Monitoring wells: measurement of permeability with minimal modification of groundwater

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It is important to verify whether a monitoring well has been correctly sealed in the ground in order to avoid vertical cross-communication between aquifers and thus prevent misleading results for the piezometric level and the degree of contamination. This may be done with an *in situ* falling-head permeability test. A monitoring well is used to sample groundwater, so it is not recommended to introduce a different quality water to perform the permeability check test. The test should be performed preferably with the local groundwater. A method is described in which a stainless steel and teflon bladder pump, a packer, a water pressure transducer, and a field computer are used to perform a falling-head permeability test. Many test results can be stored in the field computer before transferring its data into a microcomputer. The results may then be presented in the form of tables and graphics to determine the hydraulic conductivity of the tested layer, and to verify whether the installation of the monitoring well is correct. Results of field tests are presented to illustrate this method.

Key words: groundwater, contamination, permeability, monitoring.

Il est important de vérifier si un puits de contrôle a été correctement scellé dans le terrain pour éviter une contamination verticale interaquifères, et ainsi éviter des valeurs erronées du niveau piézométrique et du degré de contamination. Cette vérification peut être faite avec un essai de perméabilité *in situ* à charge descendante. Un puits de contrôle sert à échantillonner l'eau souterraine : il n'est donc pas recommandé d'introduire une eau de qualité différente pour fairè l'essai de vérification de perméabilité. On doit faire cet essai de préférence avec l'eau souterraine locale. Dans la méthode décrite, une pompe en acier inoxydable à vessie de téflon, un obturateur, un capteur de pression et un ordinateur de terrain sont utilisés pour faire un essai de perméabilité à niveau descendant. Plusieurs résultats d'essais peuvent être stockés dans l'ordinateur de terrain avant d'être transferrés dans un microordinateur. On peut présenter les résultats sous forme de tableaux et de graphiques pour déterminer la conductivité hydraulique de la zone testée, et pour vérifier si l'installation du puits de contrôle est correcte. Des résultats d'essais de terrain sont présentés pour illustrer la méthode.

Mots clés : eau souterraine, contamination, perméabilité, contrôle.

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Introduction

In groundwater contamination studies, monitoring wells (hydraulic piezometers) are installed to measure hydraulic heads and permeabilities, establish groundwater flow nets, sample water, and delineate contamination zones.

It is important to verify whether a monitoring well has been correctly sealed into the ground to avoid vertical cross-communication between aquifers and thus prevent misleading results of both the piezometric level and the degree of contamination. This may be done with *in situ* falling-head permeability tests (Chapuis 1988). A monitoring well will be used to sample groundwater, and therefore water of a different quality should not be used to perform a falling-head permeability test.

This paper describes how a permeability test may be used to check whether the monitoring well is correctly installed and how the test can be performed with minimum impact on the quality of groundwater.

Background

Use of hydraulic piezometers or monitoring wells

Hydraulic piezometers have been widely used for monitoring seepage conditions and water-pressure-related stability problems in excavations, dams, dykes, and drainage systems. In recent years, most hydraulic piezometers have been installed as sampling wells for monitoring groundwater contamination. They give the following information:

- hydraulic heads (or potentials) are directly obtained;
- hydraulic gradients are derived from the equipotentials drawn from the local values of hydraulic heads;
- hydraulic conductivity values may be determined by injecting or pumping water in the piezometer;
- groundwater velocities may be estimated from the previous results;
- chemical analyses may be performed on groundwater samples to delineate contamination zones.

Risk of hydraulic short-circuit

The quality of all this information depends on the hydraulic quality of the monitoring wells (Chapuis 1987). A preferential seepage close to the well pipe or a broken pipe will induce cross-contamination and modify the water level in the pipe. Consequently, it is important to have the sampling zones of monitoring wells hydraulically isolated within specific zones of soil or rock. Lack of isolation will result in a hydraulic short-circuit with the following consequences: (*i*) water samples are not representative of the monitored zone because there is a cross-contamination; (*ii*) the water level elevation measured in the pipe is some dynamic level related to the hydraulic short-circuit: it does not represent the piezometric head in the

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monitored zone before installation; (*iii*) gradients, hydraulic conductivities and water seepage velocities are incorrect because they are computed from erroneous values of hydraulic heads.

