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Part 9:
Field vane test (FVT and FVT-F)

Reconnaissance et essais géotechniques — Essais en place —

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Foreword

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This document was prepared by Technical Committee ISO/TC 182, *Geotechnics*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 341, *Geotechnical Investigation and Testing*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

A list of all parts in the ISO 22476 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

The field vane test is used to determine the vane shear strength of soils in the undrained condition, by insertion of a rectangular vane into fine-grained soil and rotating it. During the rotation, the torque and rotation can be measured, depending on the test configuration. From the measured torque and the dimensions of the vane, the peak shear strength, an indication of post-peak behaviour, and the remoulded shear strength can be derived by a limit equilibrium analysis. Soil sensitivity can be ascertained if peak and remoulded shear strengths have been determined.

The tests are carried out in boreholes, in trial pits and with pushed-in equipment. The torque and rotation are measured either above the ground surface using extension rods, or directly above the vane.

The field vane test is mainly applicable to saturated fine-grained soil. The vane shear strength determined by the test is commonly corrected before geotechnical analysis, using factors based on local experience.

Geotechnical investigation and testing — Field testing —

Part 9:
Field vane test (FVT and FVT-F)

1 Scope

This document deals with the equipment requirements, execution and reporting of field vane tests for the measurement of peak and remoulded vane shear strength together with the sensitivity of fine-grained soils. In addition, post-peak shear strength behaviour can be evaluated. Two types of field vane test are described: the ordinary field vane test (FVT) and the fast field vane test (FVT-F).

The uncertainties of the vane test result are described in Annex D.

NOTE 1 This document fulfils the requirements for field vane tests as part of the geotechnical investigation and testing according to EN 1997-1 and EN 1997-2.

NOTE 2 This document covers onshore and nearshore field vane testing.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 10012, *Measurement management systems — Requirements for measurement processes and measuring equipment*

3 Terms, definitions and symbols

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1.1
cased extension rod
extension rod that is sleeved inside of *protective casings* (3.1.11) during *vane* (3.1.23) testing

3.1.2
cased borehole
borehole that is cased to prevent collapse and minimize friction between the extension rods and soil

3.1.3
centralizer
equipment to keep the extension rods straight and prevent buckling

3.1.4
data acquisition system
measuring system, which converts physical quantities to digital format

Note 1 to entry: The system typically includes sensors, signal conditioning, an analogue-to-digital converter and recording unit.

3.1.5
downhole test
test configuration whereby the torque is measured close to the *vane* (3.1.23)

Note 1 to entry: The *rotation* (3.1.14) can be measured close to the vane or above the ground surface.

3.1.6
external friction torque
torque due to friction outside the measuring equipment during *rotation* (3.1.14) excluding torque caused by shearing of soil

Note 1 to entry: External friction is mainly caused by friction acting on extension rods, and it can be estimated with a *slip coupling* (3.1.16) immediately before engagement of the *vane* (3.1.23).

3.1.7
friction reducer
ring inserted between the *vane* (3.1.23) and the extension rods to reduce friction along *uncased extension rods* (3.1.20)

3.1.8
insertion length
distance from the ground surface or base of (bore)hole or trial pit to mid-height of the *vane* (3.1.23), measured along the axis of the extension rods

3.1.9
internal friction torque
torque due to friction inside the measuring equipment during *rotation* (3.1.14) when there is no torque acting on the *vane* (3.1.23) and no friction acting on the extension rods

3.1.10
protection shoe
equipment to protect the *vane* (3.1.23) while pushing into the soil

Note 1 to entry: It assists with the insertion of the vane without drilling. Usually, the tip of the protection shoe consists of four plate slots allowing the *vane plates* (3.1.24) to retract inside of the *protective casing* (3.1.11).

3.1.11
protective casing
tube that isolates the extension rods from the soil and gives support against buckling

3.1.12
protrusion length
distance between the bottom of the protective casing/shoe and the mid-height of the *vane* (3.1.23) when pushed to the *test depth* (3.1.17), measured along the axis of the rods

3.1.13
push-in equipment
equipment to push the *vane* (3.1.23) into the soil without predrilling.

3.1.14
rotation
change of angle by the circular movement of the *vane* (3.1.23) around its axis

Note 1 to entry: Apparent rotation is the rotation recorded by the rotation measurement equipment.

3.1.15
rotation rate
rate of angular *rotation* (3.1.14) of the *vane* (3.1.23)

3.1.16
slip coupling
mechanism that allows the extension rods to rotate freely while the *vane* (3.1.23) remains stationary

Note 1 to entry: The function of slip coupling is to separate the rod friction from vane torque resistance. A slip coupling mechanism shall provide free rotation with minimal friction.

3.1.17
test depth
vertical distance from the ground surface, reference level or datum to the mid-height of the *vane* (3.1.23)

Note 1 to entry: According to Annex G, the *insertion length* (3.1.8) can be corrected with inclinometer measurements to correspond to the corrected test depth. Otherwise, the test depth is based on the sum of the lengths of the extension rods from reference level or datum owing to the uncertainty of inclination.

3.1.18
test location
plan position of a test or series of tests

3.1.19
time to failure
time from the beginning of application of torque to the *vane* (3.1.23) until the maximum torque is reached

3.1.20
uncased extension rod
extension rod that is not protected by protective casing allowing friction to develop between the extension rods and the soil

3.1.21
uncased vane
vane (3.1.23) pushed into the ground without protection

3.1.22
uphole test
test configuration whereby the torque is measured above the ground surface

Note 1 to entry: The *rotation* (3.1.14) is applied and measurements registered above the ground surface.

3.1.23
vane
device formed by four *vane plates* (3.1.24) fixed at 90° to each other

3.1.24
vane plate
thin and flat rectangular plate

Note 1 to entry: Most *vanes* (3.1.23) have a (nearly) rectangular shape. For practical reasons, vanes without *protection shoes* (3.1.10) often have slightly tapered lower ends of the vane plates or with rounded corners. Some equipment using *uncased extension rods* (3.1.20) and a *slip coupling* (3.1.16) to separate the rod friction from the torque on the vane are designed with slightly tapered, sharpened, pointed or conical, vane plates in order to disengage the slip coupling during the pushing stroke.

3.1.25
vane shaft
cylindrical element of the *vane* (3.1.23) to which the *vane plates* (3.1.24) are fixed

Note 1 to entry: The vane shaft may be connected directly to the force or torque measurement equipment in a *downhole test* (3.1.5) or connected to it via extension rods in an *uphole test* (3.1.22).

