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STRUCTURAL ANALYSIS AND DESIGN OF BUILDINGS USING NEURAL NETWORK: A REVIEW

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ABSTRACT
Neural network is computationally efficient technique and has been simulated to diverse problems in the field of structural engineering. The application of this technique in this field is gaining momentum because it is simple to simulate the actual problem. This paper reviews some of the applications of neural network in the field of structural analysis and design. These applications show that the neural network modelling provides a much efficient and accurate method as compared to the conventional methods. Neural networks have also shown their ability to represent the difficult input/output relationship without the use complex and expensive programming.

KEYWORDS – Neural network, analysis, patterns, training methods

1 INTRODUCTION

Neural network is a new form of computing, inspired by the biological structure of neuron and internal operation of the human brain. A neural network’s ability to perform computation is based on the expectation that it reproduces some of the flexibility and power of the human brain by artificial means. The basic processing elements of neural networks are called artificial neurons, or simply neurons. Neurons perform as summing and nonlinear mapping junctions and operate, collectively and simultaneously on most or all the data and inputs. Strength of each connection is expressed by a numerical value (a weight), which can be modified during the process of training to get desired output. The mathematical model of neural network is composed of a large number of processing elements organized into networks. The processing element deals many inputs simultaneously, strengthening some, weakening others, to get the desired output. One of the advantages is that no predefined mathematical relationship between the variables is assumed, instead the neural network learns by examples fed to them.

Neural networks are powerful as they can process information more readily than traditional computer systems. Applications and research into the use of neural networks have evolved from their ability to understand complex relationships and hidden patterns within large data sets. Neural networks are now becoming an accepted tool for speech and image recognition in the scientific communities of engineering and medicine (Lippman 1987). Advances have been also made in applying neural networks for problems found difficult for traditional computation. Neural network also supplement the enormous processing power of the computer with the ability to make sensible decisions and to learn by ordinary experience.Neural networks have been used successfully applied in the field of structural analysis and design. These examples show the potential of this new technique. This paper updates and reviews some of the prominent applications of neural networks applied in the field of structural analysis and design. This review briefly covers the salient aspects of developed neural networks without presenting the exhaustive data and complex detailing of these neural networks.

2 EARLY DEVELOPMENTS

Van Luchene and Roufei (1990) applied neural network to arrive at the location and magnitude of the maximum bending moment of a simple supported rectangular plate. Hajela and Berke (1991) obtained optimum design of trusses using neural networks. The input data consisted of length and height of trusses while output data consisted of optimized bar areas and total weight of truss. Once the neural network has been trained, new optimum truss design can be found by propagating different sets of input data through the neural network. Flood and Kartam (1994a ; 1994b) presented the concept and application of neural networks to structural engineering in two parts. In the first part (1994a), concepts pertaining to neural networks have been discussed clearly by solving a simple structural analysis problem using the most popular form of neural networking system – a feed forward network trained using a supervised scheme. In second part (1994b), a range of different types of civil engineering problems have been considered and approaches to their solutions using different neural-network algorithms has been discussed.

Rogers (1994) applied neural network for carrying out structural analysis of structure with large degrees of freedom. Such analysis using neural network requires much less computation time. Earlier this problem was solved for optimization in structures and was found to be computationally expensive.

3 RECENT DEVELOPMENTS

3.1 Structural Analysis

Khan (1997) developed a neural network model, which simulate the results of sequential analysis from those of simultaneous analysis. This application did not take into account the effect of creep and shrinkage of concrete. In this application, the dominant structural parameters, which determine the difference in the behaviour of sequential and simultaneous analysis, were identified.

Using the dominant structural factors as input vectors, multi-layered feed forward neural network was trained for input patterns obtained from the buildings covering practical range of structural parameters. The output in this developed network yields the corresponding results of sequential analysis from the simultaneous analysis. The training was accomplished using back propagation training algorithm. The validity of this developed neural network has been demonstrated for a number of example buildings having a wide variation in their structural properties within the practical range. It has been further concluded that this network is useful in planning/ initial stage when a number of sequential analysis trials are required to be made to arrive at the optimum size of the members.