Detecting hydraulic short-circuits

A hydraulic short-circuit may be detected in the field by performing a variable-head permeability test and interpreting its results in a graph of falling flow rate versus difference in hydraulic heads, instead of the usual graph as proposed by Hvorslev (1951). This method has been supported by field tests (Chapuis *et al.* 1981) and laboratory model tests (Chapuis *et al.* 1990), and it is now included in standard 2510-135 (CAN-BNQ 1988). It may be used to verify whether piezometers are correctly sealed in the soil (Chapuis 1987, 1988).

When permeability tests are performed in driven casings, it is obvious that the casing is not tightly sealed in the soil and, consequently, there is leakage or preferential seepage along the wall of the casing. Along the pipe of a monitoring well, preferential seepage and hydraulic short-circuits between aquifers are due to internal erosion of natural soils close to the casing, during either drilling operations or development, as well as to improper sealing of the well pipe. These phenomena have been studied by Chapuis and Sabourin (1989) who proposed several recommendations to avoid hydraulic short-circuits, incorrect piezometric level readings, and nonrepresentative groundwater samples.

Field testing method with minimal modification of groundwater

As previously discussed, it is most important to control whether a monitoring well has been adequately sealed in the ground in order to avoid vertical cross-communication between aquifers. The control can be made with the falling-head permeability test as described above, which involves the injection of water. As the well will be used later to sample groundwater, a different quality water should not be injected to perform the test and check the installation. Similarly, the introduction of tools to measure the variation in water level may artificially contaminate groundwater so that precautions must be taken.

The field permeability check test must be done with minimum impact on the quality of groundwater by using the local groundwater to perform the test. Two procedures may be followed:

1. A sufficient volume of water is pumped or bailed in the monitoring well before the control test, and re-injected for the test. This method may be used when the total duration of the test is longer than a few minutes, and a water head can be created in the well pipe and easily monitored during the falling-head test. When the total duration of the test is less than 5 minutes, a water pressure transducer must be used and the second technique may be followed.

2. A stainless steel and teflon bladder pump is introduced in the monitoring well down to its intake zone as shown in Fig. 1. The water and air lines of the pump pass through a packer placed a short distance above the pump and below the water level in the well pipe. The packer is then inflated against the wall of the well pipe. An electronic water pressure transducer (lower right of Fig. 2) is lowered into the water, given a fixed elevation, and connected to a field computer (middle of Fig. 2). The pump (the long cylinder in Fig. 3) is started to drive groundwater from the intake zone up to above the packer where it is used to create a water column. At a given water height which is measured by the electronic transducer, the pump is stopped. Then the packer is rapidly deflated and the water column is injected back into the soil or the rock around the intake zone of the monitoring well. This is a field permeability test performed with the local groundwater itself. The transducer and the field computer can read the water column at any time interval from 0.1 s to 1 day. Many test results can be stored in the field computer before transferring its data into a microcomputer. The results may be presented in tables and graphics to determine the hydraulic conductivity of the monitored layer, and to verify whether the installation of the monitoring well is correct. Field data and results are presented in the following section to illustrate this method.

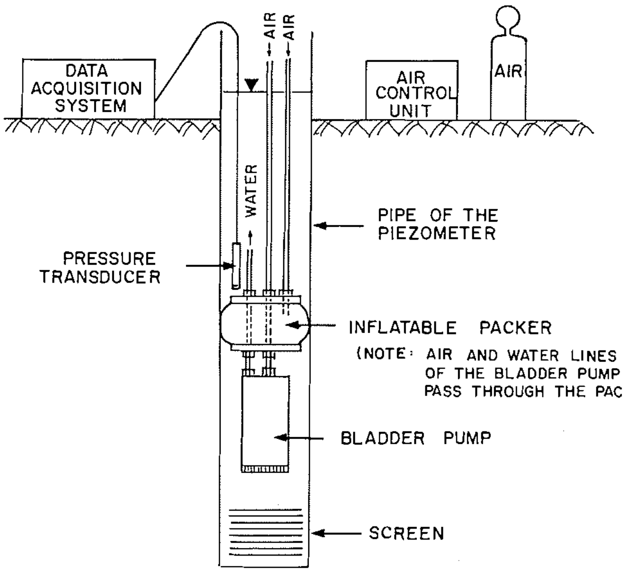

FIG. 1. Schematic representation of the installation with a bladder pump, a packer, and an electronic water pressure transducer.