3.1.26
waiting time
time between reaching the *test depth* (3.1.17) and beginning of application of the torque to the vane

3.1.27
zero shift
difference between the *internal friction torque* (3.1.9) readings of the measuring equipment prior to and after completion of the test

3.1.28
sensitivity
ratio between the undisturbed and remoulded undrained shear strengths

3.2 Symbols

Symbol	Name	Description	Unit
$A_{\text{cone,bott}}$		Lateral shear surface area of the bottom cone	mm^2
$A_{\text{cone,top}}$		Lateral shear surface area of the top cone	mm^2
$A_{cylinder}$		Lateral shear surface area of the cylinder	mm^2
α		Measured total angle between the vertical axis and the axis of the vane	°
β_1		Measured angle between the vertical axis and the projection of the axis of the field vane on a fixed vertical plane	°
β_2		Measured angle between the vertical axis and the projection of the axis of the field vane on a vertical plane that is perpendicular to the plane of angle β_1	°
C	Protective casing	Defined by term 3.1.11	
c_{u}	Undrained shear strength	Shear resistance of fine-grained soils in the undrained condition	kPa
c_{fv}	Field vane strength	Peak shear strength of soil, derived from the maximum torque measured by field vane test	kPa
$c_{\text{fv-f}}$	Fast field vane strength	Peak shear strength of soil, derived from the maximum torque measured by fast field vane test	kPa
c_{pv}	Post-peak field vane strength	Post-peak shear strength of soil, selected after desired rotation after field vane strength	kPa
c_{rv}	Remoulded field vane strength	Shear strength, as measured by field vane test, after remoulding the soil	kPa
D	Downhole measuring equipment	Equipment for measuring torque and rotation are located close to the vane	
D*	Downhole measuring equipment	Equipment for measuring torque is located close to the vane, but equipment for measuring rotation is located above the ground surface	
D		Diameter of the vane	mm
d		Diameter of vane shaft immediately behind vane	mm
D_{c}		Diameter of lower end of protective casing	mm
D_{ps}		Diameter of protection shoe	mm
F	Friction reducer	Defined by term 3.1.7	
H		Height of the vane	mm
H_{T}		The height of the vertical side of the tapered vane excluding the height influence of tapering(s).	mm
i_{T}		Angle of the taper at vane top	°
i_{B}		Angle of the taper at vane bottom	°

Symbol	Name	Description	Unit
R	Rotation unit	Rotation unit can be located close to the vane or above the ground surface	
R_a	Area ratio	Cross-sectional area ratio of vane and vane shaft compared to circular shear surface	—
r		Radius of the rounded corner of the vane plate	mm
$r_{cone,bott}$		Lever arm of the lateral surface of the bottom cone of shear surface	mm
$r_{cone,top}$		Lever arm of the lateral surface of the top cone	mm
$r_{cylinder}$		Lever arm of the lateral surface of the cylinder	mm
S	Slip coupling	Defined by term 3.1.16	
S_{fv}	Field vane sensitivity	The ratio between the field vane and remoulded field vane strengths	—
s		Thickness of the vane plates	mm
T	Torque	Torque measured during vane rotation, corrected for external friction torque reading	Nm
$T_{cone,bott}$		Component of torque required to shear the bottom cone of the shear surface	Nm
$T_{cone,top}$		Component of torque required to shear the top cone of the shear surface	Nm
T_{corner}		Component of torque required to shear a quarter circular shear surface	Nm
$T_{cylinder}$		Component of torque required to shear the side surface of the cylinder	Nm
T_{ext}	External friction torque reading	Stable output of measuring equipment during rotation when there is no torque acting on the vane (usually measured prior to the vane engagement by slip coupling)	Nm
T_{ext*}	External friction torque reading after remoulding the soil	Stable output of measuring equipment during rotation after remoulding the soil when there is no torque acting on the vane (usually measured prior to the vane engagement by slip coupling)	Nm
T_{int}	Internal friction torque reading prior to test	Stable output of measuring equipment during rotation when there is no torque acting on the vane and no friction acting on the extension rods	Nm
T_{max}	Maximum torque	Torque required to obtain failure in the soil around the vane, corrected for internal and external friction torque reading(s) if relevant	Nm
$T_{meas,max}$	Maximum measured torque	Measured torque required to obtain failure in the soil around the vane, including external friction. The maximum torque (T_{max}) can be calculated by subtracting T_{ext} from $T_{meas,max}$ ($T_{max} = T_{meas,max} - T_{ext}$) otherwise $T_{meas,max}$ is T_{max}	Nm
$T_{meas,pv}$	Measured post-peak torque	Measured post-peak torque selected after the desired rotation (post peak strength measurement) including external friction torque. The post-peak torque is calculated by subtracting T_{ext} from $T_{meas,pv}$ ($T_{pv} = T_{meas,pv} - T_{ext}$) otherwise $T_{meas,pv}$ is T_{pv}	Nm
$T_{meas,rv}$	Measured torque for remoulded conditions	The constant measured torque value after remoulding including external friction torque. The torque for the remoulded condition is calculated by subtracting T_{ext} from $T_{meas,rv}$ ($T_{rv} = T_{meas,rv} - T_{ext}$) otherwise $T_{meas,rv}$ is T_{rv}	Nm
T_{plate}		Torque caused by shearing of circular plate shear surface	Nm
T_{pv}	Post-peak torque	Post-peak torque selected after maximum torque, corrected for internal and external friction torque reading(s) if relevant	Nm
T_{rv}	Torque for remoulded conditions	Measured constant torque value after remoulding the soil, corrected for internal and external friction torque reading(s) if relevant	Nm

Symbol	Name	Description	Unit
τ	Shear stress	Stress acting along the failure surface due to external shear force	kPa
U	Uphole measuring equipment	A continuous torque measuring equipment located above the ground surface at the point for insertion of the vane	
W	Mechanical measuring device	A torque wrench or a dial indicator spring with variable lever arm	
X	Protective casing with protection shoe	Protective casing defined by term 3.1.11 and accordingly protective shoe by term 3.1.10	

4 Equipment and configurations

4.1 Test equipment

The test equipment shall include a vane and vane shaft, extension rods, rotation unit and a rotation/torque measuring equipment.

Accessories to the test equipment may include:

— a friction reducer;

— a slip coupling;

— a protective casing;

— a protective casing with protection shoe,

which are used to increase the insertion length that can be achieved and will reduce or enable to measure the friction in the system.

4.1.1 Vane and vane shaft

The vane shall consist of four identical vane plates fixed at 90° to each other with a tolerance of ±1°, see Figure 1.

NOTE 1 For practical reasons, uncased vanes can have rounded corners or can be tapered.

The shape should be rectangular with an *H*/*D* ratio of 2.

NOTE 2 An example of a mould to measure and verify the dimensions and *H*/*D* ratio requirements of the vane is given in Annex C.