Mukherjee (1997) developed a self-organizing neural network for identification of natural modes of multi-story buildings. When measured responded data is continuously changing, it will affect the dynamic behaviour of the structure. In such conditions the developed network is useful for the solution of inverse problem to refine the dynamic analysis. This network is of self-organizing type using an unsupervised learning algorithm. This developed neural network is highly noise tolerant which is desirable when site measured data is used. The developed network is also able to identify the natural modes of any multi-storied building frame from even noisy modal amplitude data.

Waszczyszyn and Ziemianski (2001) developed neural networks for various applications in structural engineering. In one of the application, the bending analysis of elasto-plastic beams was carried out by using hybrid neural network. In this application, a developed neural network was used with Finite Difference Method, FDM equations (Waszczyszyn et al. 1994). The desired neural network was trained using Resilient Propagation, Rprop learning algorithm. This hybrid simulation had given practically the same results as obtained from purely numerically program of FDM equations.

In the other application, neural network was used with the elasto-plastic constitutive equations of the Finite Element Method (Waszczyszyn et al. 1994). This hybrid application was used for the analysis of elasto-plastic plane stress problem. The desired neural network was trained by Resilient Propagation, learning algorithm and the efficiency of this network was examined on large patterns selected randomly. In the both hybrid applications, it was observed that the neural network is numerically efficient to analyse the various structural engineering problems with the use of constitutive equations available in the literature.

Maru et al. (2004) presented feasibility analysis of a neural network for the evaluation of creep and shrinkage effects in tall buildings. In this application, the neural network model has been developed, to simulate the creep and shrinkage deflections of a recently developed complex procedure, Consistent Procedure, CP from the results of available simplified procedure for a class of reinforced concrete frames. Sensitivity analysis has been carried out to determine the probable governing parameters that affect creep and shrinkage behaviour of tall buildings. Using these parameters neural network has been developed for six input parameters (stress factor, stiffness factor, no. of storeys, percentage of reinforcement in columns, normalized height of a floor and position of column) and one output parameter (creep and shrinkage deflection ratio).

Multi-layer feed forward network was trained for the training of input patterns and the corresponding training output patterns generated for a class of framed buildings covering the practical range of structural parameters. The training was carried out using back propagation algorithm. Trained neural networks were validated with a number of example buildings with a wide variation of governing structural parameters. It has been shown that the neural network model is feasible to apply for rapid estimation of creep and shrinkage deflections of complex procedure, CP from the results of available simplified procedure. This model would be of significant use at the planning stage. Further, it has been suggested in this study that this neural network model needs to be developed for the frames incorporating shear walls.

Pendarkar et al. (2007) developed a neural network model for continuous composite beams to predict the inelastic moments, due to creep and shrinkage in concrete, from the elastic moments (neglecting instantaneous cracking and time effects). This developed network enables rapid estimation of inelastic moments and requires a computational effort which is a fraction of that required for the method available in the literature. This developed neural network predicts inelastic moment ratio (ratio of elastic moment/inelastic moment) at typically 20 years due to instantaneous cracking and time effects.

Sensitivity analysis has been carried out to determine the probable governing parameters. Using these parameters neural network has been developed for eight input parameters (age of loading, stiffness ratio of adjacent spans, cracking moment ratio at the support, load ratio of adjacent span, composite inertia ratio, cracking moment ratio at left of adjacent support, cracking moment at right of adjacent support, grade of concrete) and one output parameter (inelastic moment ratio). Multilayered feed –forward network with all the layers fully connected in a feed-forward manner was trained for a sufficiently large data base. The training and testing data for the neural network was generated using a hybrid analytical-numerical method of analysis. The trained neural network models have been validated for various example beams with a wide variation of input parameters and the errors were shown to be small for practical purposes. Further, it has been concluded that this methodology can easily be extended for large composite building frames where a very large computational effort is required in the iterative methods available in the literature.

