Journal of Civil Engineering (IEB), 35 (2) (2007) 119-128

Journal of
Civil Engineering
IEB

Prediction of short and long-term deflections of two-way edge-supported reinforced concrete slabs using artificial neural network

Tahsin Reza Hossain, Md. Taslim Uddin[1] and Md. Saiful Alam Siddiquee

Department of Civil Engineering
Bangladesh University of Engineering and Technology, Dhaka 1000, Bangladesh

Received 10 July 2007

Abstract

For designing a structure, members are so proportioned that will have adequate strength against failure and at the same time must possess sufficient stiffness to ensure serviceability. ACI Code provides minimum thickness for two-way edge-supported slabs so that the deflections are not excessive. It also allows thinner slabs if calculated deflections are found tolerable. The method given in ACI Code for deflection estimation is relatively straightforward in comparison to other codes. It uses Branson's equation to take cracking into account for short-term deflection calculation. As for long-term deflection, a simplified multiplier approach is proposed in the Code. These calculation approaches, suitably incorporated in a finite element (FE) package, had been used to estimate incremental and total long-term deflections of two-way edge-supported slabs. However, use of this finite element package is neither easy to use in the design office nor it is available to everybody. An attempt has been made in this paper to train a customized Artificial Neural Network (ANN) program using the results of the FE package and use the trained network to easily predict the deflection of two-way edge supported slab. ANN is particularly suitable for predicting output parameters which depend upon a large number of input parameter like span, aspect ratio, DL, LL, f_c', f_y etc. An example demonstrates some simple steps for calculating short- and long-term deflections.

Keywords: Concrete slab, deflection, slab thickness, serviceability

1. Introduction

In strength design, the members are so proportioned that will have a proper safety margin against failure under an overload state. It is also important that the member

[1] Former graduate student

performance in normal service be satisfactory. This performance, termed as serviceability, is not guaranteed simply by providing adequate strength. Service load deflections under full load may be excessively large, or long-term deflections due to sustained load may cause damage to partition walls. There are other serviceability related problems like visually disturbing wide tension cracks and discomforts due to vibrations.

In the past, questions of serviceability were dealt with indirectly by limiting the stresses in concrete and steel at service loads to some rather conservative values that resulted in satisfactory performance. Now, with strength design methods in general use that permit more slender members through more accurate assessment of capacity, such indirect methods will no longer do. Use of high strength materials further contributes toward this trend of smaller member sizes. ACI Code (2002) proposes minimum slab thickness to ensure serviceability and at the same time allows thinner slabs if deflection calculation permits so. ACI Code also provides a simple deflection calculation procedure. A general-purpose finite element package, suitably adopted to take into consideration the effect of cracking according to ACI Code, has been proved reasonable to predict deflection in several previous studies (Hossain 1999, Hossain et al 2005, Hossain and Alam 2004, Hossain and Alam 2003). However, use of this nonlinear finite element package is neither easy to use in the design office nor it is available to everybody. Ahmed and Chowdhury (1999) proposed design charts to calculate elastic deflections of edge supported slabs. As in most cases slabs are cracked even in service load, thickness selection on the basis of elastic deflection may not be always justified. Hossain and Alam (2007) presented a number of design charts to take into account the effect of cracking. Although, deflection depends on a number of geometric, material and loading parameters which in turn control level of cracking, these charts simplified the nonlinear relation and calculates reasonable deflection multiplier on the basis of level of cracking. As deflection depends on a number of parameters, it is possible to employ an Artificial Neural Network program which can establish a relation between a large number of inputs and outputs by learning from known values. In the current work, a customized ANN computer program (Siddiquee 2007) has been trained using the nonlinear FE (Hossain 1999) results so that it can be used to predict deflections as an alternative to performing time-consuming explicit FE analysis.

