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Geological interpretation of geotechnical properties of sediments in the Vienna basin

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Introduction

Geological descriptions of sediments often bear little information for the geotechnical engineer concerned with the quantitative characterisation of the subsurface. The holistic view of field geologists may provide a complete picture of the age, stratigraphic position, depositional environment and palaeogeographic setting of a sedimentary layer but offers no help to derive friction angles, shear resistance, hydraulic conductivity or porosity. At most, relative indications about e.g. one layer being finer-grained than another, are given. The translation of geological information into numbers for engineering purposes remains the privilege of very few experts with long-term regional experience.

However, a direct correlation between geological facies of a layer and its material properties does exist and can be used for at least semi-quantitative predictions within strata. Building on a data pool of physical analyses of sediment samples, the understanding of geological setting and of sedimentary and diagenetic history can help to interpolate, extrapolate and explain trends within the distribution of soil characteristics. The aim of this paper is to bridge the gap between field geologists and geoengineers. For unconsolidated sediments of the Vienna basin, the correlation between geological facies and geotechnical characteristics is demonstrated and used to explain statistical trends in the data. The added value of geological expertise is shown to improve predictions on the distribution of soil properties.

Data processing

As part of a long-term project establishing a digital geoscientific atlas for the City of Vienna (Hofmann & Pfleiderer, 2003), geotechnical soil characteristics were compiled from 4,300 drilling samples analysed during the last 50 years. The measurements form a subset of a database which is maintained by the Municipal Department for Foundation Engineering and comprises the digital records of over 41,000 drill holes including lithologic logs as well as hydrological and geotechnical information. These drill holes were previously used to build a three-dimensional model of Vienna's subsurface (Pfleiderer & Hofmann, 2004). The study area presented here covers the eastern parts of the City of Vienna (16.5 x 20 km^2) including the subsurface around the EGU conference centre. The area is made of fluvial sediments deposited by the Danube river during the Quaternary, overlying fine-grained Neogene marine sediments.

Soil parameters include grain size expressed as percentiles of the cumulative distribution curve, soil and grain density, water content, void ratio and for cohesive specimens additionally friction angle, cohesion and plasticity. The first step of data processing consists of allocating each sample to its geological layer using X-, Y- and Z- coordinates. Subsequently, the subsets of each layer are described geostatistically, including frequency distributions for each parameter, correlations between parameters and regional scattering of values. Finally, statistical descriptions are compared between geological layers to put all the numbers into a geological context and reveal the underlying cause for the distribution of material properties.

Geological layer characterisation

Five geological layers are present within the study area. These are from top to bottom:

'A' a fine-grained sand and silt layer representing a Holocene overbank deposit

'B' gravel and sand layers corresponding to channel fill deposits of a braided river system during Pleistocene and a meandering river system during Holocene times

'C' silt intercalations within the sandy gravel layer 'B'

'D' sand-dominated marine layers of Neogene age

'E' silt-dominated marine layers of Neogene age.

The Neogene sediments form laterally irregular patterns rather than vertically distinct units.

Grain density, a material property independent on stratigraphic position or burial depth, clearly separates silt layers from sands and gravels. Median values for silt are constantly high, whether for Holocene (layer 'A'), Pleistocene (layer 'C') or Neogene sediments(layer 'E'). Values for sands (layer 'D') are distinctly lower, while gravels (layer ‘B’) show the lowest value. Variability of grain density within layers is statistically very small and regionally insignificant permitting safe extrapolation across the study area. The narrow range of values is explained geologically by the fact that grain density directly depends on the petrographic make-up of the sediment which in turn is controlled by the geology of the hinterland. The long travel distance from the hinterland to the Vienna basin causes a uniform lithology of components and as a result highly constant grain density values within layers.

Dry density, a measure of weight and volume of grains and voids, shows the effect of burial depth as deeply buried layers are compacted by overlying material and interstitial pore water gets squeezed out of the voids. As expected, silt layers of constant grain density (layers ‘A’, ‘C’ and ‘E’) exhibit dry density values increasing, and water content decreasing, with depth, caused solely by a decrease in void ratios. The dependency can be quantified and the figures will be used in future studies to calibrate models of soil compaction.

Clay content, liquid and plastic limits and plasticity index show strikingly similar values for Quaternary silt layers ‘A’ and ‘C’. Although frequency distributions of these parameters reveal slightly higher variability than e.g. for grain densities, median values suggest that the two layers are made of nearly identical material. This comes as no surprise to the geologist as the two layers’ areas of origin and depositional environments are the same. Both sediments represent overbank deposits, layer ‘C’ being a subfossil version of layer ‘A’. The only differences between the two are geometrical, layer ‘A’ being laterally more continuous than ‘C’, and concerning the effects of burial depth.

Neogene silt layers however, differ from Quaternary silt (layers ‘A’ and ‘C’) with respect to most of their properties. Clay content and, by consequence, friction angle, cohesion and Atterberg limits reveal clear statistical differences between Neogene and Quaternary material. The geological explanation lies in the fact that Neogene silt represents a marine sediment deposited at the margin of the Para-Tethys sea. Although grain sizes coincide with those of fluvially deposited Quaternary silt layers, the material properties are noticeably dissimilar. In addition, variation in the regional distribution of data is pronounced due to local effects during sedimentation. Deposition took place close to the material’s area of origin. Small rivers discharging their sediment load into the basin cause heterogeneity along the shore line which results in the observed wide range of values.

Conclusions

Geotechnical engineers concerned with the quantitative characterisation of the subsurface often face the challenging task of forecasting the properties of sediments on the basis of sparse data populations. In addition to mere statistical description and interpolation, geological know-how can contribute substantially to the prediction of vertical and horizontal trends as well as to the inference about continuity in material characteristics. This study investigates the correspondence between geotechnical parameter values and the geological setting of unconsolidated sediments in the Vienna basin.

Sediments which before deposition were transported over long distances (hundreds of kilometers long), do not show a large variation in properties within the comparatively small study area (tens of kilometers wide). On the other hand, material deposited closer to its origin reveals more heterogeneity due to local effects during sedimentation. These circumstances together with information on the predominant directions of deposition, significantly enhances the modelling of regional distribution of data.

Knowledge on the sedimentary and diagenetic history not only serves to explain why different sediments can exhibit identical material properties but also why some layers of similar grain size distribution show very different properties depending on depositional environment and geology of the hinterland. Additionally, geological experience elucidates why effects of burial depth are reflected in some properties but not in others. Rather than simply acknowledging these effects, the novelty of the study lies in establishing quantitative relationships to describe and, in the future, model these effects for sediments in the Vienna basin.

References

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