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Effectiveness of ANN for seismic behaviour prediction considering geometric configuration effect in concrete gravity dams☆

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Summary In this study, an Artificial Neural Networks (ANN) model is built and verified for quick estimation of the structural parameter obtained for a concrete gravity dam section due to seismic excitation. The database of numerous inputs and outputs obtained through Abaqus which are further converted into dimensionless forms in the statistical software (MATLAB) to build the ANN model. The developed model can be used for accurate estimation of this parameter. The results showed an excellent capability of the model to predict the outputs with high accuracy and reduced computational time.

Introduction

Like other civil engineering structures concrete gravity dams are one of the important structure in the service of human civilization from centuries. They are generally built for multiple tasks and to serve for decades. Being an important civil engineering structure, it requires proper qualified engineering attention at analysis, design, construction and service stages. However, its behaviour prediction for proper analysis and design is a quite complex subject, which requires extensive knowledge database of mass concrete properties, ageing effect behaviour, dam-foundation-reservoir interaction, site specific conditions etc. In addition to this, the concrete gravity dam has to experience some major or minor seismicity during its lifetime, this aspect makes the problem even more challenging. To predict the nonlinear seismic behaviour of concrete gravity dam, there are several readymade software's available, but they require much computational time. To overcome this problem several researchers have suggested neuro-modular tool for the behaviour prediction of concrete gravity dam. Artificial Neural Networks (ANNs) are a family of statistical learning models inspired by biological neural networks (i.e. Human Brain) (Haykin, 1999). It is used to estimate or

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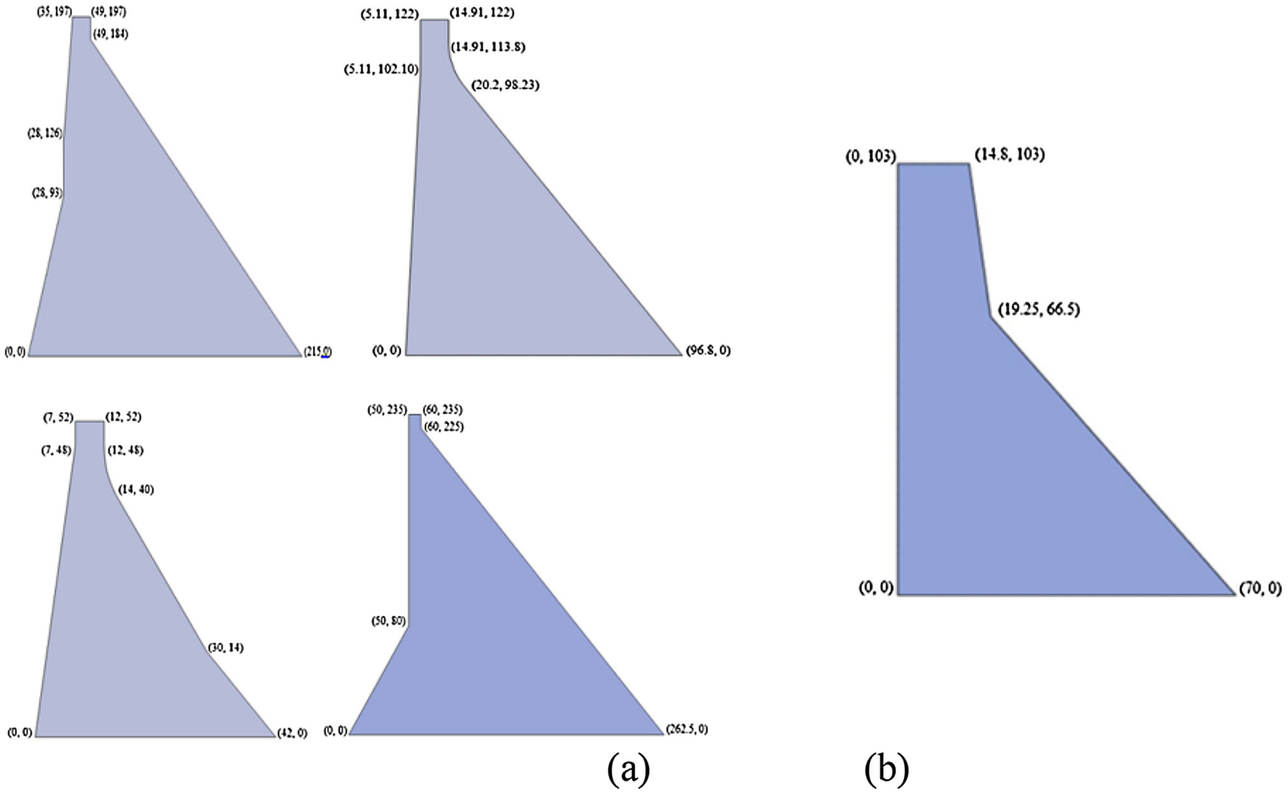

Figure 1 Geometries considered: (a) for training and (b) for prediction.

approximate certain functions which are generally depend on a large number of inputs and are generally unknown (Tully, 1997). Artificial Neural Networks are generally presented as systems of interconnected ''neurons'' which exchange messages between each other to predict the output variables (Shiffman, 2003). Neural networks can be composed of a single layer or many layers, according to the complexity of the architecture of the network (Haykin, 1999). There are several studies available in the literature conducted for the nonlinear analysis of concrete gravity dams based on Artificial Neural Network (Joghataie and Dizaji, 2009; Al-Suhaili et al. 2014; Joghataie and Dizaji, 2011; Wang and He, 2007; Hu et al. 2012 and Joghataie and Dizaji, 2013). All the above mentioned studies are focused on different aspects of concrete gravity dams like dam-reservoir-foundation interactions (Al-Suhaili et al. 2014), deformation behaviour (Hu et al. 2012), and nonlinear hysteretic response (Santillán et al. 2013) etc. and are generally based on the behaviour of concrete gravity dam with particular geometric configuration. However, the non-linear behaviour of concrete gravity dams is largely dependent on its geometry. Therefore, a specific study is needed to be conducted on ANN based prediction of non-response parameters of the concrete gravity dam which would include the geometrical configuration effects.

