*Reprinted from J. agric. Engng Res.* (1967) **12** (1) 66–70

# Apparatus for Measuring Soil Shear Strength *in situ*

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## 1. Introduction

The physical properties of the top soil vary greatly within short distances. Therefore, to obtain a representative average, it should be necessary to measure soil shear strength at a great number of sites, scattered over the plot. A measuring device that suits this purpose should preferably be portable and easy to dismantle. There should be no contact between the surrounding soil and the outer wall of the shear head in order to avoid soil-metal friction. Moreover, soil disturbance in forcing the shear head into the soil should be avoided.

From experience with Söhne's standard laboratory shear apparatus[1-3] it appeared that a cylindrical shear head with radial fins gives reliable results. Therefore, this principle was adopted in the construction of the apparatus described below.

According to Coulomb

$$\tau_{max} = c + \rho \tan \varphi$$

where $\tau_{max}$ = shear strength
$c$ = apparent cohesion
$\rho$ = normal stress on shear plane
$\varphi$ = angle of internal friction.

In the present research only the apparent cohesion was considered. Therefore, complicated and expensive provisions for recording the moment-twist curve or for measurements at different normal stresses were superfluous. To determine apparent cohesion it is sufficient to measure shear strength at a normal stress of 0 kg/cm$^2$ with a simple torquemeter. The one described by Schaffer[4] proved to be very suitable.

## 2. Apparatus

The apparatus (*Fig. 1*) consists essentially of a shear cylinder of 100 mm i.d. (A) with cutting edge and eight equally spaced fins (34 × 55 × 0·8 mm). The outer edges of the fins are welded to the inner wall of the cylinder, whilst the upper part of the inner edges are let into a central spacing ring (B) and also welded. The ring is kept in position by means of a cross with three arms (C), the ends of which are welded to the inner wall of the shear cylinder. The centre of the cross is connected to the lower end of central pipe D (15 mm o.d.). The inside of the upper end of this central pipe is made square to fit a torquemeter. A slotted disc piston (E) inside the shear cylinder is used for easy removal of the soil after the measurement. The slotted disc is jointed to pipe F (19 mm o.d.) by means of three vertical rods and a three-armed cross (G). The rods run through guide holes in the lower cross. The slotted disc can be moved up and down inside the shear cylinder by moving pipe F with respect to pipe D. It can be fixed in its uppermost position by placing a wooden spacing piece (H) between handles d and f of pipes D and F.

The shear cylinder is pushed into the soil by an outer cylinder (J). The lower end of the outer cylinder rests on a flange of the shear cylinder. Just above the flange the shear cylinder is slightly thickened to serve as centring ring. The outer cylinder is jointed to pipe K (25 mm o.d.), with which it can be moved up and down. Pipe K ends in Handle k with a cylindrical platform (L) in the centre.

Soil disturbance is minimized by forcing the cutting edge of the shear cylinder slowly into the soil by means of a 2-ton hydraulic bumper jack.[5] A frame with central U-beam provides support

