SAMPLING COHESIVE SOILS

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Introduction

Laboratories of soil mechanics get better equipped every year, and ever more and newer testing equipment is applied for determining the physical characteristics of soil samples.

By contrast, the development of sampling tools lags behind the development of laboratory apparatus in many respects. As is commonly realized, to now the problem of undisturbed sampling has not been solved satisfactorily. This fact might eventually render the development of laboratory instrumentation meaningless. No reliable foundation design is possible without the knowledge of the strength and deformation characteristics of the involved soil layers. Complicated instruments and equipment are available for their determination. Often, however, the results are valid only with reservation, since during sampling the material characteristics may be altered to such a degree that data truly describing the original, undisturbed soil masses cannot be obtained even from the most precise laboratory tests. What is more, often no idea can be formed as to how much an "undisturbed soil sample" is disturbed. (Kézdi 1953). The effect of disturbances on the physical characteristics of the soil has been demonstrated by earlier investigations (e.g. Kézdi 1954). In the following, some further effects of soil sampling method on the physical characteristics will be discussed.

Sampling macroporous soils

Loess, which covers most of the Hungarian territory, is rather problematic from sampling aspects. Its macroporous structure gets readily hurt during sampling, and especially the slump values of the sample appear to be better than they are in reality. Samples taken from drilled holes, from layers above the groundwater level are especially susceptible to damage, with a risk of alteration of the most typical physical characteristics. Therefore the Soviet Standards on soil exploration (e.g. Abelev 1948), as well as the Hungarian

Standard (MNOSz 1952) recommend to explore loess layers by means of shafts, and also to take samples from shafts, thereby undoubtedly reducing sample disturbance.

To now, however, scarce numerical data on disturbance have been available. A good opportunity was therefore to compare samples from shafts and boreholes in the loess area in the Pécs region. Relevant experience will be described in the following.

Borehole samples were 10 cm in dia. and 25 cm in height; shaft samples were cubes with 25 cm edges. Fig. 1 shows characteristics of the phase composition. Shaft and drilled samples are well distinguished. Drilled samples exhibit a significant increase in density: solids percentages by volume s differ by about $\Delta s \cong 10\%$. But drilled samples are not only more dense but also their phase composition values are more scattered, despite the fact that the tested layer was rather homogeneous with uniform density throughout.

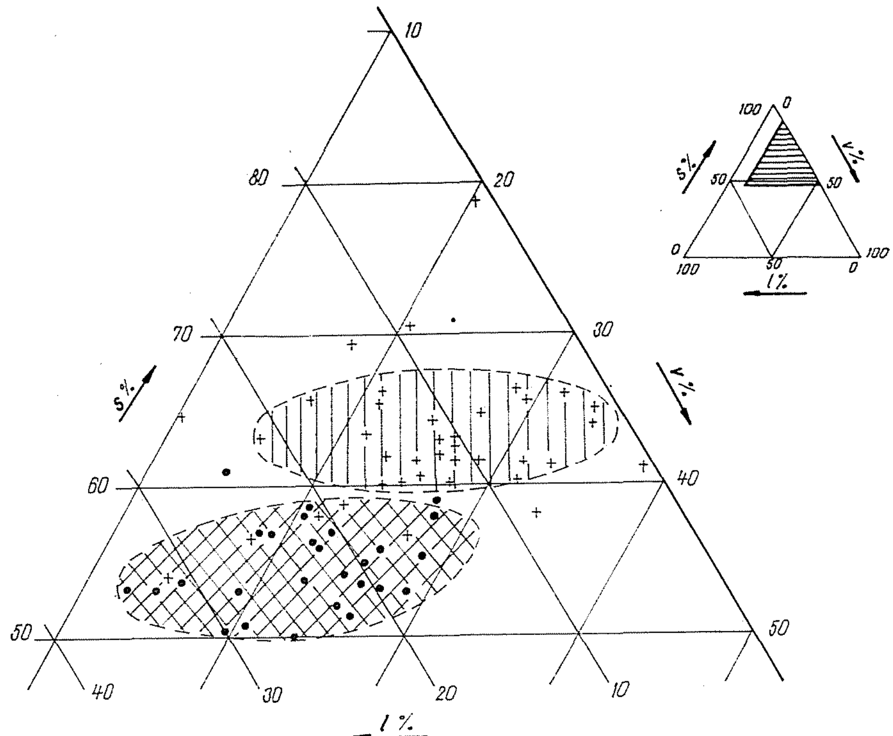

Fig. 1. Change in phase composition depending on the sampling method. Sampling: ● shaft; + borehole

The above statement is seen also from Fig. 2 showing the variation with depth of the solids percentage by volume s and reflecting the effect of groundwater. The periodic variation in groundwater level, recurring inundations and partly, the capillary rise may have contributed to the change of the loess structure, and maybe to a certain slump. Accordingly, with increasing depth towards the groundwater level, the structured appearance of the soil becomes

