Development of two Modern Continuous Sounding Methods

Deux méthodes modernes de sondage continu. Interprétation des résultats

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Summary

For more than ten years the Swedish Geotechnical Institute has used two sounding devices — the Iskymeter and the Sounding Machine — which differ from most others in that they produce continuous records ready for immediate interpretation.

The methods were radically different from the standard Swedish sounding practice and therefore time was needed to calibrate them and to gather experience. In recent years they have been widely and successfully used, especially in connection with investigations of stability conditions in the Göta River Valley in southwestern Sweden and the publication of some experience gained seems to be justified.

The Iskymeter works mainly in clay and gives shear strength data agreeing with the results of other rapid tests. The Sounding Machine is used to distinguish the soil strata and to determine their thickness and homogeneity.

When evaluating a large number of diagrams, simplified evaluation methods are necessary, but also such evaluation can yield essential information as to the ground conditions over large areas.

The continuous records enable reliable statistical evaluation to be made and permit the selection of typical layers for sampling. This procedure makes for a great reduction in the quantity of samples required and considerable savings in field work, drawing office costs and laboratory work, reducing guesswork considerably. Thus the overall economy is very good. Even the cost per metre of depth sounded is low.

Sommaire

Depuis plus de dix ans l'Institut Suédois de Géotechnique emploie deux appareils de sondage — « l'Iskymètre » et la sondeuse — qui diffèrent de la plupart des autres appareils en ce qu'ils fournissent des enregistrements continus immédiatement interprétables.

Les méthodes employées diffèrent radicalement de la pratique de sondage suédoise normale, et de ce fait il a fallu du temps pour les mettre au point et pour acquérir de l'expérience. Pendant ces dernières années elles ont été employées fréquemment et avec succès, notamment au cours de la recherche des conditions de stabilité du sol dans la vallée du fleuve Göta dans le sud-ouest de la Suède et la publication de l'expérience ainsi acquise nous a paru justifiée.

Suit une description sommaire des méthodes de l'interprétation des résultats. L'iskymètre travaille principalement dans l'argile et fournit des valeurs de la résistance au cisaillement concordant avec les résultats d'autres essais rapides. La sondeuse est utilisée pour distinguer les différentes couches du sol, pour déterminer leur épaisseur et pour apprécier leur homogénéité.

Pour l'interprétation d'un grand nombre de diagrammes, il est nécessaire d'avoir recours à des méthodes simplifiées, mais aussi une telle interprétation peut fournir des renseignements essentiels sur les caractéristiques du sol dans de vastes étendues.

Les enregistrements continus permettent une interprétation statistique très sûre et autorisent le choix de couches caractéristiques dans lesquelles seront prélevés des échantillons. Cette méthode permet une réduction importante du nombre des échantillons nécessaires et des économies considérables à la fois sur les opérations sur le terrain, les dessins et les essais de laboratoire. En outre, elle réduit considérablement les incertitudes. L'économie générale de l'opération est ainsi excellente. Les frais par mètre de sondage sont modiques.

Introduction

Mr. W. Kjellman — first head of the Swedish Geotechnical Institute — wished to develop sounding methods which were quicker and cheaper and even less dependent on human factors than simple manual sounding. During the years 1938-1942, assisted by Mr. Y. Liljedahl, he developed the prototype of a machine — now called Iskymeter — (Royal Swedish Institute for Engineering Research Proc. No. 170, Walter Kjellman, En metod att direkt i marken bestämma jordlagrens skärhållfasthet). The Author has now developed the iskymeter to its present form and has also developed another machine, the sounding machine (utilizing a principle of eliminating skin-friction given by W. KJELLMAN, cf. Statens Geotekniska Institut, *Medd.* Nr 2 1949).

The SGI Sounding machine

Principles—The machine (Fig. 1) was developed mainly for large area sounding and was intended to be an improvement of the Swedish Standard sounding method (Cf. GEOTECHNICAL COMMISSION. Swedish State Railways, *Final report*, 1922).

The machine uses a conical point fastened to a rotating rod, pushed by means of two rollers, pressed hard against the sounding rod. The rollers are mounted in a rotor. The rate between rotation and push is kept constant.

