Artificial Neural Network Aided Prediction of Frame Displacements under Seismic Load

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Abstract. The paper explored the usefulness of Artificial neural network (ANN) in predicting the frame displacements under seismic load. The acceleration that is relatively easy to measure is used as the input value and the displacements that can be used to intuitively judge the condition of structures is used as the output value. The methodology utilized the universal function approximation ability of ANN for defining the relations between two data. For training of ANN, learning data consisting of acceleration and displacements are calculated from a verified finite element model under various seismic loads. The performance of the trained ANN was evaluated by comparing the displacements from ANN and FEM for seismic loads not used for training. The study showed that the ANN trained by various seismic loads can predicts the displacements from the acceleration for the new seismic loads. The trained ANN can be used for predicting the displacements of various buildings exposed to seismic loads in real time.

1. Introduction
Among the dynamic response of the structure, the dynamic displacement is closely related to the magnitude of the damage of structure under ultimate load. Also, it is very important to know displacement history of structure since it is a long-term history of the factors that represent the overall behavior [1-2]. It can be used intuitively not only to predict the load applied to structure [3] but also to evaluate the state of the structure. Continuously measuring the displacement of the structure provides important basis for determining the degree of structural degradation and deterioration [4]. However, it is not easy to measure the displacements of the structures in the field due to various reasons such as location, expense etc.

In this study, we proposed the method to predict displacement using artificial neural network (ann) to overcome the difficulty of displacement measurement. As the input value of the artificial neural network, the acceleration which is relatively easy to measure is used and the horizontal displacement is used as the output value. The frame structure for displacement prediction was used. The load used for displacement prediction is the seismic load, which can cause serious damage to the structure in a short time. If we can predict the displacement using artificial neural network, we can predict the behavior of the real-time structure against the vibration of the ground. Also, when designing a building, it is thought that it can help to reduce the structural analysis work which requires much time and effort.
2. Methodology
In this section, we describe the method used to predict the horizontal displacement of the frame structure. For conducting the study, a commercially available MATLAB R2017b was used.

2.1 Data collection
In order to predict horizontal displacement of frame using artificial neural network (ANN), learning data is needed. As mentioned in the previous section, the input value of the artificial neural network is set as horizontal acceleration and the output value is set as horizontal displacement. In this study, finite element model was used to obtain learning data. A frame model was created using the commercial analysis program abaqus/cae 2017 (figure 1). A frame structure with a total length of 6m and a total height of 10m was made. The cross-section of the frame is the H shape and the size of the section is shown in figure 2. The analysis was performed by applying the three seismic loads (kumamoto, tokachi and el centro) shown in figure 3 to the frame structure. From the structural analysis, horizontal acceleration and displacement were obtained. Seismic analysis results under kumamoto and tokachi were used as training data of artificial neural networks. The two seismic loads were applied for 15 seconds with Δt = 0.01s and a total of 3002 training data were obtained for each 1501. Also, results under el centro seismic load, which were not used in the study, were used to verify the predictability of horizontal displacement of the trained artificial neural network. The seismic load was applied for 30 seconds with Δt =0.02 and a total of 1501 verification data were obtained. That is, 3002 data were used for training, and 1501 data were used for verification. Here, the location of the acceleration (input) and the location of the displacement (output) used in the artificial neural network are shown in figure 1. A total of 12 accelerations were used as input values, and a total of 51 displacements were used as output values.

![Figure 1. FE Model.](image1)

![Figure 2. Section of Frame.](image2)

![Figure 3. Ground acceleration records.](image3)
2.2 Neural network architecture and training parameter

Artificial neural networks are computer algorithms that simulate human central nervous system. Artificial neural networks have a very special ability to define the correlation of data in nonlinear relationships [5]. Among the neural network models, the structure of multilayer feedforward neural network (MFNN), which is the most common [6], is shown in figure 4. As shown in figure 4, the MFNN consists of an input layer for inputting data, a hidden layer for computing the input data, and an output layer for finally predicting the desired value. The nodes of each layer are mathematically connected. Weights are assigned between nodes. Also, a bias is assigned to each node of the hidden layer and the output layer. In order to accurately predict the desired value of the artificial neural network, the optimum weight and bias should be determined. This optimal value is obtained through learning.

