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Estimating earthquake performances of existing reinforced concrete buildings using ANN

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ABSTRACT: In this study, an artificial intelligence-based (ANN based) analytical method has been developed to analyze earthquake performances of the existing multi-storey reinforced concrete (RC) buildings. In the scope of the study, 66 real RC buildings with four to ten storeys were subjected to performance analysis according to 19 parameters thought to be effective on the performance of RC buildings. In addition, level of performance possible to be shown by these buildings in case of an earthquake was determined on the basis of the 4-grade performance levels specified in Turkish Earthquake Code-2007 (TEC-2007). Thus, an output performance data group was created for the analyzed buildings, in accordance with the input data. Thanks to the ANN-based fast evaluation algorithm, it will be possible to make an economic and rapid performance evaluation of four to ten-storey RC buildings in Turkey with great accuracy (about 80%). Detection of post-earthquake performances of RC buildings in the scope of the present study will facilitate reaching important results in terms of buildings, which will be beneficial for Civil Engineers of Turkey and similar countries.

1 INTRODUCTION

In the research published after earthquakes over the past 20 years, the reinforced concrete (RC) buildings damaged by the earthquakes had many common defects, and a large number of the existing RC buildings did not have sufficient strength, stiffness or ductility because of these defects. Although the existing RC buildings are weak, Turkey has an earthquake code (TEC-2007)(2007) with strict rules in regions with a high earthquake risk, just like other countries. The earthquake design criteria in the national earthquake codes are constantly upgraded and improved with the increase in knowledge about the real behavior of structures during earthquakes. Performance of the existing RC buildings in Turkey under earthquake effect is determined according to TEC-2007 criteria. By using a series of methods that are developed according to the basic principles of FEMA-356 (2000) and ATC-40 (1996) and that can be easily adapted to the Turkish building stock; TEC-2007 enables calculation of the performance of existing RC buildings. Expected earthquakes and current status of particularly the reinforced concrete (RC) building stock in Turkey require RC buildings to be urgently evaluated. Considering the current building stock and the seismicity of Turkey, this is theoretically and practically very difficult. Due to this difficulty, researchers have developed and continue to develop certain rapid evaluation methods and some structural scoring systems in recent years. The need for a rapid screening of a RC building is first recognized by FEMA (1988) and developed by various researchers as Boduroglu, et. al. (2004) and Bal et.al (2006). Main objective of these methods is to evaluate a RC building in a very short time and to obtain a result that is close to the real performance. By this way, cost and time-saving will be achieved during detailed evaluation of thousands of buildings. it is obvious that, conducting a detailed analysis of a RC building is quite difficult due to financial and time constraints. For these reason estimating the performance of a RC building within a short time period is very important.

The use of artificial neural network (ANN) models may be made to drastically reduce the computational effort in such cases. ANN is a type of artificial intelligence application implemented by engineers to carry out specialized design tasks so far. In this study, using the parameters obtained from RC buildings projects in computer media, an ANN based algorithm was developed to evaluate behaviours and performances of the RC buildings under earthquake loads. The mentioned algorithms were calibrated for the 4-storey or 10-storey RC buildings, general type of residence in Turkey, where a significant part of the existing RC building stock of this type is known to be inadequate. Earthquake performances of the RC buildings were determined and classified on the basis of the obtained results and, building performances were determined with high accuracy by using the recommended method. Thus, it was shown that this ANN based model, which brings innovations for the fast evaluation of earthquake risks of RC buildings, can be developed on a large number of sample buildings and can be used in areas with high earthquake risk.

2 PERFORMANCE ANALYSIS ACCORDING TO TEC-2007 PRINCIPLES

According to TEC-2007, performance of the RC buildings can be evaluated using two methods: linear or non-linear methods. The civil engineer chooses a method to determine the damages and the performance of the building, and there is a four-stage performance scale for both of the methods in TEC-2007. The condition of a damaged building at the time of an anticipated earthquake can be determined with this scale.

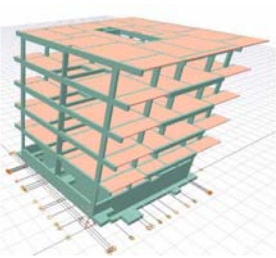
The non-linear method is based on plastic hinge hypothesis and performed by analyzing pushover analysis and the capacity curve comprising lateral load – lateral displacement. On the other hand, linear method is much simpler than non-linear method and is based on a linear structural analysis approach. In this method, earthquake load reduction coefficient (R) which is an expression of the ductility of the building, and building safety factor (I), are taken as 1. This method can be applied in two ways; a) equivalent static seismic load method (This can be used in the buildings with a coefficient smaller than 8 and a maximum height of 25 meters where torsion is insignificant) b) mode superposition method (this can be used in all buildings). According to the results of both analyses, effect capacity ratio for each cross section in the load bearing system is calculated according to Eq.(1) provided in TEC-2007 and the damage limit of the section is determined (r). In this formula R_s refers to the capacity of the related section, E to the elastic earthquake effect which is expected to be accommodated, G and Q refer to the cross section forces produced by the dead and live load.