Power is provided by an hydraulic motor mounted on a pivot. This swings on a vertical axis and is supported by the rotor. Pivot and rotor are free to move upwards and downwards and are carried by a set of helical springs. When an axial force is developed in the sounding rod the system is lifted proportionally to the force. The reaction in a tangential direction when driving the rotor is taken by a horizontal spring.

An arm fixed on the pivot moves upwards when penetration resistance increases and in a horizontal direction when the turning force increases. Disturbance from friction or from the hose supplying the hydraulic fluid joined near the centre of rotation are normally small.

The horizontal and vertical movement of the arm influence a pen recording on a waxed paper. A vertical load of 100 kg gives a deflexion of 10 mm on the chart (Total range 1 000 kg).

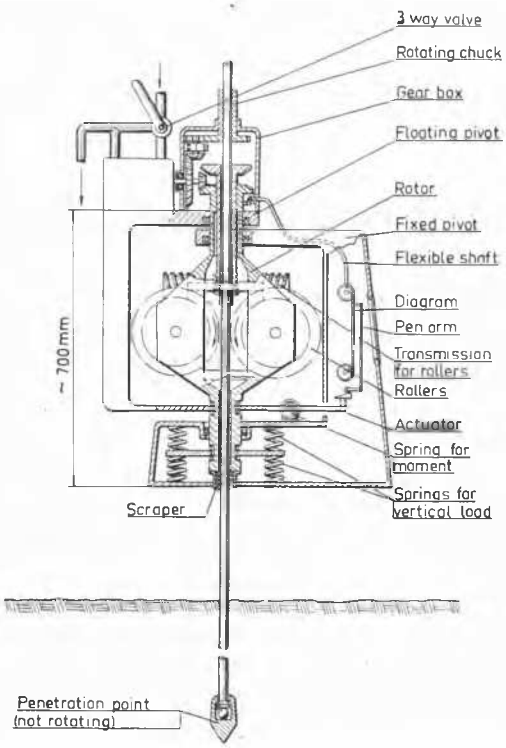

Fig. 1 General arrangement of SGI sounding machine.
Machine de sondage type SGI.

The paper is moved by the rotor over a flexible shaft (1 m of penetration corresponds to a paper travel of 10 mm).

Fig. 2 shows how skin friction is eliminated. As there is a constant relationship between penetration and rotation, the direction of travel of each surface element of the sounding rod is known. The moment required to turn the rod is measured. If the rod turns around its centre an estimate of the horizontal force can be made. Moreover it can be assumed that the frictional force (F) on any surface element will be directed opposite to the travel. The frictional force consists of one horizontal part (F_h) (already calculated from the turning moment) and one vertical part (F_v) in constant relationship to the known horizontal part. Thus, the turning moment is proportional to the vertical part of the skin friction and can be introduced as an automatic correction on the recorded total vertical force (V). This is done by a sloping curve on the actuator-arm.

The sounding rods are coupled automatically by means of a rotating chuck which makes continuous penetration possible.

Calibrations—Static calibrations have shown that with loads of 0-500 kg and moments from 0-18 kgm, the correction on the measured vertical load is normally smaller than

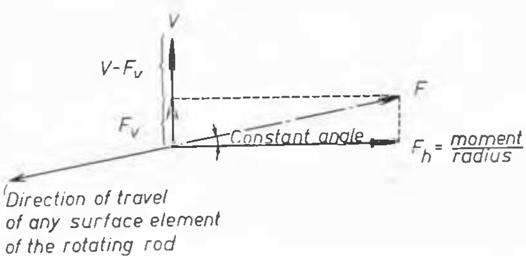

Fig. 2 Principle of separating skin friction from point resistance.
Principe de la séparation du frottement latéral de la résistance de pointe.

10 kg. A suitable correction can be made where required.

The method of using the turning moment for the elimination of skin friction has been checked by surrounding the sounding rod with a tube where sand could be put under pressure. The calibrations showed that the way to eliminate skin friction is substantially correct if a correction on point resistance of — 2·5 kg per kgm turning moment is made. In very soft clay with a rotating point of the same diameter as the sounding rods, the author found that the machine recorded only the weight of the rod as intended. (The correction in kg for rod weight is + 2·47 h, where h is sounding depth in metres).