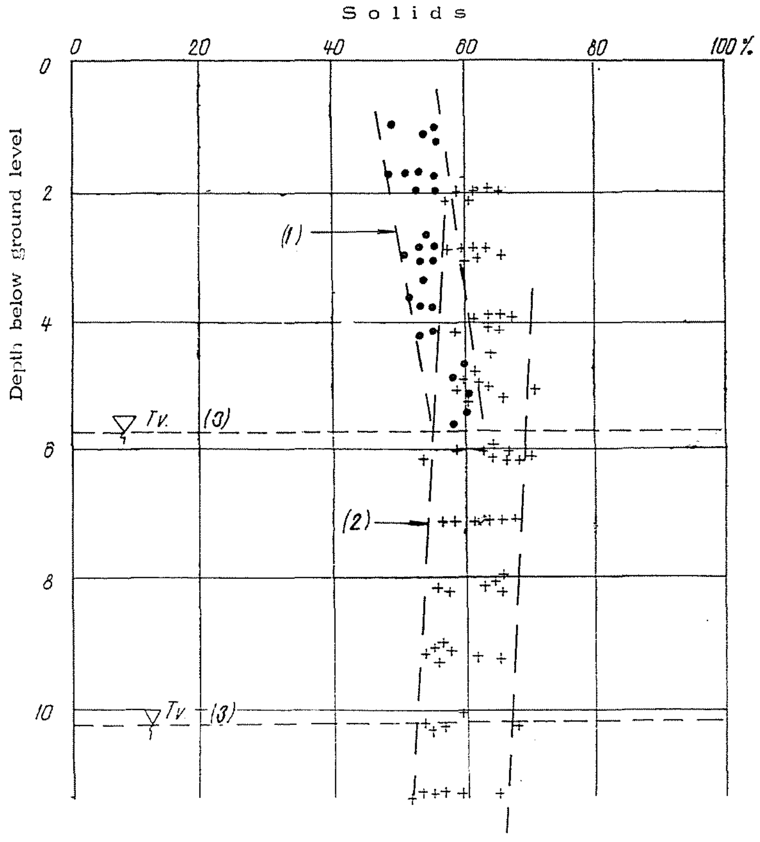

Fig. 2. Change in solids ratio (s%) vs. sampling method and depth below ground level. 1 — shaft samples; 2 — bored samples; 3 — groundwater depth below ground level

ever more blurred, the shaft samples get ever denser. The opposite tendency is manifest for borehole samples. The forced penetration of the sampler resulted in the destruction of the soil structure and an increase in density. Since the degree of compaction depends on the initial voids ratio, obviously, the layer located near the surface, which was originally the loosest one, yielded the densest sample.

The above statement was evidenced by some compression tests on shaft and borehole samples, giving also a hint of some interesting phenomena.

Table I

Characteristics of compressive test soils

Sampling method	Soil type	Sample No.	w_f%	I_p%	s_0%	v_0%	l_0%	w_0%	e_0	i_m
Boring	Silty fine sand	1	28	7.8	53	30	17	20.9	0.89	0
		2	32	8.9	56	18	26	11.9	0.79	0
		3	29	8.5	52	24	24	17.1	0.92	0
		4	30	9.2	57	25	18	16.3	0.76	0
		5	30	8.9	62	30	8	17.9	0.61	0
Shaft	Silty fine sand	a	32	8.8	55	28	17	19.1	0.82	0.035
		b	29	7.7	56	26	18	19.0	0.79	0.043
		c	31	9.1	57	23	30	14.8	0.76	0.051
		d	29	7.7	58	20	22	13.0	0.72	0.043
		e	30	9.8	50	19	31	14.3	1.00	0

Compression diagrams of the tested soils are shown in Fig. 3. In Table 1, initial soil physical characteristics are compiled. Compression diagrams of drilled samples have steeply sloping initial section, reflecting the destruction of the skeleton during sampling. Hence an initial small load brings about marked compression. With increasing loading, compression rate is much reduced. Flooding with water caused no immediate slump, but further loading resulted in a compression diagram with a steeper slope than before. This effect was the faintest for sample No. 5.

Shaft samples taken with great care suffered little change in structure, and their voids ratio corresponded to the original loose condition, hence in compression tests their compressibility was about twice the former one. The fact that the sample skeleton suffered little damage even when loaded to $p = 3$ kp/cm^2 is obvious from the marked slump after flooding by water (Fig. 3b).

Fig. 3b shows no slump for sample *e*. The cause may be that this sample was the loosest of all, and its skeleton may have been destroyed under the load of 3 kp/cm^2, so inundation could entrain no slump any more ($i_m \cong 0$). Again, this phenomenon gives a hint that the slump coefficient in itself is not sufficient to describe the behaviour of macroporous soils; a mechanical approach may be misleading. It would be more correct to characterize soils by the entire deformation diagram.

The phase is presented in a triangle diagram for two typical samples (Fig. 4). In the first section of loading by 0 to 3 kp/cm^2, compression proceeds at a constant water content. Under the same load increment, the looser shaft sample becomes more compressed. There is a decisive difference during water inundation. Water penetrates without perfectly filling soil pores, being prevent-

