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METHODOLOGICAL BASES FOR PHYSICAL MODELLING OF WATER INTAKES WITH HORIZONTAL COLLECTOR MANIFOLDS

Based on the theory of mechanical similarity and dimensional analysis, the principles of physical modelling of radial water intakes have been formulated. It has been stated that model tests, in which a full dynamic similarity would be maintained, cannot be achieved and that gravity and internal friction forces are the prevailing ones. A non-complete dynamic similarity has been achieved when Froude and Ščelkačev criteria were satisfied. The application of dimensional analysis enabled us to describe quantitatively and qualitatively the hydraulic characteristics of radial intakes, while model tests made it possible to determine numerical values of empirical coefficients. The presented method of physical modelling of radial water intakes may be used in model tests of the objects in which collectors, i.e. filter pipes, are the elements of water intake.

DENOTATIONS

a_i – dimensionless empirical coefficients,

g – acceleration of gravity [m/s^2],

Δh_s – hydraulic losses due to water flow inside perforated and full-walled segments of collector including also the losses at the water inflow to the collector well of water intake [m],

k_f – filtration coefficient of the bed (water-bearing layer) [m/s],

l – length [m],

l_f – length of perforated (filter) part of collector [m],

l_z – length of full-walled (off-filter) part of collector [m],

m – coefficient characterizing location of lateral inflows along the perforated part of the collector,

n – the number of collectors,

n_p – porosity of filter bed,

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r – internal radius of collector [m],
s – depression inside collector well [m],
t – time [s],
v – linear velocity [m/s],
v_f – filtration velocity [m/s],
v_k – mean flow velocity in a section of full-walled collector segment (final velocity) [m/s],
v_p – mean flow velocity in the most distant to the well section of perforated collector segment (initial velocity) [m/s],
A – dimensionless empirical coefficient,
F – surface [m^2],
H_w – water-bearing layer thickness [m],
Fr – Froude number,
I – hydraulic gradient,
Q – volumetric flow rate [m^3/s],
Q_u – water intake capacity [m^3/s],
Re – Reynolds number,
V – volume [m^3],
$\varkappa$ – soil permeability coefficient,
λ – coefficient of linear resistances in full-walled collector segment,
λ_p – coefficient of linear resistances in perforated segment of collector,
ν – kinematic viscosity coefficient [m^2/s],
ξ_{kf} – filtration coefficient scale: $\xi_{kf} = k_{fN}/k_{fM}$,
ξ_l – geometric (length) scale: $\xi_l = l_N/l_M$,
ξ_v – velocity scale: $\xi_v = v_N/v_M$,
ξ_F – surface scale: $\xi_F = F_N/F_M = \xi_1^2$,
ξ_Q – flow-rate scale: $\xi_Q = Q_N/Q_M = \xi_F \cdot \xi_v$,
ξ_{Qu} – capacity scale: $\xi_{Qu} = Q_{uN}/Q_{uM}$.

INDICES

M – quality in model scale,
N – quantity in real (natural) scale.

1. INTRODUCTION

Radial water intakes are the modern way of underground and infiltration water intakes, and in appropriate hydro-geological conditions (small thickness and water permeability of water-bearing layer) are much more economical than the traditional water intakes, i.e. groups of well drilled or digged. They are, moreover, characterize dby structure compactness, reliability and long-life [1]–[3], [13], [16]. An increasing interest in infiltration, as a process enriching underground water resources with surface water, has been observed since several years. This is due to the fact that infiltration gives new possibilities of the development of radial water intakes distributed in the immediate vicinity of rivers or surface water reservoirs and characterized by a high capacity. Because of the above and other advantages they more and more often replace the traditional intakes of underground and in filtration water [4], [16].

2. ADVISABILITY OF PHYSICAL MODELLING OF RADIAL WATER INTAKES

Capacity of radial water intake Q_u (fig. 1) depends on many factors characterizing the structure, hydrological and operation conditions [4]–[6]

$$Q_u = f(n, l_f, r, z, H_w, k_f, s). \tag{1}$$

It should be emphasized that the technology of radial water intakes has gone far ahead of the elaboration of scientific bases of their desing. This is, among