This correction for skin friction will not apply if the rotor is accelerated or retarded or if the couplings of the sounding rod are not quite concentric, or if the rods are not quite straight. This may only occasionally introduce errors which ought to be considered.

More serious errors are introduced by varying static pressure in the bore-hole. The author has used three different point diameters, namely 25 mm, 40 mm and 80 mm (the latter is not used any more), in combination with a 20 mm sounding rod. The pressure from above on the point (Fig. 3) gives a force dependent on conditions in the ground. We can imagine a vacuum acting above the point. In an open hole we will have the atmospheric pressure. If the hole is filled with water or clay mud with volume weight γ we have a pressure of $h \cdot \gamma$ above the point. Finally, we may have passed through layers of sand with high artesian pressure which may act on the point if the hole is closed above the sand. The possible magnitude of static influences depends on the size of the ring-shaped area accessible for pressure variations. For the 25 mm diameter point this area is only 1·76 sq. cm and disturbance is negligible. For the 40 mm diameter point area is 9·41 sq. cm and disturbance must be considered. It may be an advantage to use the 40 mm diameter point to shallow depths owing to the heavier point resistance and the lower influence of mechanical errors.

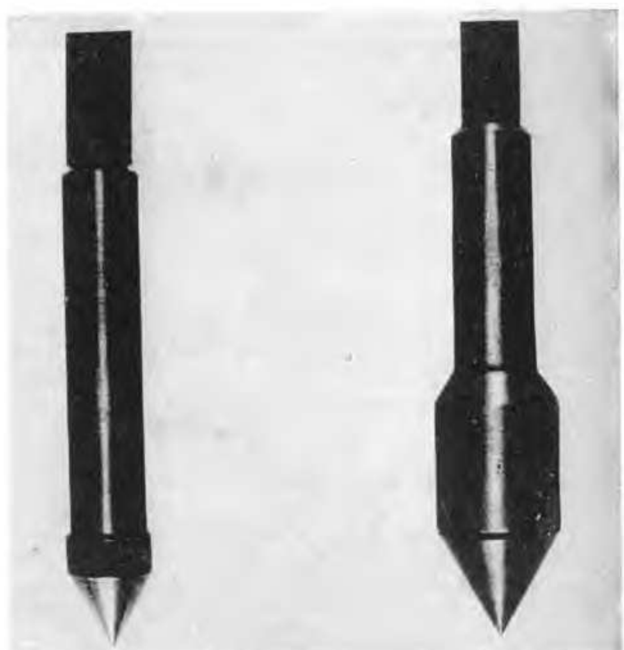

Fig. 3 Points of 25 mm and 40 mm diameter.
Pointes de 25 mm et de 40 mm de diamètre.

The sounding machine has been tried in different materials. Fig. 4 shows a rough relationship between a 25 mm diameter point resistance and the degree of packing of different sands.

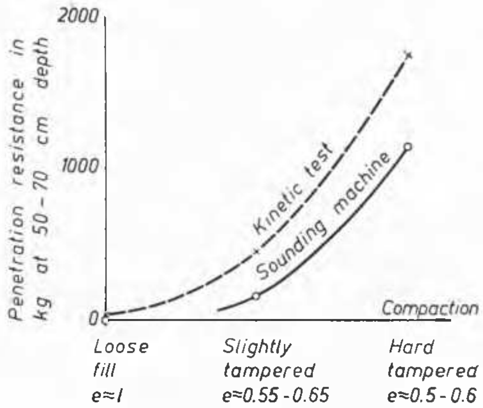

Fig. 4 Resistance of a 25 mm diameter point in sand (Calibration Test).
Résistance de pointe de 25 mm de diamètre dans le sable (Essai d'étalonnage).

The machine has given lower resistance values than a static test, probably because the rod rotates. The influence of a rotative point must be considered to allow for a possibly defective ball bearing. According to tests this reduces point resistance still more but it may also increase penetration. For sand which ranges from normal to dense packing, the machine with the 25 mm diameter point combines adequate reaction with good penetration.

