*J. Basic. Appl. Sci. Res.*, 2(4)3839-3843, 2012
© 2012, TextRoad Publication

ISSN 2090-4304
**Journal of Basic and Applied Scientific Research**
*www.textroad.com*

# Analysis of Nonlinear Seismic Ground Response Using Adaptive Nero Fuzzy Inference Systems

**Bagheripour, M. H., Asadi, M., Ghasemi, M.**

Shahid Bahonar University of Kerman, Department of Civil Engineering, Kerman, Iran

## ABSTRACT

Evaluation of ground response due to earthquake is one the most important problems in geotechnical earthquake engineering. This includes prediction of ground movements caused by the “hard bed rock” transmitting through soil layers. Several linear, semi-linear and nonlinear techniques have been proposed in this context. Linear methods, however, are not reliable since the soil material behave nonlinearly when facing large displacements occurred by earthquakes. In current study we use adaptive neuro fuzzy inference system (ANFIS) to assess this problem. Data needed to train the system are generated using the software NERA working based upon nonlinear method. Two training strategies namely gird partitioning and subtractive clustering are adopted for training the fuzzy model. Once the models are trained their predictions are compared with the well-known commercial software SHAKE. The results indicate that the model trained by subtractive clustering algorithm predicts the ground motion better than the other model.

**KEYWORDS:** Ground Response Analysis, ANFIS, NERA, SHAKE.

## 1. INTRODUCTION

The earthquake, shaking and vibration at the surface of the earth resulting from the underground movement along a fault plane, is one of the most destructive natural phenomena on the earth. The earthquake-induced ground vibration is due to the upward transmission of the stress waves from a hard rock to the softer soil layers [1]. The influence of relatively shallow earth materials on the propagation of body waves (P and S waves) during an earthquake is known as ground response [2].

Traditionally the one-dimensional frequency-domain numerical scheme has been employed to perform site response analysis, which works based upon the equivalent visco-elastic approach [3–5]. This approach has been extensively adopted in the last 30 years and is widely accepted in the engineering practice despite of its limitations.

Nowadays Time-domain finite element or finite difference schemes are also used to solve the ground response problem accounting for the solid–fluid interaction by means of a fully coupled effective stress formulation [6, 7]. In these schemes, mechanical behavior of the soil can be defined using either simple or complicated non-linear constitutive models with different level of complexity. Furthermore, using these numerical approaches one is able to analyze the site response and the corresponding interaction with the existing structures simultaneously [8–15].

The one-dimensional wave propagation analysis is probably the most widely used method to perform site response analysis because of its ease of use and conservative results [3].

The well-known computer program SHAKE firstly developed by Schnabel et al. [3], is based on the equivalent linear method. One other computer program working based on nonlinear approach is NERA (Nonlinear Earthquake site Response Analysis of layered soil deposits), first encoded by Bardet and Tobita [16]. Both SHAKE and NERA require the individual soil strata to be characterized as homogenous and isotropic. In addition, both methods are one-dimensional, analyzing only vertically propagating shear waves (S waves).

The data required to model soil layers in NERA is similar to that used in the ELM in PROSHAKE software. The input data consists of layer thickness, bulk density, initial shear modulus of soil material, and the relation of shear modulus with shear strain. Additionally, a time history of acceleration is commonly required to characterize the motion of the underlying bedrock.

In current paper we use adaptive nero fuzzy inference system (ANFIS) to solve the wave propagation problem in a simple and quick manner. Data needed to train the networks are generated using NERA, a computer code for nonlinear ground response analysis. Moreover, the predictions of the proposed ANFIS models are compared with outputs of SHAKE.

---

***Corresponding Author:** Mohammad Hosein Bagheripour, Shahid Bahonar University of Kerman, Department of Civil Engineering, Kerman, Iran. E-mail: bagheri@mail.uk.ac.ir

## 2. Ground Response Analysis

Ground response analyses are performed to predict ground displacements for design response spectra and determine the earthquake-induced forces that can lead to instability of earth-based and earth-retaining structures. Generally speaking, the methods for analyzing ground response can be grouped according to the dimensionality of wave propagation pattern into: one-dimensional (1-D), two-dimensional (2-D), and three-dimensional (3-D) shear wave propagation methods. Most of these methods are based on the assumption that the main responses in a soil deposit are caused by the upward propagation of horizontally polarized shear waves originated from the underlying rock.

