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IFAC-PapersOnLine 49-1 (2016) 095–099

ANN based methodology for active control of buildings for seismic excitation for different seismic zones of India

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Abstract: In the last two decades, many studies are reported in literature for determining the control force for the active control systems for damage mitigation of buildings due to earthquake. However, no study has been reported for prediction of control force considering the seismic zones in India. In the present study, spectrum compatible time histories are generated for the seismic zones IV and V as per Indian standard IS 1893(Part 1):2002 design spectrum. Time history analysis are carried out with spectrum compatible time histories for shear type buildings modelled as multi-degree of freedom system (MDOF) with a computer program developed in MATLAB by modal superposition using Newmark-beta method. Control forces are obtained by adopting algorithm proposed in literature and input and output patterns are generated for development of Artificial Neural Network (ANN) models in Stuttgart Neural Network Simulator (SNNS). In the present study the methodology is demonstrated with five storey building by developing 24 ANN models consisting of two ANN architectures viz., NET1 and NET2 for each seismic zone and three soil types. From the validation of results from ANN models it is observed that the maximum difference in percentage response reduction of peak displacement is less than 10% when it is compared with the target value of percentage response reduction.

Keywords: ANN, Active Control, Seismic Zones, Stochastic GM generation, Earthquake, Building.

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1. INTRODUCTION

Various semi-active and active control strategies are adopted for vibration control of civil engineering structures (Chu et al. (2005)). Recently, efforts are made to develop the structural control concept into a workable technology and full-scale implementation in several structures. Many semi-active and active control systems are implemented in buildings in Japan (Nishitani (1998)). Research studies are being carried out on various active control algorithms viz., optimal control, independent modal space control, neural network based control, pole assignment technique and bounded state control as seen in state of the art reports (Fisco and Adeli (2011), Datta (2003), Housner et al. (1997)). Numerous applications of Artificial Neural Network (ANN) for structural Control are reported in literature (Bani-Hani and Ghaboussi (1998), Ghaboussi and Joghataie (1995), Liut et al. (1999), Tang (1996), Rao and Datta, 2006).

Bani-Hani and Ghaboussi (1998) used a neural network-based controller trained using the emulator for linear control of the structure. In ANN model proposed by Bani-Hani and Ghaboussi (1998) structural displacement and acceleration responses of previous two time steps and actuator electric signals of previous three time steps are used as inputs to the neural network model. Tang (1996) used displacement and velocity of preceding time step, and the displacement and velocity of current time step as inputs for neural network model. Rao and Datta (2006) have developed a procedure for active control of structures using two sets of neural networks for general stochastic simulations of earthquake based on Kanai Tajmi power spectral density function. From the limited literature review made, it is observed that, no study has been reported for prediction of control force considering the seismic zones and soil types of India.

In the present study, control algorithm proposed by Rao and Datta (2006) is adopted and two sets of neural networks NET1, NET2 are developed for seismic zones IV and V and three soil types of India with spectrum compatible time histories developed using SHAKE2000 (Ordonez (2000), Jennings et al. (1968)). Studies reported in this paper are carried out using the computer program developed in MATLAB which uses generalized mode shape for response evaluation (Clough and Penzien (1993)).

2. CONTROL ALGORITHM

In the present study, the control algorithm proposed by Rao and Datta (2006) is adopted for determination of control force. It should be noted that, the response of a building is directly dependent upon the magnitude and epicentre distance of the earthquake. The force that a building will experience is dependent upon the mass of the building and acceleration

Peer review under responsibility of International Federation of Automatic Control.
10.1016/j.ifacol.2016.03.035

experienced at it. The earthquake design philosophy of a building is based upon the peak ground acceleration which is classified as per different seismic zones in Indian code (IS 1893(Part 1): 2002) taking into account the maximum considered earthquake for that region. Therefore, a control technique, based upon the seismic zone and utilising force matching principle, can reduce the damage of buildings taken for consideration. The control algorithm proposed by Rao and Datta (2006) based on force matching technique utilizing modal contribution of prominent modes, is suitable for extending into seismic zones. In the present study one horizontal dynamic degrees of freedom is only considered representing shear type buildings with symmetrically constructed story units. Further one horizontal component of the earthquake is only considered. However the methodology proposed can be extended to asymmetric buildings and other components of earthquake as well.