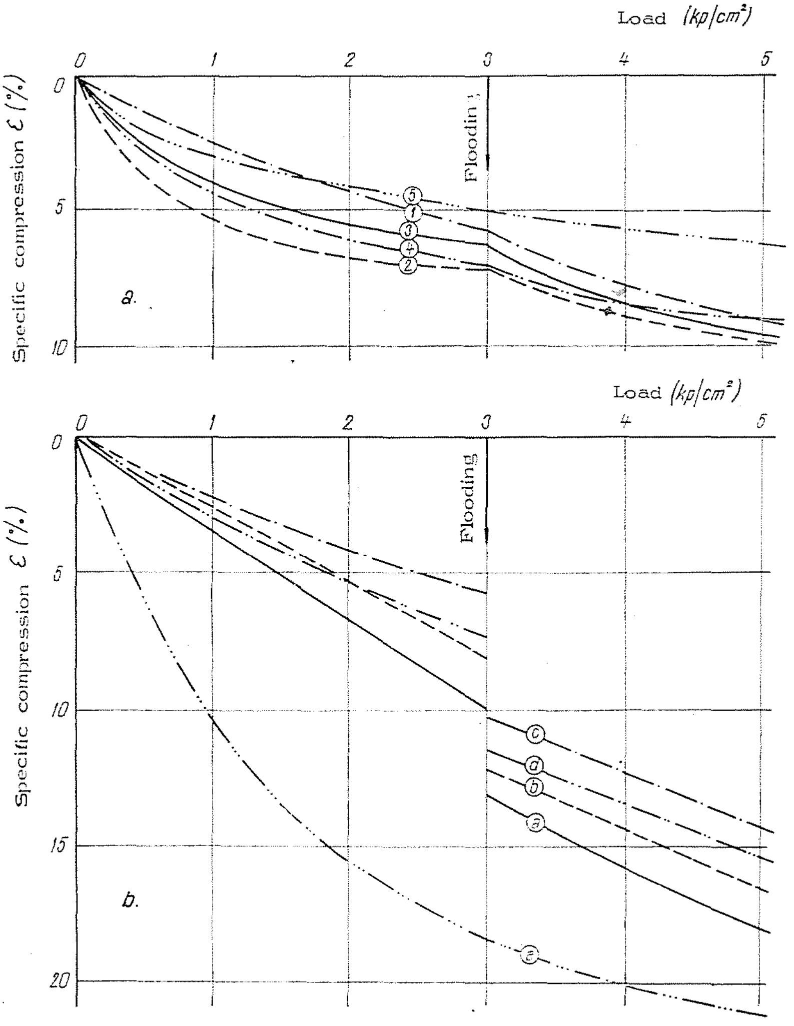

Fig. 3. Compression diagrams of tested soils. *a* — bored samples; *b* — shaft samples

ed by air inclusions. According to tests, the developing saturation depends on the initial water content, in this case S ≅ 0.85. Since drilled samples exhibited no volume gain upon inundation, but only water absorption, their vector is horizontal extending to the saturation line referred to. Shaft samples exhibited slump parallel to water absorption, therefore this section of the diagram (3—3') reflects two effects. Application of the next load increment (5 kp/cm^2) resulted in compression in both cases, involving first a further increase in saturation, then part of the water being pressed out. The sample, however, does not attain complete saturation, since the entrapped air bubbles cannot escape but become compressed or partly dissolved in water.

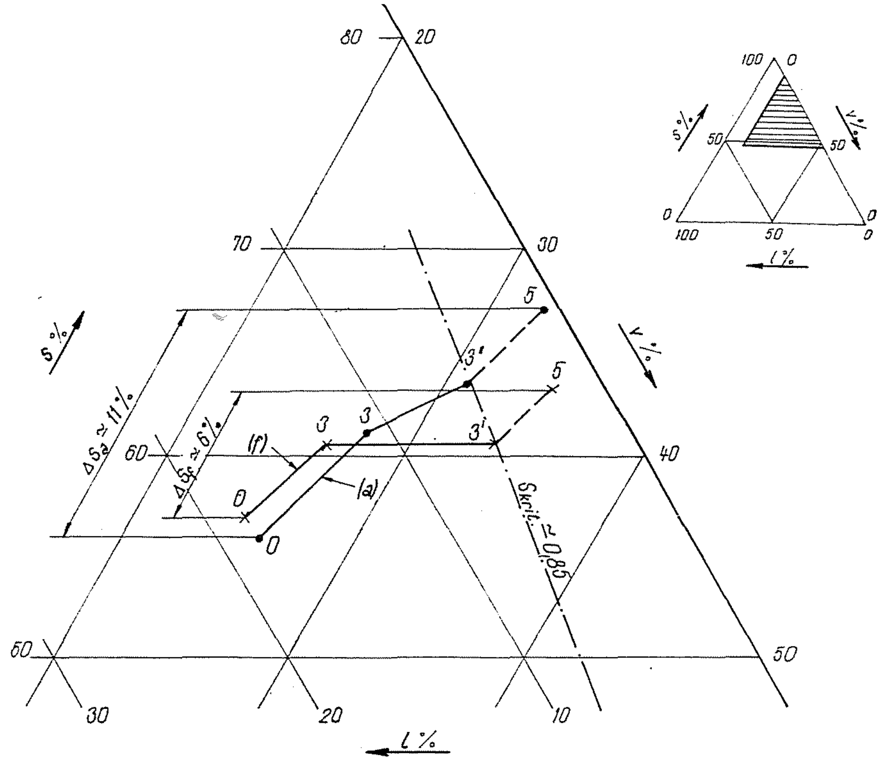

Fig. 4. Phase changes for shaft (*a*) and bored (*b*) samples in slump test: (0—3) loading up to 3 kp/cm², (3—3') water absorption upon flooding; (3—3'')failure of the macroporous structure due to water absorption and load; (3'—5) and (3''—5) load up to 5 kp/cm²

Drilled core sampling

From greater depths (> 3 to 4 m) and especially from below groundwater level, in general, drilled samples are taken. Sample quality and changes in soil physical characteristics are functions of the soil type and the sampling tool. The degree of possible disturbances is obvious from the "undisturbed" sample in Fig. 5, taken with a sampler type Mazalán driven in layered, hard clay. Evidently, this tool used in such a soil yields useless samples.