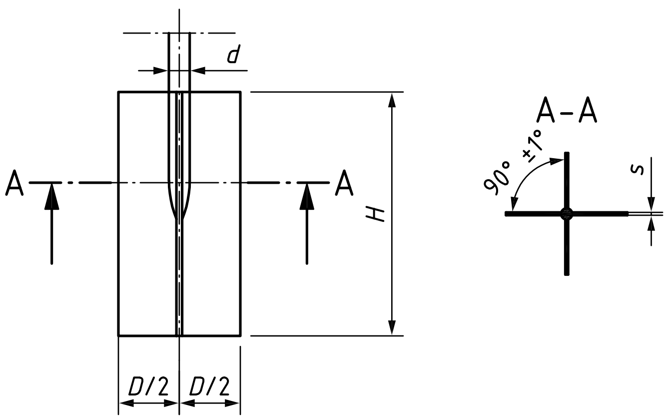
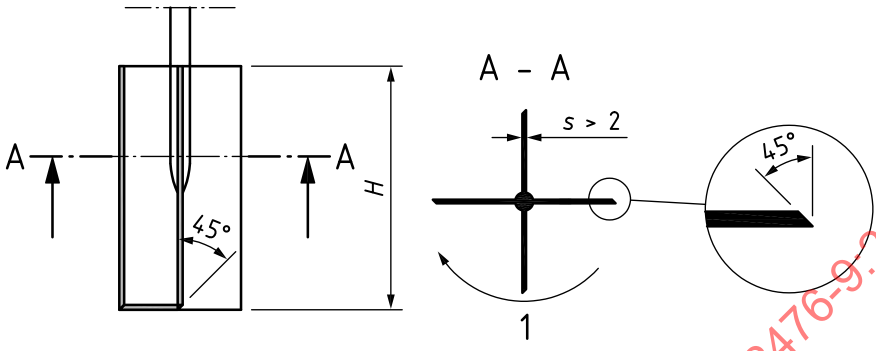


Figure 1 — Principal design of the vane

For testing of soils with a sensitivity more than 30, the vane plate thickness *s* shall not exceed 2 mm. For testing of soils with a sensitivity less than 30, the vane plate thickness may be thicker but shall not exceed 3 mm. For vane plates with a plate thickness exceeding 2 mm, the vane edges shall be sharpened with 45° edges, as shown in Figure 2.

Dimensions in millimetres



Key

1 rotation direction

Figure 2 — Principle for sharpening the vane blades for rectangular vane

The diameter of the vane shaft immediately behind the vane should be less than 16 mm for testing soils with a sensitivity more than 15 and at a maximum 20 mm for testing soils with sensitivity less than 15.

The diameter of the vane shaft, including welding seams in the centre of the vane, shall be small enough to minimize the effects of disturbance on the measured torque.

NOTE 3 Disturbance causes a loss of peak shear strength of fine-grained soil, which increases with increasing sensitivity of the soil.

The length of the vane shaft above the vane shall be at least 5 times the difference of the diameter of the friction reducer/slip coupling/extension rod and the diameter of the vane shaft for testing soils with a sensitivity higher than 15.

NOTE 4 For non-sensitive soils, the friction due to the vane shaft can be reduced by assembling a friction reducer or slip coupling close to the vane, as the disturbance is not as relevant.

The diameter of the vane shaft can gradually increase to the diameter of the friction reducer/slip coupling/extension rods over the length of the vane shaft.

4.1.2 Friction reducer

The diameter of the friction reducer shall be at least 15 % larger than the diameter of the extension rods to reduce the friction between the extension rods and the adjacent soil.

4.1.3 Slip coupling

The slip coupling should be equipped with bearings. The structure shall prevent soil from entering the slip coupling.

The distance between the top edges of the vane plates and bottom part of the slip coupling should be at least 5 times the difference of the diameter of the vane shaft and the slip coupling.

4.1.4 Extension rods, protective casings, protection shoe

Extension rods shall have a torsional stiffness large enough to transmit torque from the rotation unit to the vane. Joints, through which torque is transferred, shall be tightened to a higher torque than needed to reach the maximum torque in the soil.

The diameter of the extension rods, to be inserted into the soil, should be less than 25 mm. Rods with larger diameter may be required to increase the horizontal stiffness to prevent bending.

In the downhole configuration, the measuring unit can be covered by a protective tube attached to protective casings and the unit is installed between the vane shaft and the extension rods.

Protective casings shall have a torsional stiffness large enough to transmit reaction torque from downhole rotation to the ground surface, where the casings are fixed. Joints, through which torque is transferred, shall be tightened with a higher torque than is needed to reach the maximum torque in the soil.

Friction between the casings and the extension rods shall be minimized by, e.g. greasing and/or the use of centralizers. The internal diameter of the protective casing should be large enough to make rod friction negligible and to guide the extension rods vertically straight during insertion of the vane into the soil.

The sealing assembly at the lower end of the casing or protection shoe shall prevent soil from entering between the extension rods and casings. The sealing assembly at the lower end of the casing or protection shoe should not significantly increase friction during the vane rotation.

4.1.5 Rotation unit

The rotation unit shall be capable of applying rotation to maintain torque sufficient to fulfil the requirement of the test.

4.1.6 Equipment for measuring rotation and torque

The equipment for measuring rotation and torque shall fulfil the requirements specified in Table 1.

The recording should be automatic.

The measuring range for the angle of rotation shall be 360°.

Table 1 — Minimum requirements for measuring equipment accuracy

Vane shear strength kPa	**Angle rotation accuracy** °	**Torque accuracy**[a] Nm	**Rotation mode** —
<10	0,1	0,2	Constant rate of rotation
10 to 40	0,1	1	Constant rate of rotation
40 to 100	0,2	3	Constant rate of rotation
>100	Not applicable	7,5	Constant rate of rotation/ rotated by hand

[a] Higher torque accuracy can be needed to measure very low remoulded strengths or very low external friction torque values when using equipment with a slip coupling.

4.2 Test configurations

The test equipment can be configured in a number of combinations, see Figure 3.

The vane equipment and accessories may be configured in either uphole or downhole configurations. Typical configurations are illustrated in Figure 3 and Table 2.

In the uphole configuration, the equipment for measuring torque is located above the ground surface. Torque can be measured by a torque wrench or a dial indicator spring with variable lever arm or by a continuous torque measuring equipment.

In the downhole configuration, the equipment for measuring torque is located close to the vane. The equipment for measuring rotation can be located either close to the vane or above the ground surface. The rotation unit can be located close to the vane or above the ground surface.