For the development of generalized control scheme for MDOF structure, response feedbacks are utilized along with target percentage reduction and position of control force to get modal contributions for controlled response (equations (1-8); Rao and Datta (2006)). The control technique utilises the principle of modal superposition of structural acceleration of the structure. The structural acceleration of the structure can be determined from superposition of its modal acceleration components (equation 1). Moreover, as controlled modal accelerations are related to control force (equation 2, 5, 7 and 8); it is used for training of neural nets. The control force is applied at top and is determined from modal contributions from first three modes, which in turn are determined from uncontrolled modal accelerations based upon a target percentage reduction. It is assumed that the major contribution to control force is from first mode shape of the building having a target percentage reduction (equation 5). Therefore, the modal contribution of first mode for control force is determined from equation-6. The contributions to control force from the second and third mode are obtained from equation 7 and 8. Here, it should be noted that, modal theory is a mathematical supposition and none of its components like contributions from different modes to control force (*$u_1(t)$, $u_2(t)$ and $u_3(t)$*) can be directly measured through sensors. Therefore, a neural network model is developed based upon the realizable quantities whose values are found for various spectrum compatible time histories to develop a neural network architecture for prediction of the building's behaviour pattern. This theory is the basis for training of the neural network architecture having the controlled structural acceleration response as its input and the control force as its output, for a given set of spectrum compatible time histories.

$$\ddot{x}_i \approx \phi_i^1 \ddot{z}_1 + \phi_i^2 \ddot{z}_2 + \phi_i^3 \ddot{z}_3 \tag{1}$$

$$u_{2,3}(t) = k_{2,3} u(t) \tag{2}$$

$$u_2(t) = \frac{k_2}{k_1} u_1(t); u_3(t) = \frac{k_3}{k_1} u_1(t) \tag{3}$$

$$k_j = \frac{\phi_j^T R}{\phi_j^T M \phi_j} \tag{4}$$

$$\ddot{z}_1 = (1-p)\ddot{\bar{z}}_1 \tag{5}$$

$$u_1(t) = -\rho_1 \ddot{x}_g - (1-p)[\ddot{z}_1 + 2\eta\omega_1 \dot{\bar{z}}_1 + \omega_1^2 \bar{z}_1] \tag{6}$$

$$\ddot{z}_2 = -\rho_2 \ddot{x}_g - (1-p)[2\eta\omega_2 \dot{\bar{z}}_2 + \omega_2^2 \bar{z}_2] - u_2(t) \tag{7}$$

$$\ddot{z}_3 = -\rho_3 \ddot{x}_g - (1-p)[2\eta\omega_3 \dot{\bar{z}}_3 + \omega_3^2 \bar{z}_3] - u_3(t) \tag{8}$$

where, $\ddot{x}_i (i = 1,2,3,4,5)$ is the acceleration response of the structure at the i^{th}story of the building; $\phi_i{}^j (j = 1,2,3)$ is the mode shape coefficients for i^{th} story; and j^{th} mode; $\ddot{z}_j (j = 1,2,3)$ modal acceleration contributions to the control force; $u_j(t) (j = 1,2,3)$ are the modal contribution towards a single control force; $u(t)$ is the control force; R is the location vector; p is the target percentage reduction; $\ddot{\bar{z}}_1$ is the uncontrolled modal acceleration; ρ_2 & ρ_3 are the modal participation factors for 2nd and 3rd mode; η is the damping ratio; ω_2 & ω_3 are the natural frequencies of the building in 2nd and 3rd mode; $\dot{\bar{z}}_2$ & $\dot{\bar{z}}_3$ are the uncontrolled velocity in 2nd and 3rd mode and $\bar{z}_2$ & $\bar{z}_3$ are the uncontrolled displacement in 2nd and 3rd mode respectively.

3. MATHEMATICAL MODEL OF STRUCTURE

In order to demonstrate the application of control algorithm a five-story shear type building with identically constructed story units is considered for training and testing of the ANN as shown in the Fig. 1. The lumped mass concentrated on each story is taken as 150 x 10^3 kg. The elastic stiffness and the structural damping ratio are taken as 200x10^6 N/m and 0.02 respectively. For calculating dynamic response of the MDOF structure, the step-by-step integration procedure of differential equations as proposed by Newmark is adopted (Chopra (2012), Clough and Penzien (1993)) in the computer program. A target percentage reduction of 50% is considered in the present study.

