A method of the permeability determination of protective structures of man-made objects

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SUMMARY

Geoecological monitoring of the condition and extension of further safe operation of nuclear power plants and other potentially dangerous objects of energy infrastructure (storage dams, sludge storage facilities, etc.) involves assessing the suitability of their protective concrete structures by determining a range of physical parameters of concrete and other consolidated construction materials. One of such parameters is the permeability of the concrete of the containment shell of the nuclear power plant (NPP) unit and other potentially dangerous objects of the energy infrastructure in the conditions of operation and the maximum design basis accident (MDBA) for gases and water. To solve the above problem in the research laboratory of theoretical and applied geophysics of the Institute of Geology of Taras Shevchenko National University of Kyiv was developed a working model of the UP-1 installation and technique for determining this parameter. The UP-1 installation allows to estimate permeability (for air and water) of concrete and solid construction materials in stress-free conditions and at their stretching. The essence of the method is to determine the stationary filtration rate of air (or water) through a sample of concrete in the radial direction under the action of the pressure difference. There are no analogues of the proposed installation and technology for determining the permeability of construction materials (rocks) in tensile conditions. The developed working layout of installation and technology of its application were tested on samples of concrete. The air permeability and ultimate tensile strength of the studied concrete samples were determined.

Introduction

When addressing issues of geoecological monitoring and prolongation of safe operation of nuclear power plants and other potentially dangerous energy infrastructure facilities (storage dams, sludge storage facilities, etc.), there is a problem of assessing the usability of their protective concrete structures by determining a range of physical parameters of concrete and other materials (*Vyzhva, 2004*). One of such parameters is the permeability of the concrete of a containment shell of a nuclear power plant (NPP) unit and other potentially dangerous objects of the energy infrastructure in the conditions of operation and maximum design basis accident (MPBA) for gases and water.

To determine the air permeability of concrete, there is an installation made according to the scheme given in DSTU B V.2.6-37:2008 (DSTU – National Standards of Ukraine) "Methods for determining the air permeability of enclosing structures and their elements in the laboratory conditions" (*DSTU B V.2.6-37:2008, 2008*). However, this installation has a completely different design and cannot solve the above problem because: 1) The installation recommended by DSTU B V.2.6-37:2008 allows research when the air pressure drop is up to 2000 Pa, and not 400.000 Pa (0.4 MPa), as required by the accepted criterion for assessing the air permeability of containment shell concrete of the NPP unit. Thus, it is absolutely unsuitable for the study of air permeability of the NPP containment shells. 2) The installation recommended by DSTU B V.2.6-37:2008 does not allow to create tensile force of the concrete sample that occurs during the maximum design basis accident of the NPP unit and, accordingly, to determine its air permeability in this mode. 3) It is not suitable for determination of permeability for water.

Method and Theory

To solve the mentioned problems, the UP-1 installation and the technology of determining this parameter in the laboratory conditions were developed. The unique equipment was created in the research laboratory of theoretical and applied geophysics of the Institute of Geology. The installation has a modular design. It consists of an optimal set of equipment and measuring instruments which are included in the standard set of petrophysical laboratories (manometers, pressure sensors, laboratory gas meters, stopwatches, etc.).

The UP-1 installation allows to estimate permeability (for air and water) of concrete and solid construction materials in stress-free conditions and at their stretching. The main elements of the installation are: a specially designed measuring chamber with a hydraulic cylinder; laboratory gas meter; pressure sensor (0 - 2.5 MPa) to measure the pressure of air or water applied to the sample; pressure sensor (0 - 6 MPa) to control the oil pressure in the hydraulic cylinder; hydraulic press; reducer; compressor or cylinder with compressed air; water receiver; high pressure taps and connecting pipes.

The general view of the working layout of the UP-1 installation is shown in Fig. 1. The measuring chamber consists of: the case of measuring chamber in which a cylindrical concrete sample (the consolidated construction material or rock) is placed; core holder, in which the test sample is fixed with the help of epoxy glue; hydraulic cylinder, which is used to seal the measuring chamber (for measurements without loading the test sample) and also which creates tensile strength in the sample (for tensile tests that simulate the maximum design basis accident of a NPP unit or load of elements of hydraulic structures).