$$r = \frac{E}{R_s - (G + Q)} \quad (1)$$

An identified section damage status gives storey damage status which then gives building global damage status. Thus, the global damage and performance level to be recorded in the building in case of an earthquake are determined. General performance outcomes of RC structures are; withstanding minor earthquakes undamaged; withstanding medium-scale earthquakes with limited damage; and withstanding large-scale earthquakes without total collapse. The critical outcome is the prevention of total structural collapse. This means that the upper level withstands total collapse while the sub-level, for crucial structures, may be slightly damaged but remains fit for immediate occupancy. Between the sub- and upper-levels, the Life Safety level is required. TEC-2007 divides building performance level into four categories according to number of columns, beams and shearwalls. These are Immediate Occupancy (IO), Life Safety (LS), Collapse Prevention (CP) and Collapse (C), respectively.

3 DATABASE

Most of the residential and commercial buildings in Turkey are constructed with cast-in-situ RC. Again, most of these buildings have 4-10 floors. Total of 66 RC buildings with 4-10 storeys, which were thought to represent existing RC buildings in Turkey, were selected for the present study. Selected RC buildings were modelled with the commercial program (IDEStatik V.6.0053) program. The model of the programme can be easily converted to the SAP2000 (2000). Performance analysis of the RC buildings was performed according to the linear procedure (mode superposition method) specified in TEC-2007. In the anayses, the earthquake, ground motion with 10% probability of exceedance in 50 years**,** equivalent to a 475-year return period was chosen. TEC-2007 states that under this earthquake, the residence buildings should provide the Life Safety (LS) performance level. The building which provides this performance level will not be severely damaged in the earthquake but retains a margin against onset of partial or total collapse. Two residence building models are shown in the Figure 1 with the opinion of providing examples out of 66 residence buildings chosen in the analysis (Koyuncu, 2009).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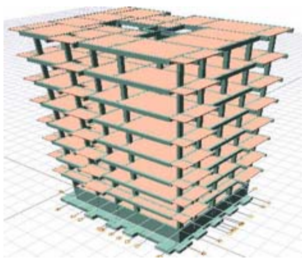
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Figure 1. Two of the RC buildings analyzed in the study

The parameters considered in the selected RC buildings were as follows: earthquake zone (EZ), project year (PY), number of storey (NS), Average Column Ratio, Average Shear Wall Ratio (ρ_{CA} , ρ_{SWA}), Average Longitudinal Bar Ratio in Columns, Average Longitudinal Bar Ratio in SW ($\rho_{\ell col}$, $\rho_{\ell SW}$), Stirrup Condition in the Load Bearing System (s_c), Basement Storey (B) Slab Types (ST), Concrete Compression Strength (C), Steel Tension Strength (S), Average Inertia of Beams (I_b) Irregularity Types (IT), Clerestory Status (CL), Soil Type (Z), Ductility Level (R), Foundation Types (FT), Living Load Reduction Coefficient (n). In addition to the mentioned input data, earthquake performance of the buildings was determined with the performance analysis (output data). Four different performance levels of the buildings during an earthquake were grouped as S_1, S_2, S_3 and S_4. Here S_1=IO, S_2=LS, S_3=CP and S_4=C. In the study, total of 19 different structural parameters are used and described above. Table 1 indicates variation intervals of some parameters for the selected 66 buildings. For the variation interval of other parameters (PY, s_c, B, S, ST, IT, CL, R, FT, EZ etc.) which are not presented in Table 1, constants such as 0,1,2,3 etc were used. For example, 0 value was entered for PY for the buildings built before 1998 and 1 value for the buildings built after 1998. The reason behind this is that TEC went through a radical change in 1998. Therefore, the buildings designed after the year 1998 are safer than the ones which were designed before 1998. Similarly, for example ST was defined as 1 in hollow-tile floor slab, 2 in plate slab and 3 in beam slab.

