# Prediction of Earthquake Damage Degree Using a Neuro-Fuzzy Systems

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**Abstract**

*Earthquakes have been a recurring phenomenon throughout history and will likely continue to occur in the future. The occurrence of such an event has, in most cases, left devastating effects on human settlements and has imposed heavy casualties on their inhabitants. Identifying damage caused by severe earthquakes to structures is crucial for several reasons, including public safety, effective resource management, infrastructure maintenance, and informed urban planning. After the earthquake, engineers must assess the safety of existing structures and decide on the actions that should be taken. Therefore, this paper presents a form of earthquake damage prediction using a neuro-fuzzy system to predict the resistance of buildings. The advantages of this method are the absence of complex formulation, high speed, and easy procedure. In this research, the 2017 Sarpol-e-Zahab earthquake in Iran is also used as a case study. The accuracy of the proposed model is evaluated using a 10-fold validation method and is equal to (94.5 ± 3.2)%.*

**Keywords:** Damage, Earthquake, Neuro-fuzzy system, Prediction

## 1. Introduction

Earthquakes are one of the major natural disasters of the present era, which always occur in a very short period of time and have caused great disasters so far. On the one hand, stability and safety against natural phenomena have always occupied the minds of mankind, and on the other hand, despite the tremendous technological advances in the past centuries, the danger and fear of earthquakes still remain strong in most parts of the world. Earthquakes are one of the major natural disasters of the present era, which always occur in a very short period and have caused great disasters so far. On the one hand, stability and safety against natural phenomena have always occupied the minds of mankind, and on the other hand, despite the tremendous technological advances in the past centuries, the danger and fear of earthquakes remain strong in most parts of the world. In fact, what makes earthquakes a threat is the lack of preparedness of mankind to deal with them[1, 2]. The complexities and certain dynamics of earthquakes have led researchers to use soft computing, which means extracting data through numerical calculations instead of the usual classical mathematics. Neural networks and fuzzy systems are both very popular techniques in soft computing. These systems include approaches that are close to human reasoning and always try to use human tolerance for uncertainty, imprecision, and ambiguity in decision-making processes. Earthquakes are caused by sudden movements of the earth's crust and cause extensive damage to buildings, bridges, and dams. The most important thing is to save human lives from this natural event. Despite the many faults on the Iranian plateau, earthquakes can be considered a natural occurrence in this part of the world. As per the report of the United

Nations Office for the Coordination of Humanitarian Affairs in 2003, Iran ranks first in the number of earthquakes with an intensity of 5.5 on the Richter scale per year and has one of the highest ranks in the field of vulnerability due to earthquakes. Based on official statistics in the past 25 years, 6% of human casualties in our country have been caused by earthquakes [3]. In recent years, many studies have been conducted using intelligent systems such as fuzzy logic, artificial neural networks, etc. In 2010, Sen proposed a new method for risk analysis using fuzzy logic. In this method, structural characteristics and characteristics and risk acceptance are classified into qualitative and quantitative linguistic descriptions. In 2012, Gerami and his colleagues studied the zoning of potential earthquake hazards using an artificial neural network. By receiving input patterns, this network can extract the characteristics of complex patterns from the input data, and then, through statistical research, zoning maps of potential earthquake locations are drawn [4]. In 2018, Da Lautour and Omenzetter presented seismic damage spectrum prediction using computational intelligence methods [5].In this research, using a neuro fuzzy system, the assessment of damage to buildings during earthquakes is presentedto determine the safety of the building and its suitability for future habitation. This damage is considered an interpretation or linguistic variable in the form of different degrees of damage or loss. In earthquake engineering, the knowledge of earthquake damage in human structures is of great importance. Earthquake prediction is one of the most challenging problems worldwide. In this regard, the use of artificial intelligence techniques, especially neuro-fuzzy systems, has been considered due to their ability to model nonlinear and complex phenomena. The very high learning ability of artificial neural networks has made this method a very suitable choice, especially when combined with fuzzy systems. The combination of artificial neural networks and fuzzy systems has resulted in a highly efficient approach for modelling various systems, allowing each method to address the weaknesses of the other and enhance the overall efficiency of the resulting neuro-fuzzy system [6]. In this study, for the first time, the degree of damage caused by earthquakes to buildings is considered according to the opinions of structural experts with three linguistic variables, such as low damage, medium damage, andhigh damage, and the results obtained are compared with the opinions of earthquake experts, and the overall accuracy of the proposed system is calculated. This paper consists of the following sections. In Section 2, a brief definition of the neuro fuzzy system is presented. In Section 3, the design of the neuro-fuzzy system for predicting the degree of damage to buildings after an earthquake is presented by introducing the input and output variables, as well as evaluating the performance of the presented system. The conclusion of the paper is presented in Section 4.

