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# Datamanagement and Datamining – a precondition for geotechnical works

## Datamanagement et d'exploitation des données - Une condition préalable pour les travaux géotechniques

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### ABSTRACT

Special ground engineering projects frequently require a systematic measuring control of any relevant data and their real-time interpretation to ensure success, quality and cost-effectiveness. For this purpose, a mostly enormous flow of information has to be organised and mapped. Apart from interfaces for data transfer (data management), links and correlations of different kinds of data (data mining) have to be defined.

In this article the application of a system is presented which has been developed for compensation grouting, a procedure to forestall settlements of constructions. Only these systems allow a reliable execution on a large scale. The mounds of data to be processed are extremely heterogeneous, depending on the different sources (e. g. subsoil investigation, design parameters, geodesic measurements, construction features). Consequently, not an isolated kind of data has to be considered but only the correlation of different kinds of data delivers reliable information for the successful application of the system.

### RÉSUMÉ

Les projets de constructions aux travaux spéciaux en sous-sol exigent très souvent et en particulier un contrôle technique complet de tous les paramètres conditionnels ainsi que leur prompte évaluation pour assurer le succès, la qualité et la rentabilité. Il est donc indispensable à reproduire et organiser systématiquement le vaste flux de données dans un système de collecte, y comprises les interfaces pour le transfert de données (gestion des données) et les corrélations des données de genre différente (exploration de données).

Le rapport suivant présente la mise en application pratique d'un système qui a été développé pour des injections de levage en sous-sol pour prévenir des tassements aux bâtiments. Seulement à l'aide de ce genre de systèmes il est possible de réaliser de tels projets à grande échelle et d'une manière qualifiée. A cela, les quantités de données à traiter sont énormes et extrêmement hétérogènes, dépendant de leurs sources (par exemple: investigations du sous-sol, paramètres de projet et de procédure, mensurations géodésique). Donc, il n'est pas possible de considérer un genre de données isolé. Uniquement la corrélation des genres de données différents apporte des informations fiables pour appliquer le système avec succès.

Keywords : Data management, Data mining, Geotechnical Measurements, Observational Method, Production control, Process engineering, Quality control, Groutcontrol, ATDS, Jetcontrol, MaxiBor

## 1 MEASUREMENT DATA IN GEOTECHNICS

Measurements in geotechnics are taken for two main reasons. First it is necessary to prevent damages of any kind to structures and buildings. This means that the necessary information for this scope is obtained by the decision makers at a time early enough to allow additional means of prevention. A systematic approach in this way is part of the so called observational method which is described in the EN 1992 (Eurocode 2) and the German national standard code DIN 1054. The observational method is applicable for cases where system behaviour cannot be predicted with reasonable and satisfactory reliability by calculations only. In such cases the predicted system behaviour has to be verified by measurements and if measured and predicted behaviour differ more than is tolerable the calculations have to be reviewed and modified to fit into the real system behaviour. Thus the observational method describes an iterative design approach.

The second reason is the need to optimize the applied geotechnical method economically. This requires additional measurements, since the monitoring should cover beside the parameters connected to safety (e.g. deformations, earth pressures, pore water pressures, water levels etc.) also parameters relevant for the productivity or the consumption of materials. This results in taking readings simultaneously with very different measurement systems as shown for the data flow during tunnelling works in figure 1 for instance.