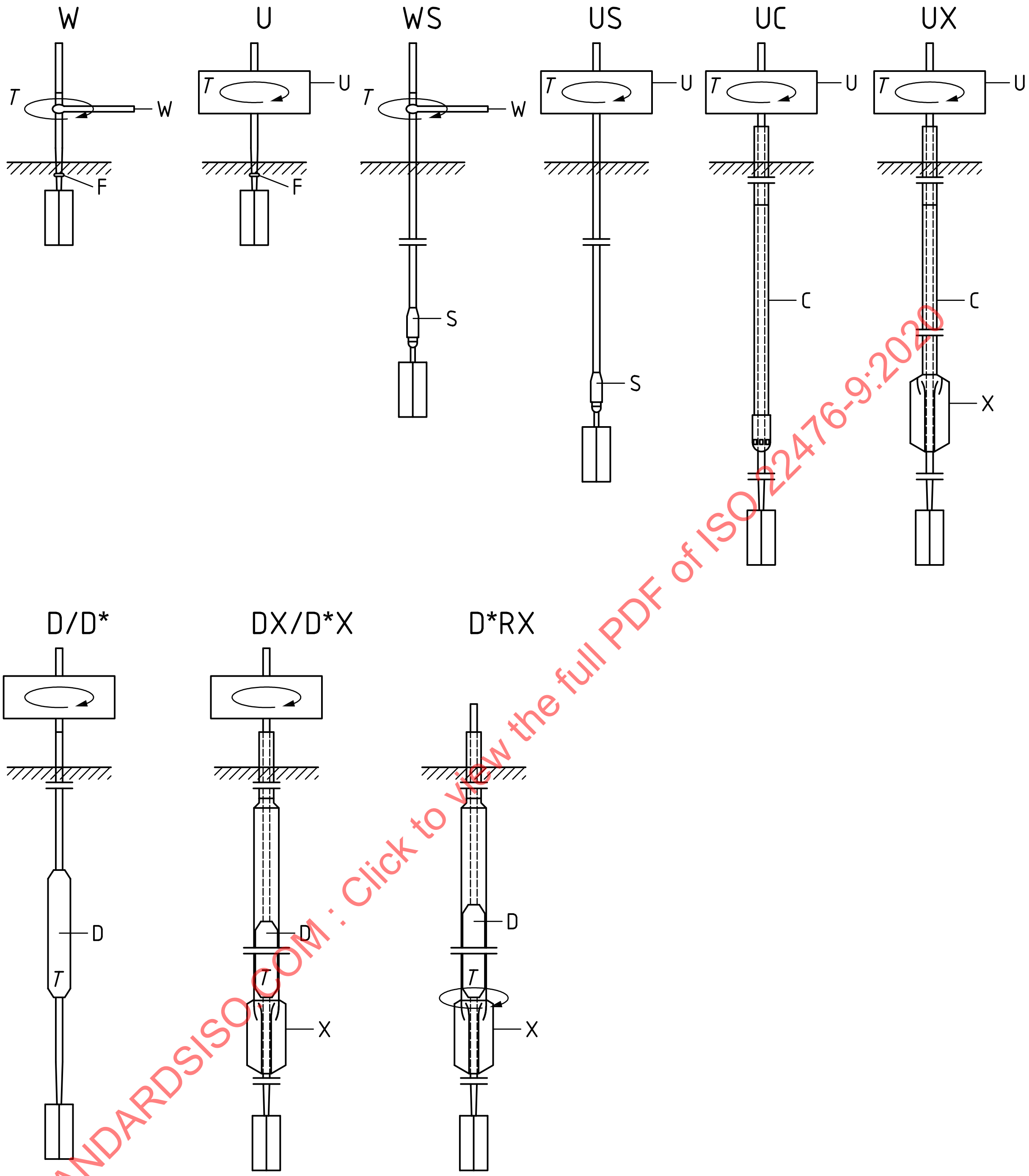


Figure 3 — Configurations of field vane test

NOTE All configurations without slip coupling and protection shoe can be equipped with friction reducer.

Table 2 — Configurations of field vane test

Configurations	Measurement	Torque transfer	Recordings
W	Uphole measurement of maximum torque	Transfer of torque by uncased extension rods without slip coupling	Maximum torque
WS	Uphole measurement of maximum torque	Transfer of torque by uncased extension rods with a slip coupling	Maximum torque
U	Continuous uphole measurement of torque versus rotation	Transfer of torque by uncased extension rods without slip coupling	Torque – apparent rotation
US	Continuous uphole measurement of torque versus rotation	Transfer of torque by uncased extension rods with a slip coupling	Torque – apparent rotation
UC	Continuous uphole measurement of torque versus rotation	Transfer of torque by cased extension rods	Torque – apparent rotation
UX	Continuous uphole measurement of torque versus rotation	Transfer of torque by cased extension rods	Torque – apparent rotation
D	Continuous downhole measurement of torque and continuous uphole measurement of rotation	Transfer of torque by an uncased extension rod	Torque – apparent rotation
D*	Continuous downhole measurement of torque versus rotation with uphole rotation	Transfer of torque by an uncased extension rod	Torque – real rotation
DX	Continuous downhole measurement of torque and continuous uphole measurement of rotation	Transfer of torque by a cased extension rod	Torque – apparent rotation
D*X	Continuous downhole measurement of torque versus rotation with uphole rotation	Transfer of torque by a cased extension rod	Torque – real rotation
D*RX	Continuous downhole measurement of torque versus rotation with downhole rotation	No transfer	Torque – real rotation
NOTE Test configuration W and WS allow the use of a torque wrench rotated by hand.			

5 Selection of equipment and test configuration

5.1 Selection of equipment

The size of the vane should be selected so that the maximum torque value during testing exceeds 20 % of the full-scale range of the torque measuring equipment.

The area ratio of the vane and vane shaft R_a should not exceed the maximum area ratio in Table 3. The area ratio is defined in Formula (1):

$$R_a = \frac{8 \cdot s \cdot (D - d) + \pi \cdot d^2}{\pi \cdot D^2} \qquad (1)$$

Table 3 — Maximum area ratio R_a for vane dimensions

The sensitivity of the soil for disturbance	Maximum area ratio R_a
>30	0,12
15 to 30	0,15
8 to 15	0,20
<8	0,35
NOTE Value of sensitivity can be based on local experience or previous test data, e.g. fall cone test or FVT.	

5.2 Selection of test configuration

The test configuration should be selected taking account of the anticipated ground conditions, the test depths required, the parameters to be obtained, and the acceptable level of uncertainty in the results.

If possible, the rotation of the vane should be measured just above the vane. Otherwise, the apparent rotation of the vane may be measured at the torque head at the surface.

Vane tests carried out according to 6.8 provide the parameter c_{fv} for the field vane test (FVT) and the parameter $c_{fv\text{-}f}$ for the fast field vane test (FVT-F). The fast field vane test is only permitted with test configurations U and W.

The test configurations should be selected, considering the recommendations in Table 4. Test configurations are explained in 4.2.

Table 4 — Application of field vane test configurations

Test Configuration	Recommended maximum insertion length	Confidence level		
		c_{fv} < 100 kPa	c_{fv} > 100 kPa	$c_{fv\text{-}f}$
D*RX DX/D*X D/D*	>30 m	High	Medium	Not applicable
UX UC	30 m	High	Medium	Not applicable
US	15 m	Medium	Low	Not applicable
U	0,5 m	High	Medium	Low
WS W	3 m 0,5 m	Medium	Medium	Low

NOTE 1 The accuracy of the vane test is significantly linked with the dimensions of the vane used in the test; the use of larger vanes results in higher accuracy, but a smaller measuring range.

NOTE 2 Uncertainties in field vane testing are listed in Annex D. The relative impact of uncertainties on the results generally increases with increasing insertion length.

NOTE 3 Conducting the vane test in cased boreholes with centralizers decreases uncertainties due to rod friction and bending of the extension rods.

