World Academy of Science, Engineering and Technology
International Journal of Civil and Environmental Engineering
Vol:11, No:8, 2017

Anticipation of Bending Reinforcement Based on Iranian Concrete Code Using Meta-Heuristic Tools

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Open Science Index, Civil and Environmental Engineering Vol:11, No:8, 2017 publications.waset.org/10007733/pdf

***Abstract*—**In this paper, different concrete codes including America, New Zealand, Mexico, Italy, India, Canada, Hong Kong, Euro Code and Britain are compared with the Iranian concrete design code. First, by using Adaptive Neuro Fuzzy Inference System (ANFIS), the codes having the most correlation with the Iranian ninth issue of the national regulation are determined. Consequently, two anticipated methods are used for comparing the codes: Artificial Neural Network (ANN) and Multi-variable regression. The results show that ANN performs better. Predicting is done by using only tensile steel ratio and with ignoring the compression steel ratio.

***Keywords*—**Concrete design code, anticipate method, artificial neural network, multi-variable regression, adaptive neuro fuzzy inference system.

I. Introduction

CONCRETE is one of the most consumed building materials in the world. The variety of seismicity, material qualities and construction criteria make the presence of different design codes inevitable for different countries. The earthquake belt passes through Iran, thus considering special measures for structural ductility is essential. The designs in most countries should be carried out by their native codes. Iran is no exception to the rule, but since the Iranian concrete code does not exist in structural design software, Iranian engineers inevitably have two choices:

A) Handheld computing, which is not practical due to the high consuming time and energy.
B) Designing with commercial software using other codes such as ACI, which is announced to be forbidden by the government.

Some engineers in Iran analyze structures using commercial software design, but the structural members manually. This point motivated us to make a communication between the Iranian code and some other well-known ones by two anticipating methods to determine the best method and also creating convenience for engineers.

Comparison among the codes was recently taken into consideration. Dheeraj et al. [1] carried out a comparative study for the prediction for 28-days compressive strength of ready mix concrete by using fuzzy logic and ANFIS modeling, where ANFIS has performed better than fuzzy logic. Zain and Abd [2] used the multiple non-linear regression model for the prediction of compressive strength at different ages. Atici [3] estimated the compressive strength of concrete that contained various amounts of blast furnace and fly ash, by an ANN. Deshpande et al. [4] predicted the 28-day compressive strength of recycled aggregate concrete by using model tree and non-linear regression. Islam and Alam [5] performed principle component and multiple regression analyses to determine the best suited in predicting the shear strength of steel fiber reinforced concrete beams. Özcan et al. [6] used an ANN and fuzzy logic to predict the compressive strength of silica fume concrete. Tayfur et al. [7] tested some high strength concrete models by using fuzzy logic and also ANN, the results of which showed that fuzzy logic predicts better than ANN. Chen [8] employed the multiple linear regression method to predict the concrete compressive strength of electric arc furnace slag to save both cost and time, and also to achieve a better compressive strength. Zain et al. [9] used nonlinear regression equation to predict the concrete compressive strength in different ages. Aggarwal et al. [10] utilized fuzzy logic techniques for predicting the compressive strength of high-strength concrete having supplementary cementitious material. Kaveh and Sabzi [11] presented the application of two algorithms to discrete optimization of reinforced concrete planar frames subject to combinations of gravitational and lateral loads based on ACI 318-08 code. Since ACI is used instead of the Iranian concrete code in conducting cases in Iran, many attempts have been made for comparing these two codes. Alizadeh et al. [12] compared the codes in physical characteristics. Despite numerous studies by Iranian scientists and engineers to compare the Iranian concrete code and ACI, other country codes have no analogy to Iranian one yet. Consequently, comparing the codes using the prediction methods because of its importance seems to be essential.