1-D method assumes that all boundaries are horizontal and that the response of a soil deposit is predominantly caused by vertically propagating shear wave originated from underlying bedrock. In spite of the fact that the soil layers are commonly inclined or bent, they are simply regarded as horizontal in most cases. Moreover, the length of a layer may be assumed infinite compared with its thickness. Consequently, it is justifiable to model them as 1-D horizontal layers. Analytical and numerical methods based on this concept, incorporating linear approximation instead of nonlinear soil behavior, have shown reasonable agreements with field observations in some cases [1].

1-D method is most widely used in ground response analysis because it is more practical to be used for quantitative analyses compared with 2-D and 3-D methods. Therefore, most of current seismic codes were developed using this method such as UBC 1994, UBC 1997, and IBC 2000 [17-19]. The other two approaches (2-D or 3-D) are commonly employed to analyze special structures such as dams, high-rise buildings, and nuclear power plants. In this study, the ground response analyses are carried out assuming 1-D shear wave propagation.

### 2.1. Soil Modeling

The ground response analysis should take account of the nonlinearity of soil material to provide reasonable results. There are two approaches to consider the nonlinear behavior of the soil material: equivalent linear and nonlinear methods. The equivalent linear approach is incapable of taking account of changes in soil stiffness which practically occurs during the earthquake due to large displacements. In equivalent linear models the strain always returns to zero after a cyclic loading, and failure will not occur since a linear material has no limiting strength. The nonlinearity of soil is taken into account by determining the values that are consistent with the level of strain induced in each layer. The equivalent linear approach and 1-D ground response analysis have been coded into widely used computer programs such as SHAKE and EERA. The equivalent linear approach is incapable of representing the changes in soil stiffness that actually occurs during the earthquake. Furthermore, this method may not be employed directly for problems in which permanent deformation or failure is likely to happen. On the other hand the nonlinear method has a number of advantages [1]:

(1) The stiffness of a real soil layer usually varies over the duration of large earthquakes; and therefore high levels of amplification emerging in equivalent linear approach, will not actually develop in the field.

(2) Nonlinear method can be formulated in terms of effective stresses to allow modeling of the generation, redistribution, and dissipation of excess pore pressure during and after the earthquake.

In current study, the ground response analyses were performed using nonlinear approach. The analyses were carried out using the program NERA [16], which stands for Nonlinear Earthquake Response Analysis. NERA is a computer code utilizing FORTRAN 90 and Excel Visual Basic programming to implement the NLM. NERA uses the model proposed by Iwan [20] and Mroz [21] to model nonlinear stress-strain curve of soil. Iwan-Mroz (IM) model consists of a set of sliding springs of varying stiffness to model hysteretic stress-strain behavior with regard to Masing rules. The parameters of IM model are selected so that the model duplicates typical shear modulus degradation curves used in ELM. Moreover, NERA uses a finite difference formulation to solve wave propagation equations in the time domain.

Ground response analysis requires some dynamic properties of the soil such as maximum shear modulus, $G_{max}$, shear wave velocity, $V_S$, and damping ratio, $\beta$. These parameters can be measured directly from field dynamic tests or determined indirectly from static field tests using empirical formulae.

## 3. METHODOLOGY

In order to train ANFIS models first a data set consisted of several individual training pairs should be collected. As mentioned earlier the nonlinear-based software NERA was employed to generate such a data set. The inputs of NERA (and consequently the inputs of the ANFIS models) are total unit weight, shear wave velocity and thickness of the soil layer as well as the frequency of base motion. In order to generate a comprehensive data set we considered a wide range of variations for above-mentioned parameters according to practical limits. These limits are 15 to 21 kN/m$^3$ for total unit weight, 100 to 1500 for shear wave velocity, 10 to 50 m for the thickness of soil layer and 2 to 106 for the frequency of base seismic motion.

Two different training techniques are chosen. These are traditional grid partitioning, Model I, and subtractive clustering, Model II. The membership function assigned were trapezoidal and Gaussian type for Model I and Model II respectively. For optimizing the parameters, the hybrid learning algorithm is used for both models which results in a fast identification of parameters and substantially reduces the time needed to reach convergence. Moreover, the minimum validation error is applied as the stopping criterion to avoid over fitting. In subtractive algorithm (Model II) the radius of influence and squash factor were selected as 0.5 and 1.2 respectively. Schematic of membership functions of input variables of Models I and II are illustrated in Figs 1 and 2

