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Assessing the ductility of moment frames utilizing genetic algorithm and artificial neural networks

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Abstract. The aim of this research is to evaluate the effects of the number of spans, height of spans, number of floors, height of floors, column to beam moment of inertia ratio, and plastic joints distance of beams from columns on the ductility of moment frames. For the facility in controlling the ductility of the frames, this paper offers a simple relation instead of complex equations of different codes. For this purpose, 500 analyzed and designed frames were randomly selected, and their ductility was calculated by the use of nonlinear static analysis. The results cleared that the column-to-beam moment of inertia ratio had the highest effect on ductility, and if this relation was more than 2.8, there would be no need for using the complex relations of codes for controlling the ductility of frames. Finally, the ductility of the most frames of this research could be estimated by using the combination of genetic algorithm and artificial neural networks properly.

Keywords: moment frame; ductility; nonlinear static analysis; genetic algorithm; artificial neural networks

1. Introduction

Nowadays, the use of ductile structural systems is expanded in areas with intense seismicity (Mishra *et al*. 2015, Deniz *et al*. 2018). Kaveh *et al*. (2017) studied optimal seismic design of 3D steel moment frames with different ductility types. Three different types of lateral resisting steel moment frames consisting of ordinary moment frames (OMF), intermediate moment frames (IMF) and special moment frames (SMF) were presented for the design of 3D frames. The optimum seismic design of 3D steel moment frames with different types of lateral resisting systems were performed. A comparison was made considering the results of the frames having different ductility types. These frames were analyzed using response spectrum analysis (RSA) method, and optimizations were performed by means of nine different algorithms. Then the performances of these algorithms were compared for introducing the most suitable algorithms for optimal design of the 3D frames. Some researchers studied the effect of increasing ductility factors on the performance of a steel moment resisting frame (Abdi *et al*. 2015, Dalal *et al*. 2017). In addition, Steneker *et al*. (2018) studied critical locations for connections in steel moment resisting frames.

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In some cases, reinforced concrete frames with non-ductile detailing represented considerable hazards during earthquakes and suffered from severe damages (Mazloom and Ahmadinejad 2017). Among different structural systems, moment frames are important due to their high ductility (Mazloom and Salehi 2016, Mazloom and Salehpour 2013). It is worth noting that a genetic algorithm-based minimum weight design method was presented for steel frames including composite beams, semi-rigid connections and column bases (Artar and Daloglu 2015). At first, optimum designs of three different plane frames with semi-rigid beam-to-column and column-to-base plate connections were carried out without considering concrete slab effects on floor beams in finite element analyses. In the next step, the same optimization procedures were repeated for the case of frames with composite beams. The results showed the applicability and robustness of the method. In addition, it was proved that the attention of the contribution of concrete on the behavior of the floor beams enabled a lighter and more economical design for steel frames with semi-rigid connections (Artar and Daloglu 2015).

Phan *et al.* (2015) presented a stressed-skin diaphragm approach to the optimal design of the internal frame of a cold-formed steel portal framing system in conjunction with considering the effect of semi-rigid joints. Ultimate and serviceability limit states and wind load combinations were considered. The designs were optimized using genetic algorithm, in which both discrete and continuous decision variables were processed. It was shown that the material cost of the internal frame could be reduced by 53% compared with a design that ignored stressed-skin action for a building with two internal frames. Artar and Daloglu (2018) used genetic algorithm method for optimum design of space frames with semi-rigid connections. Two different space frames were solved for both cases of rigid and semi-rigid connections, separately. The results showed that the type of semi-rigid connections played an essential role in the optimization of steel space frames.

In this research, the focus has been made on frame members and the following factors were considered for their ductility: number and length of spans, number of floors, height of floors, moment of inertia of beams, moment of inertia of columns, and plastic joint position of beams. Each of these variables in the range of 15 to 20 members has been considered according to Table 1. In this research, $20 \times 20 \times 6 \times 30 \times 13 \times 20$ frames, i.e., 18720000 numbers, were investigated. If the drawing and analysis of each of these frames takes a minute and 15 hours used per day, it takes about 57 years to investigate the ductility of all frames. In some researches of civil engineering, it is required to explore a wide range of information that should be analyzed with a computer software and this requires a lot of time and even they are impossible in some of the researches in some investigations (Mazloom 2013). For this purpose, there is an urgent need to use genetic algorithm method (Biabani Hamedani and Kalatjari 2018). In recent years, Genetic algorithm method has been used for analysis and design of structures repeatedly (Truong *et al.* 2017, Ramires *et al.* 2012).

In the present research, 500 frames were designed and analyzed which were selected randomly and then, they were performed with nonlinear static analysis of ETABS software, which is called push over analysis. To investigate the effect of each factor in the ductility, other variables were considered fixed; after reviewing the results obtained, the role of each of the factors involved in ductility was obtained. According to Iranian steel building code (Design Code 2012) and standard No. 2800 for seismic resistant design of buildings (Design Code 2005) relatively complex formulations have been provided for areas with intense seismicity. In this research, a number is obtained in order to simplify the design process with the review of these formulas for more than 100 designed frames. In fact, there is no need to control the mentioned relationships in the above-mentioned references if the average moment of inertia ratio of columns to beams was more than this number.

For this purpose, the most ductile frames are considered among the millions of frames. The genetic algorithm method of MATLAB software is used here; since the relationship between variables was non-linear, artificial neural networks method was needed for finding the fitness functions of genetic algorithm. Actually, the relationships between variables were obtained with the help of neural networks, and then some of the most ductile frames were obtained by genetic algorithm and the optimization of obtained relationships.