Data generation and training of neuro-modeler

Problem which deals with non-linear seismic behaviour prediction of concrete gravity dam has large number of parameters which vary site to site conditions. Some of the important parameters are geometrical configurations of dam, foundation properties, reservoir depth, height of the dam, site specific seismic conditions etc. Dealing with each of the parameter in the problem would be quite complex and time consuming task. Therefore, present study is framed to establish a neuro-modeler based on Artificial Neural Network, which can be used to deal these parametric variations in the single stretch of computation time. As the first study on the subject is to prepare a controlled precise data for training and testing of the neuro-modeler so that the precision of the method could be evaluated. A commercially available analysis software (ABAQUS) is used to obtain the data of both inputs and outputs related to non-linear seismic behaviour of concrete gravity dam. The considered geometries in the study are typical geometries which are generally used in construction of concrete gravity dams and are dependent upon the height of the dam: Fig. 1(a) shows the considered geometries of dam for training of the neuro-modeler. Fig. 1(b) shows the geometry of dam for prediction.

To obtain the sufficient data on nonlinear behaviour of concrete gravity dam, incremental dynamic analysis (IDA) (Vamvatiskos and Cornell, 2002) is performed considering each geometric configuration. Fig. 2 shows comparison between IS 1893 (2002) design spectrum with mean spectrum selected ground motions normalized (FEMA-P695, 2009) and scaled to 1.0 g hazard level.

Based on the acquired data, efficiency of the neuro-modeler is verified. Training of neuro-modeler is done using Matlab. Neuro-modeler uses certain values of input

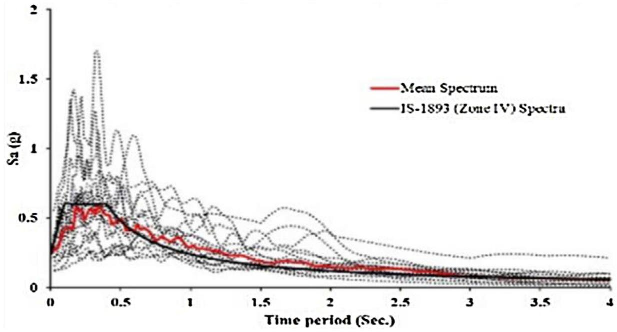

Figure 2 Acceleration response spectra.

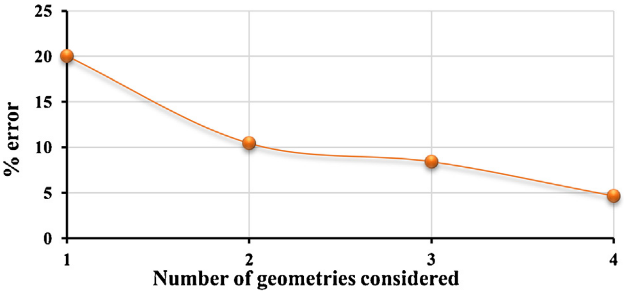

Figure 3 Efficiency of the neuro-modeler.

parameters and output parameters as network object to store all of the information that defines a neural network. There are seven general steps used by neuro-modeler for neural network design process given as follows: 1 — Data collection. 2 — Network creation. 3 — Network configuration. 4 — Weights and biases initialization. 5 — Network training. 6 — Network validation. 7 — Network used. A direct relation could be obtained using an ANN model, which needs a database of the set of output variables related to the respective input variables. In the study, peak ground acceleration (*PGA*), arial intensity (*IA*), destructiveness potential factor (P_d), maximum spectral acceleration (*Sa*(max)) and spectral acceleration at structure's first mode period (*Sa*(5%, *T*)), are representative parameters of selected ground motions used as inputs and the Max. Crest displacement as target are considered.

The reason for using representative parameters as inputs, instead of complete time history is to reduce the computational time. Levenberg—Marquardt backpropagation method (Nourani et al. 2008) is used for training of the neuro-modeler. After training the neuro-modeler for different sets of geometries, crest displacement of the geometry of dam can be calculated which were not used in training. Curve is plotted between the % error of the crest displacement of the predicted geometry ($H = 103$ m) to the total number of geometries (Fig. 3).

Discussions and conclusions

From the study conducted herein, the following conclusion can be deduced:

1. The ANN modelling technique used for obtaining a model of direct estimation of the output variable (crest displacement) for a given set of independent variables (*PGA*, *IA*, P_d, *Sa*(max), *Sa*(5%, *T*)) are found to be capable to estimate the dependent variables accurately.
2. Results obtained by the ANN model for the geometry in such a way that are not exist in the database used for building the ANN model with their corresponding results of these cases using ABAQUS software, indicates the capability of this model to give very accurate results. The % error for the four geometries varies from 20 to 4 respectively. This variation of error represents that if have more number of samples for training the error has monotonically reduced.
3. One of the benefits of this approach is that once the neuro-modeler is trained, it can be used in the analysis directly to replace the integration methods and thus can significantly reduce the time required for analysis. However the method requires a considerable time for the training of the neuro-modeler.

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