

"Method and device for surveying soils and rocky media"

The present invention relates to a method and apparatus for surveying soils and rocky media. The efficient exploitation of underground natural resources requires a precise evaluation of the resources which may be exploited. Thus in the fields of hydrogeology and in oil prospecting it is necessary to have available more and more exact knowledge of the geological, geometrical and hydraulic characteristics of underground reservoirs. This concern also affects geotechnicians who, to predict the hydromechanical behaviour of rock masses traversed by flows of water, have to have available a detailed description of the geometrical, hydraulic and mechanical parameters. Other disciplines, notably geothermics and storage of products such as radioactive products in underground rock masses, of which the development is recent, also require such information to be able to set up working models.

Thus these different disciplines, because of their objectives and their technology, encounter at some stage in their activity the same problems in determining the parameters to be introduced into a working model.

Flows in a fissured medium, initially interpreted by a classical model of a porous medium characterised by the distribution of porosity and permeability, are currently the subject of models in which the discontinuities are taken into account. This description, known as analytical description, considers the rocky medium as a homogeneous continuous material separated by discrete discontinuities known as fissures or fractures.

Very different technical methods are available to the technician to obtain information about the rocky medium to be studied. Modern methods of structural geology associated with geophysical measurements allow precise

description of the geometry of the medium. Hydraulic parameters are determined in general by trials using pumping or injection in a temporary or pseudo permanent manner.

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Methods of geological structural analysis consist of carrying out a systematic survey of fractures in the zones affected by the flow which is studied. This survey is carried out from observations in bores, galleries or on
10 outcrops.

Geophysical methods consist of the application to rocks of the general laws understood from physics. By this method there are determined the values for the rocky mass studied
15 of the parameters associated with these laws (electrical resistance, magnetic susceptibility, radioactivity, speed of sound, thermal conductivity, etc.). By the interpretation of these parameters there may be obtained information on the medium studied, such as the nature and position of layers,
20 fractures, porosity, etc. There are also known gravimetric methods, electric methods, magnetic methods and electromagnetic methods, methods using seismic prospecting, radioactive methods and thermometric methods. These known methods are described in detail in the book "Geophysique appliquee a l'hydrologie"
25 by Mr. J.L.ASTIER (Masson 1967).

Hydraulic methods consist essentially of trials using pumping or injection in bores which may be lined or unlined and partially obturated.

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These methods are associated with test techniques such as Lugeon trials, the use of a probe known as a triple hydraulic machine or use of a piezofor or piezopermeometer, and methods of interpretation which are described in a
35 report published by The International Society for Rock Mechanics in August 1977, and entitled "Suggested Method for Determining Hydraulic Parameters and Characteristics of rock Masses". These methods of interpretation may be classed as

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permanent or pseudo-permanent models which allow determination of the overall or local permeability and as transitory models which allow interpretation of measurements in the fissured medium of simple geometry and of which the scale of the fissures is small with respect to the scope of the trial.

Trials interpreted by these different methods supply information which is still very uncertain in fissured rocky media. In fact this information is expressed most often by the determination of a local permeability which is difficult to relate to an analytical parameter of the extent of the fissures of the medium. For example the extent of the fissures or fractures is a parameter which is especially difficult to estimate.

The present invention suggests a method and a device for surveying rocky media and soils allowing provision of spectral signatures of the zones explored and allowing by interpretation of the results obtained both qualitative and quantitative determination of the parameters of the media studied, especially the dimensions of fissures.

According to one aspect of the invention, there is provided a method of surveying soils and rocky media, in which there is isolated a zone of predetermined height in an exploration shaft, there is caused in said zone of the shaft an alternating flow of fluid in the shaft and the surrounding medium according to a predetermined function, preferably sinusoidal, the static pressure in said zone is equilibrated with the pressure outside the zone, the frequency of said function is caused to vary through a range of values, there is detected for each of said frequency values the dynamic back pressure generated in said zone of the shaft by said alternating flow of fluid and there is compared with reference models, which may be mathematical models, the variations as a function of said

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frequency of the ratio between the magnitude of said dynamic back pressure and the magnitude of the flow.

According to another aspect of the invention, a
5 device for carrying out such a method comprises a probe capable of being lowered into an exploration shaft at the end of a train of rods, this probe comprising inflatable obturators capable of being applied against the walls of the shaft and being fed with hydraulic fluid from the
10 surface and defining between them an isolated zone of measurement, said probe comprising means for causing from its peripheral surface an alternating flow of fluid in the shaft and the surrounding medium, a counter-pressure mechanism for equilibrating and compensating the static
15 pressure in the zone of measurement, a pressure detector in the zone of measurement of the shaft and means for connecting the probe to the surface for feeding operating fluids thereto and transmitting to the surface of information provided by the pressure detector.