2. Moment frames

2.1 Characteristics of moment frames

In general, in terms of configuration, this system was formed of rectangular grid of horizontal beams and vertical columns with rigid connections. This system must have necessary stiffness and resistance to deal with gravity loads, seismic forces and deformations caused by them.

The moment frame systems are used in most of the steel structures in terms of their behaviors, which they show against lateral loads. The most important feature of this system is how to connect its members which effectively involved in the structural behavior and system stability. The main advantages of this system can be pointed to the lack of interference in architectural considerations such as casement preparation (Gholipour and Mazloom 2018). In this system, all the spans are free for embedding the casement (doors and windows). In terms of behavior, this system is relatively ductile and shows the high potential in the energy dissipation. The stiffness of this system is relatively low and suffers due to the weakness against lateral loads. In the design of moment frames in earthquake-prone areas (special design), the philosophy of strong columns-weak beams should be considered. That is the proportionality between the stiffness of beams and columns; in fact, plastic hinges should occur in the beams and not in the columns (Mazloom *et al.* 2018).

Building Regulations have mentioned the following points for evaluating the criteria of weak beam-strong column philosophy. In fact, moment capacity of columns and beams in beam-column connections should satisfy the following relationship (Design Code 2012)

Table 1 Introducing variables and their numbers

Row	Parameter name	Upper limit	Lower limit	Change step	C
1	The number of span	20	2	One span-one span	19
2	Span length	10	2	With step of 0.5 meters	17
3	Floors number	10	2	One floor-one floor	19
4	Floor height	6	2.5	With step of 0.25 meters	15
5	Moment of Inertia beam	2IPE30	IPE160	IPE160 to IPE300, 2IPE160 to 2 IPE300	14
6	Moment of Inertia column	3IPE30	2IPE160	2IPE160 to 2IPE300, IPE160 to 3IPE300	14
7	Plastic joint distance from the column	2d	0.1d	With 0.2d step	10

$$\frac{\sum M_{pc}}{\sum M_{pb}} \geq 1 \tag{1}$$

where

$$M_{pc} = \sum Z_c \left(0.6F_{yc} - P_{ac}/A_y\right) \tag{2}$$

and

$$M_{pb} = \sum (0.6 * 1.1F_{yeb} * Z_b + M_{av}) \tag{3}$$

in these equations: Z_b = plastic modulus of beam sections, F_{yeb} = Expected yield stress of steel in beams equal to $1.15Fyb$ and F_{yc} = Yield stress of steel column, P_{ac} = Compressive axial force of columns resulting from a combination of conventional loads, and M_{av} = Additional moment caused by shear forces in the plastic hinge towards column axis in terms of allowable stress.

It is worth noting that the place plastic hinges of beams should be considered between 0.5d to d and for guiding the plastic hinges in the beams (Mirghaderi 2010). The weakening of beam method (RBS) can be used for this purpose. The philosophy of this subject also goes back after the Northridge earthquake which had occurred in the majority of moment frames (Tremblay *et al*. 1995, Tsai and Popov 2005).

2.2 Ductility in moment frames

To calculate the ductility of moment frames, a structural analysis and design software such as ETABS or SAP2000 should be used, and after the relevant settings, nonlinear static analysis (push over) should be done. As shown in Fig. 1, base shear–roof displacement diagrams can be obtained with the software. Then, ductility of frame is calculated by using the following formula:

$$\mu = \frac{\Delta m}{\Delta y} \tag{4}$$

Δm : Displacement of the first plastic hinge
Δy : Maximum horizontal displacement

2.3 The parameters considered in the analysis of nonlinear moment frames

The steels defined for moment frames were considered as ST37 with Fy = 2400 $\frac{kg}{cm^2}$ and FU = 3700$\frac{kg}{cm^2}$. In defining the sections of elements, the grades of single and double IPE sections for beams were from 16 to 30. These sections for columns were double or triple IPE sections graded from 16 to 30. The amount of dead load and live load were assumed to be 0.5 t/m and 0.2 ton/m respectively. Earthquake load is calculated with the software by applying user coefficient. In defining plastic hinges, The Iranian 360 standard was used (Design Code 2005). Moment hinges at both ends of beams were used in the distances of 0.5d to 0.1d from the end points, in which d was the height of the elements. Axial-moment hinges were defined at both ends of columns, and in the distances of 0.05 to 0.95 from both ends of columns.

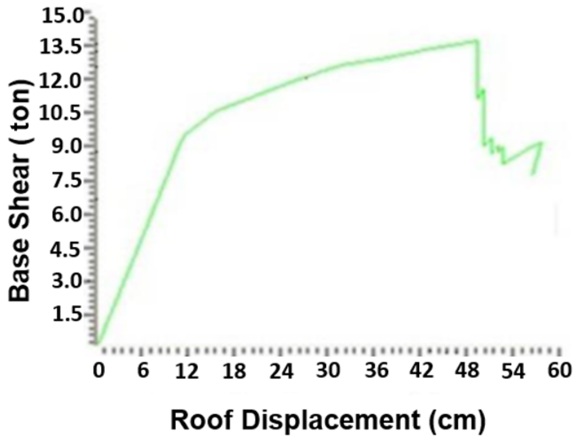

Fig. 1 Pushover diagram of a frame

In setting the parameters of nonlinear static analysis, a gravity load was defined to consider the effects of gravity loads on structural elements according to the following equation:

$$Q=1.1(DL+.25LL)=1.1DL+.275LL \tag{5}$$

The nonlinear analysis called push 1 was introduced, so that the maximum push was chosen as 3 meters, and the distribution of earthquake loading was considered as static linear.

