6th American Association for Wind Engineering Workshop (online)
Clemson University, Clemson, SC, USA
May 12-14, 2021

Artificial Neural Network models to study wind-induced response of large-span roofs and suspension bridges

Fabio Rizzo [a,*], Luca Caracoglia [b]

[a]*Dept. of Engr. & Geology, G. D'Annunzio University, Pescara, Italy, fabio.rizzo@unich.it*
[b]*Dept. of Civil & Env. Engr., Northeastern University, Boston, MA, USA lucac@coe.neu.edu*

ABSTRACT:
Artificial Neural Networks (ANNs) are a valid approach to analyze structural response. For example, they can be used to avoid experimental evaluation of wind loads during preliminary design of a structure. This document discusses recent applications of ANN-based surrogate models to predict wind-induced vertical displacements of cable net supporting hyperbolic paraboloid roofs and the flutter velocity of (pedestrian) suspension bridges. The ANN-based model, trained using wind tunnel data and numerical structural analyses, can predict the structural response with an error no larger than 10%.

Keywords: surrogate models, Artificial Neural Networks, wind tunnel tests, cable-net roofs, suspension bridges.

1. INTRODUCTION

Since the late 1990s, Artificial Neural Networks (ANNs) have been used as an effective approach to solve many problems in the field of civil engineering because of their ability to approximately model the structural response and simultaneously taking into account the uncertainty from several sources (Chen et al., 2008). Predictions via ANN have been used for: structural safety and decision-making, estimation of cable tension from vibrations, dynamic response of buildings under seismic excitation and estimation of seismic-induced structural damage through fragility curves. In the field of wind engineering ANN approaches have been explored to: control vortex shedding of circular cylinders (Fujisawa, 2002), investigate aeroelastic instability of long-span bridges (Rizzo and Caracoglia, 2020) and investigate aerodynamic wind loads due to interference of adjacent buildings. In addition, the ANN approach has been employed to interpolate experimental, wind-induced pressure time series of a low-rise building (Chen et al., 2002) and predict mean and fluctuating pressure coefficients (Dongmei et al., 2017). This study describes two recent application examples of ANNs in the field of wind engineering, i.e. the study of a cable net supporting a large roof and a suspension bridge. In the case of the cable net, the ANN estimates wind-induced vertical displacements and, for the bridge the ANN evaluates the critical flutter velocity.

2. METODOLOGY

The ANN neurons are organized in one input layer, one hidden layer and one output layer. The variables of the input layer are user-defined, e.g. geometric properties, structural properties and other physical quantities. The neurons in the hidden layer are selected by trial and error; they contain the result of intermediate calculations from the input layer. Finally, the output layer is the result of the final calculations. In an ANN, each node in each layer is connected to each node in the adjacent layer. An ANN-based surrogate model can be used for predictions only after a training

* Lead Presenter

process, which is carried out using an existing set of input–output data. The training of an ANN is commonly performed through a back-propagation, learning algorithm. This algorithm involves a minimization process that feed-forwards the input data to generate the output data.

3. ANN TRAINING USING WIND TUNNEL DATA

Wind tunnel results are used to train the ANN-based models. Pressure coefficients for several geometries of large-span hyperbolic paraboloid roofs (Rizzo et al, 2021) and a set of flutter derivatives measured for a closed-box section model of a pedestrian suspension bridge (Rizzo and Caracoglia, 2020) are employed and initially expanded through suitable polynomial representation of relevant parameters. In the case of the large-span roof, a new set of geometries is defined through polynomial representation by varying cable sags and roof spans. For the bridge section model, flutter derivatives extracted through repetition of wind tunnel tests are randomized through Monte-Carlo simulation. Figure 1 illustrates the workflow of the entire process from the wind tunnel tests to the randomization of wind tunnel data, their polynomial representation, and structural analysis results.

The ANN is trained using structural responses. For the case of cable net roofs, wind-induced vertical displacements are estimated by static, nonlinear FEM analysis. For the bridge case, the critical flutter velocity is found by generalized, two-mode (degree of freedom) model (Scanlan and Tomko, 1971). The logistic sigmoid function is employed as the transfer function between adjacent neurons. The ANN overfitting is examined by varying the number neurons from 5 to 50 and examining the errors between physical model predictions and ANN-based approximations.

4. DISCUSSION AND CONCLUSIONS

Satisfactory approximation of physical model results has been achieved, using 70% of experimental data for training, 15% for validation and 15% for testing. The coefficient of determination R is consistently larger than 0.9. In the case of the large-span roof, relative errors between FEM predictions and ANN approximations are less than 10% for 80% of the 15840 combinations of numerical calculations. For the bridge case, the relative error is less than 5% for 90% of the results.

REFERENCES

Chen C H, Wu J C, Chen J H., 2008. Prediction of flutter derivatives by artificial neural networks. Journal of Wind Engineering and Industrial Aerodynamics, 96(10-11), 1925–1937.