Examples of results from monitoring piezometers

Two examples are given in Figs. 4 and 5 for two monitoring wells successfully installed in stratified deposits and complex groundwater seepage conditions. There is a very short duration test (Fig. 4) and a long-duration test (Fig. 5). All test data were recorded by an electronic pressure transducer (Kellar), transferred from the field data acquisition unit (Terra 8/D, encased in a 75 mm sealed cylinder shown in Fig. 3) to a microcomputer and analyzed with Lotus software.

As indicated before, the results of these variable-head permeability tests are interpreted in a graph of falling flow rate versus difference in hydraulic heads. The reader may refer to cited references for equations and interpretations of different field permeability test results. An example relative to a real case of unsuccessfully sealed monitoring well was studied in detail by Chapuis (1988). For analysis of data (water level versus time), it is possible to use a table similar to that of standard 2510-135 (CAN-BNQ 1988) for a permeability test performed in a cased borehole through a gravel pack (Lefranc test). There is only one difference in interpretation: in a Lefranc test, the diameters d and D_L are the inside and outside diameters of the same casing, whereas in a monitoring well test, d is the inside diameter of the small injection pipe and D_L is the outside diameter of the casing that was used to complete the installation.

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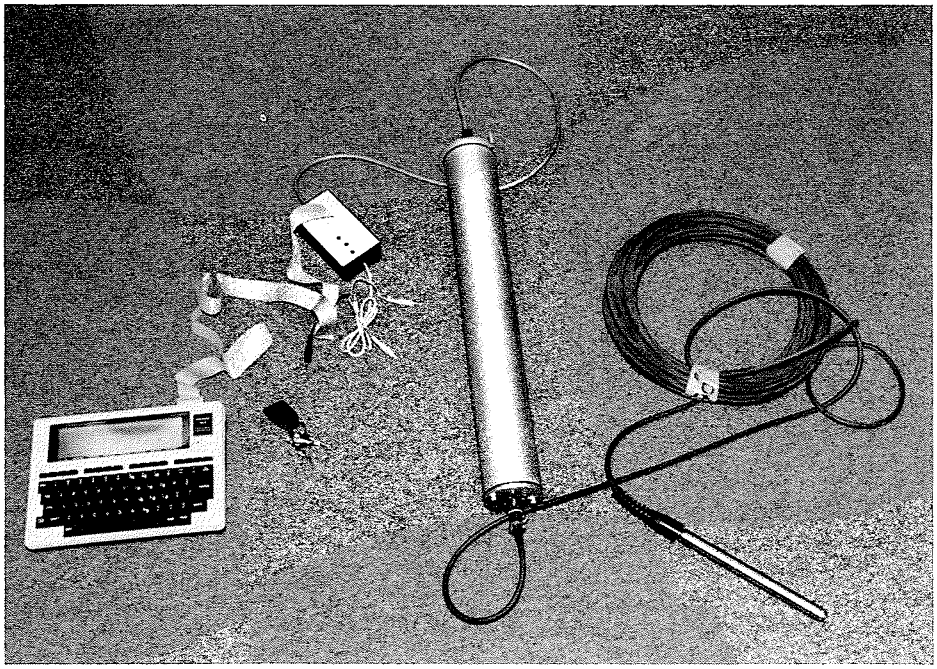

FIG. 2. Equipment used for data acquisition with an electronic pressure transducer and a Terra 8/D field computer (long cylinder).