## Perfect control for tunneling works

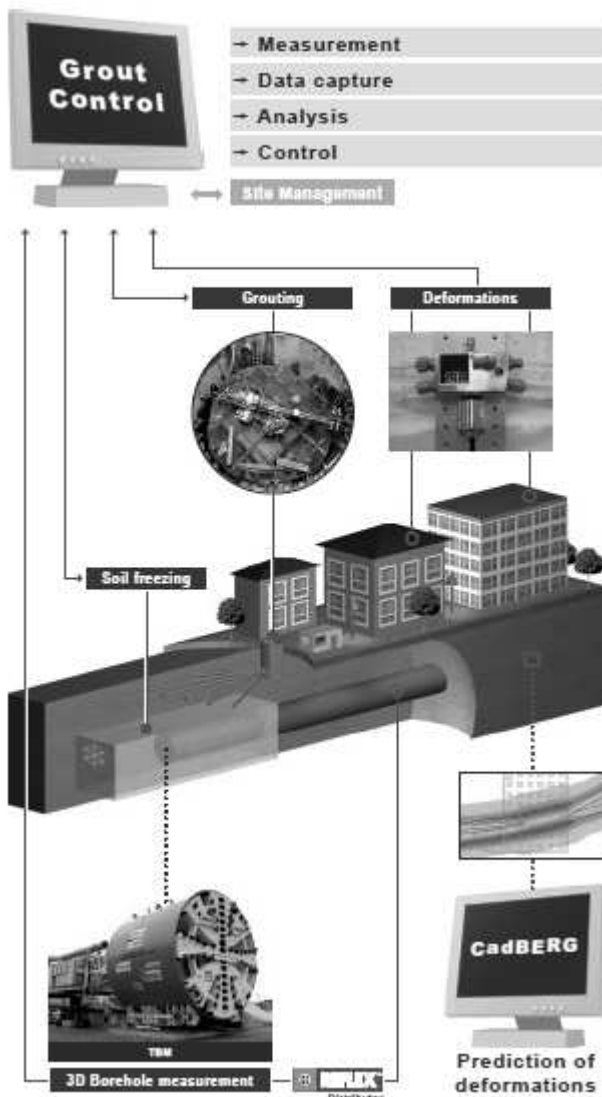


Figure 1: Data flow scheme for tunneling works

## 2 DIFFERENT TYPE OF DATA

The data mentioned in figure 1 can be obtained from quite different sources:

Table 1: Different sources of data

Geodetic measurement	<ul style="list-style-type: none"> <li>– Total station</li> <li>– Precise levelling</li> <li>– DGPS</li> <li>– Electronic distance measurements</li> <li>– Convergence measurements</li> </ul>
Geotechnical measurements	<ul style="list-style-type: none"> <li>– Pore water pressure sensor</li> <li>– Earth pressure cells</li> <li>– Water level sensors</li> <li>– Inclimeters</li> <li>– Extensometers</li> <li>– Deformation measurement</li> <li>– Drill inclinometers</li> </ul>
Multi-sensor measurement systems	<ul style="list-style-type: none"> <li>– Liquid levels</li> <li>– Crack meters</li> <li>– Tilt meters</li> <li>– Tilt beams</li> <li>– Temperature sensors</li> <li>– Vibration sensors</li> </ul>

	<ul style="list-style-type: none"> <li>– Accelerometers</li> </ul>
Parameter recording units	<ul style="list-style-type: none"> <li>– Loggers on rigs (depth, pressures, flow rates, amount of fluids, etc.)</li> <li>– Fleet management systems showing the status of machinery</li> <li>– Borehole measurement systems</li> <li>– Diameter measurement systems</li> <li>– Etc.</li> </ul>
Indirect (assumed) data	<ul style="list-style-type: none"> <li>– Assumptions for values derived from experience, tests, samples and indirect measurements (e.g. the diameter of jet grouting columns)</li> </ul>

Due to their different sources these data have different structures and hence they are heterogeneous. Data from 3D geodetic measurements usually is available as a list of xyz-coordinates (absolute or relative). Geotechnical measurements deliver one single measurement value such as pressure, stress or strain parameters. Multi-sensor systems deliver measurements of large numbers with single parameters (e.g. liquid cells or tilt meters) or multiple parameters as sets of parameters such as depth, pressures, flow rates among others for one discrete time interval in real time.

Some information can be obtained only indirectly so that assumptions have to be made derived from other data. The diameter of jet grouting columns is a perfect example for this type of data. There are a lot of different approaches to measure the diameter of jet grouting columns but none of them delivers a continuous correct measurement of the column diameter. Geotechnical contractors usually assume parameters for one type of soil from experience and verify these parameters with test columns at the beginning of their works. During progress of works a continuous 3D-measurement of the diameter usually is not possible at all or at least not at reasonable costs. But it is best practise to take continuous readings of all relevant process parameters to assume that keeping these parameters within a predefined range will result in the desired diameter. Security and quality of execution is gained by applying a variety of different measurements such as 3D geodetic measurement of the boreholes, borehole deviation measurements with inclinometers, core drillings and other key parameters. The absence of a direct measurement of the diameter is compensated by taking many other direct and indirect measurements simultaneously. As a result of all these measurements the column diameter is a qualified assumption.

The result of all measurements and assumptions can be displayed as an as-built drawing like shown in figure 2.