2. Description of the FE model

A program module based on global plate stiffness approach was developed by Hossain (1999) to incorporate the different short- and long-term models for predicting deflection of reinforced concrete slabs. The module acts as an integral part of the FE package FE77 (1999) and calculates modified elastic properties to represent cracking, creep and shrinkage for each element, on the basis of stresses of FE solution, which are then fed back into the assembly module of the FE package. Hossain and Vollum (2002) found good correlation in the analysis of the real full scale 7 storied building at Cardington using this FE module employing EC2 (1992) and CEB-FIP Model Code 1990 MC-90 (1990), where creep and shrinkage deflections are dealt with more rigorously along with the effect of construction load. Deflection estimation procedure in ACI Code is simpler than these codes where long-term deflections are calculated from instantaneous deflection using multiplier. Branson's crack model (1977) which is also adopted in the ACI Code (2002) to calculate instantaneous deflection has been used in the current work for developing the database to train the neural network. Description of the model and its incorporation was presented in previous works (Hossain 1999, Hossain and Alam 2007).

This Branson/ACI model was found to give good prediction of experimental deflections. A comparison is shown in the next section.

3. Validation of the model with experiments (Shukla slabs)

Shukla and Mittal (1976) carried out a series of tests on two-way edge-supported slabs. All the slabs were 214 cm square and 8 cm thick. The slabs were supported on reinforced concrete walls with centre to centre span of 183 cm each way. Their corners were held down by means of 40 mm diameter steel rods anchored to the floor. Loads were applied to the test slab in increments of 2 tonnes each through an inverted waffle-tree system which transferred load at 16 equidistant point of the slab. Two slabs (S-8 and S-11) from this series were analysed there. S-8 and S-11 were isotropically reinforced with 10 mm bars to provide 5.24 and 4.36 cm^2/m steel in each direction respectively. The two slabs differ in concrete strengths which were 15.9 (S-8) and 22.0 (S-11) N/mm^2. Moduli of rupture and elasticity were not reported and hence have been estimated using the ACI equations. Details of the slab dimensions and FE mesh can be found in Alam (2003). Short-term load-deflection results from FE analysis and experiment were compared for the central nodes of two slabs in Figs. 1 and 2. The FE analysis modelled experimental deflection accurately to a possible extent.

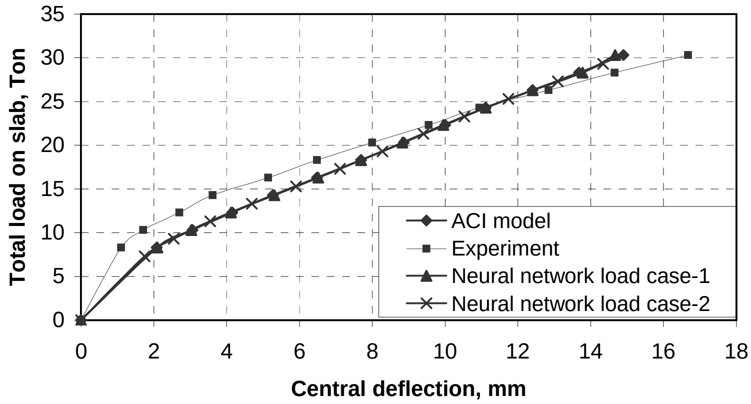

Fig. 1. Comparison of deflection for edge-supported Shukla & Mittal slab S-8 and FE analysis

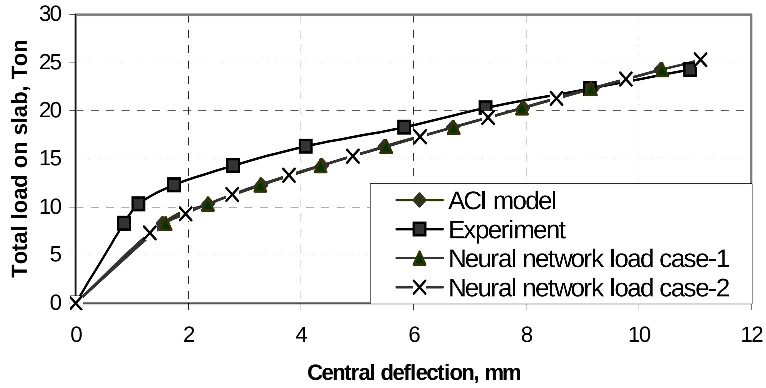

Fig. 2. Comparison of deflection for edge-supported Shukla & Mittal slab S-11 and FE analysis