3.2 Structural Design

Mukherjee and Despande (1995) presented the suitability of neural network for modeling an initial design process. The preliminary design model is of vital importance in the synthesis of a finally acceptable solution in a design problem. The design process is extremely difficult to computerise because it requires human intuition. It has often been impossible to form declarative rules to express human intuition and past experience. In this paper, development of a network for initial design of reinforced-concrete rectangular signal span beam has been developed. This network predicts a good initial design for desired output parameters (tensile reinforcement, depth and width of beam, the bending moment capacity and cost per meter) for a given set of input parameters (span, dead load, live load, concrete grade and steel type). Various stage of development and performance evaluation with respect to rate of learning, fault tolerance and generalization has been also discussed.

The back propagation training algorithm was used for training of the network and the performance of the network was evaluated using initialized random values. The neural network developed in this application is capable to generalize and model the initial design process. The robustness of the developed neural network in the form of fault tolerance has also been studied. The performance of the developed neural network has been also evaluated for the limits as expected in a new problem and it has been shown that the developed neural network is simple to simulate and needs no expensive programming.

Tashakori and Adeli (2002) developed a neural network for optimum design of cold-formed steel space frames. This neural network consists of Neural Dynamics Model and Counter Propagation Network, CPN. Neural Dynamics Model (Adeli & Park 1998) has been earlier developed and patented to solve non-linear optimization problem. Counter Propagation Network has been developed in this work to learn the relationship between the cross-sectional area and dimensions of channels. It has been shown that the Counter Propagation Network can self organize a near optimal mapping approximations to a set of input-output data.

Properties of different stiffened channel sections as used in commercial space trusses, were used to train the CPN network. This developed network has been applied to determine the minimum weight design for several space trusses used as roof structure in long span commercial buildings. These real space trusses were consisting of channel section of cold formed sections and were designed for the combination of dead load and snow load.

Accuracy of the trained CPN network was tested for the additional stiffened channel sections. The optimization model presented in this study not only results in substantial saving in the weight of the structure but also can be used to achieve minimum cost design by a simple comparison of the costs of minimum weight solution. It has been shown that developed neural network shows excellent convergence and stability characteristics without any oscillations normally found in such a complex optimization problem.

Hadi (2003) developed two neural networks for the design of steel fibreous reinforced concrete beams in accordance with Australian standard for concrete structures (AS 3600:1994). The first neural network was developed for optimum design of simply supported concrete beams. In this application five input parameters (applied moment, concrete strength, yield strength of steel reinforcement, beam width and maximum depth of beam) and four design output parameters (optimum steel ratio, optimum area of reinforcement, optimum effective depth and optimum unit cost of beam) were considered. This multi-layer network was trained for large number of training samples using Levenrg-Marquardt back propagation algorithm. The network was tested for sufficient number of samples and the average error obtained was low.

The second neural network was developed to minimize tensile reinforcement, shear reinforcement, depth and total cost of the beam. This network was developed for fourteen input parameters (applied moment, applied shear, concrete strength, yield strength of steel reinforcement, initial guessed area of tensile reinforcement, length of steel fibre, diameter of steel fibre, percentage by volume of steel fibre to concrete, minimum depth of beams, maximum depth of beams, minimum width of beams, maximum width of beams, maximum reinforcing index and minimum reinforcing index) and six output parameters (optimal area of tensile reinforcement, optimal width of beam, optimal depth of beam, optimal spacing of stirrups, ultimate flexure strength of beam and total cost of beam). Training of this multi-layer network was also done using Levenrg-Marquardt back propagation algorithm. The average error for the testing patterns was low.

It was observed in this study that the both types of neural network found to be superior to existing conventional methods. Further, it was found that these neural networks reduce the overall time required for implementation by a significant amount as compared to the existing conventional methods.

