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SCALAR DEPENDENCES BY COMPACTION FORCES ACTING ON SOIL

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CONDITIONS OF APPROXIMATE MECHANICAL SIMILARITY

In the case forces acting upon the soil, particular attention should be given to interdependence of phenomena occurring between the soil and a tool or a machine which acts with certain force upon the soil. The interdependences is influenced by both properties of the soil as well as design parametres of the investigated elements of tools or machines.

Preliminary measurements proved that results obtained from investigation of two elements of the identical construction but of different sizes can be comparable only when the conditions of similarity of the system are preserved. They are defined by respective scalar dependencies of such values as: velocity, stress, density etc.

Considering the fact that certain magnitudes of the system like: acceleration of gravity, density, and mechanical properties of soil, cannot be practically scaled in the required range, the investigations of a model and a prototype are performed on the same soil, it means that the scale of all magnitudes of soil is equal to unity. In such a case the real scalar dependencies deviate from the assumed values and that means that approximate condition of mechanical similarity occurs.

The values quoted in the Table 1 considerable influence preservation of conditions of mechanical similarity of the system in the discussed example of forces acting upon the soil.

According to the principles of dimensional analysis, interdependence of magnitudes, assumed for the discussed case, characterising the system can appear in the form of a function of dimensionless products

$$f\left[\frac{P}{\gamma b^3}; \frac{v^2}{gb}; \frac{P}{Mb^2}; \frac{z}{b}\right] = 0.$$

Table 1

List of phisical values of the system

Value	Symbol	Units
Geometrical dimension	l	L
Weight	G	F
Velocity	V	LT^{-1}
Acceleration gravity	g	LT^{-2}
Reaction of scil	P	F
Deformation of soil	z	L
Bulk density of soil	γ	FL^{-3}
Mechanical properties of soil	M	FaL^{b}

The above assumption permits to determine scale of the considered system subject to the geometrical scale

$$S_b = b_2/b_1 = \lambda.$$

For example

$$\left[\frac{P}{\gamma b^3}\right]_1 = \left[\frac{P}{\gamma b^3}\right]_2,$$

therefore

$$\frac{P_1}{P_2} = \frac{\gamma_1}{\gamma_2}\left[\frac{b_1}{b_2}\right]^3$$

or

$$S_p = S_\gamma \cdot \lambda^3 \cdot$$

Similarly

$$S_p = S_M \lambda^2 \text{ and } S_v = S_g^{0.5} S_\gamma^{0.5}.$$

Assuming that $S_\gamma = 1$ then $S_p = \lambda^3$, and $S_M = \lambda$.

But assuming that $S_M = 1$ we obtain $S_p = \lambda^2$ and $S_\gamma = \lambda^{-1}$.

As it has already been stated the scale model investigation of the same soil does not permit to change mechanical properties M of the soil to such an extent that they would correspond to the scale $S_M = \lambda$ or density in scale $S_\gamma = \lambda^{-1}$. Therefore, the real scale of forces can be expressed in the form of general dependence

$$S_p = \lambda^x,$$

while value of the exponent x will be depended on the influence of the mechanical properties of soil. Value of this exponent was determined experimentally in series of measurements performed for various kinds and states of soil.

EQUIPMENT AND SOIL CONDITION

Experiments were realized at the laboratory in soil bin on which there was installed both the hydraulic stand for soil compacting by plates with different size and shape (Fig. 1) and the set of devices for soil preparation and reproduction of soil state. The experiments were made on

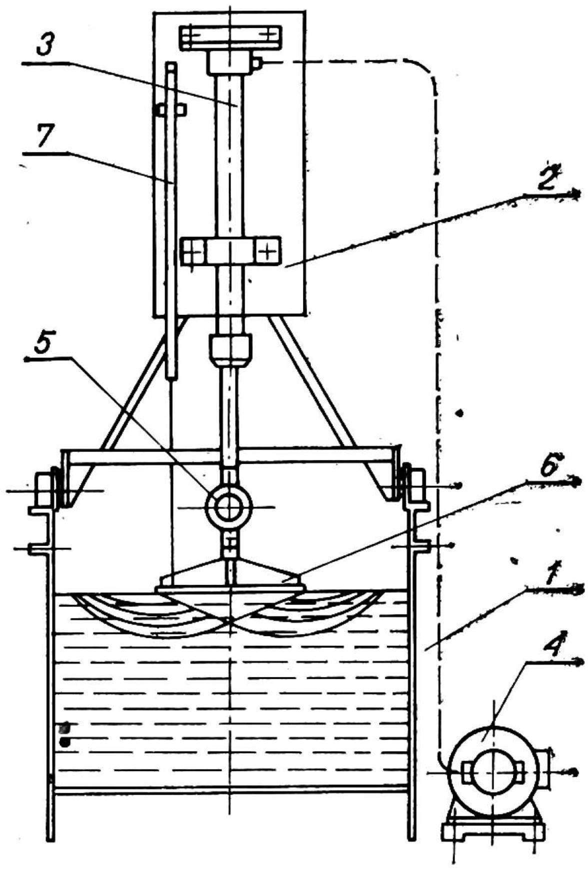

Fig. 1. The hydraulic stand for soil compaction: *1* — soil bin, *2* — frame, *3* — hydraulic cylinder, *4* — engine and oil pumpe, *5* — strain-gauge transducter, *6* — measuring plate, *7* — displacement transducter

soils with different mechanical compositions, given in the Fig. 2 and at different water contents m, running up to $m = 31$ per cent in the case of clay, for example.

