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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.

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

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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.

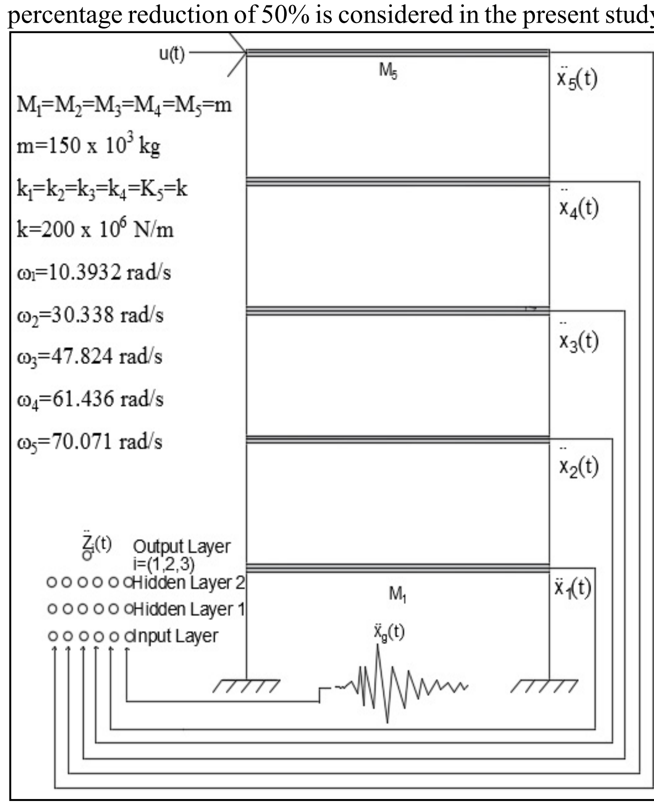

Fig. 1. Model of a five storey frame