The Mazalán sampling tool, rather familiar in this country, is thick-walled, of robust construction (Fig. 6), with a rather unfavourable area ratio:

$$\alpha = \frac{D_v^2 - D_a^2}{D_a^2} = 0,562 \tag{1}$$

Characteristics of a core sample, no matter whether taken by a sampler driven or jacked in the soil, may significantly change. Therefore, the use of this sampling tool cannot be recommended. Recently, better sampling methods have become available, suggesting comparison of sampling tools. A novel tool, sampler type F-62, developed at the Drilling Development Section of the

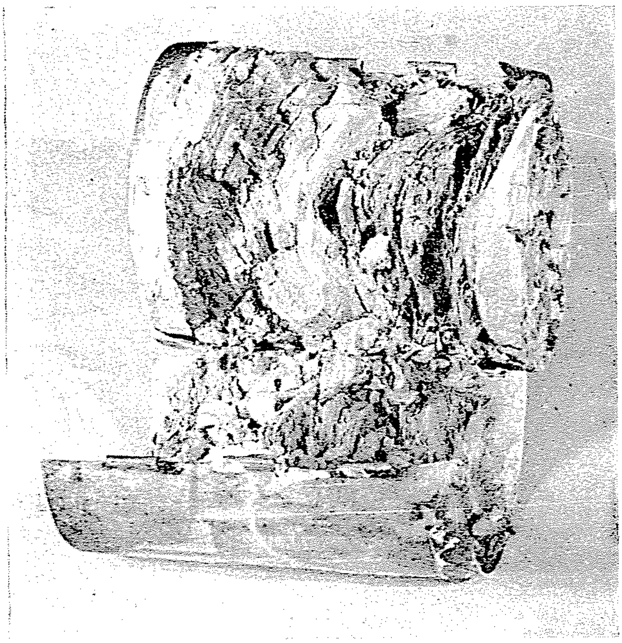

Fig. 5. A sample stated "undisturbed", taken from stiff, layered clay by a Mazalán sampler

Enterprise for Civil Engineering Mechanization, is seen in Fig. 7. The drilled hole is deepened by jetting and the sample is cut around by a rotating cylinder fitted with an outer cutting crown, so that it gets nearly without friction into the inner core cylinder.

To compare samples taken by either method, the National Enterprise for Geology, Exploration and Drilling carried out simultaneous explorations in three Budapest sites, each consisting of two drillings 1 to 1,5 m apart, one made dry, using the Mazalán core sampler, the other making use of the F-62 equipment for taking undisturbed samples.

The *first essential difference* in favour of the F-62 borer against dry boring was the *greater recovery ratio of drilled core samples*, offering a selection of fair, really undisturbed samples. The conventional "dry" drilling is known to completely destroy the soil structure so that before sampling, the borehole has to be cleaned. The core obtainable by normal sampling keeping in with regulations is about 20 to 30 cm long for every 2 m, thus in the best case, 10 to 15% of the soil taken from a borehole may be considered undisturbed. In contrast, the percentage of samples taken by F-62 was

drilling No. 1	70.7%
drilling No. 2	62.0%
drilling No. 3	82.9% .

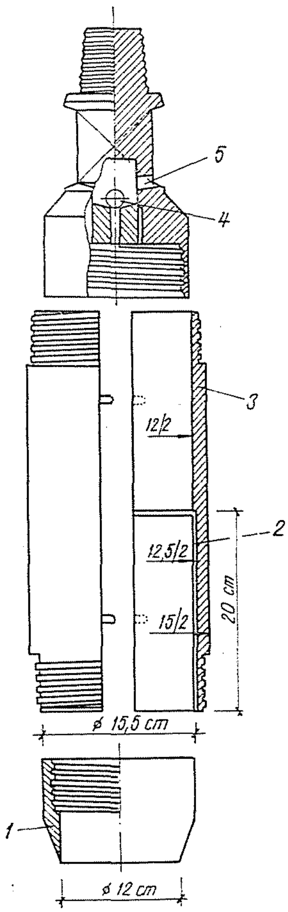

Fig. 6. Mazalán sampler: 1—cutting edge; 2 — sample box; 3 — casing; 4—ball valve; 5 — vent

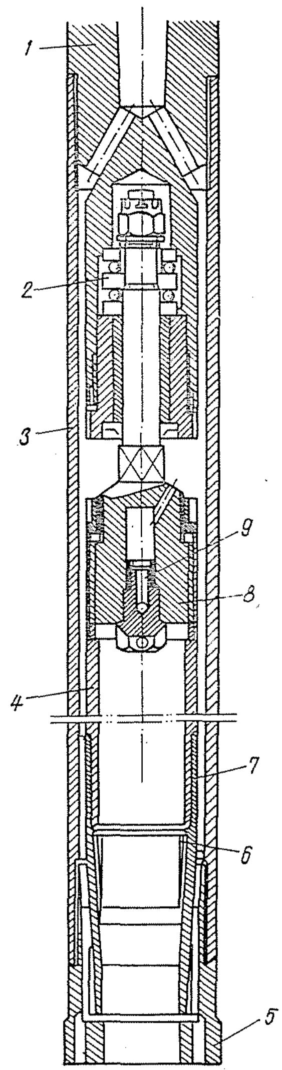

Fig. 7. Double-wall core drill F-62; 1 — outer bar; 2 — double bearing; 3 — outer tube; 4 — inner tube; 5 — crown; 6 — ring; 7 — clamping sleeve; 8 — inner bar; 9 — valve

To determine the physical condition of the soil, it is required to know the water content, the density and the shearing strength. Percentage by volume of solids s which is characteristic of the soil density and water contents w are shown in Fig. 8.