For sand the maximum water content was determined by soil wetting rapidity at which practically constant soil water content can be maintained during a series of experiments. In the case of the soil marked **50** L (50 per cent of loam) it was impossible to obtain proper recurrence of the soil state in the range of humidity $m = 2.5$-14%.

It was due to its lumping in clods during the mechanical preparation. The properties of those soils are gathered in Table 2.

MEASUREMENTS OF SOIL COMPACTION FORCES

The data obtained from measuring of soil compaction forces P by rectangular plates, size $F = 280\times80$, 210×60, 140×40, 70×20 mm are shown in Figs. 3—7. As the statistic analysis of correlation of soil compac-

Table 2

Some properties of the tested soils

Soil	0 L				25 L				50 L				75 L			100 L				
Humidity during the experiments per cent	0.7	3.7	5.0	10.0	1.7	6.5	9.8	11.9	2.5	14	17	2	19,5	21	23	25	27	29	30	31
Volume weight during the experiments g/cucm	1.65	1.3	1.45	1.51	1.46	1.3	1.74	2.06	1.41	2.14	2.07	1.311	1.99	1.97	1.95	1.87	1.91	1.78	1.74	1.71
Specific, weight g/cucm	2.65				2.63				2.67				2.68			2.66				
Humus content per cent	—				0.24				0.62				0.67			0.88				
Water capilary capacity per cent of weight	20.6				22.2				28.0				27.1			45,3				
Water field capacity	—				17.1				16.1				13.9			30.7				
Absolute porosity at the faintly campacted soil state	—				—				41.2				42.16			48.8				

