

**EVALUATION OF SOIL-STRUCTURE
INTERACTION BY USING NEURAL NETWORK
METHODOLOGY**

**M.Sc. Thesis by
Özgür SARIYAR, B.S.c.**

Department : Civil Engineering

Programme: Earthquake Engineering

MAY 2005

**EVALUATION OF SOIL-STRUCTURE
INTERACTION BY USING NEURAL NETWORK
METHODOLOGY**

**M.Sc. Thesis by
Özgür SARIYAR, B.Sc.**

501021201

Date of submission : 6 May 2005

Date of defence examination: 30 May 2005

Supervisor (Chairman): Assoc. Prof. Dr. Derin N. URAL

Members of the Examining Committee: Assoc. Prof. Dr. Gülten GÜLAY

Assist. Prof. Dr. Mehmet BERİLGEN (Y.T.Ü)

MAY 2005

**YAPAY SİNİR AĞLARI KULLANILARAK ZEMİN
YAPI ETKİLEŞİMİNİN DEĞERLENDİRİLMESİ**

YÜKSEK LİSANS TEZİ

İnş. Müh. Özgür SARIYAR

Tezin Enstitüye Verildiği Tarih : 6 Mayıs 2005

Tezin Savunulduğu Tarih : 30 Mayıs 2005

Tez Danışmanı : Doç.Dr. Derin N. URAL

Diğer Jüri Üyeleri: Doç.Dr. Gülten GÜLAY

Y.Doç.Dr. Mehmet BERİLGİN (Y.T.Ü.)

MAYIS 2005

PREFACE

I would like to express my grateful thanks to the respectful members of Earthquake Engineering Division of the Civil Engineering Department at Istanbul Technical University for giving me the chance to study for my MSc thesis. I especially would like to express my sincere thanks to my supervisor Assoc. Prof. Derin URAL for her guidance and insight throughout the research and special thanks go to Civil & Environmental Engineering Department, University of California, Los Angeles Jonathan P. STEWART for providing data for this research. I also want to thank to Assoc. Prof. H. Kerem CİĞİZÖĞLU for giving information about Neural Network approaches and his valuable help during the preparation of this thesis.

Finally, I am most grateful to my family for their endless supports. Preparation of this thesis involved several months of long working hours; I could not have done it without their insight and encouragement.

May 2005

Özgür SARIYAR

ÖNSÖZ

İstanbul Teknik Üniversitesi İnşaat Mühendisliği Bölümü Deprem Mühendisliği Anabilim Dalı'nın bana yüksek lisans yapma olanağı tanıyan saygıdeğer öğretim üyelerine minnet dolu teşekkürlerimi bildirmek isterim. Özellikle danışmanım Doç. Dr. Derin Ural'a çalışmalarım boyunca gösterdiği rehberlik ve anlayıştan dolayı ve California Üniversitesi İnşaat Mühendisliği Bölümü (Los Angeles) öğretim üyelerinden Jonathan P. STEWART' a bu çalışma için sağladığı datalardan dolayı en içten teşekkürlerimi sunmak istiyorum. Ayrıca bu tezi hazırlamam sırasında göstermiş olduğu yardımlar ve yapay sinir ağları konusunda bana verdiği bilgilerden dolayı Doç. Dr. H. Kerem CİĞİZÖĞLU'na teşekkürü borç biliyorum.

Son olarak, aileme de vermiş oldukları sonsuz destekten ötürü minnettarım. Bu tezin hazırlanması aylar süren çalışma saatleri sonunda bitmiştir; onların anlayışı ve cesaretlendirmesi olmadan bunu gerçekleştiremezdim.

Mayıs 2005

Özgür SARIYAR

TABLE OF CONTENTS

ABBREVIATIONS	viii
LIST OF TABLES	ix
LIST OF FIGURES	xi
LIST OF SYMBOLS	xiv
ÖZET	xviii
SUMMARY	xx
1. INTRODUCTION	1
1.1 General	1
1.2 Short History of Artificial Intelligence (AI) Method	2
1.3 Objectives	3
2. DATA DISCRIPTION AND SITE SELECTION	5
2.1 Data Description	5
2.2 Characterization of Geotechnical Site Conditions	13
2.2.1 General soil properties	13
2.2.2 Shear wave velocity profiles	13
a) General considerations	13
b) Estimation of shear wave velocity from published correlations	14
2.2.3 Estimation of poisson's ratio of geologic materials	17
2.2.4 Evaluation of dynamics soil properties for impedance functions	17
2.3 Site Selection	21
2.3.1 Site selection criteria of 'A' and 'B' sites	21
2.3.2 Conditions examined	21
3. DEFINITION AND PREDICTION PROCESS OF SOIL- STRUCTURE	
INTERACTION EFFECTS	26
3.1 Introduction and Problem Definition	26
3.1.1 Components of the soil-structure interaction problem	26
3.1.2 Methodologies for soil-structure interaction analysis	27
3.2 Inertial interaction	29
3.2.1 System considered	29
3.2.2 Impedance function	30
a) Basic case	30

b) Heterogeneous soil profiles	35
c) Foundation shape	36
d) Foundation flexibility	36
e) Piles and piers	38
3.3 Kinematic Interaction	39
3.3.1 Base-slab averaging	40
3.4 Results and Summary	41
3.4.1 Inputs for inertial interaction	41
3.4.2 Results	41
3.4.3 Adopted code provisions for inertial interaction	42
 4. SYSTEM IDENTIFICATION PROCEDURES FOR EVALUATING SOIL STRUCTURE INTERACTION EFFECTS (STEWART, 1997)	 46
4.1 Introduction	46
4.1.1 Objectives	46
4.1.2 Fundamental assumptions	47
4.2 Derivation of Transfer Functions from Modal Equations	48
4.3 Nonparametric System Identification	50
4.3.1 Transmissibility functions	51
4.3.2 Smoothing of frequency response functions	53
4.4 Parametric System Identification	53
4.4.1 Introduction	53
4.4.2 Representation of continuous transfer functions in discrete time	54
4.4.3 Solution procedures	55
1) Model parameter estimation by the cumulative error method (CEM)	55
2) Model parameter estimation by the recursive prediction error method (RPEM)	56
3) Evaluation of modal frequencies and damping ratios	58
4.5 Interpretation of Results	59
4.5.1 Base fixity conditions for different input-output pairs	59
a) Flexible-base	62
b) Pseudo flexible-base	64
c) Fixed-base	65
d) Summary	65
4.5.2 Estimation of fixed and flexible-base modal parameters	66
a) Estimation of fixed-base modal parameters for case of missing base rocking motions	66
b) Estimation of flexible-base modal parameters for case of missing free-field motions	70

5. ARTIFICIAL INTELLIGENCE METHOD	72
5.1 Introduction of Neural Networks	72
5.2 Differences between Biological Structures and Artificial Neural Networks	73
5.3 The Basic Structure	73
5.4 Neural Network Characteristics	74
5.5 Design Choices	76
5.5.1 Introduction	76
5.5.2 Artificial neural network model for Neuroshell2	77
5.6 Neural Network Architecture	79
5.6.1 General regression neural network architecture, GRNN	79
5.6.1.1 GRNN architecture learning algorithm	81
5.6.2 Back propagation neural network (BPNN)	83
5.6.2.1 Back-error propagation paradigm	83
5.6.2.2 BPNN structure	86
5.6.3 Scaling function	90
5.6.4 Activation functions	91
5.6.5 Other neural networks algorithm	93
5.6.5.1 PNN architecture	93
5.6.5.2 Kohonen architecture	93
5.6.5.3 GMDH architecture	94
6. NEURAL NETWORK APPROACHES FOR SOIL-STRUCTURE INTERACTION	96
6.1 Introduction	96
6.2 Input Parameters Information	96
6.3 Analysis	100
6.3.1 BPNN approaches	100
6.3.1.1 Model 1	100
6.3.1.2 Model 2	105
6.3.2 GRNN approaches	109
6.3.2.1 Model 3	109
6.3.2.2 Model 4	114
6.3.2.3 Model 5	117
7. RESULTS	122
REFERENCES	131
APPENDIX A	139
APPENDIX B	149

APPENDIX C	155
APPENDIX D	158
APPENDIX E	173
APPENDIX F	180
APPENDIX G	185
APPENDIX H	194
APPENDIX I	200
CURRICULLUM VITAE	205

ABBREVIATIONS

AI	: Artificial Intelligence
ANN	: Artificial Neural Network
ARX	: Autoregressive Model with Extra input
ATC	: Applied Technology Council
BNN	: Biological Neural Network
BPNN	: Back Propagation Neural Network
CEM	: Cumulative Error Method
CSMIP	: California Strong Motion Instrumentation Program
EERC	: Earthquake Engineering Research Center
FFT	: The Fast Fourier Transform
FIM	: Foundation Input Motion
GMDH	: Group Method of Data Handling
GRNN	: General Regression Neural Network
NEHRP	: National Earthquake Hazards Reduction Program
PEER	: Pacific Earthquake Engineering Research
PNN	: Polynomial Neural Network
RPEM	: Recursive Prediction Error Method
SASW	: Spectral Analysis of Surface Wave
SPT	: Standard Penetration Test
SSI	: Soil Structure Interaction
USGS	: United States Geological Survey

LIST OF TABLES

	Page No
Table 2.1. Sites included in this study (Stewart, 1997).....	6
Table 2.2. Measured shear wave velocity in various sedimentary deposits (Furnal, 1978).....	15
Table 2.3. SPT blow counts (Stewart 1997).....	16
Table 2.4. Site and structural data included in this study (Stewart, 1998).....	22
Table 2.5. The maximum horizontal accelerations (MHAs) produced by California earthquakes (Stewart, 1998).....	23
Table 2.6. Earthquake which contributed data to this study (Stewart, 1998)	24
Table 2.7. The building heights and lateral forces resisting system (Stewart, 1998).....	25
Table 3.1. Code-prescribed values of soil modulus and v_s degradation with effective long period ground acceleration, AV (BSSC, 1995)...	44
Table 4.1. Required input and output to evaluate system parameters for various conditions of base fixity.....	66
Table 6.1. Input and output values range for Neural Network.....	99
Table 6.2. Model 1 approach for training.....	101
Table 6.3. The contribution factors for Model 1.....	101
Table 6.4. The result of the Model 1.....	102
Table 6.5. A pieces of Model 1 output table.....	105
Table 6.6. Model 2 approach for training.....	105
Table 6.7. The contribution factors for Model 2.....	106
Table 6.8. The result of the Model 2.....	106
Table 6.9. The architecture and the configuration of the Model 3.....	110
Table 6.10. Individual smoothing factors for Model 3.....	110
Table 6.11. The result of the Model 3.....	111
Table 6.12. The architecture and the configuration of the Model 4.....	114
Table 6.13. Individual smoothing factors for Model 4.....	114
Table 6.14. The result of the Model 4.....	115
Table 6.15. The architecture and the configuration of the Model 5.....	118
Table 6.16. Individual Smoothing Factors for Model 5.....	118
Table 6.17. The result of the model 5.....	119
Table 7.1. Model 1 and Model 2 approach configurations and architecture.	122
Table 7.2. Outputs R^2 values for Model 1 and 2.....	123
Table 7.3. The first five of contribution factors for Model 1 and Model 2...	124
Table 7.4. The architecture and the configuration of the Model 3, 4 and 5..	125
Table 7.5. Outputs R^2 values for Model 3, 4, and 5.....	125
Table 7.6. The first five of individual smoothing factors for Model 3, 4, and 5.....	126
Table 7.7. Simulation success rates for each model.....	128
Table App. A1. Actual and program outputs for Model 1 (Normalized).....	139

Table App. A2.	Actual and program outputs for Model 2 (Normalized).....	144
Table App. B1.	Actual and program outputs for Model 1.....	149
Table App. B2.	Actual and program outputs for Model 2.....	152
Table App. D1.	Actual and program outputs for Model 3 (Normalized).....	158
Table App. D2.	Actual and program outputs for Model 4 (Normalized).....	163
Table App. D3.	Actual and program outputs for Model 5 (Normalized).....	167
Table App. E1.	Actual and program outputs for Model 3.....	173
Table App. E2.	Actual and program outputs for Model 4.....	175
Table App. E3.	Actual and program outputs for Model 5.....	177
Table App. G1.	Site properties 1.....	185
Table App. G2.	Site properties 2.....	188
Table App. H1.	Before normalization data properties	194
Table App. I1.	Data properties after normalization (Input Values and Output Values).....	200

LIST OF FIGURES

	<u>Page No</u>
Figure 1.1. : Schematic showing context of SSI in an engineering assessment of seismic loading for a structure (Stewart, 1998)...	1
Figure 2.1. : Map of California showing locations of sites and selected earthquakes considered in this study (Stewart, 1997).....	8
Figure 2.2. : Map of Humboldt/Arcata Bay area showing site and earthquake locations (Stewart, 1997).....	9
Figure 2.3. : Map of San Francisco Bay area showing site and earthquake locations (Stewart, 1997).....	10
Figure 2.4. : Map of Los Angeles area showing site and earthquake locations (Stewart, 1997).....	11
Figure 2.5. : Map of San Bemardino area showing site and earthquake location (Stewart, 1997).....	12
Figure 2.6. : Variation of measured shear wave velocity with void ratio for Holocene and Pleistocene sediments in the Los Angeles region. Results are for sand and cohesive soils (Furnal and Tinsley, 1985).....	15
Figure 2.7. : Modulus degradation and damping curves for clay used in this study. (adapted from Sun et al., 1988 and Vucetic and Dobry , 1991)	18
Figure 2.8. : Modulus degradations and damping curves for sand used in this study. (adapted from Seed et al.,1984).....	19
Figure 2.9. : Modulus degradations and damping curves for rock used in this study. (adapted from Schnabel.,1973).....	20
Figure 3.1. : Substructure approach to analysis of the SSI problem.....	28
Figure 3.2. : Simplified model for analysis of inertial interaction.....	29
Figure 3.3. : Foundation stiffness and damping factors for elastic and viscoelastic halfspace, $\nu=0.4$ (after Veletsos and Verbic, 1973).....	32
Figure 3.4. : Simplified surface structure considered in SSI analysis.....	33
Figure 3.5. : Embedded soil-foundation-structure system on finite soil layer	34
Figure 3.6. : Embedded soil-foundation-structure system on halfspace layer over rigid base.....	34
Figure 3.7. : Disk foundations with (a) rigid core considered by Iguchi and Luco (1982), (b) thin parameter walls considered by Liou and Huang (1994), and (c) rigid concentric walls considered walls considered by Riggs and Waas (1985).....	36
Figure 3.8. : Rocking stiffness and damping factor for flexible foundations; rigid core cases (Iguchi and Luco, 1982) and perimeter wall case (Liou and Huang,1994).....	38
Figure 3.9. : System considered for kinematic interaction analyses (Veletsos and Prasad, 1989 and Veletsos et.al., 1997)	39
Figure 3.10. : Relationship between foundation damping factor (ξ_o) and	

	period lengthening ratio for rigid disk foundations on homogeneous halfspace (BSSC, 1995; ATC, 1978).....	44
Figure 4.1.	: Schematic of the system identification problem.....	46
Figure 4.2.	: Motions used as inputs and outputs for system identification of structure.....	47
Figure 4.3.	: Simplified model for analysis of inertial interaction.....	60
Figure 4.4.	: Foundation stiffness and damping factor for elastic and viscoelastic halfspaces, $\nu=0.4$ (after Veletsos and Verbic, 1973)..	68
Figure 5.1.	: Block diagram representation of nervous system.....	72
Figure 5.2.	: Neural networks structure.....	74
Figure 5.3.	: A over-learning situation in training set from Neuroshell2.....	75
Figure 5.4.	: Best area for training completion (Efe and Kaynak, 2000).....	76
Figure 5.5.	: Design choices for a neural network application (Dayhoff, 1990).....	76
Figure 5.6.	: GRNN architecture (Frederick, 1996).....	79
Figure 5.7.	: The basic GRNN architecture.....	81
Figure 5.8.	: The GRNN architecture (Specht, 1996).....	83
Figure 5.9.	: A back propagation neural network model for different activation functions and 3 hidden slab (Frederick, 1996).....	85
Figure 5.10.	: A back propagation neural network model for different activation functions and 2 hidden slab (Frederick, 1996).....	85
Figure 5.11.	: Three-layer back-propagation network, fully interconnected (Ural and Bayrak, 2003).....	87
Figure 5.12.	: The basic back-propagation processing unit (Ural and Bayrak, 2003).....	87
Figure 5.13.	: Weight matrices of a three layered back-propagation system (Ural and Bayrak, 2003).....	88
Figure 5.14.	: Illustration of local minima and global minimum in error surface (Cigizoglu, 2003).....	90
Figure 5.15.	: Linear activation function.....	92
Figure 5.16.	: Logistic function	92
Figure 5.17.	: Symmetric logistic function.....	92
Figure 5.18.	: Gaussian function.....	93
Figure 6.1.	: Actual-Network output scatter (1) for Model 1 and error limits...	102
Figure 6.2.	: Actual-Network output scatter (2) for Model 1 and error limits..	103
Figure 6.3.	: Actual-Network output scatter (3) for Model 1 and error limits...	103
Figure 6.4.	: Variables error through pattern (4) and error limits.....	104
Figure 6.5.	: Test set error graph for Model 1.....	104
Figure 6.6.	: Actual-Network output scatter (1) for Model 2 and error limits..	107
Figure 6.7.	: Actual-Network output scatter (2) for model 2 and error limits..	107
Figure 6.8.	: Actual-Network output scatter (3) for Model 2 and error limits.	108
Figure 6.9.	: Variables error through pattern (4) and error Limits.....	108
Figure 6.10.	: Test set error graph for Model 2.....	109
Figure 6.11.	: Actual-Network output scatter (1) for model 3 and error limits...	111
Figure 6.12.	: Actual-Network output scatter (2) for model 3 and error limits...	112
Figure 6.13.	: Actual-Network output scatter (3) for model 3 and error limits...	112
Figure 6.14.	: Variables error through pattern (4) and error limits.....	113
Figure 6.15.	: Test set error graph for model 3.....	113
Figure 6.16.	: Actual-Network output scatter (1) for model 4 and error limits...	115
Figure 6.17.	: Actual-Network output scatter (2) for model 4 and error limits...	116

Figure 6.18.	: Actual-Network output scatter (3) for model 4 and error limits.	116
Figure 6.19.	: Variables error through pattern (4) and error limits.....	117
Figure 6.20.	: Test set error graph for model 4.....	117
Figure 6.21.	: Actual-Network output scatter (1) for Model 5 and error limits.	119
Figure 6.22.	: Actual-Network output scatter (2) for Model 5 and error limits.	120
Figure 6.23.	: Actual-Network output scatter (3) for Model 5 and error limits.	120
Figure 6.24.	: Variables error through pattern (4) and error limits.....	121
Figure 6.25.	: Test set error graph for Model 5.....	121
Figure 7.1.	: Test set error graph for Model 1.....	123
Figure 7.2.	: Test set error graph for Model 2.....	123
Figure 7.3.	: Test set error graph for model 3.....	126
Figure 7.4.	: Test set error graph for model 4.....	127
Figure 7.5.	: Test set error graph for Model 5.....	127
Figure App. C1.	: Error through patterns for act-net ($1/\sigma$) for Model 1.....	155
Figure App. C2.	: Error through patterns for act-net (Period Lengthening) for Model 1.....	155
Figure App. C3.	: Error through patterns for act-net (Foundation Damping) for Model 1.....	156
Figure App. C4.	: Error through patterns for act-net ($1/\sigma$) for Model 2.....	156
Figure App. C5.	: Error through patterns for act-net (Period Lengthening) for Model 2.....	157
Figure App. C6.	: Error through patterns for act-net (Foundation Damping) for Model 2.....	157
Figure App. F1.	: Error through patterns for act-net ($1/\sigma$) for Model 3.....	180
Figure App. F2.	: Error through patterns for act-net (Period Lengthening) for Model 3.....	180
Figure App. F3.	: Error through patterns for act-net (Foundation Damping) for Model 3.....	181
Figure App. F4.	: Error through patterns for act-net ($1/\sigma$) for Model 4.....	181
Figure App. F5.	: Error through patterns for act-net (Period Lengthening) for Model 4.....	182
Figure App. F6.	: Error through patterns for act-net (Foundation Damping) for Model 4.....	182
Figure App. F7.	: Error through patterns for act-net ($1/\sigma$) for Model 5.....	183
Figure App. F8.	: Error through patterns for act-net (Period Lengthening) for Model 5.....	183
Figure App. F9.	: Error through patterns for act-net (Foundation Damping) for Model 5.....	184

LIST OF SYMBOLS

a, b	: Halfwidth of foundation in direction normal and perpendicular to horizontal projection of inclined incident wave ray path, respectively
a	: Momentum factor for Back Propagation Neural Network
a₁..a_{2J}, b₁..b_{2J}	: Parameters describing discrete-time parametric transfer function
a_j	: Output values for Back Propagation Neural Network
a₀	: Normalized frequency, $\omega r/v_s$
$\tilde{a}_0$	: Normalized frequency a_0 adjusted for incoherence and wave inclination effects
A_f	: Area of foundation
A_v	: Ground acceleration coefficient
c	: Internal damping of single degree-of-freedom and damping matrix
c_u, c_θ	: Coefficients of foundational translational and rotational dashpot
d	: Delay between x(t) and y(t), used in parametric system identification
d_s	: Depth of finite soil layer
D	: Flexural rigidity of foundation
D_k	: Desire output for neural network
e	: Foundation embedment
E	: The average sum squared error for neural network
E_f	: Young Modulus of foundation
f	: Frequency in Hz
G	: Shear modulus of soil
G_{max}	: Maximum shear modulus of soil
h	: Effective height of structure
h	: Learning rate for Back Propagation Neural Network
H	: Total height of structure from base to roof
H(s)	: Complex-valued transfer function determined from parametric system identification for single input-multiple output and single input-single output motion pairs
H(iω)	: Complex-valued transmissibility function for single input-multiple output and single input-single output motion pairs
H(z)	: Discrete time transfer function for single input single output model
 H_u(ω), H_θ(ω) 	: Analytical transfer function amplitude for foundation input motion (FIM) in translation and rocking
i	: $\sqrt{-1}$, also occasionally used as modal index
I	: Rotational inertia of structure
I_f	: Moment of inertia of foundation
J	: Number of modes used to model n degree-of-freedom structure in system identification analysis ($J < n$)

k	: Lateral stiffness of single degree-of-freedom structure
$\mathbf{k}$	: Stiffness matrix of multi degree-of-freedom structure
$\bar{k}_u, \bar{k}_\theta$	: Complex-valued dynamic foundation impedance for translation and rocking deformations
k_u, K_u	: Dynamic and static translational stiffnesses for foundation on halfspace
k_θ, K_θ	: Dynamic and static rotational stiffnesses for foundation on halfspace
$(K_2)_{\max}$	: Related to the soil's relative density
$(K_u)_{FL}, (K_u)_{FL/E}$	: Static translational stiffnesses for foundation on finite soil layer and foundation embedded into finite soil layer,
$(K_\theta)_{FL}, (K_\theta)_{FL/E}$	: Static rotational stiffnesses for foundation on finite soil layer and foundation embedded into finite soil layer
L_i^*	: Generalized influence factor of structure for mode i
m_i^*	: Generalized mass of structure for mode i
$\mathbf{m}$	: Mass matrix of multi degree-of-freedom structure
$\mathbf{M}$	: Base moment in structure
$M\omega$	: Earthquake magnitude
n	: Number of structural degrees-of-freedom
N	: Number of points in time history used for system identification analysis
N_t	: Number of output neurons
N_1	: Blow counts from Standard Penetration test (SPT)
P	: Number of pattern number
PI	: Plasticity index
r_1, r_2	: Radii which match the area and moment of inertia, respectively, of assumed circular foundation in impedance function formulations to the actual foundation area and moment of inertia,
r	: Radius of circular foundation
$R_x(\tau), R_{xy}(\tau)$	: Autocorrelation function, cross correlation function
s	: Variable for Laplace-transformed functions, units of frequency
$S_x(\omega), S_{xy}(\omega)$	: Power spectral density function, cross power spectral density function (also used as S_g , S_ϕ , and S_{cir} for free-field torsional, and circumferential motions, respectively)
S_j	: Weighted sum of inputs
t	: Variable for time-dependent functions
t_f	: Thickness of foundation slab
Δt	: Data sampling interval of strong motion data
t_{hi}	: Thickness of soil layer i
T_k	: Actual output in neural network
$T_i, \tilde{T}_i, \tilde{T}_i^*$	: Fixed-, flexible-, and pseudo flexible-base periods for mode i . parameters are for the first mode if index i is not shown.
$\mathbf{u}$	: Displacement of single degree-of-freedom and multi degree-of-freedom structure relative to its base
$\mathbf{u}^t$	: Total displacement of structure, $= u_g + u_f + h\theta + u$, total displacement vector of multi degree-of-freedom structure

$\mathbf{u}_{\text{FIM}}$	: Translation of foundation due to kinematic interaction effects
$\mathbf{u}_g$	: Free-field ground displacement
$\mathbf{u}_f$	: Horizontal displacement of foundation relative to free-field
V	: Base shear in structure
v_s	: Shear wave velocity of soil
$V(\Theta)$	: Measure of cumulative error between model and recorded output in parametric system identification analysis
$\mathbf{x}$	: Input parameter for neural network
$\mathbf{x}(t)$	: Input time history used in system identification analyses
$\mathbf{X}_j(t)$	: Generalized coordinate used to express structural deformations
y	: The actual value for neural network
$\hat{y}$	: The predicted value of the y for neural network
$\bar{y}$	: The mean value of the y for neural network
$\mathbf{y}(t)$	: Output time history used in system identification analyses
z	: Variable for Z-transformed functions, dimensionless
α_u, β_u	: Dimensionless parameters expressing the frequency-dependence of foundation translational stiffness and damping, respectively
$\alpha_\theta, \beta_\theta$	: Dimensionless parameters expressing the frequency-dependence of foundation rocking stiffness and damping, respectively
α_v	: Inclination angle of incident seismic wave
β	: Soil hysteretic damping ratio
$\varepsilon(t, \Theta)$	: Error between model and recorded output in parametric system identification analysis
γ	: Ratio of structure-to-soil mass
$\gamma^2(i\omega)$	: Coherence function for single input/single output motion pair
$\gamma(\omega)$	: Coherence function for single input/single output motion pair
η	: Ratio of foundation-to-soil rigidity
$\Psi(t)$	: The case of an ARX model
κ	: Dimensionless incoherence
λ	: Forgetting factor for exponential window used in parametric system identification analyses by the Recursive Prediction Error Method
μ	: Ratio of structure/structure-plus-foundation mass
θ	: Base rocking of foundation slab
θ_{FIM}	: Base rocking of foundation slab due to kinematic interaction effects
ρ	: Mass density of soil
σ	: Ratio of soil-to-structure stiffness
σ	: Smoothing factor for general regression neural network
σ'_m	: Mean effective stress
δ	: Error value for neural network
ν	: Soil poisson ratio
ν_f	: Poisson ratio of foundation
ω	: Angular frequency in radians/sec.
$\omega_i, \tilde{\omega}_i, \tilde{\omega}_i^*$	: Fixed-, flexible-, and pseudo flexible-base angular frequencies for mode i . Parameters are for the first mode if index i is not shown.
ω_u, ω_θ	: Foundation dynamic translational and rotational stiffnesses expressed in units of frequency

$\zeta_i, \tilde{\zeta}_i, \tilde{\zeta}_i^*$	: Fixed-, flexible-, and pseudo flexible-base damping ratios for mode i. Parameters are for the first mode if index i is not shown
ζ_u, ζ_θ	: Foundation dynamic translational and rotational damping expressed in units of damping ratio
$\tilde{\zeta}_0$	: Foundation damping factor
Φ_i	: Mode shape of structure for mode i
Γ	: Function representing the effects of ground motion incoherence
$\Gamma(t)$	: Vector of input and output motions
Θ	: Vector of parameters in parametric system identification

YAPAY SİNİR AĞLARI KULLANILARAK ZEMİN YAPI ETKİLEŞİMİNİN DEĞERLENDİRİLMESİ

ÖZET

Ülkemizde inşaat mühendisliği disiplininde yapay sinir ağlarını kullanmak çok yeni bir yöntemdir. Bu olgu genelde inşaat mühendisliği disiplininde hidrolik dalında hidrometeorolojik verilerin yardımı ile nehir akımı tahminin yapılması, su kaynakları projelendirme çalışmalarında, Geoteknik disiplininde zemin sıvılaşmasının incelenmesi ve benzeri konularda kullanılmıştır. Bu çalışmada zemin yapı etkileşimi yapay zeka mantığı kullanılarak incelenmiştir. Bu da zemin yapı etkileşiminin incelenmesine farklı bir bakış açısı getirecektir.

Bu çalışmada 58 tane lokal bölgenin deprem, yapı ve zemin dataları kullanılmıştır. Bu lokal bölgeler Amerika Birleşik Devletlerinin California eyaletindedir. Çalışmada kullanılan verilerin hazırlanışı bölüm 2, 3 ve 4’de anlatılmıştır.

Yapay zeka mantığı yaklaşımında iki tane yapay sinir ağı mimarisi kullanılmıştır. Bunlar BPNN, geri yayılmalı sinir ağı mimarisi ve GRNN, genel regresyonlu yapay sinir ağı mimarisi kullanılmıştır. Bu yaklaşımlarda 21 adet girdi ve 4 tane çıkış parametreleri verilmiştir. Çıkış parametrelerinin biri olan zemin yapı etkileşiminin ihmal edilip edilemeyeceği yapay sinir ağlarının bir özelliği olan karar alma yeteneği kullanılarak bulunmuştur. Elde edilmeye çalışılan 4 adet çıktı parametreleri şunlardır; zeminin yapıya göre rijitlik oranı, periyot artım oranı, temel sönüm oranı ve zemin-yapı etkileşiminin ihmal edilip edilemeyeceğidir.

Geri yayılmalı sinir ağı modeli için 2 tane model yapılmıştır ve farklı kalibrasyonlar kullanılmıştır.

Genel regresyon yapay sinir ağı modeli kullanılarak 3 tane model yapılmıştır. En iyi sonuç veren model 5’de zeminin yapıya göre rijitlik oranında yaklaşık olarak % 98 , periyot artım oranında yaklaşık olarak %94, temel sönüm oranında yaklaşık olarak %90 ve zemin-yapı etkileşiminin ihmal edilip edilemeyeceğinde ise %98 başarı

oranı sađlanmıřtır. Sonuta genel gerilemeli yapay sinir ađı modeli zemin-yapı etkileřimin deđerlendirilmesine ok uygun bir model olduđu grlmřtr.

EVALUATION OF SOIL-STRUCTURE INTERACTION BY USING NEURAL NETWORK METHODOLOGY

SUMMARY

To use neural network approaches is a new phenomena for Civil Engineering disciplines in Turkey. This phenomena generally is used in Hydrology branch of civil engineering disciplines; by the way of hydro-meteorological data estimation of daily river flow, studies of design of water resources, and in Geotechnical disciplines liquefaction risk analysis etc. In this study, soil-structure interaction was discussed by using Neural Network approaches. This provides a new point of view for evaluations of soil-structure interaction.

In this study, 58 local sites earthquake, structure, and soil properties are used. These 58 local sites are in California. Preparedness of using data in this study is discussed in Chapter 2, 3, and 4.

In Artificial Intelligence approach, two Neural Network approaches architecture are used. These approaches are Back Propagation Neural Network architecture (BPNN) and General Regression Neural Network approach (GRNN) architecture. There are 21 input parameters and 4 output parameters. One of the four output parameters is whether Soil-Structure Interaction effects can be neglected or not, is obtained by using the decision making ability of Neural Network. Four output parameters, those that are trying to be obtained, are soil-to-structure rigidity ratio, period lengthening, foundation damping, and whether SSI effects can be neglected or not.

For Back Propagation Neural Network, two models are examined and different calibrations are used.

For General Regression Neural Network, three models are examined and different calibrations are used. In model 5 with the best results, success rates of all outputs are as follows; soil-to-structure rigidity success rate approximately 98%, period lengthening success rate approximately 94%, foundation damping success rate

approximately 90%, and whether soil-structure interaction effects can be neglected or not success rate 98%. In conclusions this study shows that General Regression Neural Network approaches are more useful model for evaluation of soil-structure interaction.

1. INTRODUCTION

1.1 General

This study was prepared to investigate the effects of Soil-Structure Interaction (SSI) on seismic structural response using structural and motion data from 58 sites with Neural Network (NN) approaches. Assessments of seismic loading for structures include the earthquake source, travel path effects, local site effects, and SSI effects in Fig. 1.1. For the purpose of engineering design, source effects generally refer to the earthquake magnitude, rupture mechanism, and location relative to the site, while travel path effects refer to the attenuation of seismic waves as they travel from the source through bedrock towards the site.

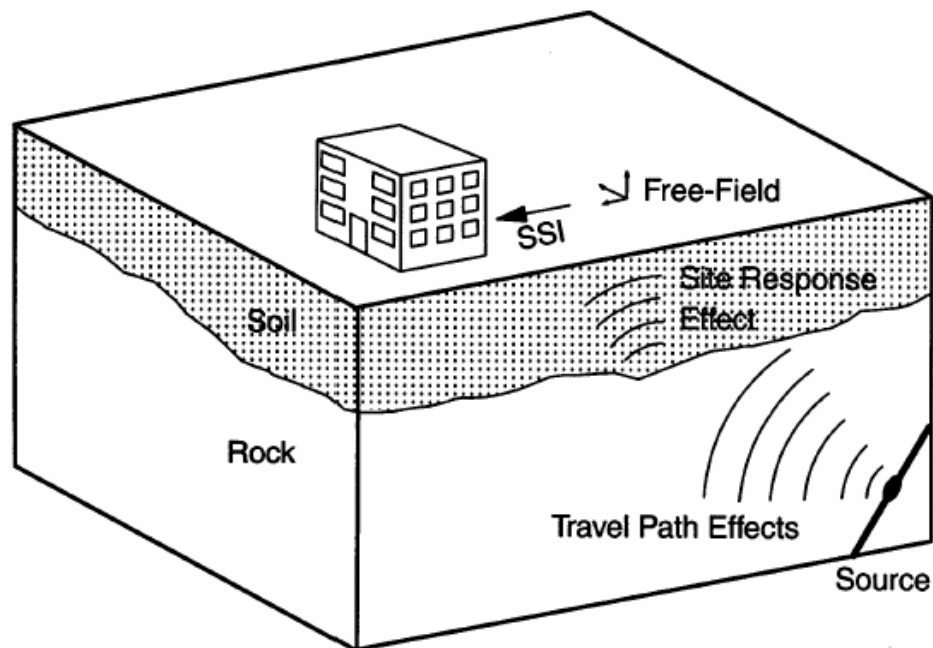


Figure 1.1. SSI in an engineering assessment of seismic loading for a structure (Stewart, 1998)

Ground motions that are not influenced by the presence of structures are referred to as free-field motions. When a structure founded on solid rock is subjected to an earthquake, the extremely high stiffness of the rock constrains the rock motion to be very close to the free-field motion. These can be considered to be fixed-base structures.

On the other hand, the same structure would response differently if supported on soft soil deposit. First the inability of the foundation to be suitable to the deformation of the free-field motion would cause the motion of the base of the structure to deviate from the free-field motion. Other point is that the dynamic response of the structure itself would induce deformation of the supporting soil. This can be explained as flexible-base structures. This process is very important for soil-structure interaction.

In this study, SSI effects are obtained accordingly with some code provisions such as National Earthquakes Hazards Reduction Program (NEHRP), seismic design code Building Seismic Safety Council (BSSC, 1997) and Applied Technology Council (ATC, 1978). BSSC (1997) investigates inertial interaction and neglects kinematic interaction. Due to this, inertial interaction is just investigated by Neural Network approaches. For analyses of inertial interaction effects, the objectives are predictions of first-mode period lengthening $\tilde{T}/T$, foundation damping factor $\tilde{\zeta}_0$, and $1/\sigma$ the ratio of the structure-to-soil stiffness. $\tilde{T}$ Flexible-base period and T is fixed-base period. These parameters are discussed in section 3 and 4.

1.2 Short History of Artificial Intelligence (AI) Method

Artificial intelligence (AI) is the study of ideas brought into machines that respond to stimulation, consistent with traditional responses from humans, given the human capacity for contemplation, judgment and intention. Each such machine should engage in critical appraisal and selection of differing opinions within itself. Produced by human skill and labor, these machines should conduct themselves in agreement with life, spirit and sensitivity, though in reality, they are imitations. Human beings have attained the ability to respond to the world by bringing previous experience, or others' experience, and AI function in this way.

Artificial Intelligence is a valuable tool of representing real-world realities. The birth of artificial intelligence is attributed to the first "intelligent" machine concept developed by Alan Turing, a scientist at Cambridge, UK. The famous "Turing Machine", from many is considered the foundation stone of artificial intelligence, and it found its first use in the, also famous, Enigma decryption project during the WWII. Nevertheless, despite the "mythological" and science fiction depictions of Artificial Intelligence (AI), its true development was closely related to the development of computers in the post-war era. The use of computers allowed Artificial Intelligence (AI) to pursue its real purpose, that is, the attempt to understand, replicate and analyze intelligent entities and processes of our world. As time progressed, the study of artificial intelligence made its first natal steps. But, the "boost" on research and analytic explorations of Artificial Intelligence became possible after the ability of researchers, organizations and institutions to perform computer-based operations and experimentations, especially in the late 1970's and 1980's. Today, artificial intelligence is a part of our everyday life. AI is used on a constantly growing number of applications and processes we use in our every-day life. Web-searches, economic models, computer games, automobile processors, etc, are only some of the most known applications that AI methods found their implementation.

1.3 Objectives

Turkey is a country where destructive earthquakes occur frequently. Since earthquakes occurs in regions at high population, earthquake loading and effects of soil on buildings are extremely important during design process.

The purpose of this study is to examine the effect of soil on structure in a way of soil-structure interaction via artificial intelligence, rather than conventional and well-known methodologies. Advantages of this innovative Artificial Intelligence approach can be listed as;

- In future, it may provide forecasting of structural, foundation, and soil effects or damage with earthquake loading. Events experienced can be taught to

Neuroshell2 (Neural Network program used in this study) and events experienced are indicators of experiences which might occur in the future.

- Like constructing robots or perceiving of human voices on mobile phone which are artificial intelligence methods; using earthquakes data can be constituted knowledge programs accordingly high risk potentials.
- Forecasting can be conducted gradually by training new data and opinions on what effects will occur. In this way, SSI effects on structure can be more obvious. This study is example for these events.
- By the way of Neural Network approaches, inertial interaction can be generalized and forecasted.
- Effects of type of soil (rock/soil), piles foundation or surface foundation, number of stories, structural lateral resisting systems, whether a basement exists or not, effective structure height, earthquake magnitude, maximum horizontal acceleration, embedment, shear wave velocity, foundation radii match, and ratio of the on SSI can be generalized and forecasted by the way of Neural Network approaches.

In this study, all the above items will be investigated with NN approaches. It should be noted that the General Regression Neural Network (GRNN) and Back Propagation Neural Network (BPNN) will be used.

2. DATA DESCRIPTION AND SITE SELECTION

2.1 Data Description

Data for this study has been obtained from “Analysis of Soil-Structure Interaction Effects on Building Response from Earthquake Strong Motion Recordings at 58 Sites by Jonathan P. Stewart and Alisa F. Stewart, Report No. UCB/EERC-97/01”

This report was prepared as part of project which investigated the effects of soil-structure interaction (SSI) on seismic structural response using strong motion data from 58 sites.

The 58 sites considered in this study are listed in Table 2.1, and many of the site and earthquake locations are shown in Figure 2.1. The sites are broken down into two broad categories: 1) ‘A’ sites which have a free-field accelerograph and a structure instrumented with at least foundation- and roof-level lateral sensors, and 2) ‘B’ sites which have structure instrumented with foundation- and roof-level lateral sensor as well as foundation-level vertical sensors to detect base rocking, but no free-field instrument.

Table 2.1. Sites included in this study (Stewart, 1997)

Site*	Station	No. Eqs.	Rock/Soil	Avg. Vs (ft./sec)	Piles (Y/N)	Embed. (ft.)	No. Stories	Structural System**
'A' Sites								
1	Eureka Silvercrest Apts.	1	S	800	N	0	5	SW
2	Fortuna 1-St. Supermarket	2	S	915	N	0	1	SW
3	Humboldt Bay Power Plant	2	S	980	N	86	1	SW
4	Emeryville Pacific Pk. Plaza	1	S	620	Y	0	31	CF
5	Hayward City Hall	1	R	2210	Y	0	11	DWF
6	Hayward 13-St. School Bldg.	1	R	1350	Y	0	13	DWF
7	Hollister 1-St. Warehouse	1	S	670	N	0	1	SW
8	Piedmont Jr. High School	1	R	1830	N	0	3	SW
9	Pleasant Valley Pump. Plant	2	S	1010	N	32	1	DWF
10	Richmond City Hall	1	S	830	N	10	3	DWF
11	San Jose 3-St. Offc. Bldg.	1	R	2690	N	0	3	SF
12	El Centro Imp. Co. Ser. Bldg.	1	S	580	Y	0	6	DWF
13	Indio 4-St. Gov't Offc. Bldg.	1	S	760	Y	16	4	DWF
14	Lancaster 3-St. Offc. Bldg.	1	S	920	Y	0	3	SW
15	Lancaster 5-St. Hospital	1	S	1030	Y	0	5	SF
16	Lancaster Fox Airfield	1	S	1000	N	0	5	SF
17	Loma Linda VA Hos.	1	S	1520	Y	0	4	SW
18	Long Beach Har. Ad. Bldg.	1	S	700	Y	0	7	SF
20	Long Beach VA Hospital	1	S	1210	N	23	11	SW
21	LA 2-St. FCCB	3	R	1030	N	0	2	BI
22	LA 3-St. Comm. Bldg.	1	S	1160	N	23	3	DWF
23	LA 6-St. Offc. Bldg.	1	S	500	N	14	5	SF
24	LA 6-St. Pkg. Garage	1	S	1200	Y	0	6	SW
25	LA 7-St. USC Hos.	2	R	1170	N	0	7	BI
26	LA 7-St. UCLA Bldg	1	S	700	N	14	7	DWF
27	LA 15-St. Offc. Bldg.	2	R	1180	N	0	17	SF
28	LA 19-St. Offc. Bldg.	1	S	1160	Y	38	19	SF
29	LA Hollywood Storage Bldg.	4	S	960	Y	9	14	CF
30	LA Wadsworth VA Hospital	1	S	1130	Y	31	6	SF
31	Newport Beach Hoag Hospital	2	S	1050	N	0	11	SW
32	Norwalk 12400 Imp. Hwy.	1	S	910	Y	14	7	SF
33	Norwalk 12440 Imp. Hwy.	2	S	1000	Y	15	7	SF
34	Palmdale 4-St. Hotel	1	S	1620	N	0	4	SW
35	Pomona 2-St. Bldg.	2	S	1280	Y	11	2	CF
36	Pomona 6-St. Bldg.	2	S	1250	N	13	6	CF
37	Rancho Cucamonga LJC	5	S	1190	N	14	4	BI
38	San Bernardino 3-St.	1	S	980	N	0	3	SF
39	San Bernardino 5-St.	1	S	1310	N	13	5	SW
40	San Bernardino Vanir Tower	1	S	920	Y	0	9	SF
41	San Bernardino Co. Govt Cntr	1	S	1060	Y	0	5	SF
42	Santa Susana Bldg 462	1	R	4500	N	0	8	SF
43	Seal Beach Rockwell Bldg 80	2	S	970	Y	16	8	BI
44	Sylmar Olive View Med. Cen	2	S	1530	N	0	6	SW
45	Ventura 12-St. Hotel	1	S	920	Y	0	12	SW

46	Lotung Containment Structure	1	S	460	N	15	1	SW
'B' Sites								
1	Milpitas 2-St. Offc. Bldg.	1	S	<i>690</i>	N	0	2	SW
2	San Bruno 9-St. Offc. Bldg.	1	S	<i>1010</i>	N	0	9	SW
3	San Fran. 47-St. Offc. Bldg.	1	S	570	Y	39	47	SF
4	San Fran. Transamerica Tow.	1	S	<i>960</i>	N	51	60	SF
5	San Jose 10-St. Resid. Bldg.	1	S	<i>840</i>	Y	0	10	SW
6	San Jose 13-St. Gov't Offc.	1	S	<i>770</i>	N	14	12	SF
7	Walnut Creek 10-St. Offc.	1	R	1450	Y	0	10	DWF
9	El Segundo 14-St. Offc. Bldg.	1	S	1010	N	0	14	SF
10	LA 9-St. Offc. Bldg.	1	S	960	N	13	9	DWF
11	LA 17-St. Resid. Bldg.	2	R	1200	Y	0	17	SW
12	LA 32-St. Offc. Bldg.	1	R	1380	N	54	32	DWF
13	LA 54-St. Offc. Bldg.	1	R	1430	N	59	54	SF
14	Whittier 8-St. Hotel	1	S	870	N	0	8	SW

Shear wave velocities in *italics* are estimated.

*Sites A19 and B8 omitted

** Lateral force resisting systems:

SW = masonry or concrete shear walls

DWF = dual wall/frame system

CF = concrete frame

SF = steel frame

BI = base isolated

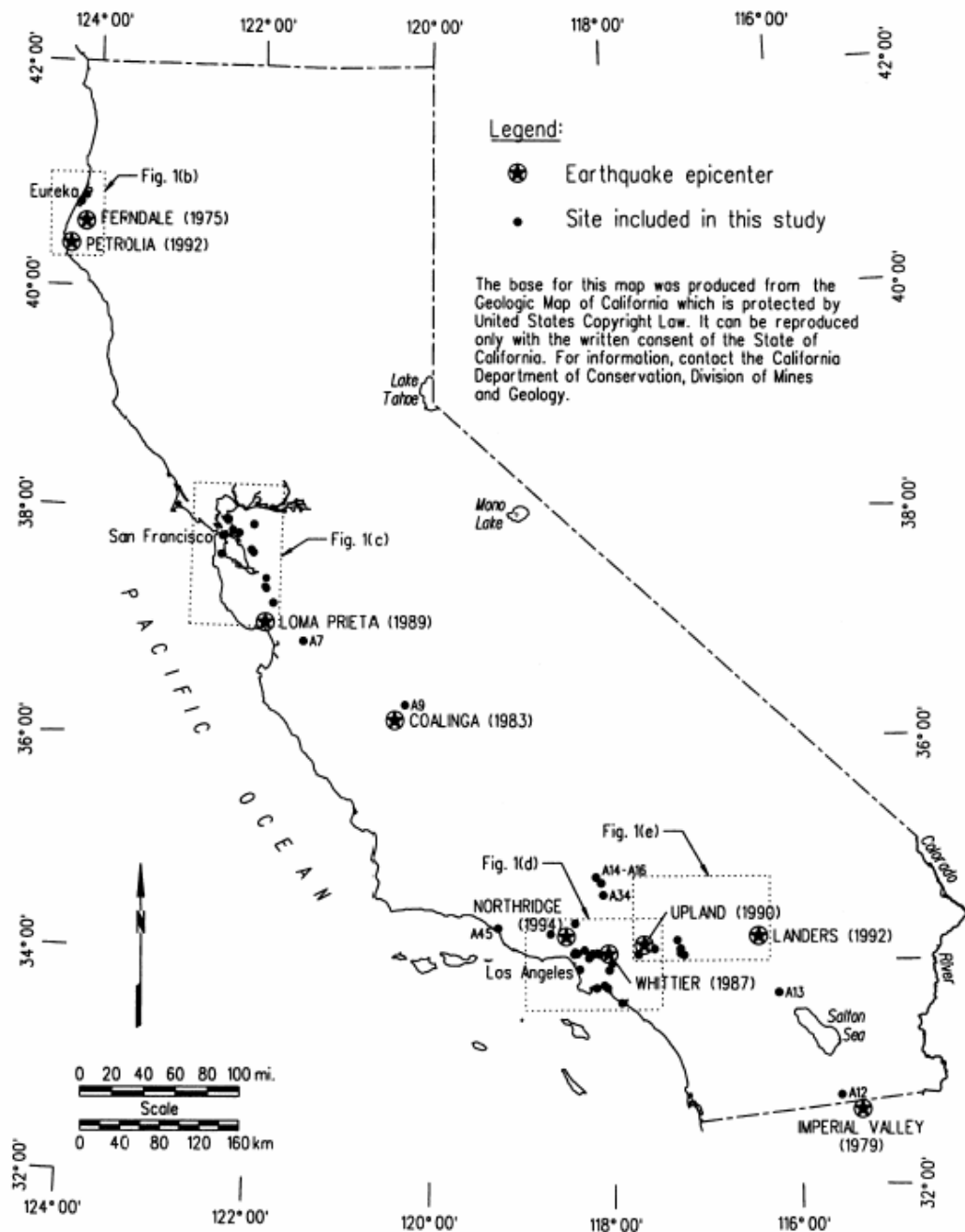


Figure 2.1. Map of California showing locations of sites and selected earthquakes considered in this study (Stewart, 1997)

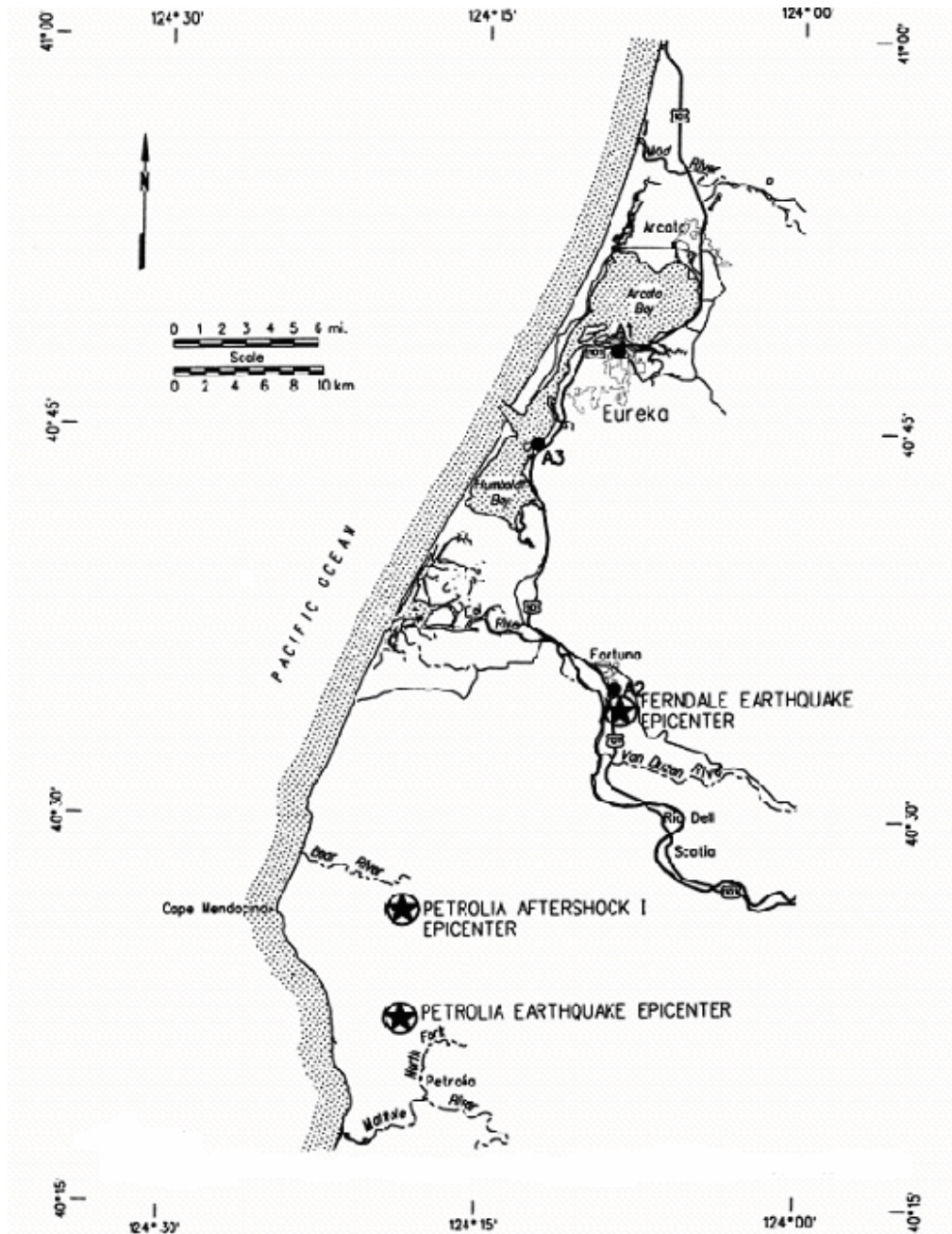


Figure 2.2. Map of Humboldt/Arcata Bay area showing site and earthquake locations (Stewart, 1997)

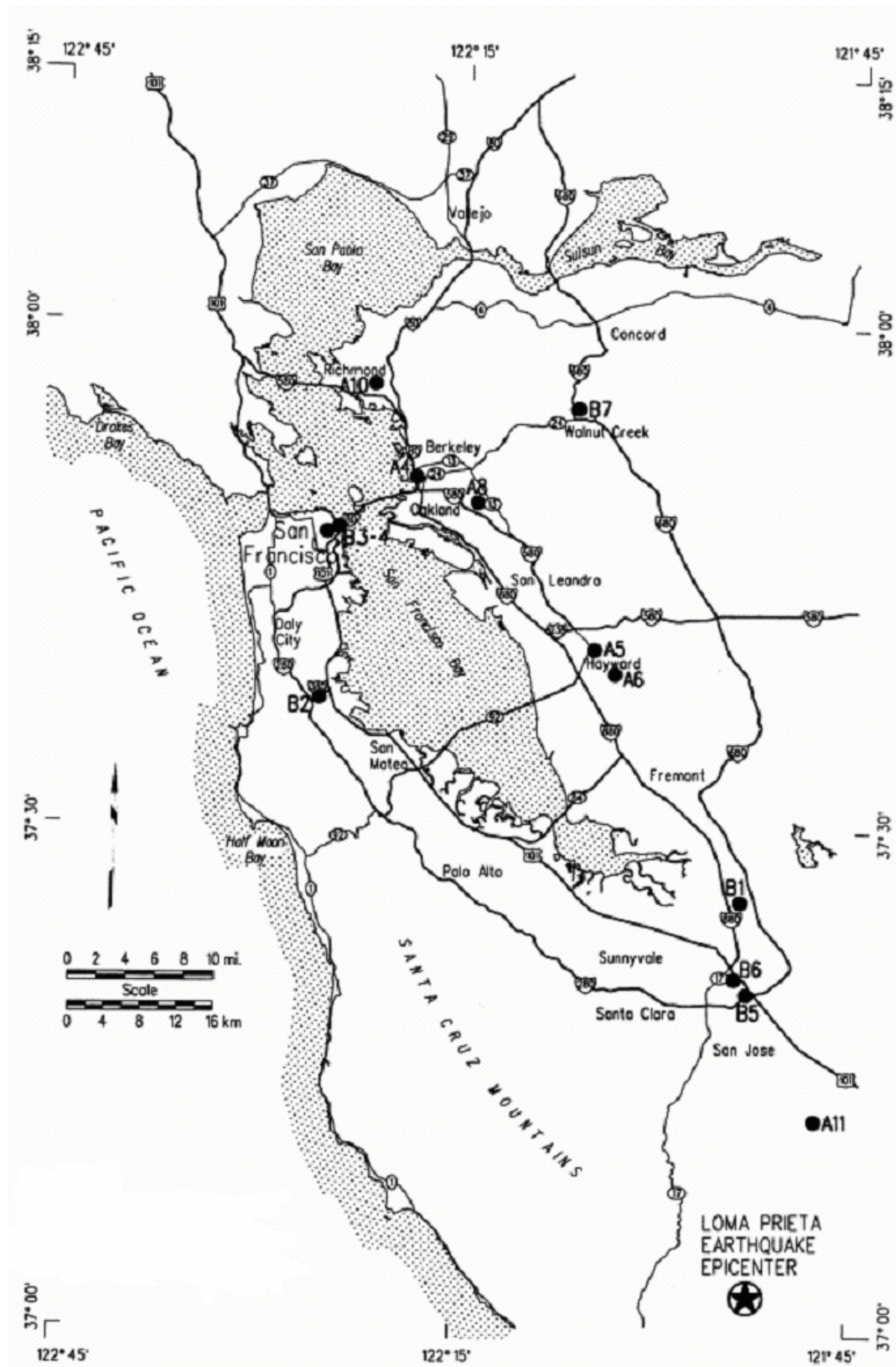
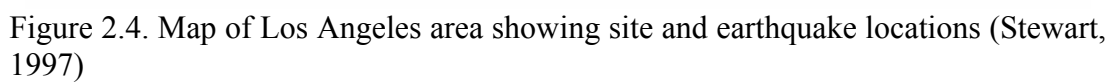


Figure 2.3. Map of San Francisco Bay area showing site and earthquake locations (Stewart, 1997)



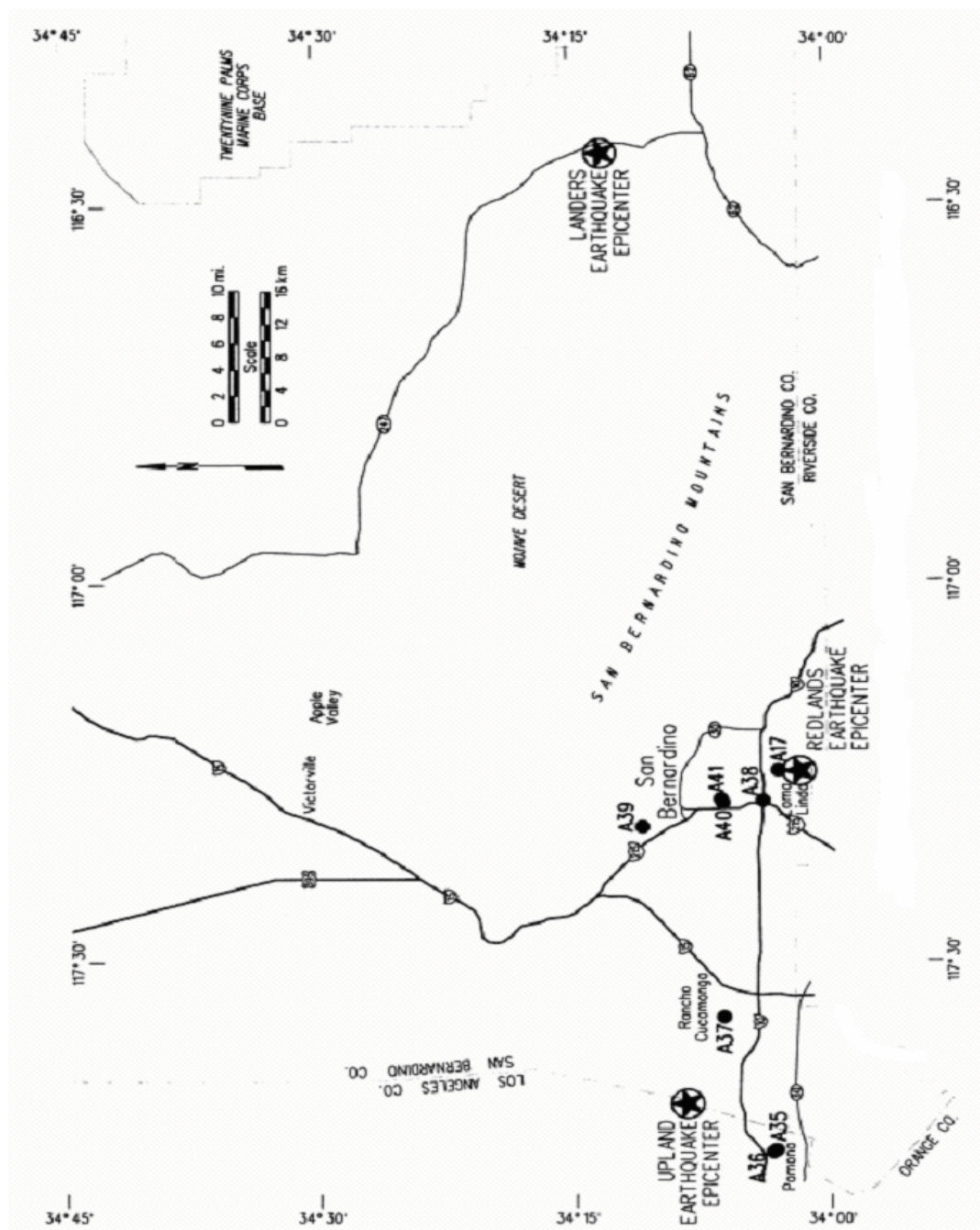


Figure 2.5. Map of San Bemardino area showing site and earthquake location (Stewart, 1997)

2.2 Characterization of Geotechnical Site Conditions

2.2.1 General soil properties

For each site, subsurface data was gathered so that geologic conditions could be characterized in the form of a generalized soil column. These soil/columns are presented for each site (Stewart, 1997). The geotechnical data reported, varies depending on the available information, but generally this report consists of the site stratigraphy, measured or estimated shear wave velocity, depth to groundwater, and various measured properties such as void ratio, density, plasticity index, SPT blow count, and unconfined-unconsolidated shear strength.

2.2.2 Shear wave velocity profiles

a) General considerations

For 29 sites, shear wave velocity (v_s) were measured in situ using techniques such as the downhole method, the cross-hole method, P-S suspension logging, spectral analysis of surface waves (SASW), or seismic refraction. For sites where measurements by one or more of these techniques have been made, the data are shown on the generalized soil profiles as “measured v_s ” and the specific measurement technique employed is reported in the notes.

For remaining 29 sites, measurements of v_s were not available. Therefore, v_s values are estimated from other geotechnical data by one of the following means:

- When v_s measurements are available from a nearby site (i.e. $< 1/2$ mile away) in geologic materials similar to those at the subject site, these data were used. Such as v_s estimates were used at six sites (A7, A18, A26, A27, A30, and B1).
- For rock sites, where in situ v_s measurements are available from other sites in a similar geologic formation (but possibly at significant distance, i.e. $> 1/2$ mile), these data were used. Profiles of v_s were estimated by the means at two sites (A21 and A42).

- For soil sites with laboratory data from soil samples and/or in situ measurements of soil penetration resistance, v_s was estimated from published correlations (Stewart, 1997). Such estimates were made at 21 sites.

The estimation of v_s from correlation relationships is discussed below.

b) Estimation of shear wave velocity from published correlations

Correlation studies have been made to relate in situ v_s measurements. These physical soil properties have been investigated in the Southern California area (Furnal and Tinsley, 1985), the San Francisco Bay area (Furnal, 1978 and Dickenson, 1994) and for the U.S. (Sykora, 1987). Other studies have sought to develop generalized relationships between key soil parameters and v_s for clayey soils (e.g. Hardin and Drnevich 1972 a, b) and sandy soils (e.g. Seed et al., 1984). According to Dickenson (1994), the correlation coefficients for these relationships are often greater for localized studies than for large regions.

For the estimations of v_s in this study, the regions specific correlations were most heavily relied upon where available. (In Fig. 2.2, for the cohesive and sandy soils in Southern California procedures were used). For sandy soils, v_s is estimated by the procedure proposed by Seed et al. (1984). Seed's procedure relates the small strain shear modulus to the mean effective pressure and relative density as follows;

$$G_{\max} = v_s^2 * \text{mass density} \quad (2.1)$$

$$G_{\max} = 1000 * (K_2)_{\max} * (\sigma'_m)^{0.5} \quad (2.2)$$

where σ'_m = mean effective stress in psf, $G_{\max}$ = is in psf, and $(K_2)_{\max}$ is related to the soil's relative density. Values of $(K_2)_{\max}$ can be related to corrected blow counts [$(N_1)_{60}$ values] from Standard Penetration Test (SPT) (Seed et al., 1984), and ranges from 30 for loose sands, to 75 for dense sands.

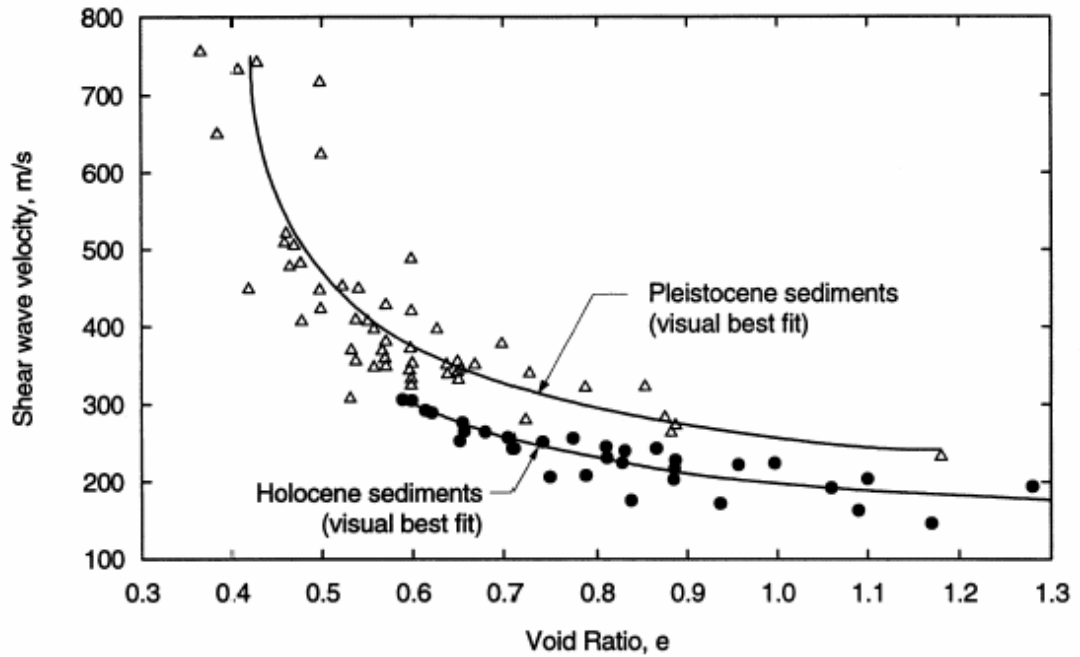


Figure 2.6. Variation of measured shear wave velocity with void ratio for Holocene and Pleistocene sediments in the Los Angeles region. Results are for sand and cohesive soils (Furnal and Tinsley , 1985).

Table 2.2. Measured shear wave velocity in various sedimentary deposits (Furnal, 1978)

Geotechnical Unit	Geologic and Physical Property of Units Included	Depth (m)	V_s (m/s)
Bay Mud	Clay-silty clay v. soft-soft	0-10 10-20	55-100 100-115
Holocene fine-grained alluvium	Clay-silty clay med.-stiff	0-7.5	160-175
Late Pleistocene fine-grained alluvium	Clay-silty/sandy clay, silt loam Interbedded fine and coarse sediment	0-12 12-30	165-275 165-300
Sand	Dune sand ($D < 7.5m$), artificial fill, Holo. v. fine-fine sand, Merritt sand, Merritt sand	0-15	150-245
Sand dense-v. dense nr. surf.	Merced Fm., Colma, Fm., Holocene coarse, Purisima Fm	0-12	250-340
Dune Sand	Dune sand, Merritt sand	5-20	300-380
Gravel and v. coarse sand	Late Pleistocene med. & crs. Santa Clara Fm.	2.5-20 10-30	340-500 320-740
Merced Fm. at depth	Merced Fm., Purisma Fm.	12-30	310-490
Colma Fm. at depth	Colma Fm.	7.5-30	450-520

Table 2.3. SPT blow counts (Stewart 1997)

$(N_1)_{60}$	$(K_2)_{\max}$
5	34
8	40
10	18
18	52
28	61
44	71

$(N_1)_{60}$ refers to the blow count from a 140 lb hammer dropping 30-inches ($\approx 60\text{cm}$) with a standard 2-inch outside diameter “split spoon” sampler, with the data corrected to an equivalent one atmosphere mean effective pressure, and 60% hammer/rod efficiency (Seed et al., 1985). When SPT blow counts were not available for sandy soils, field descriptions of soil relative density were used to estimate $(K_2)_{\max}$ for use in Eq. 2.1.

