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RHEOLOGICAL INVESTIGATION OF AGRICULTURAL SOILS

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By the term agricultural soil the uppermost, tilled layer of the earth shell, several decimeters in thickness is meant. The types of mechanical load of the soil in course of tilth can be divided into two main classes:

1) The soil particles are ruptured by the tillage tools, their continuity is broken down (such as ploughing).

2) Machines running on the soil as well as soil compactors cause deformation of the soil, but generally do not produce discontinuity.

Our main aim was the qualitative and quantitative description of the secondly mentioned process. By considering the soil continuous and isotropic, the results of the mechanics of continuous media can be applied for investigating deformation problems, that is to say, the so-called geometrical, dynamical, and material equations are available for the description of the phenomena. These latter equations offer a relationship between the stress and the deformation and, unlike the first two groups of equations, reflect the physical properties of matter. Formulae used by classical mechanics were valid mainly for elastic bodies, According to the results of soil research, soil was proved not to be regarded as an elastic body. Its deformation behaviour reminds to that of highly viscous fluids, thus falling into the framework of rheological researches. Our aim was to seek for a rheological model describing well the deformation properties of a certain type of soil (clayey soil).
Rheology constructed a great many of models from three fundamental components (elasticity, viscosity, plasticity). From among these we have taken into account only those, which are linear and do not contain more than three elements. By increasing the number of elements, the mathematical treatment of the models becomes more and more complicated and their practical application encounters great difficulties.

For choosing the appropriate model a measurement procedure was elaborated. The measuring equipment was capable to assure the conditions σ = constant, $d\sigma/dt = \dot{\sigma}$ = constant, ε = constant, and $d\varepsilon/dt = \dot{\varepsilon}$ = constant necessary for the rheological investigations in case of uniaxial stress. The measurements were made on cylindrical specimens. In the first stage of our experiments we wanted to be acquainted with the deformation properties of the solid skeleton of the soil, therefore nearly one-phase, geometrically regular specimens were prepared from the soil by pressing andy drying. By this means the reproducibility of the measurements was assured too.

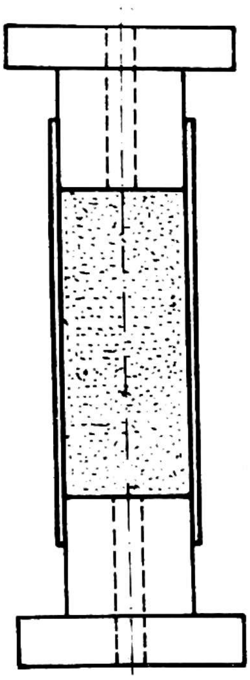

Fig. 1. Soil sample consolidation

The specimens were subjected to creeping test ($\sigma = \sigma_0$ = constant) and relaxation test ($\varepsilon = \varepsilon_0$ = constant) and the creeping curves $\varepsilon = \varepsilon(t)$ as well as the relaxation curves $\sigma = \sigma(t)$ were plotted. Based on the shape of the curves, from among the above mentioned rheological models containing not more than three elements it can be selected the one, that seems to be the most appropriate with respect to the mechanical properties. According to our measurements the creeping and relaxation curves of the soil under investigation could be best fitted to those of the Poynting—Thomson model.

The differential equation of the model is

$$\dot{\sigma} = E\dot{\varepsilon} + \lambda\dot{\varepsilon} - \vartheta\dot{\sigma},$$

where E, λ, ϑ are coefficients specific to the material, usually termed material constants.

Our further experiments aimed at determining the numerical values of these material constants and controlling the accuracy of the model in reflecting the values measured on soil.