NOTE 4 A higher confidence level in the results of field vane tests can be achieved when sampling and identification are performed in the same geological unit, appropriately close to the vane position.

Centralizer should be used when the test depth is greater than 5 m, and the test is performed in cased or predrilled boreholes.

The centralizer should not significantly increase the torque required to rotate the vane.

6 Test procedure

6.1 Equipment checks and calibrations

Prior to each test, a check of the condition of the equipment shall be carried out according to Annex C. The diameter and the height of the vane shall be measured before testing and values shall be recorded.

6.2 Position and inclination of thrust machine

The horizontal distance between the test location and the location of any previous investigation points should be enough to prevent interaction effects.

The horizontal distance between the test location and the location of any previous investigation should be at least 1 m and at least 2 m for tests at depths of more than 5 m. Some drilling techniques, such as drilling with air or water flushing medium, or recent ground improvement measures, can require larger distances to avoid interaction effects.

The thrust machine should push the vane so that the axis of the pushing force is as close to vertical as possible. The maximum deviation of the rod system from vertical line shall not exceed 2 % when starting to push down the vane.

6.3 Test depths

Before pushing or drilling, the anticipated depths of the tests shall be determined.

The minimum insertion length shall be twice the vane height or 0,2 m, whichever value is greater.

The minimum vertical spacing of tests shall be twice the vane height or 0,2 m, whichever value is greater.

6.4 Internal friction torque reading prior to testing

For all test configurations, except W and WS, the internal friction torque shall be measured above the ground surface before insertion of the vane into the soil. The measuring equipment shall be set to zero to compensate for the internal friction torque prior to testing.

6.5 Methods for reaching the level for insertion of the vane

Prior to field vane testing the overlaying material may be removed by excavation or predrilling in accordance with ISO 22475-1 or vane testing may be carried out by push-in equipment.

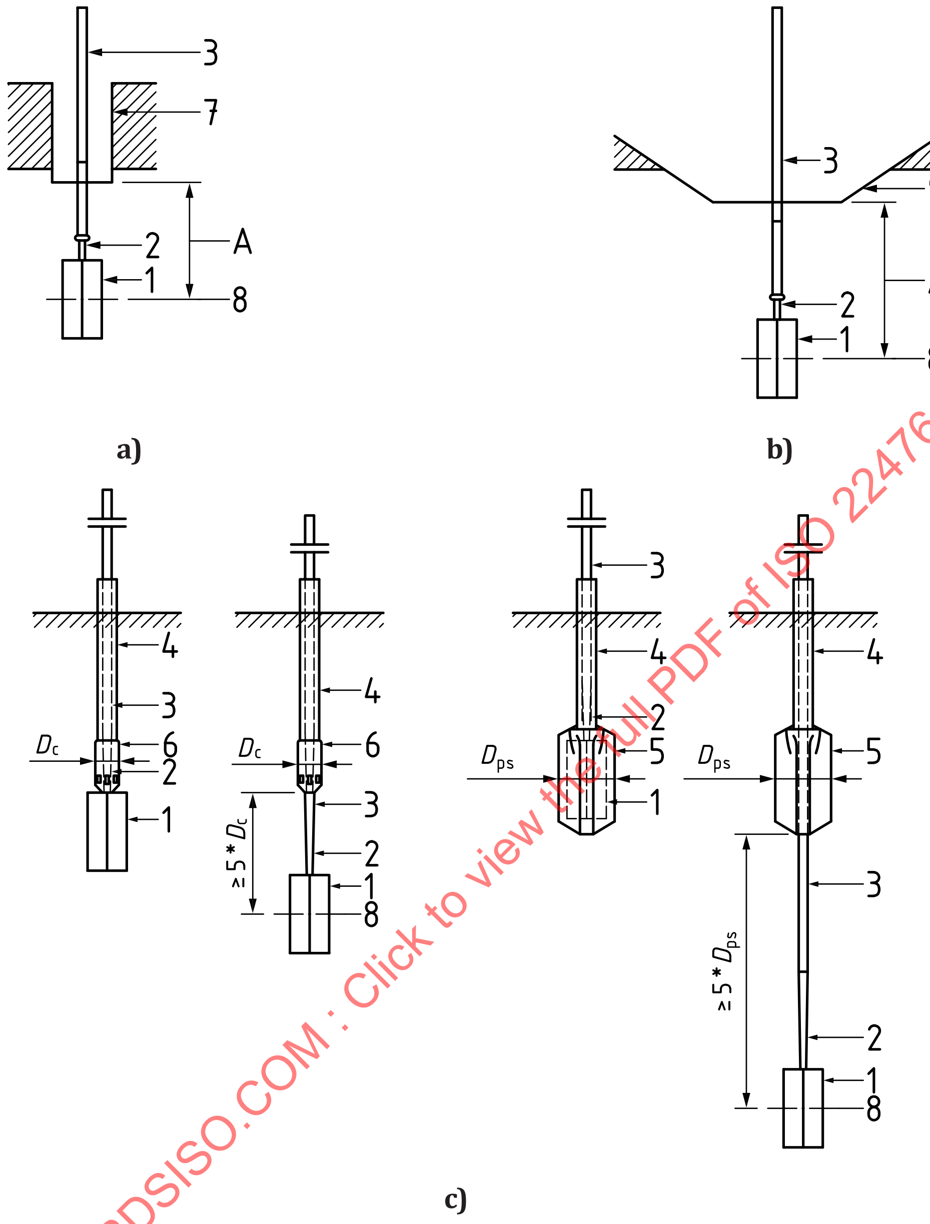
Predrilling or excavation should not disturb the soil to be tested, and the vane should be inserted for testing without undue delay. The applied method and time between reaching the level and insertion shall be reported.

The following methods may be used, see Figure 4:

a) Pre-drilled boreholes illustrated in Figure 4 a): Pre-drilling shall be stopped before reaching the test depth in accordance with 6.3. The water pressure should be the same or higher inside the casing system or borehole as that in the soil at the test level during the test. Details of groundwater observations and flushing shall be reported.

b) Trial pits illustrated in Figure 4 b): Excavation shall be stopped before reaching the test depth in accordance with 6.3. Details of groundwater observations shall be reported.

c) Push-in equipment with a protective casings equipped with or without protection shoe illustrated in Figure 4 c): Initially insert the equipment into the soil by pushing the casings down while the vane and extension rods are at a fixed position within the casings. Stop pushing at a depth of 5 times the diameter of the lower end of the protective casing before reaching the test depth. On reaching the insertion level, insert the vane using the extension rods, while casings are fixed in elevation. After the vane testing, pull back the vane into the protective casing/shoe and continue by pushing down the casings while extensions rods are fixed within the casings. This procedure is repeated at each test depth. The protrusion length should be limited so that the rod friction can be assumed to be negligible or the external friction torque shall be measured.