Seed et al. (1984) correlation for sandy soils, were developed for 15 sites in the southern California region (i.e. sites A13-16, A31 -33, A35-41, and A45), and these procedures were used for site A9 (near Coalinga, CA), which have a similar arid climate.

For sites in the San Francisco Bay area, correlations developed by Furnal (1978) for different geologic units were used (Table 2.2). These correlations were compared to results from the void ratio correlation by Furnal and Tinsley (1985) and the procedure by Seed et al. (1984) for sands. For site B2, B4, B5, B6, v_s profiles were determined in this way; for B2 (Colma Formation), B4 (Dune Sand, Holocene and Late-Pleistocene alluvium), and sites B5-B6 (Holocene and Late-Pleistocene

alluvium) the procedure in Seed et al. (1984) was used to estimate v_s for sandy soil site A2 is in Northern California.

2.2.3 Estimation of poisson's ratio of geologic materials

The Poisson ratio was estimated as $\nu=0.33$ for unsaturated sands, $\nu=0.4$ for unsaturated low-to-moderate-plasticity clays, and $\nu=0.45$ for saturated deposits and also in the upper half of the effective profile depth, where the profile depth was based on the foundation dimensions.

2.2.4 Evaluation of dynamics soil properties for impedance functions

The evaluations of foundation impedance functions under earthquake loading conditions require that the effects of ground shaking on geologic media within the zone of significant influence of the foundation be account for. Relatively simple impedance function formulations were employed in this study which require single values of shear modulus G (or shear wave velocity v_s) and soil hysteretic damping β . Small strain v_s profile is defined, the two principal factors involved in evaluating representative G and β values are: a) the degradation of soil shear stiffness and associated increase in damping with shear strain, and b) the size of the zone within the ground most significantly affected by the foundation.

The degradation effects of large ground strains on dynamic soil behaviour are often quantified by relationships for modulus degradation ($G/G_{\max}$) and damping (β) v_s shear strain. Laboratory test results were used at three sites (i.e. sites A4, A46, B3). At the other sites, published relationships for different soil types were used. For cohesive soils (Fig. 2.3), the modulus of degradation curves by Sun et al. (1988) were used in conjunction with the damping curves by Vucetic and Dobry (1991). For cohesionless soils (Fig. 2.4), the modulus degradation and damping relationships presented in Seed et al. (1984) were used. For intact bedrock material (Fig. 2.5), the modulus degradation and damping relationships proposed by Schnabel (1973) were used.

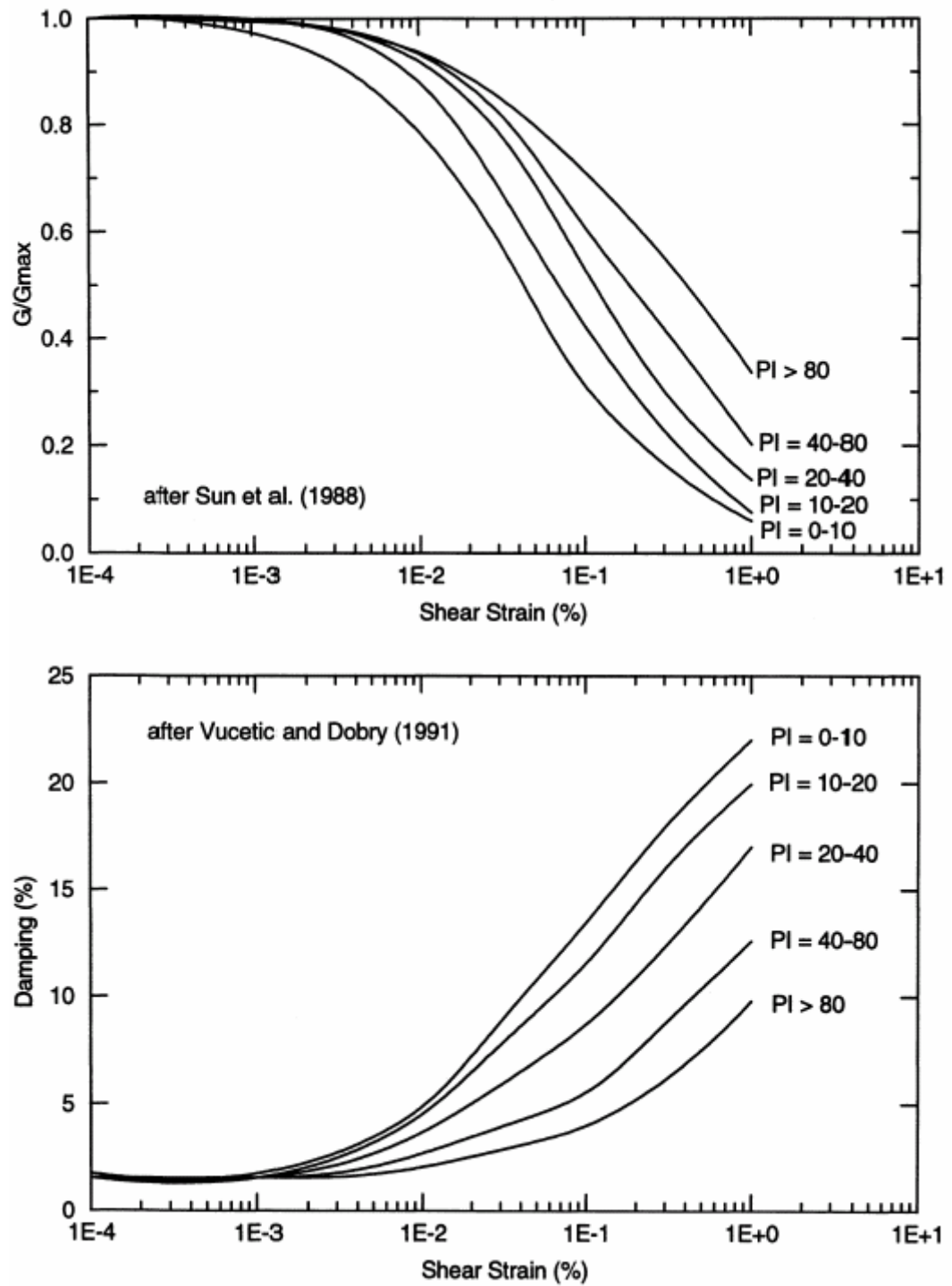


Figure 2.7. Modulus degradation and damping curves for clay used in this study. (adapted from Sun et al., 1988 and Vucetic and Dobry , 1991)

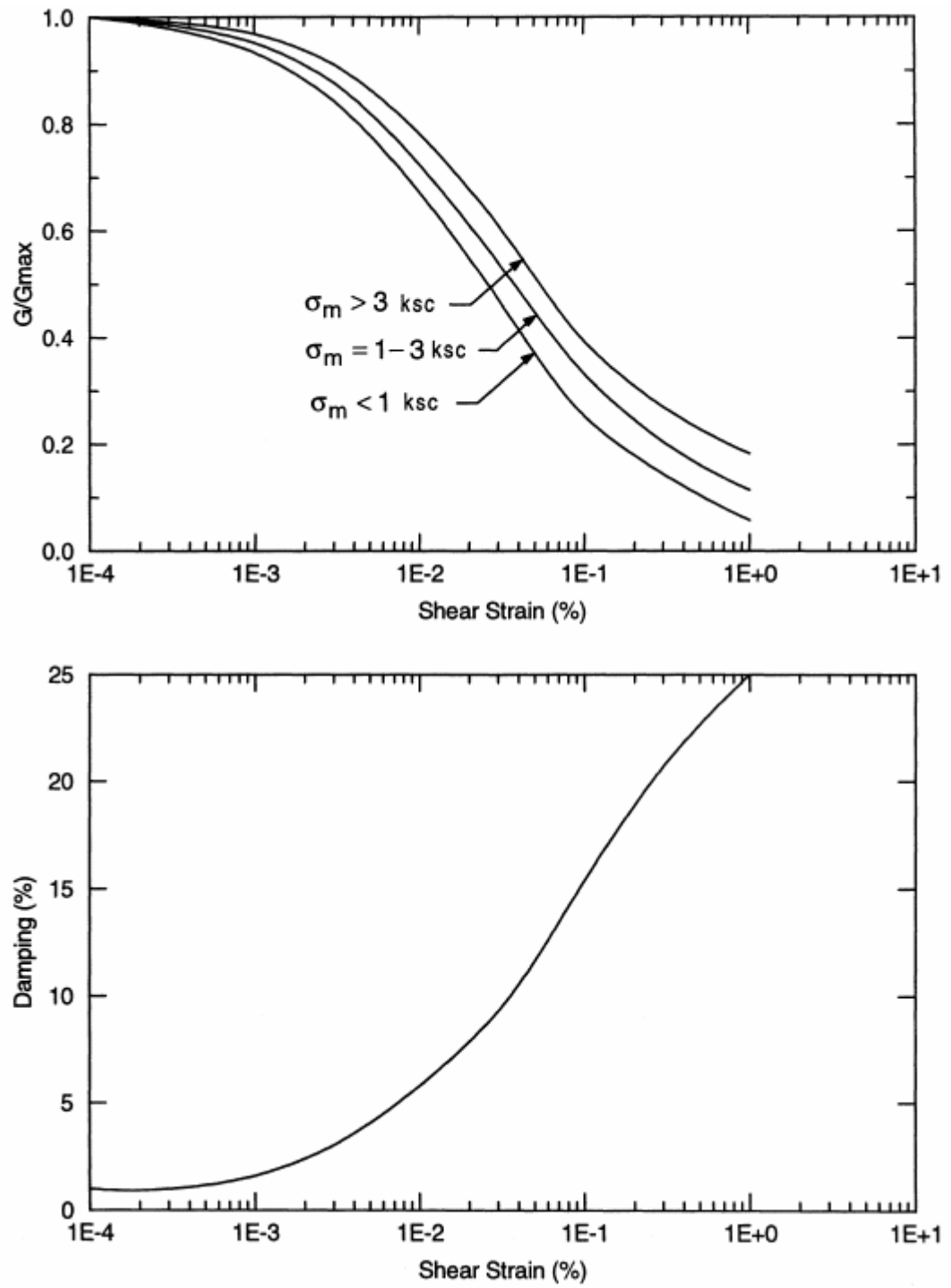


Figure 2.8. Modulus degradations and damping curves for sand used in this study. (adapted from Seed et al.,1984)

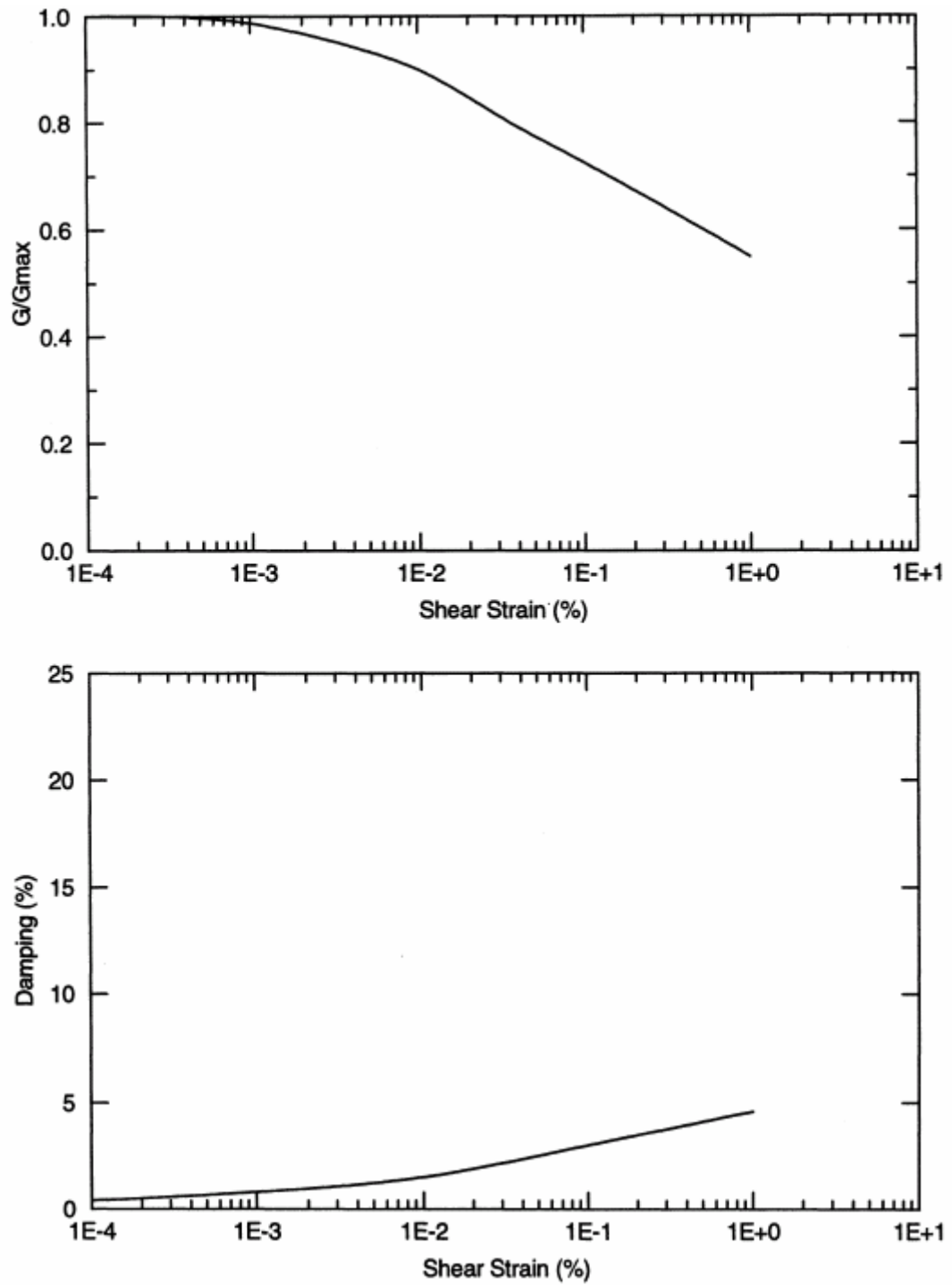


Figure 2.9. Modulus degradations and damping curves for rock used in this study. (adapted from Schnabel.,1973)

Most profiles can be characterized by an equivalent halfspace or a finite soil layer overlying a rigid base. Geologic profiles without a large, abrupt increase in v_s within a depth of about two foundation radii were modeled as a halfspace, with the shear

modulus and damping for the halfspace defined from the materials within one foundation radius of the base of structure. Only encountered at site A24, soil was modeled as uniform finite layer overlying a rigid base.

Using the appropriate modulus degradation and damping relationships, strain-dependent v_s and β values were calculated for the layers in the profile using a deconvolution procedure. The calculations were performed using the equivalent linear dynamic ground response analysis program SHAKE (Schnabel et al., 1972). Using the strain-dependent v_s and β values for the soil/rock layers within profile, the “average” v_s and β values were calculated as follow:

$$V_s = (r_1) / \left(\sum_i t_{hi} / (V_{si}) \right) \quad \beta = \sum_i w_i \beta_i \quad (2.3)$$

Where t_{hi} =thickness of layer i ($\sum_i t_{hi} = r_1$), $(V_s)_i$ and β_i are the shear wave velocity and damping of layer i , and w_i are weighting factors which sum to one and vary linearly from a maximum at the ground surface to zero at the effective depth of profile. In this way, v_s and β values are calculated close to the foundation.

2.3 Site Selection

2.3.1 Site selection criteria of ‘A’ and ‘B’ sites

The ‘A’ sites, have a free-field accelerograph and a structure instrumented to record base and roof translations. A few of the structures at ‘A’ sites are also instrumented to record base rocking. For most sites, the suitability of “free-field” recordings was evaluated based on the distance separating the structure and free-field instrument, with due consideration of the structure’s fundamental frequency and the site conditions. This section presents criteria for evaluating conditions for which “free-field” instruments are too close or too far from a structure.

‘B’ sites have structures instrumented to record base rocking as well as base and roof translations, but have no free-field accelerographs.

2.3.2 Conditions examined

All of the sites are listed in Table 2.4 As noted above, there are two classes of sites: There are 45 ‘A’ sites and 13 ‘B’ sites, with a total of 79 sets of available processed

data. Sites A19 and B8 were omitted in the final compilation for reasons discussed below.

Table 2.4. Site and structural data included in this study (Stewart, 1998)

Site*	Station	No. Eqs.	Rock/Soil	Avg. Vs (ft./sec)	Piles (Y/N)	Embed. (ft.)	No. Stories	Structural System**	Period (sec)	FF-Str. Sep. (ft.)
'A' Sites										
1	Eureka Silvercrest Apts.	1	S	800	N	0	5	SW	0.2	340
2	Fortuna 1-St. Supermarket	2	S	915	N	0	1	SW	0.4	350
3	Humboldt Bay Power Plant	2	S	980	N	86	1	SW	na	240
4	Emeryville Pacific Pk. Plaza	1	S	620	Y	0	31	CF	2.5	530/130
5	Hayward City Hall	1	R	2210	Y	0	11	DWF	1.2	470/500
6	Hayward 13-St. School Bldg.	1	R	1350	Y	0	13	DWF	1.3	1260
7	Hollister 1-St. Warehouse	1	S	670	N	0	1	SW	0.7	400
8	Piedmont Jr. High School	1	R	1830	N	0	3	SW	0.2	120
9	Pleasant Valley Pump. Plant	2	S	1010	N	32	1	DWF	0.5	300
10	Richmond City Hall	1	S	830	N	10	3	DWF	0.3	650
11	San Jose 3-St. Offc. Bldg.	1	R	2690	N	0	3	SF	0.7	510
12	El Centro Imp. Co. Ser. Bldg.	1	S	580	Y	0	6	DWF	0.7	340
13	Indio 4-St. Gov't Offc. Bldg.	1	S	760	Y	16	4	DWF	0.7	240
14	Lancaster 3-St. Offc. Bldg.	1	S	920	Y	0	3	SW	0.2	250
15	Lancaster 5-St. Hospital	1	S	1030	Y	0	5	SF	0.7	360
16	Lancaster Fox Airfield	1	S	1000	N	0	5	SF	0.3	160
17	Loma Linda VA Hos.	1	S	1520	Y	0	4	SW	0.3	400/400
18	Long Beach Har. Ad. Bldg.	1	S	700	Y	0	7	SF	1.4	200
20	Long Beach VA Hospital	1	S	1210	N	23	11	SW	0.6	980
21	LA 2-St. FCCB	3	R	1030	N	0	2	BI	0.8	100
22	LA 3-St. Comm. Bldg.	1	S	1160	N	23	3	DWF	0.6	1700
23	LA 6-St. Offc. Bldg.	1	S	630	N	14	5	SF	0.9	830
24	LA 6-St. Pkg. Garage	1	S	870 (W) 640 (L)	Y	0	6	SW	0.5	240
25	LA 7-St. USC Hos.	2	R	1170	N	0	7	BI	1.2	350
26	LA 7-St. UCLA Bldg	1	S	700	N	14	7	DWF	0.7	930
27	LA 15-St. Offc. Bldg.	2	R	1180	N	0	17	SF	3.1	750
28	LA 19-St. Offc. Bldg.	1	S	1160	Y	38	19	SF	3.2	940
29	LA Hollywood Storage Bldg.	4	S	960	Y	9	14	CF	2.2	140
30	LA Wadsworth VA Hospital	1	S	1130	Y	31	6	SF	0.9	470/1320
31	Newport Beach Hoag Hospital	2	S	1050	N	0	11	SW	0.9	650
32	Norwalk 12400 Imp. Hwy.	1	S	910	Y	14	7	SF	1.5	490-570
33	Norwalk 12440 Imp. Hwy.	2	S	1000	Y	15	7	SF	1.3	130-660
34	Palmdale 4-St. Hotel	1	S	1620	N	0	4	SW	0.2	240
35	Pomona 2-St. Bldg.	2	S	1280	Y	11	2	CF	0.3	290
36	Pomona 6-St. Bldg.	2	S	1250	N	13	6	CF	1.2	1270
37	Rancho Cucamonga LJC	5	S	1190	N	14	4	BI	0.6	330
38	San Bernardino 3-St.	1	S	980	N	0	3	SF	0.6	690
39	San Bernardino 5-St.	1	S	1310	N	13	5	SW	0.6	490
40	San Bernardino Vanir Tower	1	S	920	Y	0	9	SF	2	910
41	San Bernardino Co. Govt Cntr	1	S	1060	Y	0	5	SF	0.5	210
42	Santa Susana Bldg 462	1	R	4500	N	0	8	SF	0.6	160
43	Seal Beach Rockwell Bldg 80	2	S	970	Y	16	8	BI	1.3	460
44	Sylmar Olive View Med. Cen	2	S	1530	N	0	6	SW	0.3	460
45	Ventura 12-St. Hotel	1	S	920	Y	0	12	SW	0.7	180

46	Lotung Containment Structure	1	S	460	N	15	1	SW	0.5	100
'B' Sites										
1	Milpitas 2-St. Offc. Bldg.	1	S	690	N	0	2	SW	0.3	na
2	San Bruno 9-St. Offc. Bldg.	1	S	1010	N	0	9	SW	1.1	na
3	San Fran. 47-St. Offc. Bldg.	1	S	570	Y	39	47	SF	5.2	na
4	San Fran. Transamerica Tow.	1	S	960	N	51	60	SF	3.6	na
5	San Jose 10-St. Resid. Bldg.	1	S	840	Y	0	10	SW	0.5	na
6	San Jose 13-St. Gov't Offc.	1	S	770	N	14	12	SF	2.2	na
7	Walnut Creek 10-St. Offc.	1	R	1450	Y	0	10	DWF	0.8	na
9	El Segundo 14-St. Offc. Bldg.	1	S	1010	N	0	14	SF	2.1	na
10	LA 9-St. Offc. Bldg.	1	S	960	N	13	9	DWF	1.3	na
11	LA 17-St. Resid. Bldg.	2	R	1200	Y	0	17	SW	1.1	na
12	LA 32-St. Offc. Bldg.	1	R	1380	N	54	32	DWF	1.9	na
13	LA 54-St. Offc. Bldg.	1	R	1430	N	59	54	SF	5.9	na
14	Whittier 8-St. Hotel	1	S	870	N	0	8	SW	0.6	na

Shear wave velocities in *italics* are estimated.

*Sites A19 and B8 omitted

** Lateral force resisting systems:

SW = masonry or concrete shear walls

DWF = dual wall/frame system

CF = concrete frame

SF = steel frame

BI = base isolated

A summary of the 15 California earthquakes which contributed data to this study is presented in Table 2.6. The magnitudes range from 4.8 to 7.4, though the events contributing the vast majority of the data were the $M_w = 6.0$ Whittier, $M_w = 6.9$ Loma Prieta, $M_w = 5.6$ Upland, $M_w = 7.0$ Petrolia, $M_w = 7.3$ Landers, and $M_w = 6.7$ Northridge earthquakes. The maximum horizontal accelerations (MHAs) produced by these earthquakes at the sites, are given in table 2.5.

Table 2.5. The maximum horizontal accelerations (MHAs) produced by California earthquakes (Stewart, 1998)

MHA	DATA SETS
>0.6g	1
0.4-0.6g	4
0.2-0.4g	23
0.1-0.2g	17
<0.1g	34

Hence, moderate- and low-level shaking is well represented in the database, but data for intense shaking ($MHA > 0.4g$) is relatively sparse (only 4 data sets).

Table 2.6. Earthquake which contributed data to this study (Stewart, 1998)

Earthquake	Magnitude	Recordings
1952 Kern Country (kn)	$M_w=7.4$	1
1971 San Fernando (sf)	$M_w=6.6$	1
1975 Ferndale (fn)	$M_L=5.2$	1
1979 Imperial Valley (imp)	$M_w=6.5$	1
1983 Coalinga (cg)	$M_w=6.4$	1
1983 Coalinga Aftershock (cga)	$M_w=5.4$	1
1985 Redlands (rd)	$M_L=4.8$	1
1987 Whittier (wt)	$M_w=6.0$	9
1989 Loma Prieta (lp)	$M_w=6.9$	14
1990 Upland (up)	$M_w=5.6$	3
1991 Sierra Madre (sm)	$M_w=5.6$	1
1992 Petrolia (pt)	$M_w=7.0$	3
1992 Petrolia Aftershock (pta)	$M_w=6.2$	1
1992 Landers (ld)	$M_w=7.3$	11
1994 Northridge (nr)	$M_w=6.7$	31

The building heights and principle lateral force resisting systems are shown in table 2.7.

Table 2.7. The building heights and lateral forces resisting system (Stewart, 1998)

STORY	NUMBER OF BUILDINGS
1 to 4 stories	18
5 to 11 stories	27
> 11 stories	13
LATERAL FORCES RESISTING SYSTEM	
Masonry/concrete shear walls	20
Dual wall/frame systems	11
Concrete frames	4
Steel frames	19
Base isolated	4

3. DEFINITION AND PREDICTION PROCESS OF SOIL- STRUCTURE INTERACTION EFFECTS

3.1 Introduction and Problem Definition

3.1.1 Components of the soil-structure interaction problem

The structure, the foundation, and the geologic media underlying and surrounding the foundation interactions are between three linked systems, which are affected by earthquake shaking, leading to the deformation of a structure. A seismic Soil-Structure Interaction (SSI) analysis evaluates the collective response of these systems to a specified free-field ground motion.

The mechanism of interaction between the structure, foundation, and soil can be separated by two phenomena, which are (i) Inertial Interaction, and (ii) Kinematic Interaction.

- i. Inertial Interaction: Inertia developed in the structure due to its own vibrations gives rise to base shear and moment, which in turn cause displacements of the foundation relative to the free-field.
- ii. Kinematic Interaction: The presence of stiff foundation elements on or in soil will cause foundation motions to deviate from free-field motions. Three mechanisms can potentially contribute to such deviations: (a) Base-Slab Averaging; free-field motions associated with inclined and/or incoherent wave fields are “averaged” within the footprint area of the base-slab due to the kinematic constraint of essentially rigid-body motion of the slab, (b) Embedment effects; the reduction of seismic ground motion with depth for embedded foundations, and (c) Wave Scattering; scattering of seismic waves off of corners and asperities of the foundation. It should be noted that kinematic interaction is neglected in by BSSC 1997 and ATC 1978 and this study is adopted into with

code provisions (e.g. BSSC 1997 and ATC 1978). Because of this, kinematic interaction is discussed not very much.

The effects of these phenomena are often described by a complex-valued transfer function relating free-field and foundation motions, and a complex-valued impedance function which quantifies the stiffness and damping characteristics of foundation-soil interaction.

Both the transfer and impedance functions are dependent on the finite stiffness and damping characteristics of the soil medium.

3.1.2 Methodologies for soil-structure interaction analysis

SSI analysis has two general methods which are direct and substructure approaches. The soil and substructure are included within the same model and analyzed in a single step for direct approach. In a direct approach, generally the soil discretized with solid finite elements and structure with finite beam elements. True nonlinear analyses are possible (Stewart, 1998). However, results from nonlinear analyses can be quite sensitive to poorly-defined parameters in the soil constitutive model, and the analyses remain quite expensive from a computational standpoint. Thus, direct SSI analyses are more commonly performed using equivalent-linear methods to approximate the effects of soil nonlinearity.

In order to formulate the complete solution, the SSI problem is broken down into three distinct parts which are combined in a substructure approach. This approach requires an assumption of linear soil and structure behavior. Referring to fig.3.1, the three steps in the analysis are as follow:

- i. Evaluation of a Foundation Input Motion (FIM), which is the motion that would occur on the base-slab if the structure and foundation had no mass. The FIM is dependent on the stiffness and geometry of the foundation and soil. Since inertial effects are neglected, the FIM represents the effects of kinematic interaction only.
- ii. Determination of the impedance function. The impedance function describes the stiffness and damping characteristics of foundation-soil interaction. It should account for the soil stratigraphy and foundation stiffness and geometry, and is

computed using equivalent-linear soil properties appropriate for the in situ dynamic shear strains.

- iii. Dynamic analysis of the structure supported on a compliant base represented by the impedance function and subjected to a base excitation consisting of the FIM.

In the substructure approach, the principal advantage is its flexibility and each step is independent of the others. In this way, the analyst can focus resources on the most significant aspects of the problem.

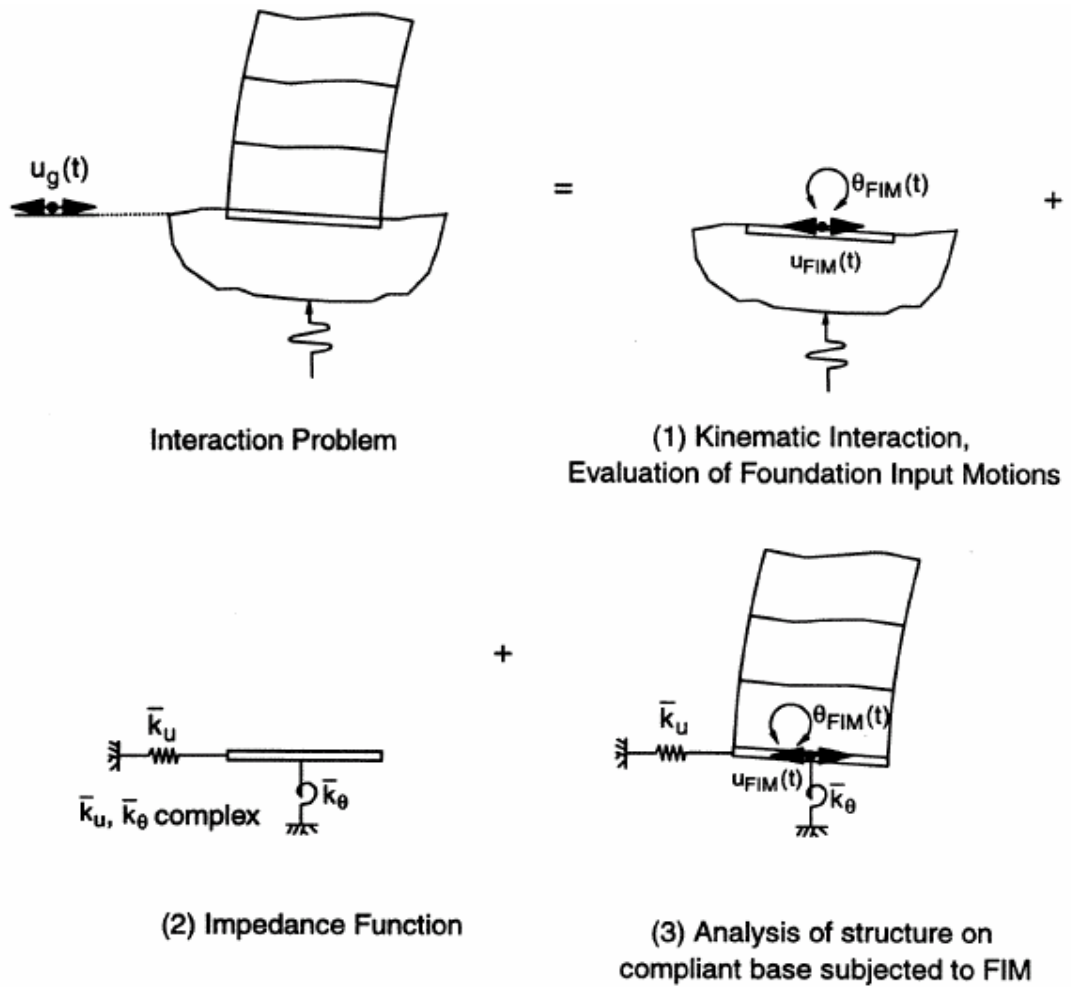


Figure 3.1. Substructure approach to analysis of the SSI problem

The simplified analytical formulations which are calibrated against “empirical” data are based on the substructure approach (Stewart, 1998). Analyses of inertial interaction effects predict the variations of first-mode period and damping ratio between the actual “flexible-base” case and a fictional “fixed-base” case. Flexible-base case is based on incorporation the flexibility of both the foundation-soil system

SSI provisions in the Applied Technology Council (ATC, 1978) and the National Earthquake Hazards Reduction Program (NEHRP) (BSSC, 1997) seismic design codes are similar to portions of the inertial interaction analysis procedures described in this chapter. Kinematic interaction effects are neglected in the code provisions, meaning that free-field motions and FIMs are assumed to be identical.

3.2.1 System considered

The diagram shows a mechanical system. A cart of mass m can move horizontally on a surface. It is connected to a fixed wall on the left by a spring with stiffness $\bar{k}_u$. The cart's horizontal displacement is u . A rigid arm of length h is pivoted to the cart. The arm has a stiffness k_θ and makes an angle θ with the vertical. The pivot point on the cart has a spring with stiffness $\bar{k}_\theta$ that resists rotation. The angular displacement of the arm is θ . The diagram also shows virtual displacements u_θ , u_r , $h\theta$, and u along the horizontal axis.

Where h is height but in the latter case, h is defined as the distance from base to the centroid of the inertial forces associated with the first mode vibration mode. Other parameters are m , k , and c which are respectively mass, stiffness, and viscous

damping coefficient. Where u_f is the structure allowed to translate relative to the free-field an amount and similarly θ is rotate an amount. The impedance function is represented by lateral and rotational springs with complex stiffness $\bar{k}_u$ and $\bar{k}_\theta$, respectively. The imaginary components of the foundation stiffness terms represent the effects of damping.

3.2.2 Impedance function

The impedance function represents the dynamic stiffness and damping characteristics of foundation-soil interaction. This impedance function is a matrix. This matrix relates the forces which are base shear and base moment. Base shear and moment are at the base of the structure. Displacements and rotations of the foundation are relative to the free-field. The terms in the impedance function are complex valued and frequency dependent. When values of impedance parameters at a single frequency must be used (as is the case for the model in Fig. 3.2), values at the predominant frequency of the soil-structure system are selected.

a) Basic case

Generally, six degrees of freedom would be necessary for each support point on the foundation. In practice, however, the foundation is often assumed to be rigid, which reduces the total degrees of freedom to two. It should be noted that vertical excitation and torsion are neglected in the simple impedance function in Eq. 3.1.

$$\begin{bmatrix} V \\ M \end{bmatrix} = \begin{bmatrix} \bar{k}_u & 0 \\ 0 & \bar{k}_\theta \end{bmatrix} \begin{bmatrix} Z \\ \theta \end{bmatrix} \quad (3.1)$$

The most widely used solution is that for a rigid circular foundation on the surface of a visco-elastic halfspace (Veletsos and Wei, 1971 and Veletsos and Verbic, 1973) and BSSC 1997 and ATC 1978 code provisions are adjusted with this model. This solution accounts for the three-dimensional nature of the problem and the frequency dependence of the stiffness and damping parameters. In the solution for a rigid disk on a halfspace, terms in the impedance function are expressed in the form

$$\bar{k}_j = k_j(a_0, \nu) + i\omega c_j(a_0, \nu) \quad (3.2)$$

Where j denotes either deformation mode u or θ , ω is angular frequency (radians/sec.), a_0 is a dimensionless frequency defined by

$$a_0 = \frac{\omega r}{v_s} \quad (3.3)$$

Where r = foundation radius, v_s = soil shear wave velocity, and ν = soil Poisson ratio. Foundation radii are computed separately for translational and rotational deformation modes to match the area (A_f) and moment of inertia (I_f) of the actual foundation, as follows,

$$r_1 = \sqrt{\frac{A_f}{\pi}} \quad r_2 = \sqrt[4]{\frac{4 \cdot I_f}{\pi}} \quad (3.4)$$

There are corresponding different values of $(a_0)_1$ and $(a_0)_2$ as well. The real stiffness and damping of the translational and rotational springs and dashpots are expressed, respectively, by

$$k_u = \alpha_u K_u \quad (3.5a)$$

$$c_u = \beta_u \frac{K_u r_1}{v_s} \quad (3.5b)$$

$$k_\theta = \alpha_\theta K_\theta \quad (3.5c)$$

$$c_\theta = \beta_\theta \frac{K_\theta r_2}{v_s} \quad (3.5d)$$

The quantities α_u , β_u , α_θ , and β_θ are dimensionless parameters expressing the frequency dependence of the results, while K_u and K_θ represent the static stiffness of a disk on a halfspace, defined by (Stewart, 1998)

$$K_u = \frac{8}{2 - \nu} Gr_1 \quad (3.6a)$$

$$K_{\theta} = \frac{8}{3(1-\nu)} Gr_2^3 \quad (3.6b)$$

Where G =soil dynamic shear modulus. Presented in Fig. 4.4 are the frequency dependent values of α_u , β_u , α_{θ} , and β_{θ} for $\nu = 0.4$ based on closed form expressions in Veletsos and Verbic (1973). Where β , r_1 and r_2 are hysteretic damping, foundation radii, respectively.

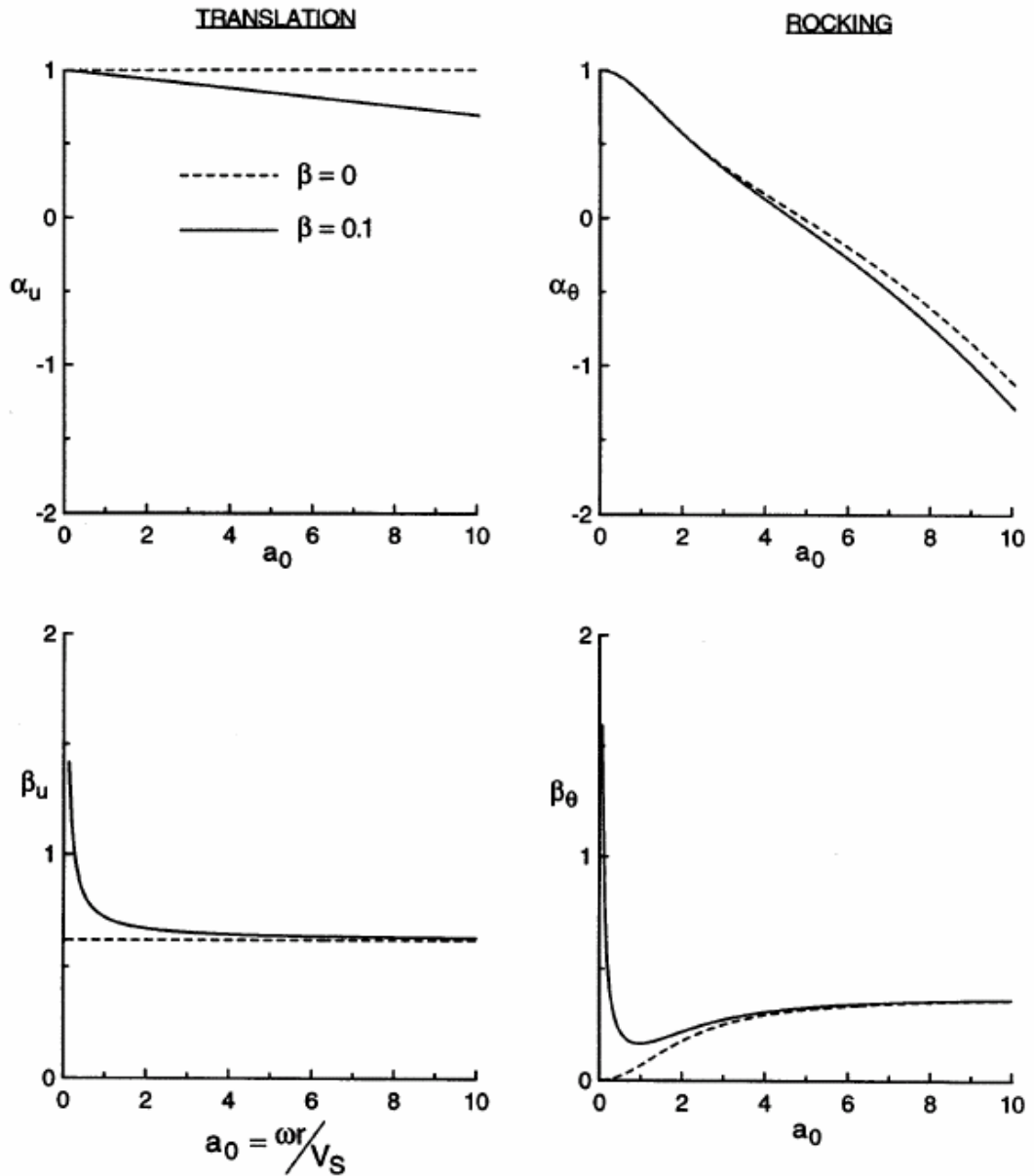


Figure 3.3. Foundation stiffness and damping factors for elastic and viscoelastic halfspace, $\nu=0.4$ (after Veletsos and Verbic, 1973)

Values of soil shear stiffness G and hysteretic damping β used in the formulation of impedance functions should be appropriate for the in situ shear strains. These are for surface foundations which are expressed by fig.3.4 for SSI.

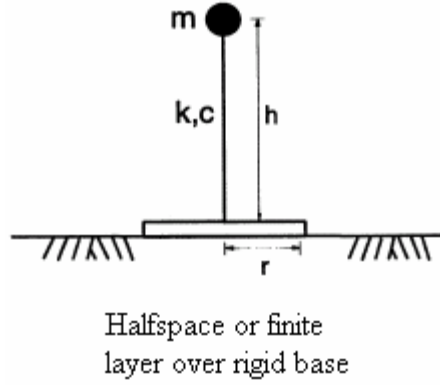


Figure 3.4. Simplified surface structure considered in SSI analysis

Where k , c and r are stiffness, dashpot and foundation radius, respectively. Where h is effective building height. The effective height of the single degree-of-freedom structural model was generally taken as the distance above the foundation level at which the building's mass could be concentrated to yield the same base moment that would occur in the actual structure assuming a linear first-mode shape, this effective height can be calculated as,

$$h^2 = \frac{\sum_i m_i h_i^2}{\sum_i m_i} \quad (3.7)$$

Where m_i = mass at level i and h_i =height of level i . For many structures, the effective height was found to be $h=0.7H$. Where H =distance from foundation to roof of structure. However, for tall buildings, the effective height using Eq. 3.7 was typically less than $0.7H$. In such cases, in order to account for potential higher mode effects, the effective height was simply taken as $0.7H$. It should be noted that the modal parameter are done for single-degree of freedom system for this study.

For embedded structures, fig. 3.5 and fig. 3.6 express SSI for embedment foundations.

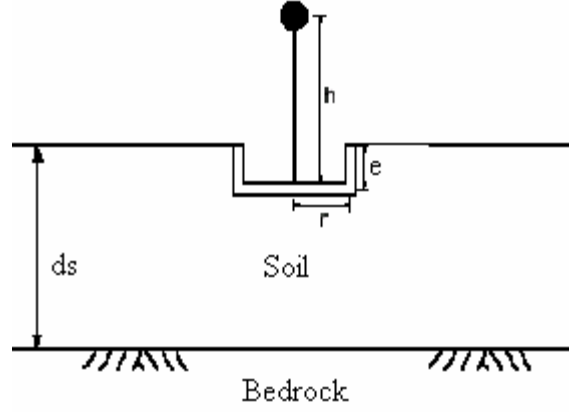


Figure 3.5. Embedded soil-foundation-structure system on finite soil layer.

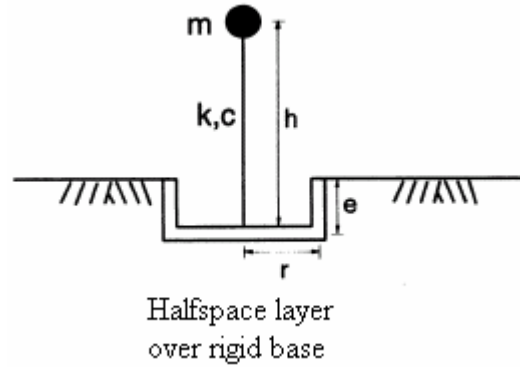


Figure 3.6. Embedded soil-foundation-structure system on halfspace layer over rigid base.

Generally, structures were modeled on halfspace layer over rigid base (Stewart, 1997 and 1998). On the other hand, finite soil layer is used in a few sites (Stewart, 1997 and 1998). Foundation embedment effects were investigated by Elsabee and Morray (1977) for the case of a circular foundation embedded to a depth e into a homogeneous soil layer of depth d_s (Fig. 3.5). It was found that the static horizontal and rocking stiffness for such foundations $[(K_u)_{FL/E}$ and $(K_\theta)_{FL/E}]$ is approximated as follows for $r/d_s < 0.5$ and $e/r < 1$:

$$(K_u)_{FL/E} = K_u \left(1 + \frac{2}{3} \frac{e}{r}\right) \left(1 + \frac{5}{4} \frac{e}{d_s}\right) \left(1 + \frac{1}{2} \frac{r}{d_s}\right) \quad (3.8a)$$

$$(K_\theta)_{FL/E} = K_\theta \left(1 + 2 \frac{e}{r}\right) \left(1 + 0.7 \frac{e}{d_s}\right) \left(1 + \frac{1}{6} \frac{r}{d_s}\right) \quad (3.8b)$$

Coupling impedance terms were found to be small relative to $(K_u)_{FL/E}$ and $(K_\theta)_{FL/E}$ for small embedment ratios (i.e. $e/r < 0.5$). Elsabee and Morray suggested that the frequency dependence of the foundation stiffness and damping terms could be approximated as per Eqs. 3.5a-d (which strictly apply only for a rigid, circular surface foundation on a halfspace). These recommendations have been adopted into the NEHRP (BSSC, 1997) code provisions, with the exception of the frequency dependence stiffness terms (α) which are assumed to be unity.

b) Heterogeneous soil profiles

Equivalent halfspace velocities were computed as $v_s = r_1/t_{r-0}$, where t_{r-0} is the travel time for vertically propagating shear waves to travel from a depth r_1 to the ground surface in this study. These equivalent halfspace velocities are often similar to the actual v_s at a depth of $0.5*r_1$. Details on the calculation of v_s for individual sites are presented in Stewart (1997). Heterogeneous soil profiles can often be characterized by gradual increases in stiffness with depth, or by a very stiff layer underlying relatively soft, surficial layers. For profiles having gradual increases in stiffness with depth, Roesset (1980) found that using soil properties from a depth of about $0.5*r$ gave halfspace impedances which reasonably simulated the impedance of the heterogeneous profile. For the case of a finite soil layer overlying a much stiffer material, the key considerations are an increase in the static stiffness and changes in the frequency dependent variations of stiffness and damping. The increased static stiffnesses can be estimated as follows (Kausel, 1974),

$$(K_u)_{FL} = K_u \left(1 + \frac{1}{2} \frac{r_1}{d_s}\right) \quad (3.9a)$$

$$(K_\theta)_{FL} = K_\theta \left(1 + \frac{1}{6} \frac{r_2}{d_s}\right) \quad (3.9b)$$

Where $(K_u)_{FL}$ and $(K_\theta)_{FL}$ are the static horizontal and rocking stiffnesses of the foundation on finite soil layer, and d_s is the depth of the layer.

c) Foundation shape

Conventional practice has been that foundations of arbitrary shape are analyzed as equivalent circular mats, provided that the foundation aspect ratio in plan (L/B) is less than 4:1 (Roesset, 1980). As noted in Eq. 3.4, an equivalent radius for translational stiffness is derived by equating the area of the mats, while an equivalent radius for rocking stiffness is derived by equating the moment of inertia of the mats. These criteria have been adopted into the NEHRP (BSSC, 1997) code.

d) Foundation flexibility

The effects of foundation flexibility on impedance functions for surface disk foundations have been investigated by Iguchi and Luco (1982) for the case of loading applied through a rigid central core, Liou and Huang (1994) for the case of thin perimeter walls, and Riggs and Waas (1985) for the case of rigid concentric walls (Fig. 3.7).

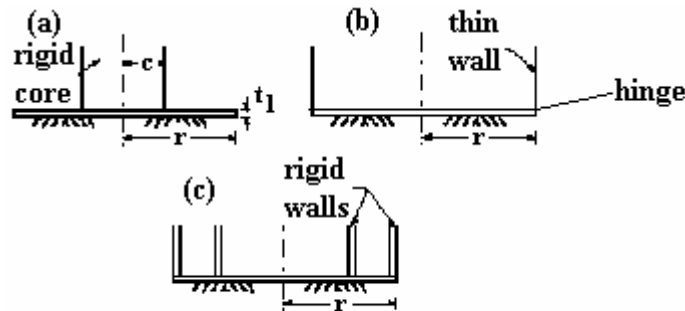


Figure 3.7. Disk foundations with (a) rigid core considered by Iguchi and Luco (1982), (b) thin parameter walls considered by Liou and Huang (1994), and (c) rigid concentric walls considered walls considered by Riggs and Waas (1985)

These studies have generally focused on foundation flexibility effects on rocking impedance; the horizontal impedance of non-rigid and rigid foundations are similar (Liou and Huang, 1994). A key parameter in the evaluation of foundation flexibility effects on rocking impedance is the ratio of the soil-to-foundation rigidity,

$$\eta = \frac{Gr^3}{D} \quad (3.10)$$

In which G is the soil dynamic shear modulus and D is the foundation's flexural rigidity,

$$D = \frac{E_f t_f^3}{12(1 - \nu_f^2)} \quad (3.11)$$

Where E_f , t_f , and ν_f are the Young's modulus, thickness, and Poisson's ratio of the foundation, respectively. For the case of rocking impedance, the significance of foundation flexibility effects depends on the wall. As shown in Fig. 3.8, these effects are most important for the rigid central core case, for which significant reductions in stiffness and damping are possible. The reductions are greatest for narrow central cores and large values of relative soil/foundation rigidity (i.e. $\eta = 10$ to 1000). For the case of thin perimeter walls, the foundation impedances are reasonably close to rigid base values for $a_0 < 3$. For the concentric wall case considered by Riggs and Waas (1985), it was similarly found that flexible foundations behave similarly to rigid foundations at low frequencies. Corrections for foundation flexibility effects were made to rocking impedance terms for structures having central core shear walls using the curves in Fig. 3.8. (Stewart, 1998).

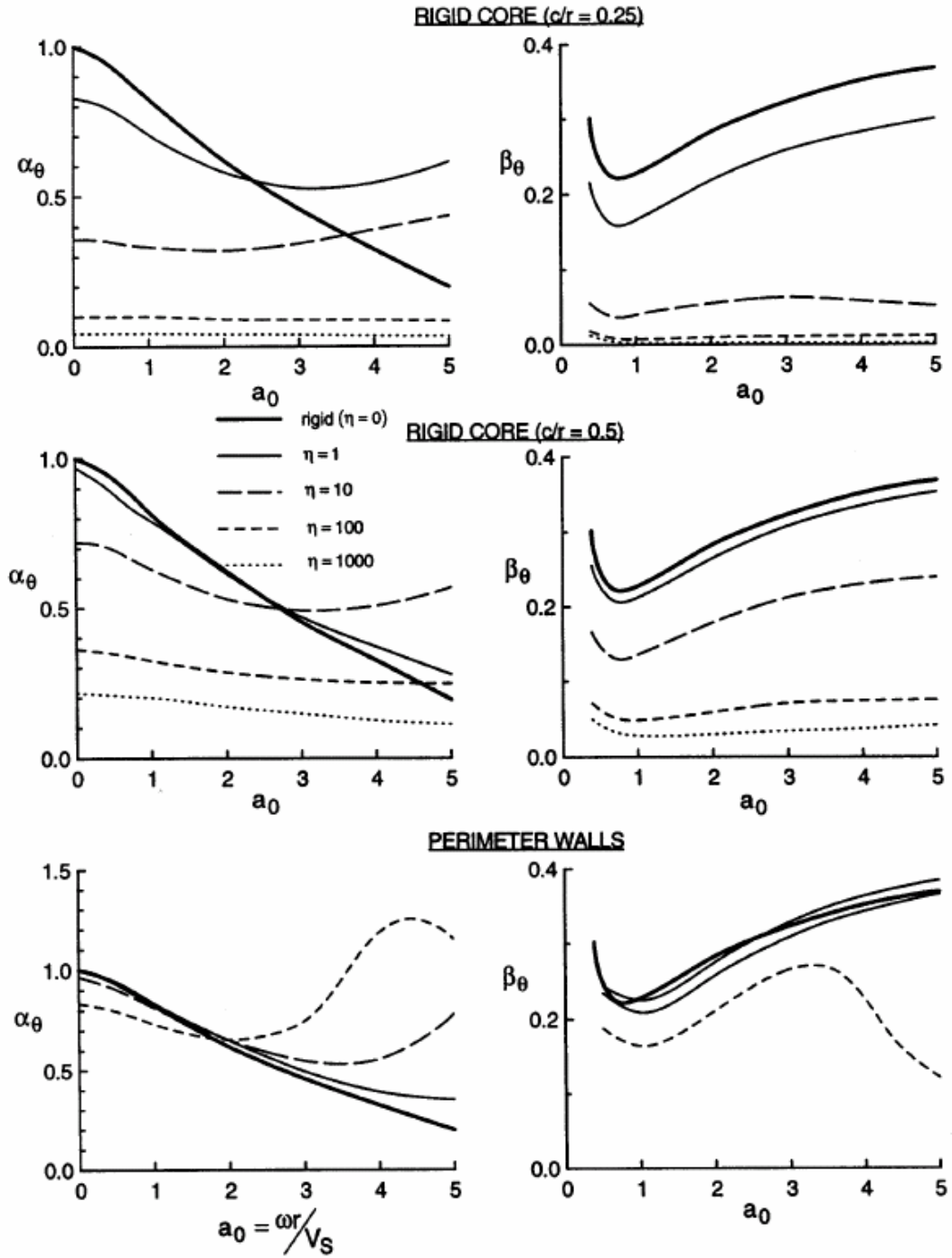


Figure 3.8. Rocking stiffness and damping factor for flexible foundations; rigid core cases (Iguchi and Luco, 1982) and perimeter wall case (Liou and Huang, 1994)

e) Piles and piers

The influence of pile foundations on impedance functions cannot easily be accounted for with simplified analyses. Many analytical techniques are available for evaluating

the impedance of pile supported foundations (e.g. Novak, 1991 and Gohl, 1993). The influence of foundation type on the final results will be evaluated empirically after Neural Network approaches.

3.3 Kinematic Interaction

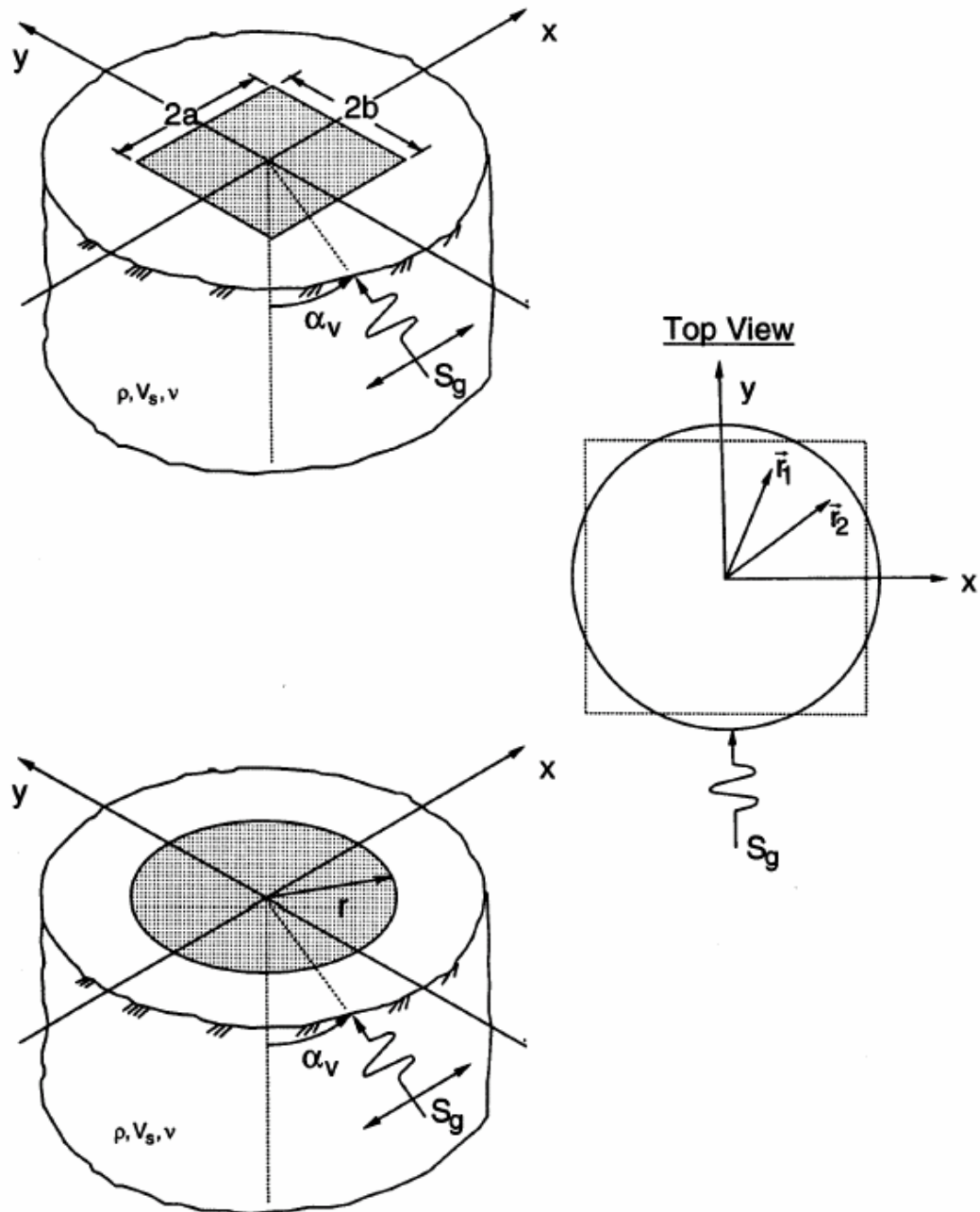


Figure 3.9. System considered for kinematic interaction analyses (Veletsos and Prasad, 1989 and Veletsos et.al., 1997)

In the free-field, an earthquake will cause soil displacements in both the horizontal and vertical directions. If a foundations on the surface of, or embedded in, a soil deposits is so stiff that it cannot follow the free-field deformation pattern, its motion will be influenced by kinematic interaction, even if it is has no mass. For surface foundations, analytical predictions of base-slab averaging effects are made using the transfer functions. A topic of recommended future study is to compare these analytical transfer functions with transfer functions computed from recordings of surface foundation and free-field motion. From such a comparison, the effects of ground motion incoherence and incident wave inclination could be approximately quantified. Similarly, for embedded structures, the analytical transfer functions in Eqs. 3.12 and 3.13 should be validated against field performance data. As part of the work by Elsabee and Morray, approximate transfer functions were proposed for the translation and rocking motions of the circular foundation as follows,

$$\left| H_u(\omega) \right| = \begin{cases} \cos\left(\frac{e}{r}a_o\right) & a_o \leq 0.7\bar{a}_o \\ 0.453 & a_o > 0.7\bar{a}_o \end{cases} \quad (3.12)$$

$$\left| H_\theta(\omega) \right| = \begin{cases} \frac{0.257}{r}(1 - \cos\left(\frac{e}{r}a_o\right)) & a_o \leq \bar{a}_o \\ \frac{0.257}{r} & a_o > \bar{a}_o \end{cases} \quad (3.13)$$

$H_u(\omega)$ is for translation and $H_\theta(\omega)$ is for rocking. Where $\bar{a}_o = (\pi/2) * (r/e)$. Normalized frequency $\bar{a}_o$ corresponds to the fundamental frequency of the soil from the surface to depth e ($\bar{a}_o = 2 \pi f_1 r / v_s$ where $f_1 = v_s / 4e$).

3.3.1 Base-slab averaging

For vertically incident, coherent wave fields, the motion of a rigid surface foundation is identical to the free-field motion. Base-slab averaging effects result from wave fields which have an angle of incidence relative to the vertical, α_v , or which are incoherent in time and space. Incoherence of seismic waves results from different wave ray paths (i.e. due to laterally traveling seismic waves in the underlying bedrock) and local heterogeneities in the geologic media through which the seismic waves have travelled.

3.4 Results and Summary

3.4.1 Inputs for inertial interaction

For analyses of inertial interaction effects, the objectives are predictions of first-mode period lengthening $\tilde{T}/T$ and foundation damping factor $\tilde{\zeta}_0$. The necessary input parameters are:

- Soil conditions: characterization of the site as a halfspace or finite soil layer over rigid base; shear wave velocity v_s and hysteretic damping ratio β which are representative of the site stratigraphy and the level of ground shaking; representative soil Poisson's ratio ν .
- Structure/Foundation Characteristics: effective height of structure above foundation level, h ; embedment, e ; foundation radii which match the area and moment of inertia of the actual foundation, r_1 and r_2 ; appropriate corrections to the foundation impedance for embedment, shape, and flexibility effects.
- Fixed Base 1st Mode Parameters: period and damping ratio, T and ζ .

3.4.2 Results

Veletsos and Meek (1974) found that the maximum seismically induced deformations of the oscillator in Fig. 3.2 could be predicted accurately by an equivalent fixed-base single degree-of-freedom oscillator with period $\tilde{T}$ and damping ratio $\tilde{\zeta}$. These are referred to as “flexible-base” parameters, as they represent the properties of an oscillator which is allowed to translate and rotate at its base (i.e. Fig. 3.2). The flexible base period is evaluated from (Veletsos and Meek, 1974),

$$\frac{\tilde{T}}{T} = \sqrt{1 + \frac{k}{k_u} + \frac{kh^2}{k_\theta}}$$

(3.14)

Where T is the fixed-base period of the oscillator in Fig. 3.2 (i.e. the period that would occur in the absence of base translation or rocking). The flexible-base damping ratio has contributions from the viscous damping in the structure as well as

radiation and hysteretic damping in the foundation. Jennings and Bielak (1973) and Veletsos and Nair (1975) expressed the flexible-base damping $\tilde{\zeta}$ as,

$$\tilde{\zeta} = \tilde{\zeta}_0 + \frac{\zeta}{(\tilde{T}/T)^3} \quad (3.15)$$

Where $\tilde{\zeta}_0$ is referred to as the foundation damping factor and represents the damping contributions from foundation-soil interaction (with hysteretic and radiation components). A closed form expression for $\tilde{\zeta}_0$ is presented in Veletsos and Nair (1975). The relationships between the fixed- and flexible-base oscillator properties depend on aspect ratio h/r_2 , soil Poisson Ratio ν , soil hysteretic damping ratio β , and the following dimensionless parameters:

$$\sigma = \frac{\nu_s T}{h} \quad (3.16)$$

$$\gamma = \frac{m}{\rho \pi r_1^2 h} \quad (3.17)$$

Parameters σ and γ represent the ratio of the soil-to-structure stiffness and structure-to soil mass, respectively. For conventional building structures, $\sigma > 2$ and $\gamma \approx 0.1$ to 0.2 and generally the representative value of $\gamma = 0.15$ is recommended by Veletsos and Meek (1974).

For the investigation of inertial interaction effects in this study, modal parameters were evaluated for two cases of base fixity: (1) a “fixed-base” case in which the system flexibility is associated entirely with the structure (i.e. no SSI effects), and (2) a “flexible-base” case in which the system flexibility is associated with foundation translation and rocking as well as structural deformations. Inertial interaction effects are quantified by the first-mode period lengthening ratio ($\tilde{T}/T$) and the foundation damping factor ($\tilde{\zeta}_0$).

3.4.3 Adopted code provisions for inertial interaction

Current SSI provisions in two U.S. building codes (BSSC, 1997 and ATC, 1978) are examined for SSI effects. The code procedures are based on the framework

developed by Veletsos and Nair (1975) and Bielak (1975) wherein inertial soil-structure interaction effects are described in terms of period lengthening ratio $\tilde{T}/T$ and foundation damping factor $\tilde{\zeta}_0$. These provisions incorporate inertial SSI effects into evaluations of seismic base shear forces in structures, but are “optional” in the current versions of these codes, and are commonly neglected in practice. Kinematic interaction effects are neglected in current code provisions, consequently the focus here is on inertial interaction.

The code provisions are based on a single degree-of-freedom structure model with a rigid disk foundation resting on the surface of a visco-elastic halfspace. Parameters needed to evaluate the system response to a given ground motion include: (1) fundamental-mode fixed-base period (T) and damping ratio (ζ), as well as effective structure height (h), (2) foundation radii for rocking (r_1) and translation (r_2), and (3) soil shear wave velocity (v_s) and hysteretic damping ratio (β). The single degree-of-freedom model is extended to multi-story structures by taking height (h) as the distance from the base to the centroid of the inertial forces associated with the first mode. This effective height is taken as 70% of the total structure height.

Eq. 3.4 is used to compute foundation radii which match the area (A_f) and moment of inertia (I_f) of the actual foundation is same to BSSC 1997 code provisions

$$r_u = r_1 = \sqrt{\frac{A_f}{\pi}} \quad r_\theta = r_2 = \sqrt[4]{\frac{4I_f}{\pi}} \quad (3.18)$$

Eq. 3.8 is used to extend the analysis to embedded foundations and soil conditions more appropriately modelled as a finite soil layer over a rigid base. The real part of the foundation impedance function is taken as the static value (i.e. α factors defined in Eq. 3.5 are taken as 1).

For heterogeneous soil profiles, effective shear moduli (or shear wave velocities, v_s) are derived from irregular v_s profiles by taking the ratio of profile depth to travel time through the profile. The code commentary recommends effective profile depths of $1.5*r_2$ for rocking, and $4*r_1$ for translations. The strain-dependence of the v_s profile is correlated with the effective long-period ground motion parameter A_v using Table 3.1

Table 3.1. Code-prescribed values of soil modulus and v_s degradation with effective long period ground acceleration, A_v (BSSC, 1995)

	Ground Acceleration Coefficient, A_v			
	≤ 0.10	≤ 0.10	≤ 0.20	≥ 0.30
G/G_{max}	0.81	0.64	0.49	0.42
$V_s/V_{s,max}$	0.90	0.80	0.70	0.65

Other soil parameters needed in the analysis are Poisson's ratio (ν) and strain dependent hysteretic damping ratio (β). The BSSC code commentary recommends $\nu=0.33$ for clean sands and gravels, $\nu=0.40$ for stiff clays and cohesive soils, and $\nu=0.45$ for soft clays. Soil damping ratio β is correlated to ground motion parameter A_v in Fig.3.10, and does not directly enter the analysis.

