TEMPJET: Continuous Quality Control and Quality Assurance

Thermal modelling software to determine the diameter of jet-grouted columns

Klaus Meinhard

The Foundation Engineering Division of PORR Bau GmbH Infrastruktur has held an Austrian patent for Tempjet since 2009. The European patent will be granted in 2012. The innovative Tempjet method allows fast and efficient determination of the diameter and cement content of jet-grouted columns – even at great depths. It is no longer necessary to excavate test columns and conduct time-consuming examinations. PORR has also been selling licences for the application of the Tempjet method for about one year now, and some renowned international companies have already purchased such a licence. The Tempjet method has already been successfully used for quality control in jet-grouting works in Austria, Germany, Hungary, Poland, the UK, Greece, Denmark and Switzerland – either as a service provided by PORR or by licence holders themselves. A company based in Cleveland, Ohio which offers quality assurance services on the global market has also expressed its interest in PORR’s Tempjet method.

General information

The thermal simulation model described in this article provides a new method for determining the diameter of columns which are produced by jet grouting, a method frequently used in specialised civil engineering. The model is based on a numerical simulation of temperature changes in hydrating jet-grouted columns and of heat transfer to the surrounding soil. The properties of the grout used in the method, the thermal characteristics of the jet-grouting suspension and the physical and thermal characteristics of the native soil constitute the input parameters. A comparison of the temperature changes at the centre of the column as measured at the construction site and of the temperature curve that results from the numerical modelling process provides an indication of the diameter and cement content of the column. The key economic advantage of this solution is that it is no longer necessary to drill additional holes or to excavate test columns to measure their diameters.

Regardless of the method used for producing the columns (single, double or triple fluid jet grouting), excellent results can be achieved with various grouts and in a wide range of different soils. The aim of the method is to allow continuous quality assurance on site throughout the entire course of the jet-grouting works.

State of the art

The most reliable way of determining the properties of a jet-grouted column until now has been to produce test columns, which are left to set for at least two days and are then excavated (see fig. 1). The European Standard EN 12716, which applies to jet-grouting procedures, also provides for using this method. A major drawback of these quality control measurements is that, apart from being rather time-consuming, they only provide very selective information about the properties of the jet-grouted elements as obtained from the measurement points. If jet-grouting works are carried out at greater depths, an excavation of test columns is often neither technically feasible nor economically defensible.

Examples of measuring methods which are currently used by specialised civil engineering companies for determining the diameter of jet-grouted columns include the use of a probe or a mechanical measuring device which folds like an umbrella, erosion measurements at pre-installed level indicators, examinations of the slurry flowing back out at the surface, sound level measurements using hydrophones and ultrasound measurements. The main constraints that limit the applicability of these methods are the characteristics of the native soil, the geometrical properties of the elements and economic considerations.

Theoretical background

A method for determining the diameter of jet-grouted columns and the material properties of the grout used for jet grouting was developed in a research project which was carried out by PORR Technobau und Umwelt AG in cooperation with the
Institute for Mechanics of Materials and Structures at Vienna University of Technology and completed in 2007. This method combines in situ temperature measurements with a simulation model that describes the exothermic setting reactions of cement-bound materials.

The temperature changes measured at the construction site generally show an initial increase of the column’s temperature due to the exothermic setting reaction taking place during the hydration of the cement. After 10 to 60 hours, a peak temperature is reached. The progress of the subsequent temperature decrease is mainly influenced by the properties of the native soil and the dimensions of the column.

Numerical parameter studies have shown that the cement content of a column mainly influences the temperature rise at the start of the setting process (see fig. 2a: Parameter study – temperature changes at the centre of jet-grouted columns having a constant diameter of 150 cm, their cement content varying from 100 to 500 kg/m³) and that an increased diameter results in a later peaking and a slower decrease of the temperature (see fig. 2b: Parameter study – temperature changes at the centre of jet-grouted columns having a constant cement content of 300 kg/m³, their diameters varying from 80 to 240 cm). These effects can also be observed in in situ temperature measurements.

Due to these significant differences, a comparison of temperature changes as measured at the construction site and the results of numerical calculations provides an indication of the cement content and the diameter of the columns.

The quality of the results, i.e. the properties of the jet-grouted element that are identified by the comparison, very much depends on the description of the cement hydration process and of the thermal properties of the soil and the grout suspension on which the model is based.

**Measuring method**

The temperature changes in the columns are determined by a measuring system consisting of a data logger and a temperature probe.