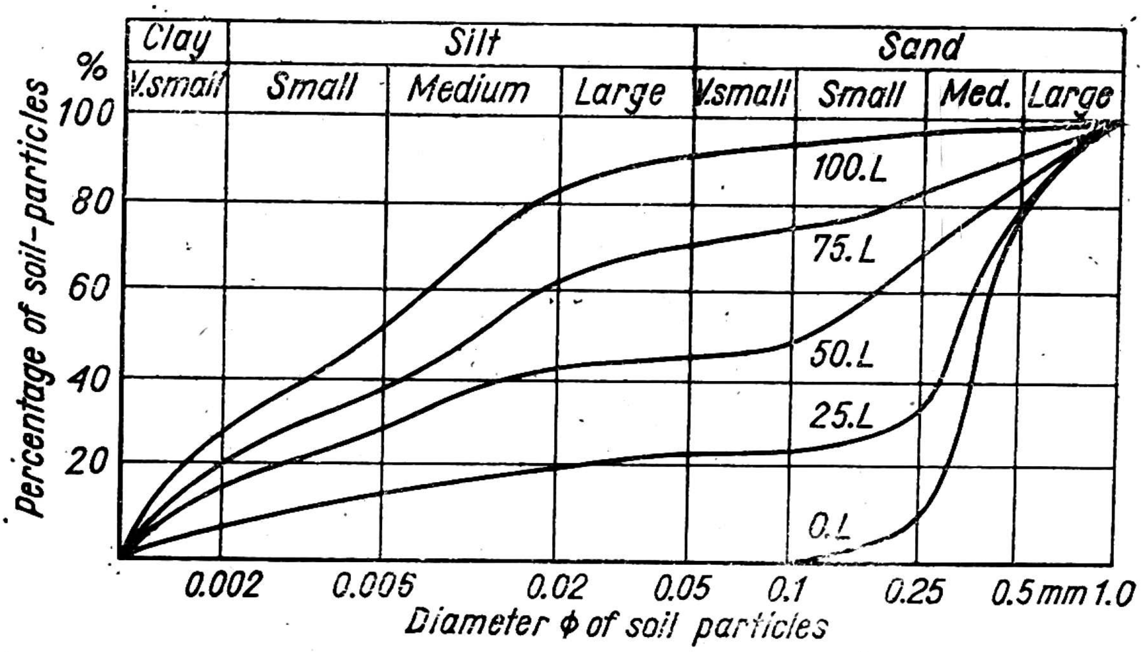

Fig. 2. Granularity of investigated soils

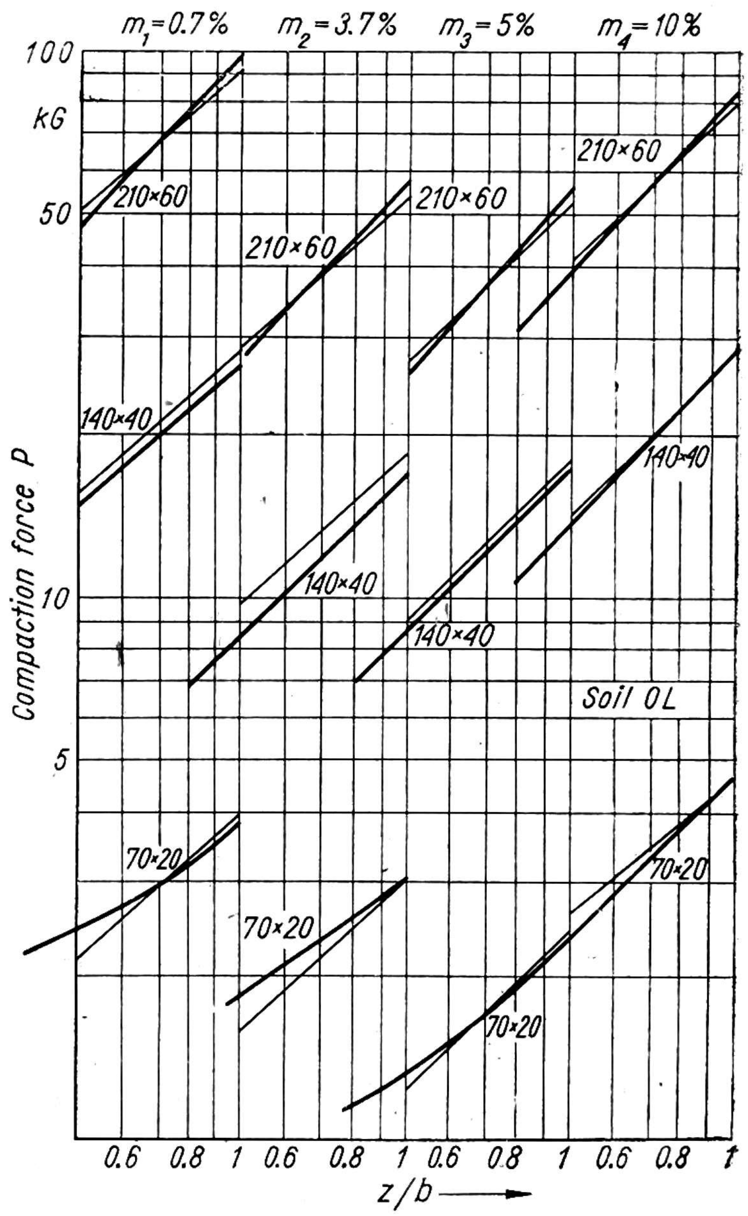

Fig. 3. The results of soil compacting forces measurements

m%	0.7	3.7	5	10
k kG/cm²	0.62	0.37	0.36	0.56
n	0.89	0.91	0.99	1.00
x	2.85	2.60	2.77	2.57

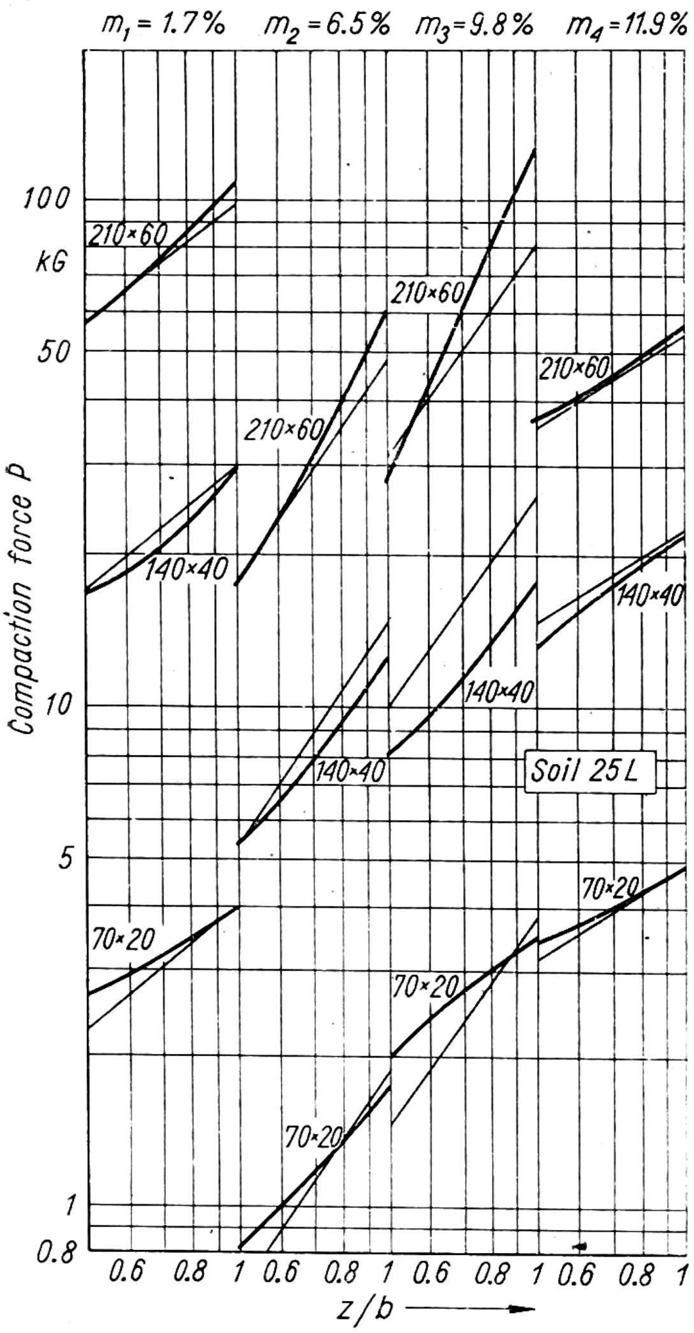

Fig. 4. The results of soil compacting forces measurements

m%	1.7	6.5	9.8	11.9
k kG/cm²	0.64	0.31	0.55	0.42
n	0.827	1.48	1.42	0.61
x	2.92	2.94	2.8	2.2

tion forces and the unitary soil deformation $\frac{z}{b}$ shows, those dependences may be defined by the aquation

$$p = \frac{P}{F} = k\left[\frac{z}{b}\right]^n \quad \text{or} \qquad P = F \cdot k\left[\frac{z}{b}\right]^n .$$

