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Artificial neural networks analysis of São Paulo subway tunnel settlement data

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Abstract

Artificial neural networks have been used to analyze a number of engineering problems, including settlement caused by different tunneling methods in various types of ground mass. This paper focuses on settlement over shotcrete-supported tunnels on São Paulo subway line 2 (West Extension) that were excavated in Tertiary sediments using the sequential excavation method. The adjusted network is a good tool for predicting settlement above new tunnels to be excavated in similar conditions. The influence of network training parameters on the quality of results is also discussed.

Keywords: Underground excavation; Neural network; Settlements; Subway; Tunnels; Instrumentation; Sequential excavation

1. Introduction

Excavating shallow tunnels in densely occupied areas currently requires strict precautions to reduce risks and possible effects on nearby structures. Being able to predict excavation effects and particularly settlement-related effects is an important step forward in this respect. Artificial neural networks (ANNs) have emerged as a new tool for analyzing geotechnical problems. Good correlations for longstanding problems have been found and conventional solutions enhanced as the ability to generate more information grows and the understanding of obscure points is deepened.

Neural networks have the ability to make generalizations: once a network has ''learned'' the characteristics of a general category of objects based on a series of examples from this category, it can provide identical or similar responses for non-trained inputs.

Neural networks have been used for the analysis of settlements caused by tunnels excavated both by TBM (e.g. Suwansawat and Einstein, 2006) and sequential excavation method (e.g. Shi et al., 1998). In this work, networks were trained and tested using instrumentation data of subway double-track shotcrete-supported tunnels, sequentially excavated though Tertiary stiff clays and compact sands from the São Paulo sedimentary basin. The tunnels are part of the work for the West extension of the São Paulo subway line 2 (Green). The network considers variations of geometrical parameters at different sections of the tunnels, geotechnical properties, ground conditioning, and construction procedures.

The adjusted network is a good tool for settlement prediction of new tunnels in the same geological environment. Furthermore, this analysis shows the influence of network training parameters and previous input data treatment on the quality of the adjustment obtained. Significantly enhanced neural network predictive ability was found due to the use of certain data processing techniques. Knowledge acquired was applied to further develop use of this technique for tunnel instrumentation.

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2. Artificial neural network background

ANNs seek to simulate human brain behavior by processing data on a trial-and-error basis and learning how to avoid repeating an error the next time a similar situation occurs. Numerous advances have been made in recent years in developing intelligent systems, particularly those in which functioning is based on biological neural networks. Researchers from a wide range of disciplines have been using ANNs to find solutions to many different types of problems. Highlights among them are those involving control of complex systems when rigorous knowledge of their behavior is lacking.

During the 1970s, the progress in the use of ANNs was very limited. Current models were unable to handle many problems proposed. Research was resumed after the work presented by Hopfield (1982), showing the relationship between physical systems and auto-associative recurrent neural networks. The multiple layer perceptron (MLP) model was proposed by Rumelhart (1986) and was based on enhancing the perceptron (proposed by Rosenblatt, 1958). MLP neurons are organized in layers, including data input, output, and hidden layers as shown in Fig. 1. Hidden layers are important because mathematical adjustment operations are largely performed in them. Flood and Kartan (1994) stated that MLPs with at least two hidden layers provide the extra flexibility required for modeling complex systems.

During training, inputs are inserted, outputs determined and error between predicted and actual values calculated. Next, on the basis of this error, weights are adjusted starting from the output layer until the input layer is reached. This process is known as back propagation.

Common practice nowadays is the use of an independent term in the sum of the weights and inputs to each neuron in order to lend more stability to the network and particularly to enhance its generalization. A constant 1 enters each neuron as an input and is multiplied by a scalar *bias.* The *bias* is similar to a weight for this input. It is modified, as are the other weights (Haykin, 1994).

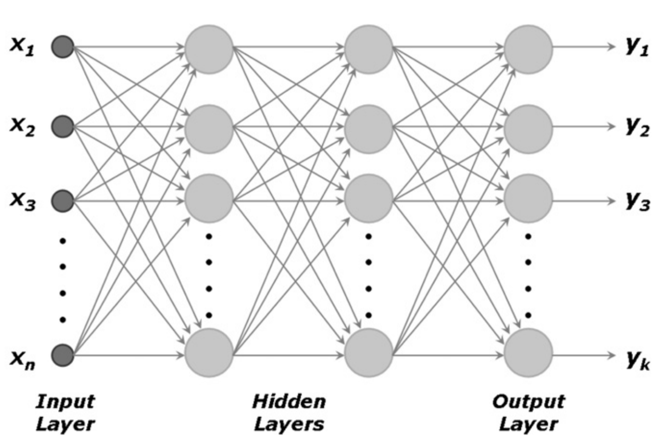

Fig. 1. Diagram showing typical MLP.

Certain tools are used to accelerate the *back-propagation* algorithm and reduce the incidence of local minima. One of the main points here is that much more effective results may be obtained by treating MLP network input and output data. Data normalization in order to obtain values with uniform amplitudes considerably enhances network performance. This is due to more homogeneous distribution of data as shown in Fig. 2.

This procedure has been used by many researches (e.g. Flood and Kartan, 1994). In addition to that, it will be shown in item 6 of this paper that non-dimensionalization by a characteristic value of each problem may lead to even better results.

3. Artificial neural networks in tunneling

Due to the high level of urbanization today, the construction of urban tunnels meets with difficulties caused by new structures interacting with existing ones. Interference with buildings and other structures affects decisions made at the design stage and during construction. Surface instrumentation above tunnels has proved to be the best way of controlling the quality of structures.

Tunneling parameters affecting surface movement may be divided in three main datasets:

- *Geometrical characteristics:* Cross-section area (equivalent diameter), excavation face height, type of support, overburden, depth, single or twin tunnel, pillar width for twin tunnels, etc.
- *Ground characteristics*: Deformability modulus, Poisson's ratio, lateral earth pressure coefficient, permeability, friction angle, cohesion, unit weight, etc.,
- *Excavation and support process*: Excavation method (Sequential Excavation or TBM), excavation type (full face or sequential mining), distance from face to support, support time, support methods (anchoring, shotcrete, steel sets), advance rate, etc.

Clearly tunnel construction is affected by a wide range of factors, so a huge volume of data is involved and analyzing it is often an arduous task that requires extensive

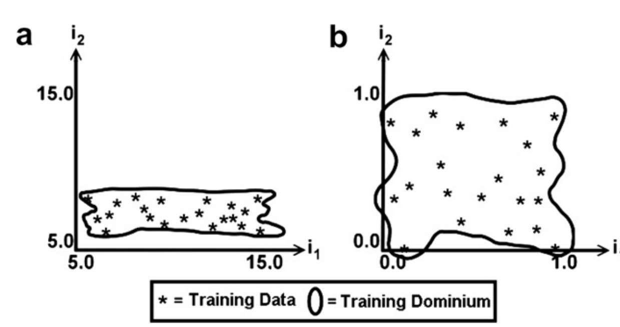

Fig. 2. Influence of data normalization on the distribution homogeneity (Flood and Kartan, 1994).