3. Genetic algorithm

Genetic algorithms can be used to find the minimum of a function. Functions which have many local maximum and minimum, genetic algorithm has approximately great helps in finding the global maximum and minimum. These algorithms take the advantage of genetic science available in nature. In genetic science, genes through mutation, integration, and elitism are combined together for the next generation and create a new generation. In genetic algorithm also a population of primary people (each number is a person and sets of numbers is the population) becomes aligned by the fitness function (function that is supposed to calculate its minimum). In this level, each person who is placed in the function and the lowest level has some points to become elite (Kia 2010).

3.1 next generation production in genetic algorithm

Each generation in genetic algorithm is created with the help of three factors of elitism, integration and mutation by the helping of previous generation. The purpose of the elitism is that a percentage of the previous generation who have the best score (function amount has been less for them) transferred directly and without any changes to the next generation. Integration and mutation are also created as follow to help other people of generation who have more score. For this purpose, the two numbers that have achieved higher scores after elite people to be considered as a parent and can be combined. For example, the two numbers of 100 and 200 can be considered. Zero and one mode of these numbers are as follow

1st person *200* *11001000*
2nd person *100* *01100100*

Combination 1 *Combination 2*
Combination 1: 11000100 = 196 *Combination 2: 01101000 = 104*

It means, the two number of 100, 200 that were selected from the previous generation, has turned to the two number of 104, 196 and transferred to the next generation. Of course, integration has several methods that in above was just explained integration of one point with a coefficient of k = 4. Mutation method also performed as follows. Just one coefficient is introduced to the program until in the introduced points zero turn to one and one turn to zero and obtains a new number: *200 = 11001000; K = 4: and 11011000 = 216*. In this way, the genetic algorithm with a small number of people can review a large number of people who have the ability to minimize the function with a smart logic (Yavari and Salehi 2010).

4. Artificial neural network

Neural networks can be described with high tolerance as electronic model of the structure of the human brain. Brain mechanisms of learning and teaching is primarily based on experience. Electronic models based on artificial neural networks have the same patterns; the computational methods have been taken by computer systems. It is worth noting that that even the simplest animal brains are able to solve some issues that the existing computers have trouble in solving them. For example, pattern recognition of various issues, is an example of cases in which the usual computational methods do not reach the desired result in solving them while the simplest animals' brains can easily cope with such issues.

The idea of most IT experts is that the new computational models are built based on neural networks, which is the next mutation shape the IT industry. Research in this field has shown that the brain is stored the informations such as patterns. The process of storing information as a pattern and analysis of its pattern constitute the basis of the new computational method. This field of computational knowledge do not use traditional programming methods and instead benefits from major networks that is training and arranged in parallel (Hand *et al*. 2001).

An artificial neural network or simply ANN is an idea that is inspired by biological nervous systems to process information similar to the brain. A key element of this idea is the new structure of information processing systems. These systems constitute a large number of interconnected extra processing elements (neurons), which act together to solve a problem. Artificial neural networks (ANN) method works similar to humans learning by example. ANN is set to perform a specific task, such as pattern recognition or data classification, through a learning process. In biological systems, like ANN, learning is accompanied with adjustments to the synaptic connections which is located between neurons (Kia 2001).

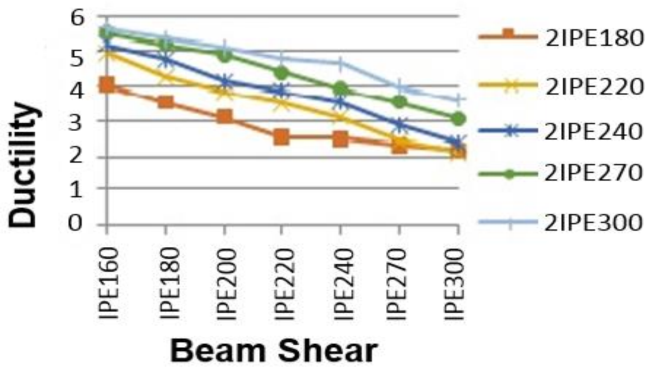

Fig. 2 Comparing the ductility by changing the column to beam moment of inertia

5. Points obtained from static nonlinear analysis

5.1 Column to beam moment of inertia

In this case, the other variables were assumed to be constant, and only the ratios of column to beam moment of inertia have been changed. For further investigations, the other variables were changed in different modes. It means, the number of spans, their length, their height and the number of floors were considered fixed, and the results is obtained in Fig. 2.
It is obvious from the diagram that the ductility of frames increased by strengthening of the columns and weakening of the beams. In other words, strong column and weak beam system has an important role in the ductility of frames.

5.2 Increasing the number of spans

Increasing the number of spans in both cases of the column to beam stiffness ratios of 2 (column 2IPE160 and beam IPE160) and 8.6 (columns 2IPE30 and beam IPE20) can be seen in Fig. 3. This diagram indicates that the number of spans have little role in the ductility of frames, and the ductility of the frames does not substantially change by increasing or decreasing the number of spans.

5.3 Increasing the number of floors

Increasing the number of floors in both cases of the column to beam stiffness ratios of 2 (column 2IPE160 and beam IPE160) and 8.6 (columns 2IPE30and beam IPE20) can be seen in Fig. 4. This diagram indicates that the number of floors as well as the number of spans have not a strong role in ductility of frames; in fact, a small amount of the increase and then decrease in ductility can be seen in this figure.