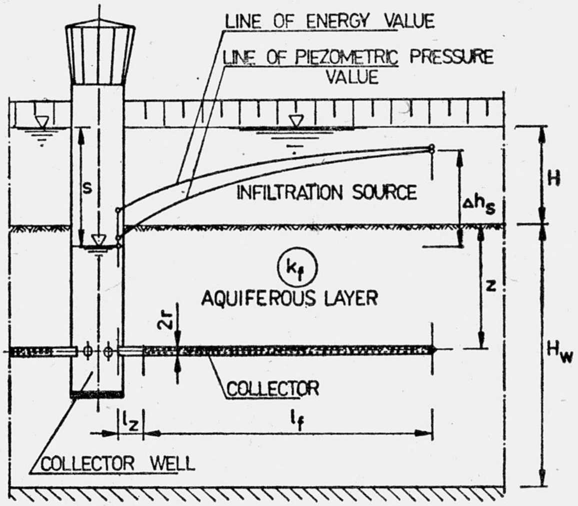


Fig. 1. Schematic representation of radial infiltration water intake
Rys. 1. Schemat ujęcia promienistego w warunkach infiltracji

others, due to the fact that water inflow to the radial intake should be considered solely in three-dimensional space, which – in turn – requires the application of an advanced analytical or experimental apparatus. That is why solution of the problem (1) is difficult.

Theoretical approach to this problem is based on equations of mathematical physics (describing water motion in soil), assuming irrotational motion of ideal liquid due to gravitation forces acting in homogeneous and isotropic soil medium.

Under such conditions the water motion is described by Laplace equation

$$\frac{\partial^2\varphi}{\partial x^2}+\frac{\partial^2\varphi}{\partial y^2}+\frac{\partial^2\varphi}{\partial z^2}=0 \tag{2}$$

where φ is velocity potential being the function of coordinates x, y, z. Laplace equation should satisfy boundary conditions resulting from physical properties of the filtration area.

To solve the problem formulated in the above way two analytical methods have been applied [4]:

conformal mapping,

source-sink method (Rankine method).

In experimental investigations, the analogies between the phenomena occuring in nature and model, which can be described by Laplace equations, have been so far examined. Here electrohydrodynamic analogy has found its practical application [4], [10], [11].

Due to diversity of simplifying assumptions taken in desing of infiltration water radial intakes a number of formulae have been obtained, e.g. Surov's, Ostrowski's, Razumow's or Maciejewski's formulae, that differ significantly in their structures [4], [16]. All these formulae, however, have some common features as they neglect energy losses inside the collectors and collector well and assume that the water inflow into filters is uniform along the whole filter length. Some attempts [6], [8], [16] made to calculate the depression of radial intakes according to these formulae, but with the energy losses being taken into account, have not brought satisfactory results. Discrepancies between values calculated from the separate formulae (exceeding often 100%) give also the evidence to the inadequacy. Usually the calculated capacities exceed also substantially the values obtained during pumpings [1], [4], [16]. All these differences are due to the mentioned above model simplifications as well as to the difficulties lying in analytical solution to this problem. Hence, in order to obtain a more accurate description of phenomena associated with water uptake from radial intakes and to find the formulae describing these phenomena in a more complex way, the appropriate tests must be performed on physical models representing appropriately real conditions of the intake operation.

3. METHODOLOGICAL FOUNDATIONS OF MODEL TESTS

Model tests of radial water collectors cannot be performed before the following questions are answered:

how to characterize the similarity between phenomena occurring in nature and model?

which scales should be thus assumed for the model?

how to convert the quantities measured in the model into the natural ones?

The answers to these questions may be obtained by applying the theory of mechanical similarity and dimensional analysis, taking account of the physical meaning of the phenomenon being investigated. Due to the theory of mechanical similarity the quantitative and qualitative description of real phenomena may be obtained from model tests. To satisfy the conditions of such a similarity, geometric (ξ_l, ξ_F, ξ_V), kinematic (ξ_t, ξ_v, ξ_g) and dynamic similarities must be fulfilled. Dynamic similarity between the nature and model holds if the Newton numbers in both the systems are equal. This definition expresses the general law of dynamic similarity of phenomena, which may be written as follws

$$\mathrm{Ne}_N = \mathrm{Ne}_M. \tag{3}$$

An arbitrary particle of the moving liquid is subject to the following forces: thrust, gravity, internal friction, elasticity, and surface tension. Detailed laws of their similarity result from equation (3):

thrust: $\mathrm{Eu}_N = \mathrm{Eu}_M$ – Euler criterion, (4)

gravity: $\mathrm{Fr}_N = \mathrm{Fr}_M$ – Froud criterion, (5)

friction: $\mathrm{Re}_N = \mathrm{Re}_M$ – Reynolds criterion, (6)

elasticity: $\mathrm{Ca}_N = \mathrm{Ca}_M$ – Cauchy criterion, (7)

surface tension: $\mathrm{We}_N = \mathrm{We}_M$ – Weber criterion. (8)

Not all the similarity conditions for the model and real phenomena can always be satisfied. Because of the fact that two liquids (fluids) satisfying simultaneously the criteria (4)–(8) are not known, the model tests in which a full dynamic similarity would be preserved cannot be performed. In practice, none of the forces mentioned above have the same influence on the course of the phenomenon examined. Most often a decisive effect is due to only one or at most two forces, and the remaining ones can be neglected. In such a case we are satisfied with the so-called incomplete similarity, by which we mean that only one or two similarity criteria connected with the forces being recognized as the prevailing ones are satisfied. If the deviation resulting from this incompleteness of similarity is within the limits of the admissible tolerance, the obtained modelling procedure allows us to perform the tests in a much wider range.