For two plates with different size one obtains

$$\frac{P_1}{P_2} = \frac{F_1 k_1 \left[\frac{z}{b}\right]_1^n}{F_2 k_2 \left[\frac{z}{b}\right]_2^n} .$$

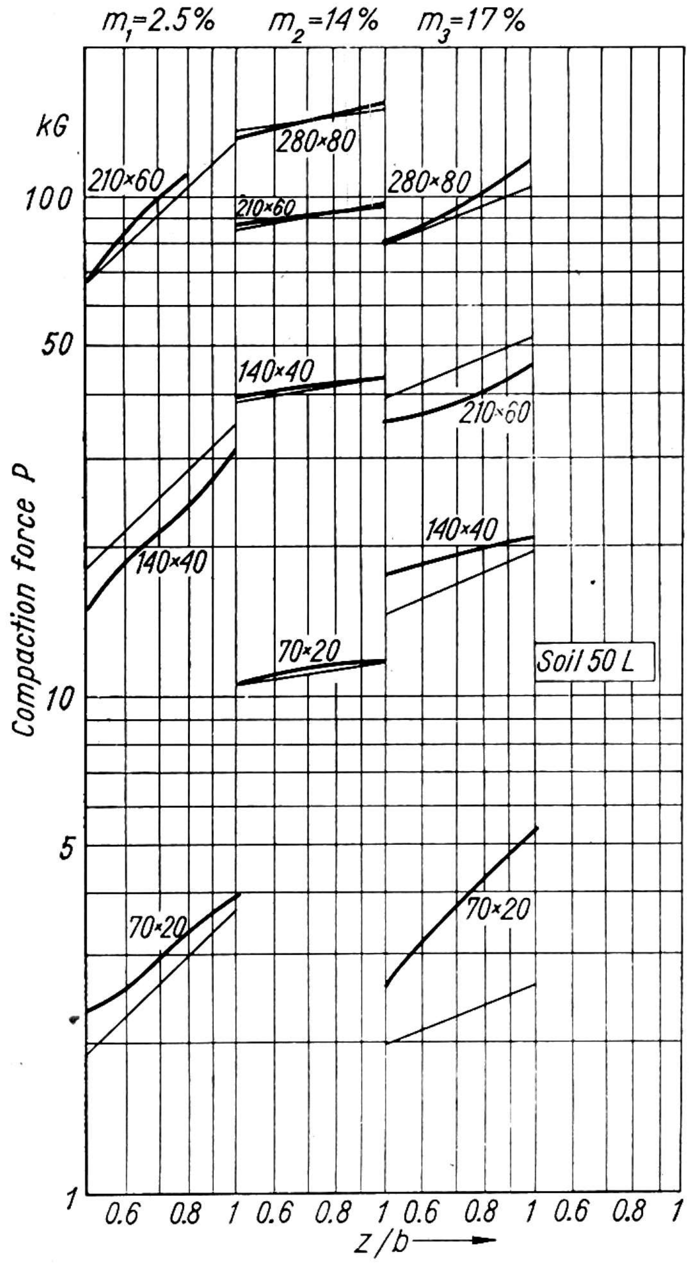

Fig. 5. The results of soil compacting forces measurements

m%	2.5	14	17
k kG/cm²	0.78	0.77	0.38
n	0.95	0.145	0.41
x	3.22	1.92	2.4

For $\frac{z}{b}$ equal to 1 the above dependences may by presented as scalar S dependences of the above mentioned values

$$S_P = S_F \cdot S_k.$$

Expressing the scale of geometrical dimensiones as $S_b = b_1/b_2 = \lambda$, scale of surface as $S_F = \lambda^2$ and the scale of forces as $S_p = \lambda^x$ we obtain