In clay points of different sizes, provided with mantles of different lengths, have been tested by the author. Fig. 5 gives a rough estimate of the influence of point diameter and mantle length on the bearing capacity. The N-value is defined as point resistance in kilograms divided by the cross-sectional area of the point in sq. cm. times shear strength in kg per sq. cm. The static conditions in the borehole and the friction along the mantle were not considered. Mantle length equal to the diameter is deemed best. If it is too long the sensitivity and soil pressure on the mantle will have a large and varying influence. If it is too short, sliding surfaces around the point may influence point resistance. To check the influence of these conditions the author has poured drilling muds of different specific gravity into the borehole. The drilling mud greatly reduced the measured point-resistance. For an 80 mm diameter point and with a mud weighing 2 kg per litre, point resistance was eliminated. At depths down to 10 to 20 m however, the author has sometimes used N-values from 20 to 25 to good advantage for an approximate estimate of clay strength when using points of 40 and 25 mm diameter.

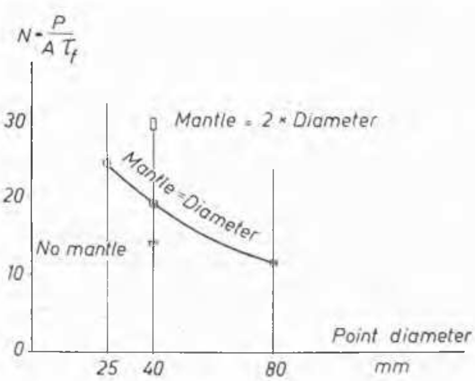

Fig. 5 Point resistance in clay (Approximate Values).
Résistance de pointe dans l'argile (Valeurs approximatives).

Application and Experience—The records of this sounding machine are claimed to give a better indication of soil stratification than alternative sounding methods.

Fig. 6 shows typical curves for clay, sand and gravel of different density. By judging the shape of the curve, the point resistance and the turning moment, sound information can be obtained. A general knowledge of site geology from a continuous core of soil is very helpful as an aid to interpretation.

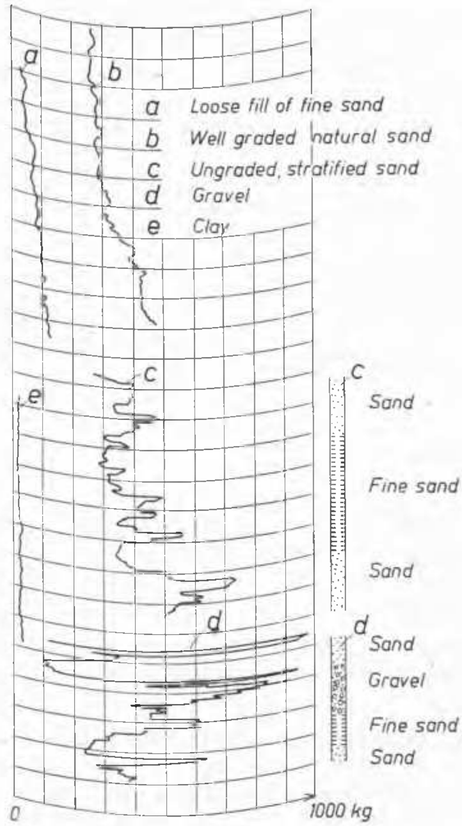

Fig. 6 Typical resistance curves for a point of 25 mm diameter.
Pointe de 25 mm de diamètre. Courbes de résistance caractéristiques.

Fig. 7 shows a curve with notations and interpretation. The operator notes on the diagram direct observations made during sounding. He can hear and feel when the point hits a stone. Bad joints or accelerations and retardations of the rotor influence the records. The operator notes the sounding depth as observed directly on the sounding rods to check possible slip of the rod between the rollers (which happens only occasionally). Moreover, the turning moments are noted at intervals to facilitate interpretation and to enable due allowance to be made for the effect of skin friction.

When using the 25 mm diameter point, the penetration and ability to distinguish sand layers in clay are far better with the sounding machine than with the traditional Swedish sounding apparatus. Near bedrock there are generally typical layers of sand and gravel which can be distinguished on the diagrams and indicate bed-rock. Silty material below the water table may give decreasing point resistance due to increased pore pressure and remoulding caused by the rotating rod.