The essence of the method is to determine the stationary filtration rate of air (or water) through a sample of concrete in the radial direction under the action of pressure difference. The filtration rate of air (water) is determined by the known volume of gas (water) that has passed through the sample for a fixed period of time at a constant pressure difference at the inlet and outlet of the sample.

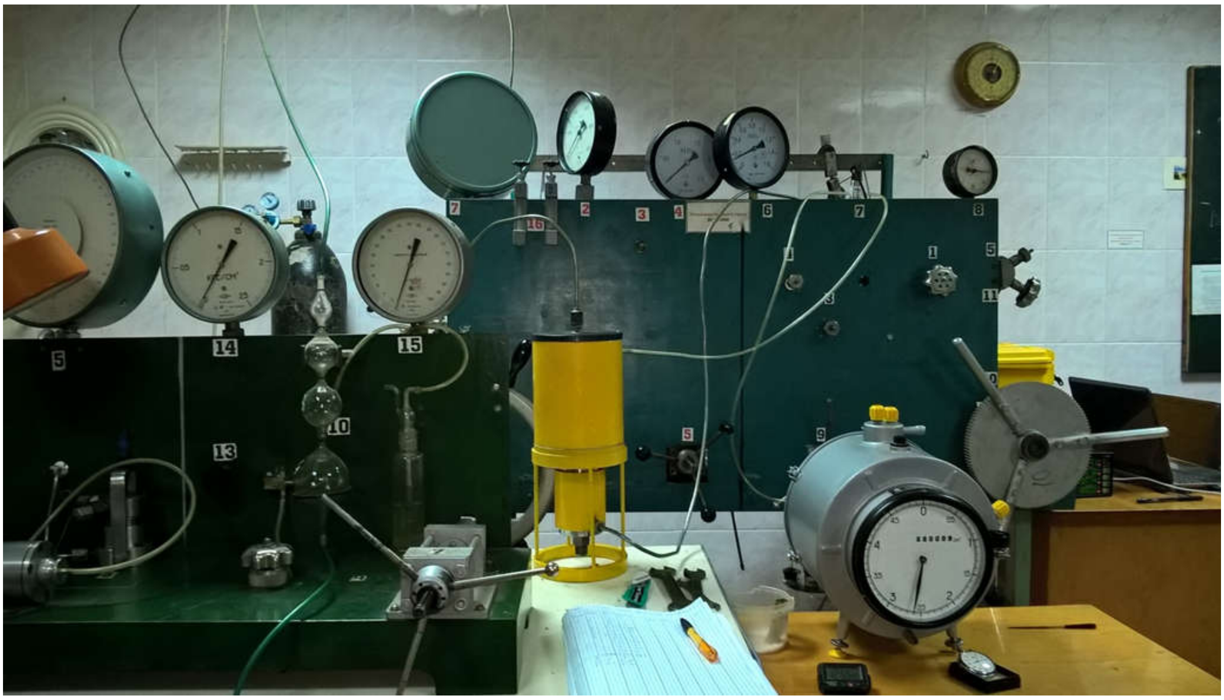

Figure 1 *General view of the working model of the UP-1 installation for determining the permeability coefficient of concrete, consolidated construction materials and rocks (stress-free and in tensile conditions)*

In laboratory tests, the prepared sample (fixed in the core holder with epoxy glue) is placed in the measuring chamber. The research is carried out at excessive air pressure (0.4 MPa), which corresponds to the maximum design basis accident (when the reactor is depressurized) of the NPP unit, or at excessive water pressure (at the design load of hydraulic elements). The pressure is created by a compressor (compressed air cylinder) and controlled by a manometer (digital sensor).

The volume of air that has passed through the sample is determined by a laboratory gas meter GSB-400. Air transmission time is measured by a stopwatch. During the experiment, the temperature and atmospheric pressure are recorded by a laboratory thermometer and barometer. In the case of water forcing – the volume is determined by a graduated burette.