$$S_k = \frac{k_1}{k_2} = \lambda^{(x-2)},$$

therefore

$$p = k_m \lambda^{(x-2)} \left[\frac{z}{b}\right]^n,$$

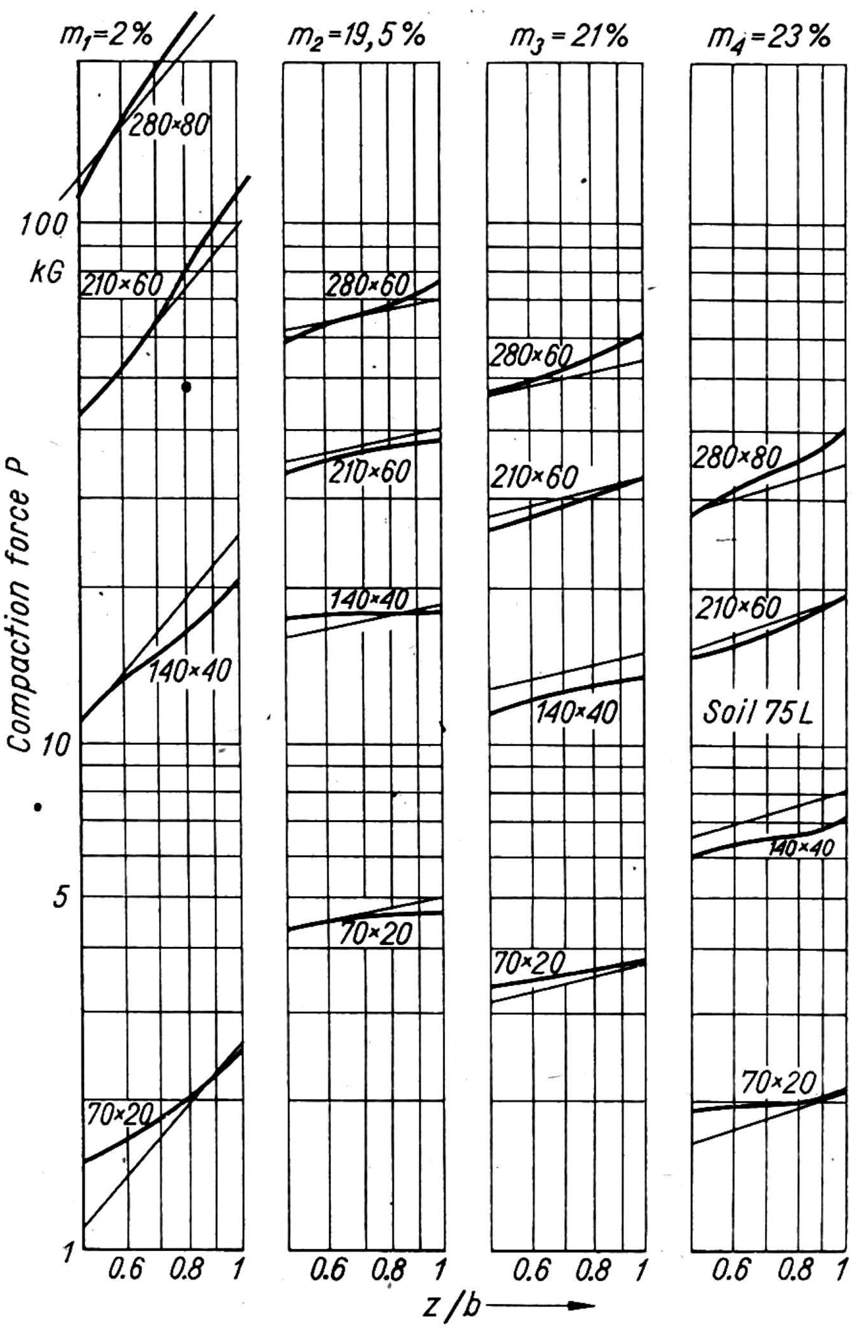

Fig. 6. The results of soil compacting forces measurements

m%	2	19.5	21	23
k kG/cm²	0.58	0.32	0.26	0.15
n	1.2	0.226	0.25	0.325
x	3.26	1.91	1.95	2.02

where k_m is a modulus of unitary soil deformation by a model plate at the given surface (e, i. $F_m = 1$ dcm²).

The above equation in this case when $x = 2$ (plate surface doesn't influence upon soil deformation) and when $\lambda = 1$ (a model plate is of the same size as the surface of a tractive element acting on soil) takes common from