The capacity of the machine with two operators in Swedish clay is 30 to 50 holes down to 5 to 10 m depth or 10 to 12 holes down to 50 m depth in eight ours, including transport of from 50 to 100 m between the holes.

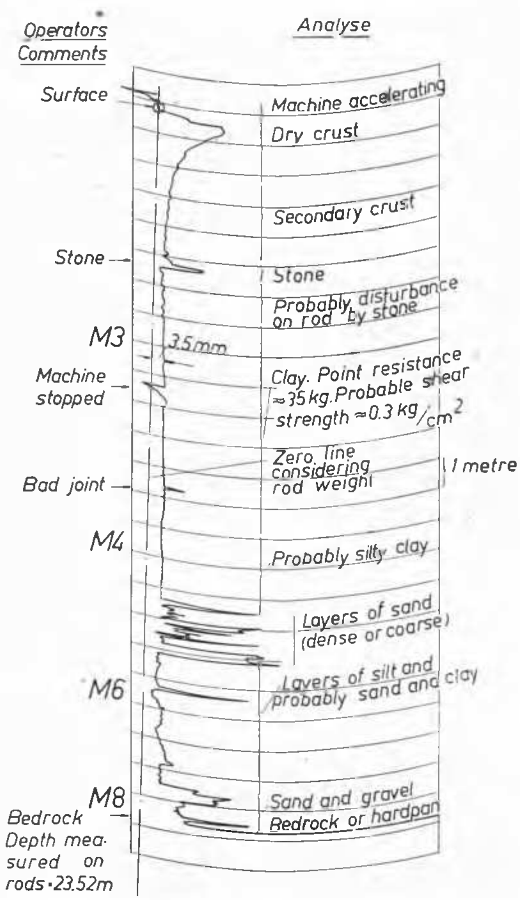

Fig. 7 Analysis of diagram for a point of 25 mm diameter.
Pointe de 25 mm de diamètre. Analyse de diagramme.

A special problem arises when studying the diagrams. If, for instance, this machine produces about 1 000 diagrams in a month, simple tables of the most important values must be prepared. Fig. 8 shows a table for vertical drainage projects where the object is to find permeable layers and the thickness and depth of the clay layers. By plotting point resistances at a certain depth on a map, weak and hard areas can be found (the weak area in Fig. 9 coincided with the lowest part of the ground surface).

With this system points and levels can be selected where a few samples or in-situ tests can give representative values for soil conditions. The sounding machine is cheap in use for jobs exceeding about 200 bored metres or depths below 20 m. It has been used, for example, in Northern Norway for an airfield near Stockholm and in the Göta River Valley in Western Sweden. Rapid setting out of the boreholes is an important factor.

Machine Sounding

Job · K 5552 — Sheet 42
Site: Skå Edeby — Point Diameter: 25 mm

Day	Hole	Litt	Total Depth m	Stratification: Dry crust	Stratification: Clay	Stratification: Silt or Sand	Resistance at Depth -5m	Resistance at Depth -10m	Notations
Line 4775									
5/9									
	1	20625	14,5	0-1,2-4,5	1,2-5 5,2-13	5-5,2	20	30	Probably stone at -12
	2	20650	32,2	0-0,6-2,5	0,6-20 23-31,2	20-2,3 31-32,2	20	30	—
	3	20675	5,2	0	0	0-5,2	—	—	

Fig. 8 Machine sounding data.
Tableau de résultats de sondage fournis par la machine.

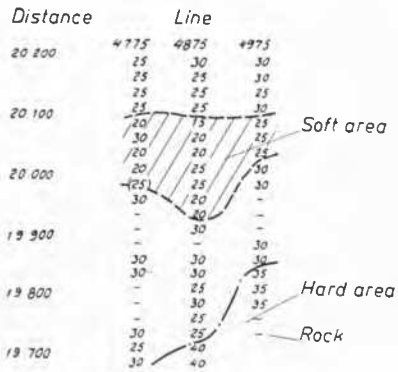

Fig. 9 Plotting of point resistances.
Graphique de la résistance de pointe.