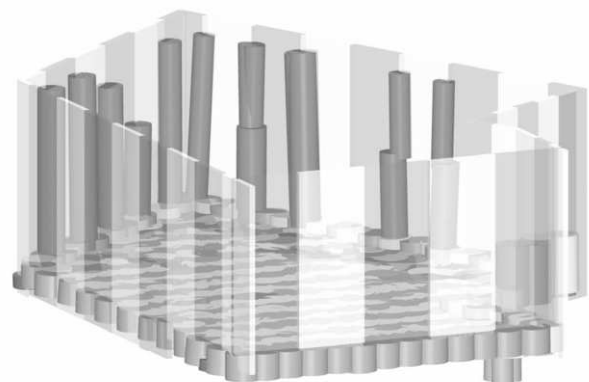


Figure 2: As built situation for a jet grouting slab for an excavation pit

## 3 INDICES AS A PRECONDITION FOR DATA ANALYSIS

Before analysing the described heterogeneous data it is necessary to provide a reasonable data infrastructure following the

data flow of the project. In practise for this purpose professional database systems can be used. The structure is represented by a number of indexes which are also a necessary precondition for the query according to a certain set of criteria.

The first important index is the time stamp of each dataset. Depending on the setup of the measurement system there can be a time gap between the registration of the measured value and the storage in the database. Especially for critical applications it is vital to have the timestamp of registration and not the one of storage in the database to prevent wrong interpretations.

The second important index is the 3D-coordinate where the reading has been made. Usually a local impact will affect the measurements taken nearby. To learn about the influence of this impact for each reading the 3D position of the sensor has to be registered as well. If this is the case it is possible to identify data coming from a certain area of the site which will be described more detailed later on.

Despite of time and location there are more indices possible like building phases and others relevant e.g. for accounting.

#### 4 SUMMATION AND INTERPOLATION AS A PRECONDITION OF DATA ANALYSIS

Depending on the applied measurement subsystem it may differ quite a lot what we call “density”. Not all subsystems measure in the same locations. E.g. for compensation grouting the position of the valves is different from the position of the liquid cells measuring settlement or heave. To allow analysis and interpretation an intermediate step has to be performed. This step is the summation or interpolation within a base area (quadrant) to obtain an equal base for comparison.

For this the site has to be divided into quadrants as shown in figure 3 for a compensation grouting site.

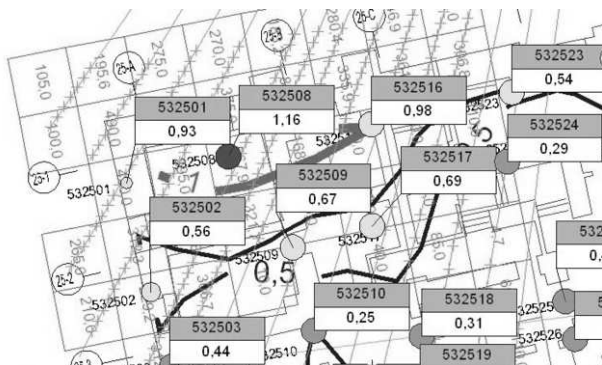


Figure 3: Division of the site in quadrants for data analysis

In figure 3 it can be seen that in one quadrant there can be far more than one single valve. For the analysis of the pressures and the amount of grout for all valves this has to be processed into a mean value of this quadrant as a base for further analyses.

In the same figure one can also see that not in each quadrant there is a liquid level meaning that the distribution density of the subsystem “liquid levels” is much smaller than the density of the subsystem “valves”. To be able to compare the results of both subsystems a common base for both subsystems is necessary. The measured values for the subsystem “valves” have to be added up for each quadrant and transformed into a mean value delivering e.g. a grout volume per square meter or an average grout pressure. The measured values for the liquid levels have to be interpolated using the existing liquid levels as base points for a calculated 3D surface for the settlement or heave. Using this 3D surface a vertical deformation for each quadrant can be calculated.

The result of this intermediate step is that each quadrant has a processed value for each measurement parameter that can be used for all further calculations and analyses.