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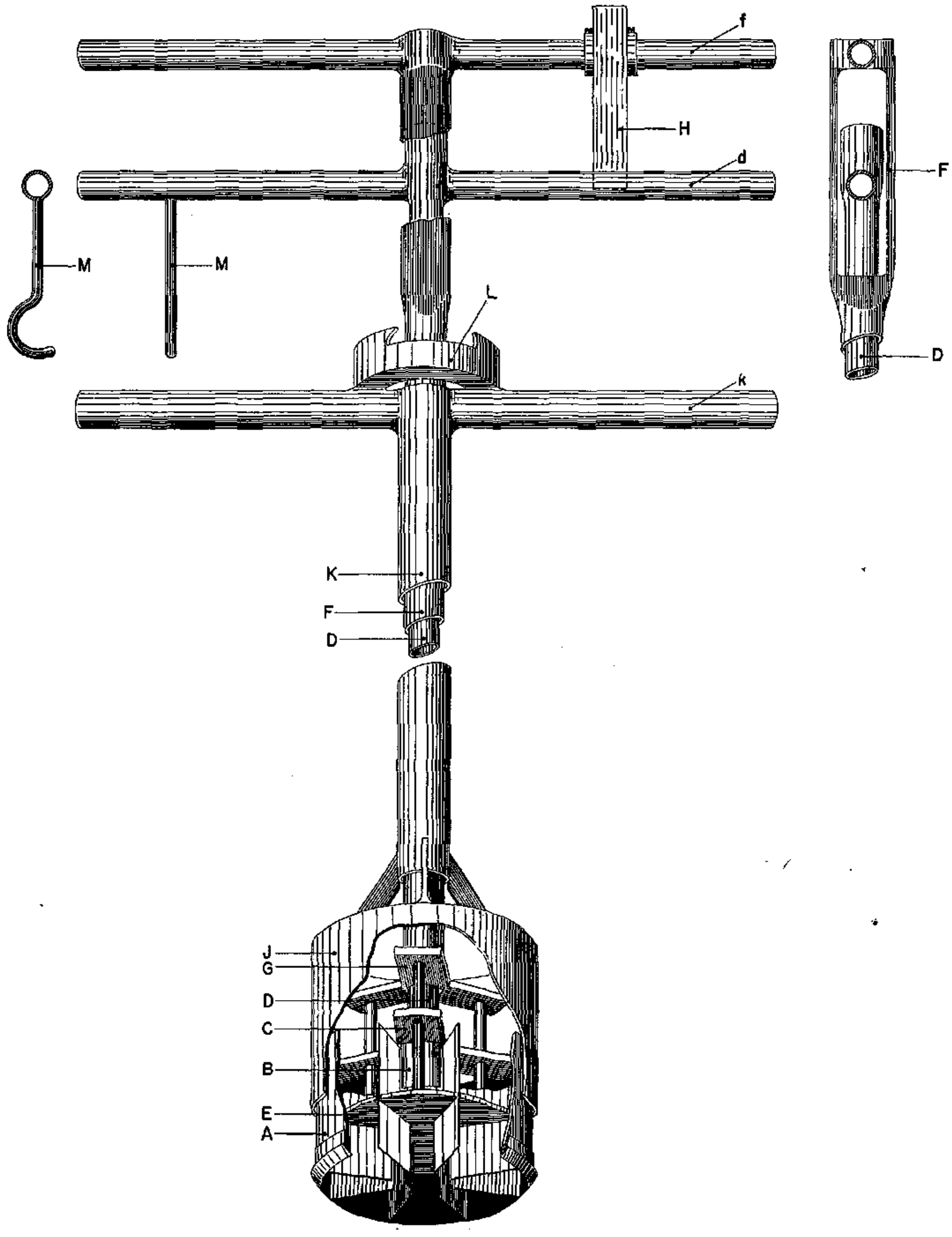


*Fig. 1. Field shear apparatus*

(*Fig. 2*). Reaction is obtained from the weight of men standing on the base frame or from two screw-type soil anchors. The jack clamp enables changing the position of the jack tube with respect to the U-beam, so that any depth of the shear cylinder up to 55 cm can be reached.