In model testing of radial intakes gravity and viscosity forces (4) should be recognized as being the decisive ones. In this case two phenomena should be distinguished:

1) water flows to the collectors through the soil layer, the Darcy law being preserved,

2) water flows inside the collector, the equations of Darcy–Weisbach and Siwoń being preserved.

Laminar flow of water inside the soil is described by the Darcy equation of the form

$$v_f = k_f I. \tag{9}$$

Criterion of linear filtration law applicability, when this phenomenon is considered from hydrogeological standpoint, is given by dimensionless number R_f. It expresses the ratio of inertial to internal friction forces occuring during percolation of liquid through a porous medium, this number being analogical to the Reynolds number (Re) in hydraulics. The Darcy law [9] is, for instance, satisfied for $R_f < 12$ [5] determined in this case from Ščelkačev's formula

$$R_f = \frac{10 v_f \varkappa^{0.5}}{n_p^{2.3} \nu}. \tag{10}$$

During the movement of water along the perforated segment of collector fed with a side affluent, there occur discrete changes in mass, momentum and energy of the main flux of liquid, and consequently, the change in the mean flow velocity. The difference in piezometric pressures (measured by the height of water column) along the collector segment of the length l_f as well as along the length l_z, and the losses due to water flowing out of collector into collector well, can be found from the formula (14), (15)

$$\Delta h_s = \frac{1.86}{2\,g}(v_k^2 - v_p^2) + \lambda_p \frac{l_f}{4\,gr} \times \left[v_p^2 + \frac{2v_p(v_k - v_p)}{m+1} + \frac{(v_k - v_p)^2}{2m+1}\right] + \left(1 + \lambda \frac{l_z}{2r}\right)\frac{v_k^2}{2g}. \tag{11}$$

Hydromechanical similarity of the flow in collectors (in nature and model) is preserved if the Froud number is a single-valued function of Reynolds number

$$\mathrm{Fr} = CI\mathrm{Re} \tag{12}$$

where C is coefficient of proportionality.

From the analysis of eq. (12) it follows that in model tests we cannot use the same liquid as that occurring in reality and that geometric similarity of inner surfaces of filtration pipes must be preserved. Thus, the modelling of water flow in collector is difficult, since in order the Froud and Reynolds criteria be satisfied simultaneously it is necessary that the following equality

$$\xi_\nu = \xi_l^{1.5}, \tag{13}$$

holds and $g_N = g_M$.

In practice, we cannot choose arbitrarily the viscosity coefficient for the liquid used in modelling (geofiltration area, the size of model being involved). As we have no other choice than to assume water as a medium, the satisfaction of the Fround criterion will be a sufficient condition of the flow similarity [4].

In both the cases of the water motion in the model, i.e. in water flow in soil and inside the collectors, the law of motion continuity holds. It means that the quantity of water flowing into collectors during a time unit equals that discharged at the same time by collectors. The facts that continuity condition as well as criteria of Ščelkačev (applicability of linear filtration law in soil) and Fround (hydromechanical similarity of flow in collectors) are satisfied allow us to refer the quantities measured on models to natural conditions by means of appropriate similarity scales. Since geometric dimensions of the model are determined with the help of one scale ξ_l, then hydraulic gradients are modelled in 1 : 1 scale. By virtue of Darcy law [9] we can write

$$\xi_v = \xi_{kf}\xi_l, \tag{14}$$

where $\xi_t = 1$.

Applying the law of voluminous flow continuity ($Q = vF$) we get

$$\xi_Q = \xi_v\xi_F. \tag{15}$$

By introducing into eq. (15) the relation (14) we obtain basic formula for the conversion of flows measured on the model into those occuring in nature

$$\xi_Q = \xi_{kf}\xi_l^2. \tag{16}$$

The essential difficulty is to establish in eq. (16) the scale of the soil filtration coefficient ξ_{kf}. Starting with the motion continuity law, the Froud criterion for the flow inside the collectors

$$\xi_v^2/\xi_g\xi_l = 1 \tag{17}$$

being satisfied, and assuming $\xi_g = 1$ the following formula for velocity scale will be obtained

$$\xi_v = \xi_l^{0.5} \tag{18}$$

and then

$$\xi_{kf} = \xi_l^{0.5}. \tag{19}$$

Velocity scale defined by means of eq. (18) is true if the scales of coefficients of linear friction resistances of the collectors are $\xi_\lambda = \xi_{\lambda p} = 1$. In particular, it means that

$$\lambda_{pN} = \lambda_{pM}. \tag{20}$$

In model test this condition cannot be satisfied, since in model and reality the values $\lambda_p = f(\mathrm{Re})$ are different [4], [9]. Because the condition (20) is not satisfied, the value of ξ_v and, speaking strictly, the a priori unknown exponent x at ξ_l in eqs. (18) and (19) which in this situation take the forms

$$\xi_v = \xi_l^x, \tag{18a}$$

and

$$\xi_{kf} = \xi_l^x \tag{19a}$$

must be determined experimentally.