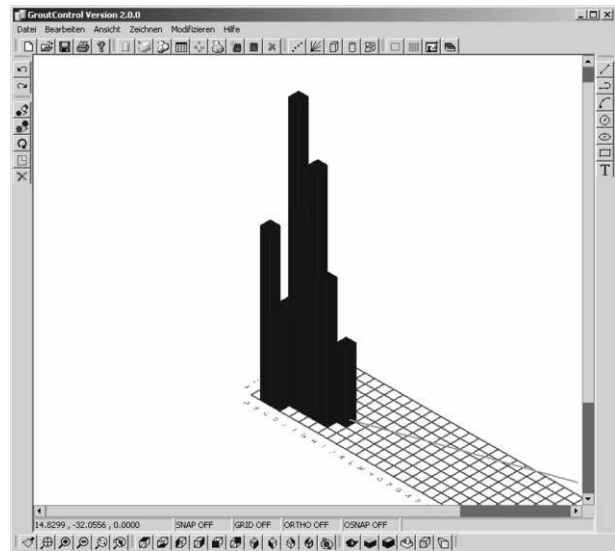


Figure 4: Processed values for each quadrant

#### 5 CORRELATIONS AS A TOOL FOR DATA INTERPRETATION

Based on the processed values for each quadrant calculated as described before, the desired information can be found by correlating different measured values. Which correlations are of importance depends on the construction method that shall be monitored and optimized.

For compensation grouting the quotient of effected heave (measured with liquid levels or precise levelling) and amount of grout or applied final pressure (measured as parameters on the grouting pump) are of interest. This is often called “grouting efficiency”. The idea is that during progress of work it is possible to learn about the specific system or soil behaviour and to predict the necessary effort to achieve a certain target of heave.

Similar correlations are used for tunnelling works between e.g. settlement and shield pressure or between meters per shift and settlements. In this case the correlations can be used to decide about the method of driving the tunnel and to approach an economic optimum between high productivity and reduced compensation measures for the affected structures.

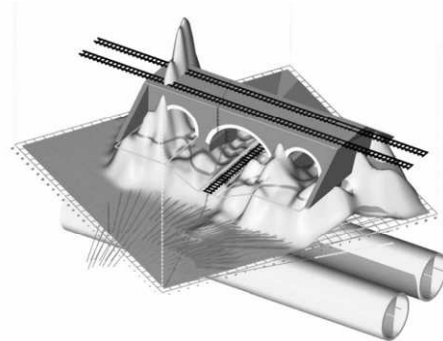


Figure 5: Grout volume for a bridge passed by a tunnel

#### 6 EXAMPLE FOR THE PRACTICAL APPLICATION

One example for the practical application of the above described principles is GroutControl®, a software developed by GeTec Ingenieurgesellschaft mbH for the control and design of compensation grouting and other grouting works.

GroutControl® is both a user interface for an SQL-database as well as a CAD-surface for the visualisation of results. GroutControl® is able to process results from the following systems:

Borehole measurement systems for the 3D as-built coordinates of the borehole	<ul style="list-style-type: none"> <li>REFLEX MAXIBOR II</li> <li>Horizontal inclinometer</li> </ul>
Monitoring of deformations	<ul style="list-style-type: none"> <li>Liquid levels</li> <li>Precise levelling</li> <li>Crack monitors</li> <li>Tilt meters</li> <li>Stress gauges</li> <li>Strain gauges</li> </ul>
Grouting parameter	<ul style="list-style-type: none"> <li>Grouting pressures (initial pressure, final pressure, mean pressure, etc.)</li> <li>Grout volumes</li> <li>Grouting Phases</li> </ul>

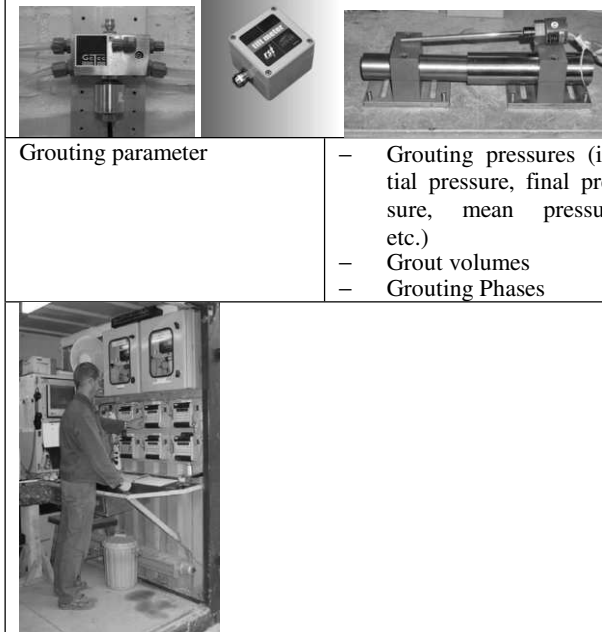


Table 2: Information processed in GoutControl®

GroutControl® was designed for assisting the site engineer to establish an iterative procedure to keep control about all relevant steps of complex grouting works.

The data itself is stored in a SQL database (several free and non-free systems available). GroutControl® provides an interface to interact with this database. Network capacities and scalability depend on the selected SQL database.

