Development of an Artificial Neural Network Model for the Calculation of Wind-Induced Acceleration on High-Rise Buildings

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SUMMARY
A Feed Forward Neural Network (FFNN) model is developed to calculate the along-wind and across-wind acceleration. To ensemble the database for training of the Artificial Neural Network (ANN) model, a methodology developed to update the Mexican wind design standard for Mexico City is considered for the calculation of the along-wind acceleration, while the across-wind acceleration is calculated according to the methodology presented in the Italian code CNR-DT 207/2008. Different architectures for the ANN models were considered. The developed ANN model was trained by using a database with more than 5000 hypothetic buildings with similar characteristics to those from Mexico City. The obtained results showed that the use of the best ANN model to predict the along-wind and across-wind accelerations on high-rise buildings is a good alternative.

Keywords: High-Rise Buildings, Wind-Induced Accelerations, Artificial Neural Networks

1. INTRODUCTION

Advances in materials allow the construction of slender structural elements in buildings, which generates taller wind-sensitive buildings. It is well-known that tall buildings with low frequencies the occupants could experiment some discomfort due to the wind action, this discomfort can be expressed as dizziness and seek for safety in the building. Human perception of wind-induced acceleration has been evaluated to stablish human perception thresholds. Different postures and body orientations are adopted during the day or night generating variable components of motions in many directions, in which case a worst combination of vibration must be applied to stablish human thresholds to motion (Irwin, 1979). Several experiments under controlled conditions have been carried out in motion simulators to study perception thresholds, these experiments showed that for peak accelerations of 5 milli-g, the acceleration is perceptible to some occupants without providing adverse response on occupants or feel insecure, for peak accelerations of 10 milli-g, the majority of the occupants perceive the motion and, in some cases, this limit cannot be acceptable to some occupants, while for peak accelerations within 35-40 milli-g, the motion is perceptible to all occupants generating concern for safety and loss of balance (Burton et al., 2006; Burton et al., 2015). Moreover, other experiments have been carried out to evaluate human perception thresholds curves which depend on the percentage of people that will perceive the acceleration (Tamura et al, 2006). Wind-induced acceleration in high-rise buildings can be evaluated with factors that depend

on the percentage of the inhabitants of a building that can perceive such oscillations, moreover, it has been observed that the coefficient of variation of the mean wind speed can significantly impact the probability of human perception of movement, even though the serviceability limit state of wind-induced acceleration is evaluated for different criteria, the probability of human perception to motion will not be the same, even if similar values of perception are taken (Pozos-Estrada et al., 2010; Pozos-Estrada et al., 2014; Pozos-Estrada, 2018). ANNs have been used to determinate the response of high-rise buildings under dynamic wind loads in along-wind and across-wind directions (Nikose and Sonparote, 2019). The use ANNs offers some advantages over other conventional procedures, furthermore, a multi-layered ANN model receives input information (database) to process and adjust weighting factors between each of the hidden layers, the training phase adjust iteratively the weights of each artificial neural connections to minimize the error between the predictions and the calculated data.
The main objective of this study is to develop an ANN model to predict the along-wind and across-wind acceleration of tall buildings. For the training, validation and testing of the ANN models, a database with more than 5000 hypothetic buildings with similar characteristics to the buildings of Mexico City was used.

2. METHODOLOGY

2.1. Database and Wind Induced Accelerations Criteria

2.1.1 Development of a database

For the development of the database, a virtual survey to identify plan dimensions and height of buildings located in Mexico City, and information reported in the literature (CTBUH, 2022; Kareem, 1988, 1990; Haviland, 1976) were used. To characterize the mean wind speed, the Manual of Civil Works for Wind Design (MOC-DV as per its acronym in Spanish, 2020) was employed. A MATLAB code was developed for the simulation of the buildings with similar characteristics to those from Mexico City by using the point estimate method proposed by Hong (1998). The simulated database includes plan dimensions, height, frequencies and damping ratios for more than 5000 buildings.

2.1.2 Wind-induced accelerations

With the information from the database, wind-induced accelerations were assessed in the along-wind direction with a methodology developed for Mexico City (Pozos-Estrada, 2018). It should be mentioned that this methodology has similar characteristics as the one presented in CNR-DT 207/2008. For across-wind accelerations, the methodology used is the one proposed in the Italian code for wind actions (CNR-DT 207/2008). Accelerations were calculated in its longitudinal and transversal components for each simulated building.

