Draft

Physical Properties

– Solidity, Thixotropic Behaviour and Piling Behaviour –

Desk Study

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SUMMARY

The “*Horizontal*” project has the objective to develop horizontal and harmonised European standards in the fields of sludge, treated bio-waste and soil to facilitate regulation of these major streams in the multiple decisions related to different uses and disposal governed by EU Directives. The Horizontal Project includes the Work Package 7 “*Mechanical properties*” consisting in the development of Desk Studies on physical consistency, because it is recognized that this property is very important for the characterization of sludge, since it affects almost all treatment, utilization and disposal operations, such as storage, pumping, transportation, handling, land-spreading, dewatering, drying, landfilling. The importance of the physical consistency is also true for the characterization of treated bio-waste and soil. Also handling and utilization of many other materials, such as cement and asphalt are strictly depending on their physical consistency. The needs for control of operations and also material characteristics are described.

The first action carried out is consisted in searching for existing standards to be possibly used or adapted for utilisation in the specific field of consistency evaluation. The complete list of standards is reported in Annex 1, from which it can be seen that more than 250 standards and non-standardised methods are potentially applicable to consistency evaluation. On the basis of the selected list of standards and non-standardised methods for further consideration the methods for the determination of solidity, thixotropic behaviour and piling behaviour of sludge, treated bio-waste and soil have been divided into several groups, according to the instruments used for measuring:

- Solidity: Shearing apparatus, Vane testing apparatus and Penetrometers
- Thixotropic behaviour: It should be investigated a combination of methods for determination of the solidity like penetration, etc. and an energy-input in terms of "flow" apparatus to simulate the shear stress.
- Piling behaviour: Slump test apparatus, Compacting apparatus, Cubic Piling Box (CPB) and "Turned Box".

For each group was evaluated the laboratory or field test feasibility. Apparatuses of the measuring procedures and existing applications to different materials were described. On this basis the applicability of the described methods to the materials for the Horizontal Project was evaluated and documented in the lists of analysed standards (Chapter 3). The recommended methods are for solidity the “Laboratory vane shear apparatus” and “Vicat needle” as laboratory reference and the pocket penetrometers for field test. The penetrometers in general could be used for both laboratory reference method and field test. Also for determination of the thixotropic behaviour the penetrometer is together with an energy-input in terms of a vibrating table or a hammer a suitable instrument. For measuring the piling behaviour the Cubic Piling Box (CPB) and the Oedometer are the recommended methods, whereby the CPB could be used in both laboratory and field while the Oedometer could be used only in the laboratory.

For the research needs first the basics of methods are explicated. Also the applicability of methods to Horizontal materials is clarified. The questions to be answered (precision, repeatability, reliability, etc.), the route, how to answer them and finally the steps to be taken are important for following procedures within the Horizontal project.

The results of the circulation within the consulting CEN/TC's/WG's/TG’s – Committee's are documented by means of listed actions, comments, which were received, and official meetings, which amount up to four WP7 meetings and two CEN/TC308/WG1 and CEN/TC308/WG1/TG3 meetings each so far. In the Horizontal-Report No. 22 a total of 11 proposals for draft standards are given, consisting of six laboratory methods and five field tests.

INTRODUCTION

1.1 The Horizontal project

The revision of the Sewage Sludge Directive 86/278/EEC, the upcoming Composting Directive on the biological treatment of biodegradable waste and the Soil Monitoring Directive call for standards on sampling, hygienic and biological parameters, methods for inorganic and organic contaminants, and for mechanical properties of these materials.
In addition, when materials cannot be utilized, landfilling becomes important, in which case leaching becomes an issue as stipulated by the Council Directive 1999/31/EC on the landfill of waste. More recently, a Council Decision establishing criteria and procedures for the acceptance of waste at landfills, pursuant to Article 16 and Annex II of mentioned Directive on the landfill of waste was issued (16/12/02) with physical consistency being one basic parameter of interest.
The "*Horizontal*" project has the objective to develop horizontal and harmonised European standards in the fields of sludge, treated bio-waste and soil to facilitate regulation of these major streams in the multiple decisions related to different uses and disposal governed by EU Directives.
Part of the work to be carried out will focus on *co-normative* work with an emphasis on horizontal standardization starting from existing standards developed for the same parameter in the fields of sludge, treated bio-waste and soil. Another part of the work will focus on *pre-normative* research required to develop standards lacking at this point and needed in the next revision of the regulations in these fields.

1.2 The Work Package 7

The Horizontal Project includes the Work Package 7 "*Mechanical properties*" consisting in the development of Desk Studies on physical consistency, because it is recognized that this property is very important for the characterization of sludge e.g., since it affects almost all treatment, utilization and disposal operations, such as storage, pumping, transportation, handling, land-spreading, dewatering, drying, landfilling.
In fact, the selection of the most suitable equipment and procedure for land application, storage and transportation of sludge e.g. is strongly connected to its consistency. Similarly, compacting sludge in a landfill or forming a pile in composting is depending on sludge shear strength rather than on its solids concentration.
In particular, with reference to the regulations requirements, according to the Sludge Directive 278/86, agricultural reused sludge must have agronomic interest, be healthy and easily usable, i.e. easily stored, transported, handled, and spread.
In Council Directive 1999/31/EC (Landfill Directive), Article 2 (q) gives a definition of "liquid waste", and Article 5 (3.a) does not allow a liquid waste to be landfilled, but a standardized method for this evaluation has to be developed yet. Further, Annex II (2. General principles) requires that "The composition, ... and general properties of a waste to be landfilled must be known as precisely as possible", and Annex I (6. Stability) is referring to "... ensure stability of the mass of waste ... particularly in respect of avoidance of slippage", so the shear strength and piling behaviour must be known. Article 2 (h) says, that "treatment means ... processes ... in order to … facilitate its handling". Finally, Article 11 (1.b) asks for: " – visual inspection of the waste at the entrance and at the point of deposit and, as appropriate, verification of conformity with the description provided in the document submitted by the holder", so simple and easy tests to be carried out on the field and followed by the operators must be defined.
Further, the Council Directive establishing criteria and procedures for the acceptance of waste at landfills, pursuant to Article 16 and Annex II of mentioned Directive on waste landfilling included "consistency" among the basic parameters to be evaluated for waste characterization

before landfilling; for specific cases it is also demanded, that EU Member States must set criteria to ensure a sufficient physical stability and bearing capacity of waste.
It is also to be pointed out that in many analytical methods for sludge characterization (e.g. pH, dry matter, leachability, etc.) different procedures are indicated depending on whether the sample to be examined is liquid or not, is solid or not, but no procedures are given for evaluating such properties. The importance of the physical consistency is also true for the characterization of treated bio-waste and soil.
For WP7 two desk studies were performed: No. 21 for the parameter "Flowability" and No. 22 for the parameters "Solidity", "Thixotropic Behaviour" and "Piling Behaviour". The work was coordinated in WP7 and done in cooperation of the involved teams. Therefore the reports No. 21 and No. 22 contain some chapters (1.1 – 1.5 and 2) and the list of standards and non-standardised methods (Annex 1) in common.

1.3 Desk studies subject

The Task Group 3 (TG3) of CEN/TC308/WG1 defined 3 physical states for sludge (CEN/TC308/WG1/TG3, 2000):

a) ***Liquid***: sludge flowing under the effect of gravity or pressure below a certain threshold.
b) ***Paste-like***: sludge capable of continuous flow under the effect of pressure above a certain threshold and having a shear resistance below a certain threshold.
c) ***Solid***: sludge having a shear resistance above a certain threshold.

This firstly involves the necessity to set up methods to measure values in the range of the boundary area between liquid and paste-like behaviours (limit of *flowability*) and that between solid and paste-like (limit of *solidity*).
Further, the *thixotropic* behaviour of solid materials (from “the solid to the liquid state and vice versa”) must be evaluated, together with the *piling* behaviour referred both to “compaction and physical stability”.
Also the CEN/TC292/WG2, in the method prEN 12457 for the characterisation of waste included in Annex B (Informative) the description of a test for determining whether waste is in the liquid state (CEN/TC292/WG2, 2002).
Although the methods to be developed are partly known and used in other technology fields, e.g. soil mechanics, materials for construction works (concrete, suspensions), etc., widely accepted methodologies for the evaluation of above properties, able to give comparable and reliable results, are not available yet.
It therefore follows the necessity to define *simple* and *reliable* measurement procedures to be applied in the *field*, together with those to be used as reference in *laboratory*.
Standardisation procedures for Horizontal material examination will consist of

- Sampling, transport, preservation, storage
- Pre-treatment
- Measurement and evaluation of results.

1.4 Evaluation of needs for control of operations and material characteristics

1.4.1 Evaluation of needs for control of operation

The purpose of using characterisation standards is to control and ascertain the material amenability to handling and different operations. Materials considered are

- Sewage sludge
- Waterworks sludge
- Treated bio-waste and
- Soil.

For handling and operating these materials many parameters should have to be known; they include homogeneity, particles sizes and shape, solids (total, suspended, volatile) that, if available, could define the range of variation of variable considerations (i.e. viscosity, etc.).

The parameters flowability is an overall parameter taking into account all above mentioned material properties or characteristics. In particular, the flowability evaluation for sludges, including wastewater, waterworks and similar sludges, is of fundamental importance in many operations such as pumping, transportation, storage, dewatering, stabilisation, spreading, etc. also considering the possible formation from a gel to a liquid (sol) and vice versa. Similarly, for treated bio-waste, including the shredded organic fraction of municipal solid waste (OFMSW), in operations such as handling, digestion, reuse, etc. the measure of the parameter flowability have to be considered. Finally, for fine-grained soils, the water content (and therefore consistency and flowability) has always been considered an important indication of their mechanical properties. Moreover in case of soil slurries it is very important to verify flowability as a measurement of their workability and time of setting.

The solidity is also a parameter, which concerns all the material properties or characteristics mentioned above. The determination of this parameter is getting more important for handling of solid materials like dewatered sludge, other treated bio-waste – e.g. in terms of pieces (compost) – and soil, where the grain size distribution and water content have to be considered, during operations like pumping, transportation, storage, etc.

The measurement of thixotropic behaviour for solid materials is especially for dewatered sludges like sewage, waterworks and related sludges relevant. By dewatering and storage the sludge will become solid. During operations such as transportation the sludge is getting due to the vibration of e.g. a truck in a liquid state.

The piling behaviour evaluation is for dewatered sludge, particular treated bio-waste and soil of importance. The determination of the piling angle is a useful instrument to characterise the storage properties and calculate the space, which is needed for e.g. storage and transportation of the above materials. Together with the thixotropic behaviour the piling behaviour refers to the compaction and stability.

However, the development of reliable measurement procedures of all parameters is not a simple matter, because measurements are influenced by below described properties or characteristics. This means that those factors must be considered with great attention and methods defined by avoiding any negative interference with them during measuring procedures. For this reason, it is first necessary to select, if any, the most adapted standards or non-standardised methods applicable to sludge, treated bio-waste and soil, or to develop a new one, and then to carry out parallel tests to evaluate how they are affected by the other specific characteristics. In addition, these aspects require to be investigated for both laboratory methods, to be adopted as a reference, and simple tests to be applied in the field.

