ELASTOMERIC BEARING'S NONLINEAR PARAMETER IDENTIFICATION USING ARTIFICIAL NEURAL NETWORK

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1. INTRODUCTION

HDR-S bearing is used to drastically improve the performance of existing bridges due to its high damping capacity. Recent studies about the nonlinear behavior of HDR-S bearings shows that it was significantly influenced by the change in temperature, Mullin's effect, deterioration, etc. Thus, more and more sophisticated nonlinear models were proposed to understand those behaviors, which makes the nonlinear model and parameter identification complicated and highly dependent on engineer's knowledge and experience. Parameter identification using optimization methods like curve fitting, KH method, Newton's method, requires an initial value assumption. The selection for initial value highly influences the stability of the process and convergence of the parameters, which requires engineer's knowledge and experience specially for newly developed seismic isolators. Therefore, this study proposed a machine learning based approach to identify the nonlinear parameters of a High Damping Rubber (HDR-S) bearing. Due to experiment data limitation, the training data for ANN was generated using numerical simulation of Modified Bouc-Wen (MBW) model and a pre-defined shear strain. The hysteresis of the ANN suggested nonlinear parameters using MBW model were plotted and compared to HDR-S quasi- static loading data. In addition to that, the ANN nonlinear parameters were used in a hypothetical 3-span bridge with 8 pier's time history analysis and the bearing's hysteresis result was compared to the hybrid simulation experiment data. The ANN suggested parameters serve as an input for other optimization method like KH method which reduces the iteration time for convergence.

2. MODIFIED BOUC-WEN MODEL

Modified Bouc-Wen (MBW) model includes stiffness degradation, pinching, hardening, and softening. The formulas were shown in Eq. 1 and Eq. 2, where F is the restoring force, x is the displacement, k is the coefficient of stiffness, α is the ratio of initial to post yield stiffness. β and γ represents the hardening and softening, and b is for pinching effect. Parameter z is the plastic component.

$$F = \alpha k x + (1-\alpha)k(1+bx^2)z \quad (1)$$

$$\dot{z} = A\dot{x} - \beta|\dot{x}\, z|z - \gamma\dot{x}z^2 \text{ , (A=1)} \quad (2)$$

3. ANN NONLINEAR PARAMETER IDENTIFICATION

A two-layer ANN model as shown in Fig. 1, was trained for the HDR-S nonlinear parameter identification. The input data consist of a pair of 60 shear strain and 60 shear stress. The output are five key parameters of Modified Bouc-Wen (MBW) model. The activation function was ReLU and the optimizer was Adam with learning rate of 0.001. After 200 epochs, the training loss was 0.047 and the validation loss was 0.134.

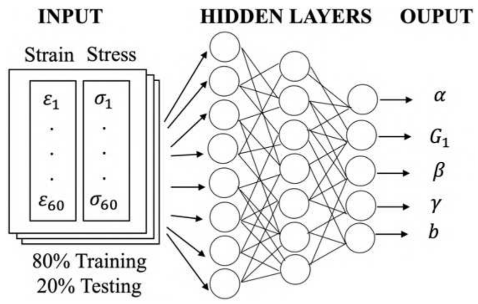

Figure 1. ANN Architecture

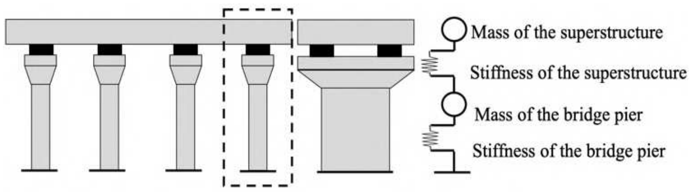

Figure 2. Bridge 2-DOF Model for Hybrid Simulation

Keywords: Modified Bouc-Wen Model, Machine Learning, HDR-S, Nonlinear, Hybrid Simulation
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4. COMPARISON TO HDR-S EXPERIMENT DATA