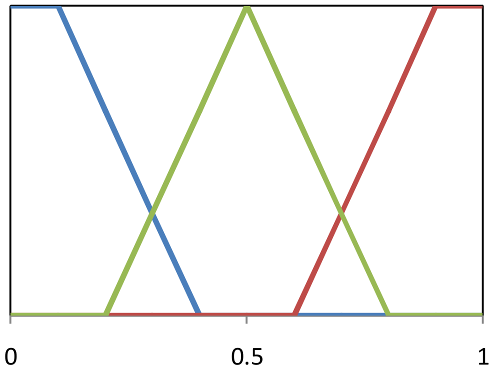

Fig 1. Typical membership functions for inputs of Model I (trapezoidal)

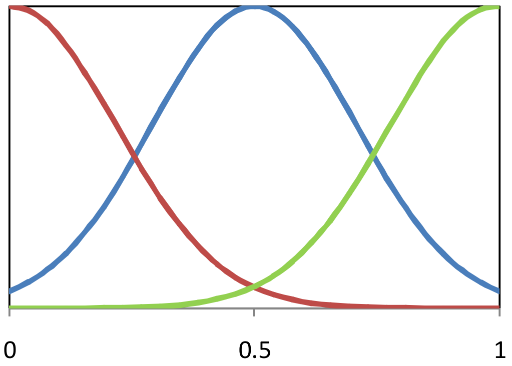

Fig 2. Typical membership functions for inputs of Model II (Gaussian)

After constructing two ANFIS models with the aforementioned architecture, we compared their predictions with the commercial software SHAKE to validate their applicability. Fig 3 presents outputs of the two proposed models versus those of SHAKE. As shown in this figure the model trained with subtractive clustering predicts the relative ground displacement precisely and can be advised for quick assessment of nonlinear ground response. Due to its high adaptability, ANFIS models may be also used for further applications in this area and this is one of the main advantages of the models proposed herein.

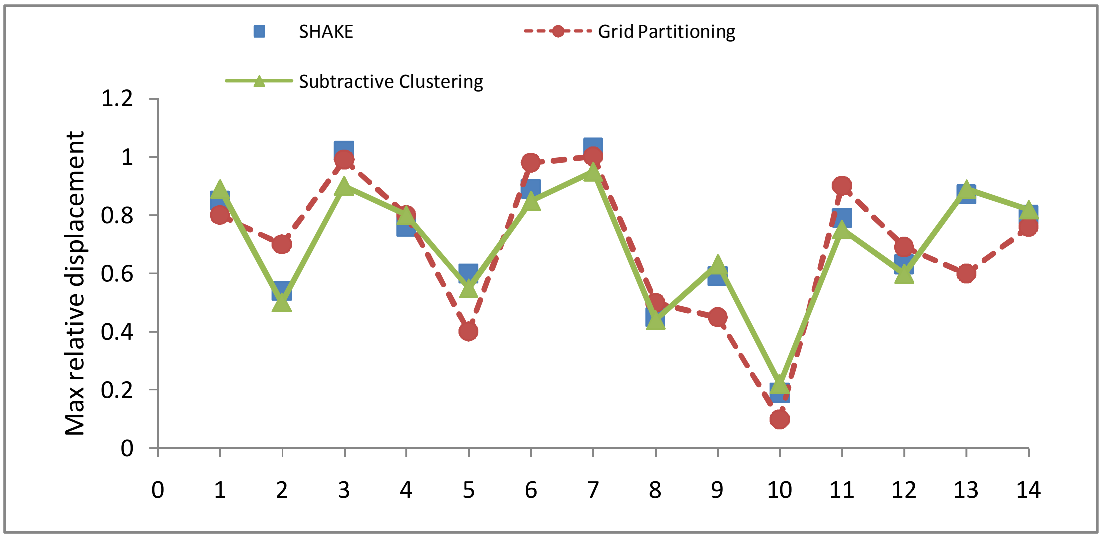

Fig. 3. Outputs of the two ANFIS models versus SHAKE's outputs

## 4. Conclusions

In current paper we studied the nonlinear response of ground to a base seismic motion using adaptive neuro fuzzy inference systems (ANFIS). Two training methods were adopted: grid partitioning and subtractive clustering. Data required to train fuzzy models were generated using NERA (a computer code to perform nonlinear analyses of ground seismic response). Comparing the results of these to ANFIS models with outputs of SHAKE showed that they both present reasonable results. Furthermore, the model trained by subtractive clustering offers high accuracy compared with the other model. This study revealed that ANFIS models are appropriate frame work to deal with the problem of nonlinear ground response to earthquake-induced motions. It is to be mentioned that some other methods, including finite element method, FEM, have been proposed before to predict this response when soil material behave nonlinearly. The method introduce herein, however, offers ease of use as well as high accuracy simultaneously. Moreover, such models may be trained on experimental data to achieve more legitimate results from practical point of view.