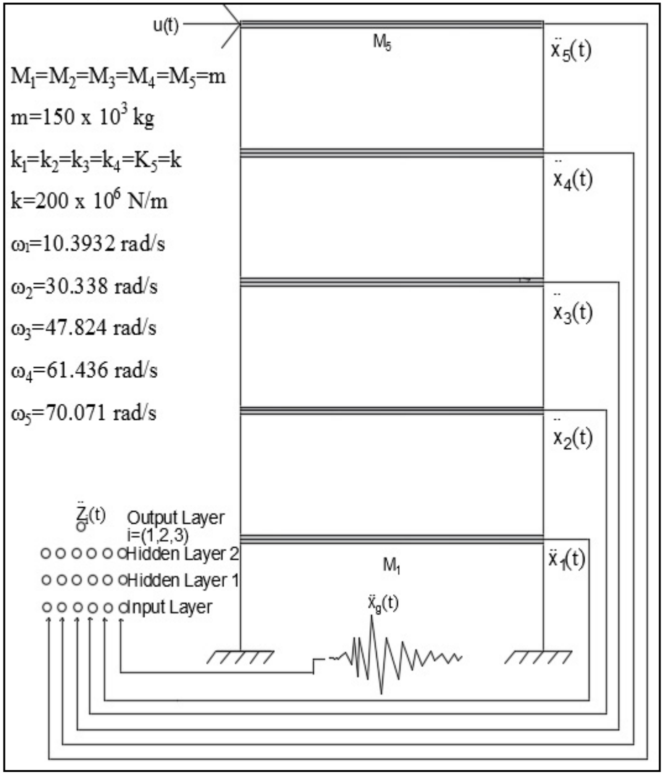

Fig. 1. Model of a five storey frame

For generation of dataset for training of neural networks, the five storey frame is analyzed using spectrum compatible ground motion accelerations obtained consistent with response spectrum of three soil types viz., rock, medium soil, soft soil and seismic zones IV and V as per Indian standard (IS 1893(Part 1): 2002) using SHAKE2000 computer program. For each response spectra eleven acceleration time histories are generated with 3002 sampling points at an interval of 0.01s out of which results for 10 simulations of earthquake are used for training and result for one simulation is used for testing of the neural networks developed.

4. NEURAL NETWORK MODELS

As it is described earlier, the **i**nputs for NET1 are acceleration feedback measurement time histories at each story, input acceleration and the output is the modal contribution acceleration time history for the first three modes for calculation of control force. From the studies made with modal superposition of five and three modes, it is seen that inclusion of three modes results in better accuracy in the prediction of control force time history. Further, mass participation of 98.4% is achieved while considering the modal superposition of first three modes. Hence three subnets NET11, NET12, NET13 are developed to predict the modal contribution of first three modes. For the second network NET2, modal acceleration time history contributions from first three modes, and the input excitation (spectrum compatible acceleration time history) are the inputs and the control force time history is the output. A systematic model of the methodology is presented in Fig. 2.