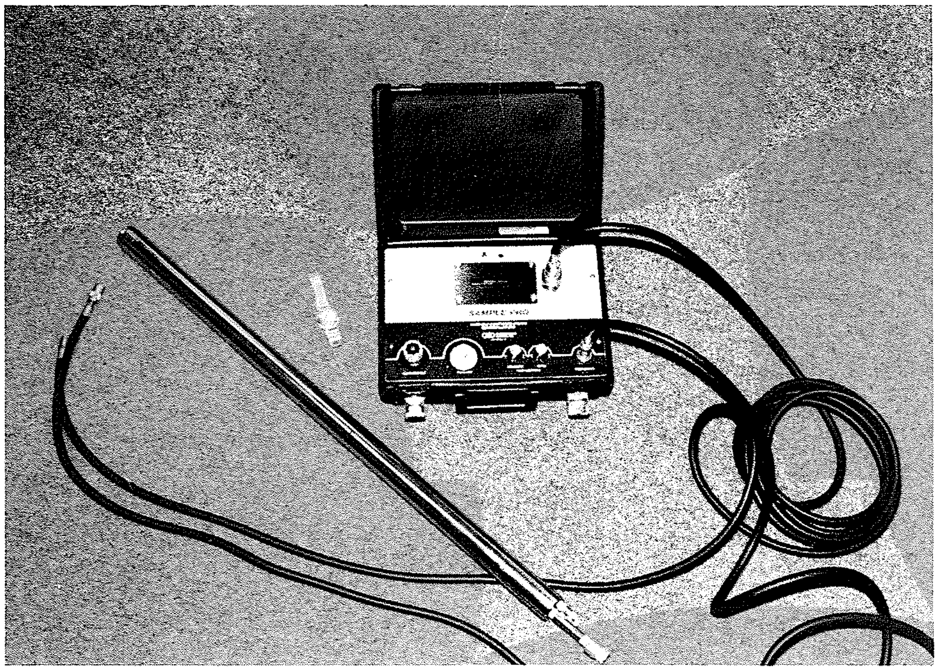

FIG. 3. Bladder pump with controller. The packer is not shown.

extreme cases for the final graph, after it was verified that the wells had been successfully installed.

During a very short test similar to that of Fig. 4, it is impossible to follow adequately the variation in water level with a measuring tape or a water level indicator. An electronic pressure transducer is mandatory for accurate readings, determination of the falling flow rate, and verification of successful installation (straight-line relationship passing through the origin).

A very long test (example of Fig. 5) is typical of a low-permeability soil, such as a clayey material which may exhibit consolidation (or swelling) during the test. The interpretation of field K tests with consolidation is more complicated than that for granular soils or fractured rocks in which the fast consolidation is neglected. In consolidating clayey soils, the field K value is usually measured with constant-head tests in piezometers rather than with variable-head tests. Tests in boreholes are avoided and not recommended (Olson and Daniel 1981; Tavenas *et al.* 1983). For constant-head tests in consolidating soils, solutions have been developed by Gibson (1963, 1966, 1970) and Wilkinson (1968) for hydraulic piezometers, and by

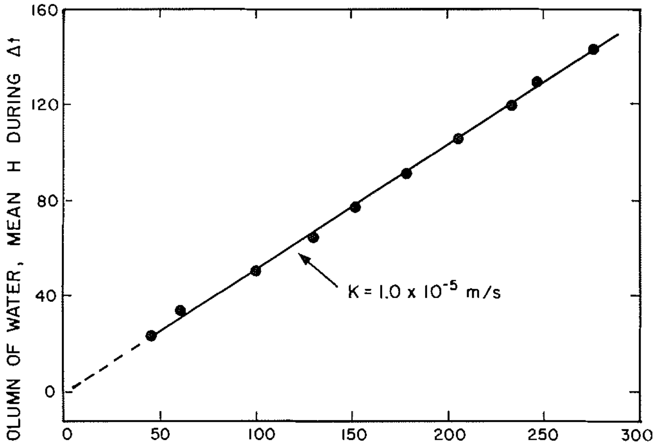

FIG. 4. Example of a field test lasting less than 1 minute. Time to reach 10% initial H is close to 1 min.