The expression adopted for the calculation of along-wind acceleration has the following functional form

$$\ddot{a}_L = g\ \frac{1}{m}\rho b C_a [V_D'(z_s)]^2 I_v(z_s) R\ K_b\ \Phi_{1,x}(z) \tag{1}$$

where g is the peak factor, m is the modal mass of the building, ρ is the density of the air, b is the width of the building, C_a is the drag coefficient, V_D’ is the mean velocity of wind for dynamics effects, $I(Z_s)$ is the turbulence intensity, R is the factor response for resonance, K_b is a factor for the correction of the modal form and $\Phi_{1,x}$ is the modal form of the fundamental mode of the structure.

The expression adopted for the calculation of across-wind acceleration has the following functional form

$$\ddot{a}_C = g_L(0.5\rho V_m^2 bh/m_L)C_L R_L \Phi_L(h)\Phi_L(z) \quad (2)$$

where g_L is the across-wind peak factor, ρ is the air density, V_m is the mean wind velocity, b is the width of the building, h is the height of the building, m_L is the generalised mass of the building, C_L is the aerodynamic force coefficient, R_D is the across-wind resonant response factor and Φ_L is the first across-wind mode shape.

2.2. Artificial Neural Networks Models

This architecture of a Feed Forward Neural Network (FFNN) is one of the simplest, where the inputs of the database travel only in one direction through hidden layers, each layer has a defined number of neurons connected through synaptic weights and each layer of neurons has activation functions; the output layer has a linear function for data processing.
The ANN model developed consider as inputs the plan dimensions, height, damping ratios, sway and torsional frequencies. The minimization of the Mean Square Error (MSE) is carried out by the Levenberg-Marquardt (L-M) train function. Several architectures with one and two hidden layers are considered, hidden layer with 3 to 50 neurons and the Tan-Sigmoid transfer function were studied, the output layer use a Linear transfer function as shown in Fig. 1.

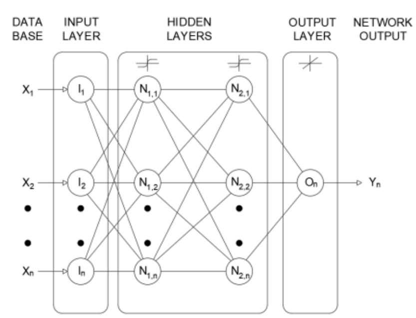

Figure 1. Feed Forward ANNs Architecture (Two Hidden Layers).

2.3. Analysis Procedure and preliminary results

The analysis procedure to predict the along-wind and across-wind using ANNs models can be summarized as follows:

1. Define the programming code for the ANNs models.
2. Establish the learn function for the bias and the weights.
3. Establish the train function for the network.
4. Define the number of hidden layers for the ANNs models.
5. Define the number of neurons in each hidden layer.
6. Run the defined program with the ANNs model to obtain the outputs.
7. Generate linear regression models to evaluate the predicted results.

8. Repeat steps 1 to 7 to evaluate the predicted results with different number of hidden layers and different number of hidden neurons.

Figure 2 presents a comparison of the predicted and actual accelerations in the along-wind and across-wind direction. It is observed in Figure 2 a good agreement between the actual and predicted data.

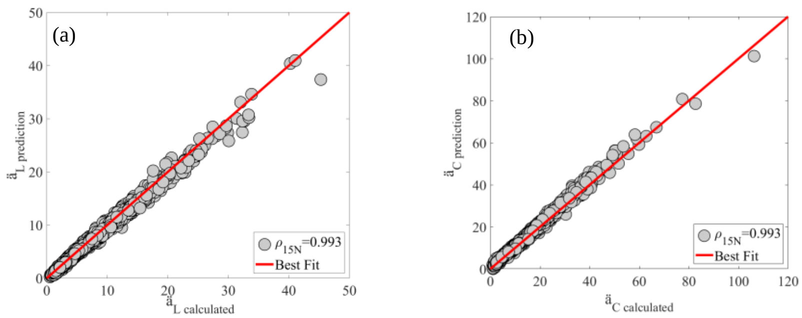

Figure 2. ANN predicted accelerations for 1HL and 15 HN: a) along-wind, b) across-wind (Units: milli-g; ρ indicates correlation coefficient).

3. FINAL REMARKS

An ANN model was developed to predict along-wind and across-wind accelerations. For the training of the ANN models, a database with more than 5000 hypothetical buildings with similar characteristics to those from Mexico City was used. A good comparison between the actual accelerations and those predicted with the best ANN model is observed.

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