Introducing relation (19a) into (16) and substituting $Q = Q_u$ we shall obtain the final form of the formula for the scale of the water intake capacity

$$\xi_{Qu} = \xi_l^{x+2}. \tag{21}$$

It should be noticed that in model tests of radial water intakes the measurements are made on a reduced real object, therefore the relative measuring errors of physical quantities most frequently increase with the value of similarity scales. Hence, it follows that the size of the model should be possibly large [4], [12].

The task of dimensional analysis to is give appropriate (with respect to dimension) forms of physical formulae. To each physical equation, describing a certain phenomenon, we can ascribe a dimensional equation in a basic system of quantities.

In kinematic phenomena, and such is modelling of water inflow to radial intakes, basic system is given by the length L and time T. Symbols and dimensions of the quantities considered in this paper are given in tab. 1.

Table 1

Dimensions of some quantities in the LT system
Wymiary niektórych wielkości układu LT

Quantity w	Symbol	Dimension W
Time	t	T
Length, caving, height, radius	l_f, z, H_w, r	L
Surface	F	L^2
Linear velocity	v	LT^{-1}
Kinematic viscosity	ν	L^2T^{-1}
Volumetric flow rate (capacity)	Q_u	L^3T^{-1}

Dimensionless products π_i of the quantities w_i form the following set of equations:

$$\begin{aligned} \pi_1 &= w_1^{x_1} w_2^{y_1} w_3, \\ \pi_2 &= w_1^{x_2} w_2^{y_2} w_4, \\ &\cdots\cdots \\ &\cdots\cdots \\ \pi_{k-2} &= w_1^{x_{k-2}} w_2^{y_{k-2}} w_k \end{aligned} \tag{22}$$

where k is the number of the quantities w taken into consideration.

By solving this set of equations we find the numerical values of exponents x_i, y_i and determine the dimensionless products π_i. This, in turn, enables us to derive the formula for the qualitative description of the given phenomena

$$\pi_1 = F(\pi_2, \pi_3, \ldots, \pi_{k-2}). \tag{23}$$

Similarity of the products π_i in nature and model is at the same time the criterion for the similarity of the phenomena being investigated.

Physical analysis of the influence of structural, hydrogeological and operating parameters on the capacity of a radial water intake [4], [6] has shown that Q_u in eq. (1) depends chiefly on: number, length, diameter (radius) and caving of collectors, thickness and filtration coefficient of water-bearing layer, as well as on the depression in collector well. Thus, in eq. (1) we have 8 quantities w that make 6 dimensionless products π.

Solving eqs. (22) we get a qualitative description of hydraulic characteristics of the water intake, which can be presented in the following forms:

$$\frac{Q_u}{k_f r^2} = F(n, l_f/r, z/r, H_w/r, s/r), \tag{24}$$

$$\frac{Q_u}{k_f r^2} = An^{a_1}\left(\frac{l_f}{r}\right)^{a_2}\left(\frac{z}{r}\right)^{a_3}\left(\frac{H_w}{r}\right)^{a_4}\left(\frac{s}{r}\right)^{a_5}. \tag{25}$$

The values of exponents a_1–a_5 and coefficient A can be determined from physical analysis or experimentally.

Similarity of products $\pi_2 = n$, $\pi_3 = l_f/r$, $\pi_4 = z/r$, $\pi_5 = H_w/r$, and $\pi_6 = s/r$ in nature and model is satisfied, since for these quantities the same geometric scale ξ_l is assumed. Comparison of dimensionless products π_1 yields the scale of flows (capacities)

$$\xi_{Qu} = \frac{Q_{uN}}{Q_{uM}} = \frac{k_{fN} r_N^2}{k_{fM} r_M^2}. \tag{26}$$

Using the definitions of filtration coefficient scale and surface scale, eq. (26 can be transformed to the form analogical to that of formula (16):

$$\xi_{Qu} = \xi_{kf}\xi_l^2. \tag{27}$$

4. APPLICATION OF THE DISCUSSED METHODOLOGY IN PHYSICAL MODELLING OF RADIAL INTAKES OF INFILTRATION WATER

The investigations undertaken at the Institute of Environment Protection Engineering of the Technical University of Wrocław included physical modelling of radial intake with collectors placed symmetrically under the bottom of infiltration source, assuming homogeneity and isotropy of the soil layer under the bottom of this source and the continuity of the water flux infiltrating through the reservoir bottom to the water-bearing layer. The investigations performed were aimed at:

i) determining the influence of basic geometric parameters of the water intake on its capacity,

ii) finding the function (1) in a form which could be used in hydraulic design of such intakes.