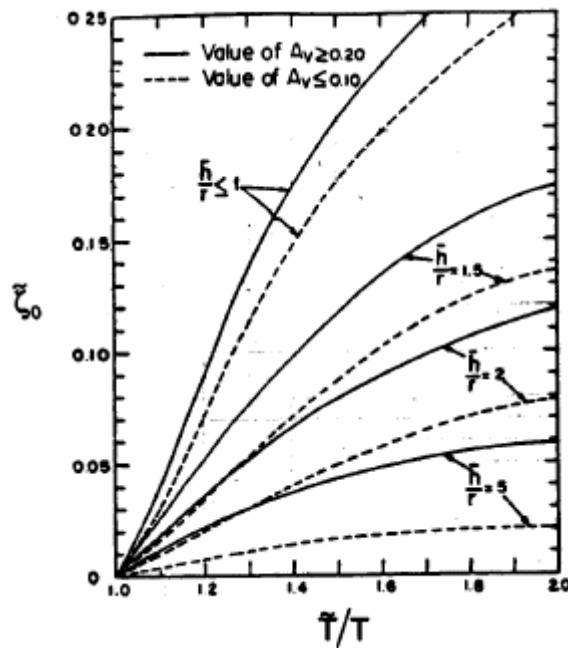


Figure 3.10. Relationship between foundation damping factor ($\tilde{\zeta}_0$) and period lengthening ratio for rigid disk foundations on homogeneous halfspace (BSSC, 1995; ATC, 1978)

For Code procedures (ATC, 1978 and BSSC, 1997), period lengthening is computed as,

$$\frac{\tilde{T}}{T} = \sqrt{1 + 25 \frac{\gamma r_1 h}{v_s^2 T^2} \left(1 + 1.12 \frac{r_1 h^2}{r_2^3}\right)} \quad (3.19)$$

Where γ is a dimensionless structure-to-soil mass ratio (Eq. 3.17) and is usually taken as 0.15, and v_s shear wave velocity. Foundation damping is evaluated from $\tilde{T}/T$ using Fig. 3.10. For damping factor (BSSC 1997),

$$\tilde{\zeta} = \tilde{\zeta}_0 + \frac{\zeta}{(\tilde{T}/T)^3} \quad (3.20)$$

$$\sigma = \frac{v_s T}{h} \quad (3.21)$$

Where σ is the ratio of the soil-to-structure stiffness (BSSC, 1997).

4. SYSTEM IDENTIFICATION PROCEDURES FOR EVALUATING SOIL STRUCTURE INTERACTION EFFECTS (STEWART, 1997)

4.1 Introduction

This chapter presents the methods of system identification used to evaluate dynamic properties of soil-structure systems from recordings of earthquake shaking (Stewart, 1997). There are two system identification techniques, parametric and nonparametric analysis, which are discussed in this chapter. The specific system identification procedures used in this study are summarized, while the interpretation of results for various input and output pairs is also discussed.

4.1.1 Objectives

The fundamental objective for any system identification analysis is, to evaluate the properties of an unknown system, given a known input, and output from, the system, as illustrated in Figure 4.1.

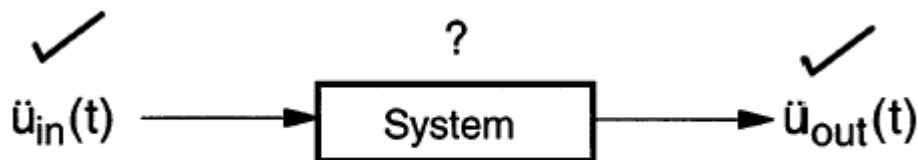


Figure 4.1 Schematic of the system identification problem

The system is generally associated with structural flexibility alone or there are the structural flexibility coupled with foundation flexibility in rocking and/or translation (Stewart, 1997). The inputs and outputs mean that they are various combinations of free-field, foundation, and roof-level recordings, as illustrated in Figure 4.2. The input-pairs used to evaluate modal parameters for various cases of base fixity are discussed in section 4.6.

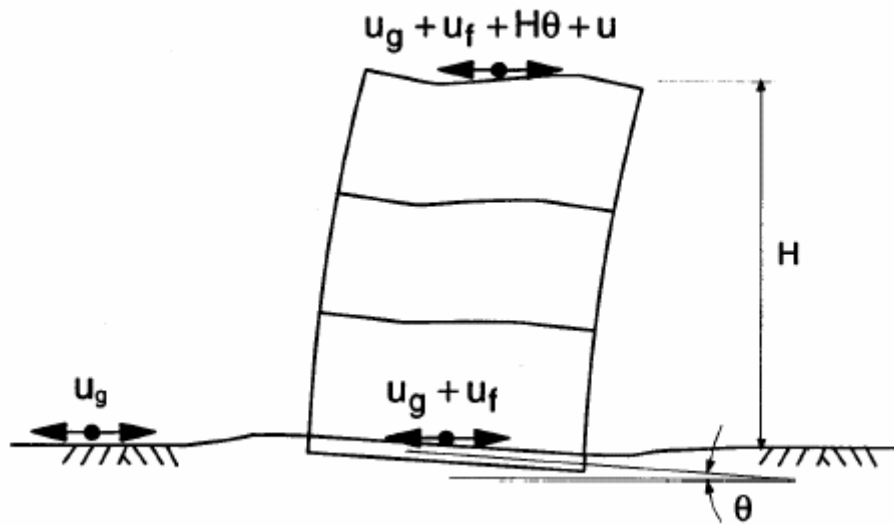


Figure 4.2 Motions used as inputs and outputs for system identification of structure

The desired results from these system identification procedures are the following system properties:

1. Modal frequencies and damping ratios of the structures for the fixed- and flexible base cases.
2. Transmissibility functions describing the frequency-dependent variations between input and output motions.

4.1.2 Fundamental assumptions

In the system identification analyses, there is a significant assumption is that the dynamic response of soil-structure systems can be described by linear dynamic models with proportional damping. There is a problem with the validity of this assumption, when structures are damaged or, have yielded, or when pronounced soil degradation occurs. However, nonlinear systems generally can be modeled by linear systems with time dependent parameters (Priestly, 1980). Hence, recursive analyses were employed to track time-dependent changes of linear system parameters (Stewart, 1998). It was also assumed that input and output motions used for system identification analyses were representative of their respective domains. For foundation motions, this implies that lateral and rocking motions at the same elevation are uniform, which strictly holds only for rigid foundation slabs. For roof

motions, there is a assumption is that roof motions are not influenced by torsional deformations in the structure. Although a given recorded motion (roof, foundation, or free-field) is unlikely to be perfectly representative of its domain, repeated identifications for sites with multiple input and output recordings generally revealed that identification results were relatively insensitive to the specific output or input motion chosen to represent a given domain.

4.2 Derivation of Transfer Functions from Modal Equations

Transfer functions describe the changes which occur to input signals as they pass through a system and emerge as output signals. Transfer functions describe the modification of motions between single input and output points (Stewart, 1998). For the properties of a linear structure, there are n degrees of freedom systems which include its mass matrix m , stiffness matrix k , and damping matrix c . The damping matrix is intended to model energy dissipation in the structure.

The dynamic displacements of the structure relative to its base are described by the $n \times 1$ vector u , with corresponding velocity and acceleration vectors $\dot{u}$ and $\ddot{u}$, respectively. The total displacement vector is u^t and u_g is the sum of ground displacement. The dynamic displacement of the structure is expressed as follows;

$$u^t(t) = u(t) + 1^T u_g(t) \quad (4.1)$$

Where 1 is $1 \times n$ vector of 1's. The equation of motion for the structure is (Clough, and Penzien, 1993):

$$m\ddot{u}(t) + c\dot{u}(t) + ku(t) = -m1^T \ddot{u}_g(t) \quad (4.2)$$

The undamped eigenvalue problem for the structure, $k\Phi_i = w_i^2 m\Phi_i$, gives the vibration frequencies, w_i , and vibration mode shapes, Φ_i , for each mode i . The generalized mass of mode i is defined as $m_i^* = \Phi_i^T m \Phi_i$, and the generalized influence factor as $L_i^* = 1^T m \Phi_i$ (Clough and Penzien, 1993, Celeb and Kumbasar, 1996). The solution to Eq. 4.2 is exactly represented by superposition of all n vibration modes using generalized coordinates $X_i(t)$, but can also be reliably approximated by $J \ll n$ modes:

$$u(t) = \sum_{i=1}^J \Phi_i X_i(t) \quad (4.3)$$

Inserting Eq.4.3 into Eq.3.2, and then it is multiplied both sides by Φ_j^T , which means taking advantage of mode orthogonality. The equation of motion for mode j can be expressed in term of generalized coordinates as:

$$\ddot{X}_j(t) + 2\zeta_j\omega_j\dot{X}_j(t) + \omega_j^2 X_j(t) = -\frac{L_j^*}{m_j^*} \ddot{u}_g(t) \quad (4.4)$$

Where ζ_j is the damping ratio for mode j. The solution to Eq. 4.4 is obtained through the use of Laplace transforms. The Laplace transform of a time-dependent function is expressed here as:

$$f(t) = f(s)e^{st} \quad (4.5)$$

Where s is the operator in the Laplace domain. Using Laplace transforms, the solution of Eq. 4.4 is:

$$X_j = \frac{-1}{s^2 + 2\zeta_j\omega_j s + \omega_j^2} \cdot \frac{L_j^*}{m_j^*} \ddot{u}_g(s) \quad (4.6)$$

Before taking its Laplace transform, strong motion recordings are of total acceleration, Eq. 4.1 is applied to Eq. 4.3.

$$\ddot{u}^t(s) = \sum_{j=1}^J \Phi_j \ddot{X}_j(s) + I^T \ddot{u}_g(s) \quad (4.7a)$$

Where $\ddot{X}_j(s) = s^2 X_j(s)$. Making use of a relation modified from Fenves and Desroches (1994) to substitute into Eq. 4.7(a),

$$I^T \approx \sum_{j=1}^J \frac{L_j^*}{m_j^*} \cdot \Phi_j \quad (4.7b)$$

and substituting Eq. 4.6 into Eq. 4.7(a), the total structure accelerations can be related to the ground acceleration as follows:

$$\ddot{u}^t(s) = \left[\sum_{j=1}^J \frac{L_j^*}{m_j} \cdot \Phi_j \left(1 - \frac{s^2}{s^2 + 2\zeta_j \omega_j s + \omega_j^2} \right) \right] \ddot{u}_g(s) \quad (4.7c)$$

To simplify this expression, the total acceleration vector can be written as:

$$\ddot{u}^t(s) = H(s) \ddot{u}_g(s) \quad (4.8a)$$

Where,

$$H(s) = \sum_{j=1}^J \frac{L_j^*}{m_j} \cdot \Phi_j \cdot H_j(s) \quad (4.8b)$$

$$H_j(s) = \frac{2\zeta_j \omega_j s + \omega_j^2}{s^2 + 2\zeta_j \omega_j s + \omega_j^2} \quad (4.8c)$$

Element j of the vector quantity $H(s)$ in Eq. 4.8(a) represents the transfer function between the ground (input) and degree-of-freedom j (output) in the superstructure. Single-output system identification analyses were used (Stewart, 1998), which reduces the vector $H(s)$ to a scalar function for the roof response. An important point is that contributions from all J modes are represented in the single-output solution, although only fundamental-mode parameters are significantly affected by SSI (Jennings and Bielak, 1973). When a component of $H(s)$ is evaluated along the imaginary axis, the transmissibility function $H(i\omega)$ is obtained, which gives the ratio of output-to-input acceleration as a function of frequency ω .

4.3 Nonparametric System Identification

For examination the dynamic response of structural systems, nonparametric system identification is used by estimating the transmissibility function $H(i\omega)$ for a given input-output pair. Transfer functions $H(s)$ cannot be directly estimated by nonparametric techniques. Calculation of transmissibility functions and smoothing procedures are obtained as follows:

4.3.1 Transmissibility functions

This section will describe how transmissibility functions are computed from an input $x(t)$ and output $y(t)$ accelerogram pair. Transmissibility functions are useful for identifying vibration frequencies and frequency ranges over which amplification or de-amplification occurs. Basically, the transmissibility function $H(i\omega)$ represents the ratio of the Fourier transform of the output signal to that of the input signal. Since the input signal is random, its Fourier transform may not exist (i.e. zero amplitude) at some frequencies, causing the $H(i\omega)$ ratio to be undefined. Because of this, $H(i\omega)$ is usually computed from power spectral density functions (S_x , S_y) and cross spectral density functions (S_{xy}) of the input and output signals, which always exist (Pandit, 1991). Power spectra and cross power spectral density functions are Fourier transforms of the auto-correlation functions $R_x(t)$ and $R_y(t)$ and the cross-correlation function $R_{xy}(t)$ for processes x and y (Clough and Penzien, 1993) for random process with zero mean:

$$S_x(\omega) = \frac{1}{2\pi} \int_{-\infty}^{\infty} R_x(\tau) e^{-i\omega\tau} d\tau \quad (4.9a)$$

$$S_y(\omega) = \frac{1}{2\pi} \int_{-\infty}^{\infty} R_y(\tau) e^{-i\omega\tau} d\tau \quad (4.9b)$$

$$S_{xy}(\omega) = \frac{1}{2\pi} \int_{-\infty}^{\infty} R_{xy}(\tau) e^{-i\omega\tau} d\tau \quad (4.9c)$$

S_x and S_y are real-valued and functions. S_{xy} is a complex-valued and function which is Hermitian function $S_{xy} = S_{yx}^*$ and also $*$ means denoting complex conjugation. The auto-correlation and cross-correlation functions are, in turn, defined from the discrete input and output signals as:

$$R_x(\tau) = \sum_{t=0}^{N-|\tau|} x(t)x^*(t+\tau) \quad (4.10a)$$

$$R_y(\tau) = \sum_{t=0}^{N-|\tau|} y(t)y^*(t+\tau) \quad (4.10b)$$

$$R_{xy}(\tau) = \sum_{t=0}^{N-|\tau|} x(t)y^*(t+\tau) \quad (4.10c)$$

Where N is number of data points in the time histories $x(t)$ and $y(t)$. After this explanation, as before, spectral density function defined in Eq. 4.9, $H(i\omega)$ can be computed two ways by using spectral density function (Ljung, 1987 and Pandit, 1991):

$$S_{yx}(\omega) = H(i\omega)S_x(\omega) \quad (4.11a)$$

$$S_y(\omega) = H(i\omega)S_{xy}(\omega) \quad (4.11b)$$

Hence, two estimates of the complex-valued $H(i\omega)$ are possible:

$$H_1(i\omega) = \frac{S_{yx}(\omega)}{S_x(\omega)} \quad (4.12a)$$

$$H_2(i\omega) = \frac{S_y(\omega)}{S_{xy}(\omega)} \quad (4.12b)$$

The two estimates of $H(i\omega)$ should theoretically be equal, but generally are not due to noise in the signals and other errors associated with the discrete Fourier transform. The $H_1(i\omega)$ estimate is less sensitive to output noise, while $H_2(i\omega)$ is less sensitive to input noise (Fenves and Desroches, 1994). The quality of transmissibility function can be assessed using the coherence function in the presence of noise and other errors. This coherence function is defined as the ratio of two estimates of $H(i\omega)$ (Ljung, 1987 and Pandit, 1991):

$$\gamma^2(i\omega) = \frac{H_1(i\omega)}{H_2(i\omega)} = \frac{|S_{xy}(\omega)|^2}{S_x(\omega)S_y(\omega)} \quad (4.13)$$

The coherence varies between zero and one, and provides insight into the noise spectrum which is proportional to $1-\gamma^2(i\omega)$. The transmissibility function $H(i\omega)$ is well estimated when the coherence is near unity because the signal to noise ratio is large.

4.3.2 Smoothing of frequency response functions

So far, in section 4.3.1, unsmoothed power spectral density, cross spectral density, and coherence functions have been described and computed using the procedure. However, section 4.3.1 can make the interpretation of these frequency response functions difficult. Due to this, some smoothing was performed using periodograms which employ an averaging procedure which smoothes the spectra by reducing the randomness associated with the estimation procedures. In addition to, periodograms performed using as estimates of spectral density functions (Oppenheim and Schaffer, 1989).

The averaging procedure is based on the method by Welch (1967). The Fast Fourier Transform (FFT) of each segment with a data window is computed and the records are divided into equal length segments in time. For all segments, the periodogram is the average of the square of the FFT amplitudes. In the case of the coherence functions, the averaging procedure is performed on each spectral density function in Eq. 4.13 before computing the coherence. Periodograms were generally computed using four equal-length segments without overlap (Stewart, 1998).

4.4 Parametric System Identification

4.4.1 Introduction

Problems can arise in identifying vibration properties of structure by spectral analysis. Essentially, recovery of the general transfer function surface $H(s)$ from a discrete estimate of $H(i\omega)$ with limited frequency resolution by the FFT can be problematic (Pandit, 1991). Because of this, in the discrete time domain, it is desirable to identify a parameterized model of the structure. Discrete time domain has to more robust estimate of the structure's vibration properties which can be computed. Eq. 4.8 must initially be converted to an equivalent model in the discrete time domain for the model of structure represented in continuous time (Stewart, 1998). This section will describe how these steps were performed (Stewart 1998). As seen in section 4.3.1, the transfer function is denoted as $H(s)$ and these formulations are based on a single input, single output model.

4.4.2 Representation of continuous transfer functions in discrete time

Eq. 4.2 is the equation of motion and based on a continuous time representations of linear structural system. Earthquake recordings of ground and structure motion are digital, and hence are data in the discrete time domain. The continuous time transfer function in Eq. 4.7 is modified to develop an equivalent discrete time representation (Stewart, 1998).

There are a number of methodologies which are presented in the literature for conversation from the continuous to discrete domain. These methodologies were developed by Safak (1988 and 1991), Franklin and Powell (1980), and Åström and Wittenmark (1984). The methodology employed and is to approximate the transfer function by the hold-equivalence technique (Franklin and Powell, 1980). The continuous input is passed through the continuous system to calculate the corresponding discrete output. After that, the discrete function is determined by taking the ratio of the Z-transforms of the discrete output to that of the input. Franklin and Powell (1980) approach is as follows;

$$H(z) = \left(1 - \frac{1}{z}\right) Z \left[\frac{H(s)}{s} \right] \quad (4.14)$$

Where $H(z)$ is the discrete time transfer function, z is the complex Z-transform operator, and $Z[f]$ denotes the Z-transform of the function f . Applying Eq. 4.14 to Eq. 4.8(b),

$$H(z) = \sum_{j=1}^J \frac{\beta_{1j} z^{-1} + \beta_{2j} z^{-2}}{\alpha_{2j} z^{-2} + \alpha_{1j} z^{-1} + 1} \quad (4.15)$$

Where α and β parameters are related to the parameters in Eq. 4.8 (b) by equations given in Åström and Wittenmark (1984). The expression in Eq. 4.15 can be expanded as a rational polynomial (Safak, 1991),

$$H(z) = \frac{b_1 z^{-1} + b_2 z^{-2} + \dots + b_{2J} z^{-2J}}{1 + a_1 z^{-1} + a_2 z^{-2} + \dots + a_{2J} z^{-2J}} \quad (4.16)$$

This represents a discrete time filter of order $2J$ (the filter order is the highest power in the denominator). Note that the order of the filter, and hence the order of the

model, is twice the number of modes being included in the structural idealization. The discrete time transfer function in Eq. 4.16 can be described as a linear difference equation which relates the input $x(t)$ and output $y(t)$ and the model represented as follows;

$$y(t) + a_1 y(t-1) + \dots + a_{2J} y(t-2J) = b_1 x(t-d-1) + b_2 x(t-d-2) + \dots + b_{2J} x(t-d-2J) \quad (4.17)$$

Where d is the time delay between the input and output, which means an input at time t creates an output at time $t+d$. The specific representation in Eq. 4.17 of the general model in Eq. 4.16 is referred to as an ARX model, for autoregressive model with extra input (Ljung, 1987).

4.4.3 Solution procedures

Eq. 4.17 describes the discrete time transfer function and least squares techniques were used to solve for the parameters a_j and b_j . There are two approaches for these analyses. First approach is that a single set of a_j and b_j parameters was determined which minimizes the sum of the errors between the model and recorded output over all N time steps. If the system properties are time invariant, its results are only accurate that means this procedure is referred to as the cumulative error method (CEM). In the second approach, separate sets of a_j and b_j parameters are determined for each time step. Referred to as the recursive prediction error method (RPEM), this approach enables the time variation of linear system properties to be tracked (Stewart, 1997).

1) Model parameter estimation by the cumulative error method (CEM)

To simplify the notation of the solution procedure, Eq. 3.16 is re-written by defining the following vectors:

$$\Gamma(t) = [-y(t-1) - y(t-2) \dots - y(t-2J) \quad x(t-d-1) \quad x(t-d-2) \dots x(t-d-2J)]^T \quad (4.18)$$

and also

$$\Theta = (a_1 a_2 \dots a_{2J} b_1 b_2 \dots b_{2J})^T \quad (4.19)$$

With these substitutions, Eq. 4.17 can be re-written as

$$y(t) = \Gamma^T(t)\Theta \quad (4.20)$$

$\Gamma(t)$ is known since $x(t)$ and $y(t)$ are the recorded time histories. After this procedure, the objective of the identification is to determine the unknown vector Θ . For a given Θ and time t , the error between the model and recorded output, $\varepsilon(t, \Theta)$, can be expressed as follows;

$$\varepsilon(t, \Theta) = y(t) - \Gamma^T(t)\Theta \quad (4.21)$$

A measure of the cumulative error $V(\Theta)$ can then be taken as the sum of the squares of the errors for each time step as follows:

$$V(\Theta) = \frac{1}{N} \sum_{t=2J+d+1}^N \varepsilon^2(t, \Theta) = \frac{1}{N} \sum_{t=2J+d+1}^N (y(t) - \Gamma^T(t)\Theta)^2 \quad (4.22)$$

The summation starts from $t=2J+d+1$ to prevent a negative time step from occurring in the formation of the Γ^T vector. The optimum set of parameters is determined by minimizing $V(\Theta)$ as,

$$\frac{dV(\Theta)}{d\Theta} = 0 \quad (4.23)$$

This leads to the following equation for Θ :

$$\Theta = \left[\sum_{t=2J+d+1}^N \Gamma(t)\Gamma^T(t) \right]^{-1} \left[\sum_{t=2J+d+1}^N \Gamma(t)y(t) \right] \quad (4.24)$$

With the vector Θ known, the discrete time transfer function for the system is completely determined.

2) Model parameter estimation by the recursive prediction error method (RPEM)

For this part, using notation is similar to part 1, as before defined in Eq. 4.18 and Eq. 4.19, respectively $\Gamma(t), \Theta$ and the error, $\varepsilon(t, \Theta)$, at time step t is defined as

$$\varepsilon(t, \Theta) = y(t) - \Gamma^T(t) \Theta(t-1) \quad (4.25)$$

The vector of estimated parameters Θ , is now time dependent. The fundamental difference between the RPEM and CEM is that the total error is defined at each time step t by,

$$V(t, \Theta) = \frac{1}{2} \gamma(t) \sum_{\tau=2J+d+1}^t \beta(t, \tau) \varepsilon^2(\tau, \Theta) \quad (4.26)$$

Where $\beta(t, \tau)$ is a weighting factor, and $\gamma(t)$ is the normalization factor for $\beta(t, \tau)$ defined by

$$\gamma(t) = \frac{1}{\sum_{\tau=2J+d+1}^t \beta(t, \tau)} \quad (4.27)$$

An exponential window was used with a constant forgetting factor λ (Ljung, 1987). For these conditions, the weighting factor is defined as,

$$\beta(t, \tau) = \lambda^{t-\tau} \quad (4.28)$$

For the smaller the value of λ , the shorter is the more sensitive are the results to time dependent changes in the system properties. However, there is a problem for less a mount of data. This problem is that small data windows can be more susceptible to noise in the input and output signals. In most cases, values of $\lambda=0.98$ to 0.99 were found to be appropriate. It is required with the RPEM to minimize the total error according to least squares criteria as with the CEM,

$$\frac{\partial V(t, \Theta)}{\partial \Theta} = V'(t, \Theta) = 0 \quad (4.29a)$$

Where V' is a vector of length $4J$. The condition in Eq. 4.29(a) is met in an average sense by requiring,

$$E[V'(t, \Theta)] = 0 \quad (4.29b)$$

Where E denotes the expected value operator. The solution of Eq. 4.29(b) is obtained using stochastic approximation techniques (Safak, 1988). The result is the following recursive relationship for $\Theta(t)$:

$$\Theta(t) = \Theta(t-1) + \alpha_t [V''(t, \Theta(t-1))]^{-1} V'(t, \Theta(t-1)) \quad (4.30)$$

Where α_t is a series of positive constants generally taken as $\alpha_t=1$ (Safak, 1998).

The solution of Eq. 4.30 requires the estimation of the total error derivatives $V''(t, \Theta)$ and $V'(t, \Theta)$. The final form of the recursion relation for the RPEM algorithm is (Safak, 1988 and Ljung, 1987),

$$\Theta(t) = \Theta(t-1) + \gamma_t R^{-1}(t) \psi(t) \varepsilon(t, \Theta) \quad (4.31)$$

Where α_t was taken as 1, $\Psi(t)$ is defined for the case of an ARX model as

$$\psi(t) = [-y(t-1) \dots -y(t-2J) \ y(t-d-1) \dots y(t-d-2J)]^T \quad (4.32)$$

and $R(t, \Theta)$, a $4J \times 4J$ matrix, is estimated as follows:

$$R(t) = R(t-1) + \gamma_t [\psi(t) \psi^T(t) - R(t-1)] \quad (4.33)$$

Numerical inversion procedures for $R^{-1}(t)$ are discussed in Safak (1988). In order to start the recursion, initial values of the vectors $\Theta(0)$ and $\Psi(0)$ and matrix $\gamma(0)R^{-1}(t)$ are taken as

$$\Theta(0)=0 \ \Psi(0)=0 \ \gamma(0)R^{-1}(t)=10^4 \times I \quad (4.34)$$

The initial conditions cause the results for $\Theta(t)$ early in the time history to be erratic and unreliable, though a stable solution is usually achieved subsequently.

3) Evaluation of modal frequencies and damping ratios

Once the parameters describing the discrete time transfer function, which are the Θ or $\Theta(t)$ vectors, have been determined, the frequencies and damping ratios corresponding to the J modes included in the analysis can be estimated. The poles of

the discrete time transfer function are first identified as the roots of the denominator from Eq. 4.16,

$$1 + a_1 z^{-1} + a_2 z^{-2} + \dots + a_{2J} z^{-2J} = 0 \quad (4.35)$$

The roots $z_1, z_2, \dots, z_{2J}$ are complex numbers in the complex plane for stable systems. The poles of the discrete time transfer function are related to the poles in the Laplace domain by (Safak, 1991),

$$s_j = \frac{1}{\Delta t} \ln z_j \quad (4.36)$$

where Δt = the data sampling interval. The poles s_j are the roots of the transfer function denominator in Eq. 4.8(b), which can be expressed as the complex conjugate pair (Fenves and Desroches, 1994),

$$s_j, s_j^* = -\zeta_j \omega_j \pm i \omega_j \sqrt{1 - \zeta_j^2} \quad (4.37)$$

From this formulation, modal frequencies and damping ratios can be computed as follows:

$$\omega_j = \sqrt{s_j s_j^*} \quad (4.38a)$$

$$\zeta_j = -\frac{\text{Re}(s_j)}{\omega_j} \quad (4.38b)$$

Where $\text{Re}(s_j)$ means to take the real part of the complex number s_j .

4.5 Interpretation of Results

In system identification analysis of structural systems, the results depends on the input and output motions used. Fixed and flexible base modal parameters are evaluated to derive by using the input and output pairs and other purpose of this section is to describe how these parameters can be estimated when a direct identification is impossible as a result of insufficient instrumentation at a site in this section.

4.5.1 Base fixity conditions for different input-output pairs

Transfer functions and corresponding pole descriptions for different input-output pairs are derived in terms of soil, foundation, and structure properties. Expressions for the frequencies and damping ratios associated with the poles are then derived so that relationships between these modal parameters and the system properties can be defined.

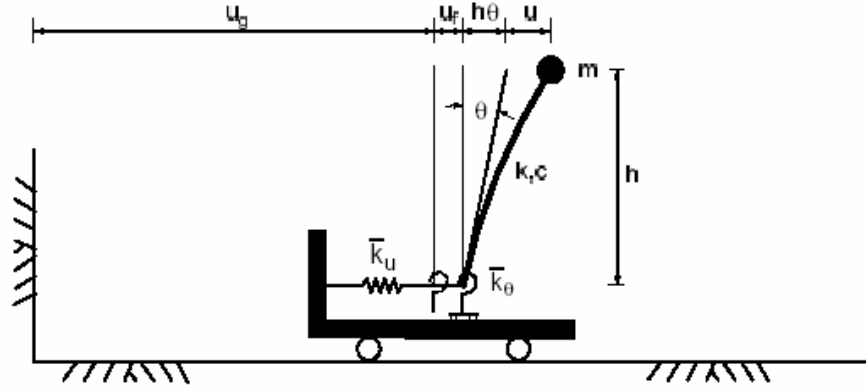


Figure 4.3 Simplified model for analysis of inertial interaction

As shown in Fig. 4.3, the displacement of mass m has contributions from structural deformation u , free-field motion u_g , and foundation translation and rocking, u_f and $h\theta$, respectively. The equations of motion describing the simple system in Fig. 4.3 are as follows (Chopra and Gutierrez, 1973),

A horizontal component of mass is as follows:

$$m(\ddot{u}_f + h\ddot{\theta} + \ddot{u}) + c\dot{u} + ku = -m\ddot{u}_g \quad (4.39a)$$

General equation of motion is as follows:

$$m(\ddot{u}_f + h\ddot{\theta} + \ddot{u}) + m_f\ddot{u}_f + c_u\dot{u}_f + k_u u_f = -(m + m_f)\ddot{u}_g \quad (4.39b)$$

and total rotation is as follows:

$$mh(\ddot{u}_f + h\ddot{\theta} + \ddot{u}) + I\ddot{\theta} + c_\theta\dot{\theta} + k_\theta\theta = -mh\ddot{u}_g \quad (4.39c)$$

Where I is the rotational moment of inertia of the structure, and k_u , c_u , k_θ , and c_θ are foundation impedance values evaluated in chapter 2 at the frequency of the soil-structure system. Eq. 4.39a-c are divided through by m , $m+m_f$, and m , respectively. The time dependent functions are transformed to the Laplace domain according to $f(t) = \hat{f}e^{st}$ and with this transformation, the quantities $\hat{k}_u$, $\hat{c}_u$, $\hat{k}_\theta$, and $\hat{c}_\theta$ are interpreted as foundation impedance values in the Laplace domain evaluated at the pole of the transfer function being sought. With these substitutions, Eqs. 4.39a-c can be re-written as,

$$s^2\hat{u}_f + s^2h\hat{\theta} + A\hat{u} = -s^2\hat{u}_g \quad (4.40a)$$

$$A_u\hat{u}_f + s^2\mu h\hat{\theta} + s^2\mu\hat{u} = -s^2\hat{u}_g \quad (4.40b)$$

$$s^2\hat{u}_f + A_\theta h\hat{\theta} + s^2\hat{u} = -s^2\hat{u}_g \quad (4.40c)$$

Where $\mu = m/(m+m_f)$. Neglecting the rotational inertia of the structure and the mass of the foundation (i.e. $I = 0$, $\mu = 1$), the A coefficients are defined as

$$A = s^2 + 2\zeta\omega s + \omega^2 \quad (4.41a)$$

$$A_u = s^2 + 2\zeta_u\omega_u s + \omega_u^2 \quad (4.41b)$$

$$A_\theta = s^2 + 2\zeta_\theta\omega_\theta s + \omega_\theta^2 \quad (4.41c)$$

The dynamic behaviour of the structure (ω , ζ) or soil-foundation system (ω_u , ζ_u and ω_θ , ζ_θ) these parameters are related to the system properties in Fig. 4.3 as follows,

$$\omega^2 = \frac{\hat{k}}{m}, \quad \zeta = \frac{\hat{c}}{2m\omega} \quad (4.42a)$$

$$\omega_u^2 = \frac{\hat{k}_u}{m}, \quad \zeta_u = \frac{\hat{c}_u}{2m\omega_u} \quad (4.42b)$$

$$\omega_\theta^2 = \frac{\hat{k}_\theta}{mh^2}, \quad \zeta_\theta = \frac{\hat{c}_\theta}{2mh^2\omega_\theta} \quad (4.42c)$$

In Eq. 4.40a-c, there are three unknown response functions (u , u_f , and θ) and three equations. Hence, the deformations can be solved for directly in terms of the system properties, with the results that follow:

$$\frac{\hat{u}}{\hat{u}_g} = \frac{-B_\theta B_u s^2}{s^2(B_u B + B_u B_\theta + B_\theta B) + B_u B B_\theta} = -\frac{B_\theta B_u s^2}{C_s} \quad (4.43a)$$

$$\frac{\hat{u}_f}{\hat{u}_g} = -\frac{B_\theta B s^2}{C_s} \quad (4.43b)$$

$$\frac{\hat{h}_\theta}{\hat{u}_g} = -\frac{B_\theta B_u s^2}{C_s} \quad (4.43c)$$

Where $B = A - s^2$, $B_u = A_u - s^2$, $B_\theta = A_\theta - s^2$, and $C_s = s^2(B_u B + B_u B_\theta + B_\theta B) + B_u B B_\theta$. Three specific input-output pairs are considered in the following Parts (a) to (c).

a) Flexible-base

For the flexible-base case, the input is the free-field ground motion (u_g) and the output is the total motion at the roof level ($u_g + u_f + h\theta + u$). The transfer function is defined as the ratio of these two motions,

$$H_a(s) = \frac{\hat{u}_g + \hat{u}_f + h\hat{\theta} + \hat{u}}{\hat{u}_g} = \frac{\hat{u}_g \left(1 + \frac{\hat{u}_f}{\hat{u}_g} + \frac{h\hat{\theta}}{\hat{u}_g} + \frac{\hat{u}}{\hat{u}_g} \right)}{\hat{u}_g} \quad (4.44)$$

Substituting Eq. 4.43 into Eq. 4.44 and simplifying,

$$H_a(s) = \frac{B_u B B_\theta}{C_s} \quad (4.45)$$

The poles for the flexible-base case are defined as those values of s for which $C_s=0$. Expanding C_s in terms of the system properties and ignoring small terms which are the product of two damping ratios, a 3rd order polynomial in s is found as follows,

$$\begin{aligned} C_s = & 2s^3 \left[\zeta\omega(\omega_u^2 + \omega_\theta^2) + \zeta_u\omega_u(\omega^2 + \omega_\theta^2) + \zeta_\theta\omega_\theta(\omega_u^2 + \omega^2) \right] \\ & + \dots + s^2(\omega^2\omega_u^2 + \omega_\theta^2\omega_u^2 + \omega^2\omega_\theta^2) + \dots + \\ & 2s(\zeta\omega\omega_u^2\omega_\theta^2 + \zeta_u\omega_u\omega^2\omega_\theta^2 + \zeta_\theta\omega_\theta\omega_u^2\omega^2) + \omega_\theta\omega_u^2\omega^2 \end{aligned} \quad (4.46a)$$

This can be re-written as,

$$C_s = A_1s^3 + A_2s^2 + A_3s + A_4 \quad (4.46b)$$

Where,

$$A_1 = 2 \left[\zeta\omega(\omega_u^2 + \omega_\theta^2) + \zeta_u\omega_u(\omega^2 + \omega_\theta^2) + \zeta_\theta\omega_\theta(\omega_u^2 + \omega^2) \right] \quad (4.46c)$$

$$A_2 = (\omega^2\omega_u^2 + \omega_\theta^2\omega_u^2 + \omega^2\omega_\theta^2) \quad (4.46d)$$

$$A_3 = 2(\zeta\omega\omega_u^2\omega_\theta^2 + \zeta_u\omega_u\omega^2\omega_\theta^2 + \zeta_\theta\omega_\theta\omega_u^2\omega^2) \quad (4.46e)$$

$$A_4 = \omega_\theta\omega_u^2\omega^2 \quad (4.46f)$$

Finding the roots of the third-order polynomial in Eq. 4.46(a) is a non-trivial algebraic problem, though it is known from the factors in Eq. 4.46c-f that the discriminant is positive and hence there are one real and two complex conjugate roots. Only the complex conjugate roots are physically meaningful. The complex conjugate roots were found to be well approximated by an expression with the same form as Eq. 4.37, but with system frequency and damping ($\tilde{\omega}$ and $\tilde{\zeta}$) defined as (Stewart, 1998),

$$\tilde{\omega}^2 = \frac{A_4}{A_1} = \frac{\omega_\theta^2 \omega_u^2 \omega^2}{\omega^2 \omega_u^2 + \omega_\theta^2 \omega_u^2 + \omega^2 \omega_\theta^2} = \frac{1}{\frac{1}{\omega_\theta^2} + \frac{1}{\omega^2} + \frac{1}{\omega_u^2}} \quad (4.47a)$$

$$\frac{\tilde{\zeta}}{\tilde{\omega}} = \frac{A_2 A_3 + A_4 A_1}{2 A_2 A_4} \quad (4.47b)$$

This simplifies to,

$$\tilde{\zeta} = \left(\frac{\tilde{\omega}}{\omega_u} \right)^3 \zeta_u + \left(\frac{\tilde{\omega}}{\omega} \right)^3 \zeta + \left(\frac{\tilde{\omega}}{\omega_\theta} \right)^3 \zeta_\theta \quad (4.47c)$$

These results indicate that flexible-base parameters are dependent on the foundation impedance in translation and rocking and the structural parameters. Terms are the product of damping ratios which are neglected.

b) Pseudo flexible-base

The pseudo flexible-base case applies for a condition of partial base flexibility, representing base rocking only. This condition is important because actual flexible-base parameters are often well-approximated by pseudo flexible-base parameters. Moreover, pseudo flexible-base parameters can be used in procedures to estimate either fixed- or flexible-base parameters. For the pseudo flexible-base parameter case, the input is $(u_g + u_f)$ which total base translation is. The output is $(u_g + u_f + h\theta + u)$ which the total motion is at the roof level. For the transfer function,

$$H_b(s) = \frac{\hat{u}_g + \hat{u}_f + h\hat{\theta} + \hat{u}}{\hat{u}_g} = \frac{\hat{u}_g \left(1 + \frac{\hat{u}_f}{\hat{u}_g} + \frac{h\hat{\theta}}{\hat{u}_g} + \frac{\hat{u}}{\hat{u}_g} \right)}{\hat{u}_g \left(1 + \frac{\hat{u}_f}{\hat{u}_g} \right)} = \frac{B_u B B_\theta}{C_S - S^2 B_\theta B} \quad (4.48)$$

The denominator is again a 3rd order polynomial in s ,

$$\begin{aligned}
C_s - s^2 B_\theta B = 2s^3 & \left[\zeta \omega \omega_u^2 + \zeta_u \omega_u (\omega^2 + \omega_\theta^2) + \zeta_\theta \omega_\theta \omega_u^2 \right] \\
& + \dots + s^2 (\omega^2 \omega_u^2 + \omega_\theta^2 \omega_u^2 + \dots + \\
& 2s(\zeta \omega \omega_u^2 \omega_\theta^2 + \zeta_u \omega_u \omega^2 \omega_\theta^2 + \zeta_\theta \omega_\theta \omega_u^2 \omega^2) + \omega_\theta \omega_u^2 \omega^2
\end{aligned} \tag{4.49}$$

from which the system frequency and damping ratio can be evaluated as,

$$(\tilde{\omega}^2)^* = \frac{\omega_\theta^2 \omega_u^2 \omega^2}{\omega^2 \omega_u^2 + \omega_\theta^2 \omega_u^2} = \frac{1}{\frac{1}{\omega_\theta^2} + \frac{1}{\omega^2}} \tag{4.50a}$$

$$(\tilde{\zeta})^* = \left(\frac{\tilde{\omega}^*}{\omega} \right)^3 \zeta + \left(\frac{\tilde{\omega}^*}{\omega_\theta} \right)^3 \zeta_\theta \tag{4.50b}$$

It should be noted that pseudo flexible-base parameters are seen to be dependent on the rocking impedance of the foundation and the structural properties. It may be noted that flexible- and pseudo flexible-base parameters are numerically similar when base rocking dominates the SSI (which, excepting broad, short structures, is often true).

c) Fixed-base

For the fixed-base case, the input is the sum of the total base translation and the contribution of base rocking to roof translation ($u_g + u_f + h\theta$), and the output is the total motion at the roof level ($u_g + u_f + h\theta + u$). For transfer function,

$$H_c(s) = \frac{\hat{u}_g + \hat{u}_f + h\hat{\theta} + \hat{u}}{\hat{u}_g} = \frac{\hat{u}_g \left(1 + \frac{\hat{u}_f}{\hat{u}_g} + \frac{h\hat{\theta}}{\hat{u}_g} + \frac{\hat{u}}{\hat{u}_g} \right)}{\hat{u}_g \left(1 + \frac{\hat{u}_f}{\hat{u}_g} + \frac{h\hat{\theta}}{\hat{u}_g} \right)} = \frac{B_u B B_\theta}{C_s - S^2 (B_\theta B + B B_u)} \tag{4.51}$$

The denominator in this case can be reduced to the product of a first- and second-order polynomial in s ,

$$C_s - s^2(B_\theta B + B B_u) = \left[2s(\zeta_u \omega_u^2 \omega_\theta^2 + \zeta_\theta \omega_\theta^2 \omega_u) + \omega_\theta^2 \omega_u^2 \right] + (s^2 + 2\zeta \omega s + \omega^2) \quad (4.52)$$

The fixed-base parameters identified from this analysis are simply ω and ζ , respectively.

d) Summary

The input and output required to evaluate system parameters for various conditions of base fixity are summarized in Table 4.1. The advantage of the present approach is that the more accurate estimates of transfer functions from parametric identification can be used to derive fundamental mode vibration parameters for various conditions of base fixity.

Table 4.1 Required input and output to evaluate system parameters for various conditions of base fixity

	SYSTEM	INPUT	OUTPUT
a	Flexible-Base	u_g	$u_g + u_f + h\theta + u$
b	Pseudo Flexible-Base	$u_g + u_f$	$u_g + u_f + h\theta + u$
c	Fixed-Base	$u_g + u_f + h\theta$	$u_g + u_f + h\theta + u$

4.5.2 Estimation of fixed and flexible-base modal parameters

It is necessary to have recordings of free-field, foundation and roof translations as well as base rocking to evaluate directly both fixed and flexible-base modal parameters of structures. This explanation is based on table 4.1. If no recordings of roof translation are available, no modal parameters can be identified. However, if one of the other three motions is missing, the set of modal parameters not directly evaluated can be estimated. The two specific cases that will be considered here are missing base rocking motions in which case fixed-base parameters are estimated, and

missing free-field motions in which case flexible-base parameters are estimated. These estimation methods are explained as follows:

a) Estimation of fixed-base modal parameters for case of missing base rocking motions

Fixed-base modal parameters for a structure can be estimated from “known” flexible- and pseudo flexible-base parameters. Hence, it is assumed that $\tilde{\omega}$, $\tilde{\zeta}$, $\tilde{\omega}^*$ and $\tilde{\zeta}^*$ have been determined from system identification analyses [Cases (a) and (b) in Table 4.1].

$$\frac{1}{\tilde{\omega}^2} = \frac{1}{\omega^2} + \frac{1}{\omega_\theta^2} + \frac{1}{\omega_u^2} \quad (4.53)$$

$$\frac{1}{(\tilde{\omega}^2)^*} = \frac{1}{\omega^2} + \frac{1}{\omega_\theta^2} \quad (4.54)$$

from which ω_u can be readily determined as,

$$\frac{1}{\omega_u^2} = \frac{1}{\tilde{\omega}^2} - \frac{1}{(\tilde{\omega}^2)^*} \quad (4.55)$$

The ratio of ω_θ to ω_u is then taken using Eq. 4.42 to evaluate ω_θ as follows,

$$\left(\frac{\omega_\theta}{\omega_u} \right)^2 = \frac{\hat{k}_\theta / mh^2}{\hat{k}_u / m} = \frac{K_\theta \cdot \hat{\alpha}_\theta(s) \cdot \frac{1}{h^2}}{K_u \hat{\alpha}_u(s)} \quad (4.56)$$

Where $\hat{\alpha}_u$ and $\hat{\alpha}_\theta$ are modifiers to the static foundation impedance defined in the Laplace domain (Stewart, 1998). For surface foundations, Eq. 4.56 can be simplified using the impedance for a rigid circular disk foundation on the surface of a homogeneous, isotropic halfspace.

$$k_u = \alpha_u K_u \quad (4.57a)$$

$$c_u = \beta_u \frac{K_u r_1}{v_s} \quad (4.57b)$$

$$k_\theta = \alpha_\theta K_\theta \quad (4.57c)$$

$$c_\theta = \beta_\theta \frac{K_\theta r_2}{v_s} \quad (4.57d)$$

The quantities α_u , β_u , α_θ , and β_θ are dimensionless parameters expressing the frequency dependence of the results, while K_u and K_θ represent the static stiffness of a disk on a halfspace, defined by (Stewart, 1998)

$$K_u = \frac{8}{2 - \nu} Gr_1 \quad (4.58a)$$

$$K_\theta = \frac{8}{3(1 - \nu)} Gr_2^3 \quad (4.58b)$$

where G =soil dynamic shear modulus. Presented in Fig. 4.4 are the frequency dependent values of α_u , β_u , α_θ , and β_θ for $\nu = 0.4$ based on closed form expressions in Veletsos and Verbic (1973). Where β , r_1 and r_2 is hysteretic damping, foundation radii, respectively.

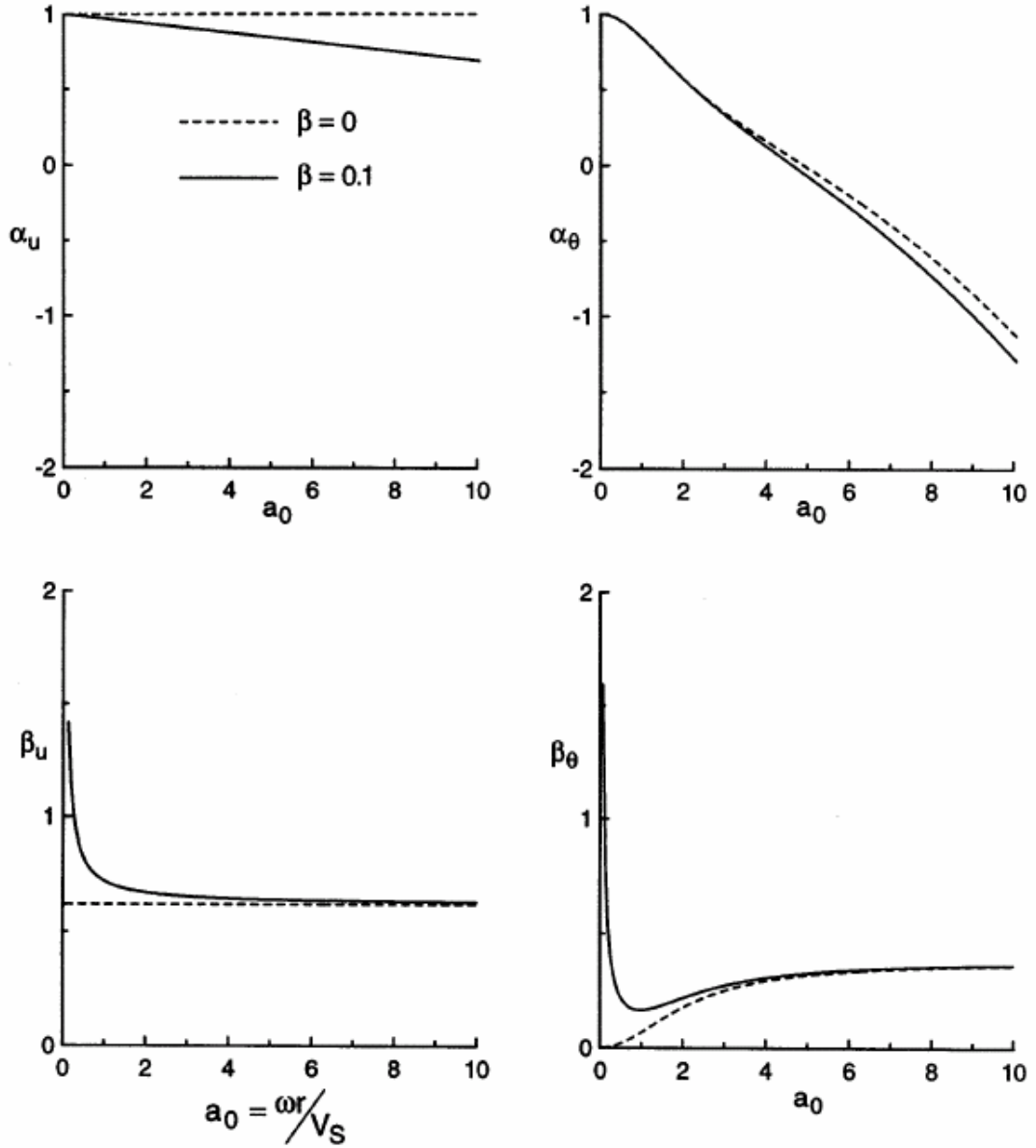


Figure 4.4 Foundation stiffness and damping factor for elastic and viscoelastic halfspaces, $\nu=0.4$ (after Veletsos and Verbic, 1973)

a_0 is a dimensionless frequency, for surface foundations, Eq. 4.56 can be simplified using the impedance for a rigid circular disk foundation on the surface of a homogeneous, isotropic halfspace. In this case, the static stiffnesses are as indicated in Eq. 4.58, and the ratio of ω_θ to ω_u can be expressed as,

$$\left(\frac{\omega_\theta}{\omega_u} \right)^2 = \left(\frac{r_2^3}{r_1 h^2} \right) \left(\frac{2 - \nu}{3(1 - \nu)} \right) \left(\frac{\hat{\alpha}_\theta(s)}{\hat{\alpha}_u(s)} \right) \quad (4.59)$$

Assuming the effective structure height, foundation geometry, and soil Poisson's ratio are known, the only unknown quantity in Eq. 4.59 is the ratio of dynamic

factors $\frac{\hat{\alpha}_\theta}{\hat{\alpha}_u}$. In the frequency domain, the factors α_u and α_θ are commonly evaluated as functions of both frequency and soil hysteretic damping. As an approximation, the ratio $\frac{\hat{\alpha}_\theta}{\hat{\alpha}_u}$ can be computed for surface foundations using the frequency dependent impedance factors for a circular foundation on a uniform viscoelastic half-space derived by Veletsos and Verbic (1973).

For embedded foundations, Eq. 4.56 can be simplified using the impedance for a rigid circular disk foundation embedded into a homogeneous, isotropic halfspace. Using the solution by Elsabee and Morray (1977) for shallowly embedded ($e/r < 1$) foundation, the solution of Eq. 4.56 is reduced to

$$\left(\frac{\omega_\theta}{\omega_u} \right)^2 = \left(\frac{r_2^3}{r_1 h^2} \right) \left(\frac{2 - \nu}{3(1 - \nu)} \right) \left(\frac{\hat{\alpha}_\theta(s)}{\hat{\alpha}_u(s)} \right) \left(\frac{1 + 2(e/r)}{1 + 0.67(e/r)} \right) \quad (4.60)$$

Where $\hat{\alpha}_\theta$ and $\hat{\alpha}_u$ are derived for surface foundations. Obviously, use of Elsabee and Morray's approximate solution for embedded foundation impedance increases the expected error in estimates of the ratio ω_θ/ω_u . However, for the moderate embedment ratios of many building structures ($e/r < 0.5$), this error is expected to be small (Stewart, 1998). ω_θ is computed from Eqs. 4.59 or 4.60, the fixed-base frequency can be readily computed from Eq. 4.50(a) as,

$$\frac{1}{\omega^2} = \frac{1}{(\tilde{\omega}^2)^*} - \frac{1}{\omega_\theta^2} \quad (4.61)$$

The evaluation of fixed-base damping involves slightly more algebra, but the same principles apply. Eqs. 4.47(c) and 4.50(b) are used in conjunction with the ratio of the damping definitions for ζ_u and ζ_θ (Eq. 4.42) to evaluate the unknown damping quantities ζ_u , ζ_θ , and ζ . The result is as follows,

$$\zeta = \frac{1}{C_1} \cdot \tilde{\zeta} - \frac{C_2}{C_1} \tilde{\zeta}^* \quad (4.62a)$$

where

$$C_1 = \left(\frac{\tilde{\omega}}{\omega} \right)^3 - C_3 \frac{\left(\frac{\tilde{\omega}^*}{\omega} \right)^3}{\left(\frac{\tilde{\omega}^*}{\omega_\theta} \right)^3} \quad (4.62b)$$

$$C_2 = \frac{C_3}{\left(\frac{\tilde{\omega}^*}{\omega_\theta} \right)^3} \quad (4.62c)$$

$$C_3 = C_4 \left(\frac{\tilde{\omega}}{\omega_u} \right)^3 + \left(\frac{\tilde{\omega}}{\omega_\theta} \right)^3 \quad (4.62d)$$

$$C_4 = \frac{\omega_\theta}{\omega_u} \cdot \frac{\hat{\beta}_u}{\hat{\beta}_\theta} \cdot \frac{r_1^2 h^2}{r_2^4} \cdot \frac{3(1-\nu)}{2-\nu} \quad (4.62e)$$

The terms $\hat{\beta}_u$ and $\hat{\beta}_\theta$ in C_4 are dimensionless dashpot coefficients similar to the β_u and β_θ terms in Eq. 4.57. The only assumption made in this analysis is that the ratio of soil damping factors $\hat{\beta}_u/\hat{\beta}_\theta$ can be computed from the formulation in Veletsos and Verbic (1973).

b) Estimation of flexible-base modal parameters for case of missing free-field motions

For the derivation of flexible-base modal parameters, it is assumed that fixed- and pseudo flexible-base system identification analyses have been performed [Cases (b) and (c) in Table 4.1]. Hence, parameters $\tilde{\omega}^*$, $\tilde{\zeta}^*$, ω , and ζ are assumed known. The derivation follows the same steps as in Part (a). ω_θ is evaluated as

$$\frac{1}{\omega_\theta^2} = \frac{1}{(\tilde{\omega}^2)^*} - \frac{1}{\omega^2} \quad (4.63)$$

Frequency ω_u is computed from the ratio ω_θ/ω_u in Eqs. 4.59 or 4.60, and the flexible-base frequency is determined directly from Eq. 4.47(a). For the case of damping, the algebra is less lengthy than Part (a). The first step is the calculation of ζ_θ from Eq. 4.50(b),

$$\zeta_{\theta} = \frac{\tilde{\zeta}^* - \left(\frac{\tilde{\omega}^*}{\omega} \right)^3 \zeta}{\left(\frac{\tilde{\omega}^*}{\omega_{\theta}} \right)^3} \quad (4.64)$$

Damping ζ_u is then evaluated from the following,

$$\zeta_u = \zeta_{\theta} \frac{\omega_{\theta}}{\omega_u} \cdot \frac{\hat{\beta}_u}{\hat{\beta}_{\theta}} \cdot \frac{r_1^2 h^2}{r_2^4} \cdot \frac{3(1-\nu)}{2-\nu} \quad (4.65)$$

and the flexible-base damping is determined directly from Eq. 4.47(c).

5. ARTIFICIAL INTELLIGENCE METHOD

5.1 Introduction of Neural Networks

Neural network applications have become broad as, covering disciplines ranging from medicine to microelectronics. Neural networks tools are derived from the parallel biological structure found in the brain. Today, many scientists are trying to understand of the architecture of the human brain. The basic building block of the nervous system is the neuron. The major components of a neuron include a central cell body. In this respect, central to the human nervous system is the brain, represented by the neural net, which continually receives information, perceives it and makes appropriate decisions. Highly interconnected processing neurons work in unison to solve specific problems. Consequently, neural networks are parallel to the biological nervous system relying on dense arrangements of interconnections and simple processors. This is called an Artificial Neural Network.

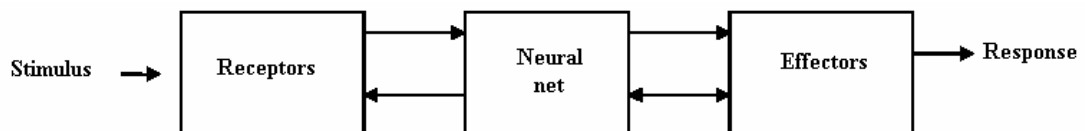


Figure 5.1. Block diagram representation of nervous system.

As shown in fig. 5.1, two sets of arrows represent forward transmission and feedback in the system, respectively. The neural networks are like people, they learn by examples. This flexibility makes them very powerful. In neural networks you do not need to know the internal mechanism, because neurons have potential to understand the internal mechanism on its own, but scientists, researchers and engineers have difficulty to understand the inertial mechanism of the task they are dealing with. The Neural networks provide an effective approach for various applications. There are many applications yet to be discovered. Their wide spectrum involving pattern mapping, pattern completion, pattern classification makes them significant

application for prediction analysis and evaluations. Neural networks are generating much interest among engineers and scientist, with its powerful capabilities and potential to solve problem.

5.2 Differences between Biological Structures and Artificial Neural Networks

- i. There are many kinds of neurons in biological systems. An Artificial Neural Networks (ANN) is typically implemented with only one type of neuron.
- ii. Neurons in Biological Structures Networks BNNs typically operate on an individual cycle time of about 10-100 milliseconds (msec).
- iii. Despite its slower cycle time, the brain is still able to perform some tasks orders of magnitude faster than today's fastest computer. This is because of the brain's massively parallel architecture.
- iv. Typically ANNs use a few dozen to several hundred neurons.

5.3 The Basic Structure

As shown in fig. 5.2, neural network structure is depicted and all neurons are interconnected with each other in a network of neurons. Sometimes there may be independent neurons and these independent neurons are rarely used in applications. The network processes have a number of inputs, hidden inputs and output neurons are obtained from inputs and hidden neurons. The neurons are connected by weights, which are depicted as lines in fig. 5.2 and which are applied to values passed from one neuron on to the next.

A group of neurons is called a slab. Neurons are also grouped into layers by their connection to the outside world. For example, if a neuron receives data from outside the network, it is considered to be in the input layer. If a neuron contains the network's predictions or classifications, it is in the output layer. Neurons in between the input and output layer are in the hidden layers. A layer may contain one or more slabs of neurons.

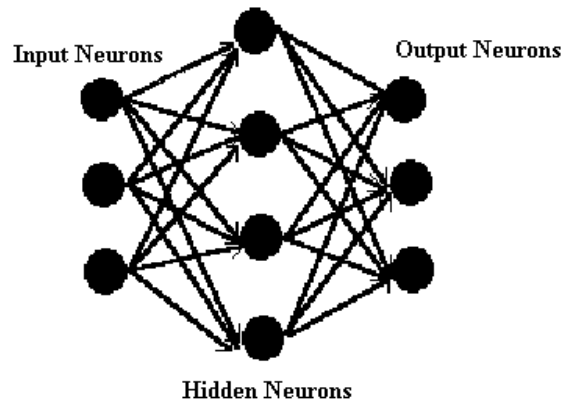


Figure 5.2. Neural networks structure

5.4 Neural Network Characteristics

Neural networks are not programed; they learn by example. Relatively simple actions, involve many individual pieces of memory, learning, and physical coordination. The complexity of such simple tasks, which most of us do all the time without thinking about them, is underscored by the difficulty involved in teaching robots to perform them. Typically, a neural network is presented with a training set consisting of a group of examples from which the network can learn. These examples, known as training patterns, are represented as vectors, and can be taken from such sources as images, speech signals, sensor data, and financial data. In this study, examples (training patterns) are obtained from California's earthquakes which are 1952 Kern Country, 1971 San Fernando, 1975 Ferndale, 1979 Imperial Valley, 1983 Coalinga, 1983 Coalinga Aftershock, 1985 Redlands, 1987 Whittier, 1989 Loma Prieta, 1990 Upland, 1991 Sierra Madre, 1992 Petrolia, 1992 Petrolia Aftershock, 1992 Landers, 1992 Landers, and 1994 Northridge and also California region soil and structures properties.

Usually, a potion of the data used in developing the neural network is used to validate the model since it has the same pattern of training data. In the validation stage, the trained networks performance is measured. Thus the network developed was tested using data whose pattern is the same as the data used for training. The most common training scenarios utilize supervised learning, during which the network is presented with an input pattern together with the target output for that

pattern. The target output usually constitutes the correct answer, or correct classification for the input pattern. In response to these paired examples, the neural network adjusts the values of inertial weights. If training is successful, the inertial parameters are then adjusted to the point. Usually, the set of training examples is presented many times during training to allow the network to adjust its inertial parameters gradually.

The neural network approach does not require human development of algorithms and programs that are specific to the classification problem at hand. The drawbacks to the neural network approach include the time to train the network may not be known beforehand, and the process of designing a network that successfully solves an application problem may be involved.

In order to develop a neural network, training set must include a variety of examples. These examples enable the generalization task. In addition, the training session must be limited in iterations, so that “over-learning” does not take place (i.e. the learning of specific examples instead of classification criteria). A typical example for over-learning is given in figure 5.3. Special considerations in constructing the training set and the training presentations must be made to permit effective generalization behaviour from a neural network. All these characteristics of neural networks may be explained through the simple mathematical structure of neural net models.

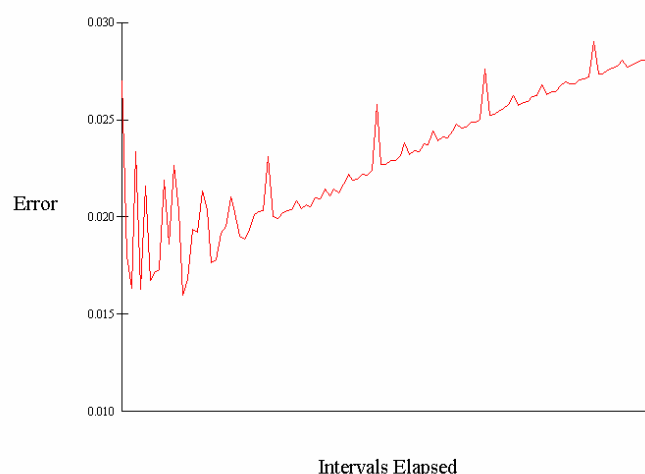


Figure 5.3. A over-learning situation in training set from Neuroshell2

This graph must be constant or decrease during training, otherwise over-learning occurs in Figure 5.3.

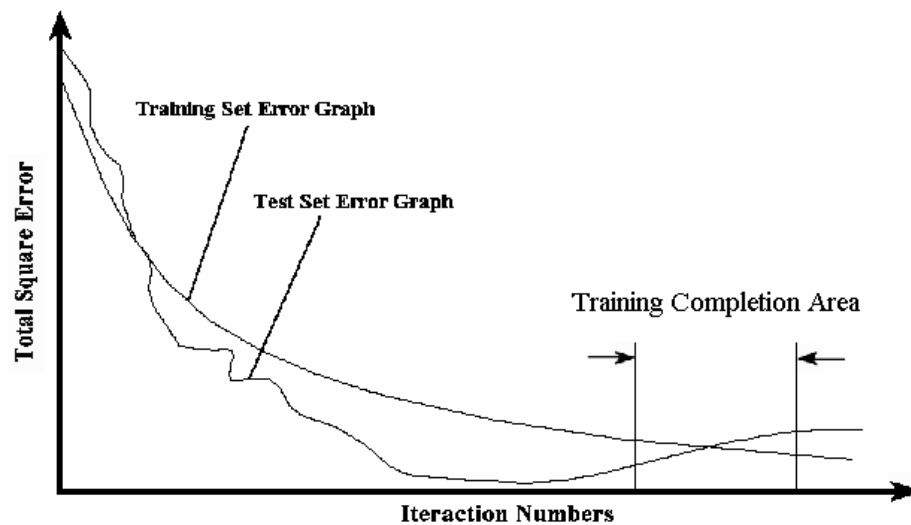


Figure 5.4. Best area for training completion (Efe and Kaynak, 2000)

After the training completion area over-learning occurs.

5.5 Design Choices

5.5.1 Introduction

Many design choices are involved in developing a neural network application.

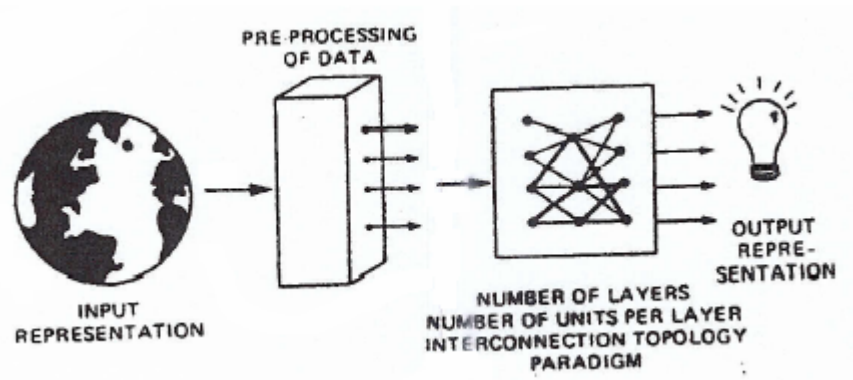


Figure 5.5. Design choices for a neural network application (Dayhoff, 1990)

The first option is selection of the application area. Generally, the existing problems have to be suitable for neural network application. Next the problem must be

identified especially so that a selection of inputs and outputs to the network may be made. Choices for inputs and outputs involve identifying the types of pattern that go into and out of the network. Researchers must design input and output patterns for best representation.

Processing units are usually organized in distinct layers, which are either fully or partially interconnected. There are additional choices for the dynamic activity of processing units. A variety of neural net paradigms are available; these differ in the specifics of the processing done at each unit and in how their internal parameters are updated. Each paradigm dictates how the readjustments of parameters take place. These readjustments result in “learning” by the network.

Next, internal parameters must be tuned to optimize the neural net. One such parameter is the learning rate from the back-error propagation paradigm (Rumelhart and McClelland, 1986). This parameter influences the rate of learning of the network. These are experiments that indicate “learning” occurs at more successful rates if this parameter is decreased during the learning session. Typically, network parameters are tuned with the help of experimental results and experience on the specific problem being examined.

In conclusion, the selection of training is very important for successful learning. How well a network will learn depends on the examples presented. Set of examples must be suitable, strong, and consistent; otherwise learning is weak and poor. Because of this, set of examples for input pattern must not be poor. The set of training examples must also reflect the variability in the patterns that the network will encounter after training.

5.5.2 Artificial neural network model for Neuroshell2

The neural network that was used for training and prediction was implemented on a commercially available simulation package, Neuroshell2 (Ward System Group, Inc., Frederick, Md.). The nodes of a neural network are organized into groups, forming layers in the network. The input layer is used to distribute the data from the environment to the other layers of the network, which process the data. The output layer passes the network’s result back to the environment. There may be multiple inner layers, which are called hidden layers in the Back Propagation Neural Network

(BPNN) algorithm, because they have no direct connection with the outside environment. All processing in the neural network is done in the hidden layer and output layers. The main type of ANN used in this study is referred to as a multilayered, feedforward neural network. The following are essential to any ANN: (1) network topology; (2) learning and momentum rate; (3) test set size; and (4) learning rule. The error back-propagation algorithm is the learning rule that will be used and the general BPNN model is used with the desired input and output variables in this study. Basically, the learning in the network is achieved through an iterative algorithm that minimizes the mean-absolute between errors desired and actual outputs.

On the other hand, a typical General Regression Neural Network (GRNN) net is composed for each training pattern. There are no training pattern parameters, such as learning, momentum rate, number of hidden layers, and test size as there are in BPNN models. However, there is a smoothing factor that is used to determine how tightly the network matches its predictions to the data in the training patterns. The GRNN architecture approximates any arbitrary function between input and output vectors, drawing the function is estimated directly from training data. GRNN is based on nonlinear regression theory for function estimation. The training set consists of values of for x , each with a corresponding y . this regression method produces the estimated value of y , which minimizes the mean-absolute error. The error of the network is computed by finding the mean-absolute error and the coefficient of multiple determinations (R^2). During the adaptation phase, the training algorithm receives part of the data (inputs and outputs) and automatically develops the ANN model. After development, the model can generate the appropriate biological activity performance responses for simulations with varying levels of data input. When the learning is complete, the neural network is used for prediction.

