ACTIVE CONTROL ALGORITHM BASED ON FUZZY METHOD FOR HIGHWAY BRIDGE

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1. DESCRIPTION

Control algorithms can affect the performance and cost-effectiveness of a structure's control system. This study presents an active neuro-fuzzy optimized control algorithm based on a new optimization method extracted from Tug of War competition, which is highly efficient for civil structures. The performance of the proposed control method has been evaluated on the finite element model of nonlinear highway benchmark bridge. It is consisted of nonlinear structural elements and isolation bearings equipped with the hydraulic actuators.

1.1. Benchmark Highway Bridge

A schematic of the benchmark structure considered in this study is shown in Figure 1 (Agrawal et al., 2009). The bridge structure is modeled after the newly constructed 91/5 (m) over-crossing in Orange County, Southern California. This bridge is of pre-stressed concrete, box-girder type. Readers are referred to the definition paper (Tan and Agrawal, 2009; Agrawal et al., 2009) for a detailed description of the structure.
The equations of motion (assumed for controller development only) for this system, in both the orthogonal directions, can be written as:

$$M\,\Delta\ddot{U}(t) + C\Delta\dot{U}(t) + K(t)\Delta U(t) = M\,\eta\Delta\ddot{U}_g(t) + b\Delta F(t) \tag{1}$$

where ΔU is the incremental displacement vector; is the vector of ground accelerations, including two horizontal components; and $\Delta F(t)$ is the incremental control force. In Equation 1, η and b are loading vector for the ground acceleration and control forces, respectively and M is the mass matrix. The stiffness matrix of the structure, $K(t)$, consists of the linear part and nonlinear part (t) .

1.2. Optimization Method

Tug of war is a strength contest in the rope pulling. Two competing teams are in an attempt to pull a rope to bring it to their own side. Naturally, the amount of the losing team displacement determines the amount of rope displacement. A tug of war tournament is shown in Figure 2.

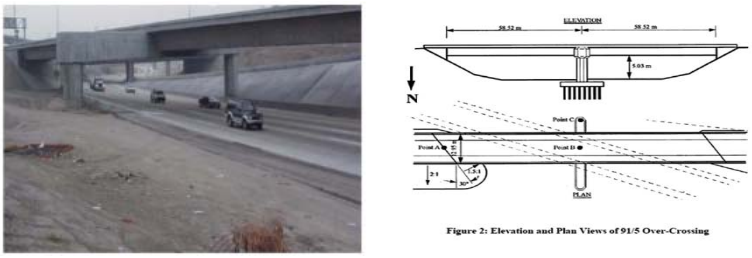

Figure 1. Elevation and plan views of 91/5 over-crossing (Agrawal et al., 2009).

Figure 2. Tug of war tournament.

1.3. Objective functions

In order to design and optimize the proposed active control algorithm, a single-objective optimization process is performed. Since the goal of the control system is to improve the seismic responses of the bridge with the priority of the base shear, and given the impact of the bridge acceleration on its base shear, the output of the fitness function must be the maximum base shear of the bridge or its maximum acceleration.

1.4. Proposed Control Algorithm

The proposed active control algorithm is a neuro-fuzzy adaptive controller that its output functions parameters are optimized by the tug of war optimization method. The active tug of war-fuzzy optimized (ATF) controller consists of two internal optimized ANFIS controllers; one for controlling the seismic behavior of the bridge under far-field earthquakes and the other for controlling the seismic behavior of the bridge under near-field earthquakes.

1.5. Optimization of ANFIS Controllers

The result functions in ANFIS are zero or first-order functions. In this paper linear result functions are used in the ANFIS controller as Equation 2:

$$f_i = p_i x + q_i y + r_i \quad , \quad i = 1,2,\ldots,36 \tag{2}$$

where x is the first network input (normalized acceleration), and y is the second input (normalized displacement). p, q, and r are parameters of i^{th} result function. These parameters are teams in the presented optimization algorithm. Therefore, the number of input parameters to the optimization algorithm for the controller adjustment is 108.

1.6. Results

The proposed algorithm reduced the bridge peak base shear, overturning moment, mid-span displacement, mid-span acceleration, normed base shear and normed mid-span acceleration under various earthquakes up to 35%. Among these, the mid-span acceleration index (J4) had the lowest reduction (15%).

The peak bearing deformation, ductility, normed overturning moment, normed mid-span displacement, normed bearing deformation, and normed ductility indices decreased by 40 to 60%, during the optimized control process. Among these, the normed bearing deformation index (J13) showed the largest decrease (60%).

Since the parameters such as curvature created in columns, energy absorbed by nonlinear behavior and hysteresis loops and the number of plastic joints directly affect the structural damage; therefore, the criteria containing these parameters will be appropriate to measure the structural damage. Thus, the indices J6, J7, J8 can indicate the potential for structural damage to the bridge.

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