The investigations included:

number n, length l_f and caving z of collectors at the given diameter $2r$ of filtration pipes,

thickness of water-bearing layer H_w and depression s in collector well for the given water permeability k_f of water-bearing layer.

The tests were performed on an experimental set-up, constructed in 1 : 25 scale. Geometric parameters of the intake were changed discretely within the range of values given in tab. 2. The following parameters have been assumed,

Table 2

Variation range of the model geometric parameters
Zakres zmian parametrów geometrycznych modelu

Parameter	Denotation	Range of variations	
		In model scale	In real scale
Number of collectors	n	1–3	4–12
Working length of collector	l_f	0.5–3.6 m	12.5–90 m
Depth at which the collectors are laid	z	0.12–0.48 m	3–12 m
Thickness of water-bearing layer	H_w	0.36–0.60 m	9–15 m
Depression in collector well	s	0.08–0.24 m	2–6 m

moreover: diameter of collectors $2r = 0.01$ m (in nature 0.25 m), perforatio degree of filtration pipes $\varphi_0 = 0.20$, length of full-walled segment of collector $l_z = 0.12$ m (3.0 m), water depth in infiltration source $H = 0.16$ m. (4.0 m)

The chief element of the model (fig. 2) is the main reservoir *1* having th shape of a quarter of cylinder filled with medium-size sand and representin the geofiltration picture of the model water intake. In this reservoir there i localized a collector well *3* of the intake with collectors *7* arranged symmetri cally on three levels. A system of telescope overflows *8*, *9* in feeding chamber and collector well *3* makes it possible to maintain the established filtratio course. A uniform distribution of water in the infiltration source was possibl due to a supplying filter pipe *6* having a variable degree of perforation. The height of piezometric pressure in filtration field (including that immediately at the collectors) was registered by point pulse heads *4*. Piezometric pressures are transferred from the inside of collectors to piezometers by means of peripheral and compensating chambers *5*. The intake capacity was measured by cone- and floatmeters, their measuring range being 10–1000 dm^3/h.

The test programme included the identification and calibration of the model elements (filtration bed, filtration pipes, collectors, measuring apparatus and instruments) and the measurements comprising geometry of the model, capacity, depression, water temperature and piezometric pressure inside and outside the collectors. Identification and calibration measurements were indispensable for the conversion of model results into the real data.

As a filtration bed of the model we have used medium-grained sand characterized by a uniform grain distribution ($d_{10} = 0.215$ mm $d_{60} = 0.400$ mm, $n_p = 37.5\,\%$). Filtration coefficient of the water-bearing layer, determined from the results of test pumpings in the model [4], according to Babuškin's scheme was $k_f = 3.732 \times 10^{-4}$m/s. Because of the lack of data as to the value of linear resistance coefficient λ_p, for the perforated small-diameter pipes used in model tests (especially within the zone of laminar flows and transient zone) we have used empirical relations, obtained by approximation of the measurement results [4], [5], [9]. Water inflow to the collector well of radial intake is caused by the given difference in piezometric water pressure, called an apparent depression s (fig. 1). Due to this depression the water inflow to collector in the model is in a defined state of energetic equilibrium. This state depends on parameters characterizing hydraulic losses in filtration bed and collectors, i.e. on filtration coefficient of water-bearing layer and on diameter and length of collectors. Thus, the changes in geometric parameters of the intake (e.g. number, length, caving) are followed by different state of energetic equilibrium, which – in turn – affects directly the size and distribution (arrangement) of side affluents along filtration pipes and indirectly – the interaction of collectors and the intake capacity.

Analysis of variations in piezometric pressure inside filtration pipes as well as in their vicinity allowed us to establish a quantitative assessment of the non-uniform water intake along the collectors, occurring in particular when these collectors are long. In extreme cases ($l_f = 3.6$ m, $s_p = 0.24$ m, $n = 4$) unit hydraulic load at the end of collector (at collector well) was about 12 times higher than that at its beginning [4].