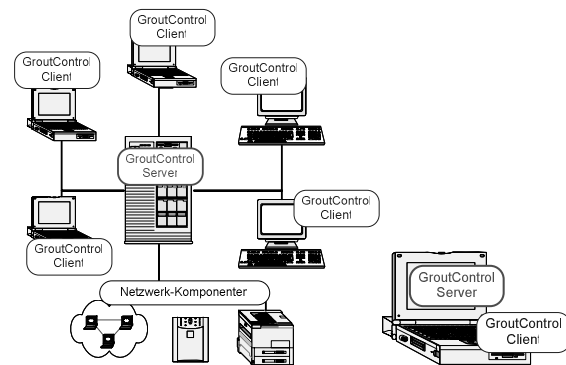


Figure 7: Possible system architecture for GroutControl®

The communication with the database is done by SQL queries for which GroutControl® provides a special mask adapted to the specific type of data for grouting works

The results of such a query are not just tables, but due to its CAD capabilities also a visualisation of the results. That means that the user is submitting a query and gets a drawing as a result like shown in figure 8.



Figure 8: Results of a query in GroutControl®

In this graphic display a lot of different CAD features are available like layer technique (figure 9), export in many common other CAD applications (DWG, DXF, DGN, etc.) for further graphical processing like rendering and others (figure 10).

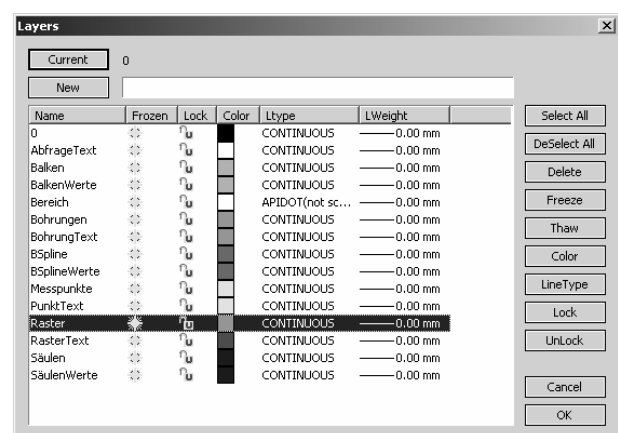


Figure 9: Layer control screen

Figure 6 : Data flow for compensation grouting

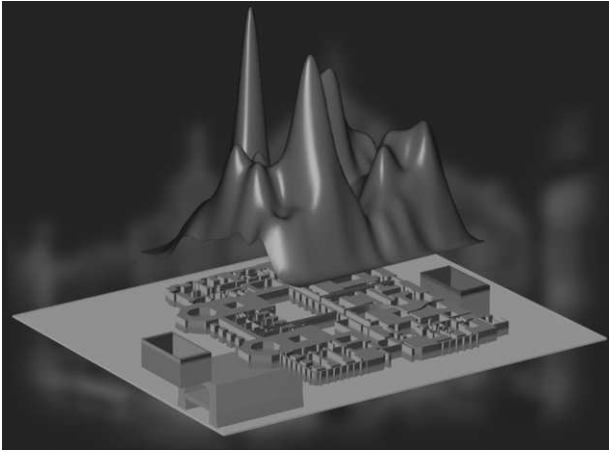


Figure 10: View of grout volumes rendered with Microstation®

GroutControl® is just one example of several software developed using the same principles.

**ATDS®** (Advanced Tunnel Drive System) was developed for monitoring and control of tunnelling machines. The parameters registered on the tunnelling machine are processed together with the results from deformation monitoring of structures. The aim of ATDS® is to have full control of all parameters of the tunnelling process and to be able to reduce additional compensation measures to an absolute minimum for reducing costs.

**JetControl®** was developed for monitoring and control of jet grouting works. JetControl® manages data from geodetic measurements for the borehole mouth, measurement of the borehole deviation over depth with inclinometers and all production parameters of the jetting process like grout volume,

grout pressure, rotations per minute of the jet, lifting speed, compressed air, etc. JetControl® is applied for complex jetting works with strict requirements in respect of the quality of the jetted body.

## 7 CONCLUSION

Today sophisticated systems are available to control all key parameters of geotechnical works continuously during progress of work. With this continuous control both safety and efficiency are improved significantly. Despite of that the information density allows a better understanding of the method in terms of soil mechanics and process engineering as a base for further research and development. With these systems geotechnical works now can be executed at a level of quality never achieved in the past.

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