4. Artificial neural network

4.1 ANN: from brain to mathematical prediction tool

Artificial Intelligence (AI) is a very versatile and potential technology in the field of computer technology, which enables computer users in various fields to solve problems for which algorithmic approach cannot be formulated and which normally requires human intelligence and expertise. Expert Systems (ESs) and Artificial Neural Networks (ANNs), the best known manifestations of AI, have today gained immense credibility and acceptance in many professional fields. ANN approaches have successfully been used in wide range Civil Engineering problems where conventional approaches based on engineering mechanics were proved to be difficult to establish an explicit relationship between causes and effects. These include a wide range of problems in the fields of structural engineering, construction engineering and management, environmental and water resources engineering, traffic engineering, highway engineering, and geotechnical engineering (Jeng et al. 2003, Flood 2001, Adeli 2001, Kartam 1997, Flood and Kartam 1994).

Artificial neural networks are biologically inspired in the sense that neural network configurations and algorithms are usually constructed with the natural counterpart in mind. The tremendous processing power of human brain is basically the result of the massively parallel processing units called neurons. A human brain functions with hundreds of thousands of such biological neurons, which are interconnected by a highly complex network. Every neuron consists of a cell body, axon and dendrites. Dendrites extend from the cell body to the other neurons where they receive signals at a connection point called the synapse. These inputs are communicated to cell body where all such inputs are essentially summed up. If the resulting sum exceeds a specified threshold value, the cell fires and a signal is sent down the axon.

An artificial neural network, also called a simulated neural network (SNN) or commonly just neural network (NN) is an interconnected group of artificial neurons that uses a mathematical or computational model for information processing based on a connectionistic approach to computation. In most cases, an ANN is an adaptive system that changes its structure based on external or internal information that flows through the network. In more practical terms, neural networks are non-linear statistical data modeling or decision making tools. They can be used to model complex relationships between inputs and outputs or to find out patterns in data.

4.2 Back-propagation and training the network

Here in this paper, a general purpose ANN program (Siddiquee, 2007) is used, which is basically a back propagation type of neural network. In this network, a set of input parameters are connected to a set of output parameters through a set of weights and hidden or middle layers as shown in the Fig. 3. The network is trained to recognise the correct input-output pattern by adjusting the weight values of the interconnecting weight matrix. The adjustment follows an error-correcting method called “error back-propagation”, from where the name of the method is developed. After sufficient number of training, when the error becomes gradually diminished, the network becomes capable of predicting any new data within the trained range of input data or any data outside the range. Number of any hidden layers actually represent the number of the data input-output relationship. The number of hidden layers is determined by gradually increasing its number and checking the error-norm of the trained data set. The best number of hidden layers is the number for which the error-norm is the lowest. In this paper the best number of hidden layers was found out to be 16.

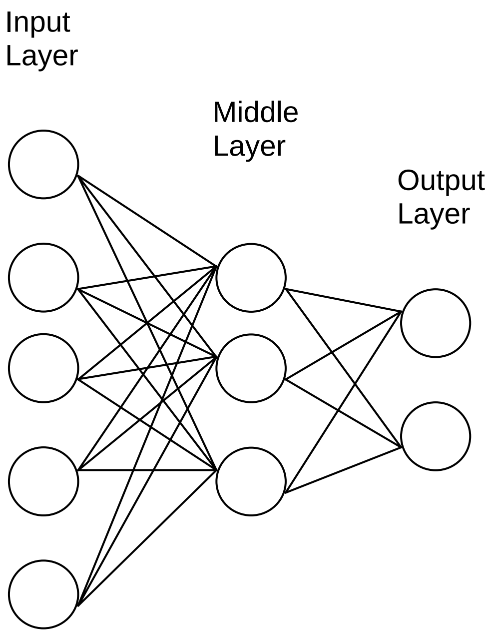

Fig. 3. Basic structure of a Neural Network

A large number of nonlinear FE analyses using Hossain's (1999) module employing Branson's crack model was carried out by varying the relevant geometric and material parameters. Using the results of these analyses, the ANN was trained as shown in Fig. 4. Once the amount of error, i.e. the residual becomes very small, the network is ready for prediction.