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The method according to the invention thus consists of studying a system which in the case of a trial for water in a fissured medium may be considered as being a medium having two phases, solid and water, in which is mounted in
25 place a trial device. There is caused in this system an excitation or input signal, which in the present case is an alternating flow, the response of the system being provided by detection and measurement of the dynamic pressure caused by this excitation. The dynamic pressure may be,
30 after establishment of a stationary regime, a sinusoidal function like the function of the exciting flow.

The method according to the invention allows provision of spectral signatures of the zones studied, these
35 spectral signatures being variations in a function of the frequency of the modulus of the transfer function of the system, a good approximation to this modulus of the transfer function being given by the ratio between the

moduli of the function of the dynamic pressure generated and of the alternating flow of the fluid created.

It is remarkable, as will be seen below, that a
5 fissure in a rocky medium behaves with regard to
excitation as a resonator, the resonance frequency being
characteristic of the extent of the fissure.

The isolation of a zone of measurement may be carried
10 out advantageously in a manner known as such, by the use of
inflatable obturators or "packers", operated hydraulically
from the surface.

An alternating sinusoidal flow may advantageously be
15 caused by alternating displacements of a membrane, notably
in the form of a metallic bellows forming a part of the
external tubular wall of a probe introduced into the shaft.

In a particular embodiment the alternating movements
20 of this membrane may be generated by the alternating to
and fro movement in a chamber of a piston integral with a
shaft driven in rotation continuously, especially from a
turbine.

25 This embodiment is especially advantageous when the
measurement or the modulus of the function of the flow is
thus, for a piston of determined characteristics, directly
proportional to the frequency of rotation of a turbine
which is easy to measure. By measurement of this
30 frequency of rotation and by an appropriate calibration
there is directly known the modulus of the flow function,
that is to say in fact, the average amplitude of the flow
generated in the fluid in a stationary sinusoidal mode.

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The device according to the invention may comprise a probe capable of being lowered into exploration shafts at the end of a train of rods, this probe comprising inflatable obturators capable of being applied against
5 the walls of the shaft and being fed with hydraulic fluid from the surface and defining between them an isolated zone of measurement, the probe comprising means for causing from its periphery an alternating flow of fluid in the shaft between the latter and the surrounding
10 medium, especially a chamber in which is movable in to and fro motion a piston, said piston being integral with the shaft driven in rotation from a turbine, said chamber being in communication with a chamber, of which the external wall is an annular membrane, preferably metallic
15 bellows, the probe comprising further a mechanism for counter pressure to equilibrate and compensate the static pressure in the zone to be measured, a pressure detector in the zone of measurement of the shaft and means for connecting the probe to the surface to channel
20 the different operating fluids and transmit to the surface the information provided by the pressure measurement device.

Advantageously the piston has a cylindrical shape of
25 which the surfaces at the end are inclined and is guided in said chamber in such a manner that the continuous movement

of rotation of the shaft of the turbine is transformed into an alternating to and fro movement of the piston.

The speed of rotation of the shaft may advantageously
5 be measured by a photoelectric means arranged in the probe.

The counter pressure mechanism comprises advantageously at the lower part of the probe a reservoir of compressed gas at a pressure at least equal to the static pressure at the
10 maximum depth to which the probe will be lowered and an orifice in the lower part of the probe isolated from the reservoir by a valve, a capillary connection being provided between said valve and a point on the periphery of the probe in the zone of measurement between the inflatable obturators.

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A device according to one embodiment of the invention will now be described by way of example with reference to the accompanying drawings in which:

20 Figure 1 shows very schematically a device according to the invention mounted in place in an exploration shaft, the left part of the figure showing the upper part of the device which is connected to the lower part of the latter shown in the right part of the figure,

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Figures 2 and 3 are graphs showing spectral signatures of fissures of different dimensions.

The device shown in Figure 1 is an elongated probe for
30 use in an underground shaft fixed to the lower end of a train of rods 1 comprising lines for hydraulic and electrical connections to provide the different energy sources necessary for the functioning of the probe, and to transmit to the surface the information recovered.

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The probe comprises an upper inflatable obturator 2 and a lower inflatable obturator 3 known as "packers" and capable of being inflated from the surface by a feed of

hydraulic fluid so as to become applied against the walls of the shaft 4.