## 2. Neuro-Fuzzy Systems (NFS)

The architecture of Adaptive Neuro-Fuzzy Inference Systems (ANFIS) was proposed in 1993. Fuzzy systems are used in situations of uncertainty. Because fuzzy rules are well-suited for such situations, the ideal combination of neural networks and fuzzy logic leads to the production of neuro-fuzzy systems that are close to human-like reasoning. The goal of NFS systems is to use the learning capabilities of neural networks and fuzzy logic to model complex systems. Fuzzy logic is suitable for dealing with uncertainties and modeling imprecise or uncertain data, while artificial neural networks are used to recognize patterns and learn from data. AnNFS system is a type of artificial neural network based on the Takagi-Sugeno fuzzy system. This human-like behavior can be developed by providing appropriate training to a data set. Fuzzy inference systems are nonlinear models that describe the input-output relationship of a real system using a set of fuzzy if-then rules. The proposed neuro-fuzzy inference system structure consists of a special five-layer network. The first layer represents the input variables, and the second and third layers represent the hidden layer, which contains fuzzy rules. T-norm is used as the activation function. The fourth layer represents the inference engine, and the fifth layer represents the output variable. The membership functions are adjusted and generated either by forward propagation (back propagation), backward propagation, or the least mean squares estimation algorithm [5]. Neuro-fuzzy systems can model and analyze complex problems that inherently have ambiguities due to mathematics and impossible rules. This system tries to create a closer relationship between the precision of mathematics and the general ambiguity of linguistic variables in the real world. Some of the features and capabilities of the neurofuzzy system are the ability to model qualitative and linguistic descriptions mathematically, the ability to model complex nonlinear functions, very high flexibility in problem-solving, and the ability to use practical and scientific experiences in the subject matter to create a dynamic model [4,6].

## 3. Designing a Neuro- Fuzzy System to Predict Earthquake Damage to Buildings

An earthquake is a natural disaster that severely affects the human race and damages buildings. In order to prevent destruction and reduce its effects, it is necessary to formulate a disaster management plan taking into account the results of damage prediction. Addressing the problems of earthquake-related damage prediction using fuzzy logic is more coherent because there are many vague and uncertain concepts in the damage prediction problem, and the relationships between the related factors are confusing. In this study, as mentioned, the 2017 Sarpol-e-Zahab earthquake in Iran has also been used as a case study. The presented NFS system has four input parameters, such as ground motion duration, soil types, building height, and maintenance, where ground motion duration is based on the magnitude of the earthquake shock, soil types are based on the Iranian standard soil classification system, building height is based on the height of buildings in meters, and maintenance is based on the number of repairs in the building, and the output parameter shows the degree of damage to predict the resistance of buildings [7, 8]. The membership functions of the input parameters of soil type and maintenance are shown in Figs 1 and 2, respectively. Therefore, the system presented in this study depends on the opinions of earthquake experts who decide on the input and output variables. The