In this paper, different concrete codes including America, New Zealand, Mexico, Italy, India, Canada, Hong Kong, Euro Code and Britain are compared with the Iranian concrete code. Next, codes of America, Canada, Italy and New Zealand are chosen for more special comparison with the Iranian ninth issue of the national regulation. There are different anticipation methods to compare the codes: ANN, multi-variable regression, Genetic Programming (GP), Fuzzy Logic (FL) and Group Method of Data Handling (GMDH); however, GMDH is not efficient for use in this paper, because this method performs by using more than 1000 data, while we have 200 sample set. In this paper, two anticipate methods are used. In Section II, the codes which are used in this paper are nominated. The anticipated methods are specified in Section III. The case study, tables and figures are demonstrated in Section IV and the result discussions and the conclusion are addressed in Sections V and VI, respectively.

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II. The Nominated Codes

A. The Iranian Ninth Issue of National Building Regulation

The ninth issue uses Limit State Design (LSD) for applying the safety factor, however concrete and steel strength reduction factors are respectively considered as $\varphi_c = 0.65$ and $\varphi_s = 0.85$ [13].

The concrete stress $\alpha_1 \varphi_c f_c$ is assumed to be uniformly distributed over an equivalent compression zone bounded by the edges of the cross section and a straight line located parallel to the neutral axis at the distance $\beta_1 x$ from the fiber of maximum compressive strain. α_1 and β_1 are taken as the following relations, depending on f_c:

$$\alpha_1 = 0.85 - 0.0015 f_c \tag{1}$$

$$\beta_1 = 0.97 - 0.0025 f_c \tag{2}$$

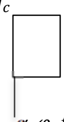
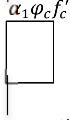
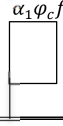
Concrete codes of several countries are used in this paper, and a brief description about some of them is given. In Table I, the concrete codes of America (ACI) and Canada (CSA) are compared briefly with the concrete code of Iran. In Iran, designing by commercial software is usually carried out by using ACI or CSA.

It should be noted that D, L and E are the symbols standing for Dead load, Live load and Earthquake load. By considering the presence of earthquake load in this paper, the dominant load combination in ABA and the ninth issue respectively are:

$$D + 1.2L + 1.2E \tag{3}$$

$$D + 1.2L + 1.2(0.7E) \tag{4}$$

TABLE I
A Brief Representation of Various Concrete Codes

Code	Drawing stress distribution	Conditions of stress distribution
America	$0.85f'_c$ $\beta_1 c$ 	$\beta_1 = \begin{cases} 1.05 - 0.00714 f'_c \geq 0.65 & , f'_c > \\ 0.85 & , f'_c \leq 3 \end{cases}$
Canada	$\alpha_1 \varphi_c f'_c$ $\beta_1 c$ 	$\alpha_1 = 0.85 - 0.0015 f'_c$ (but not less than 0.67) $\beta_1 = 0.97 - 0.0025 f'_c$ (but not less than 0.67)
The Iranian ninth issue	$\alpha_1 \varphi_c f'_c$ 	$\alpha_1 = 0.85 - 0.0015 f_c$ $\beta_1 = 0.97 - 0.0025 f_c$

III. The Anticipating Methods

As mentioned before, the Iranian concrete code does not exist in structural design software, therefore, in this paper, it has been tried to predict the needed steel ratio by making a communication between Iranian code and ACI, CSA, Italy and NZS. In fact, input is the steel ratio obtained from these four foreign concrete codes and output is the essential steel ratio of Iranian concrete code. For this purpose, several methods are used: ANN, multi-variable regression, and ANFIS which are described in detail in subsections below.

A. Artificial Neural Network (ANN)

ANNs have two operation modes, training mode and normal mode. In training mode, adjustable parameters of networks are modified. In normal mode, the trained the networks are applied for simulating outputs.

In this study, Radial Basis Function (RBF) is employed for approximating the output of the analysis of the codes. In MATLAB environment, there are several commands for RBF such as: Newrb, Newrbe, Newgrnn, Newpnn. Some data should be given to the software as the training data, after training and testing the data by the software, the chosen train could be used for anticipating. RBF networks typically have three layers: an input layer, a hidden layer with a non-linear RBF activation function and a linear output layer. They are powerful and interesting networks due to their rapid training, generality and simplicity. In Fig. 1 the topology of an RBF neural network is shown.