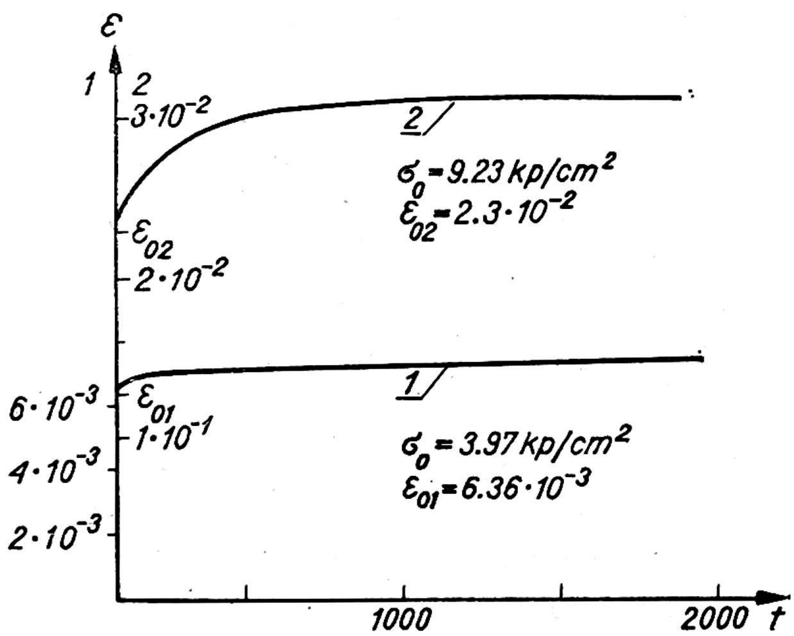

Fig. 2. The creeping results

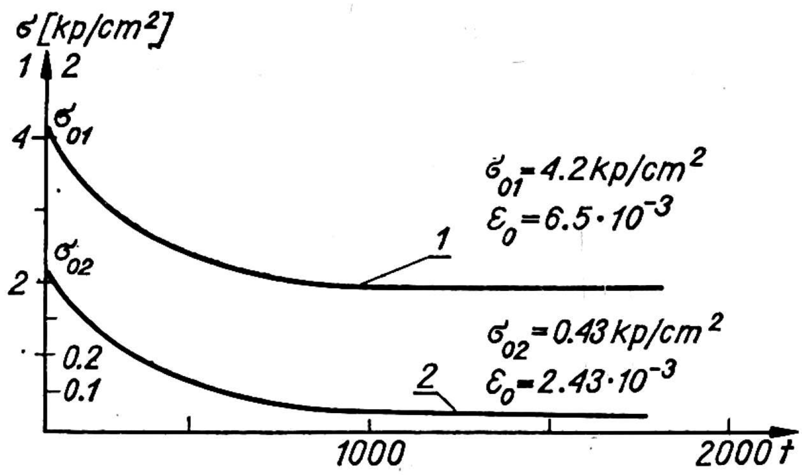

Fig. 3. Relaxation of stress

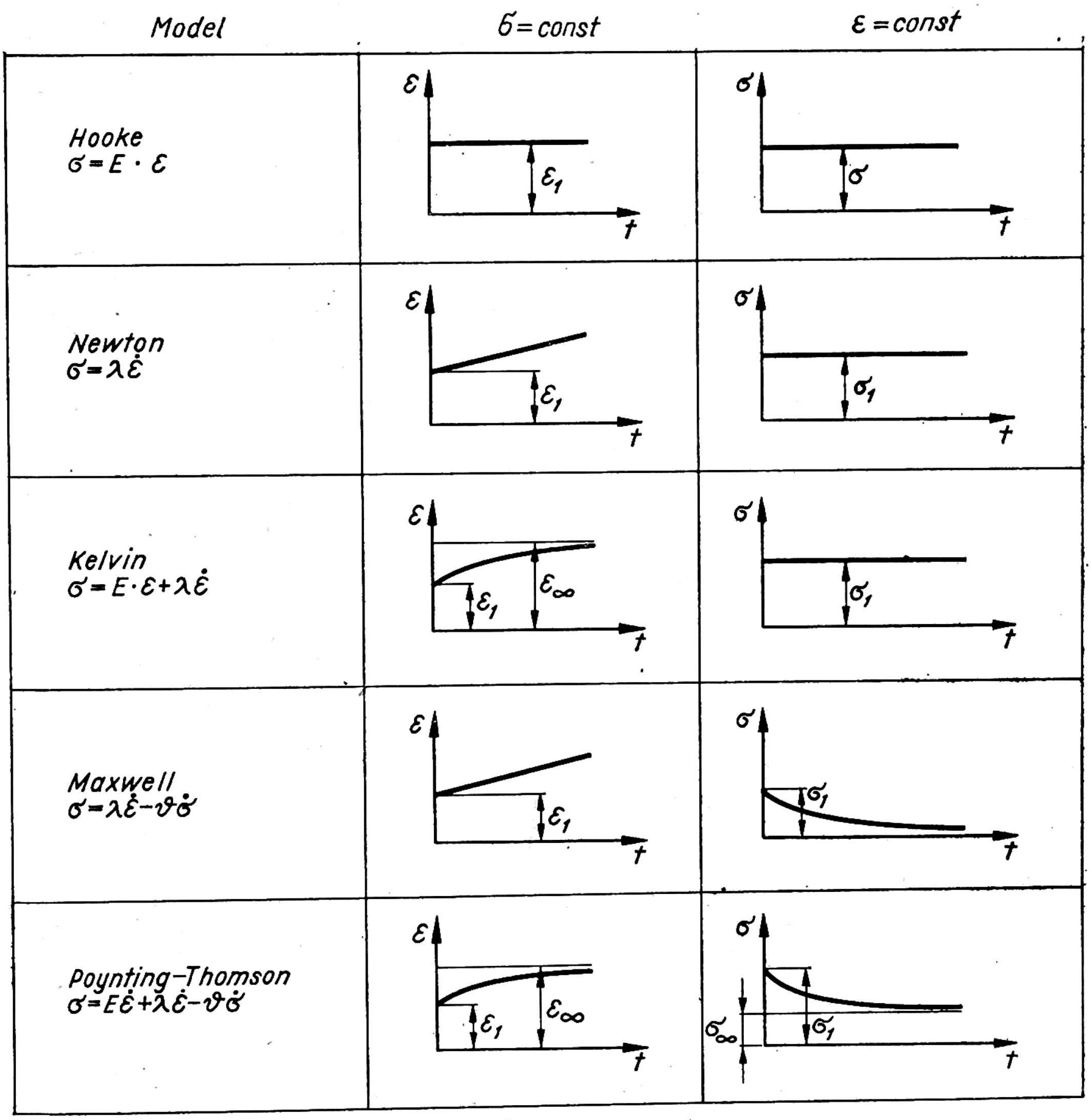

Fig. 4. Creep and relaxation in rheological models

The material constants can be determined in two ways:

1) From the results of the creeping and relaxation tests, since the material constants are contained in the equations

$$\varepsilon = \sigma_0/E + (\varepsilon_0 - \sigma_0/E)e^{-Et/\lambda}$$

and

$$\sigma = E\varepsilon_0 + (\sigma_0 - E\varepsilon_0)e^{-t/\vartheta},$$

obtained from the solution of the differential equation of the model under the conditions $\sigma = \sigma_0 =$ constant and $\varepsilon = \varepsilon_0 =$ constant, respectively. This method has the drawback that the numerical values are obtained from measurements on two separate specimens.