$$p = k\left[\frac{z}{b}\right]^n.$$

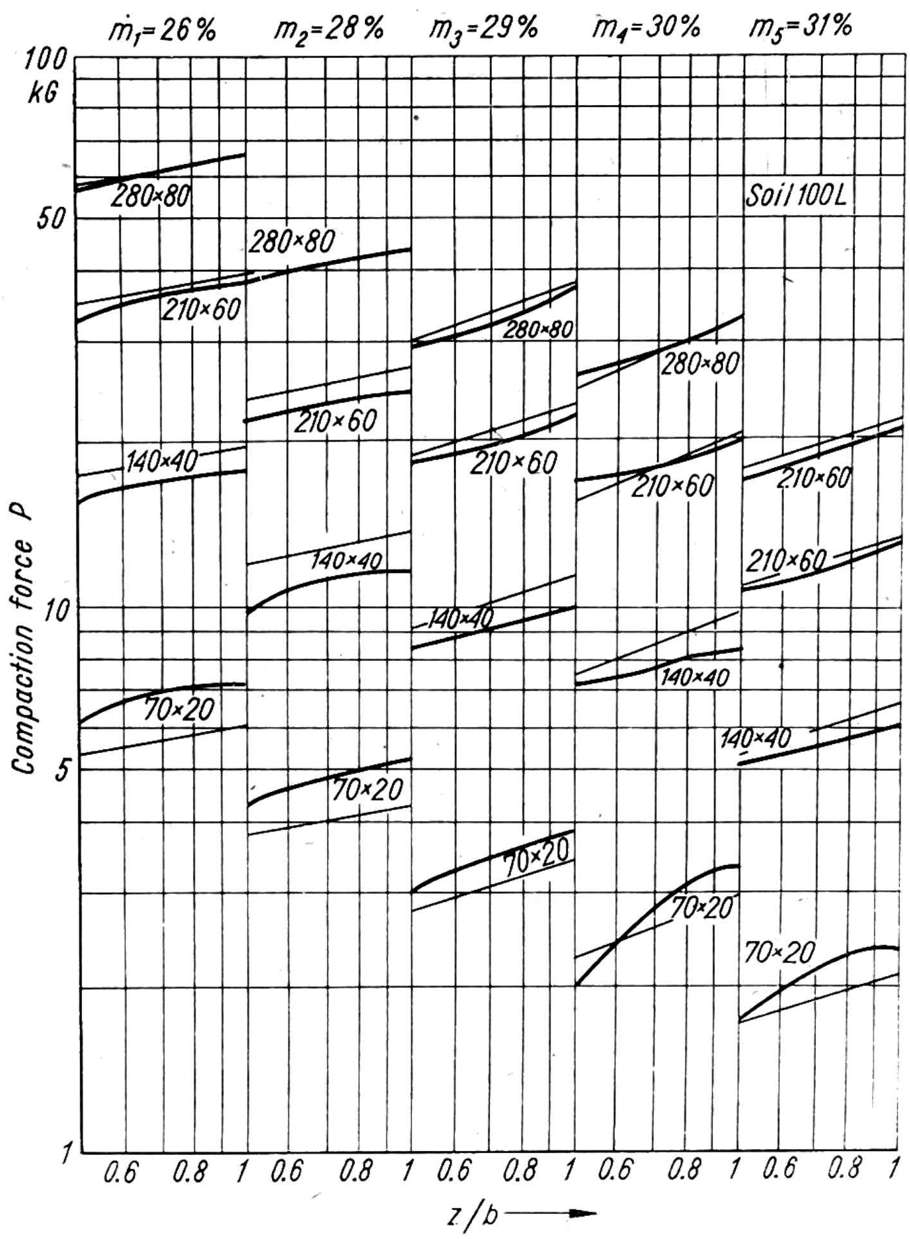

Fig. 7. The results of soil compacting forces measurements

m%	26	28	29	30	31
k kG/cm²	0.33	0.23	0.20	0.17	0.12
n	0.183	0.183	0.32	0.403	0.33
x	1.73	1.63	1.72	1.75	1.66

Computer analysis (see Fig. 8) of dates given on diagrams in Figs. 3—7 permited to determine the scalar dependences and other parameters of equation defining the unitary compaction forces.

Values of the parameters — x, k, n, are given in respective diagrams for different soils and humidity of soils (Figs. 9, 10). According to the computed values of these parameters the best fitting of theoretical lines were drawn on the same diagrams. Assumption of their parallel course in the logarithmic coordinate diagrams, means fulfilment of requirements for the exponent n = const. It is evident from the diagrams that there are two kinds of deviations of measuring curves from theoretical logarithmic lines.