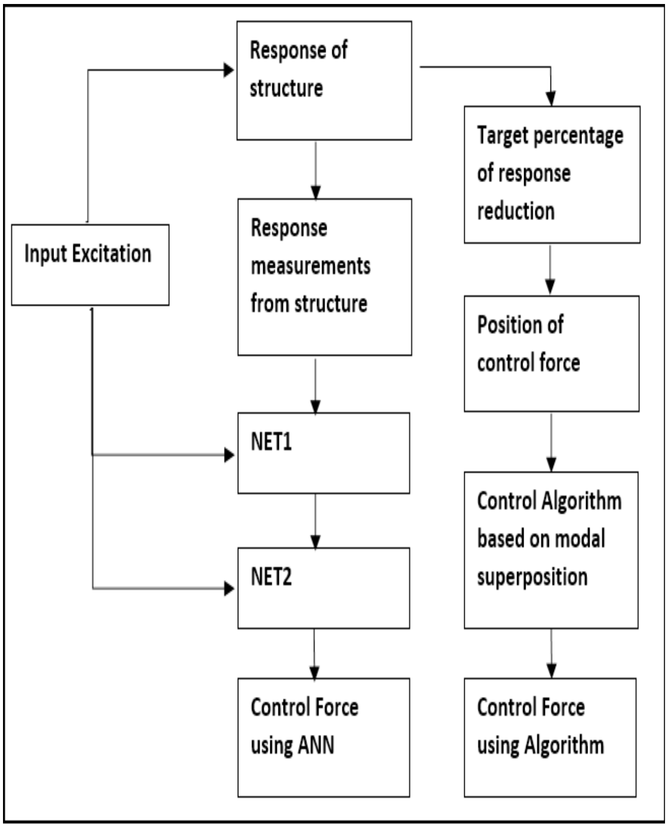

Fig. 2. Methodology for active control of buildings for seismic excitation

All the subnets in NET1 have 6 neurons in the input layer and one neuron in the output layer and NET2 has 4 neurons in the input layer and one neuron in the output layer. Number of neurons in the hidden layer for the network models are given in Table 1. Typical network architecture for the NET1 (subnets) and NET2 are shown in Fig. 3. In the present study a total of 24 neural network models are developed as given in Fig. 4 for the different seismic zones and soil types considered.

In the present study, Stuttgart Neural Network Simulator SNNS (Zell et al. (1989)) has been used for development of neural network models. The inputs to the neural network are combined linearly and feeding the neural nets will raw values will not work very well. Therefore, normalization of the input dataset in the interval of [0, 1] is preferred. In this study, we have normalized the input dataset, according to Maximum-minimum normalization principle utilizing input variables. A Multilayer fully connected feed-forward neural net architecture with logistic activation function, Backprop Momentum learning function and Topological_order update function, are used for training. The learning rate and update parameter for different network models are given in Table 2.

Table 1. Number of neurons in the hidden layer for ANN models

Seismic Zone	Soil Type	Number of nodes in Hidden Layers (1 and 2)							
		NET11		NET12		NET13		NET2	
		1	2	1	2	1	2	1	2
Zone 5	Soft	6	6	6	6	6	6	9	-
	Medium	6	6	6	6	6	6	4	4
	Rock	6	6	6	6	6	6	9	-
Zone 4	Soft	9	-	9	-	9	-	9	-
	Medium	6	6	6	6	6	6	4	4
	Rock	6	6	6	6	6	6	9	-

Table 2. Learning parameters for ANN models

Seismic Zone	Soil Type	Neural Network Configuration for Subnets (NET11, NET12, NET13) and NET2			
		Learning rate		Update Parameter	
		NET11 NET12 NET13	NET2	NET11 NET12 NET13	NET2
Zone 5	Soft	0.01	0.0001	0	0.001
	Medium	0.01	0.01	0	0
	Rock	0.01	0.0001	0	0.001
Zone 4	Soft	0.0001	0.0001	0.001	0.001
	Medium	0.01	0.01	0	0
	Rock	0.01	0.0001	0	0.001

