

A METHOD OF MONITORING THE DIAMETER OF COLUMNS MADE BY  
INJECTION

The present invention relates to a method of  
monitoring the diameter of columns made by the technique  
5 of injection under pressure known as "jet grouting".

That technique consists in drilling a substantially  
cylindrical vertical hole in the ground by using a tool  
which delivers one or more jets of liquid under pressure  
enabling the ground installation to be prepared, with the  
10 hole obtained in this way being filled with a grout or  
analogous material so as to obtain a column which is  
molded in the borehole. That technique is described in  
particular in French patent No. 2 700 128.

It will be understood that during the operation of  
15 "drilling" the hole by means of jets of liquid. Under  
pressure, the actual diameter of the borehole can vary  
significantly at successive depths, depending on the  
irregularities encountered in the subsoil, and in  
particular depending on the varying nature of the  
20 subsoil. As a result, the column obtained in this way  
can have significant relative differences of diameter  
depending on the depth under consideration. This problem  
is particularly severe when the depth of the column is  
large, which depth can be as much as 15 meters.

25 In some cases, a succession of adjacent columns are  
made so as to constitute a continuous barrier in the  
ground. It is clear that for that type of application,  
it is particularly important to be able to monitor the  
diameter of each column at different depths so as to be  
30 sure that the resulting barrier is continuous over its  
entire height.

At present there is no method of monitoring the  
diameter of columns made by jet grouting once they have  
been made. The technique used consists in making a test  
35 column whose top portion is unearthed so as to inspect  
its diameter visually. It will nevertheless be  
understood that that technique is relatively burdensome

to use and in any event does not enable the diameter of the deeper portions of the column to be monitored.

Techniques are also known for making electrical measurements in order to determine the nature of the ground to a certain depth. In those techniques, a probe comprising a succession of regularly spaced apart electrodes is installed in a borehole, and the electrodes serve both as electrodes for measuring potential difference and as electrodes for injecting electricity into the ground.

The electrodes that inject electric current create electric field lines in a cylindrical volume surrounding the borehole, and the potential difference measurements performed at different depths in the borehole enable the characteristics of the ground to be determined at different depths by measuring a physical magnitude representative of the nature of the ground. This physical magnitude is constituted by the resistivity of the ground which, when determined, can be used to evaluate the nature of the ground. One such technique is described in detail in European patent No. 0 518 686, in the name of the Applicant.

An object of the present invention is to provide a method of monitoring the diameter of columns made in the ground by jet grouting, which method is not of the destructive type, and enables monitoring to be performed over the full height of the column made.

To achieve this object, the invention provides a method of monitoring the diameter of columns made in the ground by jet grouting, the method being characterized in that it comprises the following steps:

- a measuring instrument is provided that is constituted by a tubular element of length substantially equal to that of the column, said tubular element being fitted with a plurality of emission electrodes for creating an electric field and with a plurality of measurement electrodes for measuring potential

differences created by said electric field, the electrodes being connected respectively to a source of electricity and to potential measuring means;

· a reference borehole is made in the ground close  
5 to the location where the columns are made, and said measuring instrument is placed therein to take voltage measurements representative of the physical characteristics of the ground at different depths of the reference borehole so as to obtain a series of reference  
10 measurements for said depths;

· an axial borehole is bored in the column to be tested, with the diameter of the axial borehole being much smaller than the diameter of said column;

· said measuring instrument is inserted into the  
15 borehole made in said column and voltage measurements are made corresponding to different depths, thus obtaining actual measurements of voltages representative of a physical characteristic associated with said column and with the surrounding ground at different depths; and

20 · said actual measurements are processed with reference to said reference measurements so as to obtain information representative of the diameter of said column at said different depths.

It will be understood that in this method, a  
25 reference borehole is made initially close to the location where the columns are to be made. Electrical measurements are taken in the reference borehole to obtain the reference physical magnitudes corresponding to different depths in the resulting borehole. The depth of  
30 the borehole naturally corresponds to the depth of the columns to be made.

In a second step, after the column has been made by jet grouting, an axial borehole is made in the resulting column and the same measuring apparatus is used to take  
35 measurements at different depths of the borehole, and thus of the column. The measurements taken in this way serve to obtain, for each depth, a physical parameter

which is associated firstly with the diameter of the column at said depth and secondly with the surrounding portion of ground involved in the electric field that is created. By processing these measurements at each depth  
5 in association with the results obtained when performing reference measurements in the reference borehole, it is possible to deduce values which are inherent to the column on its own, and thus to deduce the diameter thereof or at least a relative magnitude representative  
10 of variations in the diameter thereof.