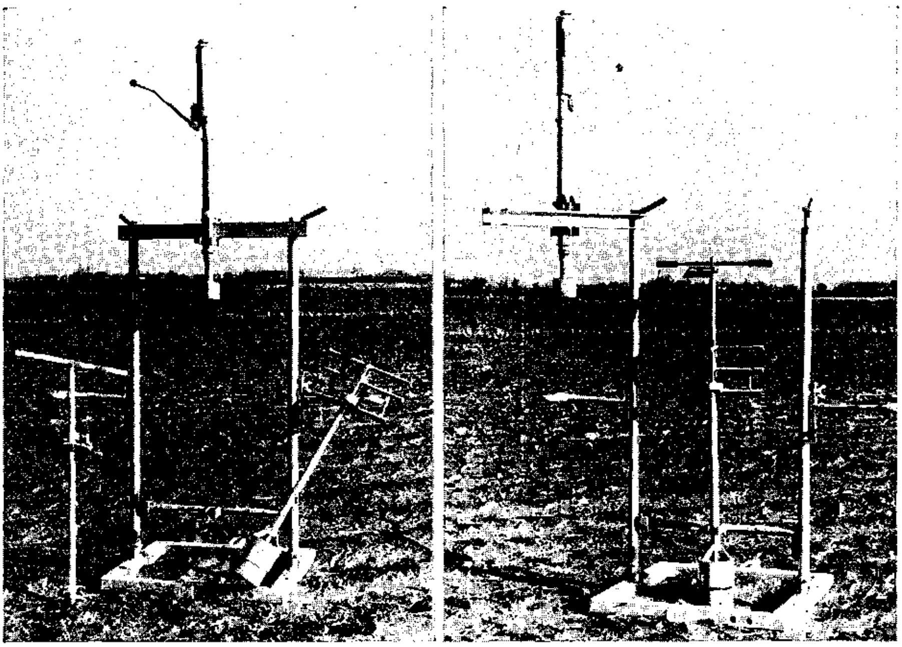

*Fig. 2. U-beam*

### 3. Operation

When the frame is placed over the selected area, the U-beam with bumper jack and the shear apparatus support are loosened at one end and turned aside to make room for the drilling of a hole, using an auger consisting of a cylinder (130 mm o.d.) with a disc plunger. When the cylinder is filled and removed from the hole, the soil is forced out with a single stroke of the plunger. When the desired depth is reached the shear apparatus is placed in the hole and secured by a clamp, the slotted disc inside the shear cylinder being secured in its uppermost position. Then the U-beam is fastened and a slotted cylinder (58 mm o.d.) is placed on top of the cylindrical platform (L) enabling the transmittance of vertical pressure from bumper jack to shear cylinder. The jack piston, to the lower end of which a short cylinder (60 mm i.d.) is jointed, is pulled downward by hand to the top of the slotted cylinder.

After closing the jack valve the shear cylinder is jacked 2 cm into the soil. Then the jack valve is opened, the jack piston is pushed upward by hand, the slotted cylinder is removed and the U-beam with bumper jack is very carefully turned aside to prevent vibration of the frame. The outer cylinder of the shear apparatus is pulled upward and secured in its uppermost position by placing the corresponding handle in a hook. As a result, a free space of 3 mm between shear cylinder and surrounding soil is obtained, so that soil-metal friction is minimized; it only acts along the periphery of the cutting edge. Then the torquemeter is attached and torque applied until failure occurs. Maximum torque is read by means of a maximum indicator. Although the fins do not extend as far as the centre of the shear cylinder, it appears that in cohesive soils the whole circular slice of soil within the shear cylinder shears off under the influence of the applied torque. So the shear plane is circular, with a radius of 5 cm.

After removing torquemeter and shear apparatus, samples for moisture content determinations are taken from the shear plane and the shear cylinder is cleaned by pushing the slotted disc piston downward. Then the hole is drilled deeper until the next soil layer to be investigated is reached.

To obtain a reliable average, shear strength determinations are usually carried out in two layers of the top soil at 15 different sites scattered over the plot. This is accomplished by two persons in about 1 h.

## 4. Results

Shear strength determinations were carried out in the laboratory with soil in different conditions with regard to pore space and moisture content. Results obtained with the field shear apparatus were compared with those from Söhne's standard laboratory shear apparatus, using the techniques developed by Kuipers and Kroesbergen.[6]

Shear strength was determined of four widely different soils (Table I). For each apparatus the