Finally, in this study BPNN and GRNN algorithm are used for soil-structure interaction. Other neural network algorithms which are Probabilistic Neural Network (PNN), Kohonen, and Group Method of Data Handling (GMDH) haven't been used. Due to this, these algorithms are discussed not very much and just given a little information about these algorithms.

5.6 Neural Network Architecture

5.6.1 General regression neural network architecture, GRNN

General Regression Neural Network (GRNN) was introduced by Dr. Donald Specht (1996). GRNN has three layers which include input, hidden, and output layer. Three-layer network have one hidden neuron for every training pattern, in addition to the total number of neurons equal to sum of input and output number. (1), (2), (3) are input neuron, hidden neuron, and output neuron, respectively in figure 5.6.

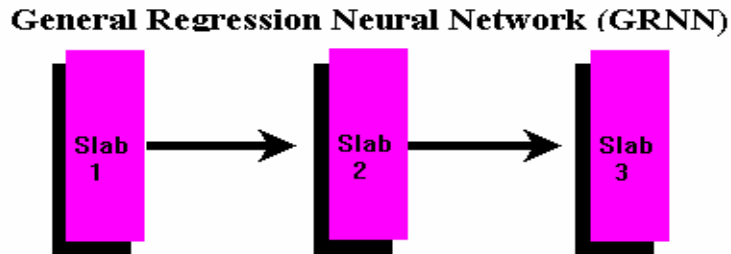


Figure 5.6. GRNN architecture (Frederick, 1996)

Unlike BPNN, as mentioned in section 5.5.2, there is a smoothing factor instead of training parameters, learning rate and momentum. The success of GRNN networks is dependent upon the smoothing factor. The individual smoothing factor adjustments values may be used as a sensitivity analysis tool: Inputs with low smoothing factor adjustments are candidates for removal for a later trial, especially if the smoothing factor adjustments approaches zero.

The fact that the GRNN network centers are determined by the training data vectors and not some artificial centers best for optimization gives the network stability and it ensures that it cannot be over-trained. This is the main feature along with its simplicity that distinguishes it from most other approaches. GRNN is more useful for continuous function approximations. GRNN can have multi-dimensional input, and it will fit multi-dimensional surfaces through data. GRNN works by measuring how far a given sample pattern is from patterns in the training set in N dimensional space, where N is the number of inputs in the problem.

When a new pattern is presented to the network, which input pattern is compared in N dimensional space to all of the patterns in the training set to determine how far in distance it is from those patterns. The output is predicted by the network and also the network is a percentage of all of the outputs in training set. The percentage is based upon how far the new pattern is from the given patterns in the training set.

Advantages:

- i. GRNN can handle both linear and non-linear data.
- ii. Adding new samples to training set does not require re-calibration to the model.
- iii. Only one adjustable parameter thereby making overtraining less likely.

Disadvantages:

- i. Requires many training samples to adequately span the variation in the data.
- ii. Requires that all the training samples be stored for future use (i.e. prediction).
- iii. Has trouble with irrelevant inputs.
- iv. No intuitive method for selecting the optimal smoothing parameter.

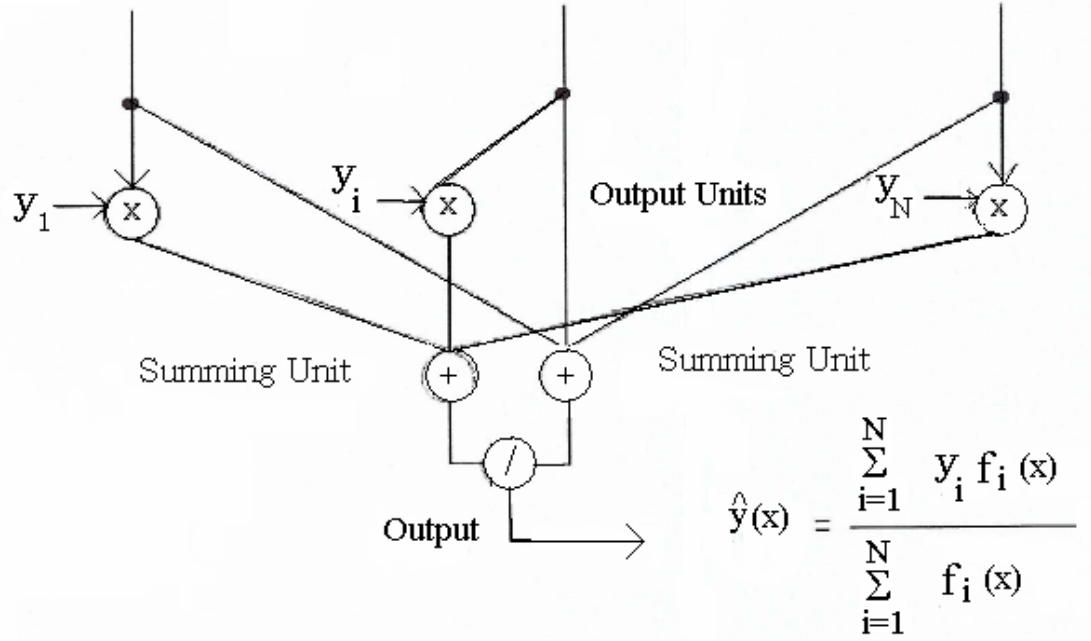


Figure 5.7 The basic GRNN architecture

5.6.1.1 GRNN architecture learning algorithm

As seen in figure 5.6 and discussed in section 5.6.1, the total number of neurons is equal to the sum of outputs and inputs (Speeth, 1991). The regression is estimation of the least mean squares of variables based on the available data. In other words, the regression is the estimation of the least mean squares of variables based on the available data. The regression decision in the GRNN architecture reveals the most probable value of all the patterns in an N-dimensional space (where N is the number of inputs) in Figure 5.7. Output values correspond to the weight average of the target values. The target values are weights which exceed from hidden layers to output layers. During the GRNN training process, smoothing factors (or bandwidths) are only weights which need to be calculated. The success of the GRNN is dependent upon the smoothing factor; however, there is no intuitive method for selecting the optimal smoothing factor (Ural and Bayrak, 2003). It is a very important point that smoothing factor ranges from 0 to 1. The GRNN can be easily extended to have a multidimensional output making it a fully general vector mapping method. With a multi-dimensional output vector the GRNN can be used for either time series analysis or for pattern classification by defining the output vector appropriately (Ural and Bayrak, 2003).

The GRNN utilizes a probabilistic relation between an independent single training vector in the input space (X) and a dependent scalar output (Y). X_i is defined as the input vector of the i^{th} training data set, and Y_i is the output related to X_i . It is assumed that x and y are defined as measured values of X and Y , respectively, and the regression of Y on X is defined as $\hat{y}$ such that;

$$\hat{y}(x) = \frac{\sum_{i=1}^P y_i f_i(x)}{\sum_{i=1}^P f_i(x)} \quad (5.1)$$

$$f_i(x) = \exp \left[\frac{-(x-x_i)^T (x-x_i)}{2\sigma^2} \right] \quad (5.2)$$

By substituting Eq. (5.2) in Eq. (5.1)

$$\hat{y}(x) = \frac{\sum_{i=1}^P y_i \exp \left[\frac{-(x-x_i)^T (x-x_i)}{2\sigma^2} \right]}{\sum_{i=1}^P \exp \left[\frac{-(x-x_i)^T (x-x_i)}{2\sigma^2} \right]} \quad (5.3)$$

Eq. 5.3 is known as the Specht's GRNN and P is the number of training pairs. In Specht's GRNN, σ is a smoothing factor shared by all the inputs and the pattern nodes. Assigning an independent smoothing factor for each of variables may improve accuracy; however, this may be impractical in many simulations (Specht, 1996).

As shown in Fig. 5.8, the GRNN is composed of one input layer, one hidden layer, a summation layer, and one output layer. The GRNN models are trained by a one-pass learning algorithm. The presented input is subtracted from each stored vector to estimate an output in the hidden layer. In order to evaluate the squared or absolute difference between the hidden neurons and inputs the probability density functions or radial basis functions are applied. The summation unit computes the sum of the outputs from all hidden neurons. Finally, output is obtained at the output layer, where

normalization is performed. This normalized output is computed by dividing the value of the weighted sum of hidden layer outputs, by the value in the summation layer.

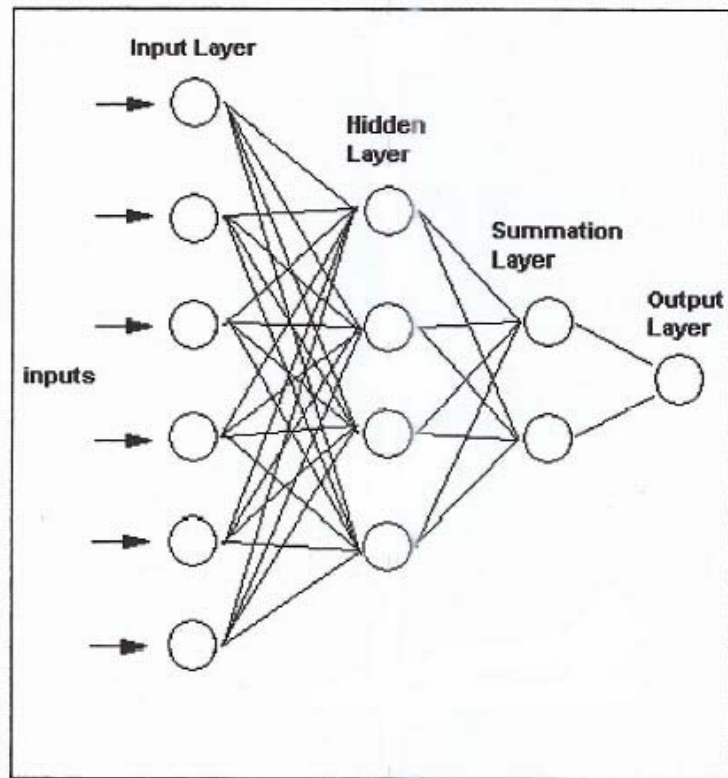


Figure 5.8. The GRNN architecture (Specht, 1996)

5.6.2 Back propagation neural network (BPNN)

Back-propagation networks are known for their ability to generalize well on a wide variety of problems. That is why they are used for the vast majority of working neural network applications. BPNN networks are a supervised type of network, e.g., trained with both inputs and outputs. Depending upon the number of patterns, training may be slower than other paradigms. When using BPNN, you can increase the precision of the network by creating a separate network for each output if your outputs are not categories (Frederick, 1996).

5.6.2.1 Back-error propagation paradigm

Back-error propagation is the most widely used of the neural network paradigms and has been applied successfully in applications in a broad range of areas.

A neural network has as input layer, a hidden layer and output layer as mentioned before. Each layer is made up of several nodes, and layers are interconnected by set of weights. The pattern of connectivity and number of neurons in each layer may vary within some constraints. No communication is permitted between the nodes within a layer, but the nodes in each layer may send their output to the nodes in the succeeding layers. The nodes receive input from either the initial inputs or the interconnections.

Back-propagation networks learning and update procedure is intuitively appealing because it is based on a relatively simple concept; if the network gives the wrong answer, then the weights are corrected so that the error is reduced and as a result, and future response of the network become more accurate.

Back-propagation networks are usually layered, with each layer fully connected to the layers below and above. When the network is given an input, the updating of activation values propagates forward from the input layer of processing units, through each internal layer, to the output layer of processing units. The output units then provide the network's response. When the network corrects its internal parameters, the correction mechanism starts with the output units and back-propagates backward through each internal layer to input layer so it is named as "back-error propagation", or "back-propagation".

Back error propagation involves two phases (Cigizoglu, 2003): (1) a feed forward phase in which the external input information at the input nodes is propagated forward to computed the output information signal at the output unit, (2) and a backward phase in which modifications to the connection strength are made based on the differences between the computed and observed information signals at the output units.

At the beginning of a training process, the connection strengths are assigned random values. The learning algorithm modifies the strength in each iteration until the successful completion of the training. When iterative process has converged, the collection of connection strengths captures and stores the knowledge and the information present in the examples used in training process. When presented with a

new input pattern, a feed forward network computation results which is the result of the generalisation and synthesis of what ANN has learned and stored in its connection strengths.

The power of back-propagation lies in its ability to train hidden layer. When two or more layers of weights are adjusted, the network has middle or hidden layers of processing units as shown fig. 5.9 and 5.10. Each hidden layer acts as a layer of “feature detectors” which are units that respond to specific feature in the input pattern. These feature detectors organizes as learning takes place, and are developed in such a way that they accomplish the specific learning task presented to the network.

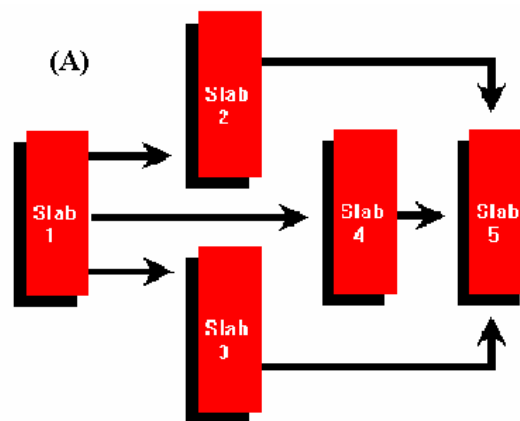


Figure 5.9. A back propagation neural network model for different activation functions and 3 hidden slabs (Frederick, 1996)

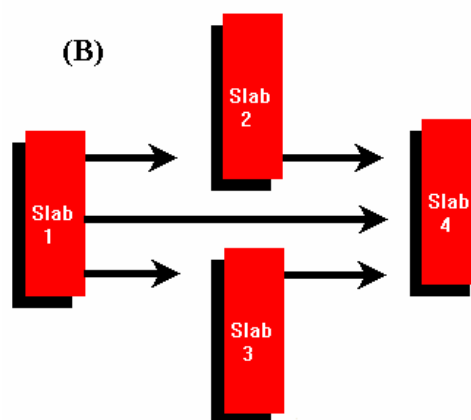


Figure 5.10. A back propagation neural network model for different activation functions and 2 hidden slabs (Frederick, 1996)

Advantages:

- i. It is easy to implement.
- ii. The training duration is short.
- iii. It is shown that the Feed Forward Back Propagation is superior to conventional stochastic and statistical methods in forecasting studies (Cigizoglu,2003)

Disadvantages:

- i. Frequently the network is caught by local minima. Global minimum is not attained.
- ii. The network is very sensitive to the selection of initial weights values, which are randomly assigned. Different mean squared error values can be produced after different initial weight selections.
- iii. Negative values can be generated after simulations, thus physically meaningless forecast can be provided (Cigizoglu, 2004)

5.6.2.2 BPNN structure

Back propagation employs three or more layers of processing units. It is the topology for a typical three layer back-propagation network in Fig. 5.11. The bottom layer of units is the input layer. Above input layer is the hidden layer. The top layer is the output layer. In the hidden layer, the processing units are interconnected to the layer above and below as in Figure 5.11, and are fully interconnected (each processing unit is connected to every unit in the layer above and below). Units are not connected to other units in the same layer.

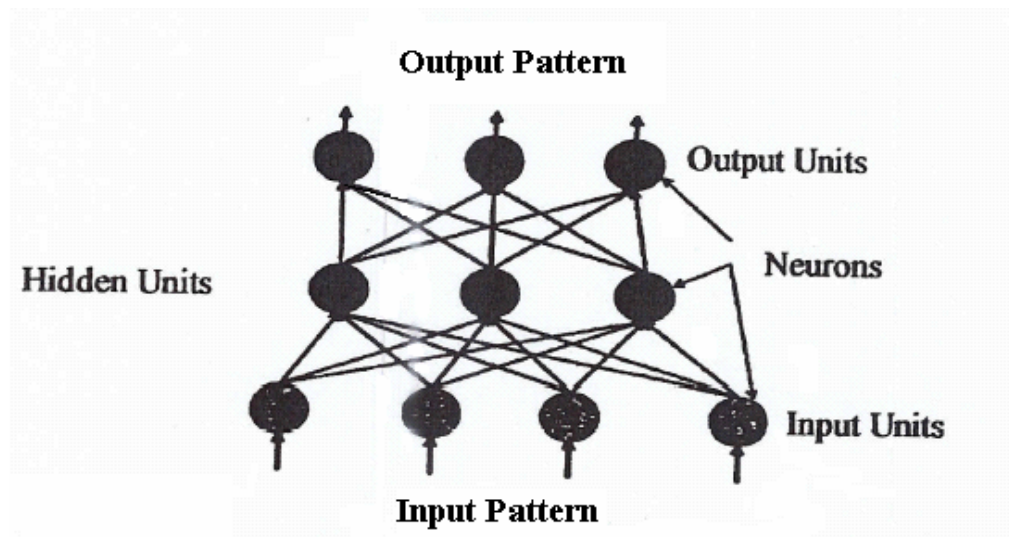


Figure 5.11. Three-layer back-propagation network, fully interconnected (Ural and Bayrak, 2003)

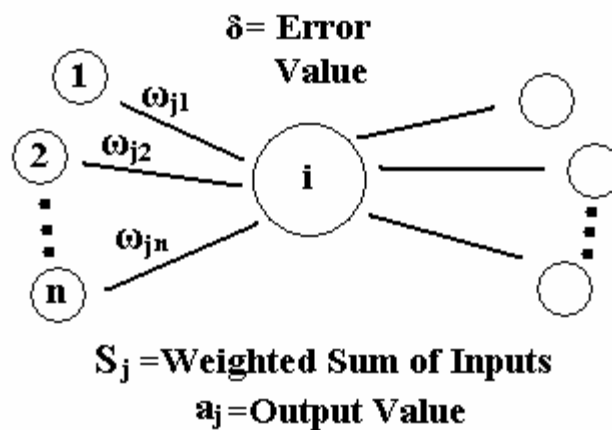


Figure 5.12. The basic back-propagation processing unit (Ural and Bayrak, 2003)

Back-Propagation networks do not have to be fully interconnected, although most applications have been done with fully interconnected layers. In Fig. 5.12, a basic back-propagation processing unit, inputs are shown at the left, and at the right are units that receive outputs from the processing unit at the center. The processing unit has a weighted sum of inputs (S_j), an output value (a_j), and an associated error value (δ_j) that is used during weight adjustments in Figure 5.12. During learning, weights associated with each interconnection are adjusted. The weight to unit j from unit i is

denoted as ω_{ij} . After learning is completed, the weights are fixed. These final values are then used during “testing” sessions. Figure 5.12 illustrates the weights along the incoming connections to the processing unit at the center. There is a matrix of weight values that corresponds to each layer of interconnections in Figure 5.13; these matrices are indexed with superscripts to distinguish weights in different layers.

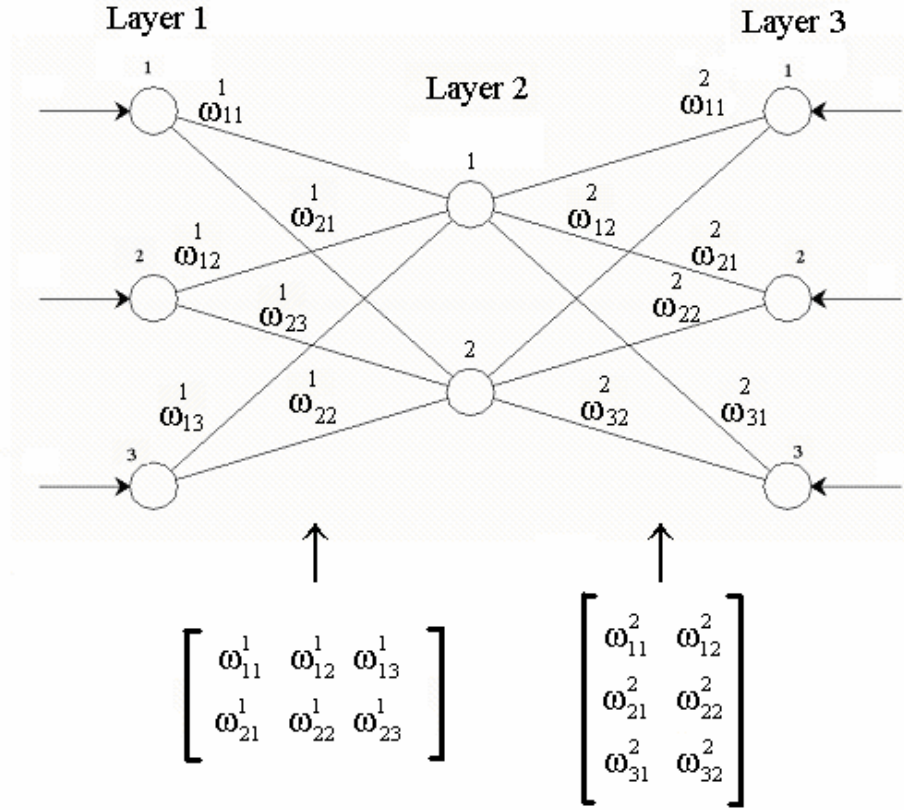


Figure 5.13. Weight matrices of a three layered back-propagation system (Ural and Bayrak, 2003)

The back-propagation learning algorithm involves a forward-propagating step followed by a backward-propagating step. Both back and forward propagation are done for each pattern presentation during training. The forward-propagation step begins with the presentation of an input pattern to input layer of the network, and continues as activation level calculations, the output value off each processing unit, propagates forward through the hidden layer. In each successive layer, every processing unit sums its inputs and then applies a sigmoid function to compute its output. The output layer of units then produces the output of the network in Figure 5.13.

The back-propagation step begins with the comparison of the network's output pattern to the target vector, when the difference or "error" is calculated. After back-propagation step error values are calculated for hidden layer and after this time weights are changed. When this process is finished, incoming weights start with the output layer and moving backward through the successive hidden layers. In this back-propagating step the network corrects its weights in such a way as to decrease the observed error.

The error value (δ) associated with each processing unit reflects the amount of error associated with that unit. This parameter is used during the weight-correction procedure, while learning is taking place. A larger value for δ indicates that a larger correction should be made to the incoming weights and its sign reflects the direction in which the weights should be changed.

The learning algorithm processes the pattern in two stages. These two stages are forward-propagation and back-propagation. In the first stage, the input pattern generates a forward flow of signals from the input layer to the output layer. The error of each output neuron is then computed from the difference between the computed and the desired output. The second stage involves the readjustments of the weights in the hidden layers to reduce the difference between the actual and desired output. The modification of the weights is carried out using a "generalized delta rule" (Rumelhart et al. 1986) through the gradient descent on the error. The aim of the back propagation algorithm is to minimize iteratively the average square error. The updating of the weights is controlled through a learning rate h and a momentum term to improve the efficiency of the learning process.

Learning Rate: $0 \leq h < 1$ "h" is learning rate.

The smaller the value of h , the smaller the changes to the synaptic weights in the network will be from one iteration to the next. This improvement, however, is attained at the cost of a slower rate of learning. On the other hand, if we take h too large the network may become unstable (Cigizoglu, 2003).

Momentum Rate: $0 \leq a < 1$ “a” is momentum rate.

The inclusion of momentum rate has a stabilizing effect. The momentum rate may prevent the learning process from terminating in a local minimum of the error surface as shown in Figure 5.14.

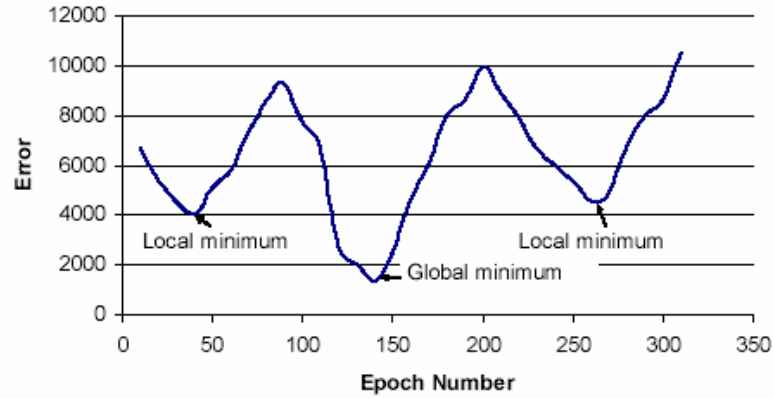


Figure 5.14. Illustration of local minima and global minimum in error surface (Cigizoglu, 2003)

Training is carried out iteratively until the average sum squared error E over all training patterns is minimized. E is defined as;

$$E = \frac{1}{(pN_t)} \left\{ \sum_{k=1}^{k=p} (D_k - T_k)^2 \right\} \quad (5.4)$$

Where D_k = desired output and T_k =actual output; p =number of patterns; and N_t =number of output neurons. On the satisfactory completion of the training phase, verification of the performance of the neural network is then carried out using patterns that were not included in the training set. This determines the quality of the predictions in the comparison to the desired output. This is called the testing phase. No additional learning occurs during this phase.

5.6.3 Scaling function

When variables are loaded into a neural network, they must be scaled in a specific interval because of the efficiency of the neural network. Depending on the type of the activation function the user uses, there are basically two main numeric ranges. Zero

to one denoted $[0, 1]$, minus one to one denoted $[-1, 1]$. Larger numbers than the numbers that we use as input are allowed later if $\langle\langle 0, 1 \rangle\rangle$ or $\langle\langle -1, 1 \rangle\rangle$ are used. In the other words, if data from 0 to 100 is scaled to $[0,1]$, then a later data value of 120 will get scale to 1. However, if the same data were scaled to $\langle\langle 0,1 \rangle\rangle$, then 120 would be scaled to 1.2.

5.6.4 Activation functions

Activation functions determine neurons behaviour. The formulas of the functions which are used in Neuroshell2 are shown below:

$$\text{Logistic} \rightarrow f(x) = 1/(1 + \exp(-x)) \quad (5.5)$$

$$\text{Linear} \rightarrow f(x) = x \quad (5.6)$$

$$\text{Tanh} \rightarrow f(x) = \tanh(x), \text{ the hyperbolic tangent function} \quad (5.7)$$

$$\text{Tanh15} \rightarrow f(x) = \tanh(1.5x) \quad (5.8)$$

$$\text{Sine} \rightarrow f(x) = \sin(x) \quad (5.9)$$

$$\text{Symmetric Logistic} \rightarrow f(x) = ((2/(1 + \exp(-x))) - 1) \quad (5.10)$$

$$\text{Gaussian} \rightarrow f(x) = \exp(-x^2) \quad (5.11)$$

$$\text{Gaussian Complement} \rightarrow f(x) = 1 - \exp(-x^2) \quad (5.12)$$

The details of these activation functions are ;

Linear: Use of this function should generally be limited to the output slab. It is useful for problems where the output is continuous variable, as opposed to several outputs which represent categories.

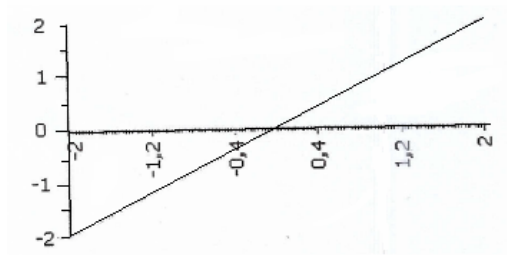


Figure 5.15. Linear activation function

Logistic (Sigmoid Logistic): This function is useful for most neural network applications, and it maps values into the $(0, 1)$ ranges. It is used when the outputs are in categories.

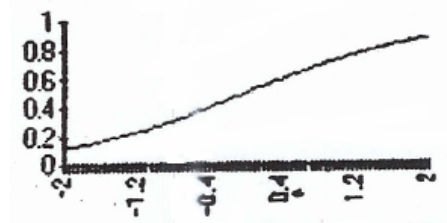


Figure 5.16. Logistic function

Symmetric Logistic: This is similar to the logistic, except that it maps to $(-1, 1)$ instead of to $(0, 1)$. When the outputs are categories, trying symmetric logistic function instead of the logistic function in the hidden and output layers may be better. In some cases, the network will train to a lower error in the training and test sets.

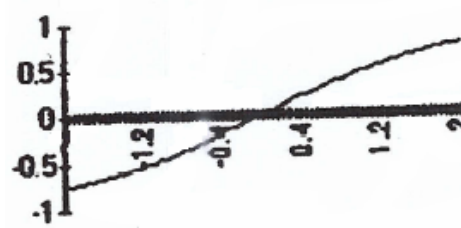


Figure 5.17. Symmetric logistic function

Gaussian: It is very useful in some set of problems. Trying it in the hidden layer and logistic function in the output layer may give good results.

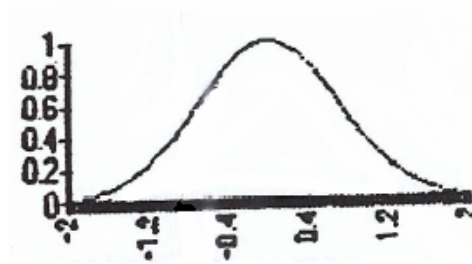


Figure 5.18. Gaussian function

5.6.5 Other neural networks algorithms

5.6.5.1 PNN architecture

Probabilistic Neural Networks (PNN) are known for their ability to train quickly on sparse data sets. PNN separates data into a specified number of output categories. PNN networks are three layer networks wherein the training patterns are presented to the input layer and the output layer has one neuron for each possible category. There must be as many neurons in the hidden layer as there are training patterns.

The network produces activations in the output layer corresponding to the probability density function estimate for that category. The highest output represents the most probable category (Frederick, 1996)

5.6.5.2 Kohonen architecture

The Kohonen Self Organizing Map network used in Neuroshell2 is a type of unsupervised network, which has the ability to learn without being shown correct outputs in sample patterns. These networks are able to separate data into a specific number of categories. There are only two layers: an input layer and an output layer which has one neuron for each possible output category.

The training patterns are presented to the input layer, then propagated to the output layer and evaluated. One output neuron is the “winner”. The network weights are adjusted during training. This process is repeated for all patterns for a number of epochs chosen in advance. This network is very sensitive to learning rate. It is

lowered slightly but steadily by Neuroshell2 as the training progresses, causing smaller and smaller weight changes. This causes the network to stabilize.

The network adjusts the weights for the neurons in a neighbourhood around the winning neuron. The neighbourhood size is variable, starting off fairly large (sometimes even close to number of categories) and decreasing with learning until during the last training events the neighbourhood is zero, meaning by then only winning neuron's weights are changed. By that time the learning rate is very small, and the clusters have been defined. Neuroshell2 automatically adjusts learning rate and neighbourhood sizes, but one has to specify the initial values as well as the total number of epochs that learning will continue (Frederick, 1996)

5.6.5.3 GMDH architecture

The technique called Group Method of Data Handling (GMDH) was invented by A.G. Ivakhnenko in the former Soviet Union, but enhanced by others, including A.R. Barron. This technique has also been called "polynomial nets".

GMDH works by building successive layers with complex links (or connections) that are the individual terms of a polynomial. These polynomial terms are created by using linear and non-linear regression. The initial layer is simply the input layer. The first layer created is made by computing regressions of the input variables and then choosing the best ones. The second layer is created by computing regressions of the values in the first layer along with the input variables. Again, only the best are chosen by the algorithm. These are called survivors. This process continues until the net stops getting better.

The resulting network can be represented as a complex polynomial (i.e., a familiar formula) description of the model. You may view the formula, which contains the most significant input variables. In some respects, it is very much like using regression analysis.

GMDH contains several evaluation methods, called selection criteria, to determine when it should stop training. One of these, called regularity, is similar to calibration in that the net uses the constructed architecture that works the best on the test set. The other selection criteria do not need a test set because the network automatically

penalized models that become too complex in order to prevent over-training. The advantage of this is that you can use all available data to train the network.

A by-product of GMDH is that it recognizes the most significant variables as it trains, and lists of them (Frederick, 1996).

6. NEURAL NETWORK APPROACHES FOR SOIL-STRUCTURE INTERACTION

6.1 Introduction

In this chapter, application of neural networks for soil-structure interaction is discussed. There are 5 models introduced for neural network approaches. Model 1 and 2 are Back-Propagation Neural Network (BPNN) approaches, and model 3, 4, 5 are General Regression Neural Network (GRNN) approaches. Data and case studies are given for Neural Network (NN). Current code provisions for SSI effects in two building codes (BSSC, 1997 and ATC, 1978) will be examined by NN approaches which are the BPNN and GRNN approaches. Values are obtained from BSSC (1997) and ATC (1978). These values will be used in NN approaches. Neural Network parameters and case study for SSI effects are given in section 6.2.

6.2 Input Parameters Information

In this study, there are twenty-five data parameter important for SSI effects, that are presented for NN approaches. It should be noted that γ is the ratio of the structure-to-soil mass, is taken 0.15 and constant value. Remaining data are 24 and these data are used in this study. All data below are obtained from Stewart (1997 and 1998).

- 1) Rock/Soil:** It is determined from in-situ test whether soil is rock or soil
- 2) Piles(Y/N):** Foundation has piles whether is yes or no and this data are obtained from structural properties.
- 3) Number of Stories (NO. Stories):** These data are obtained from structural properties.
- 4) Str. System (Lateral force resisting systems):** These data are obtained from structural properties. These types are; SW is masonry or concrete shear walls

system, DWF is dual wall/frame system, CF is concrete frame system, SF is steel frame system, BI is base isolation system.

- 5) **Basement (Y/N):** Structure has basement whether is yes or no.
- 6) **M_w (Magnitude):** These data are earthquakes magnitude and obtained from earthquake properties. These data details were given in section 2.
- 7) **MHA (g):** MHA is maximum horizontal accelerations which are obtained from earthquake and soil properties.
- 8) **h(ft):** It is effective structure height and is generally taken as 0.7*full height of structure from base of structure to roof of structure.
- 9) **e(ft):** Embedment depth.
- 10) **v_s (fps):** Soil shear wave velocity which is obtained from earthquake and soil properties.
- 11) **β(%):** Hysteretic damping ratio.
- 12) **r₁(ft):** Foundation radii match the area (A_f) is obtained from structure properties.
- 13) **r₂(ft):** Foundation radii match moment of inertia (I_f) is obtained from structure properties.
- 14) **T_{flex} (sec) ($\tilde{T}$):** is flexible-base period.
- 15) **T (sec):** is fixed-base period.
- 16) **$\tilde{\zeta}$ (%) (ζ flexible):** is flexible-base damping ratio.
- 17) **ζ (%) :** is fixed-base damping ratio.
- 18) **1/σ:** It is the ratio of the structure-to-soil stiffness.
- 19) **$\tilde{T}/T$ (Period lengthening):** Period lengthening was discussed in section 3.
- 20) **$\tilde{\zeta}_0$ (Foundation damping):** Foundation damping was discussed in section 3.

There were 115 data patterns for Neural Network approaches. After normalization, the remaining data become 99 in number and this data set is used for neural networks. Normalization is performed by dividing the largest values for each pattern values. In this way, all values are limited in a range from 0 to 1. These before normalization data and normalized data are given in Appendix H and Appendix I, respectively. By the way of normalization, numerical operations are limited. If range exceeds 1 learning phase becomes more difficult. Data points A17(tr), A4(tr), A4(L), B5(tr), A46(tr), A46(L), A2(L), A7(tr), A2(tr), A10(L), A34(L), A1(tr), A1(L), A16(L), A44(L) are omitted. Because these data points lead to expand. After normalization, “Rock/Soil” information is input as, R is 0 and S is 1, similarly “Piles(Y/N)” and “Basement(Y/N)” columns, Y is 1, N is 0. The decision making ability of Neural Network which is whether Soil-Structure Interaction (SSI) effects can be neglected or not. If SSI effects can be neglected information is input as, Yes is 1 and No 0. In Appendix H and Appendix I, before normalization data properties, and after normalization data properties are presented, respectively. The structural system is divided five patterns and value of the one of five types which are given in chapter 2 will be 1 and all rest will be 0.

There are four outputs which are $1/\sigma$, $\tilde{T}/T$, $\tilde{\zeta}_0$, and SSI effects can be negligible relative to $1/\sigma$, $\tilde{T}/T$, and $\tilde{\zeta}_0$ for NN. As discussed, $1/\sigma$, $\tilde{T}/T$, and $\tilde{\zeta}_0$ are as follows:

$$\frac{1}{\sigma} = \frac{h}{v_s T} \quad (6.1)$$

$$\frac{\tilde{T}}{T} = \sqrt{1 + 25 \frac{\gamma r_1 h}{v_s^2 T^2} (1 + 1.12 \frac{r_1 h^2}{r_2^3})} \quad (6.2)$$

$$\tilde{\zeta}_0 = \tilde{\zeta} - \frac{\zeta}{(\tilde{T}/T)^3} \quad (6.3)$$

These relations are taken from BSSC 1997 and ATC 1978. When $1/\sigma < 0.1$, $\tilde{T}/T < 1.1$, and $\tilde{\zeta}_0 < 4\%$ SSI effects (after normalization this compare is done according to $1/\sigma < 0.0645$, $\tilde{T}/T < 0.19$, and $\tilde{\zeta}_0 < 0.13\%$) are neglected (Stewart, 1998)

Table 6.1. Input and output values range for Neural Network

Parameters	Rock/Soil	Piles (Y/N)	NO.Stories	Str. system SW	Str.system DWF	Str.system CF	Str. system SF
Variable Type	I	I	I	I	I	I	I
Min	0	0	0,0185	0	0	0	0
Max	1	1	1	1	1	1	1
Mean	0,77778	0,38384	0,14272	0,28283	0,14141	0,10101	0,26263
Std. Deviation	0,41786	0,48879	0,13236	0,45267	0,35022	0,30288	0,4423
Parameters	Str.system BI	Basement (Y/N)	Mw	MHA(g)	h(ft)	e(ft)	Vs (fps)
Variable Type	I	I	I	I	I	I	I
Min	0	0	0,65753	0,0357	0,05314	0	0,10045
Max	1	1	1	1	1	1	1
Mean	0,21212	0,51515	0,90729	0,1752	0,17299	0,13509	0,24838
Std. Deviation	0,41089	0,50231	0,0746	0,15447	0,13382	0,17739	0,12887
Parameters	$\beta(\%)$	r_1 (ft)	r_2 (ft)	Tflex.(sec)	T (sec)	ζ flexible	ζ (%)
Variable Type	I	I	I	I	I	I	I
Min	0,0825	0,0260	0,0436	0,02926	0,0211	0,0254	0,0324
Max	0,93814	1	1	1	1	0,86294	0,98504
Mean	0,33354	0,36235	0,35897	0,17073	0,16943	0,25222	0,24202
Std. Deviation	0,19212	0,16833	0,19438	0,14262	0,14626	0,17353	0,18356
Parameters	$1/\sigma$	Period lengthening	Foundation damping	Negligible			
Variable Type	A	A	A	A			
Min	0,0193	0,1731	0	0			
Max	0,12304	0,21554	0,43244	1			
Mean	0,0564	0,18252	0,0701	0,58586			
Std. Deviation	0,0254	0,0095	0,0987	0,49508			

I is input value and A is actual output value in Table 6.1.

6.3 Analysis

Analysis results are presented in output tables, error through pattern graphics, and outputs value transferred into initial states ($1/\sigma$ is multiplied 1.55, period lengthening is multiplied 5.78, and foundation damping is multiplied 30.98. In this way these outputs values are transferred into before normalization) given in appendix A, B, D, and E. R^2 , defined in Neuroshell2, is a statistical indicator usually applied to multiple regression analysis. It compares the accuracy of the model to the accuracy of a trivial benchmark model, and the prediction is just the mean of all of the samples. A perfect fit would result in an R squared value of 1, a very good fit near 1, and a very poor fit near 0. The formula that Neuroshell2 uses is defined as the following:

$$R^2 = 1 - \frac{SSE}{SS_{YY}} \quad (6.4)$$

where

$$SSE = \sum (y - \hat{y})^2 \quad (6.5)$$

$$SS_{YY} = \sum (y - \bar{y})^2 \quad (6.6)$$

Where y is the actual value, $\hat{y}$ is the predicted value of y , and $\bar{y}$ is the mean of the y values.

6.3.1 BPNN approaches

6.3.1.1 Model 1

In Table 6.2, training calibration for model 1 is given. Architecture is 3 hidden slabs, and different activation functions as presented in chapter 5. Activation function is linear function. Pattern selection is rotational, not random from 99 pattern processed for training.

Table 6.2. Model 1 approach for training

Architecture	3 hidden slabs, Different activation functions
% Extraction	20
# of hidden layer	2
# of neurons in one hidden layer	21
Learning rate	0,2
Momentum Factor	0,6
Initial Weight	0,3
Calibration Interval	400
Scale Function	Linear [0,1]
Missing values	Error Condition
Pattern selection	Rotational
Pattern processed	99

Table 6.3. The contribution factors for Model 1

Parameters	The Contribution Function	Orders of The Contribution Function
ζ flexible (%)	0,32008	1
ζ (%)	0,28001	2
r_1 (ft)	0,25392	3
v_s (fps)	0,24801	4
Piles (Y/N)	0,21210	5
h(ft)	0,20412	6
Tflex,(sec)	0,20386	7
Str, system SW	0,20300	8
Basement (Y/N)	0,19731	9
NO,Stories	0,19008	10
T (sec)	0,17695	11
Str, system SF	0,17382	12
Str,system BI	0,16858	13
r_2 (ft)	0,16573	14
Mw	0,16383	15
Str,system DWF	0,15397	16
Rock/Soil	0,14187	17
MHA(g)	0,14174	18
e(ft)	0,13695	19
β(%)	0,13442	20
Str,system CF	0,12965	21

Table 6.4. The results the Model 1

	(1)	(2)	(3)	(4)
R squared	0,8517	0,8336	0,8675	0,8504
r squared	0,8665	0,8376	0,884	0,8631
Mean squared error	0	0	0,001	0,036
Mean absolute error	0,007	0,003	0,018	0,12
Min absolute error	0	0	0	0
Max. absolute error	0,039	0,017	0,165	1,013
Correlation coefficient, r	0,9309	0,9152	0,9402	0,929

(1) = $1/\sigma$, (2) = period lengthening, (3)= foundation damping, (4)= negligible.

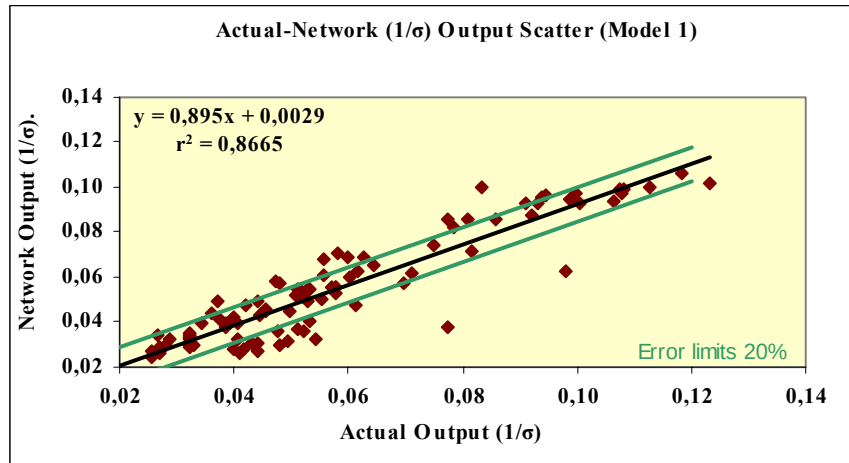


Figure 6.1. Actual-Network output scatter (1) for Model 1 and error limits

r^2 value is best fit correlation coefficient from Excel and same value from that Neuroshell2 's r^2 . This show that the process which has been performed is correct. The black line is best fit line and green lines are 20% error limits is taken from best fit line. 20% error limit means that when the difference the target output the network result is greater than 20% green lines, the network is considered as an incorrect simulation (Bayrak, 2004). According to this assumption, if the error graphs of each mode is considered and this best network gives 25 incorrect simulations, out of 99 data set for model 1. This is very high ratio and simulation error percentage 25.25%

which correspond to a success percentage is 74.75 % for this simulation shown in Figure 6.1.

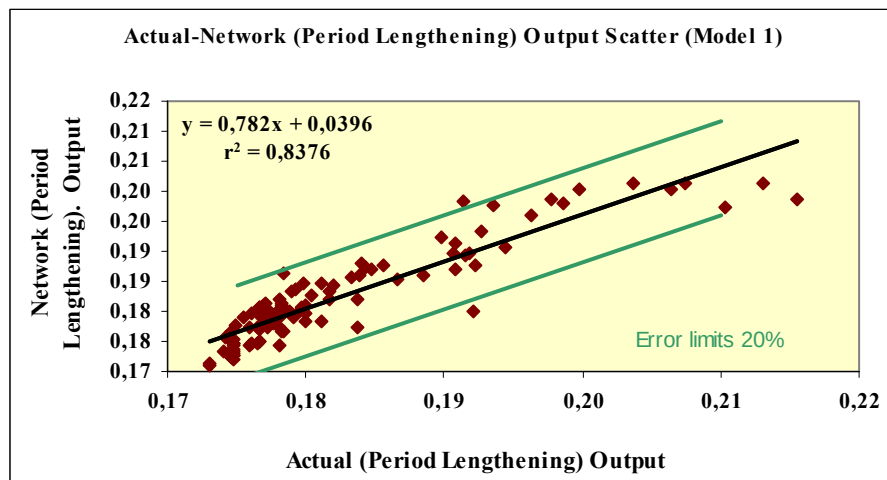


Figure 6.2. Actual-Network output scatter (2) for Model 1 and error limits

There are 3 incorrect simulations in Figure 6.2, and the simulation success percentage is 97%.

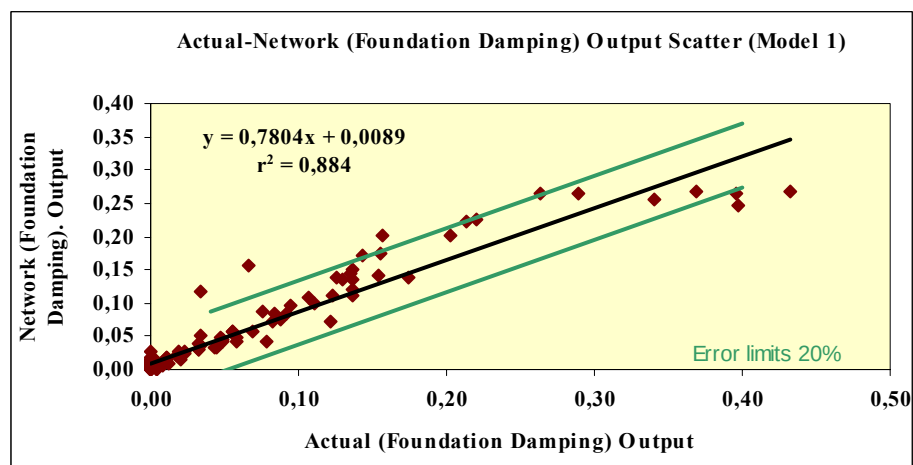


Figure 6.3. Actual-Network output scatter (3) for Model 1 and error limits

There are 5 incorrect simulations in Figure 6.3, and the simulation success percentages is 94.95%.

There are 9 incorrect simulations this means simulation success percentages 90% according to Figure 6.4.

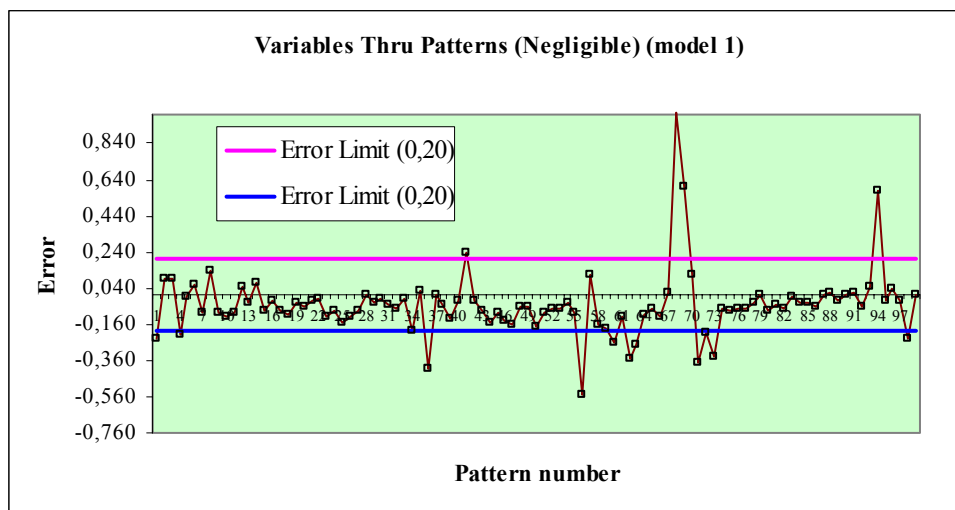


Figure 6.4. Variable error through pattern (4) and error limits

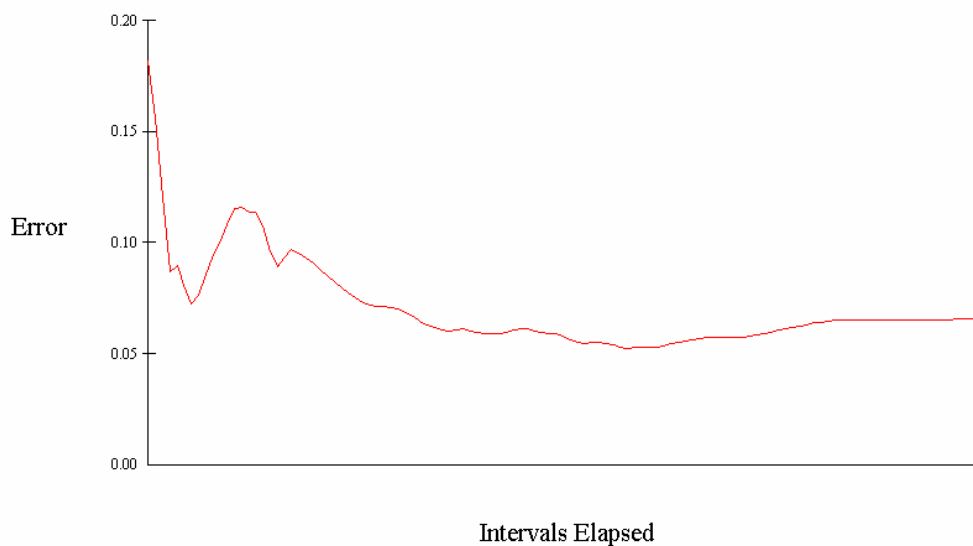


Figure 6.5. Test set error graph for Model 1

Over-learning did not occur. Because graph is decreased and after 0.05 graph is generally constant in Figure 6.5.

Table 6.5. A pieces of Model 1 output table

(3) Actual Foundation damping	(3) Network Foundation damping	(3) Act-Net Foundation damping	(4) Actual (Negligible)	(4) Network (Negligible)	(4) Act-Net (Negligible)
0,154	0,141	0,012	0,000	0,243	-0,243
0,004	0,001	0,002	1,000	0,911	0,089
0,123	0,111	0,012	1,000	0,908	0,092
0,000	-0,018	0,018	1,000	1,222	-0,222
0,136	0,121	0,015	0,000	0,002	-0,002
0,369	0,267	0,102	0,000	-0,061	0,061
0,202	0,202	0,000	0,000	0,098	-0,098
0,136	0,112	0,024	0,000	-0,134	0,134
0,048	0,049	-0,001	0,000	0,098	-0,098
0,000	-0,009	0,009	1,000	1,116	-0,116
0,020	0,014	0,006	1,000	1,097	-0,097
0,095	0,095	-0,001	1,000	0,952	0,048
0,000	0,010	-0,010	1,000	1,039	-0,039

This model has a deficiency which is in foundation damping values. Foundation damping does not take negative values but some foundation damping values are negative in Table 6.5. This is physically meaningless. Therefore Back Propagation Neural Network is not an appropriate method for evaluation of Soil-Structure Interaction (SSI) effects.

6.3.1.2 Model 2

Table 6.6. Model 2 approach for training

Architecture	3 hidden slabs, Different activation functions
% Extraction	15
# of hidden layer	2
# of neurons in one hidden layer	21
Learning rate	0,2
Momentum Factor	0,7
Initial Weight	0,3
Calibration Interval	600
Scale Function	Linear [0,1]
Missing values	Error Condition
Pattern selection	Rotational

Pattern processed	99
-------------------	----

There are certain differences between Model 2 from Model 1. Pattern extraction is 15% in Model 2. Momentum factor is 0.7 and calibration interval is 600 in Model 2.

Table 6.7. The contribution factors for Model 2

Parameters	The Contribution Function	Orders of The Contribution Function
ζ flexible (%)	0,31567	1
Z (%)	0,31361	2
Tflex,(sec)	0,26122	3
T (sec)	0,24039	4
H(ft)	0,21296	5
Mw	0,21171	6
R₁ (ft)	0,20682	7
B(%)	0,19642	8
Piles (Y/N)	0,18518	9
Rock/Soil	0,18472	10
Str,system DWF	0,17275	11
Str, system SW	0,17264	12
v_s (fps)	0,16894	13
NO,Stories	0,16710	14
E(ft)	0,15413	15
Str, system SF	0,15192	16
Basement (Y/N)	0,14993	17
R₂ (ft)	0,14553	18
Str,system BI	0,13333	19
MHA(g)	0,13288	20
Str,system CF	0,12214	21

Table 6.8. The results Model 2

	(1)	(2)	(3)	(4)
R squared	0,9317	0,8592	0,8421	0,8681
r squared	0,9386	0,8888	0,8563	0,8688
Mean squared error	0	0	0,002	0,032
Mean absolute error	0,005	0,002	0,025	0,105
Min absolute error	0	0	0	0,002
Max. absolute error	0,018	0,015	0,165	1,021
Correlation coefficient, r	0,9688	0,9428	0,9254	0,9321

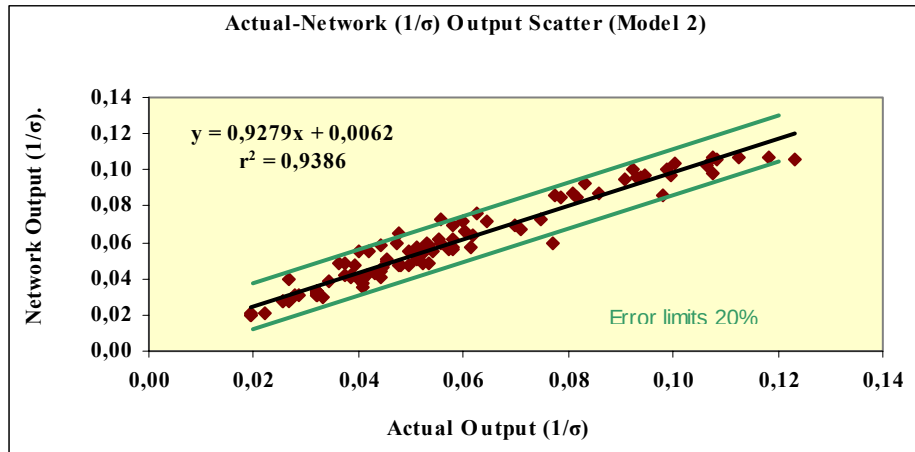


Figure 6.6. Actual-Network output scatter (1) for Model 2 and error limits

There are 3 incorrect simulations in Figure 6.6, and the simulation success percentage is 97%.

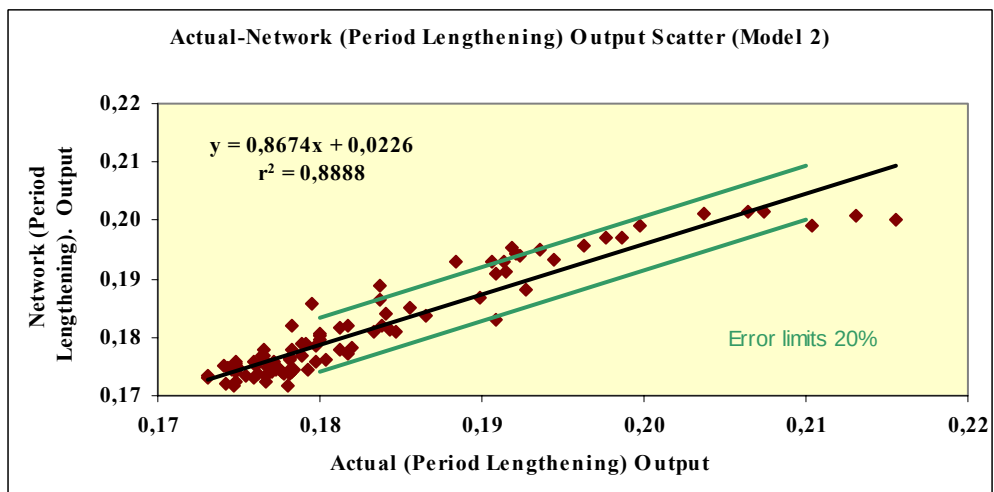


Figure 6.7. Actual-Network output scatter (2) for model 2 and error limits

There are 9 incorrect simulations in Figure 6.7, and the simulation success percentage is 90%.

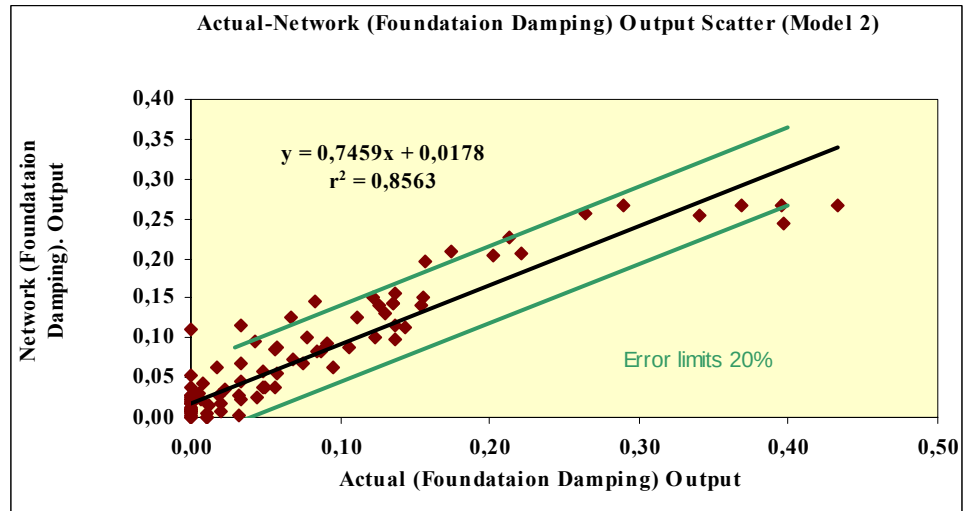


Figure 6.8. Actual-Network output scatter (3) for Model 2 and error limits

There are 8 incorrect simulations in Figure 6.8, and the simulation success percentage is 90.9%.

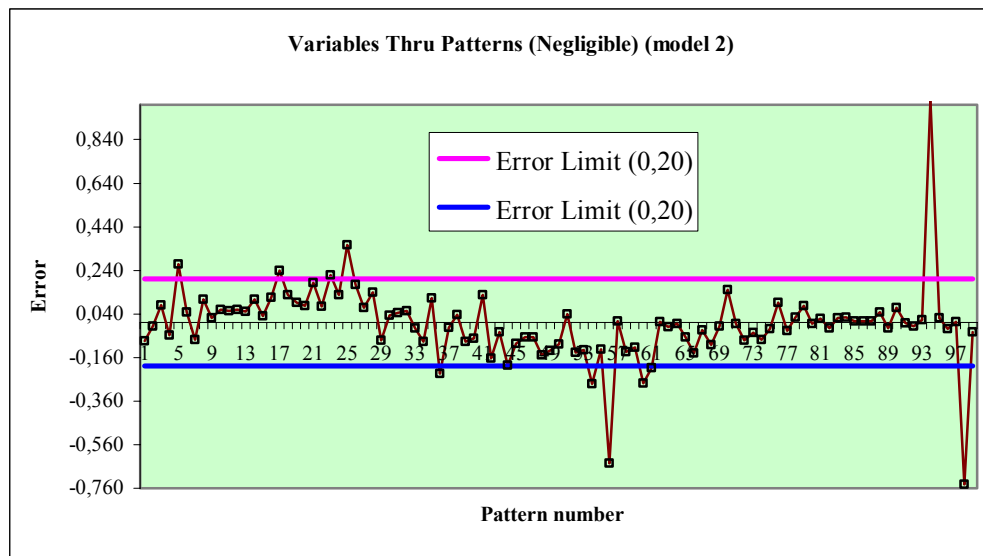


Figure 6.9. Variables error through pattern (4) and error Limits

There are 7 incorrect simulations in Figure 6.9, and the simulation success percentage of 91.9%.

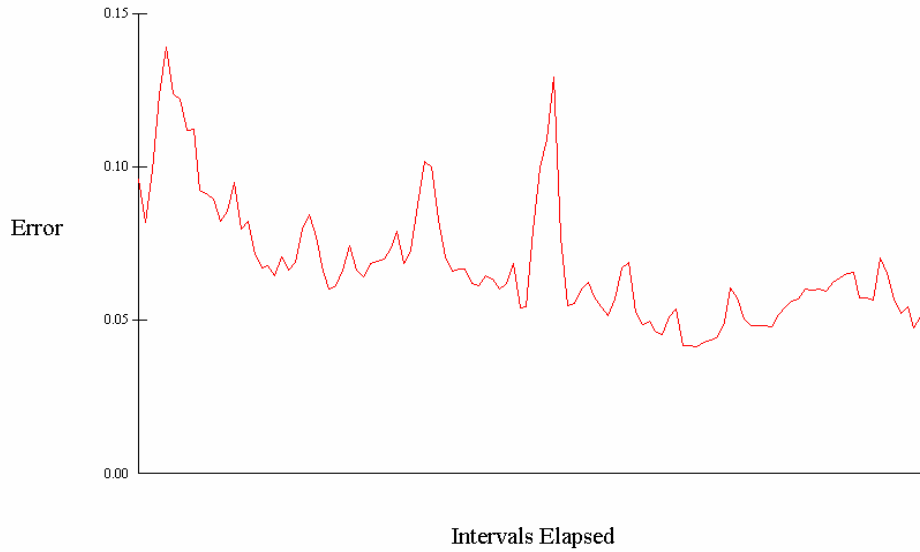


Figure 6.10. Test set error graph for Model 2

Over-learning occurred with local peaks but generally graph is decreased in Figure 6.10. This model has the challenge same model 1. Some foundation damping values takes negative values.

6.3.2 GRNN approaches

6.3.2.1 Model 3

In Table 6.9, the GRNN architecture properties are shown for Model 3. The GRNN method differs from BPNN methods by the existence of smoothing factors. On the other hand, there are no learning rate, momentum factor, and initial weights in the GRNN method. Extraction for training is 20%. There are 80 patterns for training and 19 patterns for test patterns. Genetic breeding pool size can be taken values 20, 50, 75, 100, 200, 300 respectively for Neuroshell2. In this model genetic pool size is taken 20. Missing values is taken average error values. It should be noted that smoothing factor is taken values in a range from 0 to 1 ($0 < \text{smoothing factor} < 1$).

Table 6.9. The architecture and the configuration of the Model 3

Smoothing Factor	0,1691765
Activation Function	Linear [0,1]
Distance Metric	Vanilla
Calibration	Genetic, adaptive
Missing values	Average
Genetic Breeding pool size	20
Extraction (%)	20
Number of Inputs	21
Number of Outputs	4
Number of Training Patterns	80
Number of Test Patterns	19
Pattern Processed	99

Table 6.10. Individual smoothing factors for Model 3

Input name	Individual smoothing factor	Orders
Tflex,(sec)	2,90588	1
T (sec)	2,82353	2
h(ft)	2,65882	3
Str,system BI	2,44706	4
ζ flexible (%)	2,07059	5
r₂ (ft)	1,63529	6
MHA(g)	1,54118	7
ζ (%)	1,48235	8
Str, system SF	1,08235	9
Str, system SW	0,91765	10
Rock/Soil	0,50588	11
v_s (fps)	0,47059	12
Basement (Y/N)	0,44706	13
Str,system DWF	0,41176	14
e(ft)	0,28235	15
Mw	0,23529	16
β(%)	0,20000	17
Piles (Y/N)	0,16471	18
Str,system CF	0,16471	19
NO,Stories	0,15294	20
r₁ (ft)	0,10588	21

Table 6.11. The result of the Model 3

	(1)	(2)	(3)	(4)
R squared	0,9412	0,9219	0,8593	0,9775
r squared	0,9455	0,9427	0,8873	0,9782
Mean squared error	0	0	0,001	0,005
Mean absolute error	0,003	0,001	0,016	0,023
Min absolute error	0	0	0	0
Max. absolute error	0,042	0,014	0,224	0,402
Correlation coefficient, r	0,9724	0,9709	0,9420	0,9890

(1)= $1/\sigma$, (2)=Period lengthening, (3)=foundation damping, (4)=negligible.

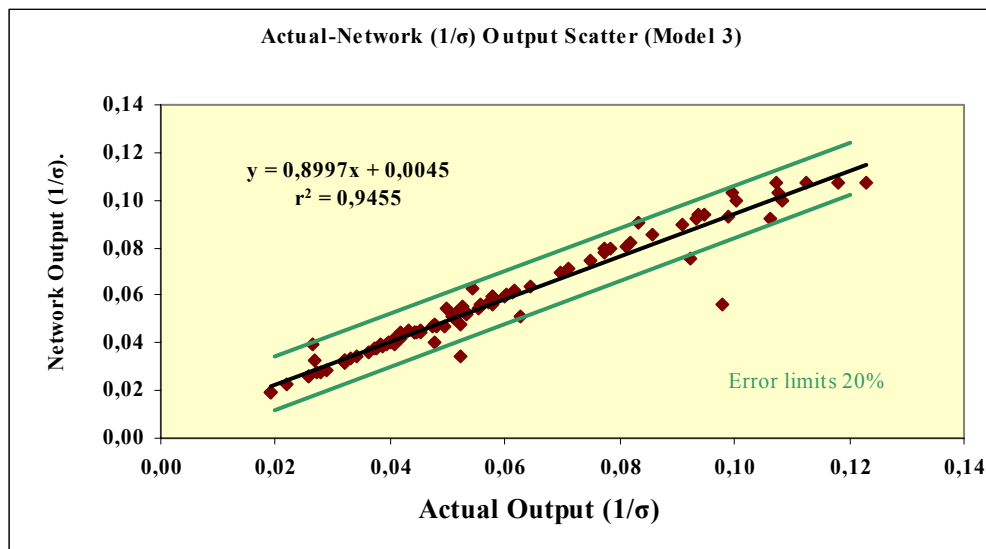


Figure 6.11. Actual-Network output scatter (1) for model 3 and error limits

There are 2 incorrect simulations in Figure 6.11 and the simulation success percentage is 97.97%.

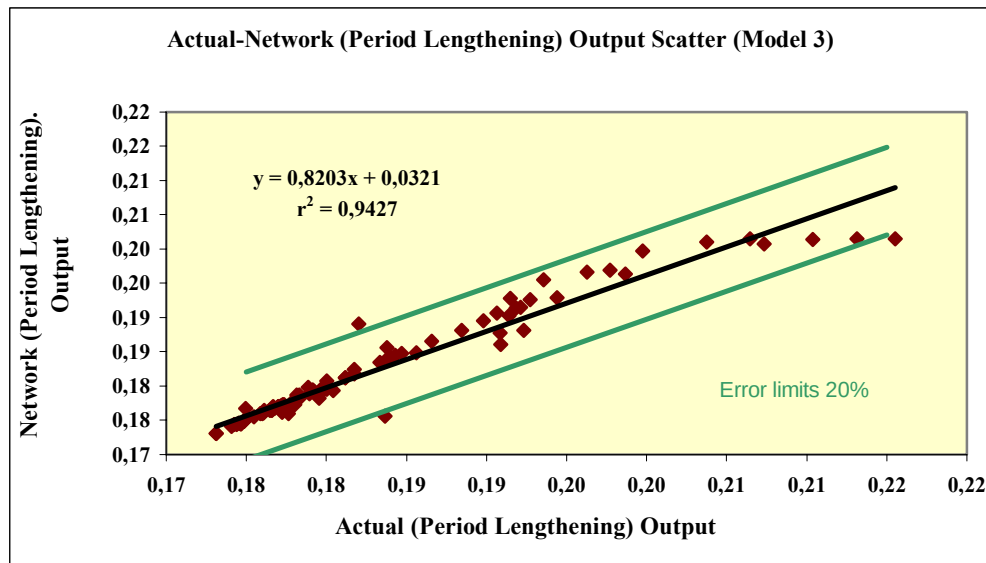


Figure 6.12. Actual-Network output scatter (2) for model 3 and error limits

There are 3 incorrect simulations in Figure 6.12, and the simulation success percentage is 97%.