After inflation the obturators thus define between them an insulated zone for measurement inside which there is shown schematically a fissure or fracture 5.

The device comprises a turbine 6 of a type used in hydraulic drilling of which the hydraulic feed fluid is removed through a valve 7 exterior to the upper inflatable obturator 2.

The output shaft 8 of this turbine 6 is connected to a piston 9 having end surfaces 10 inclined at an angle which may reach 60° , the preferred average slope being of the order of 45° . The piston 9, because of the movement in rotation of the shaft 8, is displaced in a to and fro movement vertically in the chamber 11, which is filled with oil. The piston is guided in this chamber and its displacements are limited by upper and lower cam rods.

Above the chamber 11 and in communication with the oil of the latter there is a chamber 12 of which the peripheral wall is formed by a membrane in the form of metal bellows 13. The alternating movement of the piston 9 in the chamber 11 under the action of rotation of the turbine 6, thus causes alternating pulsating displacements of the membrane 13 causing displacements of the fluid surrounding the probe in the insulated zone for measurement and, for each pulse, causing alternately a feed of fluid in the shaft towards the fissure 5 then reflex of fluid from the fissure 5 again into the shaft in the zone of measurement. The arrangement of the piston and the membrane is preferably such that the feed function thus generated has a sinusoidal form.

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In a particular embodiment there is used a piston having a cross-section of 78.5 cm^2 , and a path of travel of 10 cm which for each half turn of the shaft and thus of the path



of the piston, gives a feed of fluid in the fissure of 785 cm³ per cycle.

At its lower part the device comprises a counter-
5 pressure mechanism allowing compensation and equilibration of the static pressure prevailing at the depth at which the probe is mounted in place.

The counter-pressure mechanism comprises essentially a
10 reservoir of gas 14 compressed to a high pressure corresponding to that prevailing at the maximum depth to which the probe is to be lowered, for example 200 bars, this application of pressure being carried out at the surface. The mechanism comprises at its lower part a valve 15 outside
15 which there is an output orifice 16. A capillary 17 ensures a connection between the valve 15 and an orifice 18 opening into the shaft in the zone of measurement between the inflatable obturators.

20 It will be understood that as the probe is raised in the shaft to carry out measurements in different zones, there is produced a progressive escape of compressed gas from the reservoir 14. The pressure of the reservoir is thus constantly in equilibrium with the exterior static pressure
25 in the shaft at the level considered.

The device comprises also a pressure detector 19 possibly associated with the temperature detector.

30 The dynamic back pressure measured by the detector 19 in the form of a sinusoidal signal after establishment of a static regime at a predetermined frequency corresponding to the rotation of the turbine is transmitted towards the surface, preferably in the form of a train of waves of variable frequency (the VCO system).

The device further comprises means for measuring the speed of rotation of the shaft 8 at the output of the

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turbine, shown schematically in the form of a photoelectric cell 20.

5 Measurement of the frequency of rotation of the shaft at the output of the turbine provides, after appropriate calibration corresponding to the dimensions and the path of travel of the piston, the value of the modulus of the flow function.

10 The device also comprises, in the part corresponding to the zone of measurement, a valve 21 in communication by means of hydraulic fluid with the surface and allowing, if desired, carrying out of a modification of the opening of the fissures and the hydraulic cracking of the rock medium.

15 Finally, it is advantageous to provide at the lower part of the chamber 11 a safety mechanism shown generally by 22 and comprising valves 23 and a metal membrane 24 in a chamber 25 containing compressed air.

20 This safety mechanism allows avoidance of damage to the assembly of piston 9 and membrane 13 at the surface during refilling of the reservoir 14 and is also effective for assuring the same protection in the case of accidental excess
25 pressure during use.

To use the method according to the invention, in a zone of measurement, there is varied according to a predetermined set of values the frequency of rotation of the turbine and
30 for each of the frequencies there is recovered the signal corresponding to the function of the dynamic back pressure generated by the alternating sinusoidal flow caused in the surrounding environment.

35 The curves obtained, representing the ratio between the modulus (magnitude) of the dynamic back pressure and the modulus (magnitude) of the flow as a function of frequency, are compared with curves obtained from mathematical or

experimental models and which each correspond to defined characteristics of fissures or the nature of soils.

Thus, Figures 2 and 3 represent such curves. In Figure 2, there is illustrated the spectral signatures for fissures of an extension or radius of 300 m from the shaft and for fissure thicknesses of 0.5 mm, 2 mm and 3mm.

