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Nationwide lithological interpretation of cone penetration tests using neural networks

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The Geological Survey of the Netherlands (GSN) systematically produces 3D stochastic geological models of the Dutch subsurface. These voxel models are regarded essential in answering subsurface-related questions on, for example, aggregate resource potential, groundwater flow, land subsidence hazard and the planning and realization of large-scale infrastructural works. GeoTOP is the most recent and detailed generation of 3D voxel models. This model describes 3D stratigraphical and lithological variability up to a depth of 50 m using voxels of $100 \times 100 \times 0.5$ m. Currently, visually described borehole samples are the primary input of these large-scale 3D geological models, both when modeling architecture and composition. Although tens of thousands of cone penetration tests (CPTs) are performed each year, mainly in the reconnaissance phase of construction activities, these data are hardly used as geological model input.

There are many reasons why it is of interest to utilize CPT data for geological and lithological modeling of the Dutch subsurface, such as: 1) CPTs are more abundant than borehole descriptions, 2) CPTs are cheaper and easier to gather, and 3) CPT data are more quantitative and uniform than visual sample descriptions.

This study uses CPTs and the lithological descriptions of associated nearby undisturbed drilling cores collected by the GSN to establish a nationwide reference dataset for physical and chemical properties of the shallow subsurface. The 167 CPT-core pairs were collected at 160 locations situated in the North, West and South of the Netherlands. These locations were chosen to cover the full extent of geological units and lithological composition in the upper 30 to 40 m of the subsurface in these areas. The distance between the CPT location and associated borehole is small, varying between 0 and 30 m, with an average of 6 m. For each 2 cm CPT interval the data was automatically annotated with the lithoclass from the associated core using a lithological classification script that is also used in GeoTOP to classify the visual sample descriptions.

Based on this data a three-layer feedforward neural network was trained containing 5 different inputs: cone resistance, friction ratio, coordinates x and y, and interval depth z. Previous training attempts showed an increased performance when using additional inputs such as pore water pressure, but since these variables are not measured in the majority of CPTs, these were left out in the training procedure. The Newton conjugate-gradient algorithm was applied to train the network. 20-Fold cross-validation yielded 20 different trained nets and independent performance outcomes. Significant performance increase was found as compared to performances of conventional lithological classification charts.

A similar neural network was then applied to new CPT data from a pilot area in the city of Rotterdam. This area has a limited number of visual sample descriptions and therefore, additional lithological information of the subsurface is desirable. The results of an evaluation of the neural network's outcomes in this area by geological experts are positive, which paves the way for future nationwide application of this method.