Determination of the permeability coefficient K_{per} of concrete (construction material or rock) according to laboratory measurements is performed in two states: in the "free" (unloaded) condition and under the tensile force that occurs during MPBA. Determination of the permeability coefficient K_{per} of concrete (construction material) in the "free" (unloaded) state is performed at an oil pressure in the hydraulic cylinder of 0.1 MPa, which is required for sealing the measuring chamber. The tensile force that occurs during the MPBA in the NPP unit (pressure 0.4 MPa) is 2.0 kN. This force on the sample is created at an oil pressure in the hydraulic cylinder of 1.05 MPa (similarly for water).

In the case of the radial flow of gas (water) through the laboratory sample, the permeability coefficient is determined by the formula (*GOST 26450.2-85, 1985*):

$$K_{per} = \frac{367 \cdot Q \cdot \mu \cdot P_{bar}}{\Delta P\left(\frac{\Delta P}{2} + P_{bar}\right)} \cdot \frac{\lg \frac{D}{d}}{l}$$

where K_{per} – the permeability coefficient determined at a given pressure drop in the sample, in 10^{-3} μm^2 (millidarcy) or in fm^2; D – the outer diameter of the sample, in cm; d – the inner diameter of the central hole in the sample, in cm; l – the length of the test sample, in cm; $Q = V/T$ – gas (water) flow rate, measured at the outlet of the sample, cm^3/s; V – the volume of gas (water) passed through the sample, in cm^3; T – filtration rate, in s; μ – viscosity of gas (water) under filtration conditions (P_{bar}, t °C), in mPa·s (millipascal · second); ΔP – pressure drop on the sample between the inlet and outlet, 0.1 MPa; P_{bar} – barometric pressure, 0.1 MPa.

To determine the air permeability (water permeability) of concrete and other structures, the calculation is based on Darcy's law using the laboratory-determined permeability coefficient K_{per}. The linear Darcy's law of filtration is expressed by equation (*Dobrynin et al., 1991*):

$$\frac{Q}{F} = K_{per} \frac{\Delta P}{\mu \Delta L}.$$

Then the volume of air that is filtered through the structure under specified conditions (thickness, area, time, pressure drop) is determined by the formula:

$$V = K_{per} \frac{\Delta PFT}{\mu \Delta L},$$

where $Q = V / T$ – air (water) flow rate through the area F; V – the volume of air (water) that has passed through the area F; T – filtration time of air (water); μ – viscosity of air (water); ΔP – pressure drop between inlet and outlet; ΔL – filtration length (thickness of concrete or other structure). The volume of air (water) filtered from an area of 1 m^2 per 1 hour is the normalized value for engineering structures (for example, for concrete of a containment shell of a nuclear power unit $V < 50$ $cm^3/m^2 \cdot h$).

There is no analogue of the proposed installation and technique for determining the permeability of construction materials (rocks) in tensile conditions.

The developed installation and the technique of its application were tested under experimental laboratory research on concrete samples. The air permeability of 5 concrete samples was determined in the conditions of maximum design basis accident at 0.4 MPa, which varies from 1117 to 3847 $cm^3/m^2 \cdot h$ (without stretching) and from 1167 to 4009 $cm^3/m^2 \cdot h$ under tensile conditions with a load of 2 kN. It was determined that the tested concrete samples do not meet the requirements of the regulations for NPP containment shells.

In addition, it was found that the ultimate tensile strength of concrete samples is from 1,459 to 1,915 MPa with an average value of 1,678 MPa.

Conclusions

Summarizing the above, it should be noted the following.

1. Geoecological monitoring and extension of further safe operation of nuclear power plants and other potentially dangerous objects of energy infrastructure requires determination of permeability of concrete of their protective structures in operation and maximum design basis accident for gases and water.

2. To solve the above problem in the research laboratory of theoretical and applied geophysics of the Institute of Geology of Taras Shevchenko National University of Kyiv was developed a working model of the UP-1 installation as well as technique for determining this parameter.

3. There are no analogues of the proposed installation and technology for determining the permeability of building materials (rocks) in tensile conditions in Ukraine. The developed working model of installation and technology of its application are tested on samples of concrete. The air permeability and ultimate tensile strength of the studied concrete samples were determined.

References

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