1.4.2 Material characteristics

1.4.2.1 Sewage sludge

Sewage sludge can be produced from several processes (primary sedimentation, activated sludge process, aerobic or anaerobic digestion etc.). Their solid content cover a wide range from 1 to 30%, while different total volatile solids percentage on dry matter can vary from 75% to 45%. The presence of coarse particles is strongly related to the sieve adopted in head-works or external material used in some processes (anaerobic co-digestion, etc.). Sewage sludge covers a wide range of physical state from liquid to solid. Bibliography does not offer a characterization of particle size distribution of sewage sludge, a wide range of these characteristics is forecasting in relation to the process adopted (opening of sieves etc.) and different type of sewage sludge treated. Some indications are found for sewage sludges (see Table 1 [1]).

Material	Process	TS basis % cumulative retained w.w.			TVS basis % cumulative retained w.w.		
		5 mm	2 mm	0.84 mm	5 mm	2 mm	0.84 mm
Sewage sludges WTS	Aerobic process	0	3,7	9,4	0	4,7	8,4
Mixed primary sludges ADS	Mesophilic anaerobic digestion	0	10,5	18,5	0	15,5	30,5

Table 1: Particle size distribution of sewage sludges

Each kind of sludge was analysed for its particle size distribution by wet sieving, using three sieves with openings of 5,2 and 0.82 mm. According to these data the samples can be divided into four conventional classes: coarse (>5 mm), medium (from 5 to 2 mm), medium-fine (from 2 mm to 0.84 mm) and fine (<0.84 mm). It can be noted that the sewage sludges have no coarse particles but a different percentage of medium and fine particles.

The most diffuse sludge characterization is that rheological, beside CST – capillary suction time, R specific resistance to filtration etc.. Rheological parameters (yield stress, viscosity and thixotropy) were originally applied to calculation of the head losses in sludge pumping operations, recently it has been shown that they can affect filtration, thickening [2], pumping [3, 4] and constitute useful on line control parameters for sludge conditioning and dewatering [5, 6, 7].

Rheological measurements of sewage sludges have been performed using commercial rotational viscometer. The rheological properties normally determined by using the Bingham plastic model are the yield stress (YS) (that is the stress required to start the material flowing) the plastic viscosity (that is the internal resistance to flow under defined shear rate). The Thixotropy, determined by the hysteresis area, is only sometimes observed (Table 2) [8].

Sludge	Process	TS range %	TVS/TS	YS Pa	Plastic viscosity mPa*s
Mixed Primary Activated		3.0-14 7.0-16 3.0-9	0.52 0.43 0,73	1.90-185 1.0-49 5.0-214	30-630 20-320 70-1110
Mixed Sludges Mixed Sludges	Aerobically stabilized Anaerobically digested	4.0-10 4.0-9	0.53 0.59	0.07-58 1.0-112	10-410 20-390
Mixed sludges Mixed sludges	Mesophilic anaerobic digestion Thermophilic anaerobic digestion	3.5-5.0 3.5-5.0	0.5-0.6 0.5-0.6	0.4-1.6 0.1-0.5	8.0-24 11.0-17

Table 2: Rheological properties of sewage sludges

Mechanical properties of sewage sludge in solid state were studied with the aim to define the feasibility of landfill disposal; a correlation between shear strength and dry solid matter for sewage sludge was done using a Vane apparatus (Fig. 1) [9], sludges are suitable for landfilling if their shear strength is of 10 kN/m² at least (limit value in Italy).

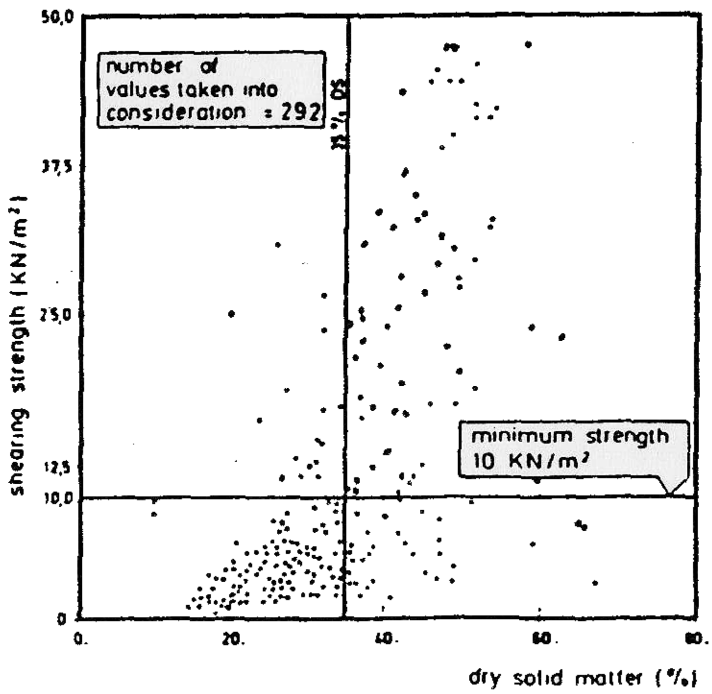


Fig. 1: Collation between shearing strength and dry solid method [9]

1.4.2.2 Waterworks sludge

In DVGW W221-1 [10] sludges are defined as solid-water suspensions capable of flowing after sedimentation, flotation or thickening. Dewatered sludges are sludges, which were dewatered by natural or mechanical treatments until they are no longer able to flow.

Sludges from water treatment contain several phases differing by their physical state and/or chemical nature. The space distribution of these phases, as well as the physical-chemical interactions between them, gives to sludges their cohesion. A too low cohesion of sludges and/or its high fluctuation in the time commonly generates handling (shovelling- and spreading-ability) and storing difficulties.

An orderly utilisation and disposal of waterworks sludges need the control of the mechanical properties in order to ensure a quality that is demanded for storage, transport and handling. The mechanical measurements are to be seen and done in connection with other measurements that have been or will be standardised. There are to be mentioned methods for chemical and physical parameters (chemical elements, dry solids, loss on ignition, pH-value) and operational methods (capillary suction time CST, specific filtration resistance). The different composition of waterworks sludges with inorganic (Fe, Ca, Al etc.) and organic (Algae, humid substances, powdered activated carbon etc.) substances depending on the source of raw water and water treatment processes must be considered. An inquiry from *Wichmann et al (2002)* [17] showed, that the waterworks sludges of different types in Germany amounted in 1998 to ca. 181.000 t DS (Lime sludge 40%, Iron sludge 14%, Fe-/Al-Flocculation sludge 13% and other 33%).

The composition of the sludge can be determined after [11] (10 parameters) in Table 3.

Parameter	**Fraction [g/kg DS] (Fictive value)**	**Conversion in:**	**Fraction [g/kg DS]**
Acid insoluble (= $HCl_{ins.}$)	40	Insoluble components (e.g. sand, activated carbon)	40
TOC	30	Total organ. content (Factor: 2)	60
Mn	20	MnO_2 (Factor: 1.58)	31.6
Mg	5	$Mn(OH)_2$ (Factor: 2.,4)	12.0
Al	20	Al_2O_3 x H_2O (Factor: 2.22)	44.4
SO_4	5	$CaSO_4$ (Factor: 1.42)	7.1 (Ca: 2.1)
CO_3 (= TIC)	80	$CaSO_3$ (Factor: 1.67)	138.6 (Ca: 57.6)
Ca –total-	65		-
Residual-Ca	5.3	$Ca_3(PO_4)_2$ (Factor: 2.58)	13.7 (PO_4: 8.4)
PO_4 –total-	10		-
Residual-PO_4	1.6	$Fe(PO_4)$ (Factor: 1.59)	2.5 (Fe: 0.94)
Fe –total-	415,7		-
Residual-Fe	414.8	Fe_2O_3 x 1,5 H_2O (Factor: 1.67)	692.6
Total			**1042.5**

Table 3: Determination of the composition of sludge

The range of 0.2 to 80 % dry solids contents of waterworks sludges to be utilized is quiet wide, so that several different mechanical properties have to be measured. Possible measuring methods are coming mainly from the soil mechanical or rheological working fields. There are only few data on mechanical properties of waterworks sludges published. In Fig. 2 after *Mc Tigue et al. (1990)* [12] e.g. the result of 72 measurement data of different waterworks sludge types and dewatering processes are shown. A laboratory vane shear apparatus was used. The vertical line marks the dry solids concentration of 35 % that was given from *LAGA (1979)* [13] as a minimum value for disposal of wastes in landfills. Sludges with more than 35 % DS were than be considered to be qualified for landfilling. The horizontal line marks the minimum value of 25 kN/m^2 for the vane shear strength that is now demanded from new regulations in the *TA Siedlungsabfall (1993)* [14]. Approximately 90 % of the waterworks sludges tested after mechanical dewatering could not fulfil the required minimum value.

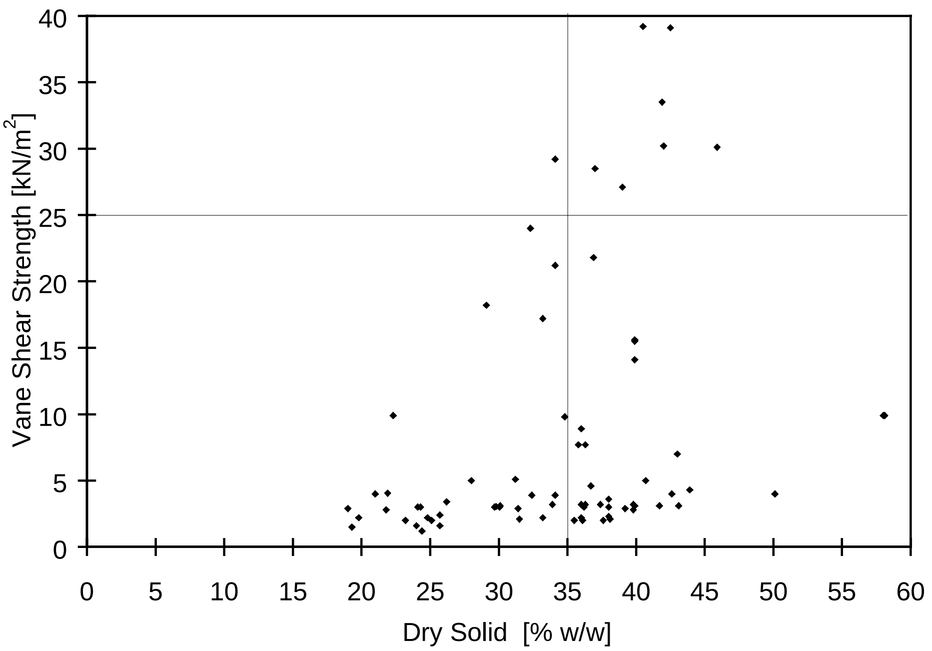


Fig. 2: Comparison dry solid contents vs. laboratory vane shear strength [12]

1.4.2.3 Treated bio-waste

Organic fraction of municipal solid waste (OFMSW) is utilized for anaerobic and composting treatment. Anaerobic digestion or co-digestion with sewage sludges is a well-known process where rheological parameters have been studied to control process.