Cladera and Mari (2004a; 2004b) developed neural networks to formulate simple expressions for the design of high strength and normal strength reinforced concrete beams from the large amount of information available in the literature. Using the developed neural network, expressions were proposed for beams without shear reinforcement (2004a) and with shear reinforcement (2004b). These simple expressions for beams without and with shear reinforcement take account of more complex models which had been shown to give very good correlation with empirical tests.

In first part (2004a) neural network for high strength & normal strength beam without web reinforcement was developed for five input parameters (effective depth, web slenderness factor, shear span/depth ratio, longitudinal steel and concrete compressive strength) and one output parameter (failure shear strength). This multi-layered network has been trained for large experimental test beam data. It has been reported that final developed network shown a satisfactory generalization with the validating data.

The trained neural network has been applied to carry out numerical studies for various parameters which influence the failure shear strength. Using these numerical studies, two shear design methods namely, a general and a simplified procedure have been proposed for the beams without web reinforcement. The general procedure was derived taking into account an expression of the size effect whereas the simplified procedure was derived by simplifying the size effect term. These proposed procedures take into account shear procedure of MC-90 (CEB/FIP 1995). These proposed procedures are compared with the large data base (ACI 318, MC-90, EC2, AASHTO LRFD). Good correlation has been observed with the data base of the members without web reinforcement.

In second part (2004 b), neural network for high strength and normal strength beam with web reinforcement was proposed for six input parameters (effective depth, web slenderness factor, shear span/depth ratio, longitudinal steel, concrete compressive strength and transverse reinforcement) and one output parameter (failure shear strength). This multi-layer network has been trained for large experimental test beam data. It has been reported that final developed network had shown a satisfactory generalization with the validating data.

The trained neural network has been used to carry out numerical studies for various parameters which influence the failure shear strength. Utilizing these numerical studies, two shear design methods namely, a general and a simplified procedure have been proposed for the beams with web reinforcement. The general procedure was derived taking into account the interaction between bending moment and shear whereas in simplified procedure; expressions were obtained independently of bending moment. These proposed methods are compared with the wide data base (ACI 318, EC2). It has been shown that the proposed procedures represented an improvement over performance of EC2 (2002) and ACI 318 (2002) procedures.

4 CONCLUDING REMARKS

Neural network is a computer model whose architecture mimics the knowledge acquisition and organisational skills of the human brain. These networks offer an ability to perform tasks outside the scope of traditional processors and are one of the promises for future computing. These can recognize patterns within vast data sets and are able to generalize the patterns into recommended courses of action. One of the significant advantages of neural networks is that they can simulate any problem easily and need no complex and expensive programming.

Neural networks have been applied to diverse problems of structural engineering in recent years. These applications of neural networks have shown their capability and advantage for the solution of various problems. Salient observations noted from the applications of the neural networks in structural analysis and design are:

a. Neural networks are powerful as these can process information more readily than traditional computer systems. They are also able to process to information when the input data is either incomplete or noisy. The true power and advantage of neural networks lies in their ability to represent, both linear and non-linear relationships.

b. The various applications of neural network shows that the neural network suit well to the processing of experimental data taken from the both, tests on laboratory specimens and measurements on real structures. In these applications, neural networks have shown there ability to capture and represent the complex input/output relationships.

c. It is also observed that neural network reduce the computational time required for the implementation by a significant amount as compared to the existing conventional methods.

d. The neural network has been efficiently used to solve problems of the structural analysis. It was found no complex and expensive programming is needed for the analysis. In these applications the capability of the neural network has been proved for the solution of the varied problems and this modelling technique provides a much efficient and accurate method as compared to the conventional methods.

e. The neural network application for optimal design problems shows excellent convergence and stability characteristics without oscillation normally found in such complex problems of optimization. It is further observed that neural networks have been shown to be powerful tool for design problems provided that sufficient and representative numbers of test results are used for the training and validating of the neural network.

f. The hybrid applications for design and analysis show that the neural networks can be efficiently applied to the implementation of programs in which the neural procedures are used instead of numerical procedure.

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