In a first implementation, while boring the axial borehole in said column, any inclination of said borehole relative to the vertical is measured at different depths so as to obtain a series of inclination measurements, and  
15 the information representative of column diameter for the different depths is corrected with the help of said inclination measurements.

In this improved implementation, it will be understood that account is taken of any inclination of  
20 the borehole made in the column prior to installing the measuring instrument. Determining inclination at different measurement depths enables the actual measurements to be corrected and thus enables diameter measurements to be corrected.

25 In a first implementation, said axial borehole is made when the material for making said column has not yet set.

In a second implementation, said axial borehole is made when the material constituting said column has set,  
30 at least partially.

Preferably, the physical magnitude is the resistivity of the ground or of the material constituting the column, and in order to process said actual measurements with the help of said reference  
35 measurements, special software is used for providing a three-dimensional interpretation of the reference resistivity measurements and of the actual resistivity

measurements relating both to the shape of the column and to the surrounding ground.

Other characteristics and advantages of the invention will appear better on reading the following  
5 description of different embodiments of the invention given as non-limiting examples. The description refers to the accompanying figures, in which:

- Figures 1A to 1D show the different steps of the method of measuring column diameter;

10     • Figure 2 shows a first implementation of the measurement method; and

- Figure 3 shows a second implementation of the method of the invention.

With reference initially to Figures 1A to 1D, there  
15 follows a description of the entire method of measuring the diameter of columns made by jet grouting, and doing so at different points along the height of the column.

In the first step shown in Figure 1A, a cylindrical hole 12 of length L is drilled in the ground 10, which  
20 length is equal to the length of the columns that are to be made. An electrical measurement instrument 14 is inserted into the borehole 12, which assembly comprises a tubular element 16 containing a set of probes 18 disposed at intervals and essentially constituted by electrodes  
25 each connected to electrical conductors 22. The electrical conductors 22 are connected electrical devices symbolized by reference 24 which essentially comprises current generators and devices for measuring potential differences. As described in greater detail in European  
30 patent No. 0 585 686, which should be considered as forming an integral portion of the present patent application, some of the electrodes are current injection electrodes for setting up electric field lines defining an electric cylinder 26 in the ground, which is a  
35 function of the position of the injection electrodes. The other electrodes are potential difference measuring electrodes enabling the potential difference between two

distinct points in the borehole to be measured, said potential difference depending simultaneously on the created electric field and on the resistivity of the medium concerned by the created electric field. It will  
5 be understood that by powering successive pairs of injection electrodes and by performing successive potential difference measurements at different levels, it is possible to draw up a map of ground resistivity for the different depths down the borehole 12. In the  
10 particular example under consideration, three distinct layers of terrain I, II, and III are determined corresponding to resistivities  $\rho_{01}$ ,  $\rho_{02}$ , and  $\rho_{03}$ ; these resistivity measurements associated with the depths corresponding to the different layers are stored in a  
15 memory 30.

In the following step, the jet grouting technique is used to make a first column 32 in the ground 10, with the interface between the column and the ground 10 being given reference 34. At each depth  $x$ , it will be  
20 understood that the grout constituting the column 32 presents an associated diameter that varies depending on the nature of the ground.

In the following step, shown in Figure 1C, an axial borehole 36 is made in the column 32. This borehole 36  
25 can be made either before the grout has set, in which case the borehole 36 consists in an axial zone in which the grout has reduced mechanical strength. Otherwise the borehole 36 is made after the grout has set at least to some extent, in which case the borehole 36 does indeed  
30 constitute an axial hole.

In the following step, shown in Figure 1D, the above-described measuring instrument 14 that is essentially constituted by its tubular element and by its current injection electrodes and potential difference  
35 measuring electrodes 18 is put into place in the axial borehole 36. By powering the injection electrodes successively and performing successive measurements using

the measurement electrodes, resistivity measurements are obtained for the different depths of the column where these measurements are performed. Each resistivity measurement  $\rho_0$  depends both on the diameter of the column, i.e. the quantity of grout involved in the potential difference measurement, and on the resistivity of the surrounding ground. It will be understood that by using the computer circuits 24 to process these different resistivity measurements  $\rho_x$  as a function of depth  $x$  using the reference resistivities  $\rho_{01}$ ,  $\rho_{02}$ , and  $\rho_{03}$  in this particular example, it is possible to deduce therefrom useful resistivities that correspond solely to the grout constituting the column 32, as a function of depth  $x$ . This resistivity measurement is representative of the diameter of the column at the depth in question. This processing of the resistivity measurements obtained in the reference borehole and of the resistivity measurements performed at different depths in the column is performed by implementing special software for interpreting the measured apparent resistivities. This software makes use of propagation laws for electric current in the ground (reference) and in both the ground and the column (measurements performed) in three dimensions while taking account of the parameters that relate to the ground and to the material constituting the column (layers in the ground, thicknesses of the layers, resistivities of the layers, resistivity of the column material, ...). In the above-mentioned patent, the principle on which this processing as applied to the ground is explained.