Commercially available temperature measuring systems which allow simultaneous measurements to be taken at several temperature measuring cables and automatically record the results are used as data loggers. PORR has developed and produced GSM measuring devices for online monitoring to enable automatic recording of measurement results at construction sites (see fig. 3: Measuring system, consisting of a data logger including a GSM module for remote monitoring, a spare battery and connected thermo sensors).

The temperature probe consists of a PVC sleeve of the type that is commonly used for electric installations in building construction. The sleeve has a diameter of approximately 14 mm, and up to six measurement cables can be inserted into it. Temperature probes are assembled as needed, depending on the conditions at the construction site, including the depth of the soil layers to be examined and the total length of the column (see fig. 4: Temperature probe with internal temperature measuring cables).
In the future, use might be made of a measuring cable protected by worldwide patent which allows digital measurement of temperatures throughout the jet-grouted column, e.g. at distances of approx. 30 cm. This cable was first tested in March 2012.

**Use at construction sites**

With the thermal modelling solution, it is no longer necessary to produce special test columns to determine the column diameter. The temperature can be measured in any column of the building structure. It is, however, important to adjust the length of the respective column if necessary, as it should extend above and below each temperature sensor by a length corresponding to the obtained diameter, in order to prevent the temperature changes from being influenced from the upper or lower edge of the column.

It is important to make sure that the sensors are positioned at the exact centre of the column and at the desired depth immediately after grouting. They are usually inserted via the drill rod of the drilling tool, allowing for the simultaneous positioning of several sensors at different depths.

The positioning of the temperature probe is illustrated in detail in the following figures.

**Fig. 5a:** The drill rod is drilled into the soil until it reaches the lower edge of the jet-grouted column.

**Fig. 5b:** The rod is broken open, and the temperature probe is inserted.

**Fig. 5c:** The temperature probe is inserted into the jet-grouted column until it reaches its lower edge.

**Fig. 5d:** The drill rod is re-assembled in order to be pulled out; the probe remains in the drilled hole.

**Fig. 5e:** The drill rod has been completely pulled out; the probe remains in the soil.

**Fig. 5f:** Data logger connected to the probe for conducting temperature measurements (this photo shows the testing of newly developed measuring devices from the Cleveland-based company PDI, conducted at the construction site of the Palais Fürth building project in Vienna.)
After the drill rod has been pulled out, the data logger is connected to the temperature sensors, and data recording starts. Although the recorded data can be checked at any
time, the presented method can only be applied after the hydration temperature has peaked (approximately after 15 hours for columns with a diameter of about 1.0 m, after 60 hours for columns with a diameter of about 2.5 m).

Once the data have been read from the data logger, each individual curve derived from the recorded measurements (see fig. 6: Read-out temperature file) is assigned to the depth at which the corresponding temperature sensor was installed. Temperature changes in the column are then numerically simulated for each depth. In addition to the input parameters, including a specification of the grout, soil parameters (raw unit weight, thermal parameters), etc., a search range is defined for the simulation by setting minimum and maximum values for the possible column diameter and cement content. The numerically calculated temperature curves for a large number of pairs of values (diameter and cement content) within this range are then compared to the actual temperature curve measured at the construction site. The pair of values that gives the best match between the calculated curve and the curve measured in situ describes the predicted properties of the jet-grouted column at the respective depth (see fig. 7: Simulation result showing matching temperature curves – blue: curve measured in situ; red: numerical simulation).

**Limitations of use**

The presented method is based on the correct recording of temperature changes in the course of hydration and of the heat transfer to the surrounding soil. If the hydration heat of the applied grout is low (e.g. grouts with a blast-furnace slag or rock flour content of > 80%), the distinct temperature rise at the centre of the jet-grouted column that is required for the simulation will not occur. In this case, the process cannot be modelled. Groundwater streams and neighbouring columns that are hydrating at the same time also adversely affect the precise determination of column diameters by means of thermal modelling, as they may prevent a steady, rotationally symmetrical dissipation of heat from the jet-grouted column.

**Summary**

In recent years, thermal modelling to determine the diameter of jet-grouted columns has been applied at numerous construction sites, yielding a high correspondence between numerically predicted diameters and the actual diameters of excavated test columns. This method also allows determination of the cement content of a jet-grouted column. Due to the low additional costs, its application has proved very efficient for quality assurance during jet-grouting works, always bearing in mind the limitations described above.