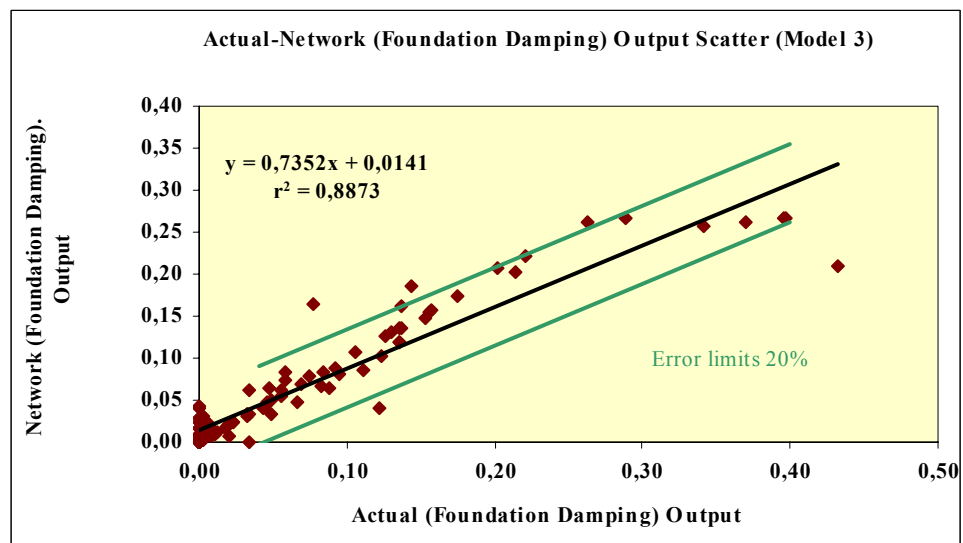


Figure 6.13. Actual-Network output scatter (3) for model 3 and error limits

There are 3 incorrect simulations in Figure 6.13, and the simulation success percentage is 97%.

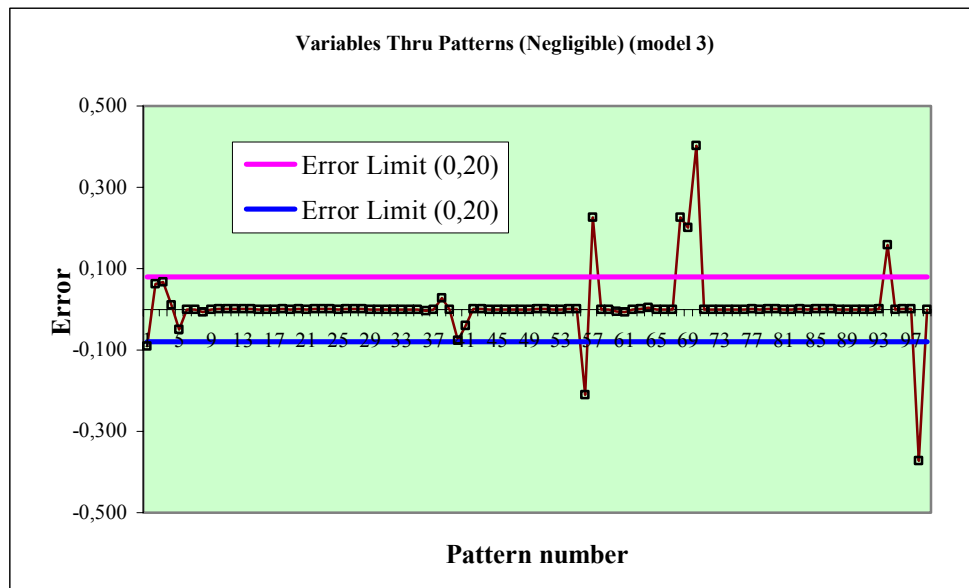


Figure 6.14. Variables error through pattern (4) and error limits

There are 7 incorrect simulations in Figure 6.14, and the simulation success percentage is 91.9%.

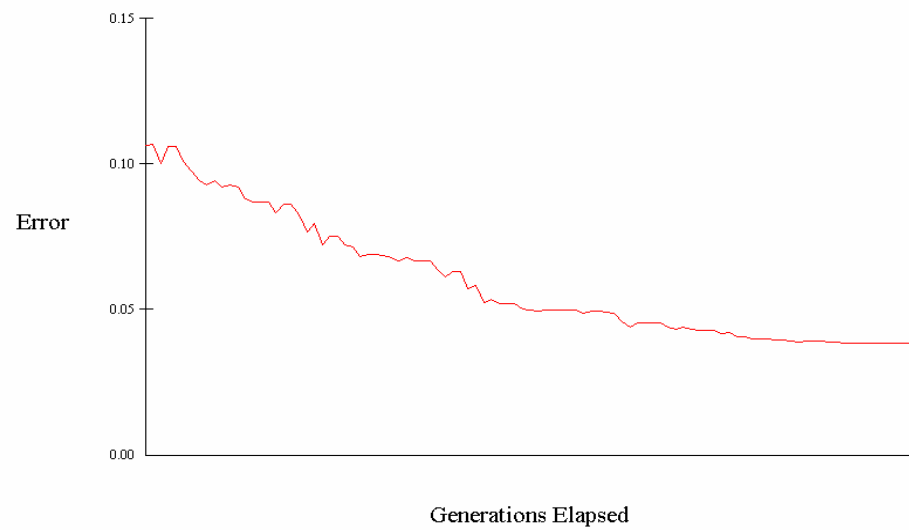


Figure 6.15. Test set error graph for model 3

Over-learning did not occur and the error gradually decreases.

6.3.2.2 Model 4

In model 4, activation function and genetic breeding pool size are different from model 3 architecture. Genetic breeding pool size is 75.

Table 6.12. The architecture and the configuration of the Model 4

Smoothing Factor	0,5069412
Activation Function	Linear [-1,1]
Distance Metric	Vanilla
Calibration	Genetic, adaptive
Missing values	Average
Genetic Breeding pool size	75
Extraction (%)	20
Number of Inputs	21
Number of Outputs	4
Number of Training Patterns	80
Number of Test Patterns	19
Pattern Processed	99

Table 6.13. Individual smoothing factors for Model 4

Input name	Individual smoothing factor	Orders
r₁ (ft)	2,98824	1
ζ (%)	2,97647	2
v_s (fps)	2,95294	3
Basement (Y/N)	2,75294	4
Tflex,(sec)	2,20000	5
Str, system SF	2,18824	6
T (sec)	2,11765	7
r₂ (ft)	2,11765	8
Piles (Y/N)	1,78824	9
ζ flexible (%)	1,47059	10
e(ft)	1,44706	11
NO,Stories	1,20000	12
Str,system DWF	1,14118	13
Str,system CF	0,77647	14
h(ft)	0,68235	15
β(%)	0,25882	16
Str,system BI	0,18824	17
MHA(g)	0,17647	18
Str, system SW	0,12941	19
Rock/Soil	0,04706	20
Mw	0,02353	21

Table 6.14. The result of the Model 4

	(1)	(2)	(3)	(4)
R squared	0,9457	0,9105	0,8280	0,9531
r squared	0,9497	0,9270	0,8667	0,9544
Mean squared error	0	0	0,002	0,0011
Mean absolute error	0,003	0,001	0,020	0,039
Min absolute error	0	0	0	0
Max. absolute error	0,037	0,016	0,219	0,524
Correlation coefficient, r	0,9745	0,9628	0,9310	0,9769

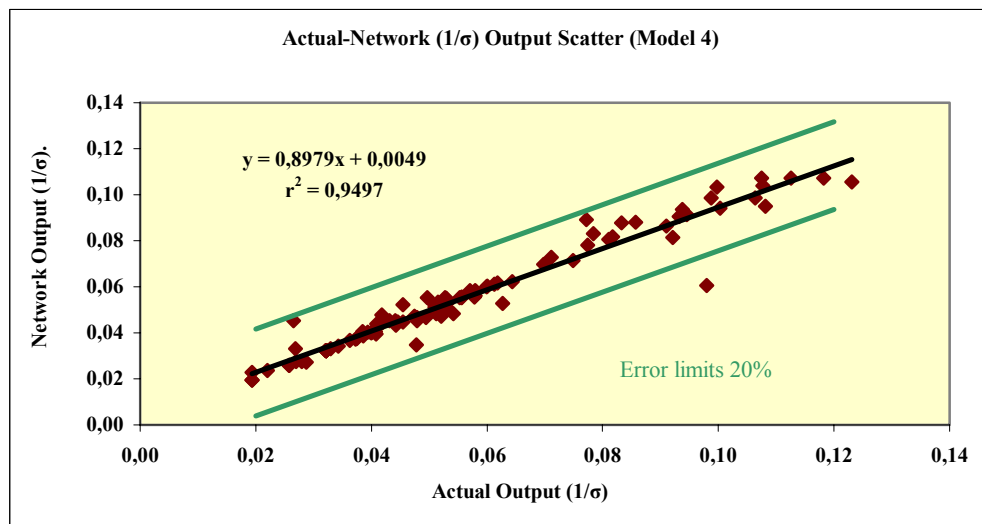


Figure 6.16. Actual-Network output scatter (1) for model 4 and error limits

There is 1 incorrect simulation in Figure 6.16, and the success simulation percentage is 98.98%.

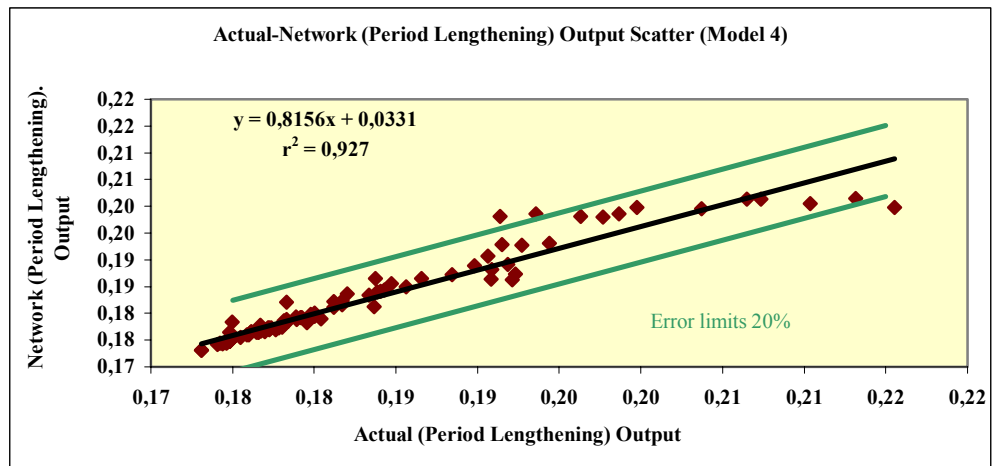


Figure 6.17. Actual-Network output scatter (2) for model 4 and error limits

There are 3 incorrect simulations in Figure 6.17, and the success simulation percentage is 97%.

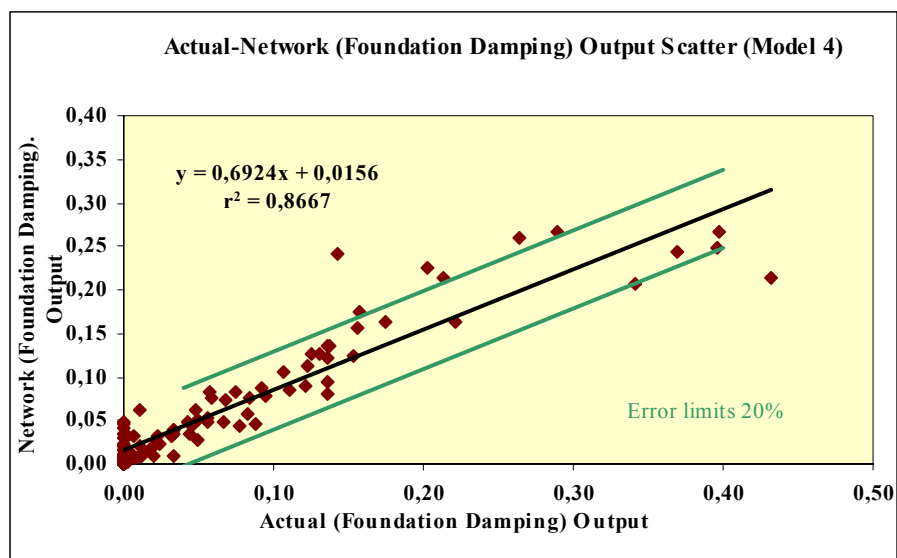


Figure 6.18. Actual-Network output scatter (3) for model 4 and error limits

There are 7 incorrect simulations in Figure 6.18, and the success simulation percentage is 91.9%.

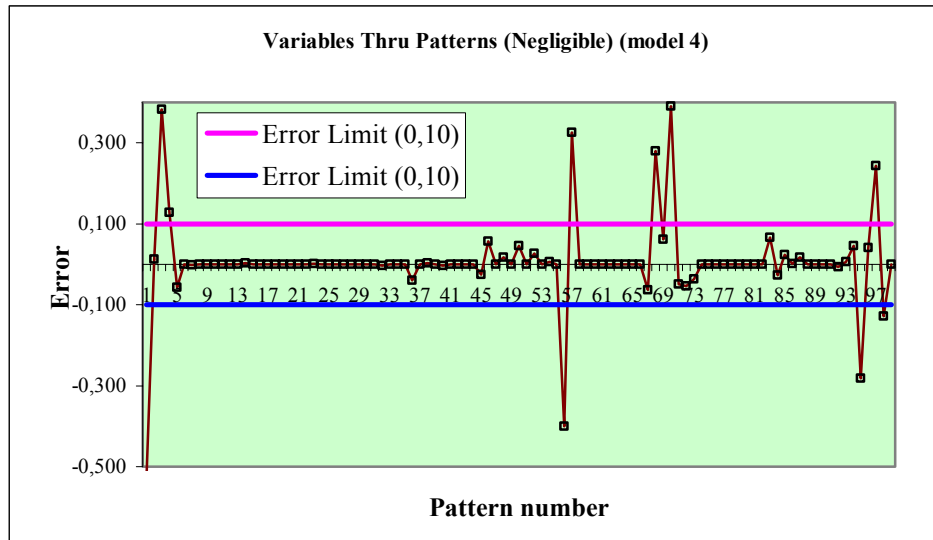


Figure 6.19. Variables error through pattern (4) and error limits

There are 10 incorrect simulations in Figure 6.19, and the success simulation percentage is 89.89%.



Figure 6.20. Test set error graph for model 4

Over-learning did not occur. Graph is close to 0,03 that means error is very little in Figure 6.20.

6.3.2.3 Model 5

Model 3 and Model 5 activation function are same and linear $[0,1]$. Model 4 activation function linear $[-1,1]$. Model 3 and 4 have the same extraction at 20%, however the Model 5 extraction is 10%. Number of training patterns are 90 patterns

and number of test patterns are 9 patterns. Genetic breeding pool size is 300 in Table 6.15.

Table 6.15. The architecture and the configuration of the Model 5

Smoothing Factor	0,1769412
Activation Function	Linear [0,1]
Distance Metric	Vanilla
Calibration	Genetic, adaptive
Missing values	Average
Genetic Breeding pool size	300
Extraction (%)	10
Number of Inputs	21
Number of Outputs	4
Number of Training Patterns	90
Number of Test Patterns	9
Pattern Processed	99

Table 6.16. Individual Smoothing Factors for Model 5

Input name	Individual smoothing factor	Orders
Tflex,(sec)	2,97647	1
T (sec)	2,90588	2
h(ft)	2,89412	3
Str,system BI	2,57647	4
v_s (fps)	2,37647	5
NO,Stories	2,36471	6
r₂ (ft)	2,36471	7
Basement (Y/N)	2,02353	8
Str, system SF	1,95294	9
ζ flexible (%)	1,24706	10
ζ (%)	1,15294	11
Mw	1,07059	12
Str,system CF	0,97647	13
Str,system DWF	0,96471	14
e(ft)	0,51765	15
Rock/Soil	0,42353	16
r₁ (ft)	0,14118	17
MHA(g)	0,09412	18
Str, system SW	0,05882	19
Piles (Y/N)	0,02353	20
β (%)	0,01176	21

Table 6.17. The result of the model 5

	(1)	(2)	(3)	(4)
R squared	0,9865	0,9398	0,8918	0,9843
r squared	0,9884	0,9592	0,9314	0,9846
Mean squared error	0	0	0,001	0,004
Mean absolute error	0,001	0,001	0,014	0,015
Min absolute error	0	0	0	0
Max. absolute error	0,016	0,014	0,165	0,477
Correlation coefficient, r	0,9942	0,9794	0,9651	0,9923

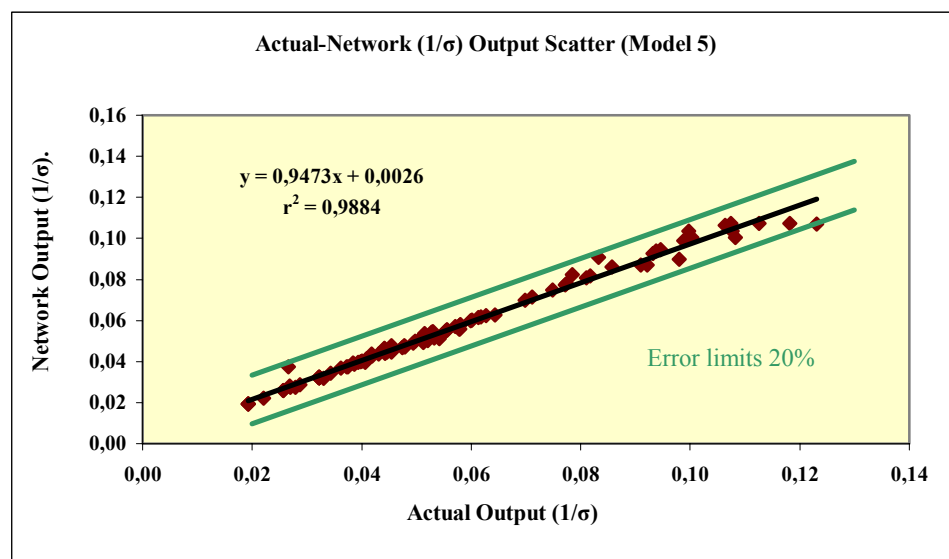


Figure 6.21. Actual-Network output scatter (1) for Model 5 and error limits

There is no incorrect simulation. Simulation success percentage is 100% as depicted in Figure 6.21.

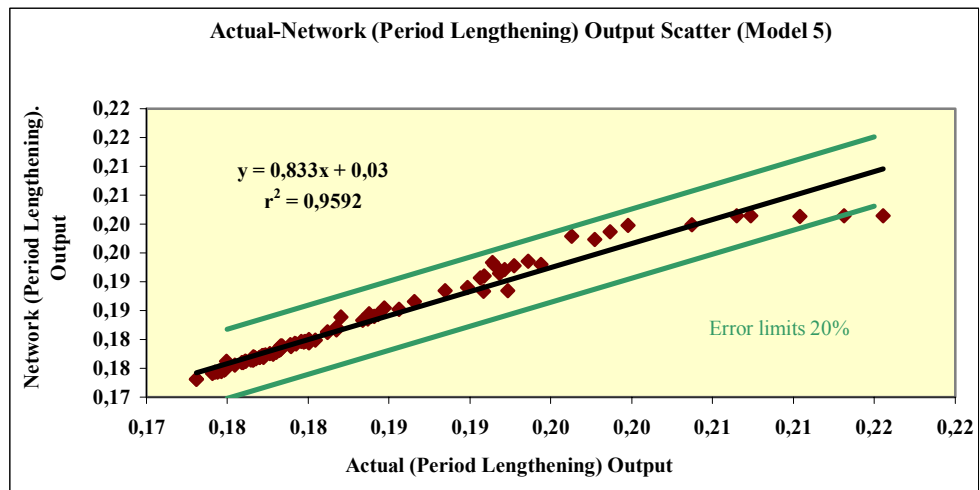


Figure 6.22. Actual-Network output scatter (2) for Model 5 and error limits

There is 1 incorrect simulation. Simulation success percentage is 98.98% as depicted in Figure 6.22.

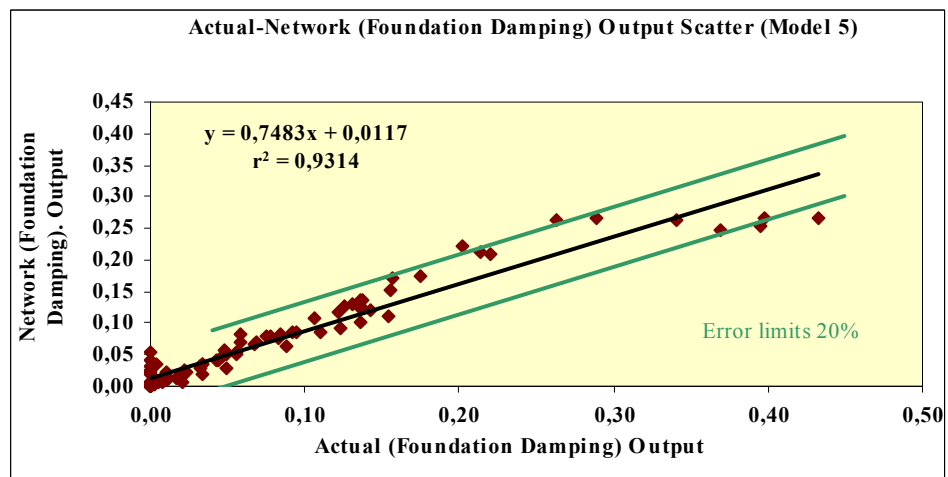


Figure 6.23. Actual-Network output scatter (3) for Model 5 and error limits

There are 4 incorrect simulations. Simulation success percentage is 95.95% as depicted in Figure 6.23.

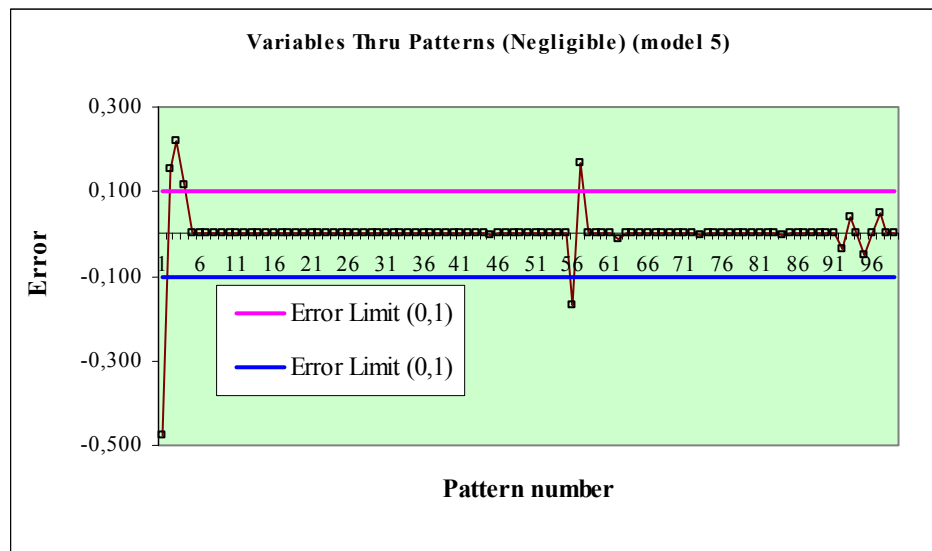


Figure 6.24. Variables error through pattern (4) and error limits

There are 6 incorrect simulations. Simulation success percentage is 93.93% as depicted in Figure 6.24.

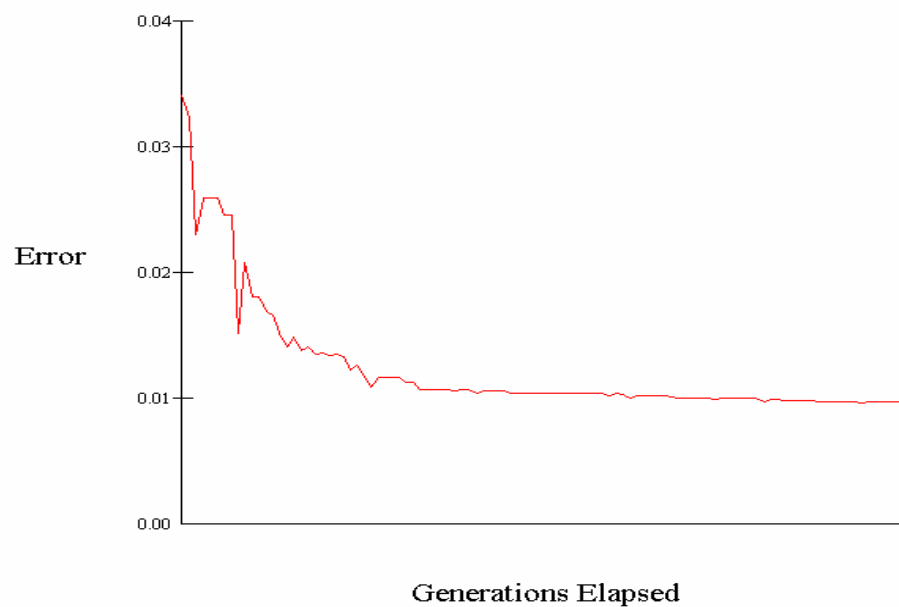


Figure 6.25. Test set error graph for Model 5

Over-learning did not occur. Graph is decreased and error graph is closed to 0.01 in Figure 6.25. Error is small compared to Model 3 and Model 4. All model's output are given in Appendix A, B, D, and E.

7. RESULTS

To reach the best results, different configurations and architectures are trained. In chapter 6, the best configurations, architectures, and error graphs for BPNN and GRNN approaches are presented. In this chapter, all models results are evaluated.

Table 7.1. Model 1 and Model 2 approach configurations and architecture

	<u>Model 1</u>	<u>Model 2</u>
Architecture	3 hidden slabs, Different activation functions	3 hidden slabs, Different activation functions
% Extraction	20	15
# of hidden layer	2	2
# of neurons in one hidden layer	21	21
Learning rate	0,2	0,2
Momentum Factor	0,6	0,7
Initial Weight	0,3	0,3
Calibration Interval	400	600
Scale Function	Linear [0,1]	Linear [0,1]
Missing values	Error Condition	Error Condition
Pattern selection	Rotational	Rotational
Pattern processed	99	99

There is a different extraction percentage form each other for training. Model 1 extraction percentage is 20% and Model 2 extraction percentage is 15%. Momentum factors are differ from each other. 0.6, 0.7 are momentum factors for model 1 and model 2, respectively. In Addition, there is a different calibration interval for Model 1 and Model 2 in Table 7.1.

As in Table 7.2, Model 2 results are better compared to Model 1

Table 7.2. Output R^2 values for Model 1 and 2

	R^2 (1)	R^2 (2)	R^2 (3)	R^2 (4)
Model 1	0,8517	0,8336	0,8675	0,8504
Model 2	0,9317	0,8592	0,8421	0,8681

(1) = $1/\sigma$, (2) = period lengthening, (3) = foundation damping, (4) = negligible.

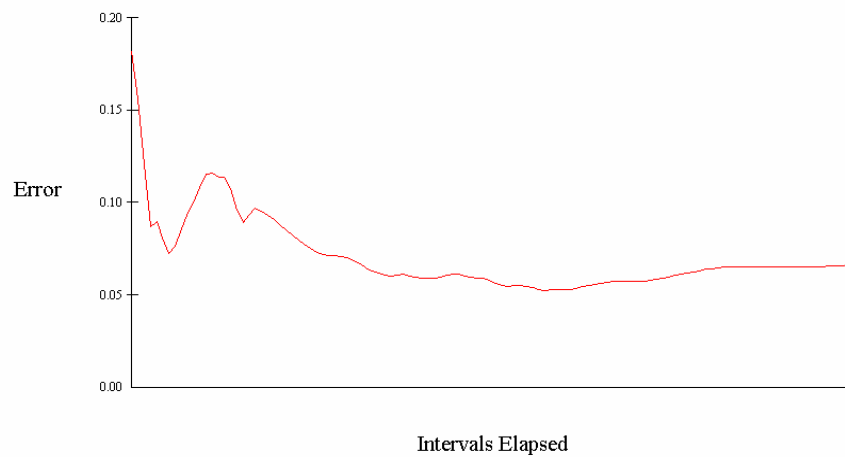


Figure 7.1. Test set error graph for Model 1

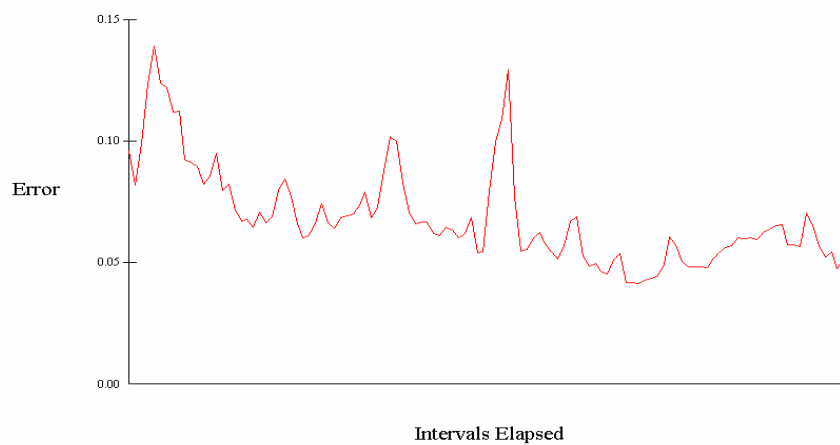


Figure 7.2. Test set error graph for Model 2

The Model 1 calibration interval is 400, and error graph is quite good, however Model 2 calibration interval is 600 and error graph is not acceptable. In Model 2, there are several local over-learning points. In summary, increasing calibration interval could lead to over-learning situations for BPNN approaches.

Table 7.3. The first five contribution factors for Model 1 and Model 2

Order	Model 1	Model 2
1	ζ flexible (%)	ζ flexible (%)
2	ζ (%)	ζ (%)
3	r_1 (ft)	Tflex,(sec)
4	v_s (fps)	T (sec)
5	Piles (Y/N)	h(ft)

$$\frac{\tilde{T}}{T} = \sqrt{1 + 25 \frac{\gamma r_1 h}{v_s^2 T^2} (1 + 1.12 \frac{r_1 h^2}{r_2^3})} \quad (7.1)$$

$$\tilde{\zeta}_0 = \tilde{\zeta} - \frac{\zeta}{(\tilde{T}/T)^3} \quad (7.2)$$

$$\frac{1}{\sigma} = \frac{h}{v_s T} \quad (7.3)$$

$\frac{\tilde{T}}{T}$ = period lengthening, $\tilde{\zeta}_0$ = foundation damping, $1/\sigma$ = soil-to-structure rigidity ratio. Generally, as seen in Table 7.3, the first five of contribution factors of Model 1 and Model 2 are parameters in output formulae. This shows that results are generally meaningful for evaluation of contribution factors for BPNN approaches.

Table 7.4. The architecture and the configuration of Models 3, 4 and 5

	Model 3	Model 4	Model 5
Smoothing Factor	0,1691765	0,5069412	0,1769412
Activation Function	Linear [0,1]	Linear [-1,1]	Linear[0,1]
Distance Metric	Vanilla	Vanilla	Vanilla
Calibration	Genetic, adaptive	Genetic, adaptive	Genetic, adaptive
Missing values	Average	Average	Average
Genetic Breeding pool size	20	75	300
Extraction (%)	20	20	10
Number of Inputs	21	21	21
Number of Outputs	4	4	4
Number of Training Patterns	80	80	90
Number of Test Patterns	19	19	9
Pattern Processed	99	99	99

Table 7.5. Output R^2 values for Model 3, 4, and 5

	R^2 (1)	R^2 (2)	R^2 (3)	R^2 (4)
Model 3	0,9412	0,9219	0,8593	0,9775
Model 4	0,9457	0,9105	0,8280	0,9531
Model 5	0,9865	0,9398	0,8918	0,9843

The activation function “Linear [0, 1]” gives better results compared to “Linear [-1, 1]” for the GRNN models in Table 7.5. In Model 3 and Model 5 all configuration parameters are the same, except test set extract and genetic breeding pool size. For GRNN approaches, when extraction decreases and genetic breeding pool size increases, success ratio gets better as seen in Table 7.5. The architecture and the configuration of the Model 3, 4 and 5 are in Table 7.4.

Table 7.6. The first five of individual smoothing factors for Models 3, 4, and 5

Order	Model 3	Model 4	Model 5
1	Tflex,(sec)	r _l (ft)	Tflex,(sec)
2	T (sec)	ζ (%)	T (sec)
3	h(ft)	v _s (fps)	h(ft)
4	Str,system BI	Basement (Y/N)	Str,system BI
5	ζ flexible (%)	Tflex,(sec)	v _s (fps)

As seen in Table 7.6, generally the first five parameters are used in Eq. (7.1), Eq. (7.2), and Eq. (7.3). Model 3 and 5 have the same activation functions “Linear [0, 1]” and generally the first five of individual smoothing parameters are same. Results are meaningful for individual smoothing parameters.

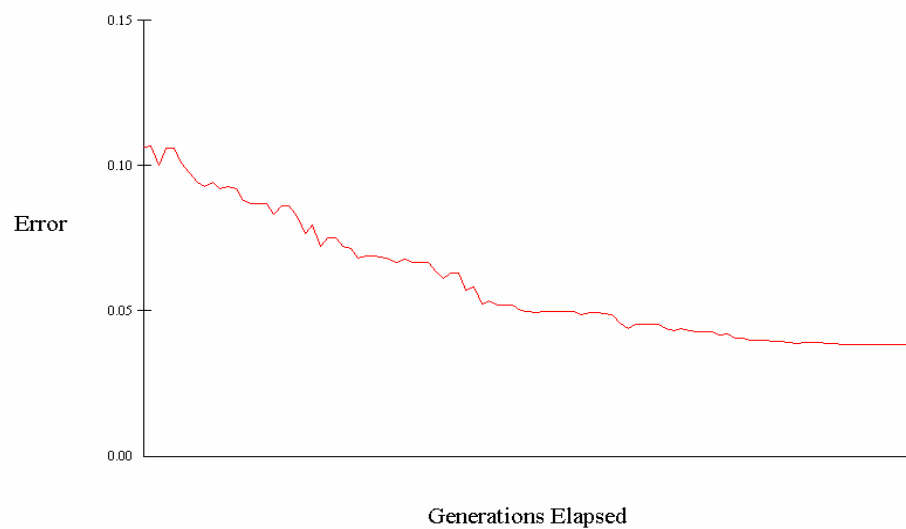


Figure 7.3. Test set error graph for model 3

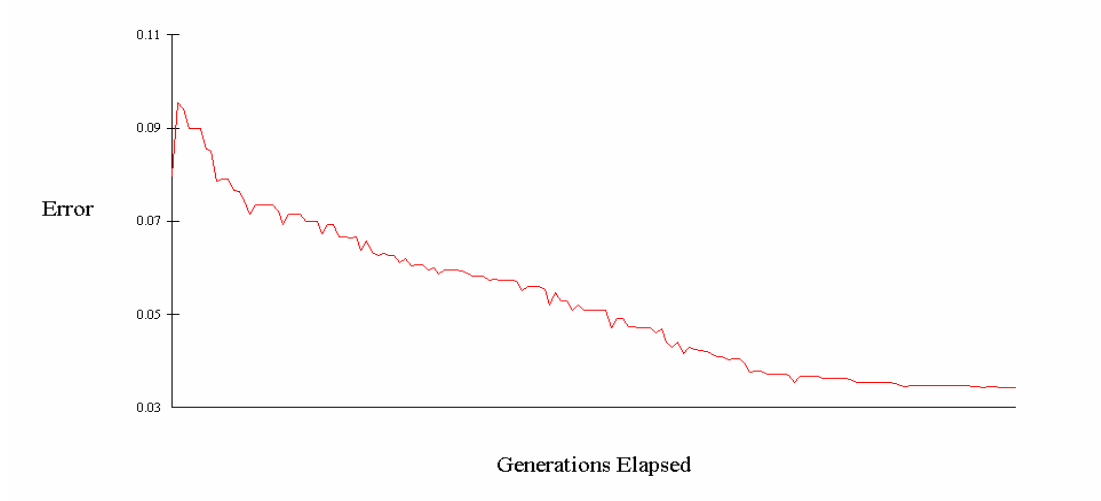


Figure 7.4. Test set error graph for model 4



Figure 7.5. Test set error graph for Model 5

From model 3 through model 5, test set error decreases. The best model number 5 has the smallest test set error value. This shows that test set improves with different calibrations. The smallest values are approximately 0.05 for model 3, 0.04 for model 4, 0.01 for model 5. On the contrary like this comparison is not made for BPNN.

Table 7.7. Simulation success rates for each model

	(1)	(2)	(3)	(4)
Model 1 (R Squared)	0,8517	0,8336	0,8675	0,8504
Model 1 (Number of incorrect simulations)	25	3	5	9
Model 1 (Simulation success rate %)	74,75	97	94,95	91
Model 2 (R Squared)	0,9317	0,8592	0,8421	0,8681
Model 2 (Number of incorrect simulations)	3	9	8	7
Model 2 (Simulation success rate %)	97	90	90,9	91,9
Model 3 (R Squared)	0,9412	0,9219	0,8593	0,9775
Model 3 (Number of incorrect simulations)	2	3	3	7
Model 3 (Simulation success rate %)	97,97	97	97	91,9
Model 4 (R Squared)	0,9457	0,9105	0,828	0,9531
Model 4 (Number of incorrect simulations)	1	3	7	10
Model 4 (Simulation success rate %)	98,98	97	91,9	89,89
Model 5 (R Squared)	0,9865	0,9398	0,8918	0,9843
Model 5 (Number of incorrect simulations)	0	1	4	6
Model 5 (Simulation success rate %)	100	98,98	95,95	93,93

(1) = $1/\sigma$, (2) = period lengthening, (3) = foundation damping, (4) = negligible.

In foundation damping and SSI is negligible outputs patterns, some values take negative values and which is physically meaningless. This is not seen in Model 3, 4, and 5 for GRNN approaches. Cigizoglu (2005), two artificial neural network models have been employed to forecast the monthly precipitation amount in Amman Airport region. Firstly, a single Artificial Neural Network (ANN) was employed for training and testing. Secondly, a separate ANN model was used for each month of the year (12 ANN models in total). The second one provided better performance criteria at the expense of increased weight number and decreased training pattern number. The Feed-Forward Back Propagation algorithm used as ANN training method, however, has some drawbacks: firstly it may produce negative rainfall in some runs, and secondly, it underestimates the peak values and same drawbacks is seen in this study.

Cigizoglu (2004 and 2005) used one type input parameters which is hydrometeorological data.

In this study, foundation damping takes negative values and whether Soil-Structure Interaction (SSI) effects can be neglected or not is underestimated the peak values in Model 1 and Model 2. On the contrary, these drawbacks are not seen in Model 3, 4, and 5. Model 1 and 2 are Back-Propagation Neural Network (BPNN) approaches, and model 3, 4, 5 are General Regression Neural Network (GRNN) approaches.

Goh (2003, 2004, and 2005) demonstrated the robustness of the Bayesian neural network approach to model complicated nonlinear relationships. Distinct advantage of the Bayesian neural network approach is that the uncertainty of data can be indicated as an error bar based on the data distribution and intrinsic noise. Goh generally studies on Bayesian Neural Network approaches. Goh used one or two type input parameter which means soil or structural data properties is used in his studies.

Bayrak (2003) searched liquefaction risk analysis with neural network approaches and used two Neural Network algorithms which are BPNN and GRNN. Generally GRNN gives best results compared to BPNN approaches in Bayrak (2003). Bayrak 2004 searched strong ground motion attenuation relationship model by using neural network methodology which is GRNN algorithms and obtained good results. Bayrak (2003 and 2004) used two type input parameters which are soil and earthquake parameters.

Neural network generally is used in Hydrology branch of civil engineering disciplines; by the way of hydro-meteorological data estimation of daily river flow, studies of design of water resources, and in Geotechnical discipline liquefaction risk analysis etc. By the way of this study Geotechnical, Earthquake and Structural Engineering work with together. Because this study is soil-structure interaction by using strong ground motion data and concerns with these three disciplines. Structural, earthquake, and soil properties are used with together in this study as input parameters. Other studies Bayrak (2003 and 2004) and Goh (2003, 2004, and 2005) used one or two type input parameters. Cigizoglu (2004 and 2005) used one type input parameters. There are four types output values in this study but Bayrak

(2003 and 2004), Goh (2003, 2004, and 2005), and Cigizoglu (2004 and 2005) obtained one type output values.

This study brings new view point to Structural Engineering, Earthquake Engineering, Foundation Engineering, and Geotechnical Engineering. This study provides convenience for evaluation of soil-structure interaction and in this way, stored data bank constitutes for SSI effects. The objective of this study is gives an idea for preliminary design. On the other hand, this study can be adapted to new conditions for SSI effects. By the way of this it can be seen that linear and nonlinear data can be used for SSI effects. In addition to, this study show that SSI effects can be predict and can be neglected without using Mathematical models.

In conclusion, for evaluation of Soil-Structure Interaction (SSI) effects, GRNN is very good and suitable approach. On the contrary, BPNN is not suitable approaches for SSI. In future, forecasting can be done by using these models. For example, there are 21 input parameters in this study, and using these 21 parameters soil-to-structure rigidity, period lengthening, foundation damping, and whether soil-structure interaction effects can be neglected or not can be predicted by the way of Neural Network. Therefore solving and forecasting engineering problems get easy for evaluation of Soil-Structure Interaction (SSI) effects.

REFERENCES

- Applied Technology Council**, 1978. "Tentative provisions for the development of seismic regulations for buildings: a cooperative effort with the design profession, building code interests, and the research community," *Rpt. No. ATC 3-06*, U.S. Dept. of Commerce, National Bur. Of Standards, Washington DC.
- Apsel, R.J., and Luco, J.E.**, 1987. "Impedance functions for foundations embedded in a layered medium: an integral equation approach," *J. Earthquake Engrg. Struct. Dynamics*, 15(2), 213-231.
- Åström, K.J., and Wittenmark B.**, 1984. *Computer Controlled Systems*, Prentice-Hall, Englewood Cliffs, NJ.
- Bayrak, B.**, 2002. Liquefaction Potential: A neural network approach. *Senior Thesis*, I.T.U. Civil Engineering Faculty, Istanbul.
- Bayrak, B.**, 2004. Strong Ground Motion Attenuation Relationship Model by Using Neural Network Methodology, *M.S.c Thesis*, I.T.U. Institute of Science and Technology, Istanbul
- Bielak, J.**, 1975. "Dynamic behavior of structures with embedded foundations," *J. Earthquake Engrg. Struct. Dynamics*, 3(3), 259-274.
- Building Seismic Safety Council, BSSC**, 1997. "NEHRP Recommended provisions for seismic regulations for new buildings, Part 1, Provisions and Part 2, Commentary" *Rpt. No. FEMA 302 & 303*, Federal Emergency Management Agency, Washington D.C.
- Celebi, M.**, 1995. "Free-field motions near buildings," *Proc. 10th European Conf. Earthquake Engrg.*, 215-221.
- Celep, Z., and Kumbasar, N.**, 1996. "Yapı Dinamiği ve Deprem Mühendisliğine giriş" İstanbul Teknik Üniversitesi, ISBN 975-95405-1-7
- Celep, Z., and Kumbasar, N.**, 2000. "Deprem Mühendisliğine giriş" (Entrance of Earthquake Engineering) İstanbul Teknik Üniversitesi, İstanbul, ISBN 975-95405-2-5
- Civalek, Ö., ve Ülker, M.**, 2002. Dikdörtgen Plakların Doğrusal Olmayan Analizde Yapay Sinir Ağı Yaklaşımı (Artificial Neural Networks Approach to

The Non-Linear Analysis of Rectangular Plates), *İMO Teknik Dergi*, 2004 3171-3190, Yazı 213

- Cığızoğlu, H.K.**, 2003. “ Soft Computational Lecturer Notes” , I.T.U. Civil Engineering Faculty, Istanbul.
- Cığızoğlu, H.K., Murat, A.**, 2004. Farklı yapay sinir ağı metotları ile yağış-akış ilişkisinin modellenmesi, *itüdergisi/d mühendislik*, cilt 3, sayı 1,80-88, şubat 2004
- Cığızoğlu, H.K.**, 2004. Estimation and forecasting of daily suspended sediment data by multi-layer perceptrons, *ELSEVIER, Advances in Water Resources* 27 (2004) 185-195
- Cığızoğlu, H.K., Muwaffaq F.**, 2005. Prediction of Total Monthly Rainfall in Jordan Using Feed Forward Back-propagation Method, *Fresenius Environmental Bulletin*, Volume 14-No.2-2005, pp. 142-151
- Chopra, A.K., and Gutierrez, J.A.**, 1973. “Earthquake analysis of multistory buildings including foundation interaction,” Rpt. No. EERC 73-13, Earthquake Engrg. Research Ctr., Univ. Of California, Berkeley.
- Clough, R.W., and Penzien, J.**, 1993. *Dynamics of Structures*, 2nd ed., McGraw Hill, New York, NY.
- Das., B.M.**, 1993. “ Principles of Soil Dynamics” Thomson Learning Academic Resource Center. ISBN 0-534-93129-4
- Dayhoff, E.J.**, 1990. “Neural Network Architecture: An Introduction”, Van Nostrand Reinhold Press
- Dobry, R., and Gazetas, G.**, 1986. “Dynamic response of arbitrarily shaped foundations,” *J.Geotech. Engrg.*, ASCE, 112(2), 109-135.
- Efe, Ö., Kaynak O.**, 2000. “Yapay Sinir Ağları ve Uygulamaları”, Bogazici Üniversitesi
- Elsabee, F., and Morray, J.P.**, (1977). “Dynamic behavior of embedded foundations,” *Rpt. No. R77-33*, Dept. of Civil Engrg., MIT, Cambridge, Mass.
- Elgaali, E., and Garcia, L.**, 2004. “Neural Network Modeling of Climate Change Impacts on Irrigation Water Supplies in Arkansas River Basin”
- Fenves, G.L., and DesRoches, R.**, 1994. “Response of the northwest connector in the Landers and Big Bear Earthquakes,” *Rpt No. UCB/EERC-94/12*, Earthquake Engrg Research Ctr., Univ. of California, Berkeley.
- Franklin, G.F., and Powell, J.D.**, 1980. *Digital Control of Dynamic Systems*, Addison-Wiley, Reading, MA.

- Frederick, M.D.**, 1996. Neuroshell2 user's manual version 3.0. Ward Systems Group
- Frost, J.D.**, 1997. "Spatial Analysis in Soil Dynamics and Earthquake Engineering", Geotechnical Special Publication no.67, ASCE
- Goh, A.T.C., and Chua, C.G.**, 2003. "A hybrid Bayesian back-propagation neural network approach to multivariate modeling", *Int. J. Numer. Anal. Meth. Geomech.*, 27: 000-000.
- Goh, A.T.C., and Chua, C.G.**, 2003. "Quantifying uncertainty in predictions using a Bayesian neural network", *GALAYAA B.V./MIT2_453:pp. 1-3*
- Goh, A.T.C., and Chua, C.G.**, 2004. "Nonlinear modeling with confidence estimation using Bayesian neural networks", eJSE.
- Goh, A.T.C., and Chua, C.G.**, 2005. "Estimating wall deflections in deep excavations using Bayesian Neural Networks", Tunneling and Underground Space Technology.
- Goh, A.T.C., Kulhawy, F.H., and Chua, C.G.**, 2005. "Bayesian Neural Network Analysis of Undrained Side Resistance of Drilled Shafts", *Journal of Geotechnical and Geoenvironmental Engineering*, Vol. 131, No. 1,
- Gohl, W.B.**, 1993. "Response of pile foundations to earthquake shaking - general aspects of behavior and design methodologies," *Seismic soil/struct. interaction seminar*, Vancouver, Canada.
- International Conference of Building Officials, ICBO**, 1997. *Uniform Building Code, 1997 Edition*.
- Iguchi, M., and Luco, J.E.**, 1982. "Vibration of flexible plate on viscoelastic medium," *J. Engrg. Mech.*, ASCE, 108(6), 1103-1120.
- Jennings, P.C., and Bielak, J.**, 1973. "Dynamics of building-soil interaction," *Bull. Seism. Soc.Am.*, 63, 9-48.
- Kaptan, A.**, 1999. Çok Katlı Çerçeve Tipi Betonarme Yapıların Elastik Zeminle Dinamik Etkileşimi (Dynamic Interaction between Frame Types Multistory Reinforced Concrete Structures and Elastic Foundation), *Doktora tezi, İ.T.Ü Fen Bilimleri Enstitüsü, İstanbul*
- Kausel, E.**, 1974. "Forced vibrations of circular foundations on layered media," *Rpt. No. R74-11*, Dept. of Civil Engrg., MIT, Cambridge, Mass.
- Koç, M.L., Balas, C.E, Arslan, A.**, 2003. "Taş Dolgu Dalgakıranların Yapay Sinir Ağları ile Ön Tasarımı (Preliminary Design of Ruble Mound Break waters by Using Artificial Neural Networks)", *İMO Teknik Dergi*, 2004 3351-3375, yazı 225

- Kramer, S.L.**, 1996. "Earthquake Geotechnical Engineering", Prentice-Hall International Series in Civil Engineering Mechanics, New Jersey, USA
- Krauss, T.P., Shure, L., and Little, J.N.**, 1994. *Signal Processing Toolbox, Users Guide*, The Math Works, Inc., Natick, Mass.
- Kartam, N., Flood L., and, Garrett J.h.**, 1997. "Artificial Neural Networks for Civil Engineers: Fundamentals and Applications", ASCE.
- Ljung, L.**, 1987. *System Identification: Theory for the User*, Prentice Hall, Englewood Cliffs, NJ.
- Ljung, L.**, 1995. *System Identification Toolbox, Users Guide*, The Math Works, Inc., Natick, Mass.
- Liou, G.-S. and Huang, P.-H.** (1994). "Effect of flexibility on impedance functions for circular foundations," *J. Engrg. Mech.*, ASCE, 120(7), 1429-1446.
- Lin, A.N., and Jennings, P.C.**, 1984. "Effect of embedment on foundation-soil impedances," *J.Engrg. Mech.*, ASCE, 110(7), 1060-1075.
- Nayef A.M., Nabil K., Parviz K., and Mubarek A.M.**, 2004. "Modeling and Predicting Biological Performance of Contact Stabilization Process Using Artificial Neural Network", ASCE,
- Nogami T.**, 1997. "Observation and Modeling in Numerical Analysis and Model Test in Dynamic Soil-Structure Interaction Problems", ASCE, Geotechnical Special Publication no: **64**, ISBN 0-7844-0252-3
- Novak, M.**, 1991. "Piles under dynamic loads," *Proc. 2nd Int. Conf. on Recent Advances in Geotech. Engrg. and Soil Dynamics*, St. Louis, MO, 2433-2456.
- Oppenheim, AV., and Schafer, R.W.**, 1989. *Discrete-Time Signal Processing*, Prentice Hall, Englewood Cliffs, NJ.
- Özaydın, K.**, 1995. "Zemin Mekaniği (Soil Mechanics)" Yıldız Tek. Üni. İnşaat fak., İnşaat Müh. Blm. Geoteknik Anabilim Dalı, ISBN 975-511-145-X
- Pandit, S.M.**, 1991. *Modal and Spectrum Analysis*, John Wiley, New York, NY.
- Prakash, S.**, 1997. "Seismic Analysis and Design for Soil-Pile-Structure Interactions", ASCE, Geotechnical Special Publication no: **70**.
- Priestly, M.B.**, 1980. "State dependent models: a general approach to nonlinear time series analysis," *Time Series Analysis*, 1(1), 47-73.
- Riggs, H.R. and Waas, G.**, 1985. "Influence of foundation flexibility on soil-structure interaction," *J. Earthquake Engrg. Struct. Dynamics*, 13(5), 597-615.

- Roesset, J.M.**, 1980. "A review of soil-structure interaction," in *Soil-structure interaction: The status of current analysis methods and research*, J.J. Johnson, ed., Rpt. No. NUREG/CR-1780 and UCRL-53011, U.S. Nuclear Regulatory Com., Washington DC, and Lawrence Livermore Lab., Livermore, CA.
- Rumelhart, D.E., and McClelland, J.L.**, 1986. *Parallel Distributed Processing*, Vols.1&2. Cambridge, Mass, MIT press.
- Safak, E.**, 1988. "Analysis of recordings in structural engineering: adaptive filtering, prediction, and control," *Open File Rpt. 88-647*, U.S. Geological Survey, Menlo Park, CA.
- Safak, E.**, 1991. "Identification of linear structures using discrete-time filters," *J. Struct. Engrg.*, ASCE, 117(10), 3064-3085.
- Schnabel, P.B., Lysmer, J., and Seed, H.B.**, 1972. "SHAKE: A Computer Program for Earthquake Response Analysis of Horizontally Layered Soil Deposits", *Rpt. No. UCB/EERC-72/12*, Earthquake Engrg. Research Ctr., Univ. of California; 1991 modifications by Idriss, I.M. and Sun, J.I.
- Seed, H.B. and Lysmer, J.**, 1980. "The seismic soil-structure interaction problem for nuclear facilities," in *Soil-structure interaction: the status of current analysis methods and research*, J.J. Johnson, ed., *Rpt. No. NUREG/CR-1780 and UCRL-53011*, U.S. Nuclear Regulatory Com., Washington DC and Lawrence Livermore Lab., Livermore, CA.
- Seed, H.B., Romo, M.P., Sun, J.I., Jaime, A., and Lysmer, J.**, 1988. "The Mexico Earthquake of September 19, 1985 - relationships between soil conditions and earthquake ground motions," *Earthquake Spectra*, EERI, 4(4), 687-729.
- Seed, R.B., Dickenson, S.E., and Mok, C.M.**, 1992. "Recent lessons regarding seismic response analyses of soft and deep clay sites," *Proc. Seminar on Seismic Design and Retrofit of Bridges*, Earthquake Engrg. Research Ctr., Univ. of California, Berkeley and Div. of Structures, California Dept. of Transportation, 18-39.
- Seed, R.B., Dickenson, S.E., Riemer, M.F., Bray, J.D., Sitar, N., Mitchell, J.K., Idriss, I.M., Kayen, R.E., Kropp, A.K., Harder, L.F. Jr., and Power, M.S.**, 1990. "Preliminary report on the principal geotechnical aspects of the October 17, 1989 Loma Prieta Earthquake", *Rpt. No. UCB/EERC- 90/05*, Earthquake Engrg. Research Ctr., Univ. of California, Berkeley.

- Stewart, J.P., and Stewart, A.F.,** 1997. "Analysis of soil-structure interaction effects on building response from earthquake strong motion recordings at 58 sites," *Rpt. No. UCB/EERC-97/01*, Earthquake Engrg. Research Ctr., Univ. of California, Berkeley.
- Stewart, J.P., Seed R .B. and Fenves G. L.,** 1998. "Empirical Evaluation of Inertial Soil-Structure Interaction" *Rpt. No. PEER-98/07*, Pacific Earthquake Research Ctr., Univ. of California, Berkeley
- Specht, D.F.,** 1996. *Fuzzy Logic and Neural Network Handbook*, Mc Graw-Hill Companies, Inc.,
- Specht, D.F.,** 1991. A generalized regression neural network, *IEEE Transactions on Neural Network*, 568-576.
- Trifunac, M.D.,** 1972. "Interaction of a shear wall with the soil for incident plane SH waves," *Bull. Seism. Soc. Am.*, 62(1), 63-83.
- Ural, D., and Saka, H.,** 1998. "Liquefaction Prediction by Neural Networks", *Electronic Journal of Geotechnical Engineering*, ISSN 1089-3032, Vol. 3, pp.1- 4.
- Veletsos, A.S.,** 1977. "Dynamics of structure-foundation systems," *Structural and Geotechnical Mechanics*, Prentice-Hall, Inc., Englewood Cliffs, N.J., 333-361.
- Veletsos, A.S., and Meek, J.W.,** 1974. "Dynamic behavior of building-foundation systems," *J. Earthquake Engrg. Struct. Dynamics*, 3(2), 121-138.
- Veletsos, A.S., and Nair V.V.,** 1975. "Seismic interaction of structures on hysteretic foundations," *J. Struct. Engrg.*, ASCE 101(1), 109-129.
- Veletsos, A.S., and Prasad, A.M.,** 1989. "Seismic interaction of structures and soils: stochastic approach," *J. Struct. Engrg.*, ASCE, 115(4), 935-956.
- Veletsos, A.S., Prasad, A.M., and Wu, W.H.,** 1997. "Transfer functions for rigid rectangular foundations," *J. Earthquake Engrg. Struct. Dynamics*, 26 (1), 5-17.
- Veletsos, A.S., and Verbic, B.,** 1973. "Vibration of viscoelastic foundations," *J. Earthquake Engrg. Struct. Dynamics*, 2(1), 87-102.
- Veletsos, A.S., and Wei, Y.T.,** 1971. "Lateral and rocking vibrations of footings," *J. Soil Mech. and Foundations Div.*, ASCE, 97(9), 1227-1248.
- Welch, P.D.,** 1967. "The use of Fast Fourier Transform for the estimation of power spectra: a method based on time averaging over short, modified

periodograms,” *Transactions on Audio and Electroacoustics*, IEEE, AU-15(2), 70-73.

Wolf J. P., 1988. “Soil-Struture Interaction Analysis in Time Domain “Prentice Hall International Series in Civil Engineering and Engineering Mechanism, Swiss Federal Institute of Technology, ISBN 0-13-822974-0.

Web Pages:

<http://www.twistedsquare.com/aiessay.pdf> (05.02.2005)

<http://www.peer.berkeley.edu> (10.07.2004)

<http://geotech.civen.okstate.edu/ejge> (13.11.2004)

APPENDIXES

Appendix A. BPNN Approach Output Tables for Model 1 and 2 (Normalized).

Appendix B. BPNN Approach Output for Model 1 and 2.

Appendix C. Error Through Patterns Graphs for Model 1 and 2.

Appendix D. GRNN Approach Output Tables for Model 3,4 and 5 (Normalized).

Appendix E. GRNN Approach Output for Model 3,4 and 5.

Appendix F. Error Through Patterns Graphs for Model 3,4 and 5.

Appendix G. Site Properties

Appendix H. Before Normalization Data Properties

Appendix I. Data Properties After Normalization (Input Values and Output Values)

Appendix A. BPNN Approach Output Tables for Model 1 and 2 (Normalized).