Table 1. Used data range

Parameter	Minimum Value	Maximum Value
Number of Storey (NS)	4	10
Average Column Ratio (ρ_{CA})	0,008197	0,024721
Average Shear Wall Ratio (ρ_{SWA})	0	0,011725
Average Longitudinal Bar Ratio in Columns ($\rho_{\ell\ col}$)	0,00843	0,012828
Average Longitudinal Bar Ratio in SW ($\rho_{\ell\ SW}$)	0	0,010643
Steel Tension Strength (S)	220	420
Concrete Compression Strength (C)	16	20
Average Inertia of Beams (I_B)	0,001092	0,0045
Importance Factor (I)	1	1,5
Soil Type (Z)	1	4
Earthquake Reduction Coefficient (R)	4	7
Living Load Reduction Coefficient (n)	0,3	0,6
Structural Performance (S_1-S_4)	1	4

4 ARTIFICIAL NEURAL NETWORK

In this study, a three-layered (input layer, hidden layer and output layer) feed-forward artificial neural network (ANN) stucture was used and trained with the error backpropagation algorithm. In the feedforward ANNs, the neurons in each layer are only fully interconnected with the neurons in the next layer. Travel of information being processed for a single "forward" direction. Its errors propagate backwards from output neurons to the inner neurons (Ripley, 1996).

4.1 Application of ANN

In classification of RC buildings under earthquake loads according to their performances, selection of appropriate ANN architecture is very important for the accuracy of the study. As indicated in the literature, optimum number of hidden nodes and learning rate values comprising the architecture of the network were found in training and testing phase of the ANN via experimentation. Firstly, by keeping the learning rate constant, number of hidden nodes was increased from 2 to 100. Optimum number of hidden nodes was determined as 80 because of lowest training and test error. Similarly, 80 hidden nodes which were found as optimum number of hidden nodes were kept constant. After the stepwise increase of learning rate from 0.001 to 5.0, it was found that the value of 2.0 had the lowest training and testing error**.** In this study, ANN was trained with 11 different algorithms which are commonly used in ANN applications in the literature: BFG, CGB, CGF, CGP, GDA, GDM, GDX, LM, OSS, RP and SCG algorithms (Arslan et al., 2007). All training procedures were performed by operating the ANN with 10000 iterations. 19 different structural parameters were presented to ANN as inputs. Outputs of ANN were labelled as four classes (S_1, S_2, S_3 and S_4) including four different performance levels of the buildings during an earthquake. Figure 2 shows the used network architecture.

4.2 Measures for Performance Evaluation 2 Fold Cross-Section

In this study, 2-fold cross-validation test was performed to confirm the accuracy of the classification procedure and to test generalization capability of the proposed network. The used data set contains the data of 66 buildings comprised of 4 classes (S_1,S_2,S_3 and S_4). Of these 66 buildings, 7 belong to S_1, 20 belong to S_2, 23 belong to S_3 and 16 belong to S_4. To apply 2-fold cross-validation test, these buildings were divided into 2 data sets. Table 2 indicates building classes. In line with the above mentioned test procedure, the ANN was trained with the 1st data set and was tested with the 2nd data set. Then it was trained with the 2nd data set and tested with the 1st data set. Figure 3. represents the relation between standart deviations-mean values for selected RC buildings.

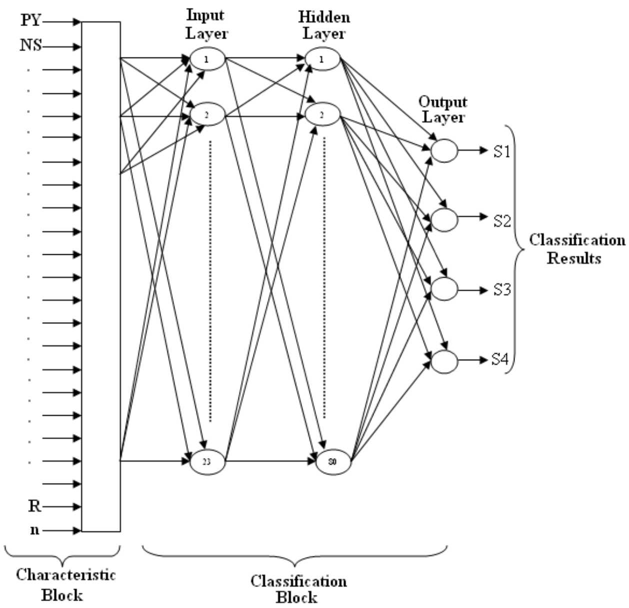

Figure 2. ANN structure

Table 2. Distribution of classified data sets according to groups

Data Set	Class 1 (S_1)	Class 2 (S_2)	Class 3 (S_3)	Class 4 (S_4)	Total
1	4	11	12	8	35
2	3	9	11	8	31