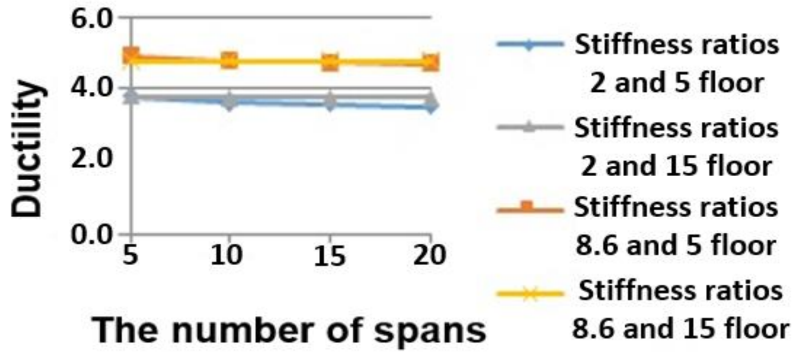

Fig. 3 Comparing the ductility by changing the number of spans

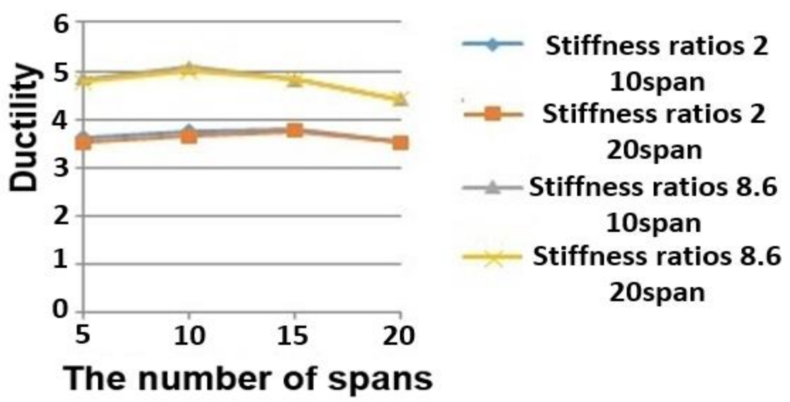

Fig. 4 Comparing the ductility by changing the number of floors

5.4 increasing the length of span

In this part, the length of span is considered for four modes of 3, 5, 7 and 9 meters, and to review diversely, the column to beam stiffness ratios are selected from 2 to 6.45. According to Fig. 5, the ductility of frames increases up to the span of 5 meters and then increasing the span length led to reduction in ductility. This issue makes no difference with the increasing in the column to beam stiffness ratio. According to Figs. 3 to 5, is clear that increasing the span length has greater influence in ductility of frames compared to the number of floors and the number of spans.

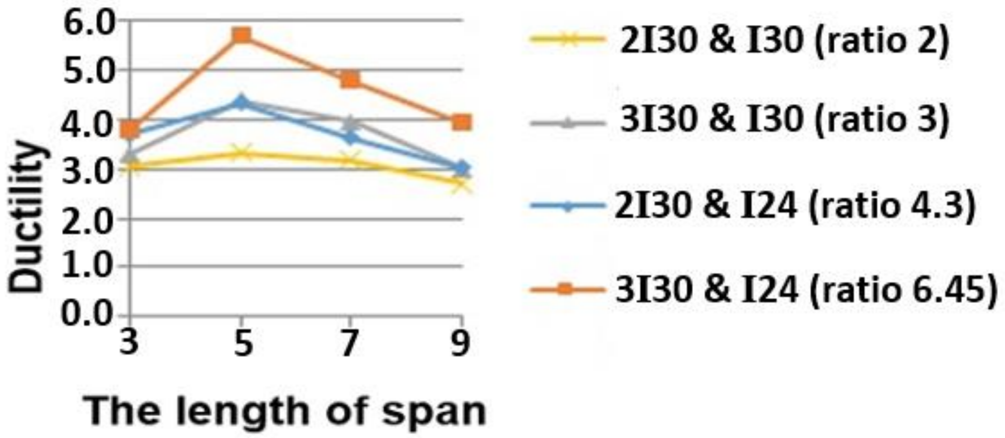

Fig. 5 Comparing the ductility by changing the length of span

5.5 Increasing the height of floors

In this section, the number of spans and their lengths are considered 4 and 3 meters respectively. The floor number was 8 and their heights were 6, 5, 4 and 3 meters.

Fig. 6 have irregularities such as the diagram of comparing the ductility by changing the length of the floors (Fig. 5). In fact, the ductility of frames can increase or decrease by increasing the height of floors, and there is not a specific rule for it.