This fact was confirmed by the analysis of the arrangement of equipotential lines in geofiltration area. The greatest hydraulic gradient s(concentration of constant potential lines) haxe been observed in the vicinity of the collector well. Qualitatively this non-uniformity depends first of all on the length of fil-

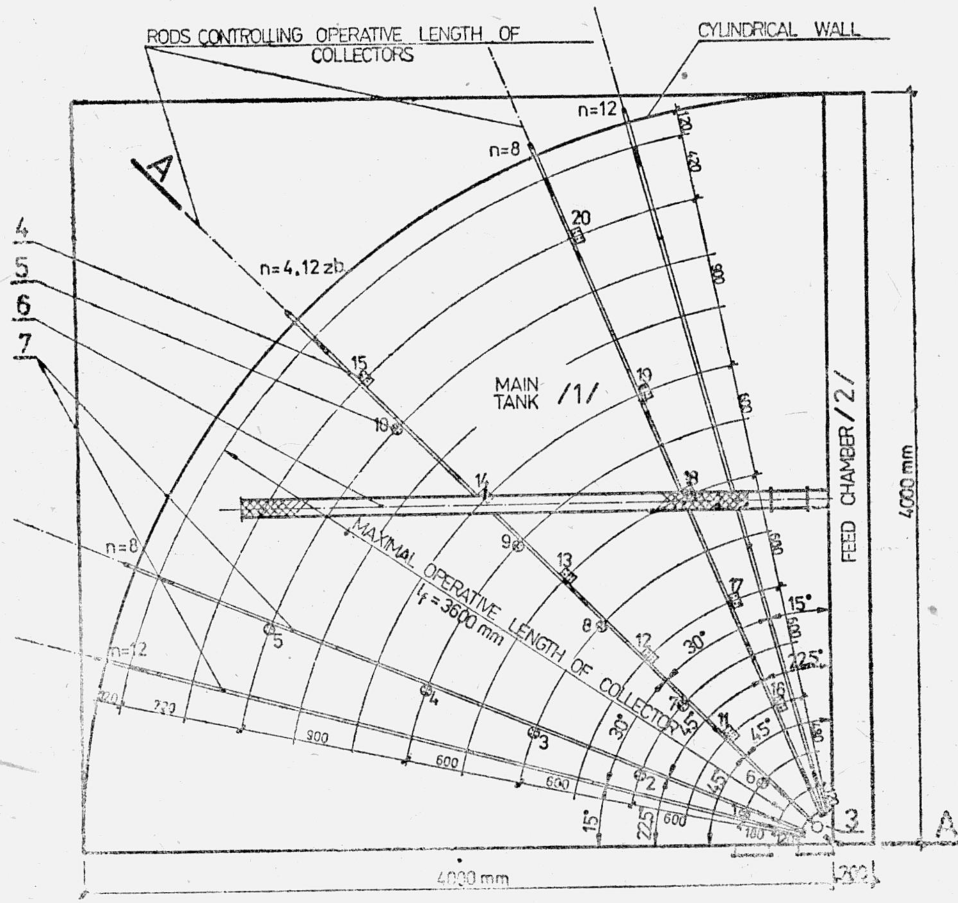


Fig. 2. Schematic representation
Rys. 2. Schemat stanowiska

tration pipes, and then on the depression in collector well and the number of collectors in the water intake. For relatively short collectors (of the lengths non exceeding 1.0 m in the model and 25 m in natural scale), the non-uniformity is negligeable and the water inflow into the collectors may by treated as being uniform.

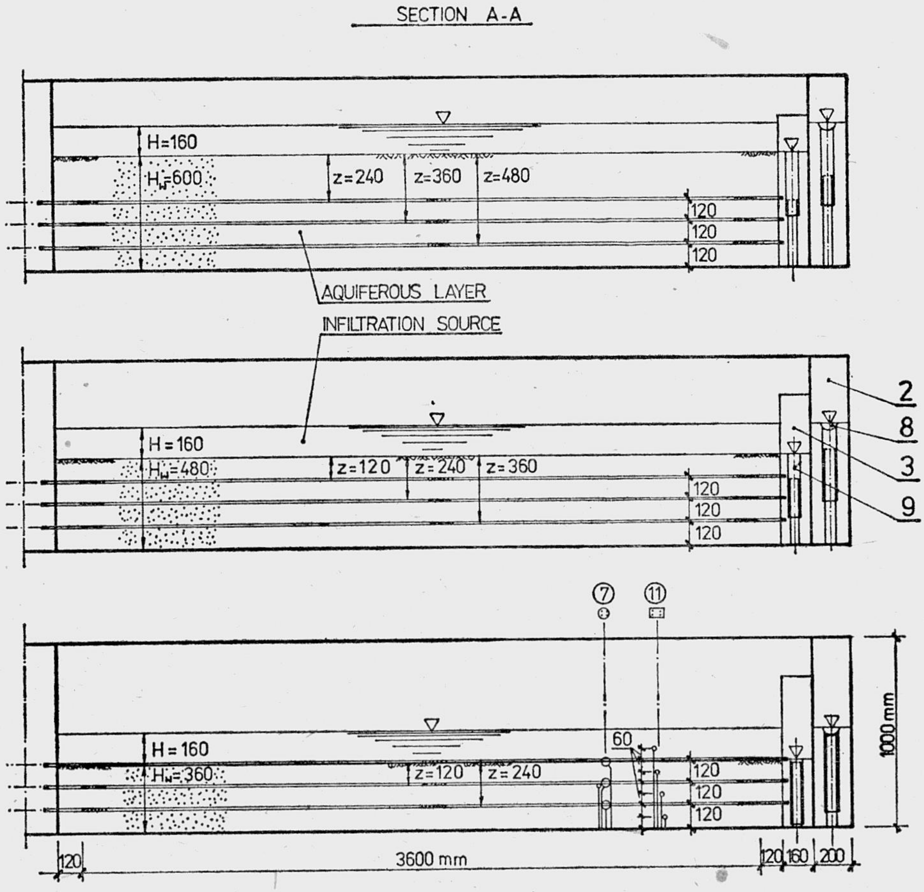
The results obtained allowed us to calculate the exponents a_1–a_5 and coefficient A in the eq. (25), gaining therefore the formula in which the water intake capacity is described quantitatively:

$$\frac{Q_u}{k_f r^2} = 28{,}35 n^{0.866} \left(\frac{l_f}{r}\right)^{0.454} \left(\frac{z}{r}\right)^{-0.180} \left(\frac{H_w}{r}\right)^{0.176} \left(\frac{s}{r}\right)^{0.736} \tag{28}$$

with the constraints:

$4 \leqslant n \leqslant 12,$

$101.01 \leqslant l_f/r \leqslant 505.05,$



of test stand (see the text for details)
doświadczalnego (oznaczenia w tekście)

$$24.24 \leqslant z/r \leqslant 96.97,$$

$$72.73 \leqslant H_w/r \leqslant 121.21,$$

$$16.16 \leqslant s/r \leqslant 48.48.$$

Numerical values of empirical coefficients in eq. (28) have been determined by multiple regression using Gauss multiplier method.

The presented above operation of a model water intake can be referred to natural conditions by means of similarity scales, defined in section 3. To this end the correctness of the performed tests should be examined with respect to the kind of water movement in filtration bed and the value of the flow velocity scale in collectors (equal to that of soil filtration coefficient) should be determined.

Maximum filtration rates and the corresponding extreme values of R_f (10) occurred at the boundary of "natural" filter (copper wire gauze) at the water inflow at the end of the collector. In all the cases the numbers R_f satisfied the linear filtration criterion of Ščelkačev ($R_{f\max} < 1.0$).

In order to determine numerical value of flow velocity scale in collectors (eq. (18a)), numerical values of hydraulic losses in collectors have been calculated for the given value of v_N/v_M ratio and the results of $\Delta h_{sN}/\Delta h_{sM}$ calculations compared with the geometric scale of the model ($\xi_1 = 25$). Hydraulic losses have been computed according to the formula (11) in which the quantities λ and λ_p in natural scale were determined from Siwoń formulae [14], [15] and in model scale – from the corresponding formulae presented by the author in [4], [5], [9]. The calculations of Δh_{sM} were additionaly veryfied by the measurements performed on the model.

Since the mean values of λ_{pM} were higher than those of λ_{pN}, the smallest differences between the measured and calculated hydraulic losses (Δh_s) were obtained for the velocity scale $\xi_v = 5.25$. Thus the exponent x in eqs. 18a and 19a takes the value of 0.530.

Hydraulic characteristics obtained on the model can be referred to the nature, if in the latter the ratio of losses in collectors to depression is similar, i.e. at $2r_N = 0.250$ m and $k_{fN} = 1.96 \times 10^{-3}$m/s. The capacity of model water intake may be converted into the natural quantities by means of the intake capacity scale (21). Then:

$$Q_{uN} = 3281.25 Q_{uM}. \tag{29}$$

5. SUMMARY AND CONCLUSIONS

Although the advantages of radial intakes, especially of those located in the vicinity of rivers or water reservoirs and concerning the economy and exploitation, are out of question, there is no universal and commonly used method of their design. Thus model tests, the results of which may contribute to the solution of this problem, should be recognized as fully justified both from scientific and practical standpoints.

The selected results of model testing of radial water intakes, presented in this paper, are a contribution to a full explanation of phenomena accompanying the operation of such intakes, and allow the formulation of the following conclusions:

1. It is not possible to perform model tests of radial water intakes in which a full dynamic similarity of phenomena would be preserved, i.e. all the criteria of similarity of forces in the nature and model be satisfied. Thus we must be satisfied with the so-called incomplete similarity, i.e. to take account of only the forces prevailing in the given phenomenon.