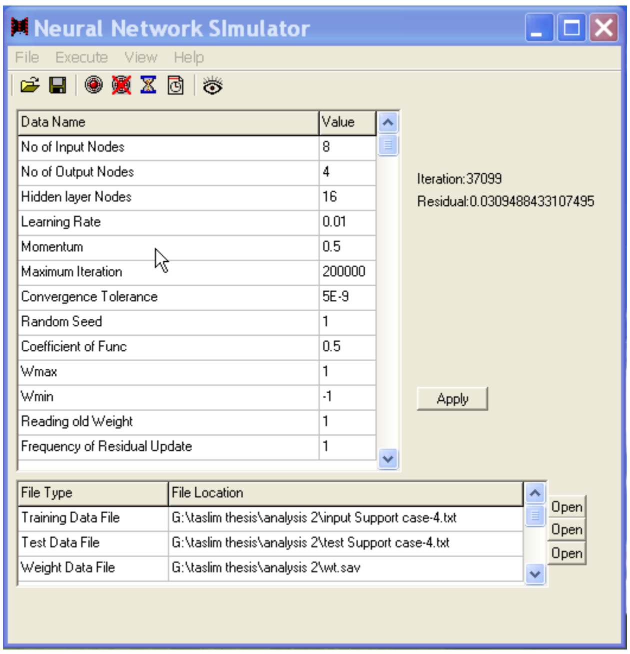

Fig. 4. The Neural network being trained for corner panel of edge-supported slab

4.3 Use of the trained network as prediction tool

The use of this ANN is shown in Fig. 5, where input parameter like span, loading and material properties were given as inputs to predict maximum stress, elastic and cracked deflections. It was found in Uddin (2005) that these predictions are reasonably accurate in comparison with the FE analysis. Prediction of the Shukla slab deflections were also tried using ANN with two different load paths and compared with the previously presented FE results in Figs. 1 and 2. ANN predictions and FE results are almost identical.

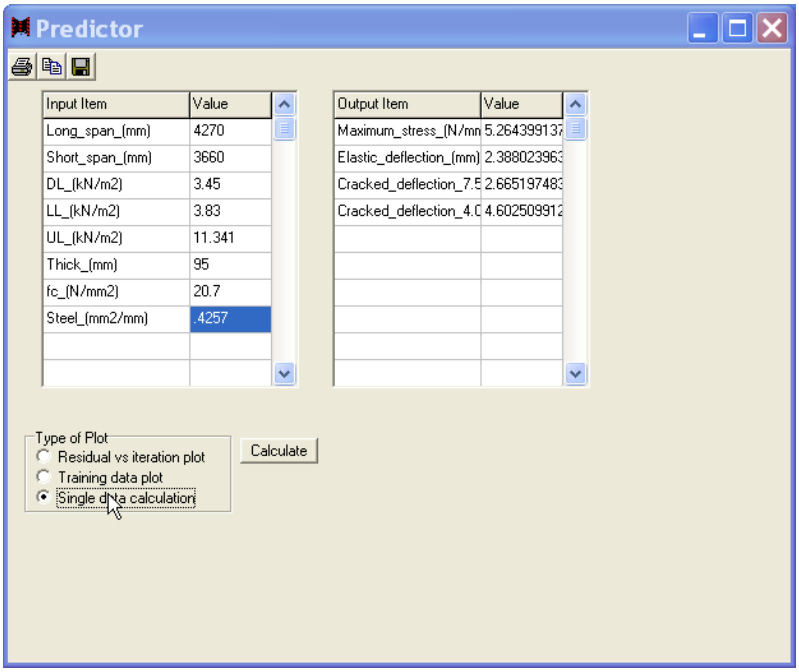

Fig. 5. The Neural network being used for predicting stresses and deflections

5. ACI serviceability provisions

There are presently two approaches to control excessive deflections. The first one is indirect and consists in setting suitable upper limits on the span-depth ratio. This is simple, and is satisfactory in many cases where spans, loads and load distributions, and member sizes and proportions fall in the usual range. Otherwise, it is essential to calculate deflections and to compare those predicted values with specific limitations that may be imposed by codes or by special requirements.