Table App. A1. Actual and program outputs for Model 1 (Normalized)

(1)Actual (1/ σ)	(1)Network (1/ σ)	(1)Act-Net (1/ σ)	(2) Actual Period lengthening	(2) Network Period lengthening	(2) Act-Net Period lengthening
0,053	0,054	-0,002	0,179	0,180	-0,001
0,051	0,054	-0,003	0,178	0,179	-0,001
0,058	0,056	0,002	0,180	0,181	-0,001
0,056	0,061	-0,006	0,179	0,179	0,000
0,092	0,088	0,004	0,191	0,198	-0,007
0,091	0,093	-0,002	0,204	0,201	0,003
0,078	0,082	-0,004	0,196	0,196	0,000
0,077	0,086	-0,008	0,186	0,188	-0,002
0,081	0,085	-0,004	0,182	0,183	-0,002
0,047	0,058	-0,011	0,179	0,183	-0,004
0,027	0,034	-0,008	0,175	0,178	-0,003
0,037	0,050	-0,012	0,177	0,181	-0,004
0,036	0,044	-0,008	0,176	0,177	-0,001
0,058	0,071	-0,013	0,184	0,188	-0,004
0,060	0,069	-0,009	0,178	0,182	-0,004
0,056	0,068	-0,012	0,180	0,185	-0,005
0,040	0,042	-0,002	0,175	0,179	-0,004
0,044	0,049	-0,005	0,178	0,181	-0,003
0,048	0,057	-0,009	0,177	0,181	-0,004
0,039	0,040	0,000	0,177	0,181	-0,004
0,042	0,048	-0,006	0,176	0,180	-0,003
0,053	0,055	-0,001	0,177	0,179	-0,002
0,050	0,045	0,005	0,178	0,180	-0,002
0,055	0,050	0,005	0,177	0,180	-0,003
0,045	0,045	0,000	0,177	0,178	-0,001
0,051	0,052	-0,001	0,177	0,179	-0,002
0,028	0,030	-0,002	0,175	0,177	-0,002
0,027	0,027	0,000	0,174	0,176	-0,001
0,095	0,097	-0,002	0,198	0,199	-0,001
0,038	0,041	-0,004	0,179	0,184	-0,004
0,034	0,040	-0,005	0,178	0,181	-0,003
0,094	0,095	-0,002	0,181	0,185	-0,003
0,118	0,106	0,012	0,200	0,200	-0,001
0,053	0,049	0,004	0,185	0,187	-0,002
0,064	0,066	-0,001	0,190	0,192	-0,002
0,054	0,032	0,022	0,182	0,184	-0,002
0,051	0,052	-0,001	0,184	0,186	-0,002
0,060	0,060	0,000	0,184	0,187	-0,003
0,107	0,099	0,008	0,183	0,186	-0,002
0,099	0,095	0,004	0,199	0,198	0,001

(1)Actual (1/σ)	(1)Network (1/σ)	(1)Act-Net (1/σ)	(2) Actual Period lengthening	(2) Network Period lengthening	(2) Act-Net Period lengthening
0,106	0,094	0,013	0,194	0,198	-0,004
0,041	0,039	0,001	0,177	0,180	-0,003
0,038	0,038	0,001	0,177	0,181	-0,004
0,082	0,071	0,011	0,193	0,193	0,000
0,061	0,047	0,014	0,182	0,182	0,000
0,052	0,036	0,016	0,180	0,183	-0,002
0,051	0,037	0,014	0,178	0,179	-0,001
0,044	0,027	0,017	0,178	0,177	0,002
0,044	0,030	0,014	0,177	0,177	0,000
0,049	0,032	0,018	0,180	0,181	-0,001
0,048	0,030	0,018	0,177	0,177	0,000
0,043	0,031	0,012	0,178	0,177	0,001
0,041	0,027	0,014	0,176	0,175	0,001
0,041	0,033	0,008	0,178	0,178	0,000
0,040	0,028	0,012	0,176	0,174	0,002
0,042	0,028	0,014	0,177	0,175	0,002
0,053	0,040	0,013	0,178	0,174	0,004
0,070	0,058	0,012	0,187	0,185	0,001
0,113	0,100	0,012	0,213	0,201	0,012
0,100	0,097	0,003	0,191	0,189	0,002
0,108	0,097	0,011	0,194	0,191	0,004
0,098	0,063	0,035	0,191	0,191	0,000
0,027	0,029	-0,002	0,175	0,172	0,002
0,033	0,030	0,003	0,175	0,173	0,002
0,123	0,102	0,022	0,210	0,197	0,013
0,071	0,062	0,009	0,181	0,178	0,003
0,075	0,074	0,001	0,216	0,199	0,017
0,048	0,036	0,012	0,178	0,186	-0,008
0,052	0,052	0,001	0,184	0,177	0,006
0,063	0,069	-0,006	0,180	0,180	-0,001
0,108	0,099	0,009	0,192	0,188	0,005
0,100	0,093	0,007	0,188	0,186	0,002
0,083	0,100	-0,016	0,191	0,187	0,004
0,093	0,093	0,000	0,184	0,182	0,002
0,086	0,086	0,000	0,192	0,190	0,002
0,045	0,046	0,000	0,177	0,175	0,002
0,045	0,043	0,001	0,176	0,175	0,002
0,062	0,063	-0,001	0,191	0,190	0,001
0,022	0,017	0,005	0,174	0,173	0,001
0,029	0,032	-0,003	0,174	0,173	0,001
0,058	0,056	0,002	0,207	0,201	0,006
0,057	0,056	0,002	0,206	0,200	0,006
0,019	0,018	0,001	0,175	0,173	0,001
0,019	0,019	0,000	0,173	0,171	0,002

(1)Actual (1/σ)	(1)Network (1/σ)	(1)Act-Net (1/σ)	(2) Actual Period lengthening	(2) Network Period lengthening	(2) Act-Net Period lengthening
0,019	0,019	0,000	0,173	0,171	0,002
0,058	0,052	0,005	0,180	0,178	0,002
0,051	0,054	-0,003	0,178	0,177	0,002
0,032	0,034	-0,002	0,175	0,172	0,003
0,032	0,035	-0,003	0,175	0,173	0,002
0,032	0,031	0,001	0,175	0,173	0,002
0,032	0,033	0,000	0,175	0,174	0,001
0,026	0,024	0,001	0,177	0,177	-0,001
0,026	0,027	-0,001	0,175	0,173	0,002
0,032	0,030	0,003	0,175	0,175	0,000
0,032	0,034	-0,001	0,175	0,174	0,001
0,032	0,029	0,003	0,175	0,175	0,000
0,032	0,034	-0,002	0,175	0,175	0,000
0,077	0,038	0,039	0,192	0,180	0,012
0,039	0,039	-0,001	0,180	0,180	0,000
(3) Actual Foundation damping	(3) Network Foundation damping	(3) Act-Net Foundation damping	(4) Actual (Negligible)	(4) Network (Negligible)	(4) Act-Net (Negligible)
0,154	0,141	0,012	0,000	0,243	-0,243
0,004	0,001	0,002	1,000	0,911	0,089
0,123	0,111	0,012	1,000	0,908	0,092
0,000	-0,018	0,018	1,000	1,222	-0,222
0,136	0,121	0,015	0,000	0,002	-0,002
0,369	0,267	0,102	0,000	-0,061	0,061
0,202	0,202	0,000	0,000	0,098	-0,098
0,136	0,112	0,024	0,000	-0,134	0,134
0,048	0,049	-0,001	0,000	0,098	-0,098
0,000	-0,009	0,009	1,000	1,116	-0,116
0,020	0,014	0,006	1,000	1,097	-0,097
0,095	0,095	-0,001	1,000	0,952	0,048
0,000	0,010	-0,010	1,000	1,039	-0,039
0,049	0,044	0,005	1,000	0,928	0,072
0,010	0,019	-0,009	1,000	1,090	-0,090
0,032	0,031	0,001	1,000	1,028	-0,028
0,046	0,040	0,007	1,000	1,082	-0,082
0,011	0,018	-0,007	1,000	1,110	-0,110
0,022	0,026	-0,003	1,000	1,040	-0,040
0,056	0,056	0,000	1,000	1,060	-0,060
0,044	0,034	0,011	1,000	1,033	-0,033
0,000	-0,002	0,002	1,000	1,015	-0,015
0,002	0,016	-0,013	1,000	1,113	-0,113
0,033	0,031	0,001	1,000	1,089	-0,089
0,000	0,012	-0,012	1,000	1,157	-0,157
0,000	0,014	-0,014	1,000	1,119	-0,119

(3) Actual Foundation damping	(3) Network Foundation damping	(3) Act-Net Foundation damping	(4) Actual (Negligible)	(4) Network (Negligible)	(4) Act-Net (Negligible)
0,000	0,000	0,000	1,000	1,085	-0,085
0,049	0,041	0,008	1,000	1,001	-0,001
0,006	0,009	-0,003	0,000	0,040	-0,040
0,137	0,150	-0,013	0,000	0,022	-0,022
0,135	0,144	-0,009	0,000	0,054	-0,054
0,019	0,028	-0,009	0,000	0,074	-0,074
0,289	0,266	0,024	0,000	0,023	-0,023
0,157	0,202	-0,046	0,000	0,199	-0,199
0,396	0,265	0,130	0,000	-0,029	0,029
0,341	0,257	0,084	0,000	0,403	-0,403
0,397	0,247	0,150	0,000	-0,009	0,009
0,126	0,139	-0,013	1,000	1,052	-0,052
0,000	0,015	-0,015	0,000	0,126	-0,126
0,214	0,222	-0,008	0,000	0,035	-0,035
0,432	0,267	0,165	0,000	-0,240	0,240
0,000	0,013	-0,013	1,000	1,025	-0,025
0,000	0,004	-0,004	1,000	1,086	-0,086
0,034	0,050	-0,017	0,000	0,152	-0,152
0,264	0,264	0,000	0,000	0,100	-0,100
0,033	0,037	-0,004	1,000	1,145	-0,145
0,056	0,056	-0,001	1,000	1,166	-0,166
0,000	-0,016	0,016	1,000	1,060	-0,060
0,000	0,008	-0,008	1,000	1,068	-0,068
0,000	0,027	-0,027	1,000	1,174	-0,174
0,088	0,075	0,013	1,000	1,098	-0,098
0,000	0,003	-0,003	1,000	1,078	-0,078
0,000	0,017	-0,017	1,000	1,070	-0,070
0,000	0,006	-0,006	1,000	1,046	-0,046
0,021	0,020	0,000	1,000	1,100	-0,100
0,136	0,135	0,001	0,000	0,550	-0,550
0,058	0,047	0,011	1,000	0,885	0,115
0,000	0,011	-0,011	0,000	0,163	-0,163
0,000	0,001	-0,001	0,000	0,186	-0,186
0,058	0,042	0,016	0,000	0,265	-0,265
0,111	0,098	0,012	0,000	0,118	-0,118
0,143	0,170	-0,027	0,000	0,354	-0,354
0,000	-0,044	0,044	1,000	1,270	-0,270
0,017	0,021	-0,003	1,000	1,106	-0,106
0,007	0,006	0,001	0,000	0,072	-0,072
0,000	0,003	-0,003	0,000	0,121	-0,121
0,175	0,140	0,035	0,000	-0,017	0,017
0,067	0,157	-0,090	1,000	-0,013	1,013
0,122	0,071	0,051	1,000	0,400	0,600
0,000	0,001	-0,001	1,000	0,883	0,117
0,000	-0,026	0,026	0,000	0,376	-0,376

(3) Actual Foundation damping	(3) Network Foundation damping	(3) Act-Net Foundation damping	(4) Actual (Negligible)	(4) Network (Negligible)	(4) Act-Net (Negligible)
0,043	0,033	0,010	0,000	0,211	-0,211
0,000	-0,090	0,090	0,000	0,337	-0,337
0,007	-0,005	0,012	0,000	0,076	-0,076
0,083	0,072	0,011	0,000	0,088	-0,088
0,000	0,005	-0,005	1,000	1,069	-0,069
0,023	0,023	0,001	1,000	1,071	-0,071
0,000	-0,013	0,013	0,000	0,044	-0,044
0,012	0,010	0,002	1,000	1,000	0,000
0,000	-0,003	0,003	1,000	1,085	-0,085
0,068	0,057	0,012	0,000	0,048	-0,048
0,084	0,084	0,000	0,000	0,070	-0,070
0,000	-0,008	0,008	1,000	1,004	-0,004
0,130	0,136	-0,006	0,000	0,041	-0,041
0,000	0,008	-0,008	1,000	1,039	-0,039
0,092	0,085	0,006	1,000	1,066	-0,066
0,075	0,087	-0,011	1,000	0,993	0,007
0,000	0,007	-0,007	1,000	0,983	0,017
0,000	-0,007	0,007	1,000	1,026	-0,026
0,003	0,014	-0,012	1,000	0,995	0,005
0,000	-0,001	0,001	1,000	0,987	0,013
0,156	0,174	-0,018	0,000	0,066	-0,066
0,106	0,109	-0,003	1,000	0,948	0,052
0,033	0,116	-0,083	1,000	0,420	0,580
0,221	0,227	-0,006	0,000	0,024	-0,024
0,033	0,038	-0,005	1,000	0,958	0,042
0,011	0,014	-0,003	1,000	1,026	-0,026
0,078	0,041	0,037	0,000	0,235	-0,235
0,000	-0,001	0,001	1,000	1,001	-0,001

Table App. A2. Actual and program outputs for Model 2 (Normalized)

(1)Actual (1/ σ)	(1)Network (1/ σ)	(1)Act-Net (1/ σ)	(2) Actual (Period lengthening)	(2) Network (Period lengthening)	(2) Act-Net (Period lengthening)
0,053	0,056	-0,003	0,179	0,179	0,000
0,051	0,053	-0,002	0,178	0,176	0,002
0,058	0,057	0,001	0,180	0,180	0,000
0,056	0,059	-0,004	0,179	0,179	0,000
0,092	0,101	-0,009	0,191	0,193	-0,001
0,091	0,095	-0,004	0,204	0,201	0,003
0,078	0,085	-0,007	0,196	0,196	0,001
0,077	0,086	-0,008	0,186	0,185	0,000
0,081	0,087	-0,006	0,182	0,182	0,000
0,047	0,059	-0,012	0,179	0,177	0,002
0,027	0,040	-0,014	0,175	0,175	0,000
0,037	0,049	-0,011	0,177	0,178	-0,001
0,036	0,048	-0,012	0,176	0,176	0,000
0,058	0,069	-0,011	0,184	0,184	0,000
0,060	0,072	-0,012	0,178	0,176	0,002
0,056	0,073	-0,017	0,180	0,178	0,001
0,040	0,056	-0,016	0,175	0,173	0,002
0,044	0,058	-0,014	0,178	0,176	0,002
0,048	0,064	-0,017	0,177	0,174	0,003
0,039	0,047	-0,008	0,177	0,176	0,001
0,042	0,055	-0,013	0,176	0,175	0,001
0,053	0,058	-0,005	0,177	0,175	0,002
0,050	0,055	-0,005	0,178	0,174	0,004
0,055	0,061	-0,006	0,177	0,175	0,003
0,045	0,051	-0,006	0,177	0,175	0,003
0,051	0,057	-0,006	0,177	0,175	0,002
0,028	0,030	-0,002	0,175	0,172	0,003
0,027	0,029	-0,002	0,174	0,172	0,002
0,095	0,097	-0,002	0,198	0,197	0,001
0,038	0,042	-0,004	0,179	0,175	0,005
0,034	0,038	-0,004	0,178	0,174	0,004
0,094	0,096	-0,003	0,181	0,178	0,003
0,118	0,107	0,011	0,200	0,199	0,001
0,053	0,059	-0,006	0,185	0,181	0,004
0,064	0,072	-0,008	0,190	0,187	0,003
0,054	0,056	-0,001	0,182	0,178	0,004
0,051	0,057	-0,006	0,184	0,182	0,002
0,060	0,066	-0,006	0,184	0,181	0,003
0,107	0,107	0,001	0,183	0,181	0,002
0,099	0,100	-0,001	0,199	0,197	0,002
0,106	0,102	0,004	0,194	0,195	-0,001
0,041	0,040	0,001	0,177	0,174	0,003
0,038	0,042	-0,004	0,177	0,173	0,003
0,082	0,085	-0,003	0,193	0,188	0,005

(1)Actual (1/σ)	(1)Network (1/σ)	(1)Act-Net (1/σ)	(2) Actual (Period lengthening)	(2) Network (Period lengthening)	(2) Act-Net (Period lengthening)
0,061	0,058	0,003	0,182	0,177	0,005
0,052	0,049	0,003	0,180	0,176	0,004
0,051	0,051	0,000	0,178	0,174	0,004
0,044	0,041	0,003	0,178	0,174	0,004
0,044	0,044	0,000	0,177	0,172	0,004
0,049	0,048	0,002	0,180	0,176	0,004
0,048	0,048	0,000	0,177	0,175	0,003
0,043	0,043	0,000	0,178	0,174	0,004
0,041	0,037	0,004	0,176	0,174	0,002
0,041	0,036	0,005	0,178	0,174	0,004
0,040	0,040	0,000	0,176	0,173	0,003
0,042	0,042	-0,001	0,177	0,174	0,003
0,053	0,049	0,004	0,178	0,172	0,006
0,070	0,069	0,001	0,187	0,184	0,003
0,113	0,107	0,005	0,213	0,201	0,012
0,100	0,097	0,003	0,191	0,191	0,000
0,108	0,098	0,009	0,194	0,193	0,001
0,098	0,086	0,012	0,191	0,183	0,008
0,027	0,028	-0,001	0,175	0,175	0,000
0,033	0,030	0,003	0,175	0,174	0,000
0,123	0,105	0,018	0,210	0,199	0,011
0,071	0,067	0,004	0,181	0,182	-0,001
0,075	0,073	0,002	0,216	0,200	0,015
0,048	0,047	0,001	0,178	0,182	-0,004
0,052	0,054	-0,001	0,184	0,186	-0,003
0,063	0,076	-0,013	0,180	0,186	-0,006
0,108	0,106	0,002	0,192	0,194	-0,002
0,100	0,104	-0,003	0,188	0,193	-0,004
0,083	0,093	-0,010	0,191	0,191	0,000
0,093	0,096	-0,002	0,184	0,189	-0,005
0,086	0,088	-0,002	0,192	0,195	-0,004
0,045	0,049	-0,004	0,177	0,176	0,000
0,045	0,046	-0,002	0,176	0,177	0,000
0,062	0,064	-0,002	0,191	0,193	-0,002
0,022	0,021	0,001	0,174	0,175	0,000
0,029	0,030	-0,002	0,174	0,175	-0,001
0,058	0,061	-0,003	0,207	0,201	0,006
0,057	0,057	0,001	0,206	0,201	0,005
0,019	0,019	0,000	0,175	0,175	0,000
0,019	0,021	-0,002	0,173	0,173	0,000
0,019	0,020	-0,001	0,173	0,173	0,000
0,058	0,056	0,002	0,180	0,181	-0,001
0,051	0,054	-0,002	0,178	0,178	0,001
0,032	0,030	0,002	0,175	0,176	-0,001
0,032	0,032	0,000	0,175	0,175	0,000
0,032	0,033	0,000	0,175	0,175	0,000

(1)Actual (1/σ)	(1)Network (1/σ)	(1)Act-Net (1/σ)	(2) Actual (Period lengthening)	(2) Network (Period lengthening)	(2) Act-Net (Period lengthening)
0,032	0,033	-0,001	0,175	0,174	0,001
0,026	0,028	-0,002	0,177	0,177	0,000
0,026	0,027	-0,002	0,175	0,174	0,000
0,032	0,031	0,001	0,175	0,172	0,002
0,032	0,032	0,000	0,175	0,174	0,000
0,032	0,031	0,001	0,175	0,175	0,000
0,032	0,033	-0,001	0,175	0,175	0,000
0,077	0,059	0,018	0,192	0,194	-0,002
0,039	0,040	-0,002	0,180	0,180	0,000
(3) Actual (Foundation damping)	(3) Network (Foundation damping)	(3) Act-Net (Foundation damping)	(4) Actual (Negligible)	(4) Network (Negligible)	(4) Act-Net (Negligible)
0,154	0,140	0,014	0,000	0,084	-0,084
0,004	-0,004	0,008	1,000	1,016	-0,016
0,123	0,100	0,023	1,000	0,920	0,080
0,000	-0,012	0,012	1,000	1,058	-0,058
0,136	0,099	0,037	0,000	-0,268	0,268
0,369	0,267	0,102	0,000	-0,048	0,048
0,202	0,204	-0,002	0,000	0,079	-0,079
0,136	0,117	0,019	0,000	-0,107	0,107
0,048	0,038	0,010	0,000	-0,022	0,022
0,000	-0,008	0,008	1,000	0,940	0,060
0,020	0,008	0,012	1,000	0,945	0,055
0,095	0,063	0,031	1,000	0,939	0,061
0,000	0,002	-0,002	1,000	0,948	0,052
0,049	0,039	0,010	1,000	0,893	0,107
0,010	0,001	0,010	1,000	0,971	0,029
0,032	0,002	0,031	1,000	0,885	0,115
0,046	-0,004	0,051	1,000	0,761	0,239
0,011	0,005	0,006	1,000	0,874	0,126
0,022	-0,003	0,025	1,000	0,908	0,092
0,056	0,037	0,019	1,000	0,923	0,077
0,044	0,025	0,019	1,000	0,817	0,183
0,000	0,012	-0,012	1,000	0,925	0,075
0,002	0,025	-0,023	1,000	0,780	0,220
0,033	0,027	0,006	1,000	0,872	0,128
0,000	0,028	-0,028	1,000	0,643	0,357
0,000	0,010	-0,010	1,000	0,827	0,173
0,000	0,019	-0,019	1,000	0,931	0,069
0,049	0,058	-0,009	1,000	0,862	0,138
0,006	0,030	-0,025	0,000	0,082	-0,082
0,137	0,156	-0,019	0,000	-0,034	0,034
0,135	0,144	-0,009	0,000	-0,045	0,045
0,019	0,027	-0,008	0,000	-0,053	0,053
0,289	0,267	0,022	0,000	0,024	-0,024
0,157	0,196	-0,039	0,000	0,086	-0,086

(3) Actual (Foundation damping)	(3) Network (Foundation damping)	(3) Act-Net (Foundation damping)	(4) Actual (Negligible)	(4) Network (Negligible)	(4) Act-Net (Negligible)
0,396	0,267	0,128	0,000	-0,113	0,113
0,341	0,253	0,088	0,000	0,235	-0,235
0,397	0,245	0,152	0,000	0,021	-0,021
0,126	0,142	-0,016	1,000	0,962	0,038
0,000	0,007	-0,007	0,000	0,088	-0,088
0,214	0,226	-0,012	0,000	0,072	-0,072
0,432	0,267	0,165	0,000	-0,126	0,126
0,000	0,023	-0,023	1,000	1,163	-0,163
0,000	0,011	-0,011	1,000	1,043	-0,043
0,034	0,045	-0,012	0,000	0,197	-0,197
0,264	0,257	0,007	0,000	0,096	-0,096
0,033	0,067	-0,034	1,000	1,066	-0,066
0,056	0,084	-0,029	1,000	1,067	-0,067
0,000	0,007	-0,007	1,000	1,148	-0,148
0,000	0,024	-0,024	1,000	1,128	-0,128
0,000	0,027	-0,027	1,000	1,100	-0,100
0,088	0,082	0,005	1,000	0,962	0,038
0,000	-0,016	0,016	1,000	1,138	-0,138
0,000	0,026	-0,026	1,000	1,124	-0,124
0,000	0,001	-0,001	1,000	1,282	-0,282
0,021	0,016	0,004	1,000	1,123	-0,123
0,136	0,143	-0,007	0,000	0,645	-0,645
0,058	0,057	0,002	1,000	0,993	0,007
0,000	0,019	-0,019	0,000	0,134	-0,134
0,000	0,011	-0,011	0,000	0,114	-0,114
0,058	0,087	-0,030	0,000	0,278	-0,278
0,111	0,126	-0,016	0,000	0,209	-0,209
0,143	0,114	0,029	0,000	-0,005	0,005
0,000	0,017	-0,017	1,000	1,021	-0,021
0,017	0,062	-0,045	1,000	1,006	-0,006
0,007	0,044	-0,036	0,000	0,066	-0,066
0,000	0,038	-0,038	0,000	0,141	-0,141
0,175	0,208	-0,033	0,000	0,035	-0,035
0,067	0,126	-0,059	1,000	1,101	-0,101
0,122	0,150	-0,028	1,000	1,016	-0,016
0,000	0,111	-0,111	1,000	0,848	0,152
0,000	0,053	-0,053	0,000	0,003	-0,003
0,043	0,095	-0,052	0,000	0,082	-0,082
0,000	-0,040	0,040	0,000	0,046	-0,046
0,007	0,021	-0,014	0,000	0,080	-0,080
0,083	0,147	-0,064	0,000	0,028	-0,028
0,000	0,018	-0,018	1,000	0,908	0,092
0,023	0,036	-0,013	1,000	1,036	-0,036
0,000	0,006	-0,006	0,000	-0,024	0,024
0,012	0,015	-0,003	1,000	0,923	0,077
0,000	-0,001	0,001	1,000	1,005	-0,005

(3) Actual (Foundation damping)	(3) Network (Foundation damping)	(3) Act-Net (Foundation damping)	(4) Actual (Negligible)	(4) Network (Negligible)	(4) Act-Net (Negligible)
0,068	0,073	-0,004	0,000	-0,018	0,018
0,084	0,084	0,000	0,000	0,027	-0,027
0,000	-0,003	0,003	1,000	0,980	0,020
0,130	0,131	-0,001	0,000	-0,024	0,024
0,000	0,000	0,000	1,000	0,992	0,008
0,092	0,094	-0,003	1,000	0,993	0,007
0,075	0,067	0,008	1,000	0,992	0,008
0,000	0,007	-0,007	1,000	0,952	0,048
0,000	-0,014	0,014	1,000	1,025	-0,025
0,003	-0,005	0,008	1,000	0,932	0,068
0,000	-0,020	0,020	1,000	1,002	-0,002
0,156	0,150	0,005	0,000	0,016	-0,016
0,106	0,087	0,019	1,000	0,989	0,011
0,033	0,115	-0,081	1,000	-0,021	1,021
0,221	0,206	0,015	0,000	-0,022	0,022
0,033	0,022	0,011	1,000	1,029	-0,029
0,011	0,000	0,011	1,000	0,996	0,004
0,078	0,100	-0,022	0,000	0,742	-0,742
0,000	-0,004	0,004	1,000	1,043	-0,043

Appendix B. BPNN Approach Output for Model 1 and 2.

Table App. B1. Actual and program outputs for Model 1

(1) Act. ($1/\sigma$)	(1) Net. ($1/\sigma$)	(2) Act. ($\tilde{T}/T$)	(2) Net. ($\tilde{T}/T$)	(3) Act. ($\tilde{\zeta}_0$)	(3) Net. ($\tilde{\zeta}_0$)	(4) Act. (Negl.)	(4) Net. (Negl.)
0,082	0,084	1,034	1,040	4,759	4,375	0,000	0,243
0,079	0,084	1,030	1,037	0,111	0,038	1,000	0,911
0,090	0,086	1,041	1,047	3,811	3,441	1,000	0,908
0,086	0,095	1,036	1,035	0,000	-0,552	1,000	1,222
0,143	0,136	1,106	1,146	4,226	3,753	0,000	0,002
0,141	0,144	1,178	1,163	11,441	8,273	0,000	-0,061
0,122	0,127	1,135	1,134	6,259	6,268	0,000	0,098
0,120	0,133	1,073	1,085	4,217	3,468	0,000	-0,134
0,126	0,132	1,050	1,060	1,479	1,516	0,000	0,098
0,074	0,091	1,034	1,059	0,000	-0,292	1,000	1,116
0,041	0,053	1,011	1,027	0,626	0,432	1,000	1,097
0,058	0,077	1,021	1,045	2,936	2,957	1,000	0,952
0,056	0,069	1,017	1,025	0,000	0,299	1,000	1,039
0,090	0,110	1,064	1,086	1,526	1,370	1,000	0,928
0,093	0,107	1,030	1,053	0,315	0,599	1,000	1,090
0,086	0,106	1,039	1,068	1,002	0,966	1,000	1,028
0,062	0,065	1,014	1,036	1,440	1,231	1,000	1,082
0,069	0,077	1,030	1,049	0,350	0,569	1,000	1,110
0,074	0,088	1,023	1,047	0,693	0,795	1,000	1,040
0,061	0,061	1,024	1,047	1,728	1,735	1,000	1,060
0,065	0,074	1,018	1,038	1,370	1,043	1,000	1,033
0,083	0,084	1,025	1,037	0,000	-0,054	1,000	1,015
0,077	0,069	1,029	1,043	0,076	0,483	1,000	1,113
0,086	0,078	1,025	1,041	1,012	0,966	1,000	1,089
0,070	0,070	1,024	1,029	0,000	0,362	1,000	1,157
0,079	0,081	1,022	1,035	0,000	0,421	1,000	1,119
0,043	0,046	1,009	1,021	0,000	-0,002	1,000	1,085
0,042	0,041	1,007	1,015	1,515	1,274	1,000	1,001
0,147	0,150	1,143	1,148	0,174	0,277	0,000	0,040
0,058	0,064	1,036	1,062	4,236	4,636	0,000	0,022
0,053	0,061	1,030	1,046	4,194	4,476	0,000	0,054
0,145	0,148	1,047	1,067	0,588	0,870	0,000	0,074
0,183	0,164	1,155	1,159	8,960	8,228	0,000	0,023
0,082	0,076	1,068	1,081	4,855	6,265	0,000	0,199
0,100	0,102	1,097	1,111	12,253	8,214	0,000	-0,029

(1) Act. (1/σ)	(1) Net. (1/σ)	(2) Act. ($\tilde{T}/T$)	(2) Net. ($\tilde{T}/T$)	(3) Act. ($\tilde{\zeta}_0$)	(3) Net. ($\tilde{\zeta}_0$)	(4) Act. (Negl.)	(4) Net. (Negl.)
0,084	0,050	1,052	1,065	10,559	7,965	0,000	0,403
0,079	0,080	1,063	1,076	12,304	7,648	0,000	-0,009
0,093	0,093	1,065	1,082	3,891	4,297	1,000	1,052
0,167	0,154	1,060	1,073	0,000	0,468	0,000	0,126
0,153	0,147	1,148	1,145	6,620	6,867	0,000	0,035
0,165	0,145	1,119	1,142	13,397	8,283	0,000	-0,240
0,063	0,061	1,023	1,039	0,000	0,418	1,000	1,025
0,060	0,059	1,021	1,045	0,000	0,109	1,000	1,086
0,127	0,110	1,114	1,117	1,038	1,551	0,000	0,152
0,095	0,073	1,050	1,052	8,164	8,167	0,000	0,100
0,081	0,056	1,043	1,057	1,033	1,148	1,000	1,145
0,079	0,057	1,028	1,034	1,726	1,749	1,000	1,166
0,068	0,042	1,031	1,021	0,000	-0,501	1,000	1,060
0,068	0,047	1,021	1,022	0,000	0,248	1,000	1,068
0,077	0,049	1,039	1,044	0,000	0,852	1,000	1,174
0,074	0,046	1,024	1,024	2,717	2,316	1,000	1,098
0,067	0,048	1,030	1,024	0,000	0,091	1,000	1,078
0,063	0,041	1,018	1,010	0,000	0,516	1,000	1,070
0,063	0,051	1,027	1,028	0,000	0,186	1,000	1,046
0,062	0,043	1,017	1,008	0,639	0,630	1,000	1,100
0,065	0,043	1,021	1,011	4,210	4,190	0,000	0,550
0,082	0,063	1,029	1,007	1,801	1,457	1,000	0,885
0,108	0,090	1,078	1,071	0,000	0,336	0,000	0,163
0,174	0,155	1,232	1,164	0,000	0,034	0,000	0,186
0,155	0,151	1,107	1,094	1,788	1,290	0,000	0,265
0,167	0,151	1,124	1,102	3,427	3,044	0,000	0,118
0,152	0,098	1,103	1,106	4,431	5,281	0,000	0,354
0,042	0,044	1,010	0,997	0,000	-1,363	1,000	1,270
0,051	0,046	1,009	0,998	0,529	0,636	1,000	1,106
0,191	0,157	1,216	1,141	0,232	0,200	0,000	0,072
0,110	0,096	1,047	1,032	0,000	0,097	0,000	0,121
0,116	0,114	1,246	1,148	5,418	4,327	0,000	-0,017
0,074	0,055	1,031	1,078	2,071	4,849	1,000	-0,013
0,081	0,080	1,062	1,025	3,770	2,197	1,000	0,400
0,097	0,106	1,038	1,041	0,000	0,045	1,000	0,883
0,168	0,153	1,112	1,085	0,000	-0,807	0,000	0,376
0,156	0,144	1,089	1,075	1,323	1,025	0,000	0,211
0,129	0,154	1,103	1,082	0,000	-2,797	0,000	0,337
0,144	0,144	1,062	1,052	0,222	-0,140	0,000	0,076
0,133	0,133	1,109	1,096	2,569	2,227	0,000	0,088
0,070	0,071	1,021	1,011	0,000	0,164	1,000	1,069
0,069	0,067	1,020	1,010	0,723	0,701	1,000	1,071

(1) Act. (1/σ)	(1) Net. (1/σ)	(2) Act. ($\tilde{T}/T$)	(2) Net. ($\tilde{T}/T$)	(3) Act. ($\tilde{\zeta}_0$)	(3) Net. ($\tilde{\zeta}_0$)	(4) Act. (Negl.)	(4) Net. (Negl.)
0,096	0,097	1,102	1,096	0,000	-0,405	0,000	0,044
0,034	0,026	1,008	1,000	0,377	0,306	1,000	1,000
0,045	0,050	1,006	1,002	0,000	-0,108	1,000	1,085
0,090	0,086	1,199	1,164	2,122	1,764	0,000	0,048
0,088	0,086	1,193	1,159	2,602	2,602	0,000	0,070
0,030	0,028	1,011	1,002	0,000	-0,262	1,000	1,004
0,030	0,030	1,001	0,989	4,039	4,224	0,000	0,041
0,030	0,030	1,001	0,990	0,000	0,233	1,000	1,039
0,090	0,081	1,041	1,030	2,840	2,644	1,000	1,066
0,080	0,084	1,031	1,021	2,330	2,680	1,000	0,993
0,050	0,052	1,011	0,995	0,000	0,206	1,000	0,983
0,050	0,054	1,011	0,999	0,000	-0,231	1,000	1,026
0,050	0,048	1,011	0,998	0,090	0,448	1,000	0,995
0,050	0,051	1,011	1,004	0,000	-0,024	1,000	0,987
0,040	0,038	1,021	1,026	4,819	5,381	0,000	0,066
0,040	0,042	1,011	0,998	3,290	3,370	1,000	0,948
0,050	0,046	1,011	1,013	1,030	3,606	1,000	0,420
0,050	0,052	1,011	1,007	6,839	7,034	0,000	0,024
0,050	0,044	1,011	1,009	1,020	1,169	1,000	0,958
0,050	0,053	1,011	1,010	0,340	0,447	1,000	1,026
0,120	0,059	1,111	1,041	2,410	1,268	0,000	0,235
0,060	0,061	1,041	1,038	0,000	-0,030	1,000	1,001

Table App. B2. Actual and program outputs for Model 2

(1) Act. (1/σ)	(1) Net. (1/σ)	(2) Act. ($\tilde{T}/T$)	(2) Net. ($\tilde{T}/T$)	(3) Act. ($\tilde{\zeta}_o$)	(3) Net. ($\tilde{\zeta}_o$)	(4) Act. (Negl.)	(4) Net. (Negl.)
0,082	0,084	1,034	1,040	4,759	4,375	0,000	0,243
0,079	0,084	1,030	1,037	0,111	0,038	1,000	0,911
0,090	0,086	1,041	1,047	3,811	3,441	1,000	0,908
0,086	0,095	1,036	1,035	0,000	-0,552	1,000	1,222
0,143	0,136	1,106	1,146	4,226	3,753	0,000	0,002
0,141	0,144	1,178	1,163	11,441	8,273	0,000	-0,061
0,122	0,127	1,135	1,134	6,259	6,268	0,000	0,098
0,120	0,133	1,073	1,085	4,217	3,468	0,000	-0,134
0,126	0,132	1,050	1,060	1,479	1,516	0,000	0,098
0,074	0,091	1,034	1,059	0,000	-0,292	1,000	1,116
0,041	0,053	1,011	1,027	0,626	0,432	1,000	1,097
0,058	0,077	1,021	1,045	2,936	2,957	1,000	0,952
0,056	0,069	1,017	1,025	0,000	0,299	1,000	1,039
0,090	0,110	1,064	1,086	1,526	1,370	1,000	0,928
0,093	0,107	1,030	1,053	0,315	0,599	1,000	1,090
0,086	0,106	1,039	1,068	1,002	0,966	1,000	1,028
0,062	0,065	1,014	1,036	1,440	1,231	1,000	1,082
0,069	0,077	1,030	1,049	0,350	0,569	1,000	1,110
0,074	0,088	1,023	1,047	0,693	0,795	1,000	1,040
0,061	0,061	1,024	1,047	1,728	1,735	1,000	1,060
0,065	0,074	1,018	1,038	1,370	1,043	1,000	1,033
0,083	0,084	1,025	1,037	0,000	-0,054	1,000	1,015
0,077	0,069	1,029	1,043	0,076	0,483	1,000	1,113
0,086	0,078	1,025	1,041	1,012	0,966	1,000	1,089
0,070	0,070	1,024	1,029	0,000	0,362	1,000	1,157
0,079	0,081	1,022	1,035	0,000	0,421	1,000	1,119
0,043	0,046	1,009	1,021	0,000	-0,002	1,000	1,085
0,042	0,041	1,007	1,015	1,515	1,274	1,000	1,001
0,147	0,150	1,143	1,148	0,174	0,277	0,000	0,040
0,058	0,064	1,036	1,062	4,236	4,636	0,000	0,022
0,053	0,061	1,030	1,046	4,194	4,476	0,000	0,054
0,145	0,148	1,047	1,067	0,588	0,870	0,000	0,074
0,183	0,164	1,155	1,159	8,960	8,228	0,000	0,023
0,082	0,076	1,068	1,081	4,855	6,265	0,000	0,199
0,100	0,102	1,097	1,111	12,253	8,214	0,000	-0,029
0,084	0,050	1,052	1,065	10,559	7,965	0,000	0,403
0,079	0,080	1,063	1,076	12,304	7,648	0,000	-0,009
0,093	0,093	1,065	1,082	3,891	4,297	1,000	1,052
0,167	0,154	1,060	1,073	0,000	0,468	0,000	0,126
0,153	0,147	1,148	1,145	6,620	6,867	0,000	0,035
0,165	0,145	1,119	1,142	13,397	8,283	0,000	-0,240
0,063	0,061	1,023	1,039	0,000	0,418	1,000	1,025
0,060	0,059	1,021	1,045	0,000	0,109	1,000	1,086

(1) Act. (1/σ)	(1) Net. (1/σ)	(2) Act. ($\tilde{T}/T$)	(2) Net. ($\tilde{T}/T$)	(3) Act. ($\tilde{\zeta}_0$)	(3) Net. ($\tilde{\zeta}_0$)	(4) Act. (Negl.)	(4) Net. (Negl.)
0,127	0,110	1,114	1,117	1,038	1,551	0,000	0,152
0,095	0,073	1,050	1,052	8,164	8,167	0,000	0,100
0,081	0,056	1,043	1,057	1,033	1,148	1,000	1,145
0,079	0,057	1,028	1,034	1,726	1,749	1,000	1,166
0,068	0,042	1,031	1,021	0,000	-0,501	1,000	1,060
0,068	0,047	1,021	1,022	0,000	0,248	1,000	1,068
0,077	0,049	1,039	1,044	0,000	0,852	1,000	1,174
0,074	0,046	1,024	1,024	2,717	2,316	1,000	1,098
0,067	0,048	1,030	1,024	0,000	0,091	1,000	1,078
0,063	0,041	1,018	1,010	0,000	0,516	1,000	1,070
0,063	0,051	1,027	1,028	0,000	0,186	1,000	1,046
0,062	0,043	1,017	1,008	0,639	0,630	1,000	1,100
0,065	0,043	1,021	1,011	4,210	4,190	0,000	0,550
0,082	0,063	1,029	1,007	1,801	1,457	1,000	0,885
0,108	0,090	1,078	1,071	0,000	0,336	0,000	0,163
0,174	0,155	1,232	1,164	0,000	0,034	0,000	0,186
0,155	0,151	1,107	1,094	1,788	1,290	0,000	0,265
0,167	0,151	1,124	1,102	3,427	3,044	0,000	0,118
0,152	0,098	1,103	1,106	4,431	5,281	0,000	0,354
0,042	0,044	1,010	0,997	0,000	-1,363	1,000	1,270
0,051	0,046	1,009	0,998	0,529	0,636	1,000	1,106
0,191	0,157	1,216	1,141	0,232	0,200	0,000	0,072
0,110	0,096	1,047	1,032	0,000	0,097	0,000	0,121
0,116	0,114	1,246	1,148	5,418	4,327	0,000	-0,017
0,074	0,055	1,031	1,078	2,071	4,849	1,000	-0,013
0,081	0,080	1,062	1,025	3,770	2,197	1,000	0,400
0,097	0,106	1,038	1,041	0,000	0,045	1,000	0,883
0,168	0,153	1,112	1,085	0,000	-0,807	0,000	0,376
0,156	0,144	1,089	1,075	1,323	1,025	0,000	0,211
0,129	0,154	1,103	1,082	0,000	-2,797	0,000	0,337
0,144	0,144	1,062	1,052	0,222	-0,140	0,000	0,076
0,133	0,133	1,109	1,096	2,569	2,227	0,000	0,088
0,070	0,071	1,021	1,011	0,000	0,164	1,000	1,069
0,069	0,067	1,020	1,010	0,723	0,701	1,000	1,071
0,096	0,097	1,102	1,096	0,000	-0,405	0,000	0,044
0,034	0,026	1,008	1,000	0,377	0,306	1,000	1,000
0,045	0,050	1,006	1,002	0,000	-0,108	1,000	1,085
0,090	0,086	1,199	1,164	2,122	1,764	0,000	0,048
0,088	0,086	1,193	1,159	2,602	2,602	0,000	0,070
0,030	0,028	1,011	1,002	0,000	-0,262	1,000	1,004
0,030	0,030	1,001	0,989	4,039	4,224	0,000	0,041
0,030	0,030	1,001	0,990	0,000	0,233	1,000	1,039
0,090	0,081	1,041	1,030	2,840	2,644	1,000	1,066
0,080	0,084	1,031	1,021	2,330	2,680	1,000	0,993
0,050	0,052	1,011	0,995	0,000	0,206	1,000	0,983
0,050	0,054	1,011	0,999	0,000	-0,231	1,000	1,026

(1) Act. (1/σ)	(1) Net. (1/σ)	(2) Act. ($\tilde{T}/T$)	(2) Net. ($\tilde{T}/T$)	(3) Act. ($\tilde{\zeta}_0$)	(3) Net. ($\tilde{\zeta}_0$)	(4) Act. (Negl.)	(4) Net. (Negl.)
0,050	0,048	1,011	0,998	0,090	0,448	1,000	0,995
0,050	0,051	1,011	1,004	0,000	-0,024	1,000	0,987
0,040	0,038	1,021	1,026	4,819	5,381	0,000	0,066
0,040	0,042	1,011	0,998	3,290	3,370	1,000	0,948
0,050	0,046	1,011	1,013	1,030	3,606	1,000	0,420
0,050	0,052	1,011	1,007	6,839	7,034	0,000	0,024
0,050	0,044	1,011	1,009	1,020	1,169	1,000	0,958
0,050	0,053	1,011	1,010	0,340	0,447	1,000	1,026
0,120	0,059	1,111	1,041	2,410	1,268	0,000	0,235
0,060	0,061	1,041	1,038	0,000	-0,030	1,000	1,001

Appendix C. Error Through Patterns Graphs for Model 1 and 2.

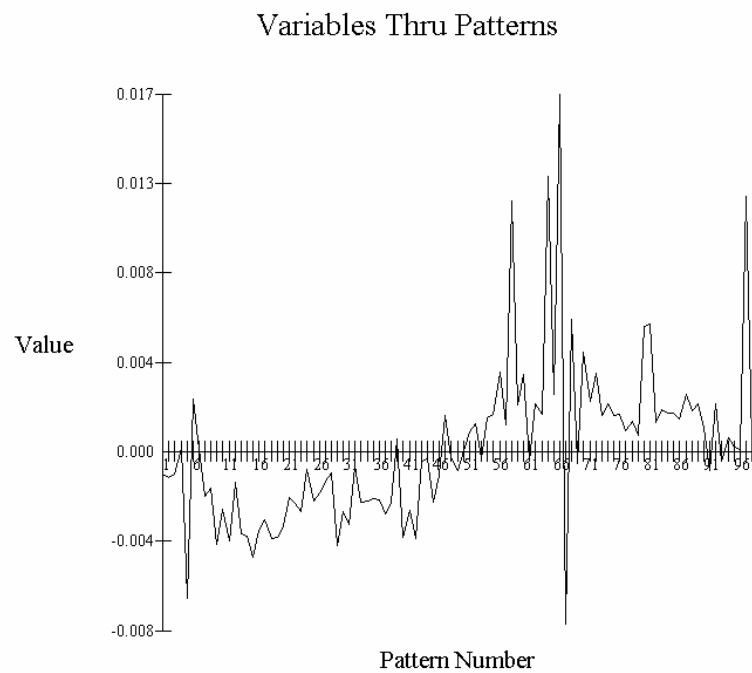


Figure App. C1. Error through patterns for act-net ($1/\sigma$) for Model 1

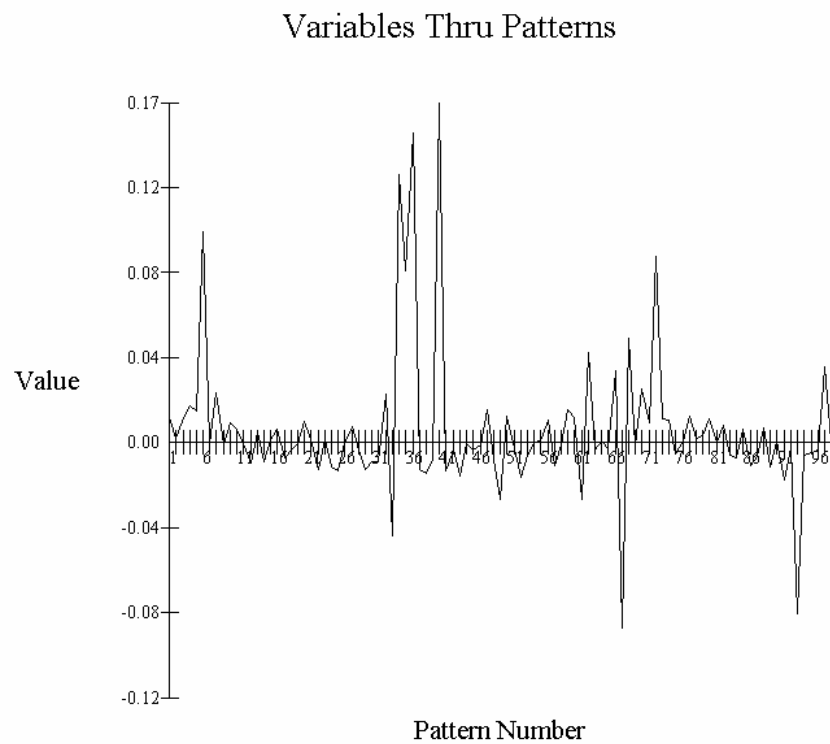


Figure App. C2. Error through patterns for act-net (Period Lengthening) for Model 1

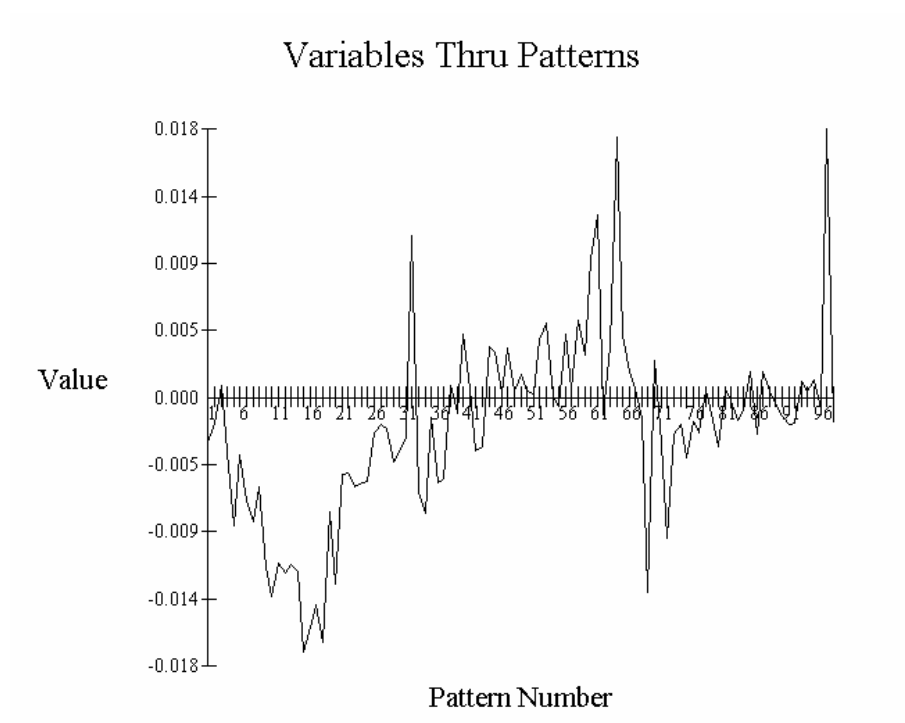


Figure App. C3. Error through patterns for act-net (Foundation Damping) for Model 1

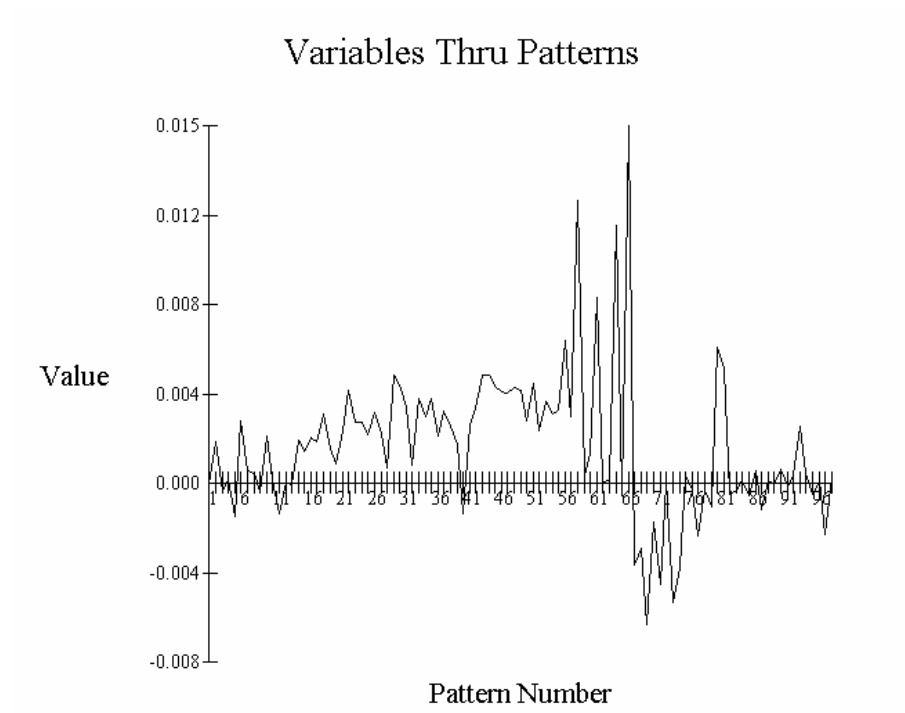


Figure App. C4. Error through patterns for act-net ($1/\sigma$) for Model 2

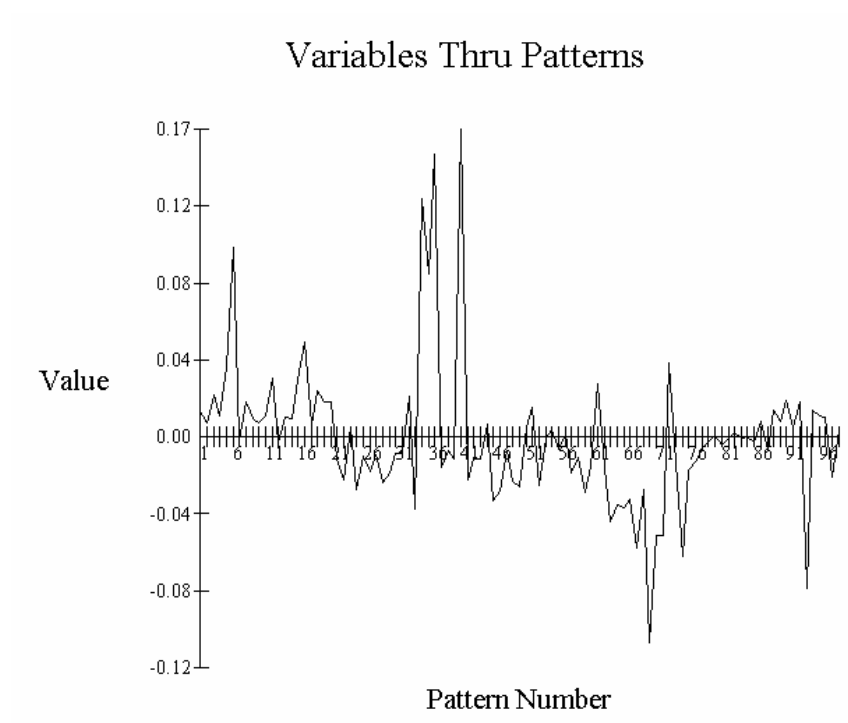


Figure App. C5. Error through patterns for act-net (Period Lengthening) for Model 2

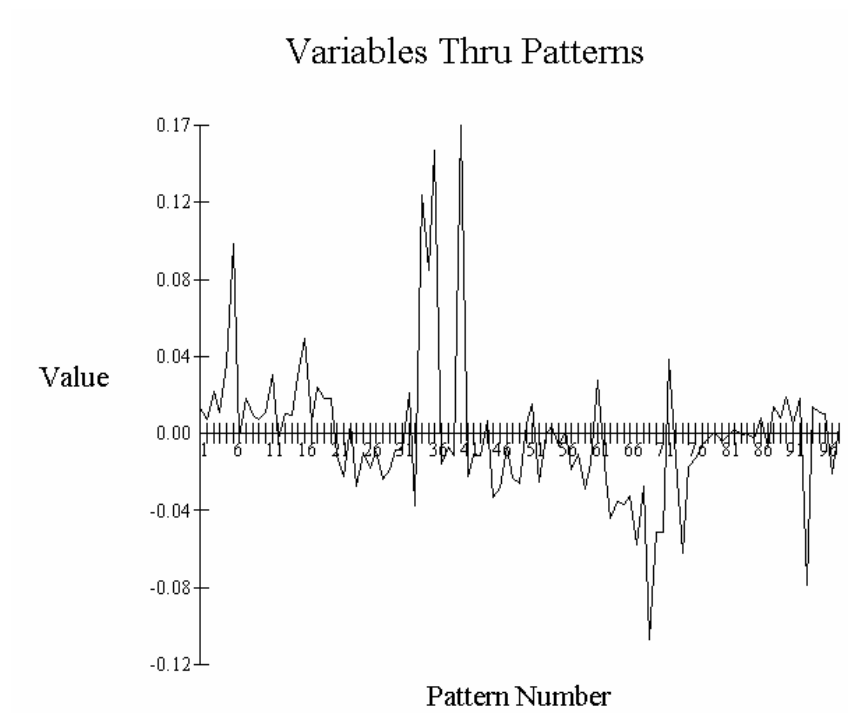


Figure App. C6. Error through patterns for act-net (Foundation Damping) for Model 2

Appendix D. GRNN Approach Output Tables for Model 3,4 and 5 (Normalized)

Table App. D1. Actual and Program Outputs for Model 3 (Normalized)

(1)Actual (1/σ)	(1)Network (1/σ)	(1)Act-Net (1/σ)	(2) Actual (Period lengthening)	(2) Network (Period lengthening)	(2) Act-Net (Period lengthening)
0,053	0,055	-0,002	0,179	0,180	-0,001
0,051	0,051	0,000	0,178	0,178	0,000
0,058	0,059	-0,001	0,180	0,181	-0,001
0,056	0,056	-0,001	0,179	0,179	0,000
0,092	0,076	0,017	0,191	0,190	0,001
0,091	0,090	0,001	0,204	0,201	0,003
0,078	0,080	-0,001	0,196	0,197	0,000
0,077	0,078	0,000	0,186	0,185	0,001
0,081	0,080	0,001	0,182	0,182	-0,001
0,047	0,047	0,000	0,179	0,179	0,000
0,027	0,040	-0,013	0,175	0,177	-0,002
0,037	0,037	0,000	0,177	0,177	0,000
0,036	0,036	0,000	0,176	0,176	0,000
0,058	0,058	0,000	0,184	0,184	0,000
0,060	0,060	0,000	0,178	0,178	0,000
0,056	0,056	0,000	0,180	0,180	0,000
0,040	0,040	0,000	0,175	0,175	0,000
0,044	0,044	0,000	0,178	0,178	0,000
0,048	0,048	0,000	0,177	0,177	0,000
0,039	0,039	0,000	0,177	0,177	0,000
0,042	0,042	0,000	0,176	0,176	0,000
0,053	0,053	0,000	0,177	0,177	0,000
0,050	0,055	-0,005	0,178	0,177	0,001
0,055	0,055	0,001	0,177	0,177	0,000
0,045	0,046	0,000	0,177	0,176	0,001
0,051	0,051	0,001	0,177	0,177	0,000
0,028	0,028	0,000	0,175	0,175	0,000
0,027	0,027	0,000	0,174	0,174	0,000
0,095	0,094	0,001	0,198	0,197	0,001
0,038	0,038	0,000	0,179	0,179	0,000
0,034	0,034	0,000	0,178	0,178	0,000
0,094	0,094	0,000	0,181	0,181	0,000
0,118	0,107	0,011	0,200	0,200	0,000
0,053	0,053	0,000	0,185	0,185	0,000
0,064	0,064	0,001	0,190	0,190	0,000
0,054	0,063	-0,009	0,182	0,189	-0,007
0,051	0,051	-0,001	0,184	0,184	0,000

(1)Actual (1/σ)	(1)Network (1/σ)	(1)Act-Net (1/σ)	(2) Actual (Period lengthening)	(2) Network (Period lengthening)	(2) Act-Net (Period lengthening)
0,060	0,061	-0,001	0,184	0,184	0,000
0,107	0,107	0,000	0,183	0,183	0,000
0,099	0,093	0,005	0,199	0,196	0,002
0,106	0,092	0,014	0,194	0,196	-0,002
0,041	0,040	0,000	0,177	0,177	0,000
0,038	0,040	-0,001	0,177	0,177	0,000
0,082	0,082	0,000	0,193	0,193	0,000
0,061	0,061	0,000	0,182	0,182	0,000
0,052	0,048	0,004	0,180	0,179	0,001
0,051	0,050	0,001	0,178	0,178	0,000
0,044	0,044	0,000	0,178	0,178	0,000
0,044	0,044	0,000	0,177	0,177	0,000
0,049	0,047	0,002	0,180	0,179	0,001
0,048	0,047	0,001	0,177	0,177	0,000
0,043	0,045	-0,002	0,178	0,179	-0,001
0,041	0,043	-0,002	0,176	0,176	0,000
0,041	0,039	0,002	0,178	0,176	0,002
0,040	0,040	0,000	0,176	0,176	0,000
0,042	0,044	-0,003	0,177	0,177	0,000
0,053	0,052	0,001	0,178	0,178	0,000
0,070	0,070	0,000	0,187	0,187	0,000
0,113	0,107	0,005	0,213	0,201	0,012
0,100	0,103	-0,003	0,191	0,193	-0,001
0,108	0,103	0,004	0,194	0,193	0,001
0,098	0,056	0,042	0,191	0,186	0,005
0,027	0,033	-0,006	0,175	0,175	0,000
0,033	0,033	0,000	0,175	0,175	0,000
0,123	0,107	0,016	0,210	0,201	0,009
0,071	0,071	0,000	0,181	0,181	0,000
0,075	0,075	0,000	0,216	0,201	0,014
0,048	0,040	0,008	0,178	0,178	0,000
0,052	0,034	0,018	0,184	0,176	0,008
0,063	0,051	0,011	0,180	0,178	0,001
0,108	0,099	0,009	0,192	0,188	0,004
0,100	0,100	0,001	0,188	0,188	0,000
0,083	0,090	-0,007	0,191	0,188	0,003
0,093	0,092	0,001	0,184	0,186	-0,002
0,086	0,086	0,000	0,192	0,191	0,000
0,045	0,045	0,001	0,177	0,176	0,000
0,045	0,045	0,000	0,176	0,176	0,000
0,062	0,062	0,000	0,191	0,191	0,000
0,022	0,022	0,000	0,174	0,174	0,000
0,029	0,028	0,000	0,174	0,174	0,000

(1)Actual (1/σ)	(1)Network (1/σ)	(1)Act-Net (1/σ)	(2) Actual (Period lengthening)	(2) Network (Period lengthening)	(2) Act-Net (Period lengthening)
0,058	0,060	-0,002	0,207	0,201	0,007
0,057	0,057	0,000	0,206	0,201	0,005
0,019	0,019	0,000	0,175	0,175	0,000
0,019	0,019	0,000	0,173	0,173	0,000
0,019	0,019	0,000	0,173	0,173	0,000
0,058	0,056	0,002	0,180	0,180	0,000
0,051	0,053	-0,002	0,178	0,179	0,000
0,032	0,032	0,000	0,175	0,175	0,000
0,032	0,032	0,000	0,175	0,175	0,000
0,032	0,033	0,000	0,175	0,175	0,000
0,032	0,033	0,000	0,175	0,175	0,000
0,026	0,026	0,000	0,177	0,177	0,000
0,026	0,026	0,000	0,175	0,175	0,000
0,032	0,032	0,000	0,175	0,175	0,000
0,032	0,032	0,000	0,175	0,175	0,000
0,032	0,032	0,000	0,175	0,175	0,000
0,032	0,032	0,000	0,175	0,175	0,000
0,077	0,079	-0,002	0,192	0,192	0,001
0,039	0,039	0,000	0,180	0,180	0,000
(3) Actual (Foundation damping)	(3) Network (Foundation damping)	(3) Act-Net (Foundation damping)	(4) Actual (Negligible)	(4) Network (Negligible)	(4) Act-Net (Negligible)
0,154	0,146	0,007	0,000	0,091	-0,091
0,004	0,013	-0,010	1,000	0,938	0,062
0,123	0,103	0,020	1,000	0,933	0,067
0,000	0,028	-0,028	1,000	0,990	0,010
0,136	0,161	-0,025	0,000	0,049	-0,049
0,369	0,262	0,107	0,000	0,000	0,000
0,202	0,206	-0,004	0,000	0,000	0,000
0,136	0,120	0,016	0,000	0,007	-0,007
0,048	0,064	-0,016	0,000	0,001	-0,001
0,000	0,000	0,000	1,000	1,000	0,000
0,020	0,007	0,013	1,000	1,000	0,000
0,095	0,081	0,013	1,000	1,000	0,000
0,000	0,009	-0,009	1,000	1,000	0,000
0,049	0,049	0,000	1,000	1,000	0,000
0,010	0,010	0,000	1,000	1,000	0,000
0,032	0,032	0,000	1,000	1,000	0,000
0,046	0,046	0,000	1,000	1,000	0,000
0,011	0,011	0,000	1,000	1,000	0,000
0,022	0,023	0,000	1,000	1,000	0,000
0,056	0,056	0,000	1,000	1,000	0,000

(3) Actual (Foundation damping)	(3) Network (Foundation damping)	(3) Act-Net (Foundation damping)	(4) Actual (Negligible)	(4) Network (Negligible)	(4) Act-Net (Negligible)
0,044	0,044	0,000	1,000	1,000	0,000
0,000	0,000	0,000	1,000	1,000	0,000
0,002	0,032	-0,029	1,000	1,000	0,000
0,033	0,032	0,001	1,000	1,000	0,000
0,000	0,005	-0,005	1,000	1,000	0,000
0,000	0,000	0,000	1,000	1,000	0,000
0,000	0,016	-0,016	1,000	1,000	0,000
0,049	0,033	0,016	1,000	1,000	0,000
0,006	0,010	-0,005	0,000	0,000	0,000
0,137	0,137	0,000	0,000	0,000	0,000
0,135	0,135	0,000	0,000	0,000	0,000
0,019	0,019	0,000	0,000	0,000	0,000
0,289	0,267	0,022	0,000	0,000	0,000
0,157	0,158	-0,001	0,000	0,000	0,000
0,396	0,266	0,129	0,000	0,000	0,000
0,341	0,258	0,083	0,000	0,005	-0,005
0,397	0,267	0,130	0,000	0,000	0,000
0,126	0,127	-0,001	1,000	0,973	0,027
0,000	0,000	0,000	0,000	0,000	0,000
0,214	0,203	0,011	0,000	0,077	-0,077
0,432	0,209	0,224	0,000	0,041	-0,041
0,000	0,005	-0,005	1,000	1,000	0,000
0,000	0,017	-0,017	1,000	1,000	0,000
0,034	0,033	0,000	0,000	0,000	0,000
0,264	0,263	0,001	0,000	0,002	-0,002
0,033	0,000	0,033	1,000	1,000	0,000
0,056	0,061	-0,005	1,000	1,000	0,000
0,000	0,000	0,000	1,000	1,000	0,000
0,000	0,000	0,000	1,000	1,000	0,000
0,000	0,000	0,000	1,000	1,000	0,000
0,088	0,064	0,024	1,000	1,000	0,000
0,000	0,000	0,000	1,000	1,000	0,000
0,000	0,023	-0,023	1,000	1,000	0,000
0,000	0,007	-0,007	1,000	1,000	0,000
0,021	0,021	0,000	1,000	1,000	0,000
0,136	0,119	0,017	0,000	0,211	-0,211
0,058	0,075	-0,017	1,000	0,773	0,227
0,000	0,000	0,000	0,000	0,000	0,000
0,000	0,000	0,000	0,000	0,000	0,000
0,058	0,083	-0,025	0,000	0,006	-0,006
0,111	0,086	0,025	0,000	0,006	-0,006
0,143	0,186	-0,043	0,000	0,000	0,000
0,000	0,017	-0,017	1,000	1,000	0,000

(3) Actual (Foundation damping)	(3) Network (Foundation damping)	(3) Act-Net (Foundation damping)	(4) Actual (Negligible)	(4) Network (Negligible)	(4) Act-Net (Negligible)
0,017	0,018	0,000	1,000	0,996	0,004
0,007	0,007	0,000	0,000	0,000	0,000
0,000	0,000	0,000	0,000	0,000	0,000
0,175	0,175	0,000	0,000	0,000	0,000
0,067	0,048	0,019	1,000	0,774	0,226
0,122	0,040	0,082	1,000	0,800	0,200
0,000	0,044	-0,044	1,000	0,598	0,402
0,000	0,040	-0,040	0,000	0,000	0,000
0,043	0,041	0,002	0,000	0,001	-0,001
0,000	0,028	-0,028	0,000	0,000	0,000
0,007	0,020	-0,013	0,000	0,000	0,000
0,083	0,068	0,015	0,000	0,000	0,000
0,000	0,023	-0,023	1,000	1,000	0,000
0,023	0,023	0,000	1,000	1,000	0,000
0,000	0,000	0,000	0,000	0,000	0,000
0,012	0,012	0,001	1,000	1,000	0,000
0,000	0,001	-0,001	1,000	1,000	0,000
0,068	0,069	0,000	0,000	0,000	0,000
0,084	0,084	0,000	0,000	0,000	0,000
0,000	0,000	0,000	1,000	1,000	0,000
0,130	0,130	0,000	0,000	0,000	0,000
0,000	0,000	0,000	1,000	1,000	0,000
0,092	0,087	0,004	1,000	1,000	0,000
0,075	0,080	-0,004	1,000	0,999	0,001
0,000	0,000	0,000	1,000	1,000	0,000
0,000	0,000	0,000	1,000	1,000	0,000
0,003	0,002	0,001	1,000	1,000	0,000
0,000	0,001	-0,001	1,000	1,000	0,000
0,156	0,156	0,000	0,000	0,000	0,000
0,106	0,106	0,000	1,000	1,000	0,000
0,033	0,062	-0,029	1,000	0,841	0,159
0,221	0,221	0,000	0,000	0,000	0,000
0,033	0,032	0,001	1,000	1,000	0,000
0,011	0,012	-0,001	1,000	1,000	0,000
0,078	0,165	-0,087	0,000	0,372	-0,372
0,000	0,000	0,000	1,000	1,000	0,000

Table App. D2. Actual and Program Outputs for Model 4 (Normalized)

(1)Actual (1/σ)	(1)Network (1/σ)	(1)Act-Net (1/σ)	(2) Actual (Period lengthening)	(2) Network (Period lengthening)	(2) Act-Net (Period lengthening)
0,053	0,055	-0,002	0,179	0,179	0,000
0,051	0,052	-0,001	0,178	0,178	0,000
0,058	0,055	0,002	0,180	0,179	0,001
0,056	0,055	0,000	0,179	0,179	0,000
0,092	0,081	0,011	0,191	0,198	-0,007
0,091	0,086	0,005	0,204	0,200	0,004
0,078	0,083	-0,005	0,196	0,198	-0,002
0,077	0,078	-0,001	0,186	0,185	0,001
0,081	0,080	0,001	0,182	0,182	-0,001
0,047	0,047	0,000	0,179	0,179	0,000
0,027	0,045	-0,019	0,175	0,178	-0,003
0,037	0,037	0,000	0,177	0,177	0,000
0,036	0,037	0,000	0,176	0,176	0,000
0,058	0,058	0,000	0,184	0,184	0,000
0,060	0,060	0,000	0,178	0,178	0,000
0,056	0,056	0,000	0,180	0,180	0,000
0,040	0,040	0,000	0,175	0,175	0,000
0,044	0,043	0,001	0,178	0,178	0,000
0,048	0,045	0,003	0,177	0,177	0,000
0,039	0,040	-0,001	0,177	0,177	0,000
0,042	0,044	-0,003	0,176	0,176	0,000
0,053	0,053	0,000	0,177	0,177	0,000
0,050	0,055	-0,006	0,178	0,177	0,001
0,055	0,055	0,000	0,177	0,177	0,000
0,045	0,052	-0,007	0,177	0,177	0,000
0,051	0,051	0,000	0,177	0,177	0,000
0,028	0,028	0,000	0,175	0,174	0,000
0,027	0,027	0,000	0,174	0,174	0,000
0,095	0,091	0,003	0,198	0,198	0,000
0,038	0,038	0,000	0,179	0,179	0,000
0,034	0,034	0,000	0,178	0,178	0,000
0,094	0,094	0,000	0,181	0,181	0,000
0,118	0,107	0,011	0,200	0,200	0,000
0,053	0,055	-0,002	0,185	0,186	-0,001
0,064	0,062	0,002	0,190	0,189	0,001
0,054	0,048	0,006	0,182	0,184	-0,002
0,051	0,051	0,000	0,184	0,184	0,000
0,060	0,060	0,000	0,184	0,184	0,000
0,107	0,107	0,000	0,183	0,183	0,000
0,099	0,099	0,000	0,199	0,199	0,000
0,106	0,099	0,008	0,194	0,199	-0,005
0,041	0,041	0,000	0,177	0,177	0,000
0,038	0,041	-0,002	0,177	0,177	0,000
0,082	0,082	0,000	0,193	0,193	0,000

(1)Actual (1/σ)	(1)Network (1/σ)	(1)Act-Net (1/σ)	(2) Actual (Period lengthening)	(2) Network (Period lengthening)	(2) Act-Net (Period lengthening)
0,061	0,061	0,000	0,182	0,182	0,000
0,052	0,047	0,005	0,180	0,179	0,001
0,051	0,048	0,003	0,178	0,177	0,000
0,044	0,045	-0,001	0,178	0,178	0,000
0,044	0,045	-0,001	0,177	0,177	0,000
0,049	0,047	0,003	0,180	0,179	0,001
0,048	0,047	0,001	0,177	0,177	0,000
0,043	0,045	-0,002	0,178	0,179	0,000
0,041	0,044	-0,003	0,176	0,177	0,000
0,041	0,040	0,001	0,178	0,177	0,001
0,040	0,040	0,000	0,176	0,176	0,000
0,042	0,048	-0,006	0,177	0,178	-0,001
0,053	0,051	0,003	0,178	0,178	0,000
0,070	0,070	0,000	0,187	0,187	0,000
0,113	0,107	0,005	0,213	0,201	0,012
0,100	0,103	-0,004	0,191	0,193	-0,001
0,108	0,104	0,004	0,194	0,193	0,001
0,098	0,061	0,037	0,191	0,188	0,003
0,027	0,033	-0,006	0,175	0,175	0,000
0,033	0,033	0,000	0,175	0,175	0,000
0,123	0,106	0,017	0,210	0,201	0,010
0,071	0,073	-0,002	0,181	0,182	-0,001
0,075	0,071	0,004	0,216	0,200	0,016
0,048	0,035	0,013	0,178	0,182	-0,004
0,052	0,052	0,000	0,184	0,181	0,002
0,063	0,053	0,010	0,180	0,178	0,001
0,108	0,095	0,013	0,192	0,187	0,005
0,100	0,094	0,006	0,188	0,187	0,001
0,083	0,088	-0,004	0,191	0,186	0,004
0,093	0,091	0,003	0,184	0,186	-0,003
0,086	0,088	-0,003	0,192	0,189	0,003
0,045	0,045	0,001	0,177	0,176	0,000
0,045	0,045	0,000	0,176	0,176	0,000
0,062	0,062	0,000	0,191	0,191	0,000
0,022	0,024	-0,001	0,174	0,174	0,000
0,029	0,027	0,001	0,174	0,174	0,000
0,058	0,058	0,000	0,207	0,201	0,006
0,057	0,058	-0,001	0,206	0,201	0,005
0,019	0,023	-0,003	0,175	0,176	-0,002
0,019	0,019	0,000	0,173	0,173	0,000
0,019	0,019	0,000	0,173	0,173	0,000
0,058	0,056	0,002	0,180	0,180	0,000
0,051	0,053	-0,002	0,178	0,179	-0,001
0,032	0,032	0,000	0,175	0,175	0,000
0,032	0,032	0,000	0,175	0,175	0,000