Key

A insertion length

1 vane

2 vane shaft

3 extension rods

4 protective casing

5 protection shoe

6 lower end of the casing

7 cased borehole, if necessary

8 test depth

9 trial pit

Figure 4 — Methods for reaching the level for insertion of the vane

6.6 Insertion of the vane

For configuration WS and US where a slip coupling is used its operation should be checked by carefully rotating the extension rods in the opposite direction to that used during the vane test itself. The slip coupling shall be disengaged before insertion of the vane into the soil.

The vane shall be clean and have a temperature greater than 0 °C before insertion.

The vane should be pushed straight down to the test depth at a constant rate not exceeding 25 mm/s, without the use of blows or vibration. In fine soils of high undrained shear strength and in gravelly and stony fine soils, light WS and W equipment may be driven using handheld equipment to reach the test depth.

If the test depth cannot be reached due to obstruction, e.g. gravel, the vane should be pulled back into the protective casing and pushed down a further 0,5 m keeping the vane protected. If this succeeds, the vane can be pushed out from the protective casing and testing can be continued. In case of testing in a borehole or trial pit, drilling or excavation can continue until the obstruction is overcome and testing can be continued.

After the vane is inserted to the test depth, unnecessary movement and vibration of the rods shall be avoided.

6.7 External friction torque reading

For test configurations with a slip coupling, the external friction torque shall be recorded immediately before the vane test at each test depth.

Before testing, the functionality of the slip coupling shall be checked by rotating by hand. If the slip coupling cannot be freely rotated, it shall be maintained or replaced.

After insertion of the vane to the test depth, rotate the extension rods above the slip coupling and record the external friction torque reading immediately before the vane is engaged.

6.8 Vane shear test

The axis of the rotation should be straight during vane tests.

The time from the moment the test depth has been reached to the beginning of the vane test (waiting time) should be no more than 5 min.

Deviant waiting times shall be recorded with the test result.

The time from the engagement of vane to failure should be 2 minutes and shall not be less than 1 minute or more than 3 minutes. The measured field vane strength shall be recorded as a result of the vane test, $c_{fv.}$

NOTE 1 The constant rotation rate is selected so that the failure of the soil occurs in undrained conditions in fine-grained soil.

The rotation of the vane is continued until the total rotation of vane is 100°, or the desired rotation is reached. During the rotation of the vane, its elevation shall be kept fixed.

The test may be terminated after reaching the maximum torque or after a specified rotation if the post-peak behaviour and/or remoulded strength are not required. Rotation should be continued long enough to be sure that the failure condition has been reached.

For configurations W and U, the use of a faster vane rotation, a time of failure of approximately 0,1 min is allowed in fine soils with a sensitivity <15. The measured field vane strength shall be recorded as a result of fast vane test, $c_{fv\text{-}f}$.

NOTE 2 The test phases are explained in Annex A.

NOTE 3 The vane rotation rate can be considered when applying transformation models to shear strengths measured by other methods.

NOTE 4 The data recorded after reaching the peak shear strength can offer valuable information on soil behaviour.

In the remoulding phase, the vane shall be rotated, at least 10 turns, at any speed above the rotation rate used during the peak shear strength phase. In the remoulding phase, torque measurements are not required, and no shear strength parameters are determined. The remoulding phase may be shortened if the torque is measured during this phase and the torque decrease is less than 5 % per two rotations.

After the remoulding of the shear surface, in the remoulded phase, the vane shall be rotated at the same rotation rate as used in the peak shear strength phase to obtain the remoulded shear strength. The vane should be rotated until the maximum torque for remoulded conditions T_{rv} is reached.

After the desired vane strengths are measured, the slip coupling (if used) should be disengaged by rotating the extension rods in the opposite direction to that of the vane shear test, before continuing to the next depth.

For reading with an indicator spring, correction is needed due to the variation of the lever arm.

During testing, plotting the recorded torque versus the rotation angle and measured torque versus time will assist in managing the test and will assist in the interpretation of the results.

6.9 Internal friction torque reading after the test

The internal friction torque reading shall be repeated after the vane is pulled back above the ground surface. The zero shift shall be recorded.

NOTE 1 As the measurement equipment was set to zero to compensate for the internal friction torque prior to testing (6.4) the zero shift is equal to the value of internal friction torque after testing.

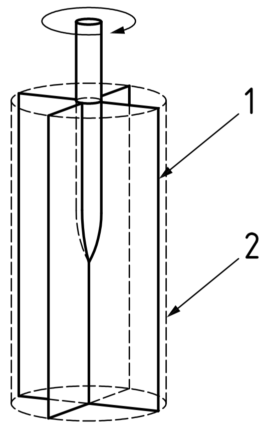
NOTE 2 Significant change in internal friction torque readings can be an indication of overloading, intrusion of dirt into the measurement equipment or inherent errors of the system. A significant change can indicate that the required torque accuracy in Table 2 has not been achieved.

7 Test results

The failure surface for a rectangular vane is assumed to be a cylindrical surface circumscribing the vane and the two planes on the top and bottom of that cylinder. The shear strength is assumed to be fully mobilised, constant and uniform at failure around the perimeter and across the ends of the cylinder, see Figure 5.

Any deviation from the rectangular shape shall be accounted for in the evaluation. If the deviation of the H/D ratio is more than 2 %, the vane shear strength shall be evaluated in accordance with Annex E.

NOTE 1 The general equation for different H/D ratio and tapered vane is given in Annex E. Annex F presents formulae for vanes with rounded corners.



Key

1 vane

2 shear surface

Figure 5 — Assumed failure surface for vane with rectangular vane plates

The measured torques shall be corrected by external friction torque when a slip coupling is used; see Figure A.1.

NOTE 2 The torque values used to calculate the shear strengths are indicated on a typical torque versus rotation curve in Annex A.

For rectangular vanes with H/D = 2, the peak shear strength value c_{fv} (kPa) of the soil shall be determined by using Formula (2):

$$c_{fv} = \frac{6\,000\,000}{7 \cdot \pi \cdot D^3} \cdot T_{max} \tag{2}$$

The post-peak shear strength value c_{pv} (kPa) shall be determined by the same formula replacing T_{max} with T_{pv}:

$$c_{pv} = \frac{6\,000\,000}{7 \cdot \pi \cdot D^3} \cdot T_{pv} \tag{3}$$

The remoulded shear strength value c_{rv} (kPa) shall be determined by the same formula replacing T_{max} with T_{rv}:

$$c_{rv} = \frac{6\,000\,000}{7 \cdot \pi \cdot D^3} \cdot T_{rv} \tag{4}$$

NOTE 3 By registering the torque as a function of rotation, information is obtained on the mode of failure of the soil.

8 Reporting

8.1 General

The following reports shall be completed:

— the field report (to be completed at the project site);

— the test report;

An example for a field report is given in Annex B.

The test report for FVT shall include plots of test results, in accordance with 8.3, if applicable.

Test results should be presented in an easily accessible format, for example in tables or as a standard archive scheme. Presentation in digital form is recommended for easier data exchange.