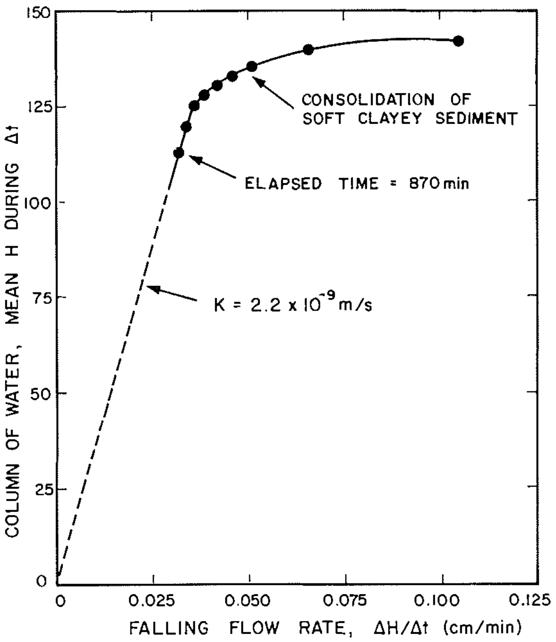

FIG. 5. Example of a long-duration field test with consolidation of the soft soil (recent clayey sediments) around the intake zone. Time to reach 10% initial H is close to 8000 min (5.6 days).

Mieussens and Ducasse (1977) for driven piezometers or self-boring permeameters. A constant-field permeability test in a consolidating or swelling soil provides both hydraulic conductivity, K, after the period of consolidation, and the coefficient of horizontal consolidation, c_h, at the beginning of the injection period.

In the case of Fig. 5, the interpretation of the consolidation period is complicated because there is no theoretical solution available for consolidation during a variable-head test. Consolidation is registered at the beginning of the test and yields a curved shape for the falling flow rate graph. However, the final part of the graph is linear, indicating that the K value remains constant and consolidation effects stop once the local gradients are lower than the critical values inducing consolidation.

Conclusion

After installation, any monitoring well must be tested to verify whether it has been correctly sealed in the ground to avoid vertical cross-communication between aquifers, which induces misleading results of both the piezometric level and the degree of contamination. This control is made with an *in situ* falling-head permeability test, which must be performed with the local groundwater so as to try to have a minimal modification in groundwater quality. Depending on the soil or rock permeability, the total duration of the test may vary between less than 1 minute to more than 1 week. This is why it is useful to have a field computer and an electronic pressure transducer, which can read the water column in the pipe at any interval from 0.1 s to 1 day. The complete testing system (stainless steel and teflon bladder pump, packer, water pressure transducer, and field computer) enables to hydraulically test, with minimal impact, any monitoring well before sampling groundwater to be analyzed for delineating contaminated zones. The testing system and the interpretation method for variable-head permeability tests (Chapuis 1988) were used on several sites in the Montreal area. They helped to explain contradictory results of groundwater contamination, which were due to local cross-contamination in the vicinity of unsuccessfully installed monitoring wells.

Acknowledgments

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CAN-BNQ. 1988. Soils — determination of Lefranc permeability. Standard 2501-135, Bureau de normalisation du Québec, Que., Standards Council of Canada, Ottawa, Ont.

CHAPUIS, R. P. 1987. Piézomètres hydrauliques et risques d'erreur associés. Technical Memorandum 143, NRCC28546, Associate Committee on Geotechnical Research, National Research Council Canada, Ottawa, Ont., pp. 117–145.

——— 1988. Determining whether wells and piezometers give water levels or piezometric levels. *In* Ground water contamination — field methods. Special Technical Publication 963, American Society for Testing and Materials, Philadephia PA, pp. 162–171.

CHAPUIS, R. P., and SABOURIN, L. 1989. Effects of installation of piezometers and wells on ground water characteristics and measurements. Canadian Geotechnical Journal, **26**(4): 604–613.

CHAPUIS, R. P., PARÉ, J. J., and LAVALLÉE, J. G. 1981. Essais de perméabilité *in situ* à niveau variable. Proceedings, 10th International Conference on Soil Mechanics and Foundation Engineering, Stockholm, Sweden, Vol. 1, pp. 401–406.

CHAPUIS, R. P., SOULIÉ, M., and SAYEGH, G. 1990. Laboratory modelling of field permeability tests in cased boreholes. Canadian Geotechnical Journal, **27**(5): 647–658.

GIBSON, R. E. 1963. An analysis of system flexibility and its effect on time-lag in pore-water measurement. Géotechnique, **13**(1): 1–11.