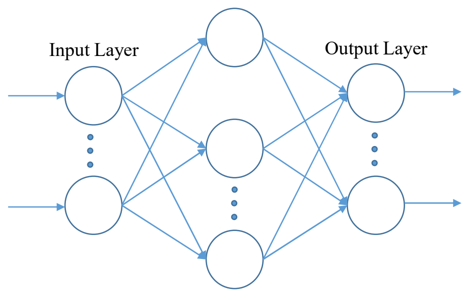


Fig. 1 The topology of RBF networks

B. Multi-Variable Regression

Regression analysis is a statistical technique for investigating and modeling the relationship between variables. In a multiple regression model, there is a single response variable and several explanatory variables and we are interested in the distribution of the response variable as a function of explanatory variables.

The equation of $y = ax + b + \varepsilon$ is a linear regression model. x, y and ε are named independent variable (regression), dependent variable (response) and random error, respectively. Now, suppose there are several independent variables as $x_1, x_2, \ldots, x_p$ instead of one. In this case, the general relationship between the dependent variable, y, with these independent variables can be shown as:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_p x_p + \varepsilon \tag{5}$$

We assume here that the variable ε follows a normal distribution for each combination of values of the explanatory variables and the mean of ε is zero. Moreover, we assume that the variance of the ε variable is constant for each combination of values of the explanatory variables. The above model can be equivalently rewritten as:

$$f(y|x_1, x_2, \dots, x_p) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \dots + \beta_p x_p + \varepsilon (6)$$

This case is named multi-variable regression. Multi-variable regression is applicable when we explore a linear relationship between some independent variables associated with several dependent variables.

C. Adaptive Neuro Fuzzy Inference System (ANFIS)

The process of a fuzzy Inference System (FIS) involves some concepts: fuzzy sets, membership functions, logical operations, and if-then rules. The FIS based on neuro-adaptive learning techniques are usually named ANFIS. Fig. 2 shows the architecture of a typical ANFIS with two inputs, four rules and one output for the first order Sugeno fuzzy model, where each input is assumed to have two associated Membership Functions (MFs).

In this paper, the ANFIS model is utilized to determine the most influential word-wide design codes to the reinforcement needed in the Iran concrete code. To implement the ANFIS, a number of beams are randomly generated and their required reinforcements for different types of structures are obtained. Then, an exhaustive search is performed within the inputs to select the set of inputs having the most influence on the output. Essentially, the exhaustive search technique builds an ANFIS model for each combination of input vector components and trains it for a little epoch and reports the performance achieved.