8.2 Reporting of test results

8.2.1 General information

		Field report	Test report	Every plot
a)	Reference to this document	x	x	
b)	Deviation from this document (e.g. specific test configurations etc.)	x	x	
c)	Project identification (job number, name and location of the project)	x	x	x
d)	Name of field manager responsible for the project		x	
e)	Name of equipment operator executing the test	x		

8.2.2 Location of the test

		Field report	Test report	Every plot
a)	Identification of test (borehole number)	x	x	x
b)	Local or general coordinates		x	
c)	Reference system and tolerances		x	
d)	Methods for reaching level for insertion of the vane, borehole diameter, depth of borehole or trial pit, backfilling	x	x	

8.2.3 Test equipment

		Field report	Test report	Every plot
a)	Field vane test type (FVT of FVT-F)	x	x	x
b)	Test configuration (for example UX)	x	x	x
c)	Identification number, geometry and dimensions of the field vane	x	x	
d)	Identification number of the torque measuring equipment	x	x	
e)	Torque and rotation measuring ranges of the equipment	x	x	
f)	Date of latest calibration and calibration factor of the sensors	x	x	
g)	The free travel of the slip coupling in degrees	x	x	

8.2.4 Test procedure

		Field report	Test report	Every plot
a)	Date of the test	x	x	x
b)	Test depth (corrected or uncorrected)	x	x	x
c)	Protrusion length or insertion length	x	x	x
d)	Stop criteria applied, after determining peak or remoulded shear strength	x	x	
e)	Observations made during or after the test, for example: — incidents, — abnormal wear of the vane, — damage to the vane, — high internal or external friction torque readings, — indications of contact with stone or gravel, — impossible to rotate the vane, — impossible to penetrate the vane, — any evidence of ground improvement in the vicinity of the test.	x	x	

8.2.5 Test results

		Field report	Test report	Every plot
a)	Measured torque	x	x	
b)	Rotation rate in the peak shear strength phase and the remoulded phase	x	x	x
c)	Rotation to failure (at peak shear strength)	x	x	x
d)	Time to failure (at peak shear strength)	x	x	x
e)	Rotation at remoulded shear strength	x	x	x
f)	Peak and remoulded shear strength		x	x
g)	Sensitivity (S_{fv}) according to the field vane tests		x	
h)	Zero shift for D*RX, D*X, DX, D*, D, UC, UX, US, U	x	x	
i)	Rotation of post-peak strength or other required reading		x	x
j)	Time to reach post-peak strength or other required reading		x	x

8.3 Presentation of test plots

The presentation of FVT results in the plot may be split into two or three parts: the peak shear strength phase, the remoulding phase (if there are measurements) and the remoulded phase.

The graphical presentation shall consist of shear stress versus rotation angle and shear stress versus time when measured.

The following axis scaling should be used:

— Rotation during the peak shear strength phase, the post-peak behaviour phase and the remoulded phase — 1 cm = 20°;

— Rotation during the remoulding phase (if relevant) — 1 cm = 400°;

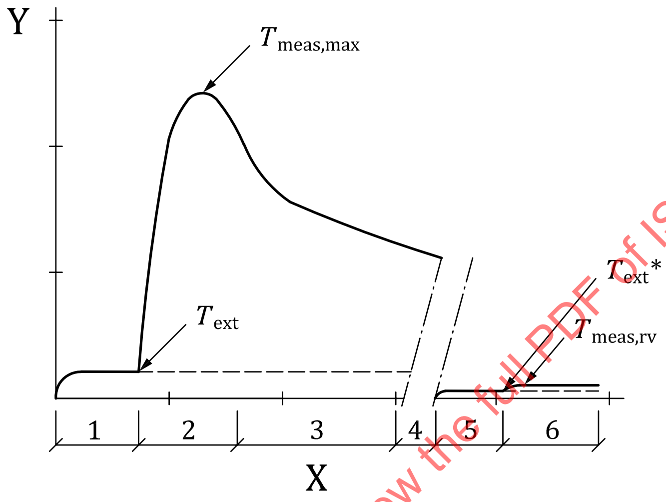
— Shear strength from the field vane test — 1 cm = 10 % of equipment measurement range.

Additional plots at different scales may be used to assist presentation, providing that plots at the recommended scales are included.

Annex A
(informative)

Test phases

Before the performance of the test, the information to be derived from the test shall be specified. This can include the peak shear strength, post-peak behaviour and/or remoulded shear strength, as shown in Figure A.1.



Key

1 phase to measure external friction torque reading when a slip coupling is used

2 phase to obtain maximum resistance of soil

3 phase to determinate post-peak behaviour

4 phase to remould soil

5 phase to measure external friction torque reading before remoulded measurements when a slip coupling is used

6 phase to measure torque for remoulded conditions

X rotation

Y torque

Figure A.1 — Typical graph of measured torque versus rotation for the equipment with slip coupling

The vane should be rotated at a same constant rotation rate during peak shear strength, post-peak behaviour and remoulded strength phases.

The post-peak strength can be determined according to Annex H.

Annex B
(informative)

Example of field report for field vane test

The user of this report can copy this present form.

General information:

Test performed according to ISO 22476-9: YES / NO			**Deviation from ISO 22476-9: YES / NO**		
Description of deviation:					
Contractor:		**Job number/ Name of the project:**		**Date:**	
Equipment operator:			**Client:**		
Test number:			**Borehole:**		
Coordinates and coordinate system:					
Weather:			**Groundwater below starting point:**		m
Predrilling of Made Ground or dry crust: YES / NO		**Description of soil predrilled:**		**Depth of predrilling:**	m
Test type and configuration:		**Identification number of the measuring equipment:**		**Torque measuring range:**	Nm
Rotation measuring range:	°	**Date of last calibration:**		**Free travel of slip coupling if used:**	°
Calibration factor of the sensors and unit of measurement:					
Torque:		**Rotation:**		**Inclination:**	
Description of measuring equipment (Manufacturer, type of rotation unit, recording):					
Other:					

Vane details:

Vane No.	Shape (rectangular, tapered, rounded)	*H*/*D*	Angle of taper at vane top/bottom	Radius of rounded corner of the vane	Conversion factor to shear stress, shear stress
—	—	mm	°	mm	kPa
		/	/		
		/	/		
		/	/		

Other:

Rotation rate in strength phases and unit of measurement:

Rotation rate in remoulding phase and unit of measurement:

Measured values:

Vane No.	Test depth	Protrusion or insertion length	T_{ext}	$T_{meas,max}$	Stop criteria for $T_{meas,max}$	T_{max} converted to c_{fv}	Time to failure	$T_{meas,rv}$	Stop criteria for $T_{meas,rv}$	T_{rv} converted to c_{rv}
—	m	m	Nm	Nm	—	kPa	s	Nm	—	kPa

Zero shift and unit of measurement:

Other data:

Notes:

Signature: ____

Name of the equipment operator or field manager:

Annex C
(normative)

Maintenance, checks and calibration

C.1 General

Metrological confirmation, according to ISO 10012, shall apply to the vane shear test. Guidelines for the vane shear test are included in C.2 and C.3 below.