Material	Process	TS basis % cumulative retained w.w.			TVS basis % cumulative retained w.w.		
		5 mm	2 mm	0.84 mm	5 mm	2 mm	0.84 mm
Fresh mechanically sorted (F) OFMSW	Mesophilic anaerobic digestion	8,2	11,1	18,3	6,7	21	23,5
Pre-composted mechanically sorted	Mesophilic anaerobic			19,7			26,1

(P) OFMSW	digestion						
Blend of source sorted and mechanically sorted OFMSW	Mesophilic anaerobic digestion	6,6	11,5	18,3	12,7	16,8	24,2

Table 4: Particle size distribution of OFMSW

The OFMSW was analysed for its particle size distribution by wet sieving, using three sieves with openings of 5, 2 and 0.82 mm. According to these data the samples can be divided into four conventional classes: coarse (>5 mm), medium (from 5 to 2 mm), medium-fine (from 2 mm to 0.84 mm) and fine (<0.84 mm). The fresh mechanical sorted OFMSW show up to 18 and 24% of particles greater than fines for TS and TVS, respectively. The coarse particles are mainly extraneous materials (plastics, baggage, etc.), which have no influence on digester fluid-dynamic [21, 22].

Rheological measurements of OFMSW aerobically and anaerobically treated have been performed using commercial rotational viscometer. The rheological properties normally determined by using the Bingham plastic model are the yield stress (YS) (that is the stress required to start the material flowing) the plastic viscosity (that is the internal resistance to flow under defined shear rate). The Thixotropy, determined by the hysteresis area, is only sometimes observed (Table 5) [21, 22].

Sludge	Process	TS range %	TVS/TS	YS Pa	Plastic viscosity mPa.s	Thixo-tropy Pa/s
OFMSW mechanically sorted and pre-composted	Thermophilic anaerobic digestion	4.8-32.7	0.43-0.49	0.4-63	9-840	
Fresh OFMSW mechanically sorted	Thermophilic anaerobic digestion	6.8-25.2	0.47-0.50	0.1-102	17-1660	
OFMSW mechanically sorted enriched with source sorted fraction	Thermophilic anaerobic digestion	5.8-35.1	0.46-0.56	0.2-61	6-560	
OFMSW	Anaerobically digested under mesophilic and	4.4-18	0.52	0.25-1.2	8.0-54	12-125

	semi-dry conditions					
OFMSW	Anaerobically digested under thermophilic and semi-dry conditions	5.0-32.7	0.48	0.26-37.7	10-420	36-161

Table 5: Rheological properties of OFMSW aerobically or anaerobically treated

Treated bio-waste includes also compost, which is derived from aerobic decomposition of recycled plant waste, bio-solids, fish or other organic material. It is a mixture of decaying organic matter, as from leaves and manure, used to improve soil structure and provide nutrients.

The sizes of compost pieces can vary within a wide range according to the type of compost e.g. organic municipal waste. From there the sampling and especially the pre-treatment are of great importance. For reliable measurements the grain size has to be uniform. If needed, the material has to be also compacted in order to avoid voids of higher dimensions, which could influence the results.

1.4.2.4 Soil

Soils are particulate systems and can cover a wide range of physical state from liquid to solid, depending mainly on the size and mineralogy of the particles and on the water content. In particular, soils are divided into coarse-grained soils and fine-grained soils. The surface of the particles has a negative electrical charge, whose intensity depends on the soil mineral. These surface forces exist in addition to the volume forces of the particles and in fine-grained soils they play a dominant role in the mechanical and rheological behaviour. The surface forces strongly depend on the water content and more in general on the chemical composition of the interstitial fluid.

For this reason, it is very important to set up standards that can define different physical states considering not only the water content but also the chemical composition of the pore fluid.
The classification of a granular soil is completely defined by the grain distribution curve, the shape of particle and its specific volume. Whereas the procedure for particle size analysis is well defined and easy to perform (by a simple sieve analysis), a procedure for characterising the particle shape is not available and it should be defined as the particle shape strongly influence the mechanical behaviour of these type of soils.

The behaviour of cohesive soils depends on its mineral composition, the water content, the degree of saturation and its structure. A fine-grained soil can be in a liquid, plastic, semi-solid or solid state, depending on its water content and this physical state is called consistency. The upper and lower limits of water content within which a clay element exhibits plastic behaviour are defined as liquid limit and plastic limit. The procedure is standardised *(ASTM D4318)* but it is recognised to be strongly affected by the operator experience. Typical values of liquid limit for natural fine-grained soils range from 40% up to 90% of water content and the plastic limit from 10%-50%. Many correlations have been proposed relating the mechanical characteristics of cohesive soils and the consistency limit; each of them is valid for the specific type of soil for which it was verified. Table 6 gives an overview of several grain distributions of different standards. The last one (British Standard) is also valid for Germany e.g. and other European countries.

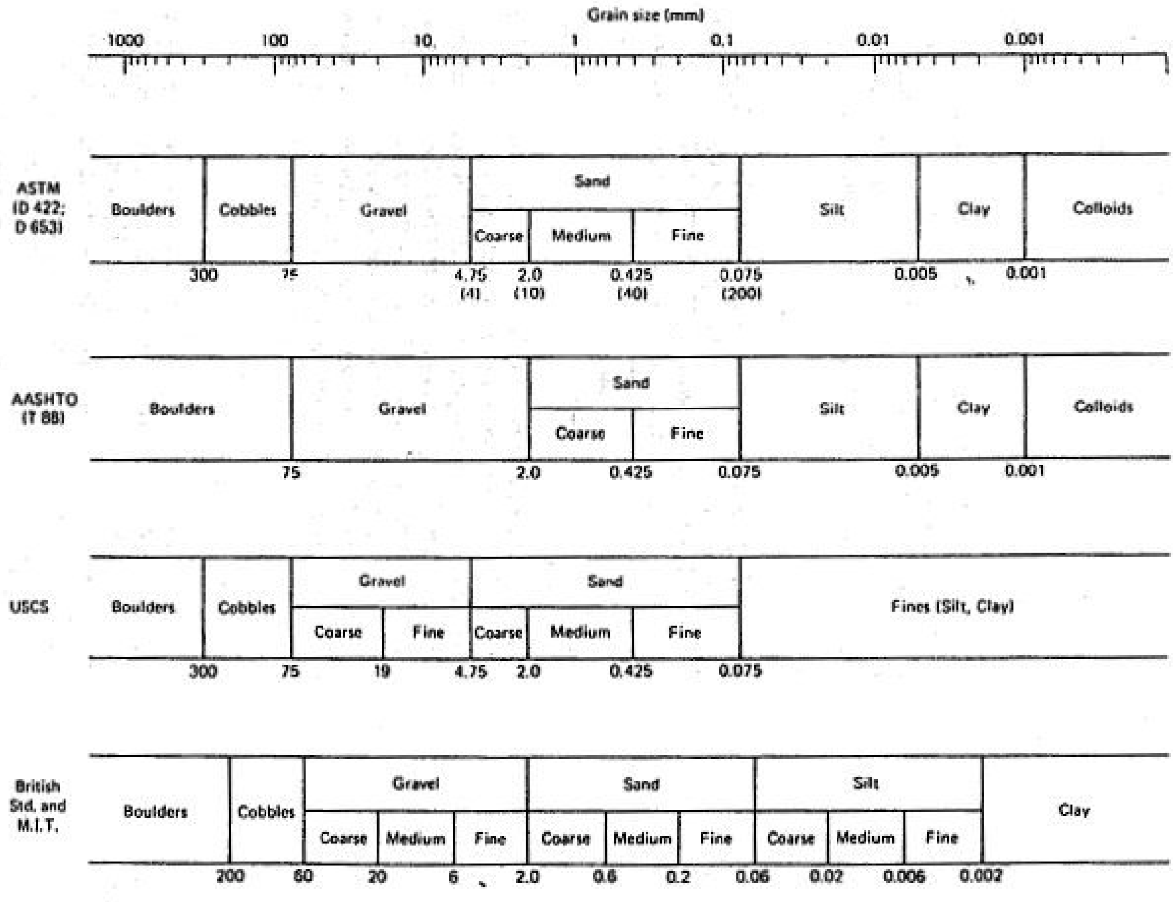


Table 6: Grain size of soils according to different classification systems

1.5 Search for existing Standards and Methods

The first action carried out is consisted in searching for existing standards and non-standardised methods to be possibly used or adapted for utilisation in the specific field of *consistency* evaluation.
To this purpose, the following *standardisation organisations* were contacted:

- **ISO** at www.iso.ch
- **ASTM** at www.astm.org
- **CEN** at www.cenorm.be
- **UNI** at www.uni.com
- **DIN** at www.beuth.de
- **AFNOR** at www.afnor.fr/portail.asp
- **BSI** at www.bsi.org.uk
- **ASAE** at http://webstore.ansi.org/ansidocstore/default.asp

Other information was obtained through personal contacts with experts in the field.
In addition, to obtain selected information, the following keywords were used for research in each web site (among other things): *consistency, viscosity, flowability, shearing, sludge, soil, physical properties, flow properties, suspensions, and compactibility*. The different materials resulted from the research were resins, plastic, lubricant, cement, asphalts/bitumen, etc.
The complete list of standards is reported in Annex 1, from which it can be seen that more than 250 standards and non-standardised methods are potentially applicable to consistency evaluation.

1.6 Basic informations

1.6.1 Solidity

Solidity is the state in which a substance has no tendency to flow under moderate stress, resists forces (such as compression) that tend to deform it, and retains a definite size and shape. It describes the consistency of a solid resp. the limit solid/ paste-like.

For determination of solidity besides the resistance to pressure, the flexural resistance and tensile strength the “undrained shear strength c_u” (compare Eq. 2) is an important parameter. Shear may be defined as the tendency of one part of e.g. a soil mass to slide with respect to the other. This tendency occurs on all planes throughout the soil mass. The singular plane of interest, however, is the plane of potential failure, called the plane of rupture. Shear strength, as measured along this plane of interest, is the ability of the mass to resist the occurrence of a shear failure between the soil above and below the plane. Masses, e.g. soils have the ability to develop strength in shear. Different material groups develop this strength in different ways.

Generally the cohesion (c), as defined by the Geotechnics, has to be determined on basis of the evolution of the shear strength (τ) as a function of the applied axial strength (σ) using the Coulomb rule:

$$\tau = c + \sigma \cdot \tan \varphi \qquad \text{(Eq. 1)}$$

where φ is the angle of shearing resistance or friction angle. For sludges it has been observed that φ is near zero (*Costet and Sanglerat*, *1975* [24]). For this reason it is reasonable to equal τ and c (see Eq. 2). Furthermore, several authors (*Gazbar*, *1993* [25]; *Tisot et al.*, *1997* [26]) considered that the yield stress (the stress above which the sludge is deformed) is equal to τ.

$$\tau_f = c_u \qquad \text{(Eq. 2)}$$

where c_u is the undrained cohesion or the undrained shear strength.