(1)Actual (1/σ)	(1)Network (1/σ)	(1)Act-Net (1/σ)	(2) Actual (Period lengthening)	(2) Network (Period lengthening)	(2) Act-Net (Period lengthening)
0,032	0,032	0,000	0,175	0,175	0,000
0,032	0,032	0,000	0,175	0,175	0,000
0,026	0,026	0,000	0,177	0,177	0,000
0,026	0,026	0,000	0,175	0,175	0,000
0,032	0,032	0,000	0,175	0,175	0,000
0,032	0,032	0,000	0,175	0,175	0,000
0,032	0,032	0,000	0,175	0,175	0,000
0,032	0,032	0,000	0,175	0,175	0,000
0,077	0,089	-0,012	0,192	0,186	0,006
0,039	0,039	0,000	0,180	0,180	0,000
(3) Actual (Foundation damping)	(3) Network (Foundation damping)	(3) Act-Net (Foundation damping)	(4) Actual (Negligible)	(4) Network (Negligible)	(4) Act-Net (Negligible)
0,154	0,124	0,030	0,000	0,524	-0,524
0,004	0,007	-0,004	1,000	0,987	0,013
0,123	0,113	0,010	1,000	0,618	0,382
0,000	0,046	-0,046	1,000	0,872	0,128
0,136	0,082	0,055	0,000	0,056	-0,056
0,369	0,243	0,126	0,000	0,000	0,000
0,202	0,226	-0,024	0,000	0,002	-0,002
0,136	0,121	0,015	0,000	0,000	0,000
0,048	0,062	-0,015	0,000	0,000	0,000
0,000	0,001	-0,001	1,000	1,000	0,000
0,020	0,009	0,012	1,000	1,000	0,000
0,095	0,078	0,017	1,000	1,000	0,000
0,000	0,016	-0,016	1,000	1,000	0,000
0,049	0,050	0,000	1,000	0,997	0,003
0,010	0,010	0,000	1,000	1,000	0,000
0,032	0,032	0,000	1,000	1,000	0,000
0,046	0,046	0,000	1,000	1,000	0,000
0,011	0,020	-0,008	1,000	1,000	0,000
0,022	0,032	-0,009	1,000	1,000	0,000
0,056	0,047	0,008	1,000	1,000	0,000
0,044	0,035	0,009	1,000	1,000	0,000
0,000	0,000	0,000	1,000	1,000	0,000
0,002	0,033	-0,030	1,000	0,999	0,001
0,033	0,032	0,000	1,000	1,000	0,000
0,000	0,008	-0,008	1,000	1,000	0,000
0,000	0,000	0,000	1,000	1,000	0,000
0,000	0,021	-0,021	1,000	1,000	0,000
0,049	0,027	0,021	1,000	1,000	0,000
0,006	0,012	-0,006	0,000	0,000	0,000
0,137	0,137	0,000	0,000	0,000	0,000
0,135	0,135	0,000	0,000	0,000	0,000
0,019	0,019	0,000	0,000	0,003	-0,003

(3) Actual (Foundation damping)	(3) Network (Foundation damping)	(3) Act-Net (Foundation damping)	(4) Actual (Negligible)	(4) Network (Negligible)	(4) Act-Net (Negligible)
0,289	0,267	0,022	0,000	0,000	0,000
0,157	0,176	-0,019	0,000	0,000	0,000
0,396	0,249	0,147	0,000	0,000	0,000
0,341	0,208	0,133	0,000	0,040	-0,040
0,397	0,267	0,130	0,000	0,000	0,000
0,126	0,126	0,000	1,000	0,997	0,003
0,000	0,000	0,000	0,000	0,000	0,000
0,214	0,213	0,000	0,000	0,003	-0,003
0,432	0,213	0,219	0,000	0,001	-0,001
0,000	0,000	0,000	1,000	1,000	0,000
0,000	0,000	0,000	1,000	1,000	0,000
0,034	0,034	0,000	0,000	0,000	0,000
0,264	0,259	0,005	0,000	0,025	-0,025
0,033	0,009	0,024	1,000	0,943	0,057
0,056	0,052	0,004	1,000	1,000	0,000
0,000	0,003	-0,003	1,000	0,983	0,017
0,000	0,030	-0,030	1,000	1,000	0,000
0,000	0,008	-0,008	1,000	0,954	0,046
0,088	0,045	0,042	1,000	1,000	0,000
0,000	0,005	-0,005	1,000	0,974	0,026
0,000	0,021	-0,021	1,000	1,000	0,000
0,000	0,002	-0,002	1,000	0,993	0,007
0,021	0,021	0,000	1,000	1,000	0,000
0,136	0,094	0,041	0,000	0,401	-0,401
0,058	0,075	-0,017	1,000	0,674	0,326
0,000	0,000	0,000	0,000	0,000	0,000
0,000	0,000	0,000	0,000	0,000	0,000
0,058	0,082	-0,025	0,000	0,000	0,000
0,111	0,086	0,025	0,000	0,000	0,000
0,143	0,242	-0,098	0,000	0,000	0,000
0,000	0,017	-0,017	1,000	1,000	0,000
0,017	0,017	0,000	1,000	1,000	0,000
0,007	0,007	0,000	0,000	0,000	0,000
0,000	0,000	0,000	0,000	0,000	0,000
0,175	0,164	0,011	0,000	0,063	-0,063
0,067	0,048	0,019	1,000	0,720	0,280
0,122	0,089	0,033	1,000	0,938	0,062
0,000	0,041	-0,041	1,000	0,610	0,390
0,000	0,048	-0,048	0,000	0,049	-0,049
0,043	0,049	-0,006	0,000	0,053	-0,053
0,000	0,035	-0,035	0,000	0,036	-0,036
0,007	0,032	-0,025	0,000	0,000	0,000
0,083	0,058	0,025	0,000	0,000	0,000
0,000	0,023	-0,023	1,000	1,000	0,000
0,023	0,023	0,000	1,000	1,000	0,000

(3) Actual (Foundation damping)	(3) Network (Foundation damping)	(3) Act-Net (Foundation damping)	(4) Actual (Negligible)	(4) Network (Negligible)	(4) Act-Net (Negligible)
0,000	0,000	0,000	0,000	0,000	0,000
0,012	0,009	0,003	1,000	1,000	0,000
0,000	0,003	-0,003	1,000	1,000	0,000
0,068	0,074	-0,006	0,000	0,000	0,000
0,084	0,075	0,009	0,000	0,000	0,000
0,000	0,011	-0,011	1,000	0,934	0,066
0,130	0,127	0,003	0,000	0,026	-0,026
0,000	0,003	-0,003	1,000	0,977	0,023
0,092	0,087	0,004	1,000	0,998	0,002
0,075	0,083	-0,008	1,000	0,983	0,017
0,000	0,000	0,000	1,000	1,000	0,000
0,000	0,000	0,000	1,000	1,000	0,000
0,003	0,002	0,001	1,000	1,000	0,000
0,000	0,001	-0,001	1,000	1,000	0,000
0,156	0,155	0,000	0,000	0,006	-0,006
0,106	0,106	0,000	1,000	0,994	0,006
0,033	0,040	-0,007	1,000	0,955	0,045
0,221	0,162	0,058	0,000	0,281	-0,281
0,033	0,039	-0,006	1,000	0,959	0,041
0,011	0,063	-0,052	1,000	0,757	0,243
0,078	0,044	0,034	0,000	0,128	-0,128
0,000	0,000	0,000	1,000	1,000	0,000

Table App. D3. Actual and program outputs for Model 5 (Normalized)

(1)Actual (1/σ)	(1)Network (1/σ)	(1)Act-Net (1/σ)	(2) Actual (Period lengthening)	(2) Network (Period lengthening)	(2) Act-Net (Period lengthening)
0,053	0,054	-0,001	0,179	0,179	0,000
0,051	0,052	-0,001	0,178	0,179	0,000
0,058	0,056	0,002	0,180	0,179	0,001
0,056	0,056	0,000	0,179	0,179	0,000
0,092	0,087	0,005	0,191	0,193	-0,002
0,091	0,087	0,004	0,204	0,200	0,004
0,078	0,082	-0,004	0,196	0,198	-0,002
0,077	0,078	0,000	0,186	0,185	0,000
0,081	0,081	0,000	0,182	0,182	0,000
0,047	0,047	0,001	0,179	0,179	0,000
0,027	0,037	-0,011	0,175	0,176	-0,001
0,037	0,037	0,000	0,177	0,177	0,000
0,036	0,037	-0,001	0,176	0,176	0,000
0,058	0,058	0,000	0,184	0,184	0,000
0,060	0,060	0,000	0,178	0,178	0,000
0,056	0,055	0,000	0,180	0,180	0,000

(1)Actual (1/σ)	(1)Network (1/σ)	(1)Act-Net (1/σ)	(2) Actual (Period lengthening)	(2) Network (Period lengthening)	(2) Act-Net (Period lengthening)
0,040	0,040	0,000	0,175	0,176	0,000
0,044	0,044	0,000	0,178	0,178	0,000
0,048	0,047	0,001	0,177	0,177	0,000
0,039	0,040	0,000	0,177	0,177	0,000
0,042	0,043	-0,001	0,176	0,176	0,000
0,053	0,053	0,000	0,177	0,177	0,000
0,050	0,050	0,000	0,178	0,178	0,000
0,055	0,055	0,001	0,177	0,177	0,000
0,045	0,048	-0,002	0,177	0,177	0,000
0,051	0,051	0,000	0,177	0,177	0,000
0,028	0,028	0,000	0,175	0,174	0,000
0,027	0,027	0,000	0,174	0,174	0,000
0,095	0,094	0,000	0,198	0,197	0,000
0,038	0,038	0,000	0,179	0,179	0,000
0,034	0,034	0,000	0,178	0,178	0,000
0,094	0,094	0,000	0,181	0,181	0,000
0,118	0,107	0,011	0,200	0,200	0,000
0,053	0,055	-0,002	0,185	0,185	-0,001
0,064	0,063	0,002	0,190	0,189	0,001
0,054	0,051	0,003	0,182	0,184	-0,002
0,051	0,051	0,000	0,184	0,184	0,000
0,060	0,060	0,000	0,184	0,184	0,000
0,107	0,107	0,000	0,183	0,183	0,000
0,099	0,099	0,000	0,199	0,199	0,000
0,106	0,106	0,000	0,194	0,194	0,000
0,041	0,040	0,001	0,177	0,177	0,000
0,038	0,039	-0,001	0,177	0,177	0,000
0,082	0,082	0,000	0,193	0,193	0,000
0,061	0,061	0,000	0,182	0,182	0,000
0,052	0,050	0,002	0,180	0,180	0,000
0,051	0,049	0,002	0,178	0,177	0,000
0,044	0,046	-0,002	0,178	0,179	-0,001
0,044	0,046	-0,002	0,177	0,177	0,000
0,049	0,049	0,001	0,180	0,180	0,000
0,048	0,048	0,000	0,177	0,177	0,000
0,043	0,044	-0,001	0,178	0,178	0,000
0,041	0,041	0,000	0,176	0,176	0,000
0,041	0,041	0,000	0,178	0,178	0,000
0,040	0,040	0,000	0,176	0,176	0,000
0,042	0,044	-0,002	0,177	0,177	0,000
0,053	0,051	0,002	0,178	0,178	0,000
0,070	0,070	0,000	0,187	0,187	0,000
0,113	0,107	0,005	0,213	0,201	0,012
0,100	0,103	-0,004	0,191	0,193	-0,001
0,108	0,104	0,004	0,194	0,193	0,001

(1)Actual (1/σ)	(1)Network (1/σ)	(1)Act-Net (1/σ)	(2) Actual (Period lengthening)	(2) Network (Period lengthening)	(2) Act-Net (Period lengthening)
0,098	0,090	0,008	0,191	0,191	0,000
0,027	0,028	-0,001	0,175	0,175	0,000
0,033	0,032	0,001	0,175	0,175	0,000
0,123	0,107	0,016	0,210	0,201	0,009
0,071	0,071	0,000	0,181	0,181	0,000
0,075	0,075	0,000	0,216	0,201	0,014
0,048	0,048	0,000	0,178	0,178	0,000
0,052	0,052	0,000	0,184	0,184	0,000
0,063	0,062	0,000	0,180	0,180	0,000
0,108	0,100	0,008	0,192	0,188	0,004
0,100	0,100	0,000	0,188	0,188	0,000
0,083	0,091	-0,008	0,191	0,188	0,003
0,093	0,093	0,000	0,184	0,184	-0,001
0,086	0,086	-0,001	0,192	0,191	0,000
0,045	0,045	0,001	0,177	0,176	0,000
0,045	0,045	0,000	0,176	0,176	0,000
0,062	0,062	0,000	0,191	0,191	0,000
0,022	0,022	0,000	0,174	0,174	0,000
0,029	0,029	0,000	0,174	0,174	0,000
0,058	0,058	0,000	0,207	0,201	0,006
0,057	0,057	0,000	0,206	0,201	0,005
0,019	0,019	0,000	0,175	0,175	0,000
0,019	0,019	0,000	0,173	0,173	0,000
0,019	0,019	0,000	0,173	0,173	0,000
0,058	0,056	0,002	0,180	0,179	0,001
0,051	0,054	-0,002	0,178	0,179	-0,001
0,032	0,032	0,000	0,175	0,175	0,000
0,032	0,032	0,000	0,175	0,175	0,000
0,032	0,032	0,000	0,175	0,175	0,000
0,032	0,032	0,000	0,175	0,175	0,000
0,026	0,026	0,000	0,177	0,176	0,000
0,026	0,026	0,000	0,175	0,175	0,000
0,032	0,032	0,000	0,175	0,175	0,000
0,032	0,032	0,000	0,175	0,175	0,000
0,032	0,032	0,000	0,175	0,175	0,000
0,032	0,032	0,000	0,175	0,175	0,000
0,077	0,077	0,000	0,192	0,192	0,000
0,039	0,039	0,000	0,180	0,180	0,000
(3) Actual (Foundation damping)	(3) Network (Foundation damping)	(3) Act-Net (Foundation damping)	(4) Actual (Negligible)	(4) Network (Negligible)	(4) Act-Net (Negligible)
0,154	0,111	0,043	0,000	0,477	-0,477
0,004	0,036	-0,032	1,000	0,848	0,152
0,123	0,092	0,032	1,000	0,780	0,220
0,000	0,053	-0,053	1,000	0,886	0,114

(3) Actual (Foundation damping)	(3) Network (Foundation damping)	(3) Act-Net (Foundation damping)	(4) Actual (Negligible)	(4) Network (Negligible)	(4) Act-Net (Negligible)
0,136	0,102	0,034	0,000	0,000	0,000
0,369	0,248	0,122	0,000	0,000	0,000
0,202	0,222	-0,020	0,000	0,000	0,000
0,136	0,126	0,010	0,000	0,000	0,000
0,048	0,058	-0,010	0,000	0,000	0,000
0,000	0,000	0,000	1,000	1,000	0,000
0,020	0,007	0,013	1,000	1,000	0,000
0,095	0,087	0,008	1,000	1,000	0,000
0,000	0,002	-0,002	1,000	1,000	0,000
0,049	0,049	0,000	1,000	1,000	0,000
0,010	0,010	0,000	1,000	1,000	0,000
0,032	0,033	0,000	1,000	1,000	0,000
0,046	0,046	0,000	1,000	1,000	0,000
0,011	0,014	-0,003	1,000	1,000	0,000
0,022	0,025	-0,002	1,000	1,000	0,000
0,056	0,054	0,002	1,000	1,000	0,000
0,044	0,042	0,003	1,000	1,000	0,000
0,000	0,000	0,000	1,000	1,000	0,000
0,002	0,004	-0,002	1,000	1,000	0,000
0,033	0,030	0,003	1,000	1,000	0,000
0,000	0,003	-0,003	1,000	1,000	0,000
0,000	0,001	-0,001	1,000	1,000	0,000
0,000	0,020	-0,020	1,000	1,000	0,000
0,049	0,029	0,020	1,000	1,000	0,000
0,006	0,007	-0,001	0,000	0,000	0,000
0,137	0,137	0,000	0,000	0,000	0,000
0,135	0,135	0,000	0,000	0,000	0,000
0,019	0,019	0,000	0,000	0,000	0,000
0,289	0,267	0,022	0,000	0,000	0,000
0,157	0,172	-0,015	0,000	0,000	0,000
0,396	0,253	0,143	0,000	0,000	0,000
0,341	0,264	0,077	0,000	0,000	0,000
0,397	0,267	0,130	0,000	0,000	0,000
0,126	0,126	0,000	1,000	1,000	0,000
0,000	0,000	0,000	0,000	0,000	0,000
0,214	0,214	0,000	0,000	0,000	0,000
0,432	0,267	0,165	0,000	0,000	0,000
0,000	0,001	-0,001	1,000	1,000	0,000
0,000	0,002	-0,002	1,000	1,000	0,000
0,034	0,034	0,000	0,000	0,000	0,000
0,264	0,263	0,000	0,000	0,001	-0,001
0,033	0,020	0,013	1,000	1,000	0,000
0,056	0,049	0,006	1,000	1,000	0,000
0,000	0,005	-0,005	1,000	1,000	0,000
0,000	0,027	-0,027	1,000	1,000	0,000

(3) Actual (Foundation damping)	(3) Network (Foundation damping)	(3) Act-Net (Foundation damping)	(4) Actual (Negligible)	(4) Network (Negligible)	(4) Act-Net (Negligible)
0,000	0,008	-0,008	1,000	1,000	0,000
0,088	0,063	0,024	1,000	1,000	0,000
0,000	0,000	0,000	1,000	1,000	0,000
0,000	0,006	-0,006	1,000	1,000	0,000
0,000	0,000	0,000	1,000	1,000	0,000
0,021	0,021	0,000	1,000	1,000	0,000
0,136	0,123	0,013	0,000	0,167	-0,167
0,058	0,071	-0,013	1,000	0,833	0,167
0,000	0,000	0,000	0,000	0,000	0,000
0,000	0,000	0,000	0,000	0,000	0,000
0,058	0,083	-0,026	0,000	0,000	0,000
0,111	0,085	0,026	0,000	0,000	0,000
0,143	0,119	0,024	0,000	0,015	-0,015
0,000	0,003	-0,003	1,000	1,000	0,000
0,017	0,014	0,003	1,000	1,000	0,000
0,007	0,007	0,000	0,000	0,000	0,000
0,000	0,000	0,000	0,000	0,000	0,000
0,175	0,175	0,000	0,000	0,000	0,000
0,067	0,067	0,000	1,000	1,000	0,000
0,122	0,119	0,003	1,000	1,000	0,000
0,000	0,003	-0,003	1,000	1,000	0,000
0,000	0,043	-0,043	0,000	0,000	0,000
0,043	0,043	0,000	0,000	0,000	0,000
0,000	0,031	-0,031	0,000	0,002	-0,002
0,007	0,012	-0,005	0,000	0,000	0,000
0,083	0,077	0,006	0,000	0,000	0,000
0,000	0,023	-0,023	1,000	1,000	0,000
0,023	0,023	0,000	1,000	1,000	0,000
0,000	0,000	0,000	0,000	0,000	0,000
0,012	0,012	0,000	1,000	1,000	0,000
0,000	0,000	0,000	1,000	1,000	0,000
0,068	0,071	-0,003	0,000	0,000	0,000
0,084	0,081	0,003	0,000	0,000	0,000
0,000	0,000	0,000	1,000	0,999	0,001
0,130	0,130	0,000	0,000	0,003	-0,003
0,000	0,000	0,000	1,000	0,997	0,003
0,092	0,086	0,005	1,000	1,000	0,000
0,075	0,080	-0,005	1,000	1,000	0,000
0,000	0,000	0,000	1,000	1,000	0,000
0,000	0,000	0,000	1,000	1,000	0,000
0,003	0,002	0,001	1,000	1,000	0,000
0,000	0,001	-0,001	1,000	1,000	0,000
0,156	0,154	0,002	0,000	0,038	-0,038
0,106	0,108	-0,002	1,000	0,962	0,038
0,033	0,033	0,000	1,000	0,999	0,001

(3) Actual (Foundation damping)	(3) Network (Foundation damping)	(3) Act-Net (Foundation damping)	(4) Actual (Negligible)	(4) Network (Negligible)	(4) Act-Net (Negligible)
0,221	0,210	0,011	0,000	0,052	-0,052
0,033	0,033	0,000	1,000	1,000	0,000
0,011	0,022	-0,011	1,000	0,949	0,051
0,078	0,078	0,000	0,000	0,000	0,000
0,000	0,000	0,000	1,000	1,000	0,000

Appendix E. GRNN Approach Output for Model 3,4 and 5.

Table App. E1. Actual and program outputs for Model 3

(1) Act. (1/σ)	(1) Net. (1/σ)	(2) Act. ($\tilde{T}/T$)	(2) Net. ($\tilde{T}/T$)	(3) Act. ($\tilde{\zeta}_0$)	(3) Net. ($\tilde{\zeta}_0$)	(4) Act. (Negl.)	(4) Net. (Negl.)
0,082	0,085	1,034	1,039	4,759	4,538	0,000	0,091
0,079	0,079	1,030	1,030	0,111	0,410	1,000	0,938
0,090	0,092	1,041	1,045	3,811	3,205	1,000	0,933
0,086	0,087	1,036	1,037	0,000	0,858	1,000	0,990
0,143	0,117	1,106	1,100	4,226	4,992	0,000	0,049
0,141	0,139	1,178	1,162	11,441	8,118	0,000	0,000
0,122	0,124	1,135	1,137	6,259	6,381	0,000	0,000
0,120	0,121	1,073	1,069	4,217	3,709	0,000	0,007
0,126	0,124	1,050	1,054	1,479	1,982	0,000	0,001
0,074	0,073	1,034	1,034	0,000	0,001	1,000	1,000
0,041	0,061	1,011	1,022	0,626	0,213	1,000	1,000
0,058	0,058	1,021	1,020	2,936	2,518	1,000	1,000
0,056	0,056	1,017	1,017	0,000	0,281	1,000	1,000
0,090	0,090	1,064	1,064	1,526	1,527	1,000	1,000
0,093	0,093	1,030	1,030	0,315	0,315	1,000	1,000
0,086	0,086	1,039	1,039	1,002	1,002	1,000	1,000
0,062	0,062	1,014	1,014	1,440	1,440	1,000	1,000
0,069	0,069	1,030	1,030	0,350	0,354	1,000	1,000
0,074	0,074	1,023	1,023	0,693	0,708	1,000	1,000
0,061	0,061	1,024	1,024	1,728	1,720	1,000	1,000
0,065	0,065	1,018	1,018	1,370	1,356	1,000	1,000
0,083	0,082	1,025	1,025	0,000	0,005	1,000	1,000
0,077	0,085	1,029	1,025	0,076	0,983	1,000	1,000
0,086	0,085	1,025	1,025	1,012	0,976	1,000	1,000
0,070	0,071	1,024	1,019	0,000	0,160	1,000	1,000
0,079	0,078	1,022	1,021	0,000	0,009	1,000	1,000
0,043	0,043	1,009	1,009	0,000	0,486	1,000	1,000
0,042	0,042	1,007	1,008	1,515	1,028	1,000	1,000
0,147	0,146	1,143	1,138	0,174	0,314	0,000	0,000
0,058	0,058	1,036	1,036	4,236	4,236	0,000	0,000
0,053	0,053	1,030	1,030	4,194	4,194	0,000	0,000
0,145	0,145	1,047	1,047	0,588	0,588	0,000	0,000
0,183	0,166	1,155	1,155	8,960	8,283	0,000	0,000
0,082	0,082	1,068	1,068	4,855	4,889	0,000	0,000
0,100	0,099	1,097	1,096	12,253	8,252	0,000	0,000
0,084	0,097	1,052	1,093	10,559	7,986	0,000	0,005
0,079	0,080	1,063	1,064	12,304	8,282	0,000	0,000
0,093	0,094	1,065	1,066	3,891	3,935	1,000	0,973
0,167	0,166	1,060	1,060	0,000	0,012	0,000	0,000
0,153	0,145	1,148	1,135	6,620	6,281	0,000	0,077
0,165	0,142	1,119	1,130	13,397	6,462	0,000	0,041
0,063	0,063	1,023	1,023	0,000	0,158	1,000	1,000

(1) Act. (1/σ)	(1) Net. (1/σ)	(2) Act. ($\tilde{T}/T$)	(2) Net. ($\tilde{T}/T$)	(3) Act. ($\tilde{\zeta}_0$)	(3) Net. ($\tilde{\zeta}_0$)	(4) Act. (Negl.)	(4) Net. (Negl.)
0,060	0,062	1,021	1,022	0,000	0,522	1,000	1,000
0,127	0,127	1,114	1,113	1,038	1,028	0,000	0,000
0,095	0,095	1,050	1,050	8,164	8,148	0,000	0,002
0,081	0,075	1,043	1,037	1,033	0,000	1,000	1,000
0,079	0,078	1,028	1,027	1,726	1,882	1,000	1,000
0,068	0,068	1,031	1,031	0,000	0,000	1,000	1,000
0,068	0,068	1,021	1,021	0,000	0,008	1,000	1,000
0,077	0,073	1,039	1,036	0,000	0,000	1,000	1,000
0,074	0,073	1,024	1,024	2,717	1,977	1,000	1,000
0,067	0,070	1,030	1,033	0,000	0,000	1,000	1,000
0,063	0,067	1,018	1,020	0,000	0,717	1,000	1,000
0,063	0,061	1,027	1,017	0,000	0,218	1,000	1,000
0,062	0,062	1,017	1,017	0,639	0,639	1,000	1,000
0,065	0,069	1,021	1,023	4,210	3,696	0,000	0,211
0,082	0,080	1,029	1,029	1,801	2,315	1,000	0,773
0,108	0,108	1,078	1,078	0,000	0,000	0,000	0,000
0,174	0,166	1,232	1,165	0,000	0,000	0,000	0,000
0,155	0,160	1,107	1,114	1,788	2,574	0,000	0,006
0,167	0,160	1,124	1,115	3,427	2,660	0,000	0,006
0,152	0,087	1,103	1,075	4,431	5,754	0,000	0,000
0,042	0,051	1,010	1,009	0,000	0,530	1,000	1,000
0,051	0,051	1,009	1,009	0,529	0,544	1,000	0,996
0,191	0,166	1,216	1,164	0,232	0,231	0,000	0,000
0,110	0,110	1,047	1,048	0,000	0,001	0,000	0,000
0,116	0,116	1,246	1,165	5,418	5,416	0,000	0,000
0,074	0,062	1,031	1,030	2,071	1,474	1,000	0,774
0,081	0,053	1,062	1,015	3,770	1,237	1,000	0,800
0,097	0,080	1,038	1,030	0,000	1,361	1,000	0,598
0,168	0,154	1,112	1,087	0,000	1,239	0,000	0,000
0,156	0,154	1,089	1,088	1,323	1,256	0,000	0,001
0,129	0,140	1,103	1,085	0,000	0,873	0,000	0,000
0,144	0,143	1,062	1,073	0,222	0,630	0,000	0,000
0,133	0,133	1,109	1,106	2,569	2,100	0,000	0,000
0,070	0,069	1,021	1,020	0,000	0,723	1,000	1,000
0,069	0,069	1,020	1,020	0,723	0,723	1,000	1,000
0,096	0,096	1,102	1,102	0,000	0,000	0,000	0,000
0,034	0,035	1,008	1,008	0,377	0,359	1,000	1,000
0,045	0,044	1,006	1,006	0,000	0,018	1,000	1,000
0,090	0,093	1,199	1,161	2,122	2,136	0,000	0,000
0,088	0,088	1,193	1,165	2,602	2,601	0,000	0,000
0,030	0,030	1,011	1,011	0,000	0,000	1,000	1,000
0,030	0,030	1,001	1,001	4,039	4,039	0,000	0,000
0,030	0,030	1,001	1,001	0,000	0,000	1,000	1,000
0,090	0,087	1,041	1,038	2,840	2,709	1,000	1,000
0,080	0,082	1,031	1,033	2,330	2,465	1,000	0,999
0,050	0,050	1,011	1,011	0,000	0,000	1,000	1,000

(1) Act. (1/σ)	(1) Net. (1/σ)	(2) Act. ($\tilde{T}/T$)	(2) Net. ($\tilde{T}/T$)	(3) Act. ($\tilde{\zeta}_0$)	(3) Net. ($\tilde{\zeta}_0$)	(4) Act. (Negl.)	(4) Net. (Negl.)
0,050	0,050	1,011	1,011	0,000	0,000	1,000	1,000
0,050	0,050	1,011	1,011	0,090	0,060	1,000	1,000
0,050	0,050	1,011	1,011	0,000	0,046	1,000	1,000
0,040	0,040	1,021	1,021	4,819	4,819	0,000	0,000
0,040	0,040	1,011	1,011	3,290	3,290	1,000	1,000
0,050	0,050	1,011	1,011	1,030	1,928	1,000	0,841
0,050	0,050	1,011	1,011	6,839	6,837	0,000	0,000
0,050	0,050	1,011	1,011	1,020	1,002	1,000	1,000
0,050	0,050	1,011	1,011	0,340	0,359	1,000	1,000
0,120	0,123	1,111	1,107	2,410	5,101	0,000	0,372
0,060	0,060	1,041	1,041	0,000	0,000	1,000	1,000

Table App. E2. Actual and program outputs for Model 4

(1) Act. (1/σ)	(1) Net. (1/σ)	(2) Act. ($\tilde{T}/T$)	(2) Net. ($\tilde{T}/T$)	(3) Act. ($\tilde{\zeta}_0$)	(3) Net. ($\tilde{\zeta}_0$)	(4) Act. (Negl.)	(4) Net. (Negl.)
0,082	0,086	1,034	1,037	4,759	3,827	0,000	0,524
0,079	0,080	1,030	1,031	0,111	0,221	1,000	0,987
0,090	0,086	1,041	1,037	3,811	3,506	1,000	0,618
0,086	0,086	1,036	1,036	0,000	1,416	1,000	0,872
0,143	0,126	1,106	1,145	4,226	2,526	0,000	0,056
0,141	0,134	1,178	1,154	11,441	7,541	0,000	0,000
0,122	0,129	1,135	1,145	6,259	6,991	0,000	0,002
0,120	0,121	1,073	1,069	4,217	3,761	0,000	0,000
0,126	0,125	1,050	1,054	1,479	1,934	0,000	0,000
0,074	0,073	1,034	1,034	0,000	0,039	1,000	1,000
0,041	0,070	1,011	1,031	0,626	0,266	1,000	1,000
0,058	0,058	1,021	1,020	2,936	2,420	1,000	1,000
0,056	0,057	1,017	1,017	0,000	0,482	1,000	1,000
0,090	0,090	1,064	1,064	1,526	1,541	1,000	0,997
0,093	0,093	1,030	1,030	0,315	0,315	1,000	1,000
0,086	0,086	1,039	1,039	1,002	1,002	1,000	1,000
0,062	0,062	1,014	1,014	1,440	1,440	1,000	1,000
0,069	0,067	1,030	1,029	0,350	0,612	1,000	1,000
0,074	0,070	1,023	1,021	0,693	0,980	1,000	1,000
0,061	0,062	1,024	1,025	1,728	1,466	1,000	1,000
0,065	0,069	1,018	1,020	1,370	1,083	1,000	1,000
0,083	0,082	1,025	1,024	0,000	0,002	1,000	1,000
0,077	0,086	1,029	1,025	0,076	1,011	1,000	0,999
0,086	0,086	1,025	1,025	1,012	1,005	1,000	1,000
0,070	0,081	1,024	1,022	0,000	0,260	1,000	1,000
0,079	0,079	1,022	1,022	0,000	0,007	1,000	1,000
0,043	0,043	1,009	1,008	0,000	0,663	1,000	1,000
0,042	0,043	1,007	1,008	1,515	0,850	1,000	1,000

(1) Act. (1/σ)	(1) Net. (1/σ)	(2) Act. ($\tilde{T}/T$)	(2) Net. ($\tilde{T}/T$)	(3) Act. ($\tilde{\zeta}_0$)	(3) Net. ($\tilde{\zeta}_0$)	(4) Act. (Negl.)	(4) Net. (Negl.)
0,147	0,142	1,143	1,144	0,174	0,360	0,000	0,000
0,058	0,058	1,036	1,036	4,236	4,236	0,000	0,000
0,053	0,053	1,030	1,030	4,194	4,194	0,000	0,000
0,145	0,145	1,047	1,047	0,588	0,594	0,000	0,003
0,183	0,166	1,155	1,155	8,960	8,283	0,000	0,000
0,082	0,085	1,068	1,073	4,855	5,442	0,000	0,000
0,100	0,096	1,097	1,092	12,253	7,707	0,000	0,000
0,084	0,075	1,052	1,061	10,559	6,444	0,000	0,040
0,079	0,079	1,063	1,063	12,304	8,279	0,000	0,000
0,093	0,093	1,065	1,065	3,891	3,898	1,000	0,997
0,167	0,166	1,060	1,060	0,000	0,000	0,000	0,000
0,153	0,153	1,148	1,148	6,620	6,611	0,000	0,003
0,165	0,153	1,119	1,148	13,397	6,613	0,000	0,001
0,063	0,063	1,023	1,023	0,000	0,001	1,000	1,000
0,060	0,063	1,021	1,023	0,000	0,001	1,000	1,000
0,127	0,127	1,114	1,114	1,038	1,038	0,000	0,000
0,095	0,095	1,050	1,050	8,164	8,017	0,000	0,025
0,081	0,073	1,043	1,035	1,033	0,293	1,000	0,943
0,079	0,075	1,028	1,025	1,726	1,604	1,000	1,000
0,068	0,069	1,031	1,032	0,000	0,097	1,000	0,983
0,068	0,070	1,021	1,022	0,000	0,917	1,000	1,000
0,077	0,072	1,039	1,034	0,000	0,246	1,000	0,954
0,074	0,072	1,024	1,023	2,717	1,403	1,000	1,000
0,067	0,070	1,030	1,032	0,000	0,145	1,000	0,974
0,063	0,068	1,018	1,021	0,000	0,654	1,000	1,000
0,063	0,061	1,027	1,023	0,000	0,057	1,000	0,993
0,062	0,062	1,017	1,017	0,639	0,638	1,000	1,000
0,065	0,074	1,021	1,028	4,210	2,927	0,000	0,401
0,082	0,078	1,029	1,029	1,801	2,339	1,000	0,674
0,108	0,108	1,078	1,078	0,000	0,000	0,000	0,000
0,174	0,166	1,232	1,165	0,000	0,000	0,000	0,000
0,155	0,160	1,107	1,115	1,788	2,550	0,000	0,000
0,167	0,161	1,124	1,116	3,427	2,665	0,000	0,000
0,152	0,094	1,103	1,087	4,431	7,482	0,000	0,000
0,042	0,051	1,010	1,009	0,000	0,529	1,000	1,000
0,051	0,051	1,009	1,009	0,529	0,529	1,000	1,000
0,191	0,164	1,216	1,159	0,232	0,221	0,000	0,000
0,110	0,113	1,047	1,053	0,000	0,011	0,000	0,000
0,116	0,111	1,246	1,155	5,418	5,075	0,000	0,063
0,074	0,054	1,031	1,052	2,071	1,478	1,000	0,720
0,081	0,080	1,062	1,048	3,770	2,748	1,000	0,938
0,097	0,082	1,038	1,030	0,000	1,277	1,000	0,610
0,168	0,147	1,112	1,083	0,000	1,475	0,000	0,049
0,156	0,146	1,089	1,082	1,323	1,512	0,000	0,053
0,129	0,136	1,103	1,078	0,000	1,078	0,000	0,036
0,144	0,141	1,062	1,078	0,222	1,005	0,000	0,000

(1) Act. (1/σ)	(1) Net. (1/σ)	(2) Act. ($\tilde{T}/T$)	(2) Net. ($\tilde{T}/T$)	(3) Act. ($\tilde{\zeta}_0$)	(3) Net. ($\tilde{\zeta}_0$)	(4) Act. (Negl.)	(4) Net. (Negl.)
0,133	0,137	1,109	1,093	2,569	1,786	0,000	0,000
0,070	0,069	1,021	1,020	0,000	0,723	1,000	1,000
0,069	0,069	1,020	1,020	0,723	0,723	1,000	1,000
0,096	0,096	1,102	1,102	0,000	0,000	0,000	0,000
0,034	0,036	1,008	1,008	0,377	0,294	1,000	1,000
0,045	0,042	1,006	1,007	0,000	0,082	1,000	1,000
0,090	0,090	1,199	1,164	2,122	2,297	0,000	0,000
0,088	0,091	1,193	1,164	2,602	2,322	0,000	0,000
0,030	0,035	1,011	1,020	0,000	0,354	1,000	0,934
0,030	0,030	1,001	1,001	4,039	3,934	0,000	0,026
0,030	0,030	1,001	1,001	0,000	0,096	1,000	0,977
0,090	0,087	1,041	1,038	2,840	2,705	1,000	0,998
0,080	0,083	1,031	1,034	2,330	2,569	1,000	0,983
0,050	0,050	1,011	1,011	0,000	0,000	1,000	1,000
0,050	0,050	1,011	1,011	0,000	0,000	1,000	1,000
0,050	0,050	1,011	1,011	0,090	0,049	1,000	1,000
0,050	0,050	1,011	1,011	0,000	0,042	1,000	1,000
0,040	0,040	1,021	1,020	4,819	4,810	0,000	0,006
0,040	0,040	1,011	1,011	3,290	3,299	1,000	0,994
0,050	0,050	1,011	1,011	1,030	1,239	1,000	0,955
0,050	0,050	1,011	1,011	6,839	5,034	0,000	0,281
0,050	0,050	1,011	1,011	1,020	1,215	1,000	0,959
0,050	0,050	1,011	1,011	0,340	1,955	1,000	0,757
0,120	0,138	1,111	1,077	2,410	1,370	0,000	0,128
0,060	0,060	1,041	1,041	0,000	0,000	1,000	1,000

Table App. E3. Actual and program outputs for Model 5

(1) Act. (1/σ)	(1) Net. (1/σ)	(2) Act. ($\tilde{T}/T$)	(2) Net. ($\tilde{T}/T$)	(3) Act. ($\tilde{\zeta}_0$)	(3) Net. ($\tilde{\zeta}_0$)	(4) Act. (Negl.)	(4) Net. (Negl.)
0,082	0,084	1,034	1,035	4,759	3,438	0,000	0,477
0,079	0,081	1,030	1,032	0,111	1,109	1,000	0,848
0,090	0,086	1,041	1,037	3,811	2,835	1,000	0,780
0,086	0,086	1,036	1,036	0,000	1,651	1,000	0,886
0,143	0,135	1,106	1,117	4,226	3,158	0,000	0,000
0,141	0,135	1,178	1,155	11,441	7,668	0,000	0,000
0,122	0,127	1,135	1,144	6,259	6,874	0,000	0,000
0,120	0,121	1,073	1,070	4,217	3,910	0,000	0,000
0,126	0,125	1,050	1,053	1,479	1,789	0,000	0,000
0,074	0,073	1,034	1,033	0,000	0,011	1,000	1,000
0,041	0,058	1,011	1,019	0,626	0,215	1,000	1,000
0,058	0,058	1,021	1,021	2,936	2,699	1,000	1,000
0,056	0,057	1,017	1,017	0,000	0,075	1,000	1,000
0,090	0,090	1,064	1,064	1,526	1,526	1,000	1,000

(1) Act. (1/σ)	(1) Net. (1/σ)	(2) Act. ($\tilde{T}/T$)	(2) Net. ($\tilde{T}/T$)	(3) Act. ($\tilde{\zeta}_0$)	(3) Net. ($\tilde{\zeta}_0$)	(4) Act. (Negl.)	(4) Net. (Negl.)
0,093	0,093	1,030	1,030	0,315	0,315	1,000	1,000
0,086	0,086	1,039	1,039	1,002	1,012	1,000	1,000
0,062	0,062	1,014	1,015	1,440	1,425	1,000	1,000
0,069	0,068	1,030	1,029	0,350	0,433	1,000	1,000
0,074	0,073	1,023	1,022	0,693	0,764	1,000	1,000
0,061	0,061	1,024	1,024	1,728	1,659	1,000	1,000
0,065	0,066	1,018	1,019	1,370	1,292	1,000	1,000
0,083	0,083	1,025	1,025	0,000	0,000	1,000	1,000
0,077	0,077	1,029	1,029	0,076	0,124	1,000	1,000
0,086	0,085	1,025	1,025	1,012	0,932	1,000	1,000
0,070	0,074	1,024	1,023	0,000	0,083	1,000	1,000
0,079	0,079	1,022	1,021	0,000	0,028	1,000	1,000
0,043	0,043	1,009	1,008	0,000	0,607	1,000	1,000
0,042	0,042	1,007	1,008	1,515	0,908	1,000	1,000
0,147	0,146	1,143	1,141	0,174	0,209	0,000	0,000
0,058	0,058	1,036	1,036	4,236	4,236	0,000	0,000
0,053	0,053	1,030	1,030	4,194	4,194	0,000	0,000
0,145	0,145	1,047	1,047	0,588	0,588	0,000	0,000
0,183	0,166	1,155	1,155	8,960	8,283	0,000	0,000
0,082	0,084	1,068	1,072	4,855	5,325	0,000	0,000
0,100	0,097	1,097	1,093	12,253	7,827	0,000	0,000
0,084	0,079	1,052	1,063	10,559	8,169	0,000	0,000
0,079	0,079	1,063	1,063	12,304	8,275	0,000	0,000
0,093	0,093	1,065	1,065	3,891	3,891	1,000	1,000
0,167	0,166	1,060	1,060	0,000	0,000	0,000	0,000
0,153	0,153	1,148	1,148	6,620	6,617	0,000	0,000
0,165	0,165	1,119	1,119	13,397	8,282	0,000	0,000
0,063	0,062	1,023	1,022	0,000	0,044	1,000	1,000
0,060	0,061	1,021	1,022	0,000	0,055	1,000	1,000
0,127	0,127	1,114	1,114	1,038	1,038	0,000	0,000
0,095	0,095	1,050	1,050	8,164	8,159	0,000	0,001
0,081	0,078	1,043	1,040	1,033	0,629	1,000	1,000
0,079	0,076	1,028	1,026	1,726	1,526	1,000	1,000
0,068	0,072	1,031	1,034	0,000	0,170	1,000	1,000
0,068	0,072	1,021	1,023	0,000	0,833	1,000	1,000
0,077	0,076	1,039	1,038	0,000	0,233	1,000	1,000
0,074	0,074	1,024	1,024	2,717	1,964	1,000	1,000
0,067	0,068	1,030	1,031	0,000	0,002	1,000	1,000
0,063	0,064	1,018	1,018	0,000	0,177	1,000	1,000
0,063	0,064	1,027	1,026	0,000	0,008	1,000	1,000
0,062	0,062	1,017	1,017	0,639	0,638	1,000	1,000
0,065	0,068	1,021	1,023	4,210	3,808	0,000	0,167
0,082	0,080	1,029	1,028	1,801	2,203	1,000	0,833
0,108	0,108	1,078	1,078	0,000	0,000	0,000	0,000
0,174	0,166	1,232	1,165	0,000	0,000	0,000	0,000
0,155	0,160	1,107	1,115	1,788	2,586	0,000	0,000

(1) Act. (1/σ)	(1) Net. (1/σ)	(2) Act. ($\tilde{T}/T$)	(2) Net. ($\tilde{T}/T$)	(3) Act. ($\tilde{\zeta}_0$)	(3) Net. ($\tilde{\zeta}_0$)	(4) Act. (Negl.)	(4) Net. (Negl.)
0,167	0,161	1,124	1,115	3,427	2,629	0,000	0,000
0,152	0,139	1,103	1,104	4,431	3,691	0,000	0,015
0,042	0,043	1,010	1,009	0,000	0,095	1,000	1,000
0,051	0,049	1,009	1,009	0,529	0,434	1,000	1,000
0,191	0,166	1,216	1,164	0,232	0,231	0,000	0,000
0,110	0,111	1,047	1,048	0,000	0,001	0,000	0,000
0,116	0,116	1,246	1,165	5,418	5,414	0,000	0,000
0,074	0,074	1,031	1,031	2,071	2,071	1,000	1,000
0,081	0,081	1,062	1,061	3,770	3,679	1,000	1,000
0,097	0,097	1,038	1,038	0,000	0,091	1,000	1,000
0,168	0,156	1,112	1,089	0,000	1,323	0,000	0,000
0,156	0,156	1,089	1,089	1,323	1,323	0,000	0,000
0,129	0,141	1,103	1,088	0,000	0,961	0,000	0,002
0,144	0,144	1,062	1,066	0,222	0,365	0,000	0,000
0,133	0,134	1,109	1,106	2,569	2,394	0,000	0,000
0,070	0,069	1,021	1,020	0,000	0,723	1,000	1,000
0,069	0,069	1,020	1,020	0,723	0,723	1,000	1,000
0,096	0,096	1,102	1,102	0,000	0,000	0,000	0,000
0,034	0,034	1,008	1,008	0,377	0,368	1,000	1,000
0,045	0,044	1,006	1,006	0,000	0,008	1,000	1,000
0,090	0,090	1,199	1,165	2,122	2,202	0,000	0,000
0,088	0,089	1,193	1,165	2,602	2,522	0,000	0,000
0,030	0,030	1,011	1,011	0,000	0,003	1,000	0,999
0,030	0,030	1,001	1,001	4,039	4,027	0,000	0,003
0,030	0,030	1,001	1,001	0,000	0,010	1,000	0,997
0,090	0,087	1,041	1,037	2,840	2,678	1,000	1,000
0,080	0,083	1,031	1,034	2,330	2,494	1,000	1,000
0,050	0,050	1,011	1,011	0,000	0,000	1,000	1,000
0,050	0,050	1,011	1,011	0,000	0,000	1,000	1,000
0,050	0,050	1,011	1,011	0,090	0,051	1,000	1,000
0,050	0,050	1,011	1,011	0,000	0,042	1,000	1,000
0,040	0,040	1,021	1,020	4,819	4,761	0,000	0,038
0,040	0,040	1,011	1,011	3,290	3,348	1,000	0,962
0,050	0,050	1,011	1,011	1,030	1,032	1,000	0,999
0,050	0,050	1,011	1,011	6,839	6,501	0,000	0,052
0,050	0,050	1,011	1,011	1,020	1,022	1,000	1,000
0,050	0,050	1,011	1,011	0,340	0,673	1,000	0,949
0,120	0,120	1,111	1,111	2,410	2,410	0,000	0,000
0,060	0,060	1,041	1,041	0,000	0,000	1,000	1,000

Appendix F. Error Through Patterns Graphs for Model 3,4 and 5.

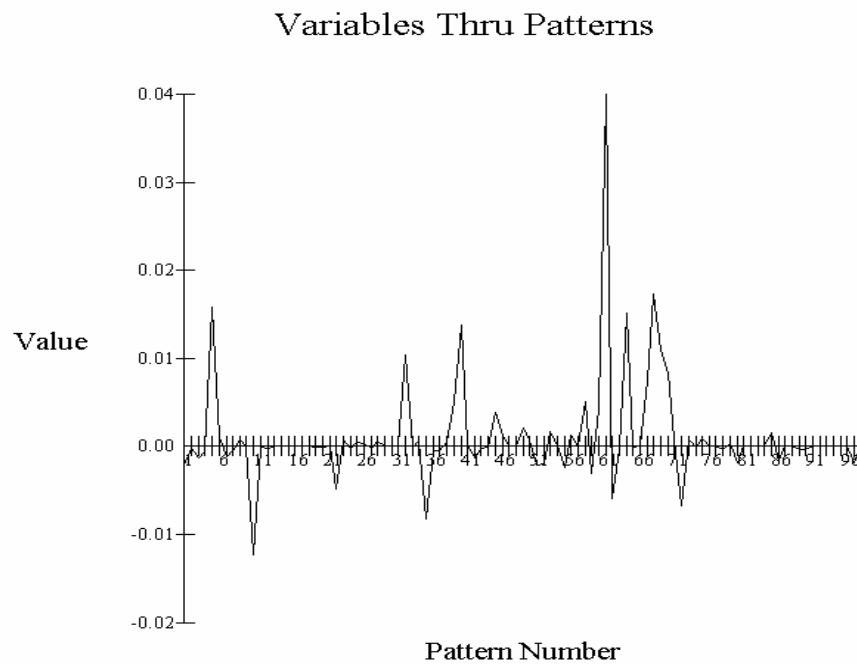


Figure App. F1. Error through patterns for act-net ($1/\sigma$) for Model 3

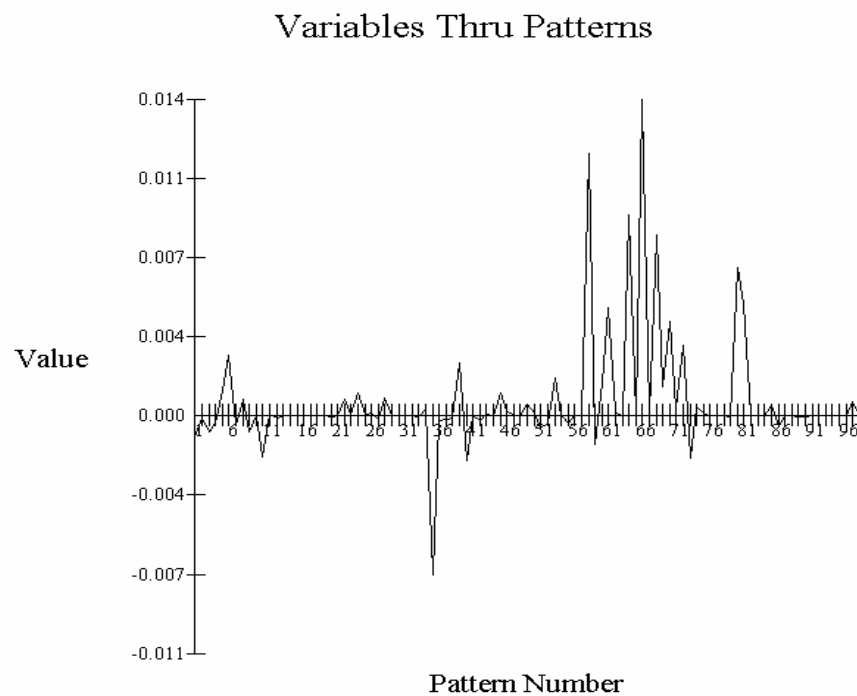


Figure App. F2. Error through patterns for act-net (Period Lengthening) for Model 3

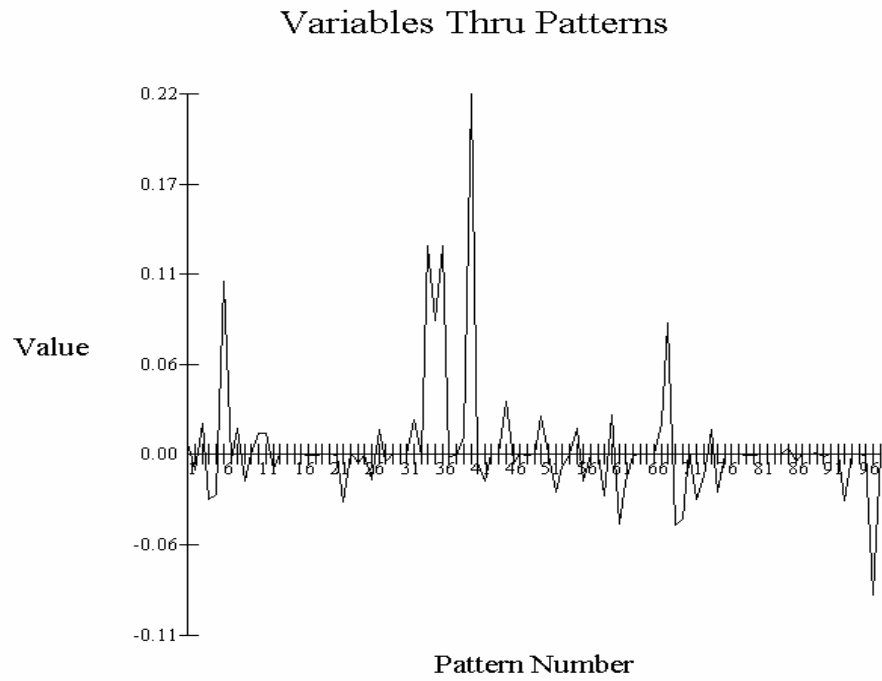


Figure App. F3. Error through patterns for act-net (Foundation Damping) for Model 3

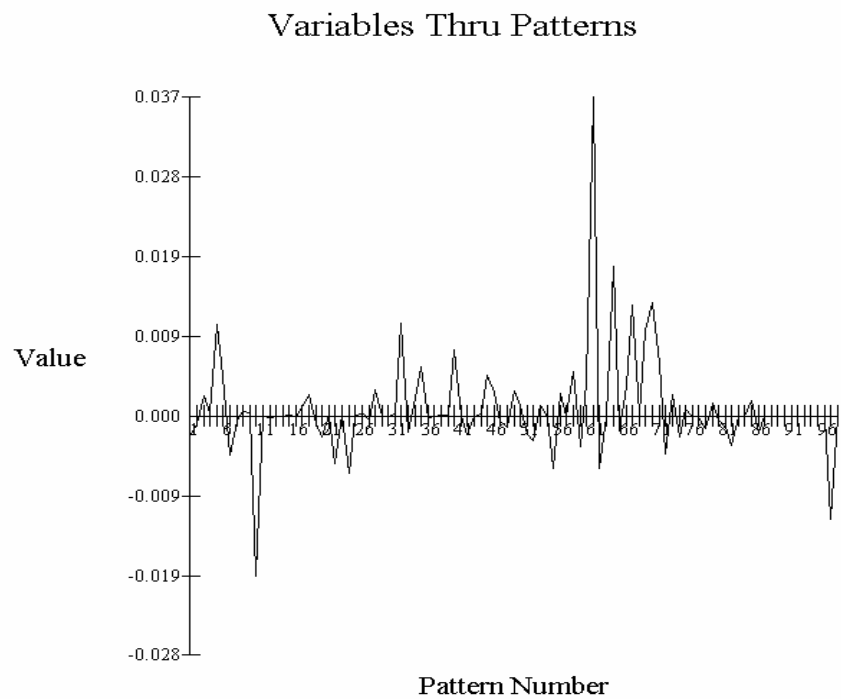


Figure App. F4. Error through patterns for act-net ($1/\sigma$) for Model 4

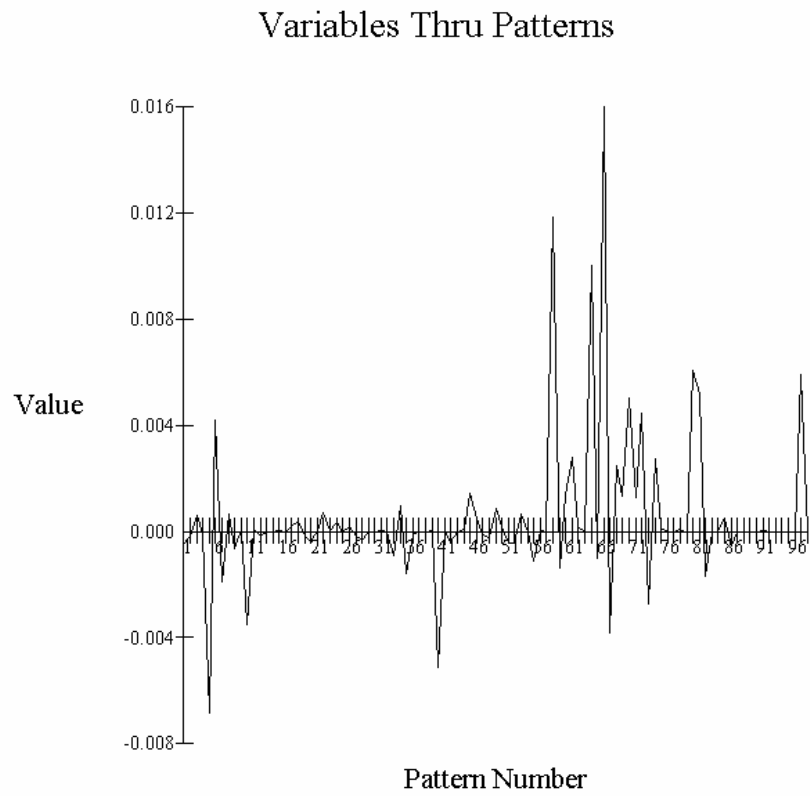


Figure App. F5. Error through patterns for act-net (Period Lengthening) for Model 4

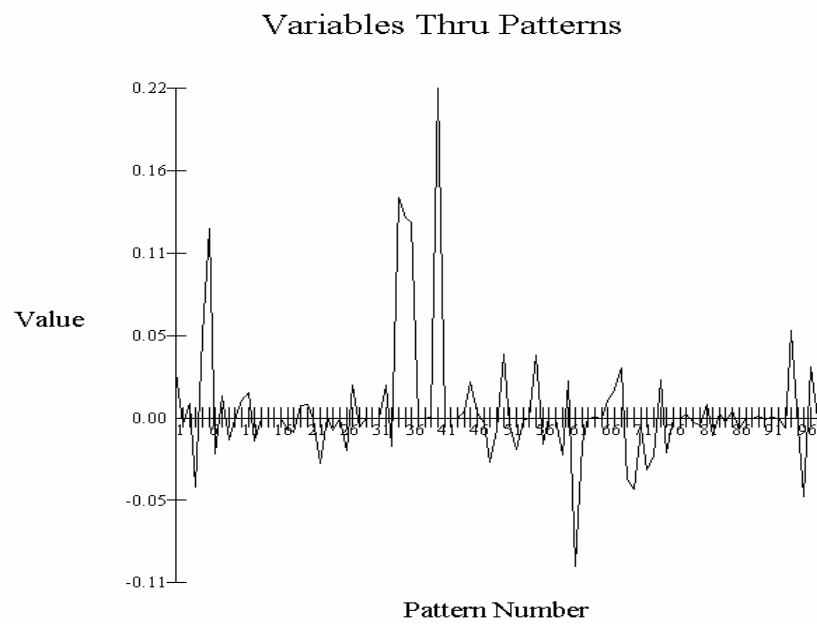


Figure App. F6. Error through patterns for act-net (Foundation Damping) for Model 4

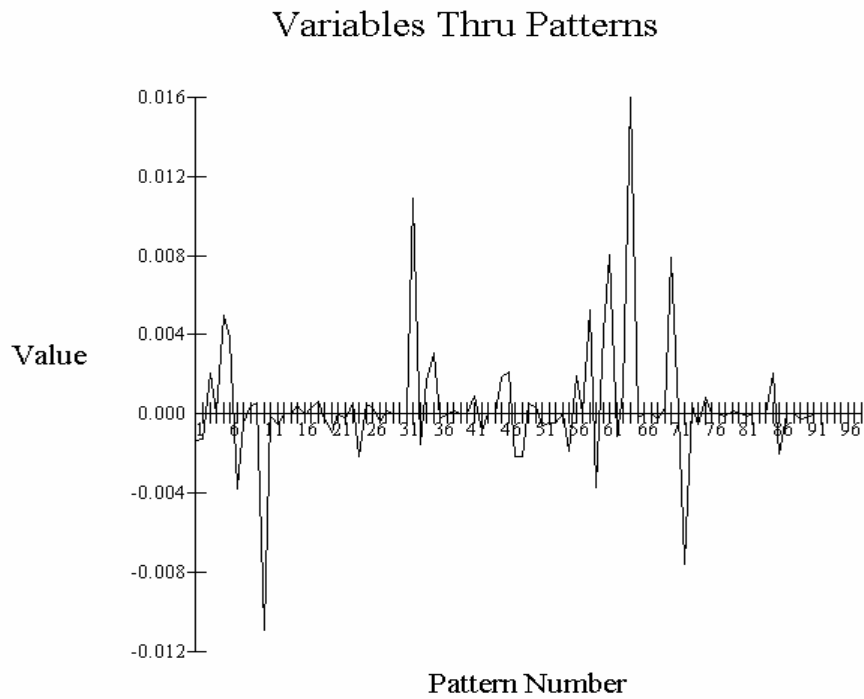


Figure App. F7. Error through patterns for act-net ($1/\sigma$) for Model 5

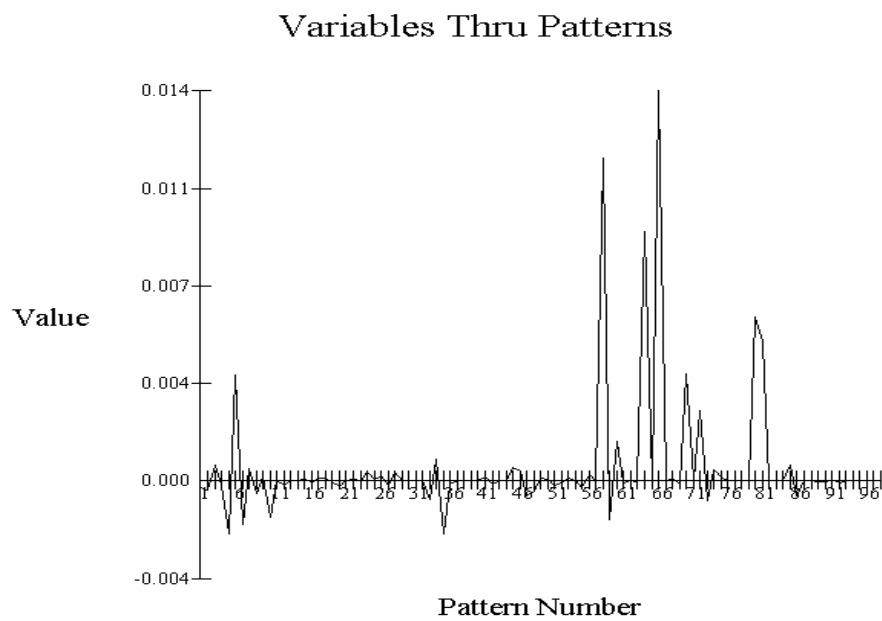


Figure App. F8. Error through patterns for act-net (Period Lengthening) for Model 5

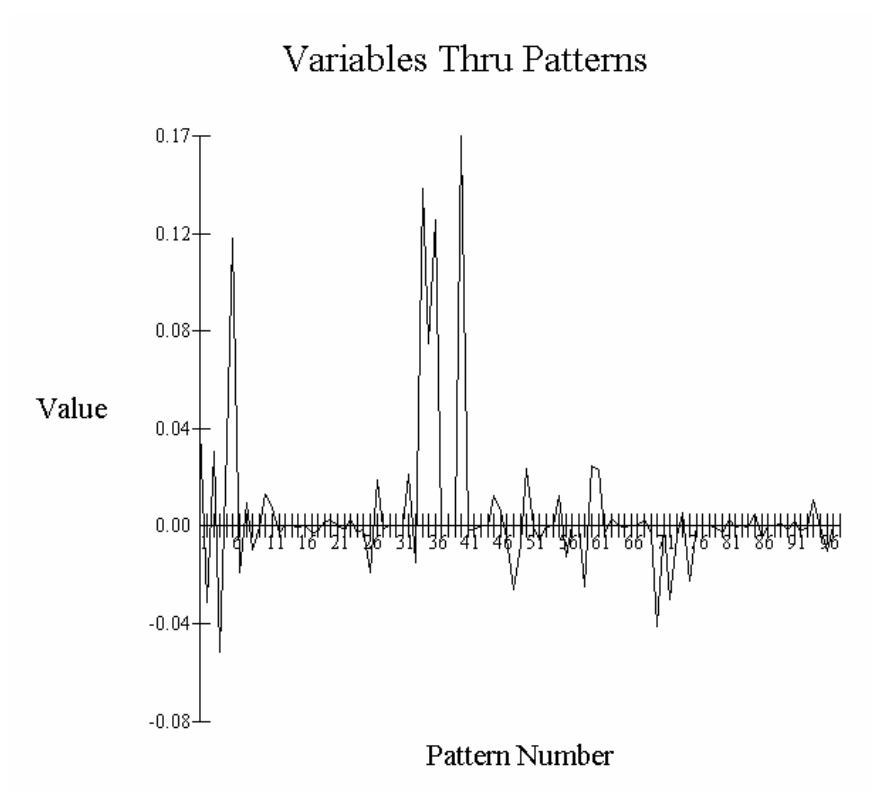


Figure App. F9. Error through patterns for act-net (Foundation Damping) for Model 5

Appendix G. Site Properties

Table App. G1. Site properties 1

Site	Station	Epk.	Rock/Soil	Piles (Y/N)	NO.Stories	Structural system	Basement (Y/N)
A35(tr)	Pomona 2-St	UP	S	Y	2	CF	Y
A35(L)	Pomona 2-St	UP	S	Y	2	CF	Y
A35(tr)	Pomona 2-St	WT	S	Y	2	CF	Y
A35(L)	Pomona 2-St	WT	S	Y	2	CF	Y
A14(tr)	Lancaster 3-st	WT	S	Y	3	SW	N
A17(tr)	Loma Linda VA	NR	S	Y	4	SW	N
A17(L)	Loma Linda VA	NR	S	Y	4	SW	N
A13(tr)	Indio 4-St	LD	S	Y	4	DWF	Y
A13(L)	Indio 4-St	LD	S	Y	4	DWF	Y
A41(tr)	San Bern.CGC	NR	S	Y	5	SF	N
A41(L)	San Bern.CGC	NR	S	Y	5	SF	N
A15(tr)	Lancaster 5-st	NR	S	Y	5	SF	N
A15(L)	Lancaster 5-st	NR	S	Y	5	SF	N
A24(tr)	LA 6-St. Garage	NR	S	Y	6	SW	N
A24(L)	LA 6-St. Garage	NR	S	Y	6	SW	N
A12(tr)	El Centro Bldg	IMP	S	Y	6	DWF	N
A12(L)	El Centro Bldg	IMP	S	Y	6	DWF	N
A30(tr)	LA Wadsworth	NR	S	Y	6	SF	Y
A32(L)	Norwalk 12400	WT	S	Y	7	SF	Y
A33(tr)	Norwalk 12440	WT	S	Y	7	SF	Y
A33(L)	Norwalk 12440	WT	S	Y	7	SF	Y
A33(tr)	Norwalk 12440	NR	S	Y	7	SF	Y
A33(L)	Norwalk 12440	NR	S	Y	7	SF	Y
A18(L)	Long Beach 7-St	WT	S	Y	7	SF	N
A43(tr)	Seal Beach 8-St	NR	S	Y	8	BI	Y
A43(L)	Seal Beach 8-St	NR	S	Y	8	BI	Y
A43(tr)	Seal Beach 8-St	LD	S	Y	8	BI	Y
A43(L)	Seal Beach 8-St	LD	S	Y	8	BI	Y
A40(tr)	San Bern. 9-St	LD	S	Y	9	SF	N
A40(L)	San Bern. 9-St	LD	S	Y	9	SF	N
A45(tr)	Ventura 12-St	NR	S	Y	12	SW	N
A29(tr)	LA Hollywood SB	WT	S	Y	14	CF	Y
A29(tr)	LA Hollywood SB	NR	S	Y	14	CF	Y
A29(L)	LA Hollywood SB	NR	S	Y	14	CF	Y
A4(tr)	Emeryville PPP	LP	S	Y	31	CF	N
A4(L)	Emeryville PPP	LP	S	Y	31	CF	N
B5(tr)	San Jose 10-st	LP	S	Y	47	SF	N
A46(tr)	Lotung Reactor	LD	S	N	1	SW	Y
A46(L)	Lotung Reactor	LD	S	N	1	SW	Y