The SGI Iskymeter

Principles—The Iskymeter is intended for sounding mainly in soft ground. Instead of a point, it uses a resistor with foldable wings which is pulled out of the ground. Fig. 10 shows this resistor in different positions, as described. It is pushed down in the soil by means of a rod provided with a special end attachment for the resistor shaft. During thrust into the ground, the wings are folded and the resistor has little resistance and therefore causes only slight disturbance of the soil. When the rod is withdrawn the resistor stays in the ground, and a wire-rope from the resistor ends in a storage-drum on the soil surface. The pushing and withdrawal is normally performed with a separate winch (e.g. the front winch of a lorry).

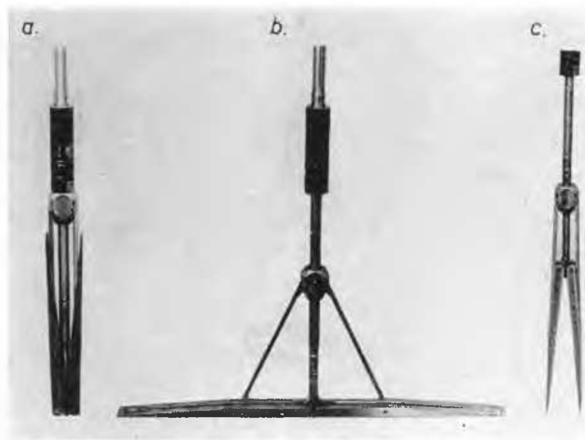

Fig. 10 Resistor for SGI Iskymeter:
(a) installation position;
(b) sounding position;
(c) position when overloaded.
Elément résistant de l'iskymètre type SGI:
(a) position de fonçage;
(b) position de travail;
(c) position de relevage.

The storage-drum is then fastened to a special winch (Fig. 11) which is driven either manually or by means of a small motor, and pulls the resistor out of the ground. During the first 60 cm pull the wings of the resistor-body unfold automatically and assume the position shown in Fig. 10b.

As the wire-rope runs out of the ground it is first cleaned from soil by a special cleaner. Then it bends 90° over a pulley, which is fastened to a lever and torsion beam in such a way that the pulley travels downwards and upwards in direct proportion to the pulling force. This travel is then extended

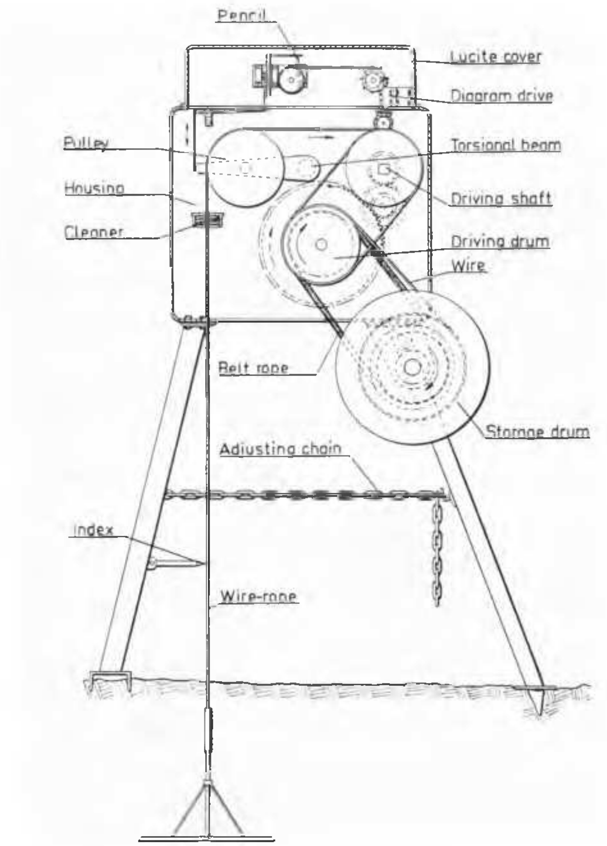

Fig. 11 SGI Iskymeter.
Iskymètre type SGI.

