MODELLING THE SEEPAGE OF GROUNDWATER: APPLICATION OF THE VISCOUS ANALOGY AND NUMERICAL METHODS

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Abstract
The application of the viscous analogy, known as the Hele-Show model, for seepage investigation is demonstrated in the paper. The changes in the viscous properties of the model fluid (glycerine) resulting from the changes of the atmospheric conditions - temperature and humidity, have been taken under consideration as factors influencing the flow discharge in the model. A method has been substantiated for the exact quantitative comparison of discharges obtained under different boundary conditions of the seepage process using parallel rheological measurements of the model fluid. The results from the viscous and mathematical models are compared for a particular two-dimensional seepage process - the operation of a horizontal drainage. The complete coincidence of these results, proves the good grounds of the method as well as its applicability as a test method for the development of mathematical models.

Kurzfassung
Im diesem Artikel wird die Anwendung des bekannten Hele-Show Modells (Spaltmodells) bei der Grundwasserströmung demonstriert. Es wird die Änderung der Viskositätseigenschaften der Modellflüssigkeit (Glyzerin) als Folge der atmosphärischen Temperatur- und Feuchtigkeitsänderungen auf die Strömungsmenge im Modellsystem vorgestellt. Durch die Untersuchungen der rheologischen Parameter des Glyzerins wird eine Methode für den genauen quantitativen Vergleich der bei verschiedenen Randbedingungen durchströmenden Glyzerinmengen im Modell gefunden. Die nach der beschriebenen Methodik erhaltenen Ergebnisse, von Simulation einer Grundwasserströmung in einer Dränage, werden mit einem mathematischen Modell verglichen. Die sehr gute Übereinstimmung beider Verfahren ist eine Bestätigung der dargestellten Methodik und zeigt ihre Anwendbarkeit bei Testen von numerischen Modellen.

Résumé
Cet article porte sur l'application de la méthode de l'analogie visqueuse appelée "le modèle de Hele-Show" pour des recherches modelant les processus de filtration. Les variations des propriétés visqueuses du fluide modèle dues aux variations dans les conditions atmosphériques - température et humidité, sont prises en considération comme facteurs agissant sur l'émission du fluide dans le modèle. La méthode est argumentée par des mesures parallèles de la viscosité du fluide modèle pour assurer la comparaison exacte quantitative de l'émission dans l'étude des variantes sur l'effet des conditions limite qui influent sur le processus de filtration. La comparaison des résultats des processus de filtration bidimensionnels obtenus par des modèles visqueux et mathématiques - l'opération d'un drainage horizontal, et la coïncidence parfaite de ces résultats prouvent d'une part la base excellente de la méthode et de l'autre - son applicabilité comme méthode de vérification pour le développement de modèles mathématiques.

Key-words:
viscous analogy method, seepage flow, alternate drainage systems, viscous and mathematical modelling

1 INTRODUCTION

The modelling of seepage processes in soils is performed using experimental and mathematical methods. The viscous analogy method is a well-known and often applied method. It is based on the analogy between the law of laminar flow of water in porous medium

$$v = kH \tag{1}$$

where v is the seepage flow velocity, k is the soil's permability coefficient, H *is* the hydraulic potential gradient of viscous flow, and the law of viscous laminar flow between two solid parallel plates at a distance of $2a$ from one another

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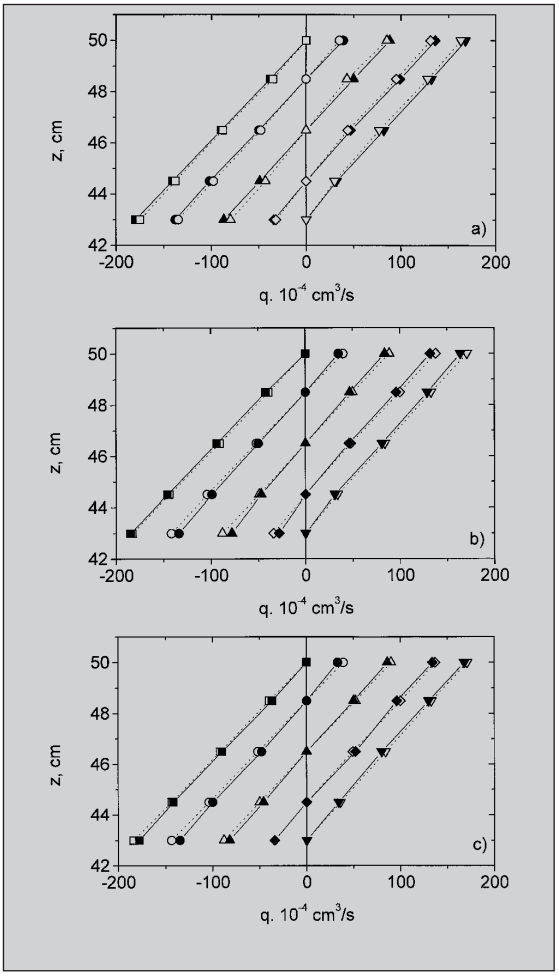