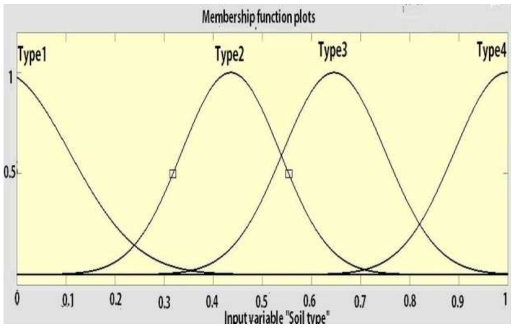


**Fig. 2.** Membership functions of blood pressure variable

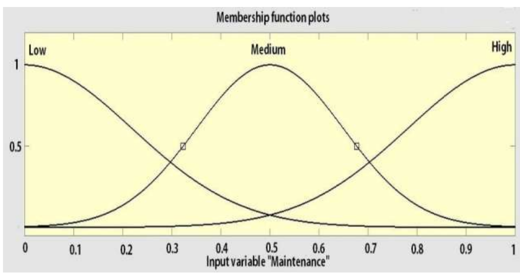


**Fig. 3.** Membership functions of blood pressure variable

**Table1.** Input-output parameters provided for predicting the degree of earthquake damage

| Input and output variables | Fuzzy set value |
|---|---|
| Ground motion duration | three fuzzy values (Low, Medium, High) |
| Types of soil | four fuzzy values (Type1, Type2, Type3, Type4) |
| Building height | three fuzzy values (Short, Medium, High) |
| Maintenance | three fuzzy values(Low, Medium, High) |
| Degree of damages | three fuzzy values (Low, Medium, High) |

Linguistic values of the input and output parameters are shown in Table 1. The membership functions of the input and output variables are considered as Gaussian curves due to the necessary accuracy and overlap. The architecture of the proposed system is shown in Fig.3. The neuro-fuzzy inference system extracts fuzzy rules from numerical data or expert knowledge and adaptively builds a rule base. The steps of designing the proposed system are as follows:

Step1: In this stage, the input data is normalized according to equation (1) in the interval between [0, 1] [9].

$$x = \frac{x - x_{min}}{x_{max} - x_{min}} \qquad (1)$$

Step2: In this stage, the membership degree of each input is determined through membership functions. Each input, which is a clear numerical value, is converted into a linguistic variable. In this research, the parameters of ground movement duration, soil types, building height, and maintenance are considered as input parameters, and the amount of damage to the building is the output variable. In this research, the input and output variables are designed as Gaussians. After defining the membership functions, the goal is to design an inferential system. The design of the presented system is considered according to the parameters and if-then rules. Fuzzy rules are used to define the relationships between inputs and outputs [4, 10]. In this system, the Sugno class is used, and the Sugno rules are written using MATLAB software. Below are some of the rules used:

If the ground movement period is short and the soil type is type 1 and the building height is medium and the maintenance is low, then the damage is low.

If the ground movement period is medium and the soil type is type 2 and the building height is high and the maintenance is medium, then the damage is medium.

If the duration of ground movement is short and the soil type is type 3 and the building height is low, and maintenance is high, then the amount of damage is low.

After writing the rules in the system, the training stage is to modify the membership degree parameters based on the acceptable error so that the input values are close to the real values. In this system, the neural network learning algorithm and fuzzy logic are used to design a nonlinear mapping between the input and output spaces, which has good capabilities in training, construction, and classification. ANFIS allows the extraction of fuzzy rules from numerical information or expert knowledge and can also regulate the complex transformation of human intelligence into fuzzy systems. This system solves the main problem of obtaining fuzzy if-then rules by effectively using the learning capability of an artificial neural network to automatically generate rules and optimize parameters, and it uses a combination of least squares error and backpropagation training methods for the training process.

Step3: The last layer is related to the defuzzification stage; the input of this process includes the fuzzy set, and its output is a numerical value. The proposed classification method consists of two stages: training and testing. In the training stage, training data is given to the system, and the back-propagation learning method is used to update the parameters of the fuzzy inference system. The learning method used is the supervised learning method, in which the input values are given to the system along with the actual output. The training process continues until the desired minimum mean square is obtained. The proposed method uses the Sugno fuzzy model, and the T-norm operator is used in the rules layer. The weighted average method is used for defuzzification [1, 11]. After training is completed, the network is evaluated using the test data using the 10-fold validation method to ensure the performance of the proposed system. In this method, nine data sets are considered for training and one data set for testing. Each time the program is run, the accuracy and recognition rate for the test data are calculated. Table 2 shows the final stage of the algorithm execution for 11 test data. The output of the system presented after completing the training is shown in Fig.4. After ten iterations, the overall accuracy of the algorithm, which is obtained from the average of the obtained accuracies, is (94.5 ± 3.2)%.