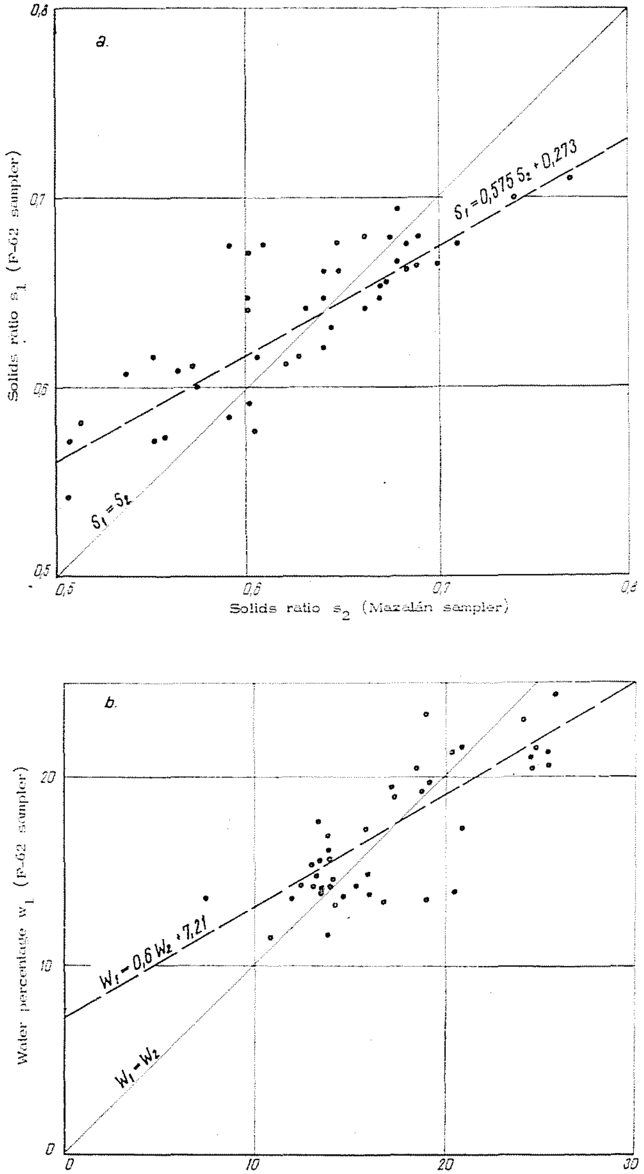

Fig 8. Variation in phase composition and water content for Mazalán and F-62 sampling; *a* —solids percentage in identical soils sampled by Mazalán (s_2) and by F-62 (s_1) samplers; *b* —water percentage in identical soils sampled by Mazalán (w_2%) and F-62 (w_1%) samplers

For the sake of comparison, results from both sampling methods have been processed in a correlation system, constructing regression lines. 50 data pairs yielded straight lines

$$w_1 = 0.6\ w_2 + 7.21 \tag{2}$$

for water contents, and

$$s_1 = 0.575\ s_2 + 0.273 \tag{3}$$

for the solids ratio by volume, where w_1 and s_1 and w_2 and s_2 refer to samples taken by sampler F-62 and sampler type Mazalán, respectively. Both cases exhibit a correlation coefficient $r = 0.72$, which indicates a fair agreement.

Thus, averages are rather similar. As concerns the density, the Mazalán sampler produced somewhat denser samples. *Strength* values exhibit marked differences.

For instance, Fig. 9 shows the samples taken with the Mazalán sampler to have unconfined compressive strength values higher by an order of magnitude than those of drilled core samples. This fact may be attributed to the different history of the samples. The cutting edge of the penetrating Mazalán sampler, often not perfectly sharp but more or less worn out, cuts a sample greater in diameter than the actual inner cylinder, which is thus squeezed into the sampler and becomes pre-loaded by radial compression.

The same phenomenon occurred in the triaxial compression test and affected the shear strength parameters. Fig. 10 shows shear diagrams (straight lines A and B) obtained from triaxial tests on two soil samples taken from a stiff clay (by means of Mazalán sampler and borer type F-62) from identical depths. Although physical characteristics are nearly the same (Table II),

Table II

Physical and strength characteristics of samples

		Sampling method	
		F – 62	Mazalán
Phase composition	s%	67	68
	w%	29	28
	l%	4	4
Triaxial test	$\varnothing°$	26.5	22.8
	C Mp/m²	8.0	36.0
Calculated	σ_{ny} Mp/m²	2.6	10.8