The ability of a mass to support vertical loads and to resist the sliding effect of lateral loads is governed to a large extent by the shear strength of the material. It is therefore important to determinate accurately the shear strength of mass situated beneath and in close proximity to the proposed construction. There are several field and laboratory tests by which shear strength can be determined with reasonable accuracy: Triaxial compression tests, vane shear tests or direct shear tests. Besides the determination of the “bearing capacity” the “unconfined compression strength", which is determined as twice the undrained shear strength (Eq. 3), and the "California bearing ratio" are important parameters.

$$q_u = 2 \cdot c_u \qquad \text{(Eq. 3)}$$

Penetration apparatuses are also being suitable for measuring the consistency resp. shearing strength, which is determined in this case with the aid of a constant depending on the dimensions of the cone tip (see chapter 4.1.1, Eq. 7).

In general the tension or compression tests consist in measuring the strain in relationship to the applied stress. From a conventional stress-strain curve (Fig. 3) it can be identify four different ways, in which the material behaves, depending on the induced strain [27]:

- Elastic behaviour: when the load acting on the material is removed, the sample returns to its original shape, (the stress is proportional to the strain),
- Yielding: a slight increase in stress above the elastic limit induces a breakdown of the material and cause it to deform permanently,
- Strain hardening: while the material is sheared, the deformation is permanent and there is no proportionality between the stress and the stress,
- Necking: a crack occurs in a localized region.

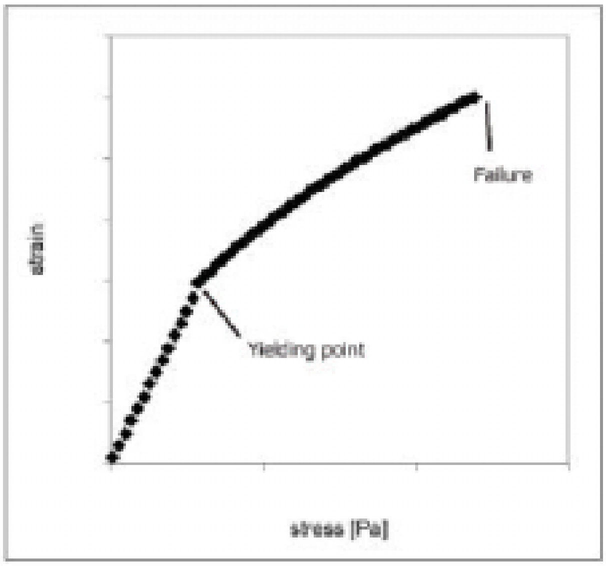


Fig. 3: Schematic stress-strain curve of solid materials [28]

1.6.2 Thixotropic behaviour of solid materials

Thixotropy or thixotropic behaviour is available, when the viscosity of a substance (shear rate $\dot{\gamma}$ = const.) decreases with the time, but after a defined period of rest the initial value of the viscosity is reached again (Fig. 4, [29]). The reasons for this behaviour are special formed chem./phys. bonding forces, which influence the relocatability against each other of those components and which are destroyed by the shear strain and during the non-operated time are complete reversible regenerated. Distinctive thixotropic properties are founded e.g. for solid materials with polar surface in covalent matters.

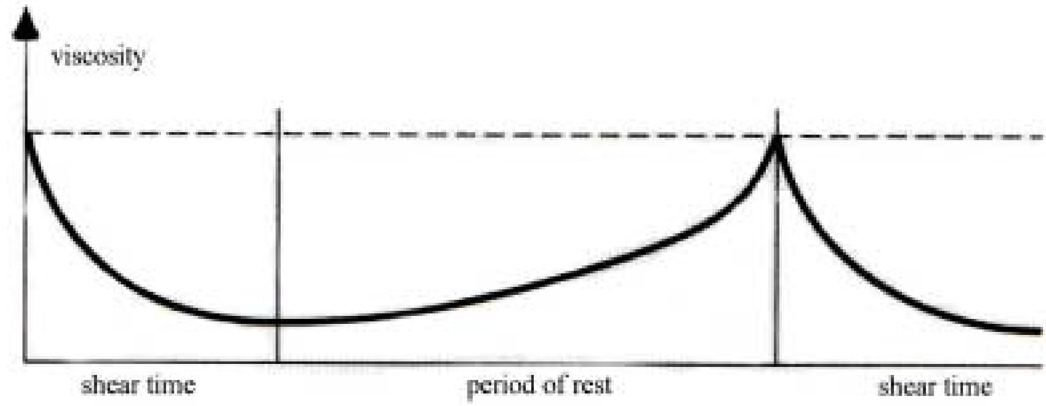


Fig. 4: Thixotropy in viscosity-time-graph ([29] modified)

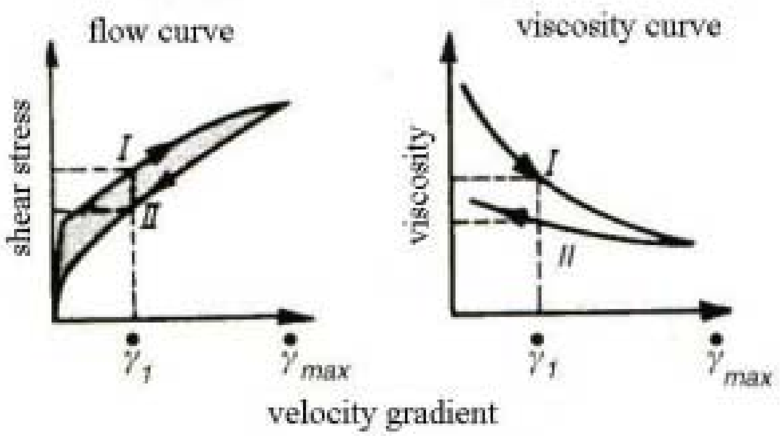


Fig. 5: Thixotropy in flow curve graph and viscosity curve ([30] modified)

When the increasing curve in the flow curve graph (Fig. 5, left, I) is located above the decreasing curve (II), this behaviour is called thixotropic. The received Hysteresis area is a degree of intensity of the constructiveness forces (e.g. structure of gel). In general this area is termed "A" and has the unit "power" related to the sheared volume. If the power is multiplied by the shear time (I+II) the "work" is resulted, which is necessary in order to destroy the thixotropic structure of the bonding forces in the substance volume [30]:

$$A = \tau \cdot \dot{\gamma} \qquad \left[Pa \cdot \frac{1}{s} \right]$$

$$A = \frac{N}{m^2} \cdot \frac{1}{s} = \frac{N \cdot m}{s} \cdot \frac{1}{m^3}$$

$$A = \frac{\text{work}}{\text{sheartime}} \cdot \frac{1}{\text{volume}} = \frac{\text{power}}{\text{volume}}$$

Beside the time-depended reduction of the viscosity (with a constant shear rate) there does exit a decrease of viscosity due to intensity of the shear rate (Fig. 5, right).

If a material is anti-thixotropic, the position of the increasing curve in the flow curve graph is below the decreasing curve. This aspect is called "rheopexy" or also negative thixotropy. In practise it means the material is getting solid during the time of shear stress [29]. However, in this report only materials with a thixotropic behaviour are considered. In particular the value “shear strength”, which is mostly determined for the parameter “solidity”, is observed, whether it falls below the given threshold - because of shear stress - or not.

Also waterwork and sewage sludges often show thixotropic behaviour. During shear stress the sludges change from the solid to the liquid state, which may hinder the utilization of the sludges during transport and handling. It must be ensured that dewatered sludges are not fluidized during transport and handling. Therefore it must be measured whether the material is behaving thixotropic and if so under which conditions.

1.6.3 Piling behaviour

The materials of interest (sludge, treated bio-waste and soil) usually have to be stored during transportation or storage in e.g. piles or containers. To avoid problems with succeeding handling operations the pieces of these materials should undergo no major changes in form and consistence. From there it is of great importance to investigate the piling behaviour, which is displayed by the Horizontal materials.

The "compactibility" or "compressibility" is a first supporting parameter for determination of the piling behaviour. These parameters could give informations about how much a stratum of piled material can settle due to the loading of the material placed above.

The measurement of the "piling angle (angle of rest)" or "slope angle" is also a very helpful parameter to determinate the piling behaviour [48]. It is a new method, which is still in a development stage, but due to the easy measurement procedure and variability (compare chapter 3.3 et seq.) a promising tool for the investigation of all materials of interest. The instrument for measuring these parameters consists of a simple box with turnable sidewalls. After filling the box - where necessary compacting the material – and the sidewalls were turned over, the natural slope angle of the remaining material can be measured on each side of the sample remaining on the box base. Because of the average of four values the result are mostly reliable. A further important aspect is that the friction between the sidewalls and the material to be tested does not affect the final result.

2. EXISTING STANDARDS OR DRAFT STANDARDS

The research of existing and draft standards to be utilized as laboratory and field methods for Horizontal standardization has been carried out in cooperation of the teams involved in WP7 by consulting the web sites of standardization boards (cp. section 1.5). Besides these standards some non-standardised methods, which are also used in practice, were acquired. The keywords used for the research have included the possible field and relevant properties for which the standards may be applicable. The expert's of WP7 has submitted titles to a preliminary examination and the selected standards (considered for further discussion) have been acquired. They can be divided generally in to four parameter groups: flowability, solidity, thixotropic behaviour and piling behaviour.

2.1 Flowability

Keywords beside the item flowability:

- Bitumen
- Cement/concrete
- Consistency
- Plasticity
- Plastics
- Sludge (sewage)
- Soil
- Slurry
- Thixotropy
- Viscosity
- Waste (solid)

In this group 128 standards and non-standardised methods have been found and 90 standards and non-standardised methods have been considered for further discussion.

2.2 Solidity

Keywords beside the item solidity:

- Cement
- Concrete
- Cone
- Consistency
- Mechanical properties
- Needle
- Penetrometer
- Plasticity
- Road materials
- Shearing strength
- Sludge (sewage)
- Soil
- Soil properties
- Vane
- Waste (solid)

In this group 68 standards and non-standardised methods have been found and 32 standards and non-standardised methods have been considered for further discussion.

2.3 Thixotropic behaviour

Keywords beside the item thixotropic behaviour:

- Cementitious & concrete materials
- Concrete
- Consistency
- Fluidity
- Penetration ball
- Road material
- Sludge (sewage)

In this group 15 standards have been found and 9 standards have been considered for further discussion.

2.4 Piling behaviour

Keywords beside the item piling behaviour:

- Cement
- Cementitious & concrete materials
- Concrete
- Consistency
- Flowability
- Oedometer
- Piling box
- Plasticity
- Soil
- Waste (solid)

In this group 13 standards and non-standardised methods have been found and 8 standards and non-standardised methods have been considered for further discussion.

The list of the collected titles is reported in Annex 1. The list of standards considered for further discussion is presented in chapter 3.

3. EVALUATION OF DRAFTING A HORIZONTAL STANDARD

On the basis of the selected list of standards and non-standardised methods for further consideration the methods for the determination of solidity, thixotropic behaviour and piling behaviour of sludge, treated bio-waste and soil have been divided into several groups, according to the instruments used for measuring:

3.1 Solidity

- Shearing apparatus
- Vane testing apparatus
- Penetrometers

3.1.1 Shearing apparatus

The shearing apparatuses in this section include among other things the apparatuses for direct shear tests, triaxial compression tests and for tests for determination of unconfined compression strength.