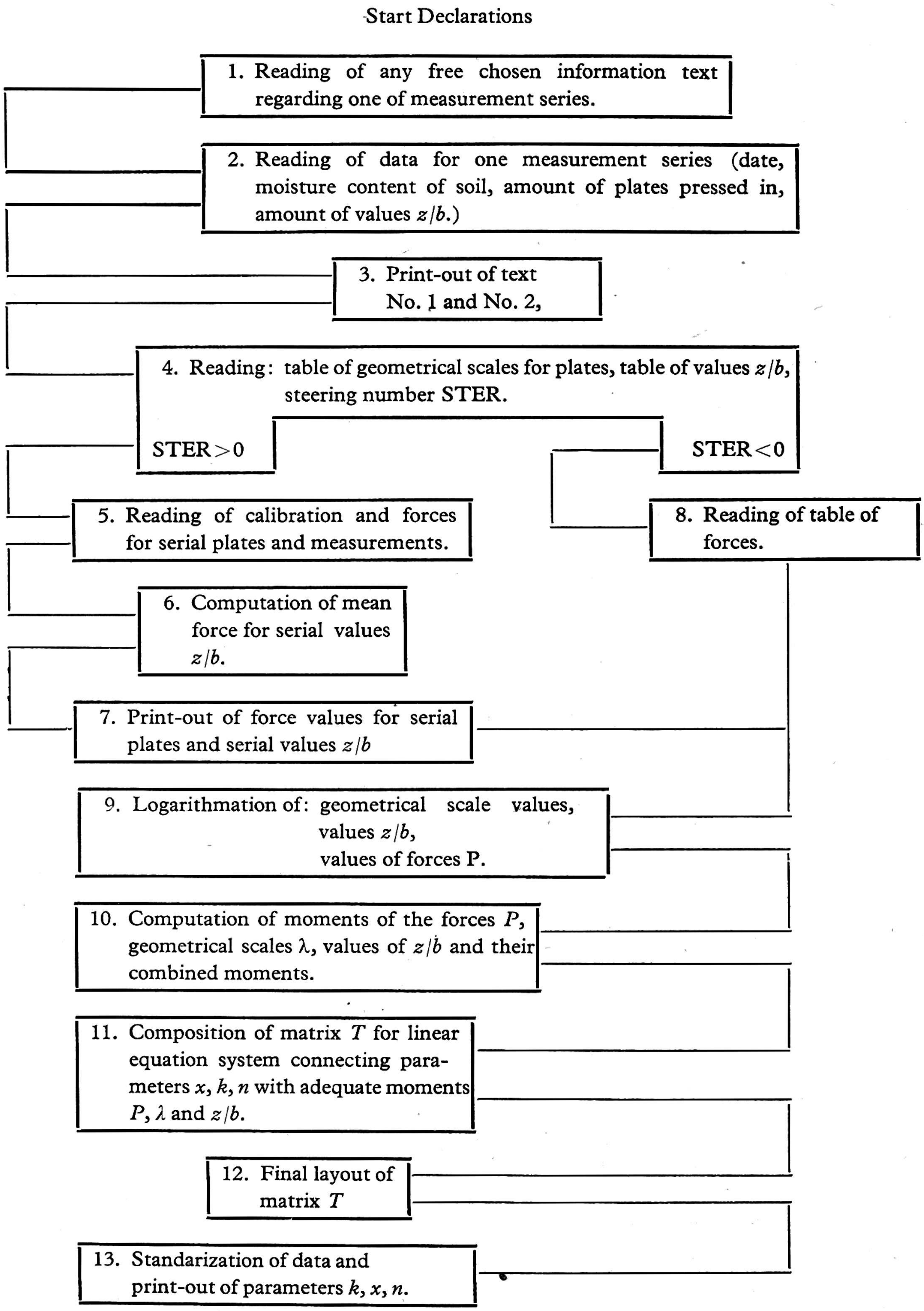

Fig. 8. Flow diagram illustrating the computation programme for soil compaction parameters

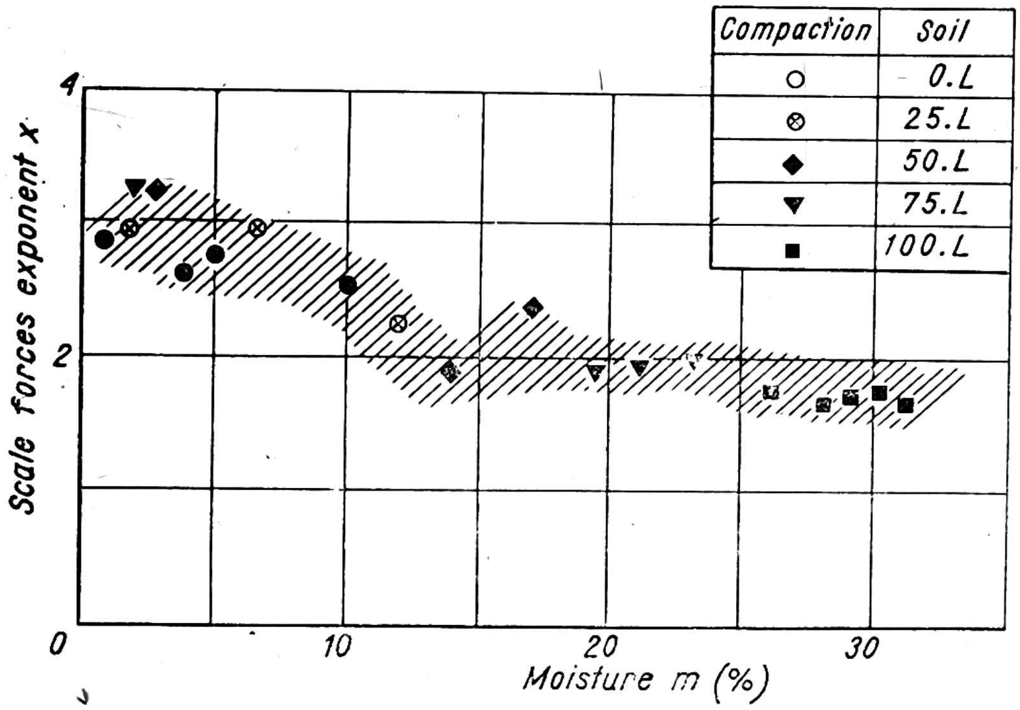

Fig. 9. Scale-forces exponent versus moisture for different soils

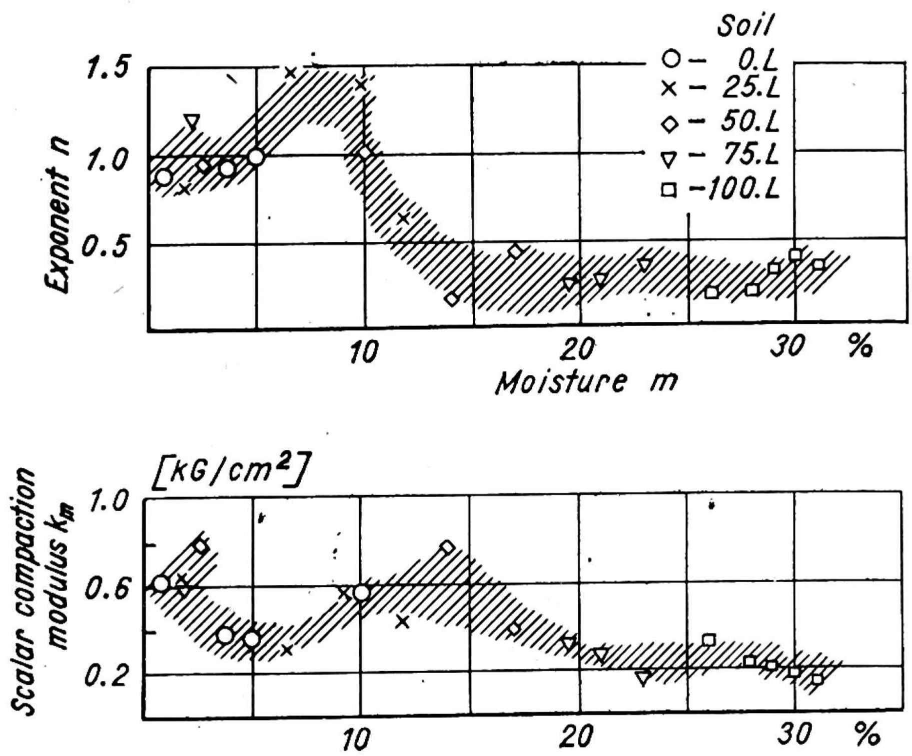

Fig. 10. Parameters k_m and n for different moistures

The first of them is caused by approximate fulfilment of conditions of mechanical similarity and is reflected in the diagrams by shifted curves in relation to the logarithmic lines resulting from scalar dependencies on the basis of the value x.