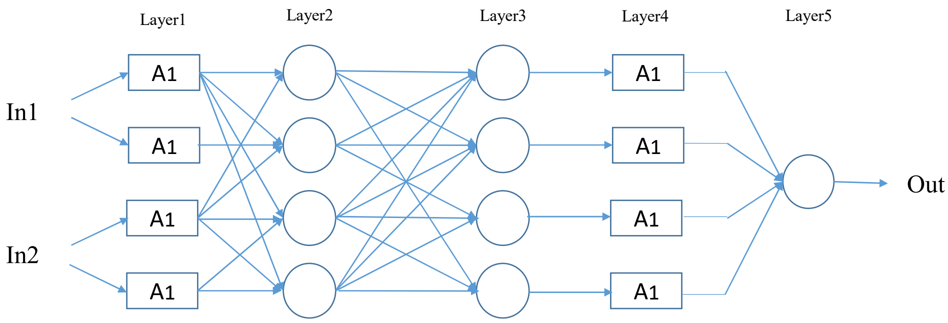


Fig. 2 Architecture of a typical ANFIS

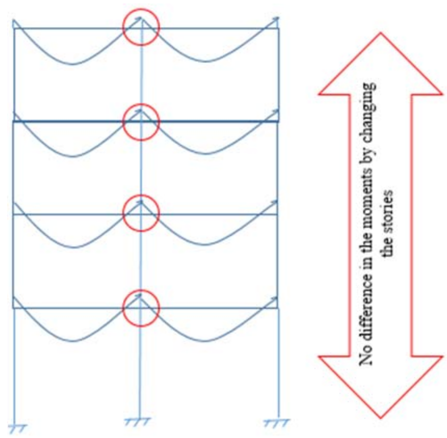


Fig. 3 The effect of height to the moments induced by gravitational loads

IV. Case Study

For designing and analyzing a structure, three load cases play important roles: dead load, live load and earthquake load. As we know, the dead and live loads do not change in a large limit, meanwhile earthquake induced moments vary within a wider range. Since dead and live loads are known as gravitational loads, the moment does not have a great variation by changing the stories. Fig. 3 shows such a uniformity in moments created by gravitational loads for beams in different heights. But, lateral loads (e.g. earthquake) create a larger range of moments by changing the stories comparing with the gravity loads (see Fig. 4). On the other side, span or the beam length affects the moment absorption caused by earthquake in a way that the shorter beams absorb more moments than the longer beams, while the gravitational loads are not influenced by the span as much as lateral loads (see Fig. 5).

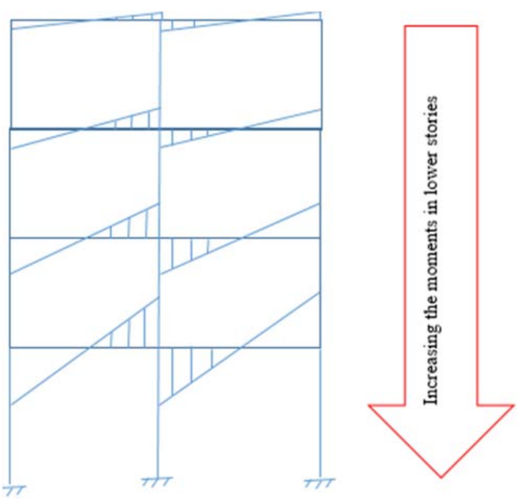


Fig. 4 The impact of story level to the moments under lateral loads

The moments in Figs. 3-5 are magnified to represent the differences better. Herein, we are to compare the four anticipate methods with each other, and the steel ratio of the exemplars are only considered. First, this research has begun by considering 50 sample beams with the heights changing from 40 cm to 162.5 cm with 2.5 cm increments, and the following fixed parameters: $f_c = 28MPa$, $W = 100\frac{KN}{m}$, $L = 5\ m, b = 40cm, d' = 6.5\ cm, d = 9\ cm$

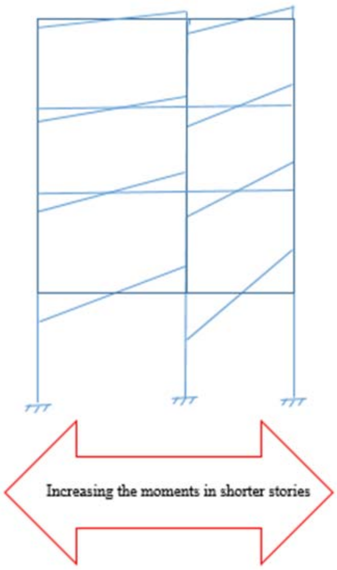


Fig. 5 The impact of the beam length to the moments of lateral loads

The 50 exemplar beams have been drawn in ETABS for the concrete codes of America, New Zealand, Mexico, Italy, India, Canada, Hong Kong, Euro Code and Britain. In this way, the required steel ratio for each beam is acquired. According to the absence of the Iranian concrete code in ETABS's codes list, the ninth issue is programmed by MATLAB and the required steel ratios for these 50 exemplar beams are obtained. Finding the most influential concrete design codes has been done by using ANFIS.