C.2 Checks and Maintenance Procedures

C.2.1 Straightness of extension rods and casing

The straightness of the extension rods shall fulfil the following:

— the extension rods shall not deviate by more than 2 mm from the centreline over a length of 1 m; this applies also for connected extension rods with a smaller length;

— two connected extension rods shall not have a maximum thread eccentricity exceeding 1 mm.

Before testing, the straightness of the extension rods shall be checked by one of the following methods:

— holding the extension rod vertically and rotating it (if the extension rod appears to wobble, the straightness is not acceptable);

— rolling the extension rods on a plane surface (if during rolling the distance between any point on the rod and the surface exceeds the specified tolerances in the straightness, the straightness is not acceptable).

The above requirements are valid for 1 m long extension rods. If other lengths of extension rod are used for special purposes, the requirements should be adjusted accordingly.

Other methods of visual checking of the straightness may be used.

Protective casings shall fulfil same straightness demands as extension rods.

C.2.2 Vane requirements

The vane should be undamaged during the test. The vane plates shall be parallel with the extension rods and without visible distortion. The condition of the vane plates shall be checked prior to each test or series of tests per location. If the damage is observed, it shall be reported with the test results.

For example, the mould shown in Figure C.1 can be used for testing the vane for requirements given in 4.1.1 together with visual inspections. The values of the general Formulae (2) to (4) for torque conversion to shear stress should be in accordance with Formulae (C.1) and (C.2), to meet the requirement of the maximum allowed deviation of 2 % for H/D ratio of 2. While the height of the vane (H) is first measured, the diameter of the vane (D) should fulfil Formula (C.1). Accordingly, while the diameter of the vane is first measured, the height of the vane should fulfil Formula (C.2).

$$H/1{,}96 \leq D \leq H/2{,}04 \quad \text{(C.1)}$$

$$1{,}96 \cdot D \leq H \leq 2{,}04 \cdot D \quad \text{(C.2)}$$

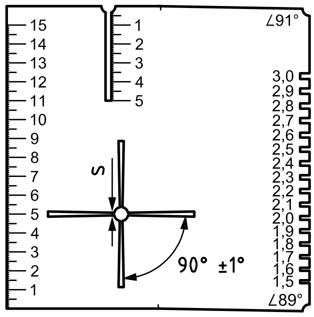


Figure C.1 — Example of the mould for vane requirements and dimension checks where dimensions are in centimetres and angles in degrees

C.2.3 Maintenance procedures

Checks and calibrations shall be carried out in accordance with the schedule in Table C.1. The frequency between calibrations may only be reduced if documented evidence is available to show that the calibration remains constant over the revised period. Shorter intervals should be used if recommended by the manufacturer.

Table C.1 — Schedule for checks and calibrations

Routine	Start of test per test position	End of test per test position	Every 12 months
Check of extension rods, protective casing and shoe, borehole casing, push-in-mechanism, bearings etc	x		
Check of vane plates and shaft	x	x	
Check of slip coupling, if used	x	x	
Calibration torque measurement			x[a]
Calibration rotation measurement			x*[a]

[a] Or after overloading, observing damage or repair.

During the fieldwork, checks on the performance of the equipment shall be carried out at least once per location and once per day. Furthermore, performance checks and calibration should be carried out if the operator suspects overloading of the load sensors or loss of calibration.

C.3 Calibration

C.3.1 General procedures

The calibrations for measuring equipment shall include the whole measuring system: mounted transducers, data acquisition system, cables, etc. Preferably calibration should be performed as “system calibration”: using the same data acquisition system, including cables, as in the field test, to enable a check of possible inherent errors of the system.

The metrological properties of the measurement system should comply with the requirements in ISO 10012.

C.3.2 Calibration of torque measuring equipment

The torque measuring equipment shall be calibrated by incrementally loading and unloading the field vane, while measuring the applied torque. The calibration factor is determined from the relationship between the applied torque and the reading from the measuring equipment.

Before the first use of the torque measuring equipment or system, the sensors shall be subjected to 15 to 20 repeated loading cycles up to the maximum load, before the actual calibration is carried out.

C.3.3 Calibration of rotation measuring equipment

The rotation measuring equipment shall be calibrated by incrementally loading and unloading the field vane while measuring the applied rotation. The calibration factor is determined from the relationship between the applied rotation and the reading from the measuring equipment.

Before the first use of the rotation measuring equipment or system, the sensors should be subjected to 15 to 20 repeated loading cycles up to the maximum load, before the actual calibration is carried out.

Annex D
(informative)

Uncertainties in field vane testing

A range of uncertainties may be encountered during field vane testing, which will affect the validity of the results. Table D.1 lists the sources of uncertainty and provides guidance on their minimisation.

Table D.1 — Vane testing related sources of uncertainty

Source of uncertainty	Comments
External friction torque	Assumed to be eliminated by greasing/bearings/centralizers. Assumed to be negligible at the length of the vane shaft. Can be estimated when slip coupling is used.
Functionality of a slip coupling	Functionality shall be tested only in unloaded condition.
Bending of extension rods/casings	Effects of bending may cause additional friction, distortion of test depths and distortion of shear planes and additional disturbance around the vane.
Rotation rate	The length of the rod system and insufficient rotational stiffness of the extension rods can allow twisting of the extension rods. This can lead to the vane rotation rate varying from the uphole rotation rate.
Distorted rotation	The twisting of extension rods causes a difference between real vane rotation angle and measured vane rotation angle in the uphole method.
Insertion of the vane	Blows, vibrations etc. can cause an extra disturbance at test depth. Too short a distance between the vane and friction reducer/slip coupling/casings/protection shoe can cause a disturbance at test depth. Some disturbance can be caused by too high a pushing rate.
Disturbance around the vane	Insertion of the vane breaks the natural structure of soil at some distance around the vane. All unnecessary movement of the vane can cause an extra disturbance.
Non-stationarity of the vane	During tests, the vane should rotate around the vane axis at the same level.
The condition of the vane	Damaged vane can cause an extra disturbance around the vane.
Waiting time	Longer waiting time increases consolidation around the vane and may increase the measured vane strength.
Zero shift	Non-functionality of measuring equipment might be indicated.
Deviation of the conversion factor	Conversion of torque to shear stress will be distorted.
Calibration factors, e.g. loss of calibration due to overloading	Regular calibrations and checks are needed.
Data acquisition system	Digital errors can occur and reading resolution can both influence accuracy
Maintenance	Lack of maintenance can cause an inconstant external or internal friction torque due to e.g. dirt.

Table D.1 *(continued)*

Source of uncertainty	Comments
Measurement of small values	Possible non-linearity of the calibration curve at the beginning of measuring range can cause an error in measurement
Other	Drilling of borehole or excavation of trial pit can cause a disturbance at test depth. Rock or shells at shear planes can affect the torque measurement.

The loss of strength around the vane during insertion and testing generally increases with increased sensitivity of the soil.

Lack of documenting soil type greatly increase uncertainty.