Chen Y, Kopp G A, Surry D, 2003. Prediction of pressure coefficients on roofs of low buildings using Artificial Neural Networks. Journal of Wind Engineering and Industrial Aerodynamics, 91(3), 423-441.

Dongmei H, Shiqing H, Xuhui H, Xue Z, 2017. Prediction of wind loads on high-rise building using a BP neural network combined with POD. Journal of Wind Engineering and Industrial Aerodynamics, 170(0),1-17.

Fujisawa N., 2002. Neural network control of vortex shedding from a circular cylinder using rotational feedback oscillations. Fluid and Structures, 16(1), 113-119.

Rizzo F, Caracoglia L., 2020. Artificial Neural Network model to predict the flutter velocity of suspension bridges. Computers and Structures, 233, 106236.

Rizzo F, Kopp A G, Giaccu G., 2021. Investigation of wind-induced dynamics of a cable net roof with aeroelastic wind tunnel tests. Engineering Structures, 229, 111569.

Scanlan R.H. and Tomko, J.J., 1971. Airfoil and bridge deck flutter derivatives. Journal of Engineering Mechanics, ASCE, 97(EM6), 1717-1737.

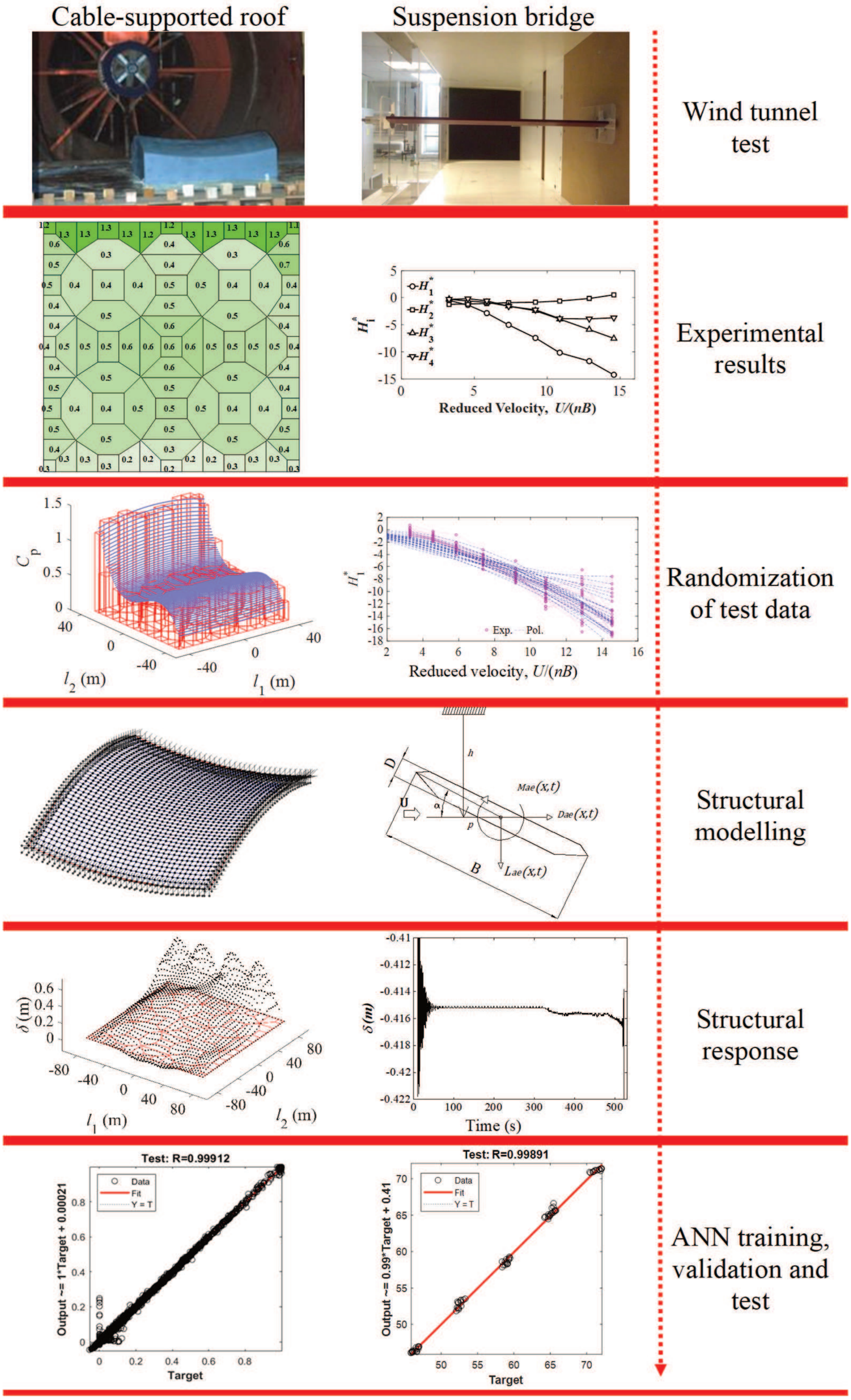

Figure 1. Workflow of the ANN-based surrogate modeling