ETABS has a special status in the engineer's community of Iran, for this reason, considering this software for designing in this paper is absolutely logical. Now, for comparing the Iranian code and some other ones, 200 sample beams are considered with the fixed parameters: $f_y = 400MPa$, $L = 5\ m$, $b = 40cm, d' = 6.5\ cm, d = 9\ cm$

Variable parameters which are used in these 200 sample beam are considered as: concrete compression strength, beam height, dead, live and earthquake moments. All these parameters are selected stochastically in the following intervals: Concrete compression from 20 to 80 megapascal, live moment from 2 to 20 ton-meter, dead moment from 1 to 3 times of live moment, earthquake moment from 0 to 20 times of live moment and beam height from 40 to 150 centimeters. By drawing these 200 exemplar beams in the software, the codes of America, Canada, Italy and New Zealand (NZS) have been utilized.

For testing and selecting the best anticipate method, 10 sample beams are randomly chosen. Table II contains the tensile steel ratio for five concrete codes: ACI, CSA, Italy, NZS and the ninth issue.

The first method is ANN which has different commands in MATLAB (newrb, newrbe, newgrnn, newpnn, etc). The newrb is chosen for use in this paper. Table III contains the gained answers in this method.

TABLE II
THE STEEL RATIO FOR CONCRETE CODES

The ninth issue	NZS	Italia	CSA	ACI
1.45 E -4	1 E -2	0.15	0.33	2 E -2
2.76 E -4	3 E -2	0.15	0.33	4 E -2
3.04 E -5	3.09 E -3	0.15	0.33	4.4 E -3
3.64 E -5	3.63 E -3	0.15	0.33	5.21 E -3
7.83 E -4	7 E -2	0.15	0.32	1 E -1
6.13 E -5	6.07 E -3	0.15	0.33	8.67 E -3
1.92 E -4	2 E -2	0.15	0.30	2 E -2
6.24 E -5	5.94 E -3	0.15	0.32	8.49 E -3
1.31 E -4	9.87 E -3	0.15	0.33	1 E -2
2.14E -4	2E -2	0.15	0.33	3E -2

TABLE III
THE STEEL RATIO FOR THE NINTH ISSUE GAINED FROM ANN METHOD

ANN
1.2978 E -4
2.8871 E -4
3.4689 E -5
3.9390 E -5
7.7174 E -4
6.7062 E -5
1.9200 E -4
6.5778 E -5
8.5939 E -5
2.0937 E -4

The error percentage for evaluating the steel ratio is a meaningful criterion for comparison between methods. The table below shows the error percentages of the ANN method mentioned above.

TABLE IV
THE ERROR PERCENTAGES GAINED FROM ANN METHOD

Newrb
1.05 E -01
-4.61 E -02
-1.41 E -01
-8.21 E -02
1.44 E -02
-9.40 E -02
00 E +00
-5.41 E -02
3.44 E -01
2.16 E -02

The second method to be considered is multi-variable regression. By using the Statistical Package Social Science (SPSS) software, the multi-variable regression is perused for concrete codes of America, Canada, Italy and New Zealand in comparison with the ninth issue, whereas ACI, Italy, CSA and NZS is entered as independent variables and the ninth issue as the dependent one.

SPSS software exhibits several tables for analyzing. The first one is 'Model Summery' in which the given R value is equal to 0.997 and represents the Pearson correlation, whereas the R^2 value offers that how much the dependant variable could be explained by the independent variables ($R^2 = 0.993$). The second table, ANOVA, presents whether the regression model could predict the dependent variable change in a significant and appropriate way. For this purpose, the 'sig' value of this table should be checked, which presents the statistical significance of the regression model. If the obtained value is lower than 0.005, it can be concluded that the used model is not an appropriate predictor of the dependent value. The significance value of this case is zero, which is lower than 0.005 and shows the regression model is significant. The next table, the 'coefficients' table, gives information of predictor variables. This table offers important information for predicting the dependent variable. The column named 'standard coefficients' represents standardized regression coefficients or beta value indicating the impact of the independent variables on the dependent one. In this case, the beta value is different from Pearson correlation coefficient (R), because there is more than one independent variable. Beta coefficients help to compare the relative contribution of each variable for predicting the dependent one; in the other words, it helps to determine which variables have the most effect on the dependent variable.