The 1963 ACI Code (1963), in which the coefficient method of analysis was introduced, provided that the slab thickness should not be less than 3.5 inch and not less than the total perimeter divided by 180. These limitations gave satisfactory results for edge-supported slabs. The more general unified method of two-way system analysis found in recent edition of ACI Code (2002) contains three equations governing minimum slab thickness. These equations account for the relative stiffness of slab and edge beams, the ratio of long to short panel side dimensions, and conditions of restraint along the edges.

The equation for beam-supported slab normally yields a higher slab thickness than obtained from perimeter divided by 180.

5.1 ACI Code (2002) Thickness: Slabs with Beams on All Sides

The parameter used to define the relative stiffness of the beam and slab spanning in either direction is α. Then α_m is defined as the average value of α for all beams on the edges of given panel. According to ACI Code (2002), for α_m equal to or less than 0.2, the minimum thickness of slabs without interior beam shall apply.

For α_m greater than 0.2 but not greater than 2.0, the slab thickness must not be less than

$$h = \frac{l_n\left(0.8 + f_y / 200{,}000\right)}{36 + 5\beta\left(\alpha_m - 0.2\right)} \tag{1}$$

and not less than 5.0 inch (125mm).

For α_m greater than 2.0, the thickness must not be less than

$$h = \frac{l_n\left(0.8 + f_y / 200{,}000\right)}{36 + 9\beta} \tag{2}$$

and not less than 3.5 inch (89mm).

where, l_n= clear span in long direction, α_m = average value of α for all beams on edges of a panel, β = ratio of clear span in long direction to clear span in short direction.

6. Deflection calculation: ACI provisions

ACI Code (2002) also permits slab thickness less than that obtained from above equations if it can be shown by computation that deflections will not exceed the limit values given in the Code. Calculation of slab deflection is complicated due to the presence of cracking even in service loads and also there are time-dependent deformations due to concrete creep and shrinkage. ACI Code incorporates Branson's equation for calculating short-term deflection considering cracking. As for long-term deflection calculation, unlike EC2 (1992) and MC90 (1990), ACI Code (2002) adopted a simplified multiplier approach. According to Nilson (1997), the philosophy behind it is that uncertainties regarding material properties, effect of cracking and load history never justifies precise deflection calculations. The calculated deflections must satisfy the maximum permissible deflection tabulated in the Code to ensure serviceability.

6.1 Long-term deflection multiplier

On the basis of empirical studies, ACI Code (2002) specifies that additional long-term deflection due to combined effects of creep and shrinkage shall be calculated by multiplying the immediate deflection by the factor:

$$\lambda = \frac{\xi}{1 + 50\rho'} \tag{3}$$

where, ξ= a time-dependant coefficient, ACI Code (2002) suggested a five-year value of ξ=2.0, and $\rho' = A_s'/bd$, is usually zero for slabs as compression steels are seldom used.

7. Example showing short- and long-term deflections estimation using the trained ANN

To demonstrate the method of deflection calculation using the trained ANN program following ACI Code, an example is worked out here. Unlike the approach shown in Nilson (1997), cracking in slab is considered in the analysis. In the current example, short- and long-term deflections of a 3.66 m x 4.27 m corner panel slab were estimated with following parameters.

Slab thickness was calculated using recent formula shown in Equation 2 and found to be 94.7 mm (rounding to 100 mm was not done in this study). The following parameters are assumed: f_c'= 20.7 MPa, f_y= 414 MPa, E_c= 20.7 GPa, Poisson's ratio =0.18 and Modular ratio, n=10. A reduced value of $0.33\sqrt{f_c'}$ (MPa) was used for rupture strength of concrete instead of $0.60\sqrt{f_c'}$ (MPa). Tam and Scanlon (1986) produced good correlation between calculated deflection with $0.33\sqrt{f_c'}$ value and mean field-measured deflection. This approach of using reduced modulus of rupture to take into the effect of cracking due to restraint shrinkage was reported in a series of papers (ACI Committee 435 1991, Thompson and Scanlon 1988, Ghali 1990). The total dead load with 1.20 kN/m^2 of floor finish and 2.25 kN/m^2 self-wt was 3.45 kN/m^2 and live load was 3.83 kN/m^2. From the trained ANN, the immediate deflection was found for total dead and live load. The calculation of long-term deflection was performed using sustained load of 30% live load and ξ=2.0 as proposed by the ACI Code. An earlier study (Hossain et al. 2005) demonstrated a deflection calculation procedure with ξ=3.0 as proposed by Branson for slabs.