3.1.1.1 Standards analysed

The examined standard methods for the determination of solidity of different substances by shearing apparatus are reported in Table 7:

Method	Material	Para-meter	Appara-tus	Standard range	Physical meaning/purpose	Utility/ field	Evaluation
ASTM D3080-98 Standard Test Method for Direct Shear Test of Soils Under Consolidated Drained Conditions	Soil material	Consolidated drained shear strength	Shear device, shear box, porous inserts, loading devices, etc.	Normal stress, moisture environment *(field conditions)*	1. Wetting and draining of the test sample (normal stress); 2. Displacing one frame horizontally, measuring the shearing force and horizontal displacement		Considered and found not appropriate
ASTM D5311: 1992 (1996) Standard Test Method for Load Controlled Cyclic Triaxial Strength of Soil *(cp. ASTM D2850)*	Saturated soils in either undisturbed or reconstituted states	Cyclic strength	Triaxial equipment	Pressure: usually 100 kN/m²	The cyclic strength of a soil is evaluated relative to a number of factors, including: the development of axial strain, magnitude of applied cyclic stress, number of cycles of stress application, development of excess pore-water pressure, and state of effective stress	Evaluating the ability of a soil to resist the shear stresses induced in a soil mass due to earthquake or other cyclic loading	Considered and found not appropriate
ASTM D6243: 1998 Standard Test Method for Determining the Internal and Interface Shear Resistance of Geosynthetic Clay Liner by the Direct Shear Method	Geosynthetic Clay Liner (GCL)	Internal and Interface Shear Resistance	Shear Device; Normal Stress and Shear Force Loading Device and other miscellaneous lab. equipment	-	This Test Method measures the total resistance to shear within a GCL or between a GCL and adjacent material. The shear force is recorded as a function of the horizontal displacement of the moving section of the shear box.		Considered and found not appropriate

Table 7: Standards for shearing apparatus

3.1.1.2 Laboratory or field test feasibility

Most of these tests are performed in the laboratory, because the shear devices often require in parts large space, thermostatic conditions, special force loading devices, which need electrical power, etc.

3.1.1.3 Apparatus

The tests examined use the following types of shearing apparatus:

- Shear devices (shear box) (Fig. 6)
- Triaxial equipment (Fig. 7)

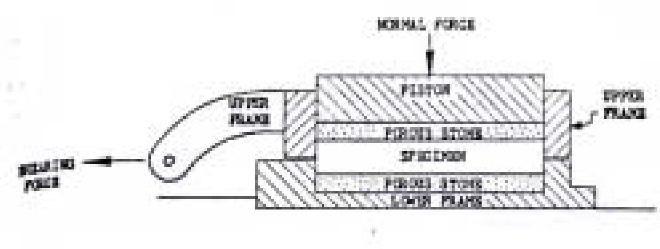


Fig. 6: Test samples in single and double shear (shear box) [32]

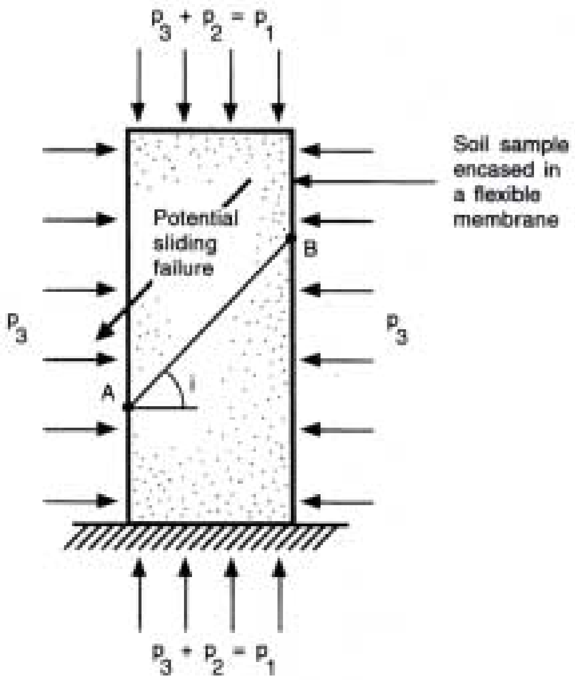


Fig. 7: Triaxial compression test showing test pressure and assumed plane of failure *AB* [33]

3.1.1.4 What is measured and how

For the determination of shear strength by direct shear test described in *ASTM D3080* first moisten and drain the test sample under normal stress. Then unlock the frames that hold the test sample, and displace one frame from the shear device (shear box) horizontally and measure the shearing force and horizontal displacement.

For the determination of the load controlled cyclic triaxial strength described in *ASTM D5311* a number of factors have to be consider. It is a very expensive procedure to determine the shearing strength (ASTM D2850). That is why this test method will be discussed no further.

The test method for determining the shear resistance of Geosynthetic clay liner (GCL) described in *ASTM 6243* measures the total resistance to shear within a GCL or between a GCL and adjacent material. The shear force is recorded as a function of the horizontal displacement of the moving section of the shear box.

3.1.1.5 Material to be examined

The tests are mainly employed for the following materials

- Soil material (e.g. saturated soils in either undisturbed or reconstituted states)
- Lime treated material
- Geosynthetic clay liner (GCL)

In general the materials are in solid forms.

3.1.1.6 Feasibility of the methods to the materials for the Horizontal project

In these existing standards only soil materials are investigated. For application to other materials like sludge or treated bio-waste these materials must have a certain threshold of the consistency to produce reasonable results. For solid material, however, the shearing apparatus can be a reliable laboratory reference method to determinate the shear strength and thus the consistency. Especially the direct shear test method is suited for relatively rapid determination of consolidated drained strength properties, because the drainage paths through the test sample are short, thereby allowing excess pore pressure to be dissipated more rapidly than with other drained stress tests.

As the methods have to be suitable for the whole range of materials and not only for soil materials the shearing apparatuses seem not appropriate for the Horizontal-Project.

3.1.2 Vane testing apparatus

Vane testing apparatus are used to measure the vane shear and determine the shearing strength of compact materials like direct shear test or triaxial compression test. For the investigated materials it is important that these materials are cohesive, because otherwise no shearing strength occurs.

3.1.2.1 Standards and non-standardised methods analysed

The examined methods for the determination of solidity of different substances by vane testing apparatus are reported in Table 8:

Method	**Material**	**Para-meter**	**Appara-tus**	**Standard range**	**Physical meaning/purpose**	**Utility/ field**	**Evaluation**
ASTM D2573: 2001 Standard Test Method for Field Vane Shear Test in Cohesive Soil	Soft, saturated, cohesive soils	Shear strength of soil	Four bladed vane	-	Determination of the torsional force required causing a cylindrical surface by the vane; this force is then converted to a unit shearing resistance of the cylindrical surface.	Testing shear strength of clayey soils for engineering design and construction	Considered and found not appropriate
ASTM D4648: 2000 Laboratory Miniature Vane Shear Test for Saturated Fine-Grained Clayey Soil	Saturated fine-grained clayey soil	Shear strength	Vane blade Vane device with torque measuring system	Applied torque: 60-90°/min	Determination of torque required causing a cylindrical surface to be sheared by vane. The torque is converted in shear resistance by a calibration constant. (Method A: Conv. calibr. torque spring unit. Method B: electrical torque transducer units)	Testing consistency and shear strength of clay soils for engineering design and construction.	Considered for further investigation

DIN 4094-4:2002-01 Subsoil – Field testing – Part4: Field vane test	Saturated, fine-grained soils (clay, silt and organic soils (DIN 4022-1, DIN 18196);	Consistency:	Shear vane apparatus (four bladed vane)	Consistency $0 \leq I_c \leq 1{,}0$ (paste-like (pulpy)/solid(stiff)) Soft soils: major vane; stiff soils: minor vane	Determination of torque required causing a cylindrical surface to be sheared by vane.	Testing shear strength of saturated, fine-grained soils for engineering design and construction	Considered and found not appropriate
ATV- Work report/ ATV-Arbeitsbericht [23]	Sludges	Vane shear strength	Laboratory vane shear apparatus	Cohesive materials	Determination of horizontal torque by the angle of rotation indicated by the apparatus and then converting the torque into a shearing strength with the aid of a spring constant.	Investigation of sludges for landfilling/disposal	Considered for further investigation
Mechanical properties of waterworks' sludges – Shear strength [15]	Waterworks' sludges	Vane shear strength	Pocket vane shear apparatus, several vanes of different sizes	-	Measuring of a value, which is converted to a shearing strength with the aid of a constant: The manufacturer of the apparatus has given scaling factors to transform the measured values to shearing strength.	Investigation of mechanical properties of waterworks' sludges	Considered and found not appropriate

Table 8: Standards and non-standardised methods for vane testing apparatus

3.1.2.2 Laboratory or field test feasibility

In general vane shear tests are applicable for both laboratory and field test. There are simple apparatus for measuring in the field and special apparatus for vane shear tests as laboratory reference. The laboratory apparatus can be driven by electric power or manually.

3.1.2.3 Apparatus

The tests examined use the following types of vane testing apparatus:

- Shear vane apparatus (four bladed vane; in situ; Fig. 8)
- Vane device with torque measuring system (laboratory miniature vane; Fig. 9)

Besides these apparatuses another types of apparatuses, which are not reported in the standards, but may be considered as a promising tool to test the solidity of the analysed materials - like concentrated sludges e.g.-, are the following apparatuses:

- Laboratory vane shear apparatus (Fig. 10)
- Pocket vane shear apparatus (Fig. 11)

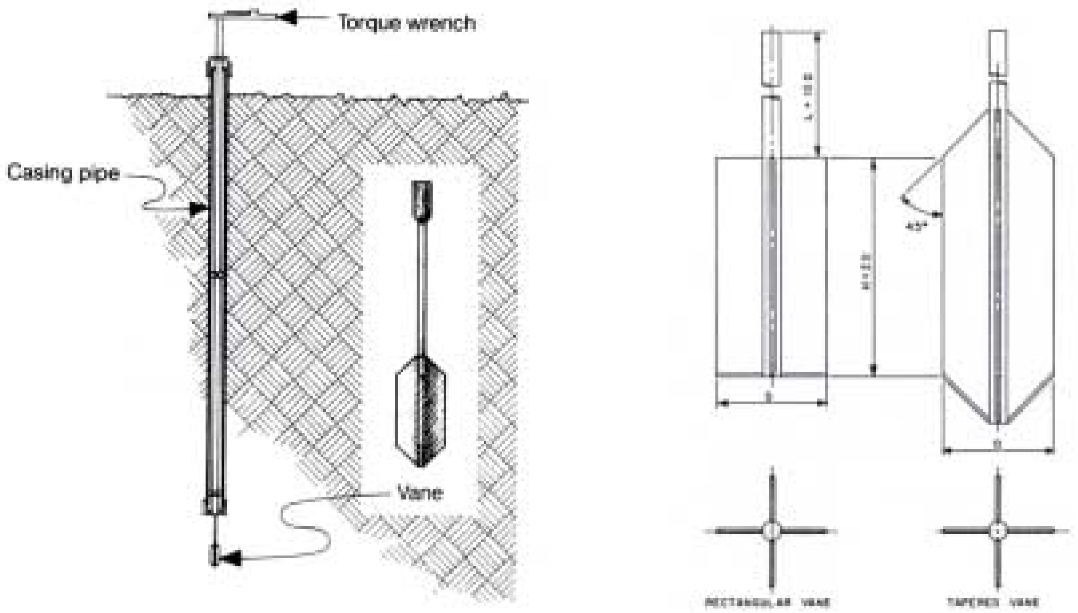


Fig. 8: Vane shear apparatus and geometry of field vanes [33, 34]