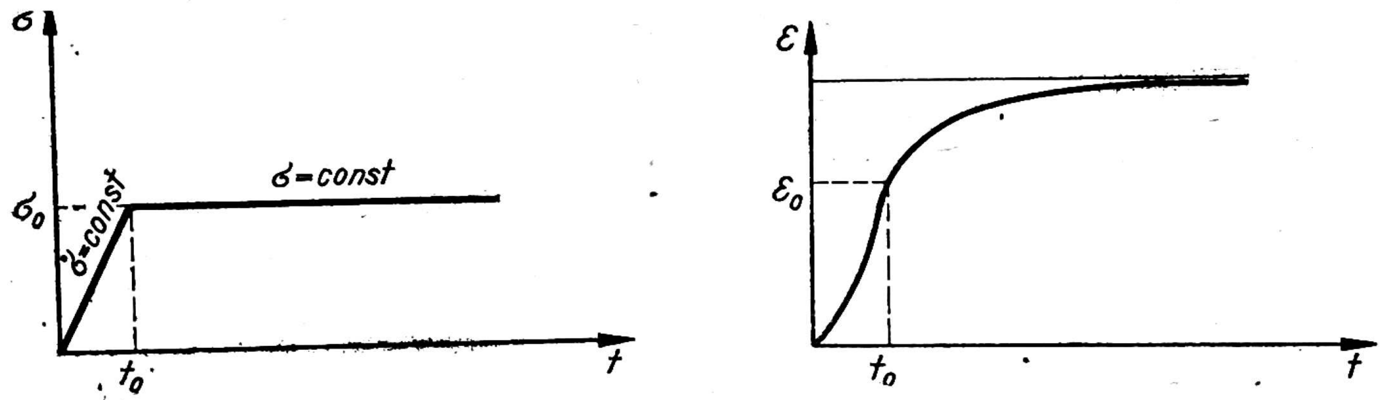

Fig. 5. Test programs

2) Following an increasing load with $\dot{\sigma} =$ constant, the stress σ is fixed at values $\sigma = \sigma_0$, $\varepsilon = \varepsilon_0$, $t = t_0$, that is to say, the specimen is subjected to creeping test at $\sigma = \sigma_0$. The material constants required are now contained in the equation

$$\varepsilon = \dot{\sigma}/E[t + (\vartheta - \lambda/E)(1 - e^{-Et/\lambda})],$$

valid for the period of constantly increasing load ($\dot{\sigma} =$ constant) and the formerly mentioned equation of the creeping curve. This method has the advantage that a single specimen is sufficient for performing the measurement, moreover the technically much more complicated relaxation test can be avoided.