To form regression equation, the unstandardized coefficient value (B) is at attention. The regression equation is used for predicting the dependent variable values.

The regression in below is obtained:

$$(4.26e-4)+(0.00766)\rho_{ACI}+(-0.001774)\rho_{CSA}+(9.54e-4)\rho_{Italy}+(4.639e-4)\rho_{NZS}=\rho_{The\ ninth\ issue} \quad (7)$$

Table V shows the steel ratio in both modes A and B gained by multi-variable regression and also the error percentage for this method.

TABLE V
THE STEEL RATIO AND THE ERROR PERCENTAGE FOR THE NINTH ISSUE OBTAINED FROM THE MULTI-VARIABLE REGRESSION METHOD

Error percentage	Multi-variable regression
2.41 E -02	1.42 E -04
-1.01 E -01	3.04 E -04
3.82 E -01	1.88 E -05
3.05 E -01	2.53 E -05
-2.16 E -02	8.00 E -04
1.37 E -01	5.29 E -05
-3.85 E -02	1.99 E -04
-1.09 E -01	6.92 E -05
5.05 E -01	6.49 E -05
-4.11 E -02	2.23 E -04

V. RESULTS DISCUSSION

Fig. 6 exhibits the comparison of the two prediction methods: ANN (which includes Newrb command in MATLAB) and multi-variable regression. As shown in the figure below, both methods predicted acceptably, while the ANN with the Newrb command performed better.