Site	Station	Eqk.	Rock/Soil	Piles (Y/N)	NO.Stories	Structural system	Basement (Y/N)
A2(tr)	Fortuna M.	PTA	S	N	1	SW	N
A2(L)	Fortuna M.	PTA	S	N	1	SW	N
A7(tr)	Hollister 1-st	LP	S	N	1	SW	N
A2(tr)	Fortuna M.	PT	S	N	1	SW	N
A2(L)	Fortuna M.	PT	S	N	1	SW	N
A9(tr)	PVPP	CGA	S	N	1	DWF	Y
B1(tr)	Milpitas 2-St	LP	S	N	2	SW	N
A10(tr)	Richmond CH	LP	S	N	3	DWF	Y
A10(L)	Richmond CH	LP	S	N	3	DWF	Y
A38(tr)	San Bern. 3-St	LD	S	N	3	SF	N
A38(L)	San Bern. 3-St	LD	S	N	3	SF	N
A34(tr)	Palmdale 4-St	NR	S	N	4	SW	N
A34(L)	Palmdale 4-St	NR	S	N	4	SW	N
A37(tr)	Rancho Cuc. LJC	RD	S	N	4	BI	Y
A37(L)	Rancho Cuc. LJC	RD	S	N	4	BI	Y
A37(tr)	Rancho Cuc. LJC	UP	S	N	4	BI	Y
A37(L)	Rancho Cuc. LJC	UP	S	N	4	BI	Y
A37(tr)	Rancho Cuc. LJC	WT	S	N	4	BI	Y
A37(L)	Rancho Cuc. LJC	WT	S	N	4	BI	Y
A37(tr)	Rancho Cuc. LJC	NR	S	N	4	BI	Y
A37(L)	Rancho Cuc. LJC	NR	S	N	4	BI	Y
A37(tr)	Rancho Cuc. LJC	LD	S	N	4	BI	Y
A37(L)	Rancho Cuc. LJC	LD	S	N	4	BI	Y
A39(tr)	San Bern. 5-St	NR	S	N	5	SW	Y
A1(tr)	Eurake Apts.	PT	S	N	5	SW	N
A1(L)	Eurake Apts.	PT	S	N	5	SW	N
A39(L)	San Bern. 5-St	NR	S	N	5	SW	Y
A23(tr)	LA 6-St. Bldg	NR	S	N	5	SF	Y
A16(tr)	Lancaster Airfield	NR	S	N	5	SF	N
A16(L)	Lancaster Airfield	NR	S	N	5	SF	N
A44(tr)	Sylmar Hos.	WT	S	N	6	SW	N
A44(L)	Sylmar Hos.	WT	S	N	6	SW	N
A44(tr)	Sylmar Hos.	NR	S	N	6	SW	N
A44(L)	Sylmar Hos.	NR	S	N	6	SW	N
A36(tr)	Pomona 6-St.	LD	S	N	6	CF	Y
A36(L)	Pomona 6-St.	LD	S	N	6	CF	Y
A26(tr)	LA 7-St. Bldg.	NR	S	N	7	DWF	N
A26(L)	LA 7-St. Bldg.	NR	S	N	7	DWF	N
B14(tr)	Whittier 8-St.	NR	S	N	8	SW	N
B2(tr)	San Bruno 9-St	LP	S	N	9	SW	N
B10(tr)	LA 9-St.	NR	S	N	9	DWF	Y
B10(L)	LA 9-St.	NR	S	N	9	DWF	Y
A20(tr)	Long Beach VA	N R	S	N	11	SW	Y
A20(L)	Long Beach VA	NR	S	N	11	SW	Y

Site	Station	Eqk.	Rock/Soil	Piles (Y/N)	NO.Stories	Structural system	Basement (Y/N)
A31(tr)	Newport Beach	NR	S	N	11	SW	N
A31(L)	Newport Beach	NR	S	N	11	SW	N
A31(tr)	Newport Beach	LD	S	N	11	SW	N
B6(tr)	San Jose 13-st	LP	S	N	12	SF	Y
B6(L)	San Jose 13-st	LP	S	N	12	SF	Y
B7(tr)	Walnut Crk 10-St.	LP	R	Y	10	DWF	N
A5(tr)	Hayward city hall	LP	R	Y	11	DWF	Y
A5(L)	Hayward city hall	LP	R	Y	11	DWF	Y
B11(tr)	LA 17-St.	LD	R	Y	17	SW	N
B11(tr)	LA 17-St.	NR	R	Y	17	SW	N
A21(tr)	LA 2-St. FCCB	SM	R	N	2	BI	N
A21(L)	LA 2-St. FCCB	SM	R	N	2	BI	N
A21(tr)	LA 2-St. FCCB	NR	R	N	2	BI	N
A21(L)	LA 2-St. FCCB	NR	R	N	2	BI	N
A21(tr)	LA 2-St. FCCB	LD	R	N	2	BI	N
A21(L)	LA 2-St. FCCB	LD	R	N	2	BI	N
A8(tr)	Piedmont Jr. HS	LP	R	N	3	SW	N
A8(tr)	Piedmont Jr. HS	LP	R	N	3	SW	N
A11(tr)	San Jose 3-st	LP	R	N	3	SF	N
A11(L)	San Jose 3-st	LP	R	N	3	SF	N
A25(tr)	LA 7-St. Hos.	NR	R	N	7	BI	Y
A25(L)	LA 7-St. Hos.	NR	R	N	7	BI	Y
A25(tr)	LA 7-St. Hos.	LD	R	N	7	BI	Y
A25(L)	LA 7-St. Hos.	LD	R	N	7	BI	Y
A42(tr)	Santa Susana	NR	R	N	8	SF	N
A42(L)	Santa Susana	NR	R	N	8	SF	N
A27(tr)	LA 15-St. Bldg.	NR	R	N	17	SF	N
A27(L)	LA 15-St. Bldg.	NR	R	N	17	SF	N
A27(tr)	LA 15-St. Bldg.	LD	R	N	17	SF	N
A27(L)	LA 15-St. Bldg.	LD	R	N	17	SF	N
B12(tr)	LA 32-St.	NR	R	N	32	DWF	Y
B13(tr)	LA 54-St.	NR	R	N	54	SF	Y

Table App. G2. Site properties 2

Site	Mw	MHA(g)	h(ft)	e(ft)	Vs (fps)	β (%)	γ	r1 (ft)	r2 (ft)	Tflex.(sec)	T (sec)	ζ flexible	ζ (%)	1/ σ	Period lengthening.	Foundation damping
A35(tr)	5,6	0,21	28	10,5	1178	3,2	0,15	59	57	0,29	0,29	9,20	4,90	0,08	1,03	4,76
A35(L)	5,6	0,21	28	10,5	1178	3,2	0,15	59	63	0,3	0,30	11,20	12,10	0,08	1,03	0,11
A35(tr)	6,0	0,06	28	10,5	1246	1,6	0,15	59	57	0,26	0,25	8,70	5,50	0,09	1,04	3,81
A35(L)	6,0	0,06	28	10,5	1246	1,6	0,15	59	63	0,27	0,26	5,80	8,60	0,09	1,04	0,00
A14(tr)	6,0	0,07	26	0	908	2,1	0,15	54	47	0,2	0,20	13,40	12,40	0,14	1,11	4,23
A17(tr)	6,7	0,06	50	0	1415	3,4	0,15	246	248	0,29	0,25	15	5,8	0,14	1,18	11,44
A17(L)	6,7	0,06	50	0	1415	3,4	0,15	246	250	0,32	0,29	10,1	5,6	0,12	1,13	6,26
A13(tr)	7,3	0,09	56	15,5	695	4,1	0,15	69	58	0,71	0,67	10,3	7,5	0,12	1,07	4,22
A13(L)	7,3	0,09	56	15,5	695	4,1	0,15	69	85	0,66	0,64	10,9	10,9	0,13	1,05	1,48
A41(tr)	6,7	0,04	38	0	1011	2,4	0,15	114	114	0,51	0,51	2,6	3,4	0,07	1,03	0,00
A41(L)	6,7	0,04	38	0	1011	2,4	0,15	114	114	0,93	0,91	4,5	4	0,04	1,01	0,63
A15(tr)	6,7	0,07	40	0	1001	2,5	0,15	99	83	0,73	0,69	10	7,5	0,06	1,02	2,94
A15(L)	6,7	0,07	40	0	1001	2,5	0,15	99	121	0,72	0,71	8,2	9,1	0,06	1,02	0,00
A24(tr)	6,7	0,22	40	0	870	7,3	0,15	159	154	0,52	0,51	6,6	6,1	0,09	1,06	1,53
A24(L)	6,7	0,22	40	0	640	6,2	0,15	54	47	0,44	0,28	6,1	6,5	0,22	1,22	2,52
A12(tr)	6,5	0,24	54	0	464	6,6	0,15	61	55	0,74	0,5	16	23,4	0,23	1,23	3,32
A12(L)	6,5	0,24	54	0	464	6,6	0,15	61	69	1,23	1,25	33,9	36,6	0,09	1,03	0,32
A30(tr)	6,7	0,25	78	17	981	6,3	0,15	189	199	1	0,92	9,3	9,3	0,09	1,04	1,00
A32(L)	6,0	0,23	70	13,5	730	6,8	0,15	93	106	1,48	1,54	9,6	8,5	0,06	1,01	1,44

Site	Mw	MHA(g)	h(ft)	e(ft)	Vs (fps)	β (%)	γ	r1 (ft)	r2 (ft)	Tflex.(sec)	T (sec)	ζ flexible	ζ (%)	1/ σ	Period lengthening.	Foundation damping
A33(tr)	6,0	0,23	72	15	794	7,3	0,15	142	105	1,32	1,32	2	1,8	0,07	1,03	0,35
A33(L)	6,0	0,23	72	15	794	7,3	0,15	142	195	1,2	1,22	3,5	3	0,07	1,02	0,69
A33(tr)	6,7	0,08	72	15	906	4	0,15	142	105	1,28	1,3	6,3	4,9	0,06	1,02	1,73
A33(L)	6,7	0,08	72	15	906	4	0,15	142	195	1,2	1,22	4,6	3,4	0,07	1,02	1,37
A18(L)	6,0	0,07	58	0	615	3,5	0,15	49	53	1,12	1,14	5,5	6,5	0,08	1,02	0,00
A43(tr)	6,7	0,08	83	16	911	2,3	0,15	103	90	1,21	1,18	6,6	7,1	0,08	1,03	0,08
A43(L)	6,7	0,08	83	16	911	2,3	0,15	103	121	1,09	1,06	9,1	8,7	0,09	1,02	1,01
A43(tr)	7,3	0,05	83	16	933	2,6	0,15	103	90	1,28	1,26	11,5	13,2	0,07	1,02	0,00
A43(L)	7,3	0,05	83	16	933	2,6	0,15	103	121	1,16	1,12	13,7	16,2	0,08	1,02	0,00
A40(tr)	7,3	0,1	74	0	848	3,4	0,15	55	52	2,01	2,01	5	6,8	0,04	1,01	0,00
A40(L)	7,3	0,1	74	0	848	3,4	0,15	55	59	2,05	2,08	7,4	6	0,04	1,01	1,51
A45(tr)	6,7	0,06	69	0	886	2,8	0,15	62	47	0,71	0,53	4	5,7	0,15	1,14	0,17
A29(tr)	6,0	0,21	96	9	930	2,8	0,15	59	42	1,8	1,77	9,1	5,4	0,06	1,04	4,24
A29(tr)	6,7	0,39	96	9	879	4,4	0,15	59	42	2,1	2,05	18,3	15,4	0,05	1,03	4,20
A29(L)	6,7	0,39	96	9	879	4,4	0,15	59	86	0,8	0,75	8	8,5	0,15	1,05	0,59
A4(tr)	6,9	0,25	218	0	448	6,8	0,15	87	94	2,5	2,45	13	7,4	0,20	1,18	8,48
A4(L)	6,9	0,25	218	0	448	6,8	0,15	87	94	2,58	2,65	12,8	5,9	0,18	1,15	8,96
B5(tr)	6,9	0,12	61	0	768	4,1	0,15	65	49	0,48	0,29	6,7	18,6	0,27	1,41	0,07

Site	M _w	MHA(g)	h(ft)	e(ft)	V _s (fps)	β(%)	γ	r ₁ (ft)	r ₂ (ft)	T _{flex} (sec)	T (sec)	ζ _{flexible}	ζ (%)	1/σ	Period lengthening.	Foundation damping
A46(tr)	7,3	0,11	47	15	275	9,7	0,15	16,3	16,3	0,49	0,12	30,6	3	1,42	5,31	30,58
A46(L)	7,3	0,11	47	15	275	9,7	0,15	16,3	16,3	0,45	0,11	31	3	1,55	5,78	30,98
A2(tr)	6,2	0,19	22	0	786	5,8	0,15	115	112	0,35	0,34	17,2	15	0,08	1,07	4,86
A2(L)	6,2	0,19	22	0	786	5,8	0,15	115	122	0,29	0,28	25,6	17,6	0,10	1,10	12,25
A7(tr)	6,9	0,36	30	0	502	7,7	0,15	97	75	0,73	0,71	26,9	19	0,08	1,05	10,56
A2(tr)	7,0	0,12	22	0	772	5,6	0,15	115	112	0,37	0,36	34	26	0,08	1,06	12,31
A2(L)	7,0	0,12	22	0	772	5,6	0,15	115	122	0,31	0,29	39,4	18	0,10	1,09	25,63
A9(tr)	5,4	0,21	48	32	970	3,2	0,15	53	37	0,53	0,53	8,2	5,2	0,09	1,06	3,89
B1(tr)	6,9	0,14	26	0	649	4,1	0,15	6,4	10,9	0,25	0,24	15,3	21,9	0,17	1,06	0,00
A10(tr)	6,9	0,13	33	10	768	3,7	0,15	75	54	0,3	0,28	9,2	3,9	0,15	1,15	6,62
A10(L)	6,9	0,13	33	10	768	3,7	0,15	75	106	0,27	0,26	14,4	1,4	0,17	1,12	13,40
A38(tr)	7,3	0,09	29	0	883	3,8	0,15	76	77	0,56	0,52	6,2	7,2	0,06	1,02	0,00
A38(L)	7,3	0,09	29	0	883	3,8	0,15	78	80	0,57	0,55	7,6	10,9	0,06	1,02	0,00
A34(tr)	6,7	0,08	24	0	1575	1,7	0,15	69	49	0,2	0,12	18,5	24,1	0,13	1,11	1,04
A34(L)	6,7	0,08	24	0	1575	1,7	0,15	69	100	0,2	0,16	12,4	4,9	0,10	1,05	8,17
A37(tr)	4,8	0,04	56	14	1172	1,4	0,15	120	87	0,6	0,59	4,3	3,7	0,08	1,04	1,03
A37(L)	4,8	0,04	56	14	1172	1,4	0,15	120	170	0,6	0,6	5,6	4,2	0,08	1,03	1,73
A37(tr)	5,6	0,24	56	14	1060	4,5	0,15	120	87	0,76	0,77	4,7	7,8	0,07	1,03	0,00
A37(L)	5,6	0,24	56	14	1060	4,5	0,15	120	170	0,75	0,77	6	6,7	0,07	1,02	0,00
A37(tr)	6,0	0,06	56	14	1157	1,7	0,15	120	87	0,65	0,63	4,4	5	0,08	1,04	0,00
A37(L)	6,0	0,06	56	14	1157	1,7	0,15	120	170	0,66	0,65	8,4	6,1	0,07	1,02	2,72

Site	M _w	MHA(g)	h(ft)	e(ft)	V _s (fps)	β(%)	γ	r ₁ (ft)	r ₂ (ft)	T _{flex} (sec)	T (sec)	ζ flexible	ζ (%)	1/σ	Period lengthening.	Foundation damping
A37(tr)	6,7	0,07	56	14	1114	2,8	0,15	120	87	0,76	0,75	4,6	6,9	0,07	1,03	0,00
A37(L)	6,7	0,07	56	14	1114	2,8	0,15	120	170	0,81	0,79	7,5	8,9	0,06	1,02	0,00
A37(tr)	7,3	0,11	56	14	1039	4,4	0,15	120	87	0,87	0,85	11,2	12,5	0,06	1,03	0,00
A37(L)	7,3	0,11	56	14	1039	4,4	0,15	120	170	0,89	0,87	17,2	17,4	0,06	1,02	0,64
A39(tr)	6,7	0,07	52	13	1233	2,6	0,15	95	86	0,63	0,65	9,1	5,2	0,06	1,02	4,21
A1(tr)	7,0	0,18	31	0	701	5,1	0,15	57	42	0,24	0,15	19,6	15,9	0,29	1,45	14,36
A1(L)	7,0	0,18	31	0	701	5,1	0,15	57	77	0,25	0,22	12,8	5,5	0,20	1,15	9,16
A39(L)	6,7	0,07	52	13	1233	2,6	0,15	95	107	0,5	0,51	7,5	6,2	0,08	1,03	1,80
A23(tr)	6,7	0,25	56	14	630	5,2	0,15	21,4	20,6	0,89	0,82	5,5	6,9	0,11	1,08	0,00
A16(tr)	6,7	0,08	45	6	953	1,7	0,15	11,9	11,9	0,34	0,27	9,9	24,5	0,17	1,23	0,00
A16(L)	6,7	0,08	45	6	953	1,7	0,15	11,9	11,9	0,33	0,24	8,9	13,6	0,20	1,29	2,50
A44(tr)	6,0	0,05	63	0	1506	1,9	0,15	126	132	0,3	0,27	9,1	9,9	0,15	1,11	1,79
A44(L)	6,0	0,05	63	0	1506	1,9	0,15	126	132	0,29	0,25	9,5	8,6	0,17	1,12	3,43
A44(tr)	6,7	0,84	63	0	1119	9,1	0,15	126	132	0,38	0,37	18,9	19,4	0,15	1,10	4,43
A44(L)	6,7	0,84	63	0	1119	9,1	0,15	126	132	0,34	0,26	17,5	0,21	0,22	1,20	17,38
A36(tr)	7,3	0,07	53	12,5	1188	2,2	0,15	50	43	1,26	1,07	9,3	13,4	0,04	1,01	0,00
A36(L)	7,3	0,07	53	12,5	1188	2,2	0,15	50	59	1,2	0,87	9,8	9,5	0,05	1,01	0,53
A26(tr)	6,7	0,47	66	13,5	548	7,6	0,15	33	30	0,66	0,63	9,2	16,1	0,19	1,22	0,23
A26(L)	6,7	0,47	66	13,5	548	7,6	0,15	33	37	1,04	1,09	7	11,5	0,11	1,05	0,00
B14(tr)	6,7	0,17	48	0	842	3,2	0,15	64	28,5	0,56	0,49	12,1	12,9	0,12	1,25	5,42
B2(tr)	6,9	0,11	66	0	916	3,6	0,15	72	59	1,1	0,97	12,5	11,4	0,07	1,03	2,07

Site	Mw	MHA(g)	h(ft)	e(ft)	Vs (fps)	β (%)	γ	r1 (ft)	r2 (ft)	Tflex.(sec)	T (sec)	ζ flexible	ζ (%)	1/ σ	Period lengthening.	Foundation damping
B10(tr)	6,7	0,16	89	13	878	3,7	0,15	50	38	1,25	1,25	10,3	7,8	0,08	1,06	3,77
B10(L)	6,7	0,16	89	13	878	3,7	0,15	65	67	1,06	1,04	11,5	13	0,10	1,04	0,00
A20(tr)	6,7	0,07	98	23	1143	2,9	0,15	84	83	0,58	0,51	3,1	4,6	0,17	1,11	0,00
A20(L)	6,7	0,07	98	23	1143	2,9	0,15	84	87	0,58	0,55	4,5	4,1	0,16	1,09	1,32
A31(tr)	6,7	0,11	94	0	969	3,2	0,15	61	52	0,86	0,75	3,2	8,5	0,13	1,10	0,00
A31(L)	6,7	0,11	94	0	969	3,2	0,15	61	74	0,77	0,67	3,9	4,4	0,14	1,06	0,22
A31(tr)	7,3	0,04	94	0	1009	2,3	0,15	61	52	0,84	0,7	4,7	2,9	0,13	1,11	2,57
B6(tr)	6,9	0,1	109	13,5	725	3,5	0,15	83	84	2,16	2,13	1	1,3	0,07	1,02	0,00
B6(L)	6,9	0,1	109	13,5	725	3,5	0,15	83	84	2,19	2,17	2,8	2,2	0,07	1,02	0,72
B7(tr)	6,9	0,1	89	14	1405	1,2	0,15	32	26	0,77	0,66	6,6	13,3	0,10	1,10	0,00
A5(tr)	6,9	0,05	84	0	2210	0,8	0,15	66	54	1,16	1,11	3,8	3,5	0,03	1,01	0,38
A5(L)	6,9	0,05	84	0	2210	0,8	0,15	66	82	0,87	0,85	3,2	4,2	0,04	1,01	0,00
B11(tr)	7,3	0,04	91	0	1190	0,9	0,15	76	35,2	0,96	0,85	4,1	3,4	0,09	1,20	2,12
B11(tr)	6,7	0,26	91	0	1140	1,4	0,15	76	35,2	1,05	0,9	4,9	3,9	0,09	1,19	2,60
A21(tr)	5,6	0,11	22	0	1006	1,3	0,15	71	59	0,79	0,79	9,4	13,3	0,03	1,01	0,00
A21(L)	5,6	0,11	22	0	1006	1,3	0,15	71	88	0,79	0,82	21,5	17,7	0,03	1,00	4,04
A21(tr)	6,7	0,32	22	0	981	1,7	0,15	71	59	0,92	0,95	34,4	40,1	0,02	1,00	0,00
A21(L)	6,7	0,32	22	0	981	1,7	0,15	71	88	0,83	0,84	33,4	39,5	0,03	1,00	0,00
A21(tr)	7,3	0,05	22	0	1010	1,2	0,15	71	59	0,97	0,98	14,2	14,9	0,02	1,00	0,00
A21(L)	7,3	0,05	22	0	1010	1,2	0,15	71	88	0,9	0,9	18,4	18,9	0,02	1,00	0,00
A8(tr)	6,9	0,08	25	0	1820	1,3	0,15	52	46	0,18	0,16	4,8	2,2	0,09	1,04	2,84
A8(tr)	6,9	0,08	25	0	1820	1,3	0,15	52	59	0,17	0,17	7	5,1	0,08	1,03	2,33

Site	Mw	MHA(g)	h(ft)	e(ft)	Vs (fps)	β (%)	γ	r1 (ft)	r2 (ft)	Tflex.(sec)	T (sec)	ζ flexible	ζ (%)	1/ σ	Period lengthening.	Foundation damping
A11(tr)	6,9	0,27	35	0	2642	0,9	0,15	86	68	0,64	0,67	20,6	24,8	0,02	1,00	0,00
A11(L)	6,9	0,27	35	0	2642	0,9	0,15	86	111	0,6	0,66	20,3	23,6	0,02	1,00	0,00
A25(tr)	6,7	0,49	68	0	1065	2,5	0,15	110	110	1,19	1,27	27,1	29,3	0,05	1,01	0,00
A25(L)	6,7	0,49	68	0	1065	2,5	0,15	110	110	1,21	1,19	21,1	28	0,05	1,01	0,00
A25(tr)	7,3	0,04	68	0	1148	1,2	0,15	110	110	1,14	1,18	11,8	12,1	0,05	1,01	0,09
A25(L)	7,3	0,04	68	0	1148	1,2	0,15	110	110	1,09	1,11	10,1	13,1	0,05	1,01	0,00
A42(tr)	6,7	0,28	91	0	4460	1	0,15	23,5	20,5	0,54	0,53	19,1	15,1	0,04	1,02	4,82
A42(L)	6,7	0,28	91	0	4460	1	0,15	23,5	27,6	0,54	0,55	11,4	8,3	0,04	1,01	3,29
A27(tr)	6,7	0,19	174	0	1120	2	0,15	131	110	3,12	3,2	3,9	3	0,05	1,01	1,03
A27(L)	6,7	0,19	174	0	1120	2	0,15	131	161	3,07	3,09	8,8	2	0,05	1,01	6,84
A27(tr)	7,3	0,03	174	0	1161	1,2	0,15	131	110	3,15	3,2	3,9	3	0,05	1,01	1,02
A27(L)	7,3	0,03	174	0	1161	1,2	0,15	131	161	3,09	3,1	2,1	1,8	0,05	1,01	0,34
B12(tr)	6,7	0,11	300	54	1339	1,2	0,15	93	91	1,94	1,84	7,6	7,1	0,12	1,11	2,41
B13(tr)	6,7	0,14	414	57,5	1317	3,4	0,15	96	87	5,81	5,7	7,7	15	0,06	1,04	0,00

Appendix H. Before Normalization Data Properties

Table App. H1. Before normalization data properties

Rock/Soil	Piles (Y/N)	NO.Stories	Str. system SW	Str.system DWF	Str.system CF	Str. system SF	Str.system BI	Basement (Y/N)	Mw	MHA(g)	h(ft)	e(ft)	V _s (fps)	β(%)	r ₁ (ft)	r ₂ (ft)	T _{flex} (sec)	T (sec)	ζ flexible	ζ (%)	1/σ	Period lengthening	Foundation damping
S	Y	2	0	0	1	0	0	Y	5,6	0,21	28	10,5	1178	3,2	59	57	0,29	0,29	9,20	4,90	0,08	1,03	4,76
S	Y	2	0	0	1	0	0	Y	5,6	0,21	28	10,5	1178	3,2	59	63	0,3	0,30	11,20	12,10	0,08	1,03	0,11
S	Y	2	0	0	1	0	0	Y	6,0	0,06	28	10,5	1246	1,6	59	57	0,26	0,25	8,70	5,50	0,09	1,04	3,81
S	Y	2	0	0	1	0	0	Y	6,0	0,06	28	10,5	1246	1,6	59	63	0,27	0,26	5,80	8,60	0,09	1,04	0,00
S	Y	3	1	0	0	0	0	N	6,0	0,07	26	0	908	2,1	54	47	0,2	0,20	13,40	12,40	0,14	1,11	4,23
S	Y	4	1	0	0	0	0	N	6,7	0,06	50	0	1415	3,4	246	248	0,29	0,25	15	5,8	0,14	1,18	11,44
S	Y	4	1	0	0	0	0	N	6,7	0,06	50	0	1415	3,4	246	250	0,32	0,29	10,1	5,6	0,12	1,13	6,26
S	Y	4	0	1	0	0	0	Y	7,3	0,09	56	15,5	695	4,1	69	58	0,71	0,67	10,3	7,5	0,12	1,07	4,22
S	Y	4	0	1	0	0	0	Y	7,3	0,09	56	15,5	695	4,1	69	85	0,66	0,64	10,9	10,9	0,13	1,05	1,48
S	Y	5	0	0	0	1	0	N	6,7	0,04	38	0	1011	2,4	114	114	0,51	0,51	2,6	3,4	0,07	1,03	0,00
S	Y	5	0	0	0	1	0	N	6,7	0,04	38	0	1011	2,4	114	114	0,93	0,91	4,5	4	0,04	1,01	0,63
S	Y	5	0	0	0	1	0	N	6,7	0,07	40	0	1001	2,5	99	83	0,73	0,69	10	7,5	0,06	1,02	2,94
S	Y	5	0	0	0	1	0	N	6,7	0,07	40	0	1001	2,5	99	121	0,72	0,71	8,2	9,1	0,06	1,02	0,00
S	Y	6	1	0	0	0	0	N	6,7	0,22	40	0	870	7,3	159	154	0,52	0,51	6,6	6,1	0,09	1,06	1,53
S	Y	6	1	0	0	0	0	N	6,7	0,22	40	0	640	6,2	54	47	0,44	0,28	6,1	6,5	0,22	1,22	2,52
S	Y	6	0	1	0	0	0	N	6,5	0,24	54	0	464	6,6	61	55	0,74	0,5	16	23,4	0,23	1,23	3,32
S	Y	6	0	1	0	0	0	N	6,5	0,24	54	0	464	6,6	61	69	1,23	1,25	33,9	36,6	0,09	1,03	0,32

Rock/Soil	Piles (Y/N)	NO.Stories	Str. system SW	Str.system DWF	Str.system CF	Str. system SF	Str.system BI	Basement (Y/N)	Mw	MHA(g)	h(ft)	e(ft)	Vs (fps)	β (%)	r1 (ft)	r2 (ft)	Tflex.(sec)	T (sec)	ζ flexible	ζ (%)	1/ σ	Period lengthening	Foundation damping
S	Y	6	0	0	0	1	0	Y	6,7	0,25	78	17	981	6,3	189	199	1	0,92	9,3	9,3	0,09	1,04	1,00
S	Y	7	0	0	0	1	0	Y	6,0	0,23	70	13,5	730	6,8	93	106	1,48	1,54	9,6	8,5	0,06	1,01	1,44
S	Y	7	0	0	0	1	0	Y	6,0	0,23	72	15	794	7,3	142	105	1,32	1,32	2	1,8	0,07	1,03	0,35
S	Y	7	0	0	0	1	0	Y	6,0	0,23	72	15	794	7,3	142	195	1,2	1,22	3,5	3	0,07	1,02	0,69
S	Y	7	0	0	0	1	0	Y	6,7	0,08	72	15	906	4	142	105	1,28	1,3	6,3	4,9	0,06	1,02	1,73
S	Y	7	0	0	0	1	0	Y	6,7	0,08	72	15	906	4	142	195	1,2	1,22	4,6	3,4	0,07	1,02	1,37
S	Y	7	0	0	0	1	0	N	6,0	0,07	58	0	615	3,5	49	53	1,12	1,14	5,5	6,5	0,08	1,02	0,00
S	Y	8	0	0	0	0	1	Y	6,7	0,08	83	16	911	2,3	103	90	1,21	1,18	6,6	7,1	0,08	1,03	0,08
S	Y	8	0	0	0	0	1	Y	6,7	0,08	83	16	911	2,3	103	121	1,09	1,06	9,1	8,7	0,09	1,02	1,01
S	Y	8	0	0	0	0	1	Y	7,3	0,05	83	16	933	2,6	103	90	1,28	1,26	11,5	13,2	0,07	1,02	0,00
S	Y	8	0	0	0	0	1	Y	7,3	0,05	83	16	933	2,6	103	121	1,16	1,12	13,7	16,2	0,08	1,02	0,00
S	Y	9	0	0	0	1	0	N	7,3	0,1	74	0	848	3,4	55	52	2,01	2,01	5	6,8	0,04	1,01	0,00
S	Y	9	0	0	0	1	0	N	7,3	0,1	74	0	848	3,4	55	59	2,05	2,08	7,4	6	0,04	1,01	1,51
S	Y	12	1	0	0	0	0	N	6,7	0,06	69	0	886	2,8	62	47	0,71	0,53	4	5,7	0,15	1,14	0,17
S	Y	14	0	0	1	0	0	Y	6,0	0,21	96	9	930	2,8	59	42	1,8	1,77	9,1	5,4	0,06	1,04	4,24
S	Y	14	0	0	1	0	0	Y	6,7	0,39	96	9	879	4,4	59	42	2,1	2,05	18,3	15,4	0,05	1,03	4,20
S	Y	14	0	0	1	0	0	Y	6,7	0,39	96	9	879	4,4	59	86	0,8	0,75	8	8,5	0,15	1,05	0,59
S	Y	31	0	0	1	0	0	N	6,9	0,25	218	0	448	6,8	87	94	2,5	2,45	13	7,4	0,20	1,18	8,48
S	Y	31	0	0	1	0	0	N	6,9	0,25	218	0	448	6,8	87	94	2,58	2,65	12,8	5,9	0,18	1,15	8,96
S	Y	47	0	0	0	1	0	N	6,9	0,12	61	0	768	4,1	65	49	0,48	0,29	6,7	18,6	0,27	1,41	0,07

Rock/Soil	Piles (Y/N)	NO.Stories	Str. system SW	Str.system DWF	Str.system CF	Str. system SF	Str.system BI	Basement (Y/N)	Mw	MHA(g)	h(ft)	e(ft)	Vs (fps)	β (%)	r1 (ft)	r2 (ft)	Tflex.(sec)	T (sec)	ζ flexible	ζ (%)	1/ σ	Period lengthening	Foundation damping
S	N	1	1	0	0	0	0	Y	7,3	0,11	47	15	275	9,7	16,3	16,3	0,49	0,12	30,6	3	1,42	5,31	30,58
S	N	1	1	0	0	0	0	Y	7,3	0,11	47	15	275	9,7	16,3	16,3	0,45	0,11	31	3	1,55	5,78	30,98
S	N	1	1	0	0	0	0	N	6,2	0,19	22	0	786	5,8	115	112	0,35	0,34	17,2	15	0,08	1,07	4,86
S	N	1	1	0	0	0	0	N	6,2	0,19	22	0	786	5,8	115	122	0,29	0,28	25,6	17,6	0,10	1,10	12,25
S	N	1	1	0	0	0	0	N	6,9	0,36	30	0	502	7,7	97	75	0,73	0,71	26,9	19	0,08	1,05	10,56
S	N	1	1	0	0	0	0	N	7,0	0,12	22	0	772	5,6	115	112	0,37	0,36	34	26	0,08	1,06	12,31
S	N	1	1	0	0	0	0	N	7,0	0,12	22	0	772	5,6	115	122	0,31	0,29	39,4	18	0,10	1,09	25,63
S	N	1	0	1	0	0	0	Y	5,4	0,21	48	32	970	3,2	53	37	0,53	0,53	8,2	5,2	0,09	1,06	3,89
S	N	2	1	0	0	0	0	N	6,9	0,14	26	0	649	4,1	6,4	10,9	0,25	0,24	15,3	21,9	0,17	1,06	0,00
S	N	3	0	1	0	0	0	Y	6,9	0,13	33	10	768	3,7	75	54	0,3	0,28	9,2	3,9	0,15	1,15	6,62
S	N	3	0	1	0	0	0	Y	6,9	0,13	33	10	768	3,7	75	106	0,27	0,26	14,4	1,4	0,17	1,12	13,40
S	N	3	0	0	0	1	0	N	7,3	0,09	29	0	883	3,8	76	77	0,56	0,52	6,2	7,2	0,06	1,02	0,00
S	N	3	0	0	0	1	0	N	7,3	0,09	29	0	883	3,8	78	80	0,57	0,55	7,6	10,9	0,06	1,02	0,00
S	N	4	1	0	0	0	0	N	6,7	0,08	24	0	1575	1,7	69	49	0,2	0,12	18,5	24,1	0,13	1,11	1,04
S	N	4	1	0	0	0	0	N	6,7	0,08	24	0	1575	1,7	69	100	0,2	0,16	12,4	4,9	0,10	1,05	8,17
S	N	4	0	0	0	0	1	Y	4,8	0,04	56	14	1172	1,4	120	87	0,6	0,59	4,3	3,7	0,08	1,04	1,03
S	N	4	0	0	0	0	1	Y	4,8	0,04	56	14	1172	1,4	120	170	0,6	0,6	5,6	4,2	0,08	1,03	1,73
S	N	4	0	0	0	0	1	Y	5,6	0,24	56	14	1060	4,5	120	87	0,76	0,77	4,7	7,8	0,07	1,03	0,00
S	N	4	0	0	0	0	1	Y	5,6	0,24	56	14	1060	4,5	120	170	0,75	0,77	6	6,7	0,07	1,02	0,00
S	N	4	0	0	0	0	1	Y	6,0	0,06	56	14	1157	1,7	120	87	0,65	0,63	4,4	5	0,08	1,04	0,00

Rock/Soil	Piles (Y/N)	NO.Stories	Str. system SW	Str.system DWF	Str.system CF	Str. system SF	Str.system BI	Basement (Y/N)	Mw	MHA(g)	h(ft)	e(ft)	Vs (fps)	β (%)	r1 (ft)	r2 (ft)	Tflex.(sec)	T (sec)	ζ flexible	ζ (%)	1/ σ	Period lengthening	Foundation damping
S	N	4	0	0	0	0	1	Y	6,0	0,06	56	14	1157	1,7	120	170	0,66	0,65	8,4	6,1	0,07	1,02	2,72
S	N	4	0	0	0	0	1	Y	6,7	0,07	56	14	1114	2,8	120	87	0,76	0,75	4,6	6,9	0,07	1,03	0,00
S	N	4	0	0	0	0	1	Y	6,7	0,07	56	14	1114	2,8	120	170	0,81	0,79	7,5	8,9	0,06	1,02	0,00
S	N	4	0	0	0	0	1	Y	7,3	0,11	56	14	1039	4,4	120	87	0,87	0,85	11,2	12,5	0,06	1,03	0,00
S	N	4	0	0	0	0	1	Y	7,3	0,11	56	14	1039	4,4	120	170	0,89	0,87	17,2	17,4	0,06	1,02	0,64
S	N	5	1	0	0	0	0	Y	6,7	0,07	52	13	1233	2,6	95	86	0,63	0,65	9,1	5,2	0,06	1,02	4,21
S	N	5	1	0	0	0	0	N	7,0	0,18	31	0	701	5,1	57	42	0,24	0,15	19,6	15,9	0,29	1,45	14,36
S	N	5	1	0	0	0	0	N	7,0	0,18	31	0	701	5,1	57	77	0,25	0,22	12,8	5,5	0,20	1,15	9,16
S	N	5	1	0	0	0	0	Y	6,7	0,07	52	13	1233	2,6	95	107	0,5	0,51	7,5	6,2	0,08	1,03	1,80
S	N	5	0	0	0	1	0	Y	6,7	0,25	56	14	630	5,2	21,4	20,6	0,89	0,82	5,5	6,9	0,11	1,08	0,00
S	N	5	0	0	0	1	0	N	6,7	0,08	45	6	953	1,7	11,9	11,9	0,34	0,27	9,9	24,5	0,17	1,23	0,00
S	N	5	0	0	0	1	0	N	6,7	0,08	45	6	953	1,7	11,9	11,9	0,33	0,24	8,9	13,6	0,20	1,29	2,50
S	N	6	1	0	0	0	0	N	6,0	0,05	63	0	1506	1,9	126	132	0,3	0,27	9,1	9,9	0,15	1,11	1,79
S	N	6	1	0	0	0	0	N	6,0	0,05	63	0	1506	1,9	126	132	0,29	0,25	9,5	8,6	0,17	1,12	3,43
S	N	6	1	0	0	0	0	N	6,7	0,84	63	0	1119	9,1	126	132	0,38	0,37	18,9	19,4	0,15	1,10	4,43
S	N	6	1	0	0	0	0	N	6,7	0,84	63	0	1119	9,1	126	132	0,34	0,26	17,5	0,21	0,22	1,20	17,38
S	N	6	0	0	1	0	0	Y	7,3	0,07	53	12,5	1188	2,2	50	43	1,26	1,07	9,3	13,4	0,04	1,01	0,00
S	N	6	0	0	1	0	0	Y	7,3	0,07	53	12,5	1188	2,2	50	59	1,2	0,87	9,8	9,5	0,05	1,01	0,53
S	N	7	0	1	0	0	0	N	6,7	0,47	66	13,5	548	7,6	33	30	0,66	0,63	9,2	16,1	0,19	1,22	0,23
S	N	7	0	1	0	0	0	N	6,7	0,47	66	13,5	548	7,6	33	37	1,04	1,09	7	11,5	0,11	1,05	0,00

Rock/Soil	Piles (Y/N)	NO.Stories	Str. system SW	Str.system DWF	Str.system CF	Str. system SF	Str.system BI	Basement (Y/N)	Mw	MHA(g)	h(ft)	e(ft)	Vs (fps)	β (%)	r1 (ft)	r2 (ft)	Tflex.(sec)	T (sec)	ζ flexible	ζ (%)	1/ σ	Period lengthening	Foundation damping
S	N	8	1	0	0	0	0	N	6,7	0,17	48	0	842	3,2	64	28,5	0,56	0,49	12,1	12,9	0,12	1,25	5,42
S	N	9	1	0	0	0	0	N	6,9	0,11	66	0	916	3,6	72	59	1,1	0,97	12,5	11,4	0,07	1,03	2,07
S	N	9	0	1	0	0	0	Y	6,7	0,16	89	13	878	3,7	50	38	1,25	1,25	10,3	7,8	0,08	1,06	3,77
S	N	9	0	1	0	0	0	Y	6,7	0,16	89	13	878	3,7	65	67	1,06	1,04	11,5	13	0,10	1,04	0,00
S	N	11	1	0	0	0	0	Y	6,7	0,07	98	23	1143	2,9	84	83	0,58	0,51	3,1	4,6	0,17	1,11	0,00
S	N	11	1	0	0	0	0	Y	6,7	0,07	98	23	1143	2,9	84	87	0,58	0,55	4,5	4,1	0,16	1,09	1,32
S	N	11	1	0	0	0	0	N	6,7	0,11	94	0	969	3,2	61	52	0,86	0,75	3,2	8,5	0,13	1,10	0,00
S	N	11	1	0	0	0	0	N	6,7	0,11	94	0	969	3,2	61	74	0,77	0,67	3,9	4,4	0,14	1,06	0,22
S	N	11	1	0	0	0	0	N	7,3	0,04	94	0	1009	2,3	61	52	0,84	0,7	4,7	2,9	0,13	1,11	2,57
S	N	12	0	0	0	1	0	Y	6,9	0,1	109	13,5	725	3,5	83	84	2,16	2,13	1	1,3	0,07	1,02	0,00
S	N	12	0	0	0	1	0	Y	6,9	0,1	109	13,5	725	3,5	83	84	2,19	2,17	2,8	2,2	0,07	1,02	0,72
R	Y	10	0	1	0	0	0	N	6,9	0,1	89	14	1405	1,2	32	26	0,77	0,66	6,6	13,3	0,10	1,10	0,00
R	Y	11	0	1	0	0	0	Y	6,9	0,05	84	0	2210	0,8	66	54	1,16	1,11	3,8	3,5	0,03	1,01	0,38
R	Y	11	0	1	0	0	0	Y	6,9	0,05	84	0	2210	0,8	66	82	0,87	0,85	3,2	4,2	0,04	1,01	0,00
R	Y	17	1	0	0	0	0	N	7,3	0,04	91	0	1190	0,9	76	35,2	0,96	0,85	4,1	3,4	0,09	1,20	2,12
R	Y	17	1	0	0	0	0	N	6,7	0,26	91	0	1140	1,4	76	35,2	1,05	0,9	4,9	3,9	0,09	1,19	2,60
R	N	2	0	0	0	0	1	N	5,6	0,11	22	0	1006	1,3	71	59	0,79	0,79	9,4	13,3	0,03	1,01	0,00
R	N	2	0	0	0	0	1	N	5,6	0,11	22	0	1006	1,3	71	88	0,79	0,82	21,5	17,7	0,03	1,00	4,04
R	N	2	0	0	0	0	1	N	6,7	0,32	22	0	981	1,7	71	59	0,92	0,95	34,4	40,1	0,02	1,00	0,00
R	N	2	0	0	0	0	1	N	6,7	0,32	22	0	981	1,7	71	88	0,83	0,84	33,4	39,5	0,03	1,00	0,00

Rock/Soil	Piles (Y/N)	NO.Stories	Str. system SW	Str.system DWF	Str.system CF	Str. system SF	Str.system BI	Basement (Y/N)	Mw	MHA(g)	h(ft)	e(ft)	Vs (fps)	β (%)	r1 (ft)	r2 (ft)	Tflex.(sec)	T (sec)	ζ flexible	ζ (%)	1/ σ	Period lengthening	Foundation damping
R	N	2	0	0	0	0	1	N	7,3	0,05	22	0	1010	1,2	71	59	0,97	0,98	14,2	14,9	0,02	1,00	0,00
R	N	2	0	0	0	0	1	N	7,3	0,05	22	0	1010	1,2	71	88	0,9	0,9	18,4	18,9	0,02	1,00	0,00
R	N	3	1	0	0	0	0	N	6,9	0,08	25	0	1820	1,3	52	46	0,18	0,16	4,8	2,2	0,09	1,04	2,84
R	N	3	1	0	0	0	0	N	6,9	0,08	25	0	1820	1,3	52	59	0,17	0,17	7	5,1	0,08	1,03	2,33
R	N	3	0	0	0	1	0	N	6,9	0,27	35	0	2642	0,9	86	68	0,64	0,67	20,6	24,8	0,02	1,00	0,00
R	N	3	0	0	0	1	0	N	6,9	0,27	35	0	2642	0,9	86	111	0,6	0,66	20,3	23,6	0,02	1,00	0,00
R	N	7	0	0	0	0	1	Y	6,7	0,49	68	0	1065	2,5	110	110	1,19	1,27	27,1	29,3	0,05	1,01	0,00
R	N	7	0	0	0	0	1	Y	6,7	0,49	68	0	1065	2,5	110	110	1,21	1,19	21,1	28	0,05	1,01	0,00
R	N	7	0	0	0	0	1	Y	7,3	0,04	68	0	1148	1,2	110	110	1,14	1,18	11,8	12,1	0,05	1,01	0,09
R	N	7	0	0	0	0	1	Y	7,3	0,04	68	0	1148	1,2	110	110	1,09	1,11	10,1	13,1	0,05	1,01	0,00
R	N	8	0	0	0	1	0	N	6,7	0,28	91	0	4460	1	23,5	20,5	0,54	0,53	19,1	15,1	0,04	1,02	4,82
R	N	8	0	0	0	1	0	N	6,7	0,28	91	0	4460	1	23,5	27,6	0,54	0,55	11,4	8,3	0,04	1,01	3,29
R	N	17	0	0	0	1	0	N	6,7	0,19	174	0	1120	2	131	110	3,12	3,2	3,9	3	0,05	1,01	1,03
R	N	17	0	0	0	1	0	N	6,7	0,19	174	0	1120	2	131	161	3,07	3,09	8,8	2	0,05	1,01	6,84
R	N	17	0	0	0	1	0	N	7,3	0,03	174	0	1161	1,2	131	110	3,15	3,2	3,9	3	0,05	1,01	1,02
R	N	17	0	0	0	1	0	N	7,3	0,03	174	0	1161	1,2	131	161	3,09	3,1	2,1	1,8	0,05	1,01	0,34
R	N	32	0	1	0	0	0	Y	6,7	0,11	300	54	1339	1,2	93	91	1,94	1,84	7,6	7,1	0,12	1,11	2,41
R	N	54	0	0	0	1	0	Y	6,7	0,14	414	57,5	1317	3,4	96	87	5,81	5,7	7,7	15	0,06	1,04	0,00

Appendix I. Data Properties After Normalization (Input Values and Output Values)

Table App. I1. Data properties after normalization (Input Values and Output Values)

Rock/Soil	Piles (Y/N)	NO,Stories	Str, system SW	Str,system DWF	Str,system CF	Str, system SF	Str,system BI	Basement (Y/N)	Mw	MHA(g)	h(ft)	e(ft)	Vs (fps)	β (%)	r1 (ft)	r2 (ft)	Tflex,(sec)	T (sec)	ζ flexible(%)	ζ fixed(%)	1/ σ (Output)	Period lengt. (Output)	Foundation damping(%) (Output)
1	1	0,04	0	0	1	0	0	1	0,77	0,25	0,07	0,18	0,26	0,33	0,24	0,23	0,05	0,05	0,23	0,12	0,05	0,18	0,15
1	1	0,04	0	0	1	0	0	1	0,77	0,25	0,07	0,18	0,26	0,33	0,24	0,25	0,05	0,05	0,28	0,30	0,05	0,18	0,00
1	1	0,04	0	0	1	0	0	1	0,82	0,07	0,07	0,18	0,28	0,16	0,24	0,23	0,04	0,04	0,22	0,14	0,06	0,18	0,12
1	1	0,04	0	0	1	0	0	1	0,82	0,07	0,07	0,18	0,28	0,16	0,24	0,25	0,05	0,05	0,15	0,21	0,06	0,18	0,00
1	1	0,06	1	0	0	0	0	0	0,82	0,08	0,06	0,00	0,20	0,22	0,22	0,19	0,03	0,04	0,34	0,31	0,09	0,19	0,14
1	1	0,07	1	0	0	0	0	0	0,92	0,07	0,12	0,00	0,32	0,35	1,00	0,99	0,05	0,04	0,38	0,14	0,09	0,20	0,37
1	1	0,07	1	0	0	0	0	0	0,92	0,07	0,12	0,00	0,32	0,35	1,00	1,00	0,06	0,05	0,26	0,14	0,08	0,20	0,20
1	1	0,07	0	1	0	0	0	1	1,00	0,11	0,14	0,27	0,16	0,42	0,28	0,23	0,12	0,12	0,26	0,19	0,08	0,19	0,14
1	1	0,07	0	1	0	0	0	1	1,00	0,11	0,14	0,27	0,16	0,42	0,28	0,34	0,11	0,11	0,28	0,27	0,08	0,18	0,05
1	1	0,09	0	0	0	1	0	0	0,92	0,05	0,09	0,00	0,23	0,25	0,46	0,46	0,09	0,09	0,07	0,08	0,05	0,18	0,00
1	1	0,09	0	0	0	1	0	0	0,92	0,05	0,09	0,00	0,23	0,25	0,46	0,46	0,16	0,16	0,11	0,10	0,03	0,17	0,02
1	1	0,09	0	0	0	1	0	0	0,92	0,08	0,10	0,00	0,22	0,26	0,40	0,33	0,13	0,12	0,25	0,19	0,04	0,18	0,09
1	1	0,09	0	0	0	1	0	0	0,92	0,08	0,10	0,00	0,22	0,26	0,40	0,48	0,12	0,12	0,21	0,23	0,04	0,18	0,00
1	1	0,11	1	0	0	0	0	0	0,92	0,26	0,10	0,00	0,20	0,75	0,65	0,62	0,09	0,09	0,17	0,15	0,06	0,18	0,05
1	1	0,11	0	1	0	0	0	0	0,89	0,29	0,13	0,00	0,10	0,68	0,25	0,28	0,21	0,22	0,86	0,91	0,06	0,18	0,01
1	1	0,11	0	0	0	1	0	1	0,92	0,30	0,19	0,30	0,22	0,65	0,77	0,80	0,17	0,16	0,24	0,23	0,06	0,18	0,03
1	1	0,13	0	0	0	1	0	1	0,82	0,27	0,17	0,23	0,16	0,70	0,38	0,42	0,25	0,27	0,24	0,21	0,04	0,18	0,05
1	1	0,13	0	0	0	1	0	1	0,82	0,27	0,17	0,26	0,18	0,75	0,58	0,42	0,23	0,23	0,05	0,04	0,04	0,18	0,01
1	1	0,13	0	0	0	1	0	1	0,82	0,27	0,17	0,26	0,18	0,75	0,58	0,78	0,21	0,21	0,09	0,07	0,05	0,18	0,02

Rock/Soil	Piles (Y/N)	NO,Stories	Str, system SW	Str,system DWF	Str,system CF	Str, system SF	Str,system BI	Basement (Y/N)	Mw	MHA(g)	h(ft)	e(ft)	Vs (fps)	β (%)	r1 (ft)	r2 (ft)	Tflex,(sec)	T (sec)	ζ flexible(%)	ζ fixed(%)	1/ σ (Output)	Period lengt. (Output)	Foundation damping(%) (Output)
1	1	0,13	0	0	0	1	0	1	0,92	0,10	0,17	0,26	0,20	0,41	0,58	0,42	0,22	0,23	0,16	0,12	0,04	0,18	0,06
1	1	0,13	0	0	0	1	0	1	0,92	0,10	0,17	0,26	0,20	0,41	0,58	0,78	0,21	0,21	0,12	0,08	0,04	0,18	0,04
1	1	0,13	0	0	0	1	0	0	0,82	0,08	0,14	0,00	0,14	0,36	0,20	0,21	0,19	0,20	0,14	0,16	0,05	0,18	0,00
1	1	0,15	0	0	0	0	1	1	0,92	0,10	0,20	0,28	0,20	0,24	0,42	0,36	0,21	0,21	0,17	0,18	0,05	0,18	0,00
1	1	0,15	0	0	0	0	1	1	0,92	0,10	0,20	0,28	0,20	0,24	0,42	0,48	0,19	0,19	0,23	0,22	0,06	0,18	0,03
1	1	0,15	0	0	0	0	1	1	1,00	0,06	0,20	0,28	0,21	0,27	0,42	0,36	0,22	0,22	0,29	0,33	0,05	0,18	0,00
1	1	0,15	0	0	0	0	1	1	1,00	0,06	0,20	0,28	0,21	0,27	0,42	0,48	0,20	0,20	0,35	0,40	0,05	0,18	0,00
1	1	0,17	0	0	0	1	0	0	1,00	0,12	0,18	0,00	0,19	0,35	0,22	0,21	0,35	0,35	0,13	0,17	0,03	0,17	0,00
1	1	0,17	0	0	0	1	0	0	1,00	0,12	0,18	0,00	0,19	0,35	0,22	0,24	0,35	0,36	0,19	0,15	0,03	0,17	0,05
1	1	0,22	1	0	0	0	0	0	0,92	0,07	0,17	0,00	0,20	0,29	0,25	0,19	0,12	0,09	0,10	0,14	0,09	0,20	0,01
1	1	0,26	0	0	1	0	0	1	0,82	0,25	0,23	0,16	0,21	0,29	0,24	0,17	0,31	0,31	0,23	0,13	0,04	0,18	0,14
1	1	0,26	0	0	1	0	0	1	0,92	0,46	0,23	0,16	0,20	0,45	0,24	0,17	0,36	0,36	0,46	0,38	0,03	0,18	0,14
1	1	0,26	0	0	1	0	0	1	0,92	0,46	0,23	0,16	0,20	0,45	0,24	0,34	0,14	0,13	0,20	0,21	0,09	0,18	0,02
1	1	0,57	0	0	1	0	0	0	0,95	0,30	0,53	0,00	0,10	0,70	0,35	0,38	0,44	0,46	0,32	0,15	0,12	0,20	0,29
1	0	0,02	1	0	0	0	0	0	0,85	0,23	0,05	0,00	0,18	0,60	0,47	0,45	0,06	0,06	0,44	0,37	0,05	0,18	0,16
1	0	0,02	1	0	0	0	0	0	0,85	0,23	0,05	0,00	0,18	0,60	0,47	0,49	0,05	0,05	0,65	0,44	0,06	0,19	0,40
1	0	0,02	1	0	0	0	0	0	0,95	0,43	0,07	0,00	0,11	0,79	0,39	0,30	0,13	0,12	0,68	0,47	0,05	0,18	0,34
1	0	0,02	1	0	0	0	0	0	0,96	0,14	0,05	0,00	0,17	0,58	0,47	0,45	0,06	0,06	0,86	0,65	0,05	0,18	0,40
1	0	0,02	0	1	0	0	0	1	0,74	0,25	0,12	0,56	0,22	0,33	0,22	0,15	0,09	0,09	0,21	0,13	0,06	0,18	0,13
1	0	0,04	1	0	0	0	0	0	0,95	0,17	0,06	0,00	0,15	0,42	0,03	0,04	0,04	0,04	0,39	0,55	0,11	0,18	0,00
1	0	0,06	0	1	0	0	0	1	0,95	0,15	0,08	0,17	0,17	0,38	0,30	0,22	0,05	0,05	0,23	0,10	0,10	0,20	0,21
1	0	0,06	0	1	0	0	0	1	0,95	0,15	0,08	0,17	0,17	0,38	0,30	0,42	0,05	0,05	0,37	0,03	0,11	0,19	0,43

Rock/Soil	Piles (Y/N)	NO,Stories	Str, system SW	Str,system DWF	Str,system CF	Str, system SF	Str,system BI	Basement (Y/N)	Mw	MHA(g)	h(ft)	e(ft)	Vs (fps)	β (%)	r1 (ft)	r2 (ft)	Tflex,(sec)	T (sec)	ζ flexible(%)	ζ fixed(%)	1/ σ (Output)	Period lengt. (Output)	Foundation damping(%) (Output)
1	0	0,06	0	0	0	1	0	0	1,00	0,11	0,07	0,00	0,20	0,39	0,31	0,31	0,10	0,09	0,16	0,18	0,04	0,18	0,00
1	0	0,06	0	0	0	1	0	0	1,00	0,11	0,07	0,00	0,20	0,39	0,32	0,32	0,10	0,10	0,19	0,27	0,04	0,18	0,00
1	0	0,07	1	0	0	0	0	0	0,92	0,10	0,06	0,00	0,35	0,18	0,28	0,20	0,03	0,02	0,47	0,60	0,08	0,19	0,03
1	0	0,07	1	0	0	0	0	0	0,92	0,10	0,06	0,00	0,35	0,18	0,28	0,40	0,03	0,03	0,31	0,12	0,06	0,18	0,26
1	0	0,07	0	0	0	0	1	1	0,66	0,05	0,14	0,24	0,26	0,14	0,49	0,35	0,10	0,10	0,11	0,09	0,05	0,18	0,03
1	0	0,07	0	0	0	0	1	1	0,66	0,05	0,14	0,24	0,26	0,14	0,49	0,68	0,10	0,11	0,14	0,10	0,05	0,18	0,06
1	0	0,07	0	0	0	0	1	1	0,77	0,29	0,14	0,24	0,24	0,46	0,49	0,35	0,13	0,14	0,12	0,19	0,04	0,18	0,00
1	0	0,07	0	0	0	0	1	1	0,77	0,29	0,14	0,24	0,24	0,46	0,49	0,68	0,13	0,14	0,15	0,17	0,04	0,18	0,00
1	0	0,07	0	0	0	0	1	1	0,82	0,07	0,14	0,24	0,26	0,18	0,49	0,35	0,11	0,11	0,11	0,12	0,05	0,18	0,00
1	0	0,07	0	0	0	0	1	1	0,82	0,07	0,14	0,24	0,26	0,18	0,49	0,68	0,11	0,11	0,21	0,15	0,05	0,18	0,09
1	0	0,07	0	0	0	0	1	1	0,92	0,08	0,14	0,24	0,25	0,29	0,49	0,35	0,13	0,13	0,12	0,17	0,04	0,18	0,00
1	0	0,07	0	0	0	0	1	1	0,92	0,08	0,14	0,24	0,25	0,29	0,49	0,68	0,14	0,14	0,19	0,22	0,04	0,18	0,00
1	0	0,07	0	0	0	0	1	1	1,00	0,13	0,14	0,24	0,23	0,45	0,49	0,35	0,15	0,15	0,28	0,31	0,04	0,18	0,00
1	0	0,07	0	0	0	0	1	1	1,00	0,13	0,14	0,24	0,23	0,45	0,49	0,68	0,15	0,15	0,44	0,43	0,04	0,18	0,02
1	0	0,09	1	0	0	0	0	1	0,92	0,08	0,13	0,23	0,28	0,27	0,39	0,34	0,11	0,11	0,23	0,13	0,04	0,18	0,14
1	0	0,09	1	0	0	0	0	1	0,92	0,08	0,13	0,23	0,28	0,27	0,39	0,43	0,09	0,09	0,19	0,15	0,05	0,18	0,06
1	0	0,09	0	0	0	1	0	1	0,92	0,30	0,14	0,24	0,14	0,54	0,09	0,08	0,15	0,14	0,14	0,17	0,07	0,19	0,00
1	0	0,09	0	0	0	1	0	0	0,92	0,10	0,11	0,10	0,21	0,18	0,05	0,05	0,06	0,05	0,25	0,61	0,11	0,21	0,00
1	0	0,11	1	0	0	0	0	0	0,82	0,06	0,15	0,00	0,34	0,20	0,51	0,53	0,05	0,05	0,23	0,25	0,10	0,19	0,06
1	0	0,11	1	0	0	0	0	0	0,82	0,06	0,15	0,00	0,34	0,20	0,51	0,53	0,05	0,04	0,24	0,21	0,11	0,19	0,11
1	0	0,11	1	0	0	0	0	0	0,92	1,00	0,15	0,00	0,25	0,94	0,51	0,53	0,07	0,06	0,48	0,48	0,10	0,19	0,14

Rock/Soil	Piles (Y/N)	NO,Stories	Str, system SW	Str,system DWF	Str,system CF	Str, system SF	Str,system BI	Basement (Y/N)	Mw	MHA(g)	h(ft)	e(ft)	Vs (fps)	β (%)	r1 (ft)	r2 (ft)	Tflex,(sec)	T (sec)	ζ flexible(%)	ζ fixed(%)	1/ σ (Output)	Period lengt. (Output)	Foundation damping(%) (Output)
1	0	0,11	0	0	1	0	0	1	1,00	0,08	0,13	0,22	0,27	0,23	0,20	0,17	0,22	0,19	0,24	0,33	0,03	0,17	0,00
1	0	0,11	0	0	1	0	0	1	1,00	0,08	0,13	0,22	0,27	0,23	0,20	0,24	0,21	0,15	0,25	0,24	0,03	0,17	0,02
1	0	0,13	0	1	0	0	0	0	0,92	0,56	0,16	0,23	0,12	0,78	0,13	0,12	0,11	0,11	0,23	0,40	0,12	0,21	0,01
1	0	0,13	0	1	0	0	0	0	0,92	0,56	0,16	0,23	0,12	0,78	0,13	0,15	0,18	0,19	0,18	0,29	0,07	0,18	0,00
1	0	0,15	1	0	0	0	0	0	0,92	0,20	0,12	0,00	0,19	0,33	0,26	0,11	0,10	0,09	0,31	0,32	0,07	0,22	0,17
1	0	0,17	1	0	0	0	0	0	0,95	0,13	0,16	0,00	0,21	0,37	0,29	0,24	0,19	0,17	0,32	0,28	0,05	0,18	0,07
1	0	0,17	0	1	0	0	0	1	0,92	0,19	0,21	0,23	0,20	0,38	0,20	0,15	0,22	0,22	0,26	0,19	0,05	0,18	0,12
1	0	0,17	0	1	0	0	0	1	0,92	0,19	0,21	0,23	0,20	0,38	0,26	0,27	0,18	0,18	0,29	0,32	0,06	0,18	0,00
1	0	0,20	1	0	0	0	0	1	0,92	0,08	0,24	0,40	0,26	0,30	0,34	0,33	0,10	0,09	0,08	0,11	0,11	0,19	0,00
1	0	0,20	1	0	0	0	0	1	0,92	0,08	0,24	0,40	0,26	0,30	0,34	0,35	0,10	0,10	0,11	0,10	0,10	0,19	0,04
1	0	0,20	1	0	0	0	0	0	0,92	0,13	0,23	0,00	0,22	0,33	0,25	0,21	0,15	0,13	0,08	0,21	0,08	0,19	0,00
1	0	0,20	1	0	0	0	0	0	0,92	0,13	0,23	0,00	0,22	0,33	0,25	0,30	0,13	0,12	0,10	0,11	0,09	0,18	0,01
1	0	0,20	1	0	0	0	0	0	1,00	0,05	0,23	0,00	0,23	0,24	0,25	0,21	0,14	0,12	0,12	0,07	0,09	0,19	0,08
1	0	0,22	0	0	0	1	0	1	0,95	0,12	0,26	0,23	0,16	0,36	0,34	0,34	0,37	0,37	0,03	0,03	0,05	0,18	0,00
1	0	0,22	0	0	0	1	0	1	0,95	0,12	0,26	0,23	0,16	0,36	0,34	0,34	0,38	0,38	0,07	0,05	0,04	0,18	0,02
0	1	0,19	0	1	0	0	0	0	0,95	0,12	0,21	0,24	0,32	0,12	0,13	0,10	0,13	0,12	0,17	0,33	0,06	0,19	0,00
0	1	0,20	0	1	0	0	0	1	0,95	0,06	0,20	0,00	0,50	0,08	0,27	0,22	0,20	0,19	0,10	0,09	0,02	0,17	0,01
0	1	0,20	0	1	0	0	0	1	0,95	0,06	0,20	0,00	0,50	0,08	0,27	0,33	0,15	0,15	0,08	0,10	0,03	0,17	0,00
0	1	0,31	1	0	0	0	0	0	1,00	0,05	0,22	0,00	0,27	0,09	0,31	0,14	0,17	0,15	0,10	0,08	0,06	0,21	0,07
0	1	0,31	1	0	0	0	0	0	0,92	0,31	0,22	0,00	0,26	0,14	0,31	0,14	0,18	0,16	0,12	0,10	0,06	0,21	0,08
0	0	0,04	0	0	0	0	1	0	0,77	0,13	0,05	0,00	0,23	0,13	0,29	0,24	0,14	0,14	0,24	0,33	0,02	0,17	0,00

Rock/Soil	Piles (Y/N)	NO,Stories	Str, system SW	Str,system DWF	Str,system CF	Str, system SF	Str,system BI	Basement (Y/N)	Mw	MHA(g)	h(ft)	e(ft)	Vs (fps)	β (%)	r1 (ft)	r2 (ft)	Tflex,(sec)	T (sec)	ζ flexible(%)	ζ fixed(%)	1/ σ (Output)	Period lengt. (Output)	Foundation damping(%) (Output)
0	0	0,04	0	0	0	0	1	0	0,77	0,13	0,05	0,00	0,23	0,13	0,29	0,35	0,14	0,14	0,55	0,44	0,02	0,17	0,13
0	0	0,04	0	0	0	0	1	0	0,92	0,38	0,05	0,00	0,22	0,18	0,29	0,35	0,14	0,15	0,85	0,99	0,02	0,17	0,00
0	0	0,06	1	0	0	0	0	0	0,95	0,10	0,06	0,00	0,41	0,13	0,21	0,18	0,03	0,03	0,12	0,05	0,06	0,18	0,09
0	0	0,06	1	0	0	0	0	0	0,95	0,10	0,06	0,00	0,41	0,13	0,21	0,24	0,03	0,03	0,18	0,13	0,05	0,18	0,08
0	0	0,13	0	0	0	0	1	1	0,92	0,58	0,16	0,00	0,24	0,26	0,45	0,44	0,20	0,22	0,69	0,73	0,03	0,17	0,00
0	0	0,13	0	0	0	0	1	1	0,92	0,58	0,16	0,00	0,24	0,26	0,45	0,44	0,21	0,21	0,54	0,70	0,03	0,17	0,00
0	0	0,13	0	0	0	0	1	1	1,00	0,05	0,16	0,00	0,26	0,12	0,45	0,44	0,20	0,21	0,30	0,30	0,03	0,17	0,00
0	0	0,13	0	0	0	0	1	1	1,00	0,05	0,16	0,00	0,26	0,12	0,45	0,44	0,19	0,19	0,26	0,33	0,03	0,17	0,00
0	0	0,15	0	0	0	1	0	0	0,92	0,33	0,22	0,00	1,00	0,10	0,10	0,08	0,09	0,09	0,48	0,38	0,03	0,18	0,16
0	0	0,15	0	0	0	1	0	0	0,92	0,33	0,22	0,00	1,00	0,10	0,10	0,11	0,09	0,10	0,29	0,21	0,03	0,17	0,11
0	0	0,31	0	0	0	1	0	0	0,92	0,23	0,42	0,00	0,25	0,21	0,53	0,44	0,54	0,56	0,10	0,07	0,03	0,17	0,03
0	0	0,31	0	0	0	1	0	0	0,92	0,23	0,42	0,00	0,25	0,21	0,53	0,64	0,53	0,54	0,22	0,05	0,03	0,17	0,22
0	0	0,31	0	0	0	1	0	0	1,00	0,04	0,42	0,00	0,26	0,12	0,53	0,44	0,54	0,56	0,10	0,07	0,03	0,17	0,03
0	0	0,31	0	0	0	1	0	0	1,00	0,04	0,42	0,00	0,26	0,12	0,53	0,64	0,53	0,54	0,05	0,04	0,03	0,17	0,01
0	0	0,59	0	1	0	0	0	1	0,92	0,13	0,72	0,94	0,30	0,12	0,38	0,36	0,33	0,32	0,19	0,18	0,08	0,19	0,08
0	0	1,00	0	0	0	1	0	1	0,92	0,17	1,00	1,00	0,30	0,35	0,39	0,35	1,00	1,00	0,20	0,37	0,04	0,18	0,00

CURRICULLUM VITAE

Özgür Sarıyar was born on March 14, 1979 in Ordu. He completed his primary school at 19 Eylül Primary School in 1990, his secondary school in Hamdullah Suphi Tanrıöver Secondary School in 1993, and his high school in Fatih Super High School in 1997 in Ordu. He started his BS degree at the Civil Engineering Department of the Kocaeli University and completed a four-year undergraduate education and graduated in 2002. At the same year, he started his MS education as a graduate student in the Earthquake Engineering Division of Civil Engineering Department at the Istanbul Technical University.

ÖZGEÇMİŞ

İnş. Müh. Özgür Sarıyar 14.03.1979'da Ordu'da doğdu. İlkokulu 1990'da 19 Eylül İlkokulu (Ordu), ortaokulu 1993'de Hamdullah Suphi Tanrıöver Ortaokulu'nda (Ordu), liseyi de 1997'de Fatih Süper Lisesi'nde (Ordu) bitirdi. Lisans eğitimini Kocaeli Üniversitesi İnşaat Mühendisliği bölümünde 4 yılda 2002 yılında tamamladı. Yine aynı yıl İstanbul Teknik Üniversitesi Fen Bilimleri Enstitüsü Deprem Mühendisliği Anabilim Dalında yüksek lisans eğitimine başladı.