7.1 Long-term deflection calculation

Immediate deflection for dead load and live load predicted using the ANN as shown in Fig. 4.

$\Delta_{d+l} = 4.60\,\text{mm}$ (With nonlinear FE analysis for the same slab, the deflection found was 4.57 mm)

Assuming 50% of creep due to self-weight occurs before the finishing of the building starts. The time-dependent portion of dead load deflection was

$$\Delta_d = 4.60 \times \frac{2.25}{7.28} \times 1 + 4.60 \times \frac{1.20}{7.28} \times 2 = 1.42 + 1.52 = 2.94\,\text{mm}$$

The long-term deflection due to sustained portion of the live load was

$$\Delta_{0.3L} = 4.60 \times \frac{3.83}{7.28} \times 0.3 \times 3 = 2.17\,\text{mm}$$

The instantaneous deflection due to application of short-term portion of the live load was

$$\Delta_{0.7L} = 4.60 \times \frac{3.83}{7.28} \times 0.7 = 1.69\,\text{mm}$$

The total incremental deflection is $\Delta = 2.94 + 2.17 + 1.69 = 6.8\,\text{mm}$

The ACI Code limitation of incremental deflection is $\frac{span}{480} = 7.63\,\text{mm}$

It is observed that slab thickness is adequate from incremental deflection consideration. The total deflection was

$$\Delta_{total} = 4.6 \times \frac{2.25}{7.28} \times 3 + 4.6 \times \frac{1.20}{7.28} \times 3 + 2.17 + 1.69 = 10.40 \text{ mm}$$

The ACI Code limitation of total deflection is $\frac{span}{240} = 15.24 \text{ mm}$

From calculation, slab thickness was found to be adequate from total deflection consideration.

8. Conclusions

Hossain & Alam (2004) showed that in most cases the thickness provided by the ACI Code are proved to be adequate where spans, live loads and concrete strength are within normal range and when the slabs are mostly uncracked or slightly cracked. For shorter spans with lighter loads, a smaller thickness may suffice from serviceability point of view. The ACI Code allows slab thickness less than the specified value if calculated values are within code-specified limits. So it would be economical to use thinner slabs in such situations where deflection analysis permits so. On the contrary, for excessive live load and larger panels, which generate high level of cracking in slab, providing ACI Code minimum thickness may not be adequate. In such conditions, deflection calculations should be mandatory to decide a higher thickness. In either case, a quick estimation of slab deflection as demonstrated in the current paper using the trained ANN software which is capable of producing results as good as the nonlinear FE analysis, should indicate if ACI minimum thickness is appropriate to use.

References

ACI Committee 435 (1991), “State-of-the-Art Report on Control of Two-way Slab Deflections”, Detroit: American Concrete Institute.

ACI Publication 318-02 (2002), “Building Code Requirements for Reinforced Concrete”, Detroit: American Concrete Institute.

ACI Publication 318-63 (1963). “Building Code Requirements for Reinforced Concrete”, Detroit: American Concrete Institute.

Adeli, H. (2001), “Neural Networks in Civil Engineering: 1989-2000”, Computer-Aided Civil and Infrastructure Engineering , 16 (2), 126–142.

Ahmed, B. and Chowdhury, S.R. (1999), Simplified calculation method for serviceability deflection of edge supported slabs; Part 1: Modelling slab response, Journal of the Civil Engineering Division, IEB, 27, 29-40.

Ahmed, B. and Chowdhury, S.R. (1999), Simplified calculation method for serviceability deflection of edge supported slabs; Part 2: Coefficient method, Journal of the Civil Engineering Division, IEB, 27, 41-57.

