response spectra for site class A between D-MOD2000 and PROSHAKE with *loma0.7g*	187
Figure 5.121	Response spectra and mean response spectrum for site class B with *loma0.7g* from PROSHAKE	187
Figure 5.122	Response spectra and mean response spectrum for site class B with *loma0.7g* from D-MOD2000	188
Figure 5.123	Comparison of mean acceleration response spectra for site class B between D-MOD2000 and PROSHAKE with *loma0.7g*	188
Figure 5.124	Response spectra and mean response spectrum for site class C with *loma0.7g* from PROSHAKE	189
Figure 5.125	Response spectra and mean response spectrum for site class C with *loma0.7g* from D-MOD2000	189
Figure 5.126	Comparison of mean acceleration response spectra for site class C between D-MOD2000 and PROSHAKE with *loma0.7g*	190
Figure 5.127	Response spectra and mean response spectrum for site class A with *kobe0.7g* from PROSHAKE	191
Figure 5.128	Response spectra and mean response spectrum for site class A with *kobe0.7g* from D-MOD2000	191
Figure 5.129	Comparison of mean acceleration response spectra for site class A between D-MOD2000 and PROSHAKE with *kobe0.7g*	192
Figure 5.130	Response spectra and mean response spectrum for site class B with *kobe0.7g* from PROSHAKE	192

Figure 5.131	Response spectra and mean response spectrum for site class B with *kobe0.7g* from D-MOD2000	193
Figure 5.132	Comparison of mean acceleration response spectra for site class B between D-MOD2000 and PROSHAKE with *kobe0.7g*	193
Figure 5.133	Response spectra and mean response spectrum for site class C with *kobe0.7g* from PROSHAKE	194
Figure 5.134	Response spectra and mean response spectrum for site class C with *kobe0.7g* from D-MOD2000	194
Figure 5.135	Comparison of mean acceleration response spectra for site class C between D-MOD2000 and PROSHAKE with *kobe0.7g*	195
Figure 5.136	Maximum ground acceleration versus maximum acceleration on rock for very dense soil and soft rock sites.	197
Figure 5.137	Maximum ground acceleration versus maximum acceleration on rock for stiff soil sites.	197
Figure 5.138	Maximum ground acceleration versus maximum acceleration on rock for soft soil sites.	198
Figure 5.139	Maximum ground acceleration versus maximum acceleration on different sites from PROSHAKE	198
Figure 5.140	Maximum ground acceleration versus maximum acceleration on different sites from D-MOD2000	199
Figure 5.141	Normalized response spectra for three categories (Damping=5%)	201
Figure 5.142	Normalized response spectra for different local soils profile. (Damping=5%) (Sae Teng, 2009)	201
Figure 5.143	Comparison of calculated response spectra for different local soil conditions with Chinese Code, GB50011-2001. (Damping=5%)	203
Figure 5.144	Proposed site-dependent response spectra. (5% damping)	203

ACKNOWLEDGMENTS

This work is a success because it involves generous assistance of many kind people.

I would like to express my sincere thanks to my supervisor, Dr. LOK Mai Hoi, for his serious guidance and careful instruction. With his kindness understanding on my background and support, I can have courage and determination to study in geotechnical area. It is him who gives me the second chance for my master study in University of Macau, I appreciate him for his understanding, for his insight and perception of engineer, for his useful advice, for his help to improve my knowledge, and for making me stronger.

I would like to express my appreciation to my committee members, Prof.G.K.Er and Dr. W.H. Zhou, for their insightful and helpful comments and suggestions.

I want to express my appreciation to the teachers taught me in University of Macau, thanks them to provide me technical knowledge and useful concept on civil area. They are Professor Iu Vai Pan, Prof. KaVeng Yuen, Prof. G.K.Er, Prof. K.P. Kou, Dr.C.C.Lam, Dr. M.H.Lok, Dr. T.M. Aoieong, Dr. W.M. Quach, Dr. W.M. Yan, Dr. W.H. Zhou, Heartfelt thanks to them for their generous help and understanding.

I also want to give thank you to my classmates and friends in geotechnical and structure groups, especially Bing Yang, Cai Zhongmou, Dong Jingjing, Guo Xiuxiu, Hebe Kuok, Huang Junfie, Jastin Zhang, Ku Wengkeong, Lan Shuangwen, Liu Bing, Luo Sai, Ma Yongfeng, Mu Heqing, Qiu Pei, Sin Waihong, Terry Ieong, Wang Dong, Zhao Jing, Zhang Lizhi, Zhu Haitao, Sincere thanks to their valuable advices and kind supports in different way.

Thanks to the technician of the geotechnical laboratory, Mr. Sein Ye Htut, for his technical support and suggestions.

Finally, Great thanks to my parents and sister for their selfless supporting and understanding on my study and life. I may have no chance to be here for study and finishing this work without them. Sincere thanks to my parents to give me life and kindness on rearing and educating. Thank you to my sister for her love and sunny attitudes and suggestions, which influence me deeply.