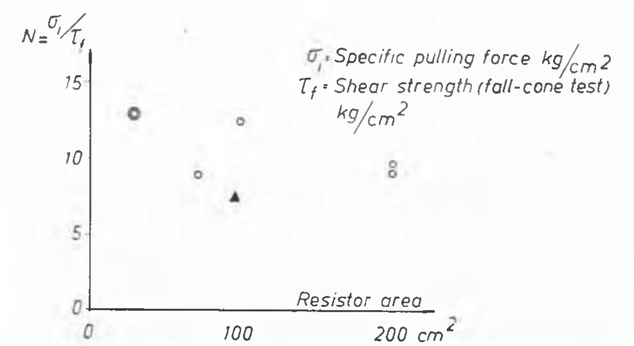

Fig. 12 Early calibration of Iskymeter (Kjellman and Liljedahl, 1939-1941).
Etalonnage de l'iskymètre à l'origine (Kjellman et Liljedahl, en 1939-1941).

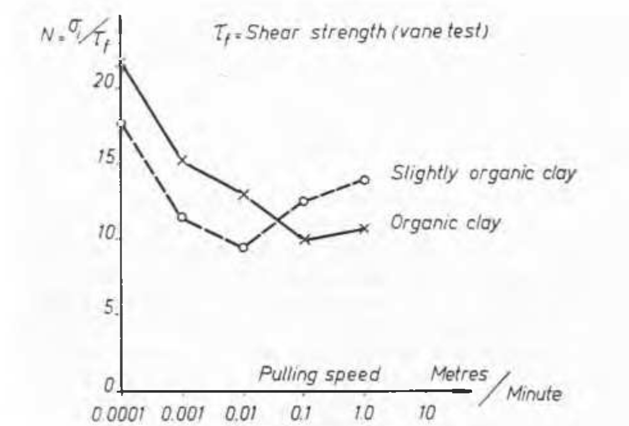

Fig. 13 Influence of clay and pulling speed (Jakobson and Wager, 1955).
Influence de la nature de l'argile et de la vitesse de traction (Jakobson et Wager, en 1955).

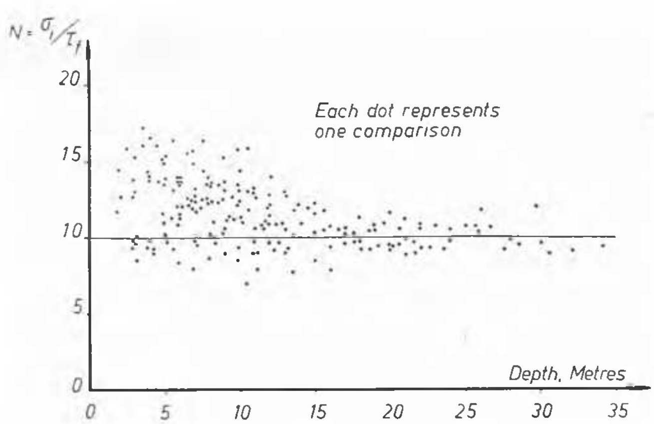

Fig. 14 Uncorrected Iskymeter values (Compared with Field Vane Test).
Valeurs données par l'iskymètre non corrigées (comparées avec des essais de chantier faits avec un moulinet).

and is used to move a pencil across a paper chart, a pulling force of 1 000 kg giving a pencil travel of 100 mm.

The wire rope is wound around two drums (one of which is driven by the winch) and continues to the storage drum. The rotation of one of the drums is used to move the diagram paper 10 mm for each metre of pull.

Resistors with horizontal cross sectional areas of 200, 100 and 30 sq. cm have been used. If the forces exceed 1 000 kg, a small pin on the resistor shaft breaks and the wings can fold backwards.

The Iskymeter is normally transported on a light trailer but can also be carried by the operating crew between adjacent boreholes.

Calibration—A first calibration of the Iskymeter was performed as early as 1939-1941 by Mr. W. Kjellman and assistants. Fig. 12 shows the relationship between specific vertical pressure on reistors of different cross-section area and shear strengths determined by fall-cone tests. Considerable scatter has been noted.

