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Reinforced Concrete Frame Failure Prediction Using Neural Network Algorithm

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Abstract: Middle height reinforced concrete frames are widely used in construction in residual areas and they can cause catastrophic disaster if they can't withstand during the destructive earthquakes. Hence determining the status of these buildings after earthquake and detecting mechanism formation are essential for safety insurance in the urban areas. This paper aims to determine the failure and non-failure modes of the flexural RC frames according to the damage status of the beam and column joints. To achieve this goal, a 5-storey flexural RC frame is modeled via IDARC software and Nonlinear Dynamic Time History Analysis is performed through 60 seismic accelerations. Then the frame collapse and non-collapse arrays are constructed obtaining the results of dynamic analysis in both modes. Artificial Neural Network is used for the Classification of the obtained modes. The results show good agreement in every class and make it possible to introduce the simple weight factor for frame status identification.

Key words: Reinforced concrete frame, plastic hinge, seismic, artificial intelligence

INTRODUCTION

Seismic prone regions have frequently caused injuries and financial loss for years to densely populated urban and industrial areas. In these areas, earthquake occurrence can grapple humans for long time. In these areas the only escape is to makes the building and its location safe against this phenomenon. Despite the application of different criteria and factors in the design and construction of a structure, different modes of damage and loss are possible during an earthquake and hence, fully trusted structures can't be designed. Evaluation of the seismic damage in structures is a technique that helps in building strengthening (ACI, 2002; Alsulayfani and Saaed, 2009; Adedeji and Ige, 2011). Another way to prevent the occurrence of structural failure is to define failure modes to avoid them. In this method we will seek to answer the following questions:

- Will the structure collapse during earthquakes?
- Does the main earthquake cause damages in the structure which can brought it to the brink of destruction in aftershocks?

Haselton *et al.* (2011) evaluated the Safety of Reinforced Concrete buildings in seismic zones. They conclude that the code provisions delay but do not prevent, column yielding and the formation of story collapse mechanisms. Goulet *et al.* (2007) considered seismic hazard to collapse safety and economic losses for this type of structures.

In this research, the frame damage on the verge of collapse will be evaluated by IDARC software through the Nonlinear Dynamic Time History Analysis (Shahidzadeh *et al.*, 2011; Reinhorn *et al.*, 2006). The results of these analyses were used to train a neural network to improve the possibility of decision making and to state structural conditions and modes of failure based on nodes status.

NONLINEAR DYNAMIC TIME HISTORY ANALYSIS

Structural modeling: The five-storey /four- bay frames are modeled according to the ACI code based on the median ductility. We assume that the building is located in high risk seismic area with soil type 2 (Al-Dabbeek and El-Kelani, 2008).

Mortezaei and Kheyroddin (2008) according to UBC Code. Concrete pressure strength and steel yield stress in beams and columns are 25 and 400 mPa, respectively. Frame geometrical properties are shown in Fig. 1-3.

Experience from past earthquakes show that the behavior of reinforced concrete structures during an earthquake is not elastic but is nonlinear and follows

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hysteresis model (Fig. 4). According to different experimental concrete hysteresis behaviors, different models have been proposed (Reinhorn *et al.*, 2006; Abdul Rahim and Hillis, 2011) such as bilinear models, models with no loss of strength, stiffness reduction model, the model based on energy reduction and tri-linear model. In this study, the tri-linear model which is the most complete model for the hysteresis and nonlinear behavior of concrete. In this model, the degradation in stiffness and strength, pinching, asymmetric slip for different values of