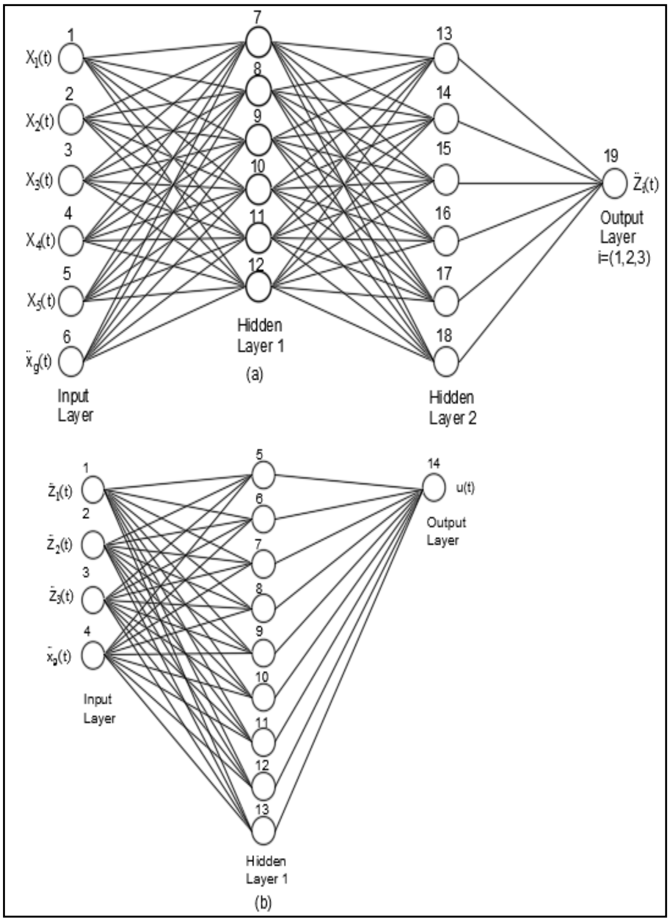

Fig. 3. Architecture of ANN models (a) NET11, NET12, NET13 and (b) NET2

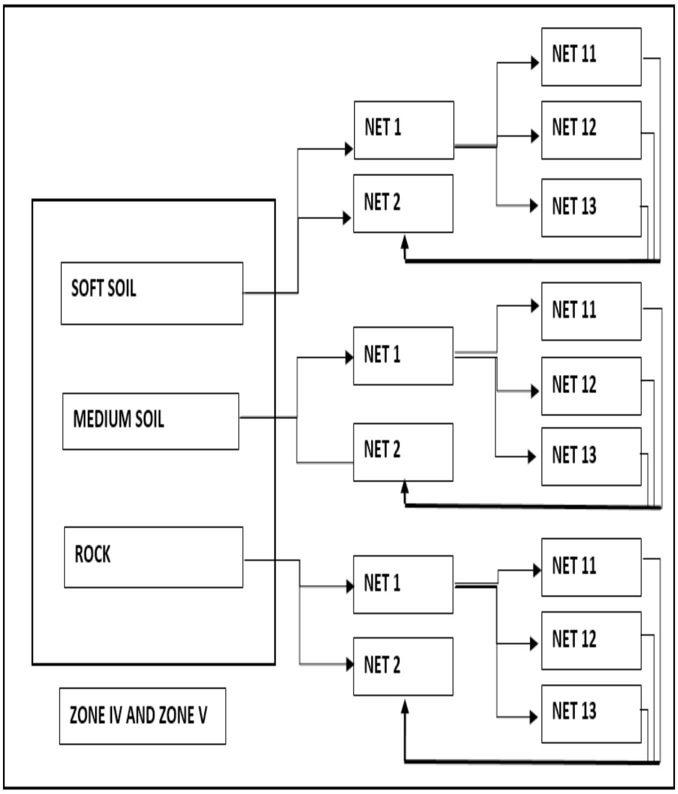

Fig. 4. A schematic view of the ANN models developed for seismic zone IV &V in the present study

5. TESTING OF NEURAL NETWORK

For testing the neural network, the building frame is analyzed for one simulation of spectrum compatible accelerogram which has not been used in training. Maximum percentage errors of results from ANN models with respect to algorithm based detailed analysis for the test pattern are given in Table 3. The percentage reduction in the peak response displacement obtained from ANN model for a typical input is given Table 4. It is observed that maximum difference in peak displacement of the controlled and uncontrolled building is less than 10% when it is compared with the target response reduction percentage.

Table 3. Maximum percentage error of results from ANN models with respect to algorithm based detailed analysis

Seismic Zone	Soil Type	Maximum error			
		NET11	NET12	NET13	NET2
Zone 5	Soft	30.816	8.803	7.479	31.779
	Medium	13.959	9.1	8.251	33.05
	Rock	31.13	13.86	13.59	17
Zone 4	Soft	12.424	15.095	11.51	3.71
	Medium	10.533	12.418	10.185	19.999
	Rock	4.171	7.708	5.802	18.85

Table 4. Percentage reduction in the story displacement

Story Level	Percentage Reduction
1st story	43
2nd story	45
3rd story	49
4th story	53
5th story	56

6. CONCLUSIONS

In this paper, an ANN based methodology for active control of buildings for earthquake excitation is demonstrated for different seismic zones and soil types of India. Input and output patterns are generated from time history analysis results with spectrum compatible time histories for shear type buildings using a computer program developed in MATLAB by modal superposition using Newmark-beta method. Inputs for NET1 are acceleration feedback measurement time histories at each floor, input acceleration and the output is acceleration contribution time history from each mode for calculation of control force. The inputs for NET2 are the modal acceleration time history contributions from first three modes and the spectrum compatible acceleration time history and the output from NET2 is the control force time history. Twenty-four ANN models are developed and tested. Methodology demonstrated can be extended for any building and any location wherever the relevant information is available.

ACKNOWLEDGEMENTS

The authors acknowledge The Director and Advisor [Management], CSIR-Structural Engineering Research Centre, Chennai, for granting permission to carry out the studies reported in this paper at CSIR-SERC. The support extended by Dr. K. Balaji Rao, Chief Scientist and Head Risk and Reliability of Structures, Dr. N. Gopalakrishnan, Chief Scientist and Head, ASTAR lab and Dr. M. B. Anoop, Pr. Scientist, Risk and Reliability of Structures is highly acknowledged.

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