ANN Application in the Field of Structural Concrete

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INTRODUCTION

Artificial Intelligence (AI) mechanisms are more and more frequently applied to all sorts of civil engineering problems. New methods and algorithms which allow civil engineers to use these techniques in a different way on diverse problems are available or being made available. One AI techniques stands out over the rest: Artificial Neural Networks (ANN). Their most remarkable traits are their ability to learn, the possibility of generalization and their tolerance towards mistakes. These characteristics make their use viable and cost-efficient in any field in general, and in Structural Engineering in particular. The most extended construction material nowadays is concrete, mainly because of its high resistance and its adaptability to formwork during its fabrication process. Along this chapter we will find different applications of ANNs to structural concrete.

Artificial Neural Networks

Warren McCulloch and Walter Pitts are credited for the origin of Artificial Networks in the 1940s, since they were the first to design an artificial neuron (McCulloch & Pitts, 1943). They proposed the binary mode (active or inactive) neuron model with a fixed threshold which must be surpassed for it to change state. Some of the concepts they introduced still hold useful today.

Artificial Neural Networks intend to simulate the properties found in biological neural systems through mathematical models by the way of artificial mechanisms. A neuron is considered a formal element, or module, or basic network unit which receives information from other modules or the environment; it then integrates and computes this information to emit a single output which will be identically transmitted to subsequent multiple neurons (Wasserman, 1989).

The output of an artificial neuron is determined by its propagation or excitation, activation and transfer functions.

The propagation function is generally the summation of each input multiplied by the weight of its interconnection (net value):

$$n_i = \sum_{j=0}^{N-1} \left[W_{ij} \cdot p_j \right] \tag{1}$$

The activation function modifies the latter, relating the neural input to the next activation state.

$$a_i(t) = FA\left[a_i(t-1), n_i(t-1)\right] \tag{2}$$

The transfer function is applied to the result of the activation function. It is used to bound the neuron's output and is generally given by the interpretation intended for the output. Some of the most commonly used transfer functions are the sigmoid (to obtain values in the [0,1] interval) and the hyperbolic tangent (to obtain values in the [-1,1] interval).

$$out_i = FT\left(a_i(t)\right) \tag{3}$$

Once each element in the process is defined, the type of network (network topology) to use must be designed. These can be divided in forward-feed networks, where information moves in one direction only (from input to output), and networks with partial or total feedback, where information can flow in any direction.

Finally, learning rules and training type must be defined. Learning rules are divided in supervised and non-supervised (Brown & Harris, 1994) (Lin & Lee, 1996) and within the latter, self-organizing learning and reinforcement learning (Hoskins & Himmelblau, 1992). The type of training will be determined by the type of learning chosen.

An Introduction to Concrete (Material and Structure)

Structural concrete is a construction material created from the mixture of cement, water, aggregates and additions or admixtures with diverse functions. The goal is to create a material with rock-like appearance, with sufficient compressive strength and the ability to adopt adequate structural shapes. Concrete is moldable during its preparation phase, once the components have mixed together go produce a fluid mass which conveniently occupies the cavities in a mould named formwork. After a few hours, concrete hardens thanks to the chemical hydration reaction experimented by cement, generating a paste which envelops the aggregates and gives the ensemble the appearance of an artificial rock somewhat similar to a conglomerate.

Hardened concrete offers good compressive strength, but very low tensile strength. This is why structures created with this material must be reinforced by use of steel rebars, configured by rods which are placed (before pouring the concrete) along the lines where calculation predicts the highest tensile stresses. Cracking, which reduces the durability of the structure, is thus hindered, and sufficient resistance is guaranteed with a very low probability of failure. The entirety formed by concrete and rebar is referred to as Structural Concrete (Shah, 1993).

Two phases thus characterize the evolution of concrete in time. In the first phase, concrete must be fluid enough to ensure ease of placement, and a time to initial set long enough to allow transportation from plant to worksite. Flowability depends basically on the type and quantity of the ingredients in the mixture. Special chemical admixtures (such as plasticizers and superplasticizers) guarantee flowability without grossly increasing the amount of water, whose ratio relative to the amount of cement (or water/cement ratio, w/c) is on reverse proportion to strength attained. The science of rheology deals with the study of the behavior of fresh concrete. A variety of tests can be used to determine flowability of fresh concrete, the most popular amongst them being the Abrams cone (Abrams, 1922) or slump cone test (Domone, 1998).

The second phase (and longest over time) is the hardened phase of concrete, which determines the behavior of the structure it gives shape to, from the point of view of serviceability (by imposing limitations on cracking and compliance) and resistance to failure (by imposing limitations on the minimal loads that can be resisted, as compared to the internal forces produced by external loading), always within the frame of sufficient durability for the service life foreseen.

The study of structural concrete from every point of view has been undertaken following many different optics. The experimental path has been very productive, generating along the past 50 years a database (with a tendency to scatter) which has been used to sanction studies carried along the second and third path that follow. The analytical path also constitutes a fundamental tool to approach concrete behavior, both from the material and structural point of view. Development of theoretical behavior models goes back to the early 20th century, and theoretical equations developed since have been corrected through testing (as mentioned above) before becoming a part of codes and specifications. This method of analysis has been reinforced with the development of numerical methods and computational systems, capable of solving a great number of simultaneous equations. In particular, the Finite Element Method (and other methods in the same family) and optimization techniques have brought a remarkable capacity to approximate behavior of structural concrete, having their results benchmarked in may applications by the aforementioned experimental testing.

Three basic lines of study are thus available. Being complementary between them, they have played a decisive role in the production of national and international codes and rules which guide or legislate the project, execution and maintenance of structural concrete works. Concrete is a complex material, which presents a number of problems for analytical study, and so is an adequate field for the development of analysis techniques based on neural networks (Gonzalez, Martínez and Carro, 2006)