The suggested ANN parameters were numerically simulated under Modified Bouc-Wen (MBW) model to produce a hysteresis curve and it was compared to HDR-S quasi-static loading data as shown in Fig. 3. The suggested parameters were also used as an initial input for other optimization method like KH method, Kuroda (2001). On the other hand, the ANN suggested HDR-S nonlinear parameters were used for time-history analysis of a hypothetical 3-span bridge and the nonlinear response of the seismic isolator was plotted and compared to the hybrid simulation experiment data as shown in Fig. 4. A significant difference can be observed at low temperature to both HDR-S quasi-static data and hybrid simulation.

5. CONCLUSION

The proposed machine learning based approach successfully suggested five nonlinear parameters of an HDR-S quasi-static loading data with limitation of Modified Bouc-Wen (MBW) model. After the ANN model learned from a large amount of simulated MBW hysteresis curve with corresponding five parameters, it can be used to predict the nonlinear parameters of HDR-S quasi-static data or any other elastomeric quasi-static loading data. The plotted hysteresis curve using the suggested parameters had a good fit at HDR-S quasi-static loading data under ambient temperature (23°C) but had a significant difference under low temperature (-20°C). The same pattern was observed during the hybrid simulation comparison. Mullins and temperature effect can be clearly observed from the HDR-S quasi-static experiment data, but these were not included in the parameters of MBW model, therefore a more complicated nonlinear model was needed. This study will consider more nonlinear models and used the proposed machine learning based approach.

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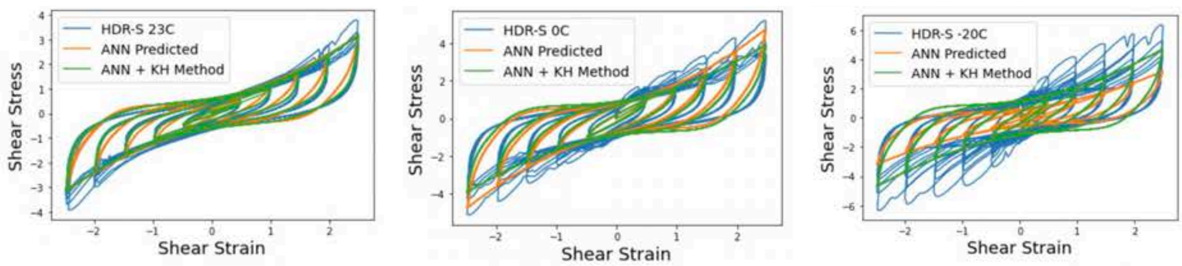
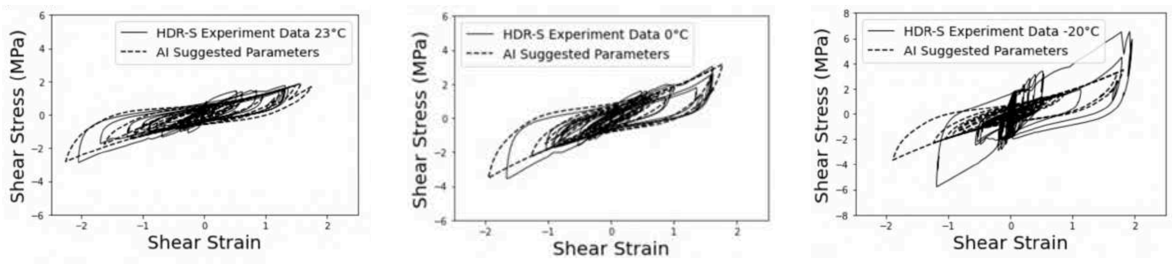


(a) 23°C b) 0°C (c) -20°C

Figure 3. HDR-S Quasi-Static Loading Comparison Result



(a) 23°C (b) 0°C (c) -20°C

Figure 4. Hybrid Simulation Comparison Result