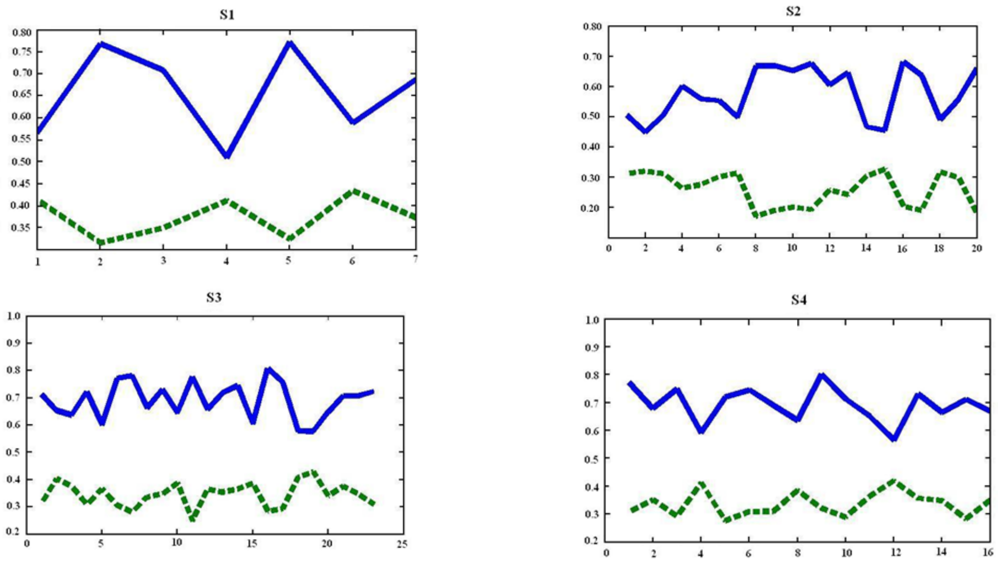

Figure 3. Standart deviations-mean values relation for selected RC buildings

4.3 Pre-processing and classification

Classification was made by using four approximations. In three approximations, pre-processing stage was implemented to original data set. Mean value, standard deviation value and these values together were extracted from data and obtained features were presented to ANN for classification task. In other approximation, original data set was given to ANN without any pre-processing. Input data (19 different structural parameters) is applied to ANN, directly. Obtained training and test errors for 2-fold validation sets using proposed approaches are presented in Table 3. In the Table Approaches 1 indicates Mean, Approaches 2; Standard deviation, Approaches 3; Mean and standard deviation, Approaches 4; No pre-processing, respectively.

5 RESULTS

According to the data used;

1. The performances of the RC buildings under earthquake loads were determined with an accuracy of 80.46%.
2. The best classification result of ANN using pre-processing is obtained as 71.84 % with extraction of mean and standard deviation values of input data.
3. This classification accuracy was lower than 80.46 % of ANN without pre-processing, but time consumption of network with pre-processing was nearly half of without pre-processing.
4. Especially, it has been seen that (Table 3) the performance levels of the 66 RC buildings are 10.61 % S_1, 30.3 %S_2, 34.85 % S_3, 24.24 % S_4. In TEC-2007, the RC residence buildings have to provide at least S_2 Life Safety (LS) in order to be in the sufficient performance level during the earthquake. According to this statement, 59.09 % of the buildings chosen as examples were the buildings not having sufficient earthquake performance according to the TEC-2007 criteria. It was obvious that especially the buildings included in the S_4 group were at great risk and the complete collapse risk of these buildings under a probable earthquake in the region is very high.
5. Since the study was carried out on the basis of TEC-2007 norms, structure performance

after the earthquake was determined according to the related code criteria. There are not any other studies taken TEC-2007 as the basis and using ANN in the literature.

Table 3. Training and test errors of ANN

Training Algorithm of ANN	1. Approach		2. Approach		3. Approach		4. Approach	
	Training Error (%)	Test Error (%)	Training Error (%)	Test Error (%)	Training Error (%)	Test Error (%)	Training Error (%)	Test Error (%)
BFG	3.54	37.82	6.08	29.50	2.17	31.55	-*	-*
CGB	2.02	37.54	2.09	32.39	0.38	29.83	0.40	24.97
CGF	2.29	35.98	4.38	31.20	3.79	29.10	1.76	**19.54**
CGP	1.12	37.09	1.82	31.32	0.36	30.31	2.15	26.62
GDA	3.60	38.37	5.54	32.28	2.80	29.85	0.06	25.15
GDM	7.56	35.74	10.06	31.35	6.79	30.51	7.22	22.70
GDX	2.48	37.66	5.82	30.63	1.54	29.23	0.41	24.80
LM	5.77	36.80	5.28	30.49	0.00	28.16	-*	-*
OSS	1.41	37.55	1.90	31.14	0.35	29.11	0.02	25.32
RP	8.58	39.42	11.87	31.82	5.30	29.47	0.41	19.66
SCG	0.76	39.38	3.18	30.48	2.15	28.75	0.41	24.40

*: *Result is not obtained using BFG and LM algorithm*

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