TABLE I

**Characteristics of soils**

| *Location* | *Soil class* | *pH-KCl* | *$CaCO_3$, %* | *Org. matter, %* | *Particles <16μ, %* |
|---|---|---|---|---|---|
| Nieuw Beerta | Clay | 7·1 | 0·7 | 3·7 | 77·4 |
| Marknesse | Loam | 7·5 | 10·3 | 2·2 | 32·0 |
| Wijnandsrade | Loess loam | 4·7 | 0 | 1·8 | 29·4 |
| Heino | Sand | 4·3 | 0 | 4·5 | 3·8 |

readings of maximum torque in kg cm were converted to shear strength in kg/cm². It was assumed that the stress distribution across the shear plane is uniform ($\tau_{max}$ = const) when maximum torque is reached. Then the relation between shear strength and maximum torque is given by the formula[7, 8]

$$\tau_{max} = \frac{3\, M_{max}}{2\,\pi\,(R_o^3 - R_i^3)}$$

where $\tau_{max}$ = shear strength, kg/cm²
$M_{max}$ = maximum torque, kg cm
$R_i$ = inner radius of shear plane
$R_o$ = outer radius of shear plane.

For the laboratory apparatus $R_i$ = 6·5 cm and $R_o$ = 9·5 cm, hence $\tau_{max} = \frac{M_{max}}{1221}$ kg/cm²; for the field apparatus $R_i$ = 0 cm and $R_o$ = 5·0 cm, hence $\tau_{max} = \frac{M_{max}}{262}$ kg/cm².

For corresponding pore spaces and moisture contents, shear strengths determined both with the field and the laboratory apparatus are plotted in *Fig. 3*. The relation seems to be linear and only slightly dependent on soil type. It appears, however, that shear strengths indicated by the field apparatus are over twice as high as those from the laboratory apparatus.

From preliminary investigations it appeared that this may be due partly to soil-metal friction, acting along the periphery of the cutting edge, and partly to higher rate of shearing of the field apparatus. Kuipers and Kroesbergen[6] found that smaller dimensions of torsional shear heads can give up to 20% higher shear strengths. Finally, attention may be drawn to the fact that the weight of the field apparatus is not counter-balanced, which may increase shear strength.

Further research will be required to establish the influence of each of these factors on the absolute level of the shear strength values. That does not alter the fact, however, that the results

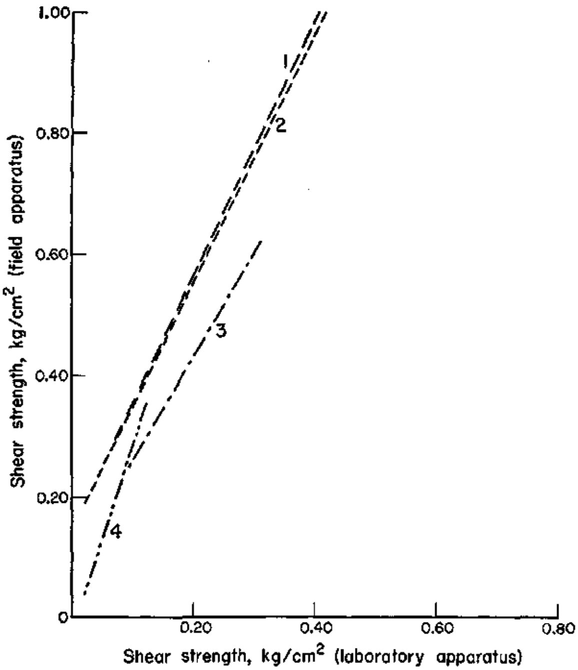


*Fig. 3. Relation between results of field and laboratory shear tests*

| | | | |
|---|---|---|---|
| (1) | *Loam* | $y = 2{\cdot}094x + 0{\cdot}144$ | $r = 0{\cdot}99$ |
| (2) | *Clay* | $y = 2{\cdot}055x + 0{\cdot}140$ | $r = 0{\cdot}92$ |
| (3) | *Loess loam* | $y = 1{\cdot}723x + 0{\cdot}084$ | $r = 0{\cdot}97$ |
| (4) | *Sand* | $y = 3{\cdot}169x - 0{\cdot}031$ | $r = 0{\cdot}95$ |

of determinations with the field shear apparatus described above give a reliable impression of relative soil shear strength differences *in situ.*

## Acknowledgements

Thanks are due to E. Ebels (drawing office) and H. K. Stokla (workshop).

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