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Computational intelligence tools for the prediction of slope performance

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Abstract

The current paper illustrates the application of computational intelligence tools in slope performance prediction both in static and dynamic conditions. We present the results obtained by using the back-propagation algorithm, the theory of Bayesian neural networks and the Kohonen self-organizing maps, one of the most realistic models of the biological brain functions. We estimate slope stability controlling variables by combining computational intelligence tools with generic interaction matrix theory. Our emphasis is given to the prediction and estimation of the following: slope stability, coefficient of critical acceleration, earthquake induced displacements, unsaturated soil classification, classification according to the status of stability and failure mechanism for dry and wet slopes. Finally, we present an integrated methodology for assessing landslide hazard coupling computational intelligence tools and geographical information systems.

Keywords: Artificial neural networks; Kohonen self-organizing maps; Back propagation; Slope stability; Earthquake induced displacements

1. Introduction

Geotechnical engineering is a complex area of engineering due to the fact that it is dealing with natural data. This is the reason this area of engineering is concerned not only with calculations and numerical analysis, but also with concepts, perception, judgment and employment of experience that cannot be represented strictly numerically. Geotechnical engineers often employ empirical relationships in order to estimate design parameters and engineering properties. It is a challenging task to develop an adequate model to efficiently simulate site specific engineering geological conditions and follow the appropriate design approach in order to eliminate the possibility of failure and propose the most cost-effective design. For these reasons, Jing [1] refers to rock mechanics modeling and rock engineering design as both a science and an art. We propose the extension of this notion in soil mechanics modeling and soil engineering design. Both areas of geotechnical mechanics lay on a scientific foundation but require empirical judgment supported by accumulated experience and long-term practice.

In Fig. 1 a flowchart of rock mechanics modeling and rock engineering design approaches is presented [2]. A categorization into eight approaches of modeling within the framework of a project objective, based on four basic methods and two levels, is illustrated. There are two rows in the central box: the top row Level 1 includes methods where there is an attempt to achieve 1:1 mechanism mapping. The term 1:1 mapping refers to the attempt of modeling geometry and physical mechanisms directly, either specifically or through equivalent properties [3]. Conversely the lower row, Level 2, includes methods in which such a mapping mechanism is not totally direct, e.g. the rock mass classification systems. The neural network approach is a "non 1:1 mapping", located in boxes 2C and 2D as indicated in Fig. 1 (box with gray pattern). In this approach the rock or soil mass is represented indirectly by a system of interconnected nodes [4].

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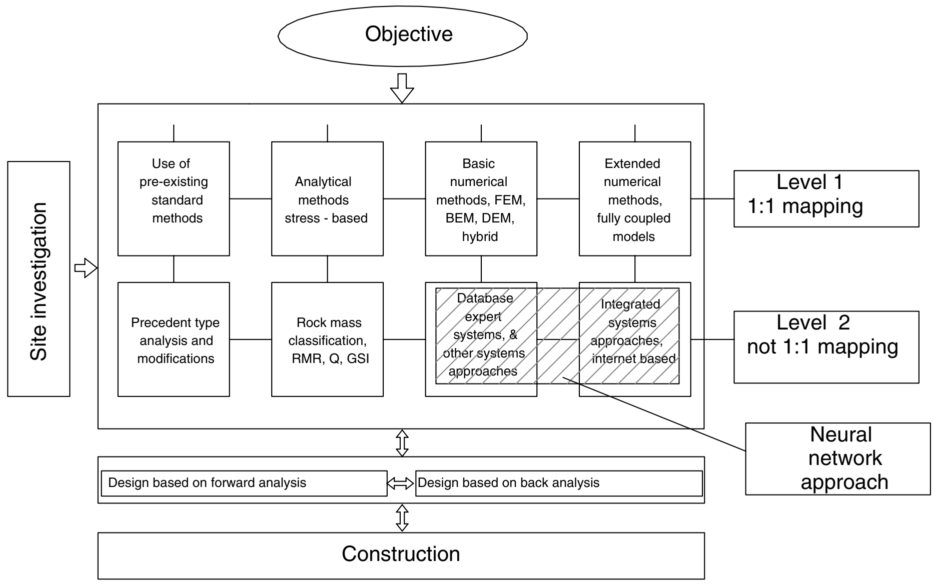

Fig. 1. The four basic methods, presented in two levels which comprise eight different approaches to rock mechanics modeling [2].

The determination of the nonlinear behavior of multivariate dynamic systems often presents a challenging and demanding task. Therefore, complex geomechanics systems could be an ideal area for the application of intelligent methods, as the physical problem is often described by nonlinear relationships which lead to the use of nonlinear transformation functions. Such networks are able to include creative ability, perception and judgment. An artificial neural network implementation is not an easy task and requires sophisticated modeling techniques, experience, deep knowledge of engineering and a vast number of experimental data.

The accurate estimation of the performance of a rock or soil slope is a difficult problem mainly because of the complexity of the physical system itself and the difficulty in the determination of the necessary input data associated with geotechnical and physical parameters. The system under investigation is a nonlinear dynamic system spatially distributed. Slope stability assessment includes a further difficulty due to the fact that only a rough overall description of the physical and geometric characteristics of the slope is usually available. For the above reasons it is hard to determine the representative values of the required input data (physical properties, strength parameters, appropriate geometry), in order to conduct reliable analysis.

According to Cilliers [5], the importance of the above modeling technique for the understanding of complex systems can be summarized in the ability to conserve the complexity of the systems they model because they have complex structures themselves. They also encode information about their environment in a distributed form and are capable to self-organize their internal structure.

In this paper we aim at illustrating our experience with applications of intelligent methods in the field of slope stability performance under static and dynamic conditions. In the following sections:

- We present a background of the applied computational intelligence methods.
- We focus on our experience with the back-propagation algorithm, the theory of Bayesian neural networks and the Kohonen self-organizing maps.

It is of theoretical importance in geomechanics to rate the geometrical and physical input variables that are used to describe a geotechnical model and/or a geotechnical engineering problem. Our goal was to recognize the hierarchy rules that control the variables describing the engineering system, ‘‘slope-landslide’’. Towards this end we applied the methodology of partitioning the connection weights and used information theory algorithms to reveal the most ‘‘important’’ or the most ‘‘relevant’’ variables. Finally we applied the interaction matrix theory in order to assess the parameters ‘‘dominance’’ and ‘‘interaction intensity’’ in rock or soil engineering system.

For the task of supervised encoding we used gradient descend methods, such as the back-propagation algorithm and the Bayesian back-propagation in order to predict slope stability and earthquake induced displacements. In terms of unsupervised encoding we used vector quantization methods, such as the self-organizing maps in order to reveal the tendency of certain data sets to create clusters. These data sets describe unsaturated soil classification, classification according to the status of stability and failure mechanism for dry and wet slopes. Additionally several qualitative factors (altitude, lithology, mean annual rainfall height, etc.) controlling landslide hazard were examined employing self-organizing maps.

At the last section of this paper, we present an integrated methodology for assessing landslide hazard linking the computational intelligence methods with geographical information systems (GIS) [6,7]. It is worth noting, that the application of these methods was successful both in