The second kind of deviations is illustrated in the diagrams by different inclination of measuring curves in relation to the logarithmic lines whose inclination is determined by the value of the index n.

While deviations occurring in scalar dependencies are accidental, deviations of the value of the index n are proportional to the size of measuring plates. In other words the bigger measuring plates the greater are the real values of the index n.

It means that assumed equation only approximately defines character of the measuring curves. However, before more precise mathematical model defining interdependence of stresses and deformation of soil is introduced in future, now it is necessary to refer the analysis to the given range of loads and deformations.

CONCLUSION

The carried out analysis has shown that:

1. The measured properties of soil defined by the parameters x, k, n remain under greater influence of the state of soil, and specially humidity, than the kind of soil described by mechanical composition.

2. In the case of compaction forces acting upon the soil it should be considered the scalar dependencies of this forces specially when humidity of soil does not exceed 12 per cent ($x > 2$).

3. The velocity of soil deformation $v = 24 \div 30$ mm/sec has not practically influenced on the obtained values of forces (Fig. 11).

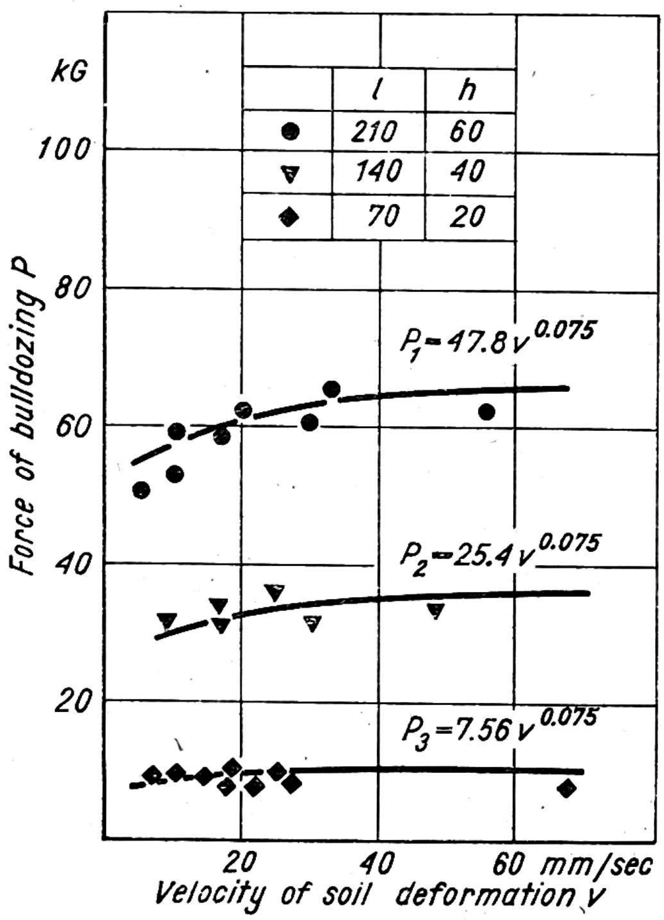

Fig. 11. The influence of deformation velocity on soil characteristics

A. Sołtyński

ZALEŻNOŚCI SKALARNE PRZY DZIAŁANIU SIŁ ZAGĘSZCZAJĄCYCH GLEBĘ

Streszczenie

W przypadku płyt (narzędzi) o różnych rozmiarach działających na glebę wyniki działania sił w dwu układach (np. model i proces rzeczywisty) można porównywać tylko w warunkach mechanicznego podobieństwa układów. Często przy konstruowaniu modeli procesów w skali geometrycznej zapewnia się tylko przybliżone podobieństwo mechaniczne.

W pracy porównano siły i ich skalarne zależności w serii testów zagęszczenia zrealizowanych na glebach o różnych wilgotnościach i składzie. Badania numeryczne pozwoliły wyznaczyć matematyczne zależności i parametry równań.

А. Солтыньски

СКАЛЯРНЫЕ ЗАВИСИМОСТИ ПРИ ДЕЙСТВИИ СИЛ УПЛОТНЯЮЩИХ ПОЧВУ

Резюме

В случае плит (орудий) разных размеров, действующих на почву, результаты действия сил в двух системах (напр. модель и действительный процесс) можно сревнивать только в условиях механического сходства систем. Часто при конструировании модели процессов в геометрическом масштабе обеспечивается только приближенное механическое сходство.

В труде сравниваются силы и их скалярные зависимости в серии тестов сгущения выполненных на почвах с различным увлажнением и составом. Нумерические исследования позволили определить математические зависимости и параметры уравнений.