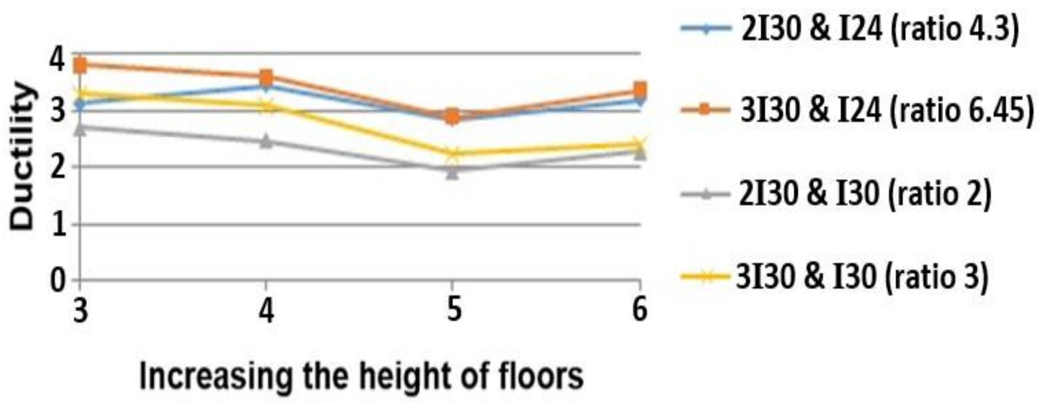

Fig. 6 Comparing the ductility by changing the height of floors

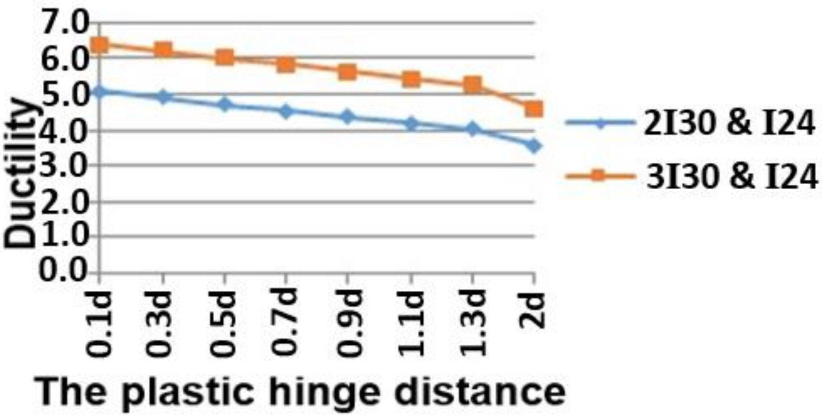

Fig. 7 Comparing the ductility by changing the plastic hinge distance from the column

5.6 Increasing the plastic hinge distance from the column

In this case, three span frames with the length of 5 meters, 6 floors, story height of 3 meters and IPE 240 beams were created in two modes of 2IPE300 and 3IPE300 columns in ETABS software. The plastic hinge distances from the columns were considered 0.1d, 0.3d, 0.5d, 0.7d, 0.9d, 1.1d, 1.3d and 2d. Fig. 7 shows that that by increasing the plastic hinge distance from the column, the ductility decreases. According to the Iranian steel design code, the place of the plastic hinge formation at both ends of the beams should be considered at the distance of 0.1 d to 0.5d from the columns.

5.7 Providing the relation to control the ductility

Eq. (1) was calculated for 100 analyzed frames. Finally, it became clear that if the following relation is established, the ductility of frames are perfect and there is no need to control Eq. (1).

$$\frac{I_C}{I_B} \geq 2.8 \tag{6}$$

Of course, this number is only for the frames of this research, which have equal span lengths and equal floor heights. However, the existence of such number is important, and it can be found in different circumstances.

6. Using genetic algorithm method

6.1 Genetic algorithm method in the initial stage

Genetic algorithm was implemented with the following parameters and features: the number of initial population of each generation was selected 200; 10 percent was used for elitism; the number of 80 chromosomes of the top initial population was selected as parents; both methods of crossover and mutation were used in the production of new generations; a number of chromosomes were randomly selected consistently at every generation. It is worth noting that another research has used genetic algorithm for optimization process recently too (Kim and Lee 2017).

After doing these settings, the most important item which has to be accurately determined was the fitness function of genetic algorithm. To obtain this function, the relationship between the six variables should be firstly obtained. To reach this purpose, a total of 100 frames were used and their ductility were calculated by ETABS software. In fact, 70 numbers of these frames were introduced to genetic algorithm as training data. The remaining 30 frames were selected as the test data. The aim of this data was to assess the relation obtained in the training phase. It should be noted that these inputs are data which so far, the genetic algorithm has not seen yet. The following relation is considered as the fitness function for training data

$$\text{Error}=\text{Target}-(w_1x_1+w_2x_2+w_3x_3+w_4x_4+w_5x_5+w_6x_6) \tag{7}$$

The parameters of above relation are as follow: the amount of ductility in training data, x1; number of spans, x_2; number of floors, x_3; length of spans, x_4; height of floors, x_5; column to beam moment of inertia ratio, x_6; w_1, w_2, w_3, w_4, w_5 and w_6 were coefficients that should be multiplied in varying amounts to obtain the ductility of moment frames. This is the unknown fitness function that the genetic algorithm should find so that the amount of error function became minimum. Stopping the genetic algorithm is considered as follows: reaching the amount of error function to 0.1; having fixed error number in 10,000 consecutive generations. After performing genetic algorithms and creating more than 60,000 generations, the error function value did not reach 0.1 and the algorithm was stopped because it was about 10,000 generations that the amount of error function had not changed. Then, the results were compared with test data and a relatively large difference were observed between the ductility of test data obtained from the ETABS software and genetic algorithm. Fig. 8 shows this difference.

The results show that the hypothesis of a linear relationship between parameters determining the ductility is a wrong theory. So, artificial neural networks were used to follow a proper way in order to estimate the functions between ductility and its determining parameters. In all practical purposes, the combination of genetic algorithm and neural networks looks very admirable. Actually, neural networks can be used as the primary means of modeling and finally genetic algorithm method was used to optimize the network parameters.