![Figure 4. Structure of multilayer feedforward neural network(Architecture i-j-k).](image)

The calculation between the input layer and the hidden layer is shown in equation (1).

$$\text{net}_{\text{hidden}_j} = \sum_{i=1} w_{ij} I_i + \theta_j$$  \hspace{1cm} (1)

Where, $I_i$ is the variable input to the $i$th node of the input layer and $w_{ij}$ is the weight assigned between the $i$th node of the input layer and the $j$th node of the hidden layer. $\theta_j$ is the bias assigned to the $j$th node of the hidden layer. $\text{net}_{\text{hidden}_j}$ is the sum of weighted all input variable and bias, which is input to the $j$th node of the hidden layer. The value $\text{net}_{\text{hidden}_j}$ input to the hidden layer derives the function value through the transfer function

$$Z_j = f(\text{net}_{\text{hidden}_j})$$  \hspace{1cm} (2)

Where, $f$ is a transfer function in the hidden layer, $Z_j$ is the output value of the $j$th node of the hidden layer calculated through the transfer function and at the same time, a variable that is input to the output layer. The same process is applied between the hidden layer and the output layer. The value input to the output layer predict the final value (P) through the transfer function of the output layer. An error between the output (predicted) value (P) and the target output (T) of the training data is calculated (feedforward). If the error does not meet the criteria set by the user, the artificial neural network go back to the hidden layer and the input layer and corrects the weight and bias using the training algorithm [7]. The final (predicted) value (P) output through the iterative process reduces the error with the output (T) value of the training data, and stops training if it meets the criteria set by the user. In this
study, two hidden layers were used for prediction accuracy from many trials. Table 1 shows the variables used for the training of artificial neural networks.

**Table 1. General information of the ANN model.**

|                                |       |
|--------------------------------|-------|
| Number of input nodes(=accelerations) | 12    |
| Number of hidden layers        | 2     |
| Number of hidden nodes         | 12(each hidden layer) |
| Number of output nodes(=displacements) | 51    |
| Number of training data        | 3002  |
| Number of testing data         | 1501  |
| Training Algorithm             | Scaled conjugate gradient backpropagation |
| Transfer function              | Logsig(Hidden), Purelin(Output) |
| Learning rate                  | 0.01  |
| Momentum                       | 0.9   |

With the variables in table 1, training of artificial neural networks was performed using matlab. In this study, the process from learning data acquisition to verification of artificial neural network is shown in figure 5.

![Figure 5. Flow of the research.](image-url)
3. Results of verification
Artificial neural networks were trained using data and variables obtained in chapter 2. A total of 3000 iterations were set up. After finishing the training, correlation coefficient (R) was 0.9997 and the mean squared error (MSE) was 1.8838e-06. For the verification of the trained neural network, the horizontal acceleration value derived from fe model under el centro seismic load, which is not used for the training, was inputted to the trained neural network as the input value. We compared the horizontal displacement predicted by the ann and the displacement derived from the fe model. Figure 6 shows the time-dependent displacement at the left top of the frame. As can be seen from figure 6 and 7, it can be seen that the displacements predicted by the trained ann are very similar to the displacements from the fe model. The results show that the displacement at other locations in the frame is also very similar.

![Figure 6](image1.png)

**Figure 6.** Displacement by FEM and ANN at left-top of the frame.

![Figure 7](image2.png)

**Figure 7.** Deformed shape of the frame at Δt=15s.
4. Conclusion
In this paper, we propose a method to predict horizontal displacement of a frame structure under seismic load. Artificial neural network was used for prediction. Acceleration was used as the input value of the ann, and displacement was used as the output value. To overcome the difficulties of obtaining actual field data, learning data was obtained from the fe model. The seismic load was applied to the fe model, and the acceleration and displacement obtained from the analysis were used to train the ann. We confirmed the predictability of displacement from acceleration by using ann. From the study, the following conclusions were drawn.

1. The trained ann can predict the displacement of the structure over time for seismic loads.

2. When training the ann, if the number of input values and output values are set appropriately, the ann can predict not only the displacements at the location of the acceleration used as the input value but also the displacements of other location.

If the ann is trained through data from actual field or verified fe model, the displacements of actual structure can be predicted in real time. Also real-time displacement can be predicted by ann for various structures such as bridges, LNG gas tanks, and various loads.

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