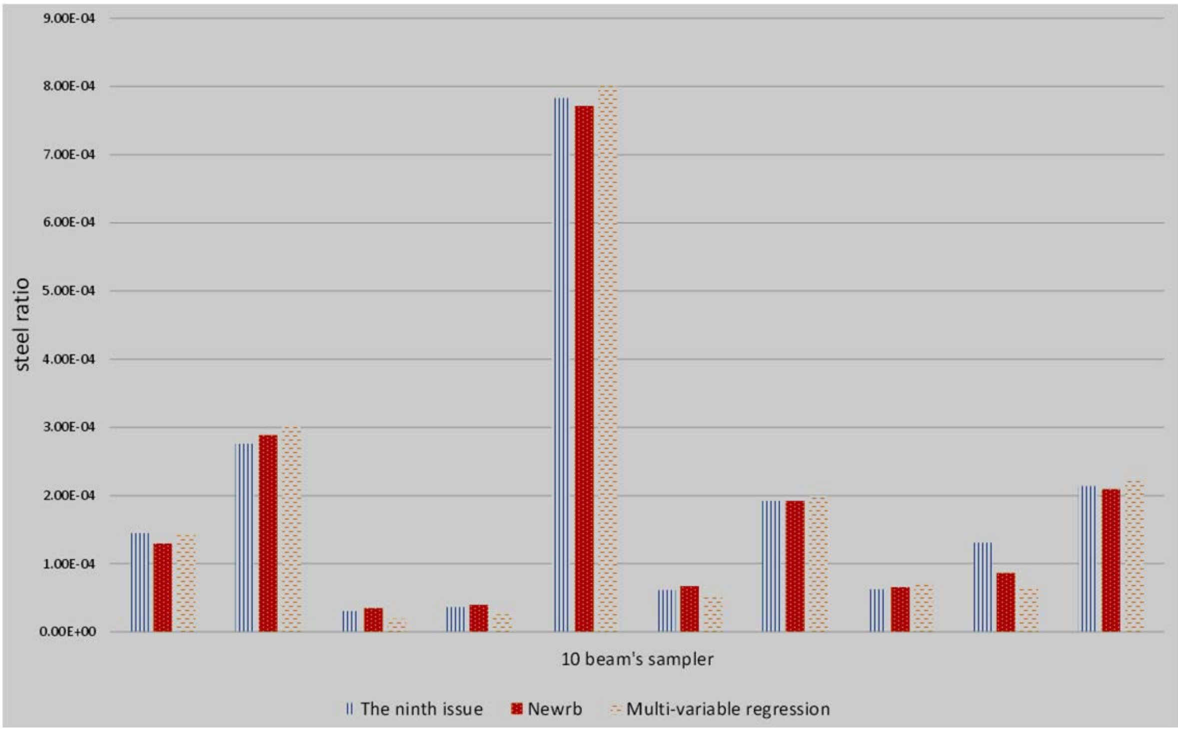


Fig. 6 The comparison of the prediction methods

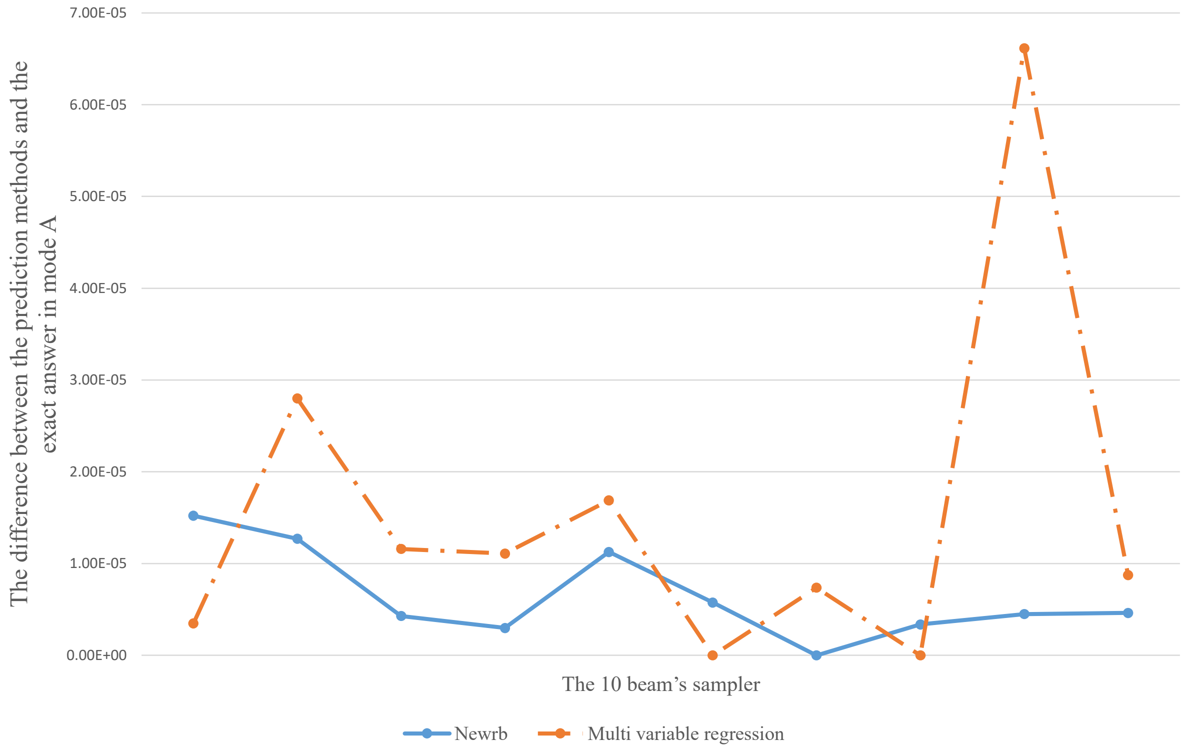


Fig. 7 The differences between the prediction methods and the exact answers

Fig. 7 shows differences between the exact answers and answers obtained from prediction methods.

The most difference between the exact answers and answers obtained by the method of ANN, is equal to 4.51E-5, while this value for multi-variable regression is 6.40E-5.

VI. Conclusion

In this paper, we have made a relationship between the Iranian concrete design code and some other world-wide ones by two well-known general anticipate methods: ANN and multi-variable, predicting by using only the tensile steel ratio and with ignoring the compression steel ratio. As the results show, the better method in this paper, belongs to Newrb with almost 6.77E-3% error and the next grade belongs to multi-variable regression.

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