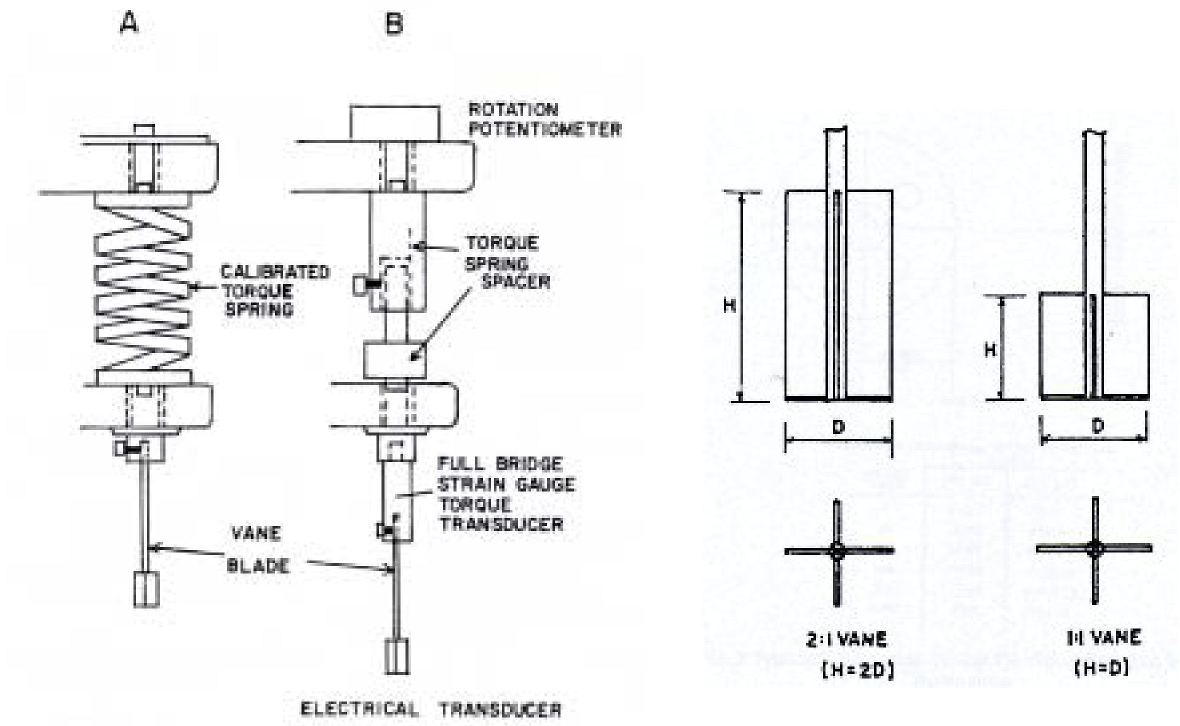


Fig. 9: Vane torque spring, electrical transducer details geometry and miniature vane blade geometry [35]

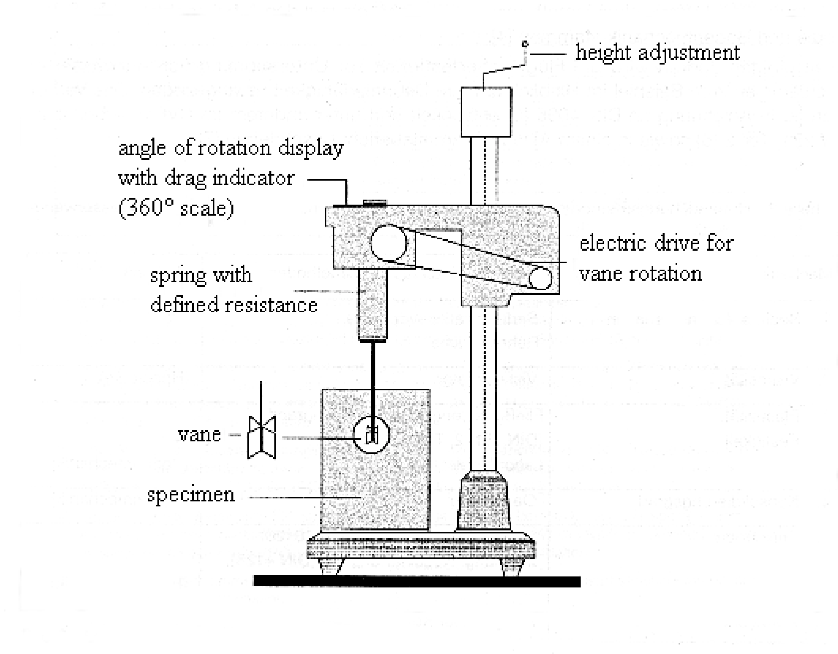


Fig. 10: Laboratory vane shear apparatus [23]

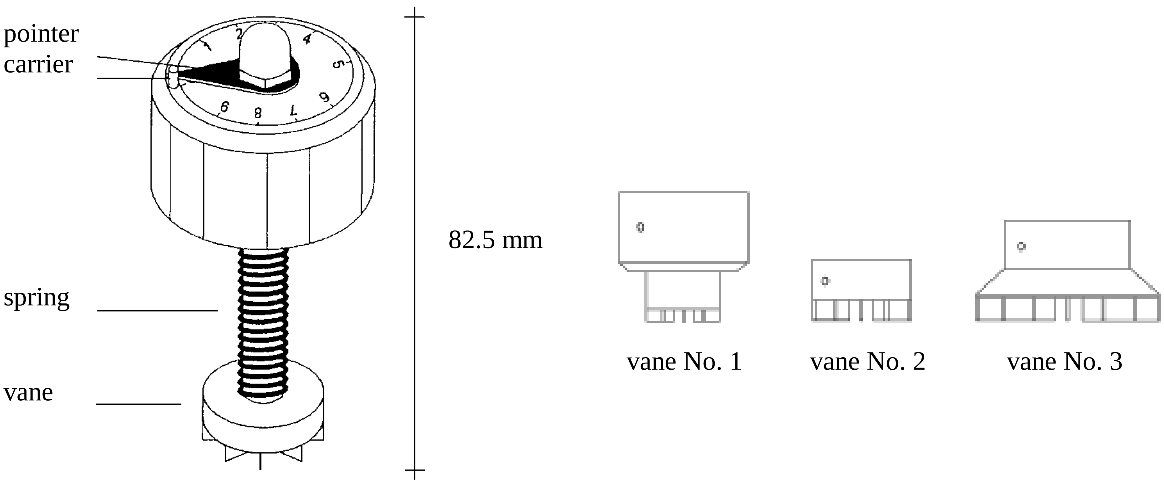


Fig. 11: Pocket vane shear apparatus [15]

3.1.2.4 What is measured and how

<u>Vane shear testing</u> described in *ASTM D2573* and *DIN 4094-4* is one of the most common in-situ methods for the estimation of the undrained shear strength of the soil. The vane is introduced into the borehole to the depth where the measurement of the undrained shear strength is required. Then it is rotated and the torsional force required to cause shearing is calculated.

The <u>Laboratory miniature vane shear test</u> described in *ASTM D4648* may be used to obtain estimates of the shear strength of fine-grained soils. The vane assembly shall consist of four rectangular blades. The vane inserted in a cylindrical tube containing the sample that is rotated at a constant rate of 60 to 90°/min by a motorised vane device.

A torque transducer measures the torque required to cause a cylindrical surface to be sheared by the vane. The torque is then converted to a unit shearing resistance (Pa) of the cylindrical surface area by means of a vane blade calibration constant.

For determination shearing strength by laboratory vane shearing apparatus described in the *ATV-Arbeitsbericht (1989)* [23] first prepare the sample (e.g. *after DIN 18127 (1997)* [31]): The material – in this case sludge e.g. – is filled into the small Proctor vessel in three equal portions and is compressed with ten knocks by the small Proctor hammer (2.5 kg weight). Then the horizontal torque form shearing the sample through the penetrated vane is determined. The vane consists of four rectangular blades. The vane apparatus, which is connected with the display over a torque spring, is manually or electrically rotated and the vane cuts a cylindrical sample. The torque is determined by the angle of rotation and the spring constant. When the sample shears, the angle of rotation and the applied max. torque is kept by the scale. The torque is then converted to a shearing strength with the aid of a constant.

The pocket vane shear apparatus described in the publication *Mechanical properties of waterworks' sludges* [15] has only a height of 82,5mm and does not need electrical power. Because of the small size this apparatus is capable for simple field tests. It consists of a shear apparatus with several vanes of different sizes, which can be applied for a wide range of materials. The pointer and carrier of the display indicate the value, which is converted to a shearing strength with the aid of a constant: The manufacturer of the apparatus has given scaling factors to transform the measured values to shearing strength. These factors are developed for soil measurements.

3.1.2.5 Material to be examined

The tests are mainly employed for the following materials

- Soft saturated, cohesive soils
- Saturated fine-grained clayey soils
- Saturated fine-grained soils (clay, silt and organic soils)
- Sewage sludges for landfilling
- Waterworks' sludges

3.1.2.6 Feasibility of the methods to the materials for the Horizontal project

In general the vane shear test is a test whose use is limited to the testing of cohesive materials and cannot be used on coarse-grained materials. For soil materials e.g. it is not suitable for clays containing any appreciable amount of silt or sand. Most of the materials, which should be investigated in the Horizontal project, have this property.

The described standards and investigations in the past [23, 15] showed the feasibility of the vane shearing test methods for cohesive materials like soils and sludges. For treated bio-waste and related wastes of interest further investigations are necessary.

3.1.3 Penetrometer

A lot of standard and non-standardised methods are provided for testing the consistency of a wide range of materials from fluid fresh mortars to solid soils by measuring the resistance to penetration of cylindrical, conical or spicular tips. The methods can also be used to establish a relationship between penetrometer resistance and water content of samples of identical materials.