Figure 7: Comparison of the results obtained from the viscous (full symbols) and mathematical (open symbols) model for drainage pipe distance: a) 10 m; b) 17 m; c) 30

described by the mathematical and viscous models and using the relationships from Eq. 4 and Eq. 5, we obtain for α_s:

$$a_s = \frac{3kv}{2a^2 g} \qquad (10)$$

The value of α_s = 10.9 is calculated from the data for the particularly considered model, reduced to equal dimensions: k = 1 m/day, v = 89 m²/day, a = 5.5 10⁻⁴ m, g = 7.323 10¹⁰ m/day². The permeability of the real drainage accepted in the mathematical model is: $S = \alpha_s S_{mD}$ = 2.35 m²/day. This value is introduced in the mathematical model.

4 COMPARISON OF THE RESULTS OBTAINED FROM THE NUMERICAL AND VISCOUS MODELS

The mathematical model of alternate irrigation drainage is described in detail in [2-4] and will not be discussed here. As mentioned in paragraph 2.1 the mathematical model is based on orthogonal discretization of the filtration area and is solved by the well-known finite-difference method [1] and the depression lines are obtained by an iterative procedure. The drainage discharges and the depression line co-ordinates were obtained for the real conditions by means of this model and the developed software [3].

In this study the results are shown in the reverse manner using the reciprocal value of the transfer coefficient, $\alpha_Q' = 1/\alpha_Q$, to correlate the data obtained from the mathematical model to the data obtained from the viscous one. All data from the mathematical model, reduced to the size of the viscous one, are presented in Fig.7. The coincidence of the results from both methods is very good. This proves the reliability of the mathematical model.

5 CONCLUSIONS

The applied method for elimination of the effect of external atmospheric factors on the quality of the used fluid (glycerine) is easily realised under laboratory conditions and ensures the accuracy of the method. Consequently, the described method can be used for testing the accuracy of other methods. Except for the possibility of describing the seepage process as a whole, the viscous modelling provides the possibility of determining specific local characteristics as the drainage pipe permeability, S. The substitution of the S value in the numerical model allows the verification of the mathematical model. The described method of the viscous analogy for investigation of seepage processes exhibits qualities which are not possessed by other methods. For this reason, within the frames of its specific possibilities, it can be used as a criterion for the accuracy of other methods, especially numerical methods.

ACKNOWLEDGEMENT

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[h''] cm	[z] cm	[time] day	[t] °C	$[Q_i^t]^*$ cm3/s	$[\eta]$ Pas	η_o^{20}/η_i^t	$[Q_o^{20}]^*$ cm3/s
50	48.5	2	23.1	-47	0.94	1.38	-34
	46.5	2	23.5	-128	0.9	1.44	-89
	44.5	2	24.1	-208	0.86	1.51	-138
	43	1	24.2	-255	0.9	1.44	-177
48.5	50	4	24.4	61	0.74	1.76	35
	46.5	3	22.8	-67	0.91	1.42	-47
	44.5	3	23.1	-141	0.9	1.44	-98
	43	1	24.1	-194	0.9	1.44	-135
46.5	50	4	24.2	147	0.75	1.73	85
	48.5	5	24.4	88	0.69	1.88	47
	44.5	3	24	-70	0.83	1.56	-45
	43	1	23.9	-113	0.91	1.42	-80
44.5	50	4	23.4	214	0.79	1.64	131
	48.5	5	23.8	169	0.73	1.78	95
	46.5	3	24	69	0.83	1.56	44
	43	1	23.9	-44	0.91	1.42	-31
43	50	4	23.1	260	0.81	1.6	163
	48.5	5	23.6	224	0.74	1.75	128
	46.5	5	25.3	156	0.64	2.03	77
	44.5	8	25.3	64	0.61	2.13	30

Table 1: Experimental data for measured discharges, Q_i^t, and reduced discharges, Q_o^{20} ($b_m/2$ = 25 cm).

Erratum

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ACADEMIC RHEOLOGY AND INDUSTRIAL RHEOLOGY – A PERSONAL REFLECTION [TO THE YEARS 1960- 1970]. ERRATUM

Author: Nobuyuki Nakajima

p 123: Caption for Figure 8 'Viscoelastic data and normal stress data' should read 'Agreement of data obtained from different instruments'