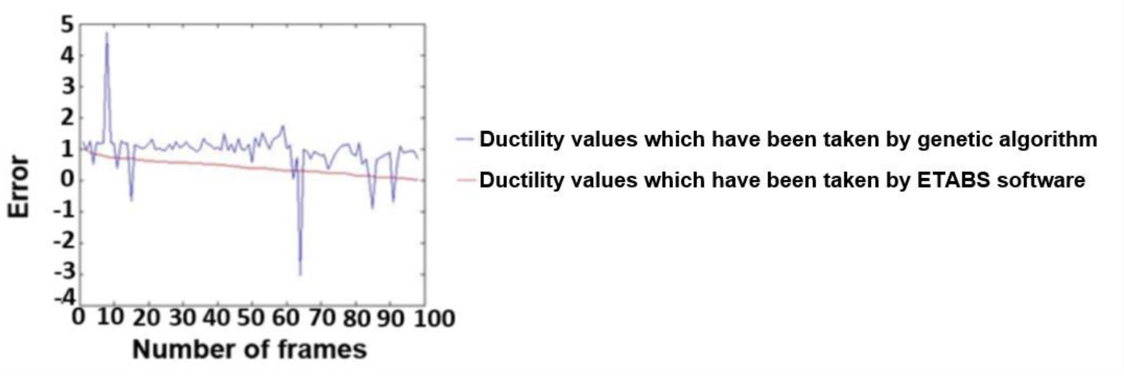

Fig. 8 Comparing the ductility of test data

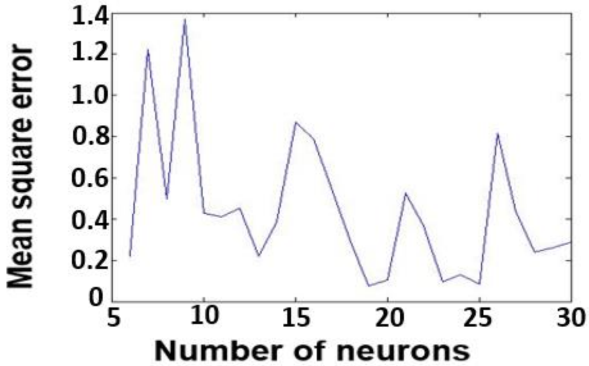

Fig. 9 The mean square error of the networks in training phase

The next step of the research was to find suitable neural networks to estimate the function. In fact, the new idea of this experiment was to find the optimal parameters of the function that has been estimated by neural networks. Among the artificial neural networks, MLP network as a global estimator can solve any problem in its training phase. Therefore, the optimal parameters of this network were used to achieve the best estimate with the lowest error. The MLP network structure included six input neurons (equivalent to 6 parameter determining the ductility) and 1 output neuron (the amount of ductility). In Fig. 9, the mean square error of network in training phase is plotted for the number of neurons in the middle layer variations from 6 to 30 neurons.

As seen in Fig. 9, the error reaches to its minimum value in the number of 19 neurons in training data. Therefore, in the continuation of the experiments, 19 neurons were used for the middle layer. To get the number of AIPAC and in other words the number of repeating the training phase, small groups of data were used, which had not participated in training phase. Fig. 10 shows the training error of the networks in every step of training. As it can be seen in the diagram of VALID data, the minimum error for the number of AIPAC was obtained in 1500. The networks may go ahead toward learning or maintaining the training data by increasing the number of AIPAC. Thus, according to this experiments, the number of learning network AIPAC was considered to be 1500. Table 2 shows the designed MLP neural network parameters.

Training network could estimate the output value with sufficient accuracy, which means the average of calculated error in test data was equal to 0.2118. This error was the average of running the program for 10 times. Then, the training networks found a relation between the determining parameters of ductility and the optimal value for this function by using genetic algorithm.

Table 2 Designed MLP neural network parameters

Learning rate	Number of AIPAC	Output neurons	Central Neurons	Input neurons
0.68	1500	1	19	6

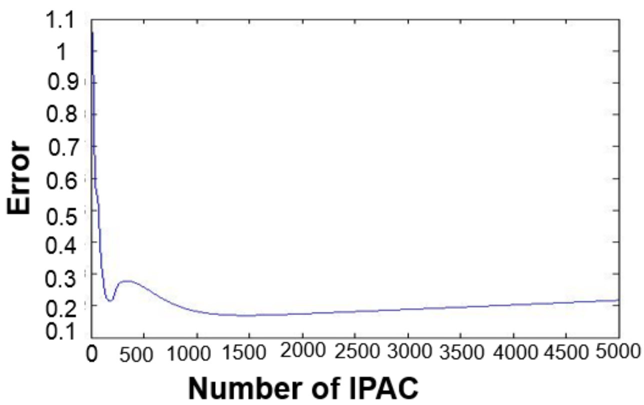

Fig. 10 Train network error in every step of training

6.2 Genetic algorithm method in the final stage

It should be noted that the characteristics of genetic algorithm of this part is completely different from the previous one. At this time, the input space that determines the ductility is 6 parameters, the best input for the highest ductility should be determined by using genetic algorithm method. Also compliance with the inputs and outputs should be obtained from neural networks. Since among inputs only two variables of height and length of spans are continuously changing, each chromosome has two genes in the genetic algorithm of this experiment. In evaluating each generation, output was calculated for all other 4 variables which makes possible in 78400 modes, and parents and elite chromosome in each generation obtained with this assessment. Due to the very large volume of calculations, each generation was only composed to 20 chromosomes. That will be paid to produce a new generation by the two mutation and crossover methods.