Influence of sensitivity of the soil and of variations in the pulling speed were suspected as the reasons for this scatter. Mr. B. Jakobson and Mr. O. Wager performed tests with pulling speeds varying from 0·001 to 10 metres per minute. The results indicate dependence on pulling speed and type of material (Fig. 13). Organic matter (which influences e.g. the modulus of elasticity) may also have an influence. At normal speeds (0·50-2·0 m per minute) the influence of speed should be small for a certain material. Fig. 14 shows uncorrected results (as compared with vane tests) from the Göta River Valley. The average scatter was about $\pm$ 35 per cent. Both depth and sensitivity have some influence. Mr. J. Osterman, now head of the Swedish Geotechnical Institute, derived a semi-empirical expression for correction of the pulling force for sensitivity and for depth. His expression, as derived mainly for the 100 sq. cm resistor body, is the following:

$$\tau_f = \frac{0{\cdot}092\ P}{\left(1 + \frac{2}{S_t}\right)A} + \frac{0{\cdot}06 \cdot \gamma \cdot h \cdot \left(1 - \frac{1}{S_t}\right)}{1 + \frac{2}{S_t}}$$

Where P = pulling force in kg
A = area of resistor body in sq. cm
S_t = sensitivity of the clay
γ = volume weight in tons per cub. m.
h = depth below ground surface in metres.

(The dimensions were chosen to suit existing practice.)

The expression is mainly based on sliding circle calculations and considerations of shear strength reduction in relation to the sensitivity close to the resistor and below it. After aplying the formula the average scatter of results was reduced to the order ± 10 per cent.

It is possible to produce an expression for the evaluation based on the theory of plasticity, where the modulus of elasticity can also be considered. The scatter should therefore be reduced but it is difficult to determine accurately the modulus of elasticity of the soil.

Experience

The Iskymeter has been used in recent years both for preliminary and for detailed investigations, especially in the Göta River Valley. The results agree reasonably well with other rapid tests and, the Iskymeter has the particular advantage of providing continuous records. Fig 15 shows a typical diagram. The capacity under normal conditions is 3-4 holes in eight hours. The Iskymeter can be used for soft clays for depths down to 100 metres as friction against the wire rope is small and can easily be compensated for. A special problem for such great depths is the difficulty of driving the resistor vertically into the ground.

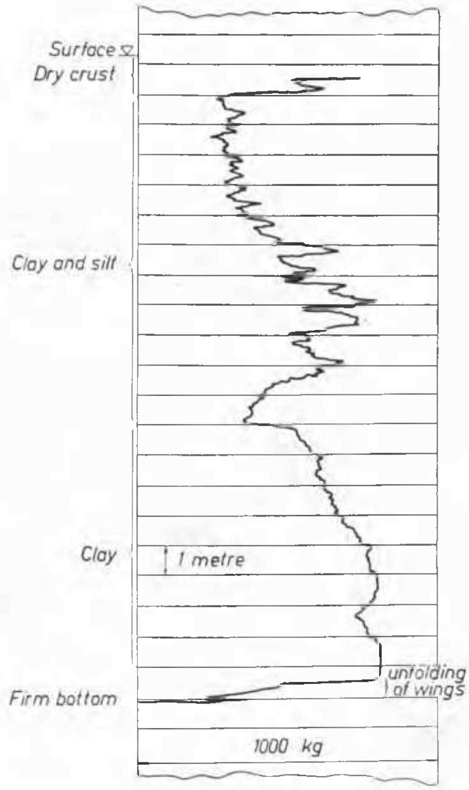

Fig. 15 Iskymeter-diagram (Göta, 1957).
Diagramme d'iskymètre (Göta, en 1957).

Conclusions

The continuity of both methods provides better knowledge of stratification than is possible with discontinuous sampling or in-situ testing. The written records enable an estimate to be made of soil conditions by studying the curves. There is also a considerable reduction in the number of samples required on a site.

The diagrams are ready for reading at the exploration site. This means that the operator can make another sounding in case of dubious results and that the field work can be organised in accordance with the ground conditions. This may also entail fewer boreholes and the provision of more immediate information on the most suitable foundation methods to be adopted.

The two methods have revealed that the use of different equipments can be both rational and economical. For any site, calibration can be done by testing only a few samples.