**Table 3.** Comparison of the experts' opinions with the proposed model for the algorithm's last step

| | Low risk | Medium risk | High risk |
|---|---|---|---|
| Low risk | 1 | 0 | 0 |
| Medium risk | 0 | 0 | 1 |
| High risk | 0 | 0 | 9 |

The proposed model the mean opinion of experts

$$\text{Recognition rate low}=\frac{1}{1+0+0}=1$$

$$\text{Recognition rate medium}=\frac{0}{0+0+1}=0$$

$$\text{Recognition rate low}=\frac{9}{0+0+9}=1$$

$$\text{Accuracy percentage}=\frac{9+0+1}{11}=\%90$$

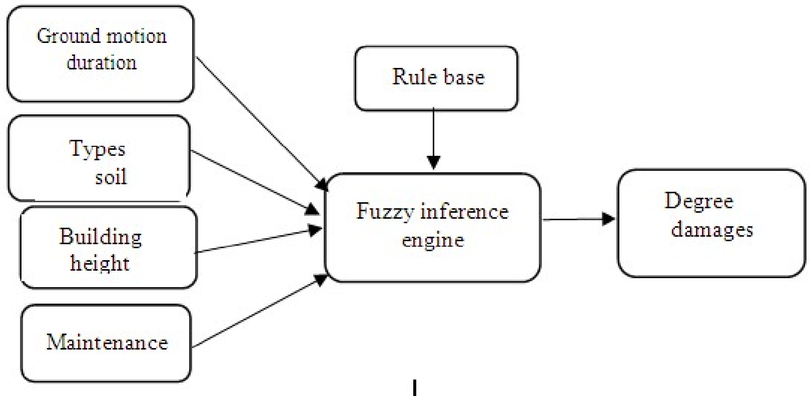


**Fig. 3.** The architecture of the proposed system

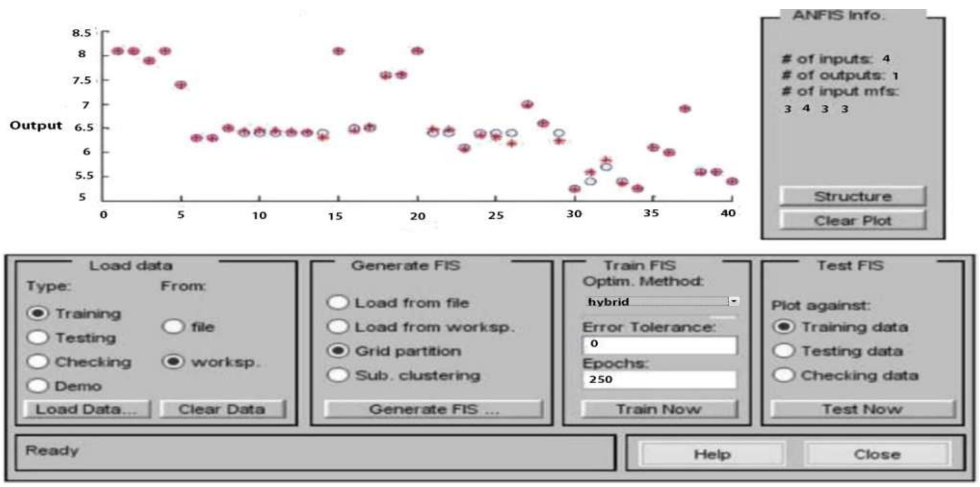


**Fig. 4.** The output of the system presented after completing the training of data set

## 4. Conclusions

Using a neuro-fuzzy system to predict the extent of damage to buildings due to earthquakes is an effective and efficient method. Because this system, by combining fuzzy logic and neural networks, has high power in modeling complex and imprecise phenomena, the accuracy of calculationsincreases significantly. Recent research shows that the combination of fuzzy logic neural networks and fuzzy logic can overcome the limitations of this method.This system, by combining neural networks and fuzzy logic, can use the capabilities of both. The results show that the proposed system for predicting the extent of damage to buildings has an excellent accuracy of (94.5±3.2)%. It can be said that the proposed system is a flexible and reliable decision-making system for earthquake experts and can predict the degree of earthquake damage to buildings.

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