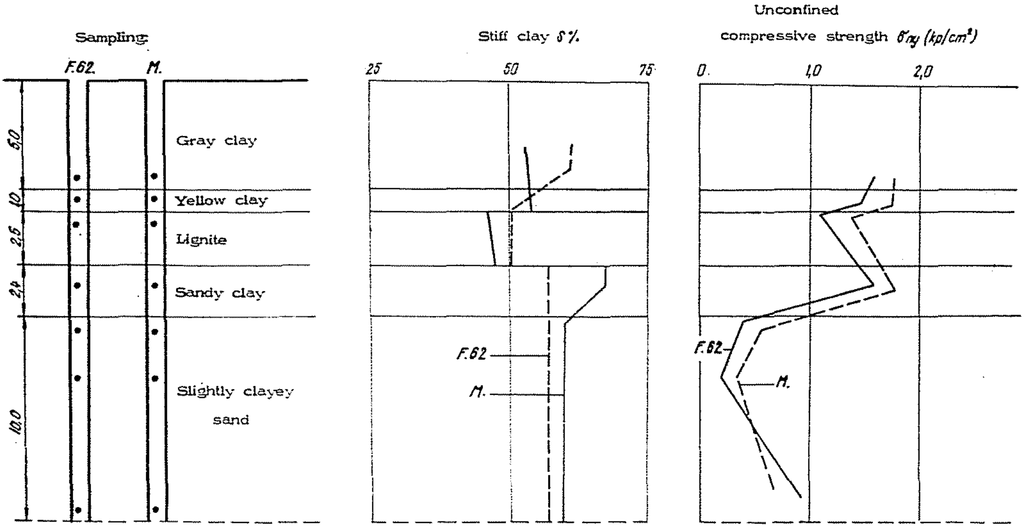

Fig. 9. Variation in phase composition and in unconfined compressive strength of samples obtained by Mazalán and F-62 samplers

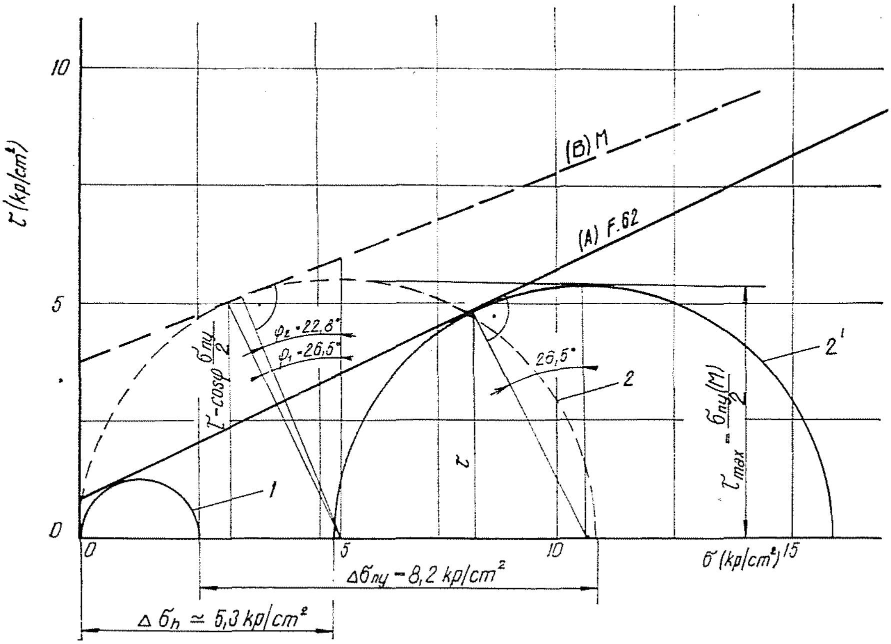

Fig. 10. Preloading due to sampling

shear strength of the Mazalán sample is seen to be higher (straight line B). The increment affected primarily the cohesion, hence, also the calculated unconfined compressive strength values are rather different (circles No 1 and 2).

It is interesting to shift circle 2 parallel to itself until it contacts shear diagram A. Now, circle 2' results. The $\Delta\sigma_h$ value shows the effect due to the pre-loading of the Mazalán sample. Sample F-62 ought to be exposed to a hydrostatic stress $\Delta\sigma_h \simeq 5.3$ kp/cm^2 in the triaxial set to cause the deviator stress to equal the unconfined compressive strength of the Mazalán sample.

Test results unequivocally show that the Mazalán sampler, originally devised for exploring soft materials, causes significant disturbance even when the phase composition is apparently slightly changed.

Sampling soft, sensitive clays

Soft, sensitivite clays may suffer significant changes during sampling. From this aspect, experiments carried out in Sweden to investigate the effect of the cutting edge angle as well as Japanese research on the disturbance of the sampled zone (FUKUOKA, 1968) are of interest.

The Swedish Geotechnical Institute (KALLSTENIUS, 1958) made comparative explorations in several test fields on thick, homogeneous clay layers by means of fixed-piston samplers with technical data compiled in Table 3.

Table III

Data of Swedish samplers

Sampler symbol	Sampler size				Cutting edge angle	Wall thickness	$\alpha = \frac{D_v^2 - D_a^2}{D_a^2}$	$\beta\% = \frac{D_f - D_a}{D_a} 100$
	D_a(mm)	D_v(mm)	D_f(mm)	h(mm)	δ	v(mm)		
SJ . . .	44	51	44	640	45	3.5	0.34	0
Gk . . .	42.5	45.5	43	488	10.5	4.75	0.15	1.1
NGI . . .	54	57	54.7	800	12	1.5	0.11	1.3
SGI. IV . . .	60.5	83.5	60.5	224	26.5	11.5	0.90	0
SGI. VI. . .	60.5	75	60.5	428	8.3	7.25	0.55	0
SGI. VIII. . .	60.5	76	60.5	464	9.7	7.55	0.57	0

Note — D_f means the increased inner diameter beyond the cutting edge.

Unconfined compressive strength values have been used for comparison, shown in Fig. 11 vs. depth. Within the range of tests shown in the diagrams, the wall thickness does not seem to be decisive. Namely, curves SJ and SGI-

IV are approximately parallel, although the wall thickness of the latter sampler is about three times the former.