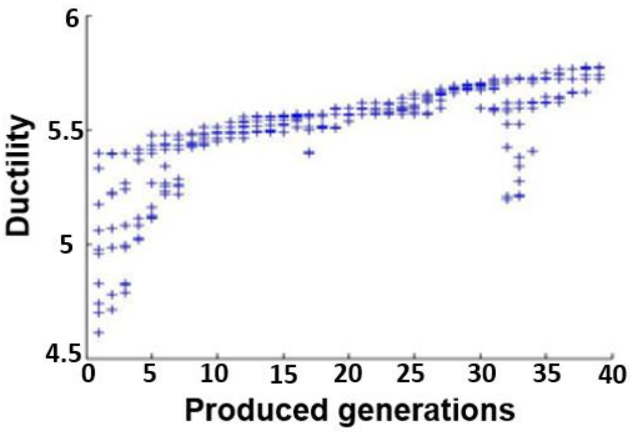

Fig. 11 Converging of produced generations in the process of genetic algorithm

Table 3 The optimal parameters obtained after 400 generations

Row	Number of floors	Number of span	Span length	Floor height	Δm	Δy	μ
1	8	2	5.52	5.93	2.372	0.410	5.788
2	8	2	5.04	5.83	2.602	0.456	5.709
3	6	2	3.94	6.19	1.914	0.338	5.665
4	8	2	4.70	5.65	2.305	0.413	5.581
5	10	2	6.59	5.75	3.472	0.629	5.523
6	10	2	6.74	5.98	3.693	0.671	5.505
7	6	2	3.59	5.82	1.590	0.297	5.355
8	6	2	3.59	5.86	1.602	0.299	5.350
9	6	2	3.92	6.27	1.751	0.327	5.349
10	5	2	6.34	2.69	1.040	0.200	5.201
11	5	2	2.69	6.30	1.040	0.200	5.201
12	5	2	2.69	6.19	1.036	0.200	5.178
13	5	2	2.67	5.52	0.814	0.177	4.605
14	5	2	2.48	5.36	0.738	0.163	4.533
15	5	2	2.11	5.12	0.571	0.141	4.040

Fig. 11 shows the converging of produced generation in the process of genetic algorithm to achieve the best ductility. In other words, the combination of genetic algorithm and neural networks could find the most ductile structures properly. Table 3 shows the optimum parameters obtained after the production of 400 generations. These numbers can be useful in other researches. In fact, if the ductility values more than 5.5 is assumed to be ideal, the results show that the number of floors should be more than 5. In other words, low rise moment frames are not able to compete with high rise ones if ductility is the main character for judgment.

7. Conclusions

In this research, by reviewing the ductility of a large number of frames, the following results were obtained:

- Number of spans and number of floors have very little impact on the ductility of moment frame structures so that their effects can be ignored.
- Span lengths and floor heights are effective in the ductility of frames, but their effects have not definite order; it means that the ductility of frames may increase or decrease by increasing the span lengths and floor heights of the systems.
- The column to beam moment of inertia ratio has the main effect on the ductility of frames, and the ductility improves by increasing this ratio.
- Place of plastic hinge is one of the factors that is very effective in the ductility of moment frames, so that if the place of plastic hinge formation moves from the column to the inside of the span, the ductility decreases. If this distance becomes greater than 2d (d is the height of

beam), the ductility significantly reduces.

- In this research, if the ratios of column to beam moments of inertia became more than 2.8, the relations provided in existing steel structure designing codes could be established. Although this number is only for the frames of this research, which have equal span lengths and equal floor heights, the existence of such number is important, and it can be found in different conditions.
- Studying 18720000 frames became possible utilizing the combination of artificial neural networks and genetic algorithm. The number of floors in this study were from 2 to 10. The results of this part on numerous frames show that if the ductility values more than 5.5 is assumed to be perfect, the number of floors should be more than 5.

References

Abdi, H., Hejazi, F., Saifulnaz, R., Karim, I.A. and Jaafar, M.S. (2015), "Response modification factor for steel structure equipped with viscous damper device", *Int. J. Steel Struct.*, **15**(3), 602-622.

Afkar, H. and Mazloom, M. (2011), "Review the ratio of column to beam stiffness in ductility of moment frames", *Proceedings of the 1st Regional Conference on Civil Engineering*, Jouybar, Iran, May.

Artar, M. and Daloglu, A. (2015), "Optimum design of composite steel frames with semi-rigid connections and column bases via genetic algorithm", *Steel and Composite Structures*, **19**(4), 1035-1053.

Artar, M. and Daloglu, A. (2018), "Optimum weight design of steel space frames with semi-rigid connections using harmony search and genetic algorithms", *Neural Comput. Appl.*, **29** (11), 1089-1100.

Augusto, T., Albuquerque, D. and Mounir, K. (2012), "A cost optimization - based design of precast concrete floors using genetic algorithm", *Automat. Constr.*, **22**, 348-356.

Baavi, O. and Salehi, M. (2010), "Genetic algorithms and optimization of composite structures", Abed, Tehran, Iran.

Biabani Hamedani, K. and Kalatjari, V.R. (2018), "Structural system reliability-based optimization of truss structures using genetic algorithm", *Int. J. Optimiz. Civil Eng.*, **8**(4), 565-586.

Chaekuk, N., Kwak, G.H. and Kim, S.P. (2011), "Structural damage evaluation using genetic algorithm", *J. Sound Vib.*, **330**, 2772-2783.

Dalal, S.P., Dalal, P.D. and Desai, A.K. (2017), "Effect of increasing ductility factors on the performance of a steel moment resisting frame designed by the performance based plastic design method attuned with Indian code of practice", *Procedia Eng.*, **173**, 1862-1869.

Deniz, D., Song, J. and Hajjar, J.F. (2018), "Energy-based sidesway collapse fragilities for ductile structural frames under earthquake", *Eng. Struct.*, **174**, 282-294.

Erbatur, F., Hasan Cebi, O. and Tutuncu, I. (2000), "Optimal design of planar and space structures with genetic algorithm", *Comput. Struct.*, **75**, 534-541.

Gholipour, M. and Mazloom, M. (2018), "Seismic response analysis of mega-scale buckling-restrained bracing systems in tall buildings", *Adv. Comput. Des.*, **3**(1), 17-34.

Hand, D., Mannila, H. and Padhraic, S. (2001), "*Principles of Data Mining*", The MIT Press, Massachusetts, New England, USA.

Hayalioylv, M.S. and Deyertekin, S.O. (2006), "Minimum cost of steel frames with semi - Rigid connections and column bases via Genetic optimization", *Comput. Struct.*, **83**, 1849- 1863.