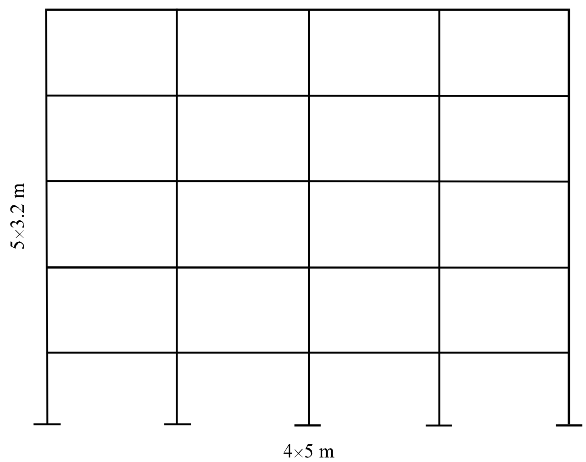

Fig. 1: Frame elevation

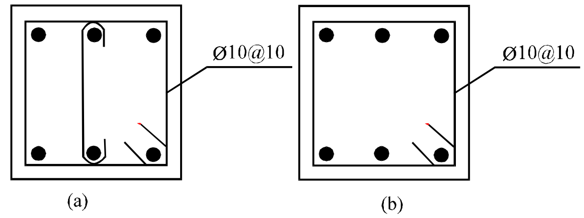

Fig. 2: (a) Columns and (b) beams sections

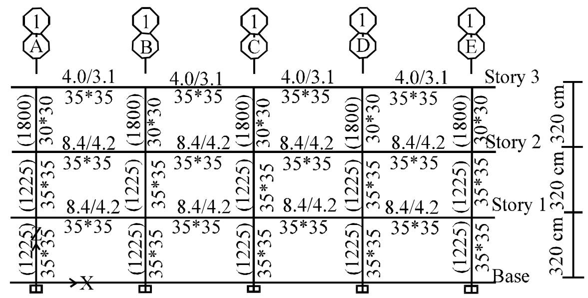

Fig. 3: Steel percentage in beams and columns sections frame analysis is performed using IDARC software which is able to model RC frames and conduce Nonlinear Dynamic Time History Analysis are (Reinhorn *et al.*, 2006; Nahas, 2002; Arafa *et al.*, 2011)

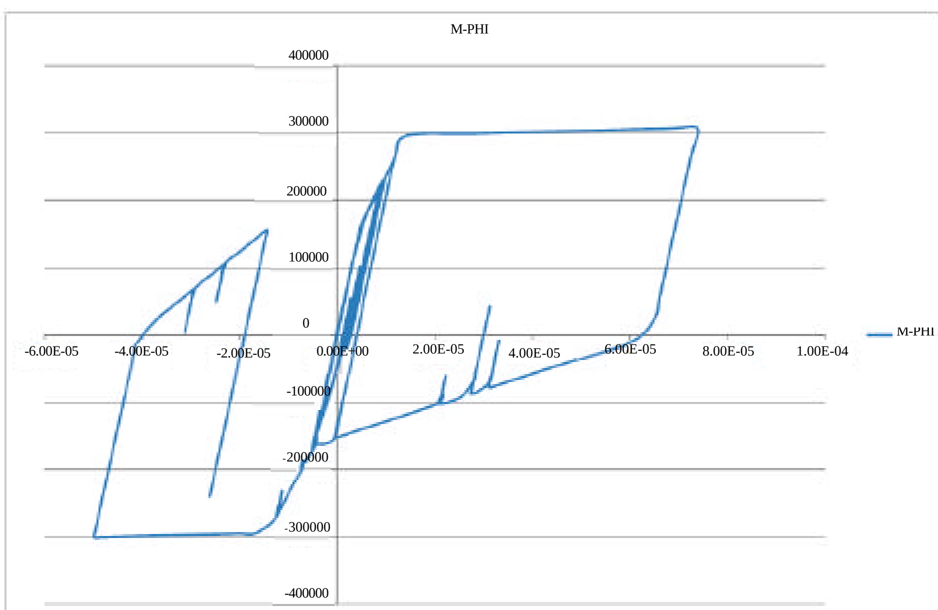

Fig. 4: Sample of hysteresis pattern

model parameters is applicable. The values of the parameters of this model are selected based on empirical (Sharbatdar and Saatcioglu, 2009; Laeng *et al*., 2006; El-Kafrawy and Bagchi, 2007).

After the frame analysis, different response parameters such as period, storey shear, relative displacement, displacement, velocity, acceleration and overall structural damage index can be used, some of which has been used in previous researches (Alam and Jumaat, 2009; Goulet *et al*., 2007; Al-Dabbeek and El-Kelani, 2008; Amiri *et al*., 2008).

Earthquake database: Earthquakes are selected from peer database which were compatible with the building site condition. Names and peak ground accelerations of earthquakes are shown in Table 1.

Data processing and results: After non-linear dynamic analysis, the output data including the damage status in the ends of members will be displayed in the array format. The number of members of this array will be equal to 2 m, for a frame with m members. For example, in the above frame which contains 25 columns and 20 beams, the array will have 90 members.

For each end, four states are considered, namely, no-damage (0), cracking (1), the plastic hinge (2) and local failure (3). It can be seen that the total number of possible collapse-noncollapse scenarios equals to 4^{2m} which would constitute the sample space. In the 120 seismic analysis of the frame, containing 60 analyses of the failure mode and 60 analysis of the non-failure mode, 60 seismic acceleration time series has been used. Therefore we have 60 arrays for failure mode and 60 arrays for non-failure mode. The number of arrays increase for training the neural network using Taguchi method (Laeng *et al*., 2006). The accuracy of predictions is shown in the Table 2 in term of the number of train samples. As it can be seen, with 100 samples an acceptable precision is achieved. The precision values are shown in the Table 3 for a different set of data.