Just the opposite is true of the cutting edge angle. Curves of the samplers with very acute cutting edge angle are seen to differ markedly from those

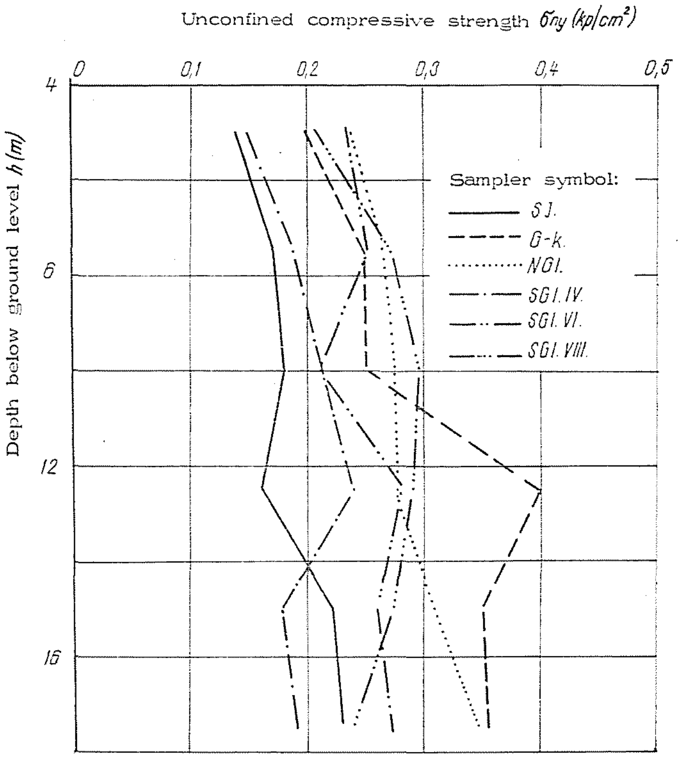

Fig. 11. Unconfined compressive strengths vs. depth for various samplers

with flat angles. These latter are nearly parallel down to 10 m but at increasing depths they diverge considerably. Tests on samples Gk and NGI show an increase in unconfined compressive strength proportional to the depth (as a natural consequence of increasing pre-loading — due to geostatic pressure), while both other samples exhibit reduction.

This fact was likely to result from an increase by 0.5 to 0.7 mm in the sampler diameter beyond the cutting edge, greatly reducing the friction between the cut sample and the cylinder wall. (Sizes and sampler data see in Table 3.) The importance of the cutting edge angle is obvious from Fig. 12. An inclination exceeding 10° is seen to greatly affect the soil structure.

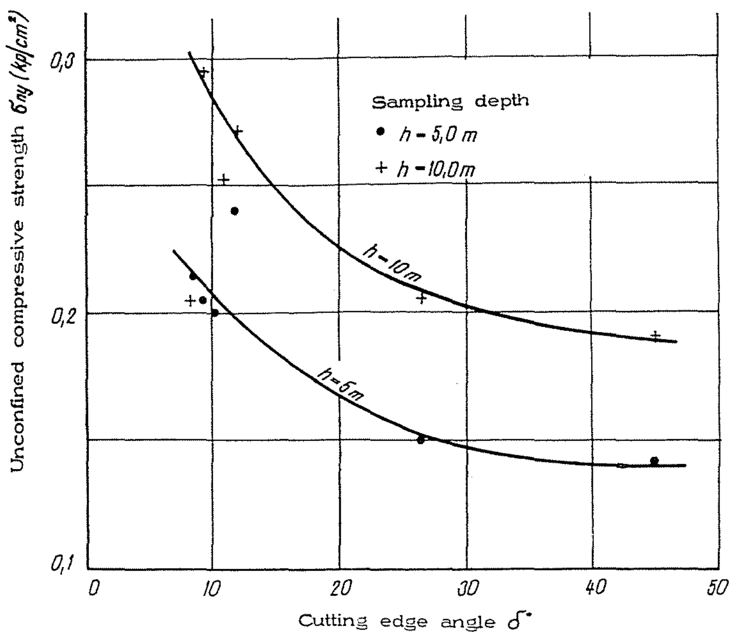

Fig. 12. Effect of cutting angle on unconfined compressive strength

It has been mentioned that, when forced into the soil, the cutting edge of the sampler exerts mechanical effects causing changes in the soil mass. To prove this hypothesis, Japanese research workers made shear vane tests in a borehole before and after sampling. Shear strength results versus depth are shown in Fig. 13. It is interesting to see that with respect to the pre-sampling (undisturbed) condition, the peak stress τ_{max} is lower in post-sampling shear tests, while the τ needed for continuous shear is somewhat higher. This is probably due to a certain destruction of the structure (reduction in τ_{max}) and to the increase in density (increase in τ) resulting from the sampler penetration.