## REFERENCES

[1] Kramer, S.L. 1996. Geotechnical Earthquake Engineering, Prentice-Hall Inc., New Jersey (NJ).

[2] Tsai, N.C. 1969. Influence of local geology on earthquake ground motion, PhD Thesis in California Institute of Technology, Pasadena, CA, USA.

[3] Schnabel PB, Lysmer J, Seed HB. SHAKE: a computer program for earthquake response analysis of horizontally layered sites. Report no EERC72-12, Earthquake Engineering Research Center, University of California, Berkeley; 1972.

[4] Idriss IM, Lysmer J, Hwang R, Seed HB. QUAD-4: a computer program for evaluating the seismic response of soil structures by variable damping finite element procedures. Report no EERC 73-16, Earthquake Engineering Research Center, University of California, Berkeley; 1973.

[5] Idriss IM, Sun JI. SHAKE91: a computer program for conducting equivalent linear seismic response analyses of horizontally layered soils deposits. Center for Geotechnical Modeling, University of California, Davis; 1992.

[6] Biot MA. General theory of three-dimensional consolidation. J ApplPhys 1941;12:155–64.

[7] Zienkiewicz OC, Chan AHC, Pastor M, Schrefler BA, Shiomi T. Computational geomechanics (with special reference to earthquake engineering). Chichester: Wiley & Sons; 1999.

[8] Dewoolkar MM, Ko HY, Pak RYS. Seismic behaviour of cantilever retaining walls with liquefiable backfills. J GeotechGeoenvironEng 2001;127(5): 424–35.

[9] Elgamal AW, Parra E, Yang Z, Adalier K. Numerical analysis of embankment foundation liquefaction countermeasures. J Earthquake Eng 2002;6(4): 447–71.

[10] Aydingun O, Adalier K. Numerical analysis of seismically induced liquefaction in earth embankment foundations. Part I. Benchmark model. Can Geotech J 2003;40(4):753–65.

[11] Muraleetharan KK, Deshpande S, Adalier K. Dynamic deformations in sand embankments: centrifuge modelling and blind, fully coupled analyses. Can Geotech J 2004;41(1):48–69.

[12] Dakoulas P, Gazetas G. Seismic effective-stress analysis of caisson quay walls: application to Kobe. Soils Found 2005;45(4):133–47.

[13] Madabhushi SPG, Zeng X. Simulating seismic response of cantilever retaining walls. J GeotechGeoenvironEng 2007;133(5):539–49.

[14] Amorosi A, Elia G. Analisidinamicaaccoppiatadelladiga Marana Capacciotti. ItalGeotech J 2008;4:78–96.

[15] Sica S, Pagano L, Modaressi A. Influence of past loading history on the seismic response of earth dams. ComputGeotech 2008;35(1):61–85.

[16] Bardet, J.P., and Tobita, T. (2001). NERA: A Computer Program for NonlinearEarthquake site Response Analysis of Layered Soil Deposits, University ofSouthern California, Department of Civil Engineering.

[17] Building Seismic Safety Council. (1995). 1994 Edition NEHRP Recommended Provisions forthe Development of Seismic Regulations for New Buildings, FEMA 222A/223A. Vol. 1(Provisions) and Vol. 2(Commentary).Developed for the Federal Emergency ManagementAgency. Washington, DC.

[18] Building Seismic Safety Council. (1998). 1997 Edition NEHRP Recommended Provisions forthe Development of Seismic Regulations for New Buildings, FEMA 302/303. Part 1(Provisions) and Part 2 (Commentary).Developed for the Federal Emergency ManagementAgency. Washington, DC.

[19] International Code Council. (2000). International Building Code 2000.International CodeCouncil.International Conference of Building Officials.Whittier, CA, and others.

[20]Iwan, W. D. (1967). On A Class of Models for The Yielding Behavior Of Continuous AndComposite Systems. Journal of Applied Mechanics, ASME. Vol. 34: 612-617.

[21]Mróz, Z. (1967). On The 'Description of Anisotropic Work hardening.Journal of Mechanicsand Physics of Solids. Vol. 15: 163-175.