This is clear that with about 500 data samples 5-storey concrete structures condition can be predicted accurately.

Regarding to each of the categories of damage which Consists of no-damage, cracking, hinge formation and local collapse in order of weight 0, 1, 2 and 3, respectively, the total weight $w_{collaps}$ of the collapse mode is equal to:

$$w_{ave.collaps} = \frac{w_{collaps}}{2m}$$

Weight of the above mentioned frame is obtained as follows. It should be noted that this weight means collapse of the building:

$$w_{collaps} = 190$$

$$W_{ave.collaps} = \frac{190}{90} = 2.11$$

Thus a very simple model is achieved which determines the status of the structure and can be generalized to other frames. The frame is stable if its weight is lower than this number and the structure will collapse otherwise.

Table 1: Earthquake data base

Seismic	PGA	Seismic	PGA	Seismic	PGA
A41-2BZ000_AT2	0.188	A55-2TCU046-W_AT2	0.128	A72-BZ270_AT2	0.143
A42-2BZ270_AT2	0.143	A56-2TCU046-W_AT2	0.208	A73-BZ-UP_AT2	0.207
A43-2BZ-UP_AT2	0.207	A57-2TCU046-W_AT2	0.443	A74-IZT090_AT2	0.219
A44-2IZT090_AT2	0.219	A61-ABY000_AT2	0.119	A75-IZT180_AT2	0.176
A45-2IZT180_AT2	0.176	A62-ABY090_AT2	0.148	A76-IZT-UP_AT2	0.154
A46-2IZT-UP_AT2	0.154	A63-ABY-UP_AT2	0.089	A77-LCN000_AT2	0.777
A47-2LCN000_AT2	0.777	A64-01-UP_AT2	0.068	A81-LCN275_AT2	0.677
A51-2LCN275_AT2	0.677	A65-01090_AT2	0.510	A82-LCN-UP_AT2	0.678
A52-2LCN-UP_AT2	0.678	A66-01230_AT2	0.104	A83-TAP103-N_AT2	0.182
A53-2TCU046-N_AT2	0.111	A67-01320_AT2	0.143	A84-TAP103-V_AT2	0.027
A54-2TCU046-V_AT2	0.119	A71-BZ000_AT2	0.188	A111-A-TW090_AT	0.179
A85-TAP103-W_AT2	0.128	A96-A-RN270_AT2-2	0.205	A112-A-MTW-_AT2	0.113
A86-TCU046-N_AT2	0.111	A97-A-RN270_AT2-2	0.226	A113-A-MTW-AT2-	0.113
A87-TCU046-V_AT2	0.119	A101-A-RN-UP_AT2-1	0.226	A114-A-MTW-AT2-	0.113
A88-TCU046-W_AT2	0.128	A102-A-RN-UP_AT2-	0.226	A115-ARM270_AT2	0.111
A91-A-RN180_AT2	0.316	A103-A-MTW000_AT2	0.122	A116-ARM270_AT2-	0.111
A92-A-RN180_AT2-1	0.316	A104-A-TW000_AT2-1	0.122	A117-ARM360_AT2	0.128
A93-A-RN180_AT2-2	0.304	A105-A-TW000_AT2-2	0.122	A121-ARM360_AT2-	0.128
A94-A-RN270_AT2	0.205	A106-A-MTW090_AT2	0.179	A122-ARM-UP_AT2	0.07
A95-A-RN270_AT2-1	0.205	A107-A-TW090_AT2-1	0.179	A123-ARM-P_AT2-1	0.07

Table 2: Accuracy of predictions

No.	Precision	No. of train and test samples (70 to 30%)
1	88.3	100
2	98.30	500
3	98.35	1000
4	98.60	1500
5	99.17	2000
6	99.40	2500

Table 3: Accuracy of predictions

No.	Precision	No. of train and test samples (70 to 30%)
1	88.3	100
2	90.01	100
3	88.65	100

CONCLUSION AND DISCUSSION

According to the results of nonlinear dynamic analysis processing in the neural network algorithm, the following points can be concluded:

- Reinforced concrete frames are subject to certain patterns of failure. It means that certain compounds of the no-damage, cracking formation and local collapse can be used to determine the structural condition, as is shown by Al-Dabbeek and El-Kelani (2008)
- Processing the results in neural network showed that the average weight of the structure failure can be obtained and used for all the cases
- Using the Methods or algorithms like neural network, models can be produced for engineers to identify structural condition

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