The numerical determination of the material constants was carried out by the least squares method of curve fitting. Using the calculated values

$$\varepsilon_{ik}^{I} = \varepsilon_{ik}^{I}(t_i, E, \lambda, \sigma), (\dot{\sigma} = \text{constant}),$$

$$\varepsilon_{ik}^{II} = \varepsilon_{ik}^{II}(t_i, E, \lambda)\,(\sigma = \sigma_0 = \text{constant})$$

Table 1

The material constants

Sign of specimen	E [kp/cm²]	λ [kp h/cm²]	ϑ [h]	H
T 3	$5.34 \cdot 10^2$	$1.073 \cdot 10^3$	1.696	$6.3 \cdot 10^{-8}$
P 1	$1.357 \cdot 10^4$	$2.599 \cdot 10^4$	2.12	$2.91 \cdot 10^{-7}$
P 2	$1.105 \cdot 10^4$	$4.340 \cdot 10^4$	2.59	$1.25 \cdot 10^{-5}$
G 1	$4.734 \cdot 10^3$	$1.170 \cdot 10^3$	0.952	$3.65 \cdot 10^{-7}$
G 4	$2.386 \cdot 10^3$	$4.054 \cdot 10^3$	0,109	$1.86 \cdot 10^{-6}$

and the measured values of ε_i, the sum of the squared deviations was formed:

$$\Delta = \Sigma (\varepsilon_{ik}^{\mathrm{I}} - \varepsilon_i)^2 + \Sigma(_{ik}^{\mathrm{II}} - \varepsilon_i)^2.$$

The necessary condition of the minimum is

$$\frac{\delta \Delta}{\delta E} = 0, \frac{\delta \Delta}{\delta \vartheta} = 0, \frac{\delta \Delta}{\delta \lambda} = 0.$$

The solution of this system of equations yields the sought-for material constants. Because of computational difficulties the functions $\varepsilon_{ik} - \varepsilon_i$ in the brackets were linearized by expansion into power series, and in order to perform the vast number of numerical calculations an ALGOL program of the evaluation procedure was constructed for an ODRA 1204 type computer.

Table 2

Rheological constants

Sign of specimen	Moisture content %	E [kp/cm²]	λ [kp h/cm²]	ϑ [h]
P_1	—	$1.357 \cdot 10^4$	$2.599 \cdot 10^4$	2.12
P_3	7,15	$2.315 \cdot 10^3$	$1.876 \cdot 10^4$	2.69
P_5	18,7	$6.87 \cdot 10^2$	$2.46 \cdot 10^4$	2.64
P^7	18,8	$4.11 \cdot 10$	$1.39 \cdot 10^3$	10,37

The fitness of the model was characterized by the numerical value

$$H = \frac{\sum\limits_{i=1}^{n} (\varepsilon_{ik} - \varepsilon_i)^2}{n}.$$

On the basis of our measurements the Poynting—Thomson body proved to be an appropriate model for the deformation of solid particles of clayey soils (dried specimens).

The question was raised up, whether for case of wet clayey soils the same procedure is applicable or not. Measurements were made on specimens of various moisture content and in case of moderate loads (corresponding to the pressure values caused by agricultural machines) the chosen rheological model proved to be applicable. Naturally, due to the alteration of deformation properties, the material constants in the differential equation changed too.

In addition to the moisture content the values of E, λ, and ϑ are influenced by some other factors too. The research of the relation between these changes and their causes necessitates further measurements.

CONCLUSION

The Poynting—Thomson body yields sufficiently precise results for the technical practice for the mathematical description of deformation properties of perturbed specimens of clayey soils under uniaxial stress and moderate loads. Considering the problems being raised up examinations are to be extended also to unperturbed specimens for case of spatial stress.

L. Csorba

REOLOGICZNE POMIARY GLEB ROLNICZYCH

Streszczenie

Praca zawiera wyniki badań reologicznych gleb przy pomocy urządzenia skonstruowanego na Wydziale Mechaniki Uniwersytetu Rolniczego w Gödöllö. Wysuszoną próbkę gleby gliniastej poddawano jednoosiowemu obciążeniu. Wyniki badań pełzania i relaksacji dopasowywano numerycznie do modelu reologicznego ciała Poyntinga-Thomsona. Stwierdzono, że na stałe materiałowe wpływa wilgotność i naprężenie, dlatego efekty te warto śledzić oddzielnie.

Л. Чорба

РЕОЛОГИЧЕСКИЕ ИЗМЕРЕНИЯ СЕЛЬСКОХОЗЯЙСТВЕННЫХ ПОЧВ

Резюме

В труде публикуются результаты реологических исследований почв с помощью устройства конструированного в Механическом факультете Сельскохозяйственной академии в Гёдёллё. Высушенный образец глинистой почвы подвергали одноосевой нагрузке. Результаты исследований ползучести и релаксации нумерически приспосабливали к реологической модели типа Пойнтинга-Томсона. Установлено что на материальные константы воздействуют влажность и напряженность и поэтому эти воздействия следует рассматривать отдельно.