3.1.3.1 Standards and non-standardised methods analysed

The examined methods for the determination of solidity of different substances by penetrometer are reported in Table 9:

Method	Material	Para-meter	Appara-tus	Standard range	Physical meaning/purpose	Utility / field	Evaluation
ASAE S313.2 (94) ASAE S313.3 (99) Soil cone penetrometer	Soil	Penetration resistance	Cone penetrometer (hand operated)	-	Measuring of the Cone index: The force per unit base area required to push the penetrometer through a specified very small increment of soil. Values max be reported as X kPa at Y mm depth or […]	-	Considered for further investigation
ASTM C187-98 Standard test method for normal consistency of hydraulic cement	Hydraulic cement	Consistency	Vicat Apparatus, Weights and Weighing Devices	Temp. : 20 - 27.5°C (mixing water: 23±1.7°C; Procedure: <30s	Determination of the amount of water required to prepare hydraulic cement pastes for testing	-	Considered for further investigation
ASTM C405-82 (1997) Standard practice for estimating consistency of wet-mixed thermal insulating cement	Thermal insulating cements	Consistency	Penetration Tester (Three pointed steel rods/spears)	Sample Preparation: 21-24°C; average difference < ± 25.4 mm.	Measure the depth of penetration of each of the spears 30s later, and take the average depth of penetration of the three spears as the measure of the consistency for that test.	Estimation of the proper amount of water to be used in mixing insulating cement.	Considered and found not appropriate
ASTM C 807 - 99 Time of Setting of Hydraulic Cement Mortar by Modified Vicat Needle	Hydraulic Cement Mortar	Consistency	Mod. Vicat apparatus	-	Time required to obtain the stipulate penetration of the sample	Determination of the time of setting of cement expansive	Considered for further investigation
ASTM D1883-99 Standard Test Method for CBR (California Bearing Ratio) of Laboratory Compacted Soils	Soils (pavement subgrade, subbase and base/course material	CBR (California Bearing ratio)	Bearing Ratio Test Apparatus (Loading Machine, Mould, spacer disc, etc.) Penetration Piston	Max. particle sizes less than ¾ in. (19mm)	Curves of Load-Penetration-relation; Determination of the Water Content (D 698 or D 1557)	-	Considered and found not appropriate
ASTM D217-97 (-82) Standard test method for cone penetration of lubricating grease (Compare ASTM D937)	Lubricating greases	Consistency	Penetrometer, Standard Cone	Water or air bath: 25 ± 0.5°C; freely drop for 5s; Classification of Penetration (table) => several cones	Determination of the depth, in tenth of a millimetre, that the standard cone penetrates the sample under prescribed conditions of weight, time, and temperature	Measurement of unworked, worked, prolonged worked, and block penetration	Considered for further investigation
ASTM D2884: 1993 (1998) Standard test method for yield stress of heterogeneous propellants by cone penetration method	Heterogeneous propellants (gel and emulsion types, containing 0-70% soil additives)	Yield stress	Magnesium penetration cone and cup	42-60 mm of cone penetration at 25°C	Penetration of the cone after 5s. The yield stress is calculated by the use of a proper equation	The yield stress is a measure of the forces required to initiate and maintain flow	Considered for further investigation
ASTM D3441-98 Standard test method for deep, quasi-static, cone and friction-cone penetration tests of soil	Soil and soft rocks	Penetration resistance (end bearing and side friction)	Field cone and friction cone penetrometer Mechanical and electric types	-	Penetration resistance with depth during the steady slow penetration of a pointed rod into soil	Engineering properties of soil related to design a. construct. of earthworks and foundations for structures	Considered and found not appropriate
ASTM D5778-95 Standard test method for	Subsurface soils at a slow,	Resistance to penetrati	Friction cone penetromet	-	Cone tip projected area is commonly referred to in	Evaluation of site stratigraphy,	Considered and found not

performing electronic friction cone and piezocone penetration testing of soils	steady rate	on	er with several cone tips		centimetres for convenience. The values stated in each system are not equivalents; therefore each system must be used independently of the other.	homogeneity and depth of firm layers, voids or cavities, and other discontinuities	appropriate
ASTM D937-97 Standard test method for cone penetration of petrolatum	Petrolatum	Consistency (empirical)	Penetrometer, Cone, Oven (sample preparation)	Temperature: 25 ± 0.5°C (water bath)	Cone penetration is a means of measuring with the firmness or consistency of petrolatum	These measurements are useful for selecting or specifying, or both, a petrolatum of a particular consistency or firmness.	Considered for further investigation
BS 2000-49:1993 Methods of test for petroleum and its products. Part49: Determination of needle penetration of bituminous material	Semi-solid and solid bituminous material	Consistency	Pene-tration apparatus, timing device, penetration needle, water bath, etc.	Normal conditions: test temperature 25°C, applied load 100g, duration of loading 5s	This consistency is expressed as the distance in tenth of a millimetre that a standard needle penetrates vertically into a sample of the material under specified conditions of temperature, load and duration of loading	-	Considered for further investigation
BS 3712: Part 1: 1991 Building and construction sealants: Part 1. Methods of test for homogeneity, relative density and penetration	Sealants	Methods of test for penetration	Penetrometer, penetration cones and needles	-	The primary aim of these test methods is to enable the properties of sealants to be assessed and for their quality to be controlled, particularly in relation to their compatibility with other materials and their suitability for application to building joints.	Providing a body of test methods suitable for the wide range of sealants of different types and properties now available on the market.	Considered for further investigation
CEN 00227146 prEN 13880-2 Hot applied joint sealants – Part 2: Test method for the determination of cone penetration at 25°C	Hot applied joint sealants	Consistency (cone penetration value)	Pene-trometer, suitable penetration cone, water bath, etc	Test conditions: temperature 25±0.3°C, applied load 150±0.1mg, duration of loading 5±0.1s	Value: Depth to which a standard cone penetrates the test sample under defined conditions of mass, time and temperature	-	Considered for further investigation
DIN 1168-2:1975-07 Building Plasters; Requirements, Testing, Control	Building Plasters	Beginning of stiffening	Vicat apparatus with cone (form of a needle)	Temperature 18-25°C	Measure of the duration (in minutes) the cone sticks at a defined depth	-	Considered for further investigation
DIN 51580:1989-04 Testing of petroleum waxes; Determination of cone penetration	Petroleum waxes	Consistency (Cone penetration)	Penetrometer, Pene-tration Cone, etc.	Test conditions: temperature 25°C, applied load (weight of penetration cone) 150g, duration of loading 5±0.1s	Evaluation and qualification of the usability for determined application. Measurement: tenth of millimetre.	-	Considered for further investigation
BS EN 1426:1999 Bitumen and bituminous binders – Determination of needle penetration	Bitumen and bituminous binders	Consistency	Penetrometer, Penetration needle, water bath, etc.	Normal range: 500x0.1 mm, 25°C, applied load 100g, and duration of	Consistency, expressed as depth in tenth of millimetre which a stand. needle under determined conditions (temperature, load and	-	Considered for further investigation

				loading 5s. Penetration > 500x0.1: 15°C	duration of load) vertical in a sample relines.		
ISO/DIS 13765-1:2001-12 Refractory mortars - Part 1: Determination of consistency using the penetrating cone	Refractory mortars	Consistency	Penetrometer, cone, container for the sample, etc.	Test conditions: applied load/mass of the cone 150±0.25g,	The consistency of a refractory mortar is assessed by the depth of penetration of a specified cone into the sample	-	Considered for further investigation
ISO 2137:1985-11 (DIN ISO 2137:1997-08) Petroleum products – Lubricating grease and petrolatum. Determination of cone penetration	Lubricating greases and petroleum	Consistency	Penetrometer, Cones (standard and optional, cp. range), etc.	Test conditions: temperature 25°C, duration of loading 5s	The distance that a standard cone penetrates into a test portion under standardized conditions of load, time, and temperature	Measure-ment of unworked, worked, prolonged worked, and block penetration	Considered for further investigation
ATV-Arbeitsbericht (ATV-Work Report) [23]	Sludges	Shear strength	Pocket penetrometer	-	After putting manually a force via a spring on the sample the penetration resistance can be read directly from the scale. With the aid of a nomogram (and a regression line) the shearing strength can be determined.	Investigation of sludges for landfilling/disposal	Considered for further investigation
Geotester	Soils, water work sludges	Shear strength	Pocket cylinder penetrometer with several cylinders (plungers) of different sizes	-	Measuring the force required for shearing the material. (It is loaded in compression to failure). Calculating the stress by dividing the force by the surface area of the cylinder.	Subsoil; investigation of mechanical properties of waterworks' sludges	Considered for further investigation

Table 9: Standards and non-standardised methods for penetrometer

3.1.3.2 Laboratory or field test feasibility

Laboratory penetrometers are quite simple instruments, which could also be used for field tests as they do not request electric power supply and can operate at room temperature.
The field soil penetrometers are specific apparatus designed to supply data on engineering properties of soil and include cone and friction-cone penetrometers of both mechanical and electric types.

3.1.3.3 Apparatus

The tests examined use the following types of penetrometer:

- Soil cone penetrometer (Fig. 12)
- Vicat apparatus with different forms of needles (Fig. 13)
- Laboratory penetration tester with three pointed steel rods/spears (Fig. 14)
- Penetration piston, loading machine (CBR)
- Penetrometer, standard cone and other forms of cone tips (Fig. 15)
- Magnesium cone penetrometer for yield stress measurements (Fig. 16)
- Field soil penetrometer (Field cone and friction cone penetrometer)

Besides these apparatuses another types of apparatuses, which are not reported in the standards, but may be considered as a promising tool to test the solidity of the analysed materials - like concentrated sludges -, are the following apparatuses:

- Pocket penetrometer after Neuschäfer (Fig. 17)
- Pocket cylinder penetrometer (Fig. 18)

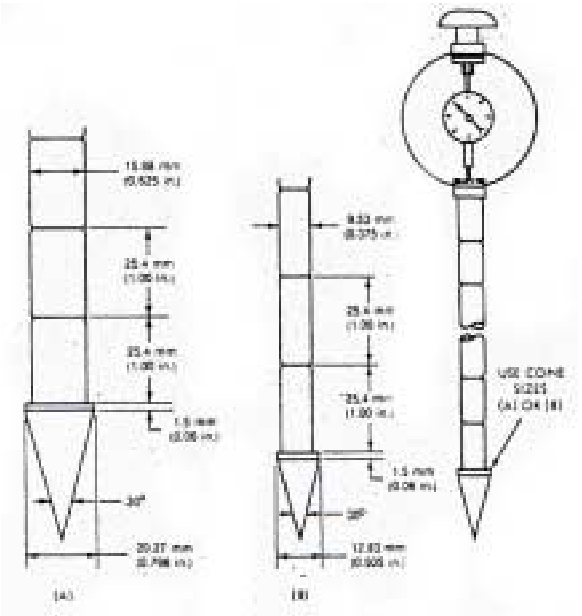


Fig. 12: Soil cone penetrometer [36]