——— 1966. A note on the constant head test to measure soil permeability in situ. Géotechnique, **16**(3): 256–257.

——— 1970. An extension to the theory of the constant head in situ permeability test. Géotechnique, **20**(2): 193–197.

HVORSLEV, M. J. 1951. Time-lag and soil permeability in ground water observations. Bulletin 36, U.S. Army Engineering Waterways Experimental Station, Vicksburg, MS.

Mieussens, C., and Ducasse, P. 1977. Mesure en place des coefficients de perméabilité et des coefficients de consolidation horizontaux et verticaux. Canadian Geotechnical Journal, **14**(1): 76–90.

Olson, R. E., and Daniel, D. E. 1981. Measurement of the hydraulic conductivity of fine-grained soils. *In* Permeability and groundwater contaminant transport. Special Technical Publication 746, American Society for Testing and Materials, Philadelphia, PA, pp. 18–64.

Tavenas, F. A., Jean, P., Leblond, P., and Leroueil, S. 1983. The permeability of natural soft clays. Part 2: permeability characteristics. Canadian Geotechnical Journal, **20**(4): 645–660.

Wilkinson, W. B. 1968. Constant head in situ permeability tests in clay strata. Géotechnique, **18**(2): 172–194.

Pumping more than 100 m^3/min from excavations for open-air amphitheatres in the city of Québec

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Two agoras, or open-air public amphitheatres, were built during 1982 in the old port of the city of Québec. They are encased in uncontrolled backfill materials which were dumped during the last hundred years as the remodelled wharfs advanced into the St. Lawrence River. Old wooden wharfs were known to have been buried in backfill materials, and thus a large water inflow was expected to occur there and to depend on tide levels. The water inflows through the old wooden wharfs constituted less than 2% of the total infiltration, which reached a rate of 114 m^3/min (25 000 gpm) at the highest tide. It was necessary to install a pumping system consisting of twelve 25-cm pumps connected to a collector 91 cm in diameter. The sources of these water inflows were determined with the help of old drawings, boreholes, water tests, and tracer tests. Most pumped water was coming through cobbles and boulders backfilled around a pressure sewer pipe 2.1 m in diameter. This note describes the work carried out to control the exceptional water inflows in order to complete construction within the required time.

Key words: construction, dewatering, groundwater.

Deux agoras, amphithéâtres publics en plein-air, furent construites en 1982 dans le vieux port de la ville de Québec. Elles sont encastrées dans des remblais non contrôlés déversés depuis près de cent ans au fur et à mesure du remodelage des quais qui s'avançaient dans le fleuve. On savait que d'anciens quais de bois avaient été engloutis dans les remblais, ce qui faisait anticiper des venues d'eau importantes influencées par le cycle des marées. Les venues d'eau par les anciens quais de bois n'ont constitué que moins de 2% de l'infiltration totale qui atteignit 114 m^3/min (25 000 gpm) à la plus haute marée. Il a fallu installer un système de pompage comprenant douze pompes de 25 cm raccordées à un collecteur de 91 cm de diamètre. Les origines de ces venues d'eau furent déterminées à l'aide d'anciens plans, de forages, d'essais d'eau et d'essais de traceurs. La majeure partie de l'eau pompée provenait des blocs et cailloux enrobant une conduite de refoulement d'eaux d'égout, de 2,1 m de diamètre. La note décrit les travaux spécifiques réalisés pour contrôler ces venues d'eau exceptionnelles afin de compléter les travaux dans les délais voulus.

Mots clés : construction, assèchement, eau souterraine.

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Introduction

In preparation for celebrating the 450th anniversary of Jacques Cartier's landing, several projects were completed in the old port of the city of Québec. Two open-air amphitheatres, called agoras, were built in 1982 for public meetings (Fig. 1). The site investigation carried out during the design phase revealed that they would rest in and on uncontrolled backfill materials which were used to fill the spaces between the successive wharfs built during the last hundred years. The backfill contains gravel, sand, and silt, with a fines content usually higher than 10%. It is 8–17 m thick in a loose to compact condition. The backfill materials cover the natural soil described as sand, trace gravel to gravelly, and trace to some silt. It is 10–15 m thick over the bedrock, a highly fractured

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