2. In model tests of radial water intakes the gravity and internal friction forces must be recognized as being dominant. Thus a dynamic similarity of phenomena takes place if Fround's and Ščelkačev's criteria are satisfied.

3. If both these criteria as well as the condition of the motion continuity are satisfied, then the nature and model can be recognized as being sufficiently similar, and the physical quantities measured on the model can be transferred on the natural conditions by means of the appropriate similarity scales.

4. The application of the mechanical similarity theory and dimensional analysis enabled qualitative and quantitative descriptions of hydraulic characteristics of radial water intakes. The performed model tests allowed us to determine the numerical values of empirical coefficients.

5. Methodological foundations of physical modelling of radial water intakes, presented in the paper, may be used in model tests of such objects, in which filtration pipes perform the role of collectors.

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METODOLOGICZNE PODSTAWY MODELOWANIA FIZYCZNEGO UJĘĆ Z POZIOMYMI ZBIERACZAMI

Sformułowano zasady modelowania fizycznego promienistych ujęć wody na podstawie teorii podobieństwa mechanicznego i analizy wymiarowej. Stwierdzono, iż prowadzenie badań modelowych z zachowaniem pełnego podobieństwa dynamicznego zjawisk jest nieosiągalne. Za dominujące uznano siły ciężkości i tarcia wewnętrznego. Niepełne podobieństwo dynamiczne osiągnięte zostało przez spełnienie kryterium Froude'a i kryterium Ščelkačeva. Zastosowanie analizy wymiarowej umożliwiło sformułowanie jakościowego i ilościowego opisu charakterystyk hydraulicznych ujęć promienistych, przeprowadzone zaś badania modelowe pozwoliły określić wartości liczbowe współczynników empirycznych. Prezentowana metoda modelowania fizycznego ujęć promienistych wody może być wykorzystana w badaniach modelowych takich obiektów, w których elementem ujmującym wodę są zbieracze, tj. rury filtrowe.

METHODOLOGISCHE GRUNDLAGEN EINES PHYSIKALISCHEN MODELLS FÜR FILTERROHRENSTRÄNGE

Das hier besprochene Modell ist auf den Prinzipien der Ähnlichkeitstheorie und der Dimensionsanalyse gestützt. Es wird festgestellt, daβ das Modell nicht imstande ist, eine volle Ähnlichkeit der dynamischen Effekte zu gewährleisten. Schwere und Reibungskraft werden als überwiegende Erscheinungen betrachtet. Die Erfüllung des Froudeschen und des Ščcelkačevschen Kriteriums trägt zu einer unvollständigen, dynamischen Ähnlichkeit bei. Die Anwendung der Dimensionsanalyse gestattet eine quantitative und qualitative Formulierung der hydraulischen Kennlinien der Stränge. Modellversuche führen zur Bestimmung empirischer Koeffizientenwerte. Die besprochenen Methoden dürfen in den Modelluntersuchungen solcher Objekte angewandt werden, die Filterrohre in Betrieb nehmen.

МЕТОДОЛОГИЧЕСКИЕ ОСНОВЫ ФИЗИЧЕСКОГО МОДЕЛИРОВАНИЯ ВОДОЗАБОРОВ С ГОРИЗОНТАЛЬНЫМИ ВОДОСБОРНИКАМИ

Сформулированы основные принципы физического моделирования радиальных водозаборов. На основе теории механического подобия и теории размерностей определены: сущность подобия явлений в действительности и в модели, масштабы модели, методы пересчёта результатов, полученных из измерений при применении моделей на натуральные величины. Отмечено, что проведение модельных испытаний с сохранением полного динамического подобия явлений, т. е. удовлетворение всех критериев подобия сил, выступающих в действительности и в модели, является не-

достигаемым. В модельных испытаниях радиальных водозаборов доминирующими были признаны силы тяжести и внутреннего трения. Следовательно, динамическое подобие явлений заключается в удовлетворении критерия Фруда относительно протекания в водосборниках и критерия Щелкачёва линейного закона фильтрации в грунте. Принятие вышеотмеченных критериев, при одновременном удовлетвотении условий непрерывности движения, позволяет признать реальность и модель достаточно подобными и даёт возможность отнесения физических величин, измеряемых на модели для реальных условий с помощью соответствующих коэффициентов подобия.

Применение анализа размерностей дало возможность сформулировать качественное и количественное описание гидравлических характеристик радиальных водозаборов. Это описание требовало проведения модельных испытаний для определения числовых значений эмпирических коэффициентов. Приведены избранные результаты таких исследований, проведенных в Институте техники охраны среды.

Предлагаемый метод физического моделирования радиальных водозаборов может применяться в модельных испытаниях таких объектов, в которых водозабирающим элементом являются водосборники, т. е. фильтровые трубы.