Journal 360 (2006), Instructions of Seismic Rehabilitation of Existing Buildings, Development of Criteria and Reduce the risk of Earthquake, Tehran, Iran.

Kameshki, E. and Saka, M.P. (2001), "Genetic algorithm based optimum bracing design of non-swaying tall plane frames", *J. Constr. Steel Res.*, **57**, 1081-1097.

Kameshki, E. and Saka, M.P. (2001), "Optimum design of nonlinear steel frames with semi-rigid connections using a genetic algorithm", *Comput. Struct.*, **79**, 1593-1604.

Kameshki, E.S, and Saka, M.P. (2001), "Optimization design of non-linear steel frames with semi-rigid convection using genetic algorithm", *Comput. Struct.*, **97**, 1593-1604.
Kargharian, M. (2009), "Optimization of composite roof by using genetic algorithms", Master of Science Thesis, Tafresh University, Tafresh.
Kaveh, A., Ghafari, M.H. and Gholipour, Y. (2017), "Optimal seismic design of 3D steel moment frames: different ductility types", *Struct. Multidiscip.O.*, **56**(6), 1353-1368.
Kia, S.M. (2001), "Neural Networks in MATLAB", Kian Rayane Sabz, Tehran, Tehran, Iran.
Kia, S.M. (2010), "Genetic Algorithm in MATLAB", Abed, Tehran, Iran.
Kim, B. and Lee, Y. (2017), "Genetic algorithms for balancing multiple variables in design practice", *Adv. Comput. Des.*, **2**, 241-256.
Mazloom, M. (2013), "Incorporation of steel frames in masonry buildings for reduction of earthquake-induced life loss", *KSCE J. Civil Eng.*, **17**(4), 736-745.
Mazloom, M. and Ahmadinejad, A. (2018), "Effect of vertical shear link on the operation of elements and response modification factor of rehabilitated concrete structures", *J. Civil Environ. Eng.*, **47**(4), 85-96.
Mazloom, M. and Salehi, V. (2016), "Studying the behavior of central gusset plate connections on inverted V-braces", *J. Civil Environ. Eng. (University of Tabriz)*, **46**(2).
Mazloom, M. and Salehpour, A.S. (2013), "Assessment of resistance and behavior of link beam in eccentric braced frames by finite element method", *J. Civil Environ. Eng. (University of Tabriz)*, **44**(2), 47-55.
Mazloom, M., Pourhaji, P., Moosa Farash, A. and Sanati, A. (2018), "Strengthening of concrete structures with buckling braces and buckling restrained braces", *Struct. Monit. Maint.*, **5**(3), 391-416.
Mirghaderi, R. (2011), "Structural Steel Design", Arkan - e Danesh, Tehran Tehran, Iran.
Mishra, R., Militky, J., Gupta, N., Pachauri, R. and Behera, B.K. (2015), "Modeling and simulation of earthquake resistant 3D woven testile structural concrete composites", *Compos. Part B: Eng.*, **81**, 91-97.
Nobahari, M. and Seyedpoor, S.M. (2011), "Structure damage detection using an efficient correlation - based index and a modified genetic algorithm", *Math. Comput. Model.*, **53**, 1798-1809.
Pezenshk, S., Camp, C. and Chen, D. (2000), "Design of non-linear framed structures using a genetic algorithm", *ASCE Struct. J.*, **126**, 382-388.
Phan, D., Lim, J., Tanyimboh T., Wrzesien A.M., Sha, W. and Lawson, R.M. (2015), "Optimal design of cold-formed steel portal frames for stressed-skin action using genetic algorithm", *Eng. Struct.*, **93**, 36-49.
Ramires, F.B., Andrade, S.A., Vellasco, P.C. and Lima, L.R. (2012), "Genetic algorithm optimization of composite and steel endplate semi-rigid joints", *Eng. Struct.*, **45**, 177-191.
Ramires, F.B., Rodrigues, L. and Lopes, A. (2012), "Genetic algorithm optimization of composite and steel endplate semi - rigid joints", *Eng. Struct.*, **45**, 177-191.
Safari, D., Maheri, M.R. and Maheri, A. (2011), "Optimum design of steel frames using multiple - deme GA with improved reproduction operators", *J. Constr. Steel Res.*, **67**, 1232-1243.
Saka, M.P. (2000), "Optimal design of pitched roof steel frames with hunched rafter by genetic algorithm", *Comput. Struct.*, **81**, 1967-1978
Standard No. 2800-05 (2015), Iranian Code of Practice for seismic Resistant Design of Buildings, Building and Housing Research Center, Tehran, Iran.
Steneker, P., Wiebe, L. and Filiatrault, A. (2018), "Identifying critical locations for connection ductility in steel moment resisting frames", *Proceedings of the 11th U.S. National Conference on Earthquake Engineering*, Los Angeles, June.
Tenth Topic of Design code (2012), Design and Implementation of Steel Buildings, Development of National Building Regulations Office (fourth Edition), Tehran, Iran.
Tremblay, R., Timler, P., Bruneau, M. and Filiatrault, A. (1995), "Performance of steel structures during the January 17, 1994, Northridge earthquake", *Can. J. Civil Eng.*, **22**, 338-360.
Truong, V., Nguyen, P. and Kim, S. (2017), "An efficient method for optimizing space steel frames with semi-rigid joints using practical advanced analysis and the micro-genetic algorithm", *J. Constr. Steel Res.*, **128**, 416-427.
Tsai, K.C. and Popov, E. (2005), "Experimental performance of seismic steel beam-column moment joints", *ASCE Struct. J.*, **121**, 925-931.

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