Alam, M.R. (2003), “Computation of deflection of edge supported reinforced concrete slab under service loads”, M.Sc.Engg Thesis, BUET, Dhaka.

Branson, D.E. (1977), “Deformation of concrete structures”, New York: McGraw-Hill Book Co.

CEB-FIP (1993), “CEB-FIP Model Code 1990- Design Code”, Lausanne: Comite Euro-International du Beton (CEB).

EC2 Editorial Group (1991), “Design of concrete structures, Part 1, General rules and rules for buildings”, EuroCode2.

Flood, I. (2001), Neural networks in civil engineering: a review, Civil and structural engineering computing: 2001, Saxe-Coburg Publications.

Flood, I. and Kartam, N. (1994), Neural networks in civil engineering. I: principles and understanding, J. Comp. in Civ. Engrg, 8, 131.

Flood, I. and Kartam, N. (1994), Neural networks in civil engineering. II: principles and understanding, J. Comp. in Civ. Engrg, 8, 149.

Ghali, A. (1990), Deflection of prestressed two-way floor systems, ACI Structural Journal, 87, 60-65.

Hitchings, D. (1999), FE77 User Manual Version 2.54.

Hossain, T.R. and Alam, M.R. (2007), Deflection estimation of two-way edge-supported slabs, Journal of Civil Engineering , IEB , 35, 1-15.

Hossain T. R., Uddin, M. T. and Siddiquee M.S.A. (2005), "Deflection Estimation of Two-way Edge-supported Reinforced Concrete Slabs using Artificial Neural Network" in Third Annual Paper Meet and International Conference on Civil Engineering, organized by Institution of Engineers Bangladesh (IEB), held in March 2005.

Hossain, T.R. and Alam, M.R. (2004), ACI minimum thickness provisions and estimated deflection for two-way edge-supported reinforced concrete slabs, Progress in Structural Engineering, Mechanics and Computation, Taylor & Frances Group, London. : 1701-1706.

Hossain T. R. and Alam M. R. (2003), "Adequacy of ACI Minimum Thickness Provisions For Two-way Edge-supported Slabs", in Second Annual Paper Meet and International Conference on Civil Engineering, jointly organized by Institution of Engineers Bangladesh (IEB) and Bangladesh University of Engineering & Technology (BUET), held at BUET during 17-18 July 2003.

Hossain, T.R. and Vollum, R.L. (2002), Prediction of slab deflections and validation against Cardington data, Structures and Building 152, 235-248.

Hossain T.R. (1999), "Numerical Modelling of Deflections of Reinforced Concrete Flat Slabs under Service Load". PhD thesis. University of London.

Jeng, D. Cha, H and Blumenstein, M. (2003), Application of artificial neural network in civil engineering problems, The International Internet-Processing-Systems-Interdisciplinaries (IPSI-2003) Conference, Seveti-Stefan, Montenegro, October 5-11.

Kartam, N, Flood, I., Garrett, J.H. and Agarwal, G. (1997), Artificial Neural Networks for Civil Engineers: Fundamentals and Applications, ASCE.

Nilson, A.H. (1997), Design of concrete structures. New York: McGraw-Hill Book Co.

Polak, M.A. (1996), Effective stiffness model for reinforced concrete slabs. Journal of Structural Engineering, ASCE, 122, 1025-1030.

Shukla, S.N. and Mittal, M.K. (1976), Short-term deflection in two-way reinforced concrete slabs after cracking, ACI Journal 73, 416-419.

Siddiquee, M.S.A (2007), Artificial Neural Network Simulator, http://203.208.166.84/sid/download/

Thompson, D.P. and Scanlon, A. (1988), Minimum thickness requirements for control of two-way slab deflections, ACI Journal, 12-22.

Tam, K.S.S. and Scanlon, A. (1986), Deflection of two-way slabs subjected to restraint volume change and transverse loads, ACI Journal 83, 737-744.

Uddin M.T. (2005), "Deflection estimation of edge supported reinforced concrete slabs using Artificial Neural Network." M. Engg. thesis, Department of Civil Engineering, Bangladesh University of Engineering and Technology, Dhaka.