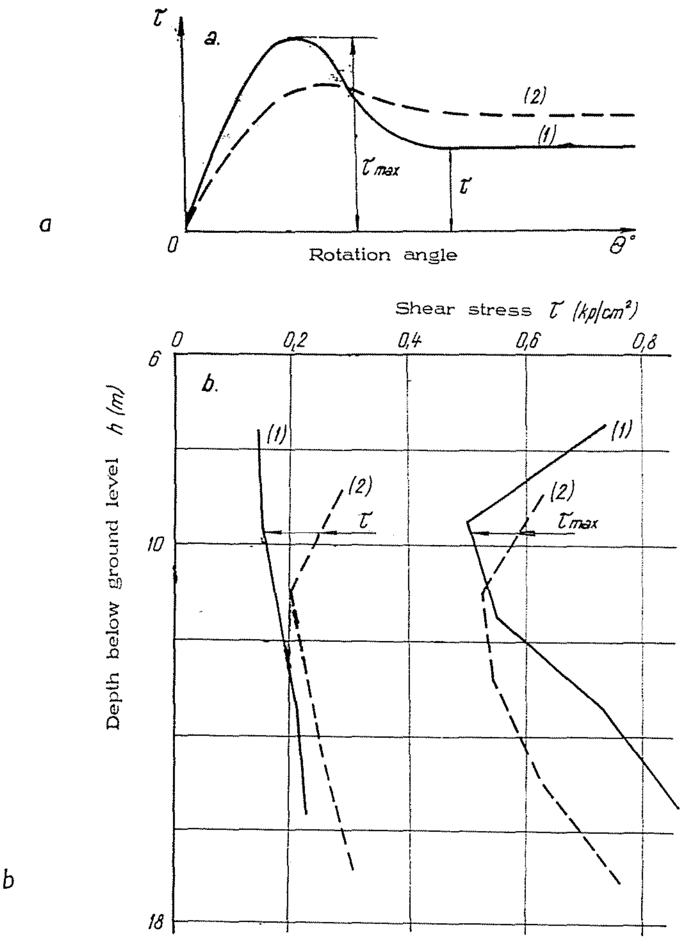

Fig. 13. Shear strengths in the borehole before and after sampling. *a* — shear stress vs. rotation (1 — before sampling; 2 — after sampling); *b* — shear stress vs. depth

Sampling compacted soils

The preceeding sections have been concerned with the sampling of, and disturbances in natural soils. Analysis of sampling in compacted soils is equally important. Let us make here some comments on the measurement of density of compacted-transition — soils. Grading curves of the tested soils are shown in Fig. 14. Proctor tests were carried out on each of the four soils and cylindrical samples 4 cm dia. and 6 cm high were taken of the compacted soil by driving in the trepan cylinder with a wall thickness factor $\alpha = 0.107$.

Mean solids percentage of the compacted soil s_0 and of the sample s taken with the cylinder are shown in Fig. 15, clearly demonstrating the important disturbance caused by the sampler in spite of its favourable wall thickness

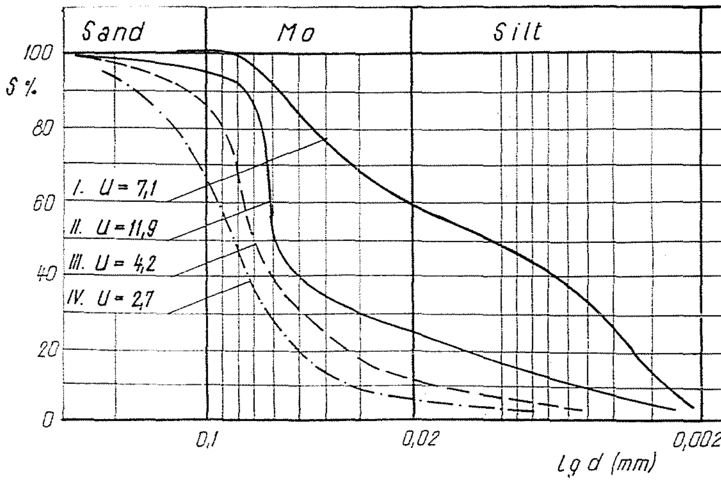

Fig. 14. Grading of tested soils

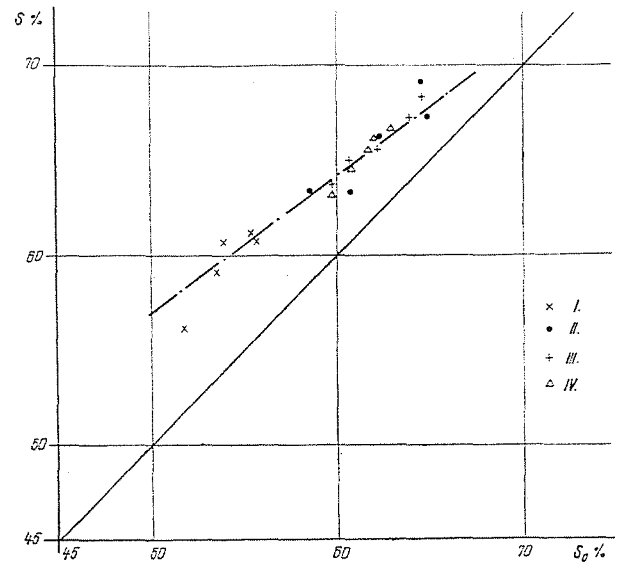

Fig. 15. Relationship between solids ratio s_0 of the compacted soil and that after sampling s

factor. The disturbance due to driving in the sampling cylinder is the greater, the less the solids percentage s_0. The disturbance is due to deformations around the cutting edge, and to frictional forces on the cylinder surface. The disturbance effect must not be omitted because of the great error introduced.

The disturbance could be reduced by eliminating or minimizing both effects. Direct sampling in compacted, cohesive soils could conveniently be made by samplers cutting round the sample at a static pressure as low as possible, such as by air jetting, water jetting, and crown borers.

Summary

This modest contribution to the problem of sampling and the resulting disturbances points out again the known fact that an undisturbed sample can hardly be conceived. Among available means and methods, those providing for the most reliable (undisturbed) sampling have to be chosen.

Special attention is due to the exploration of macroporous structure areas. In such cases, sampling from shafts is absolutely superior.

The sampling tool should be chosen, guided by experience in this country, so as to fit best soil conditions. Reliability of soil testing cannot be improved unless increasing the reliability of sampling; without that any refinement of laboratory tests is meaningless.

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