The peak of resonance corresponding to a frequency of 2.84 hertz is characteristic of the extension of the fissure.

Figure 3 shows the curves obtained for fissures having a thickness of 1 mm and extensions respectively of 175 m, with a frequency of resonance of 4.86 hertz, and 225 m with a frequency of resonance of 3.78 hertz. The third peak shown in Figure 3 corresponds to the second frequency of resonance for the fissure of 225 m.

In practice, there will be available catalogues of spectral signatures and the comparison of the values obtained by using the method according to the invention with the theoretical curves will provide the desired information.

The example described shows the use of the invention for the quantitative determination of dimensions of fissures in rocky media.

It should however be understood that the invention is not limited to such a type of ground and finds application in numerous fields, notably hydrogeology and study of water resources, not only in fissured rocks but also in porous or Karstic rocks and in soils, in the field of geothermics of wet rock for studying geothermal resources and in the oil-fields whatever the nature of the storage rocks are. The

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same invention may be used in the domain of geothermics at great depth for dry rocks, to geotechnology using one or more explorations or to determination of the characteristics of a medium to be used for storage of waste material,

5 especially radioactive material at great depths.

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CLAIMS:

1. A method of surveying soils and rocky media, in which there is isolated a zone of predetermined height in an exploration shaft, there is caused in said zone of the shaft an alternating flow of fluid in the shaft and the
5 surrounding medium according to a predetermined function, the static pressure in said zone is equilibrated with the pressure outside the zone, the frequency of said function is caused to vary through a range of values, there is detected for each of said frequency values the dynamic back
10 pressure generated in said zone of the shaft by said alternating flow of fluid and there is compared with reference models, the variations as a function of said frequency of the ratio between the magnitude of said dynamic back pressure and the magnitude of the flow.
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2. A method according to claim 1, in which said predetermined function is a sinusoidal function.
3. A method according to claim 1 or 2, in which said
20 reference models are mathematical models.
4. A method according to any preceding claim, in which said alternating flow is caused by alternating displacements of a membrane, forming a part of the external
25 tubular wall of a probe introduced into the shaft.
5. A method according to claim 4, in which the membrane comprises metallic bellows.
- 30 6. A method according to claim 4 or 5, in which the alternating displacements of said membrane are caused by alternating movements to and fro in a chamber of the probe of a piston integral with a shaft driven in continuous rotation, measurement of the frequency of rotation of the
35 said shaft determining said modulus of the flow function.



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7. A device for carrying out a method according to any one of the preceding claims, which comprises a probe capable of being lowered into an exploration shaft at the end of a train of rods, this probe comprising inflatable 5 obturators capable of being applied against the walls of the shaft and being fed with hydraulic fluid from the surface and defining between them an isolated zone of measurement, said probe comprising means for causing from its peripheral surface an alternating flow of fluid in the 10 shaft and the surrounding medium, a counter-pressure mechanism for equilibrating and compensating the static pressure in the zone of measurement, a pressure detector in the zone of measurement of the shaft and means for connecting the probe to the surface for feeding operating 15 fluids thereto and transmitting to the surface of information provided by the pressure detector.

8. A device according to claim 7, in which said means for causing an alternating flow of fluid comprises 20 a chamber filled with fluid, in which is movable to and fro a piston, said piston being integral with a shaft driven in rotation from a turbine and said chamber being in communication with a second chamber of which the external wall comprises an annular membrane.

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9. A device according to claim 8, in which the membrane comprises metallic bellows.

10. A device according to claim 8 or 9, in which 30 said piston has a cylindrical shape and the faces of the ends of the piston are inclined and guided in said chamber in such a manner that continuous movement in rotation of the shaft of the turbine is transformed into an alternating to and fro movement of the piston.

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11. A device according to any one of claims 8 to 10, in which the speed of rotation of the shaft is measured by photoelectric means in the probe.

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12. A device according to any one of claims 7 to 11, in which the counter-pressure mechanism comprises at the lower part of the probe a reservoir of compressed gas at a pressure at least equal to the static pressure at the maximum depth to which the probe is to be lowered, an orifice at the lower part of the probe isolated from the reservoir by a valve and a capillary connection between said valve and a point at the periphery of the probe in the zone of measurement between the inflatable obturators.
13. A method of surveying soils and rocky media, substantially as hereinbefore described with reference to the accompanying drawings.
14. A device for surveying soils and rocky media, substantially as hereinbefore described with reference to the accompanying drawings.

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