In an improved implementation, when the axial borehole 36 is made, any inclination of the borehole is also measured. For this purpose, the boring tool is fitted, for example, with an inclinometer. When the depth  $L$  of the column is large, it is difficult to ensure that the axial borehole 36 is accurately vertical. It will be understood that by correcting the useful

resistivity values as determined above using a coefficient associated with any inclination of the borehole, it is possible to obtain the diameter of the column 32 at the different depths  $x$  with greater  
5 accuracy. The measuring instrument can be one of two different types, as shown respectively in Figures 2 and 3.

In Figure 2, the tubular element of the measuring instrument is constituted by tubes of perforated plastics  
10 material 40 which are connected to one another so as to obtain a tubular element of suitable length. Probes 18 are stored in the tubular element together with their electrical conductors 22. The bottom tube 40a is closed by a plug 42. To facilitate installing the tubular  
15 element in the axial borehole and to prevent particles from penetrating into the tubular element via the perforations, it is possible to put a "sock" of engineering fabric or "geotextile" around the tubes 40. The probes can be installed inside the tubes 40 before  
20 the instrument is inserted in the axial borehole of the column.

The probes 18 can also be installed in the tubes 40 after they have been placed in the axial borehole. Naturally, an electrically conductive liquid must be  
25 introduced into the perforated tubular element so as to provide electrical continuity between the probes 18 and the material constituting the column 32.

In Figure 3, the tubular element of the measuring instrument is constituted by insulating tubes 50  
30 interconnected by conductive sleeves 52 which constitute the electrodes. A set of electrical conductors 54 connects the different conductive sleeves 52 to the electrical equipment disposed on the surface. The bottom tube 50a is fitted with a plug 56.

35 Such a measuring instrument is described in detail in European patent application EP 0 863 412 in the name of the Applicant.



## CLAIMS

1/ A method of monitoring the diameter of columns made in the ground by jet grouting, the method being characterized in that it comprises the following steps:

- 5       · a measuring instrument is provided that is constituted by a tubular element of length substantially equal to that of the column, said tubular element being fitted with a plurality of emission electrodes for creating an electric field and with a plurality of  
10 measurement electrodes for measuring potential differences created by said electric field, the electrodes being connected respectively to a source of electricity and to potential measuring means;
  - a reference borehole is made in the ground close  
15 to the location where the columns are made, and said measuring instrument is placed therein to take voltage measurements representative of the physical characteristics of the ground at different depths of the reference borehole so as to obtain a series of reference  
20 measurements for said depths;
  - an axial borehole is bored in the column to be tested, with the diameter of the axial borehole being much smaller than the diameter of said column;
  - said measuring instrument is inserted into the  
25 borehole made in said column and voltage measurements are made corresponding to different depths, thus obtaining actual measurements of voltages representative of a physical characteristic associated with said column and with the surrounding ground at different depths; and
  - 30       · said actual measurements are processed with reference to said reference measurements so as to obtain information representative of the diameter of said column at said different depths.
- 35 2/ A method according to claim 1, characterized in that while boring the axial borehole in said column, any inclination of said borehole relative to the vertical is



measured at different depths so as to obtain a series of inclination measurements, and the information representative of column diameter for the different depths is corrected with the help of said inclination measurements.

3/ A method according to claim 1 or 2, characterized in that said axial borehole is made when the material for making said column has not yet set.

4/ A method according to claim 1 or 2, characterized in that said axial borehole is made when the material constituting said column has set, at least partially.

5/ A method according to any one of claims 1 to 4, characterized in that the tubular element of said measuring instrument is constituted by a plurality of interconnected perforated tubes, said electrodes being placed inside said tubular element, and in that said tubular element is filled with an electrically-conductive liquid.

6/ A method according to any one of claims 1 to 4, characterized in that said tubular element of the measuring instrument is constituted by a plurality of assembled-together tubes made of insulating material, said tubes being provided on their outside faces with annular conductive zones forming said electrodes, and in that the electrical conductors are disposed inside said tubular element to connect said conductive annular zones to said electrical power supply and to said voltage measuring means.

7/ A method according to any one of claims 1 to 6, characterized in that said physical characteristic is resistivity.



8/ A method according to claim 7, characterized in that  
in order to process said actual measurements with the  
help of said reference measurements, special software is  
used for providing a three-dimensional interpretation of  
5 the reference resistivity measurements and of the actual  
resistivity measurements relating both to the shape of  
the column and to the surrounding ground.