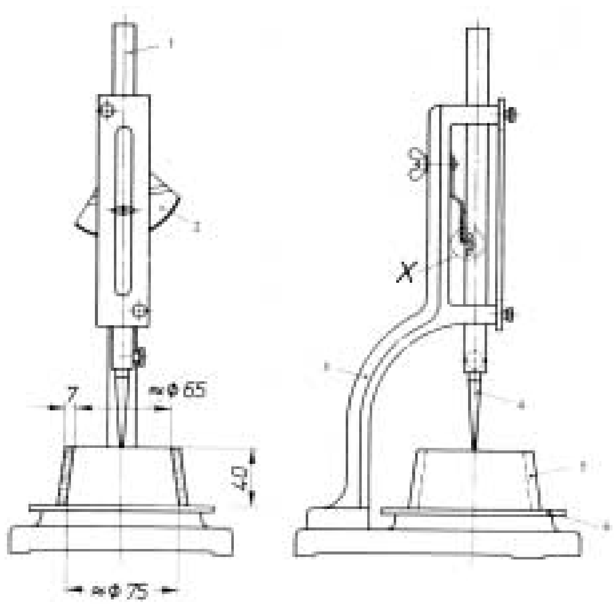
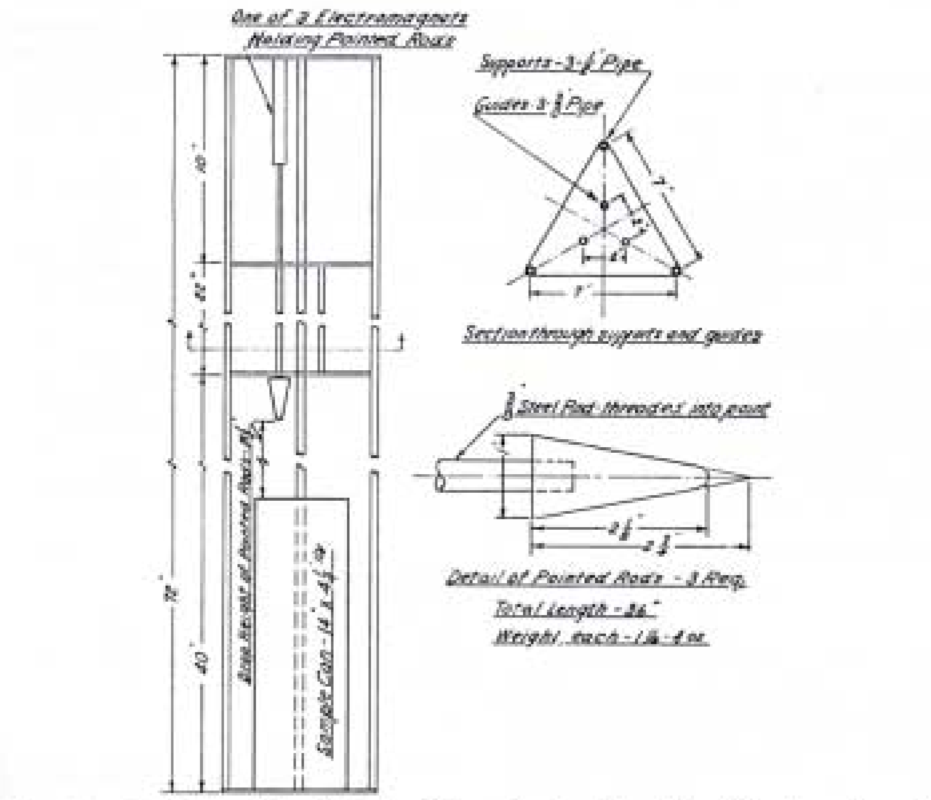


Fig. 13: Vicat apparatuses [37]



in.	3/8	1	2	2 1/8	2 3/4	3 3/8	3 1/2	4 1/2	7	10	14	15 1/2	22	36	40	72
mm	10	25	51	54	70	86	89	114	178	254	356	394	559	914	1016	1829

Fig. 14: Apparatus for measuring consistency by penetration [38]

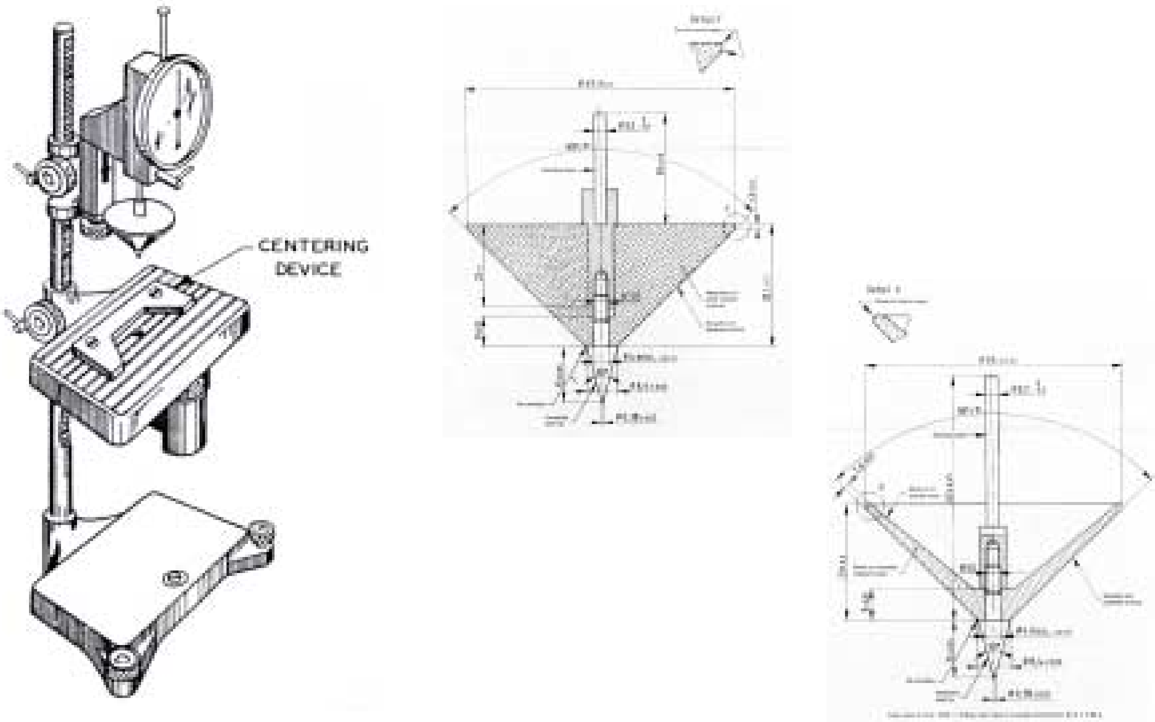
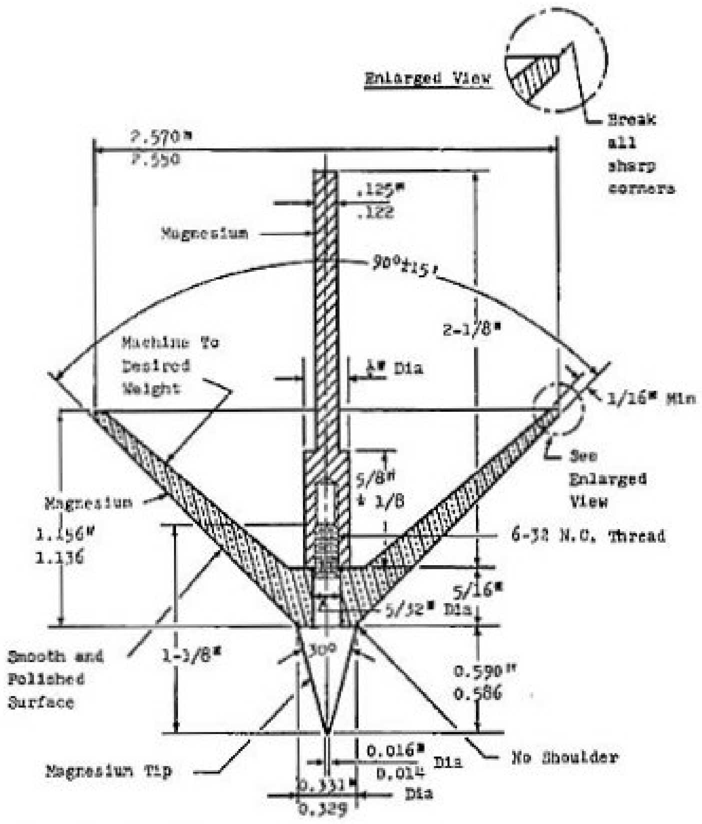


Fig. 15: Penetrometer with standard and optional penetration cone (dim. in mm) [39, 40]



NOTE 1—Tolerances on all fractional dimensions shall be 1/64 in.
NOTE 2—The total mass of the cone shall be 15.00 + 0.05 g and the total mass of its movable attachments shall be 15.00 ± 0.05 g.
NOTE 3—Table of Metric Equivalents

in.	mm	in.	mm	in.	mm	in.	mm
0.014	0.356	1/8	3.18	0.331	8.407	1.136	28.854
0.016	0.406	5/32	3.98	0.586	14.884	1.156	29.362
1/16	1.59	1/4	6.35	0.590	14.986	2 1/8	53.98
0.122	3.10	5/16	7.94	5/8	15.88	2.550	64.77
0.125	3.18	0.329	8.357	1 1/8	28.575	2.570	65.28

Fig. 16: Magnesium penetrometer cone [41]

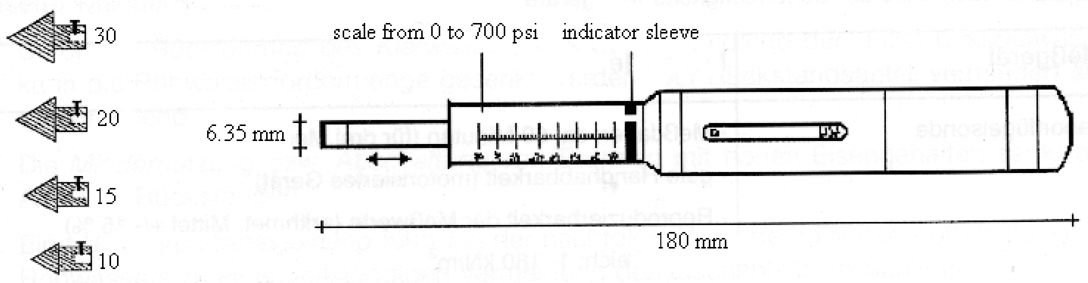


Fig. 17: Pocket penetrometer after Neuschäfer [23]

Fig. 18: Pocket cylinder penetrometer [42]

3.1.3.4 What is measured and how

The Soil Cone Penetrometer described in *ASAE S313.2 / ASAE S313.3*, which is operated by hand, has two cone base sizes. After selection the adequate cone is pushed into the soil at a uniform rate of approximately 30 mm/s. The surface reading is measured at the instant the base of the cone is flush with the soil surface. Marking on the shaft of the cone penetrometer indicates the depths. Five to seven readings should be taken to establish the cone index and to verify the presence of unique layers in the soil profile.

For determination of consistency by Vicat apparatuses described in *ASTM C187*, *ASTM C807* and *DIN 1168-2* first the sample is prepared. Contact the needle with the surface of the sample and then release the needle. For the standard ASTM C187 the paste shall be a normal consistency if the rod settles to a point 10 ± 1mm below the orig. surface in 30s after being released. For the standard ASTM C807 the Vicat apparatus is modified and the preparation is much more complex. Settlement for 30s, then determine the penetration of the needle at this time and every 30 min until the needle fails to penetrate to the bottom of the mould (time of setting). In the standard DIN 1168-2 the duration (in minutes) the cone sticks at a defined depth is measured. The beginning of stiffening is reached if the needle remains in the sample at 18±2mm above the bottom. The duration is measured from the filling in the mould till sticking in the sample. The tips can also be in form of a plunger.

The penetration tester described in *ASTM C405* consists of three pointed steel rods resp. spears. After preparation of the sample release the spears by means of the electrical switch. Measuring the depth of penetration of each of the spears 30s later, and take the average depth of penetration of the three spears as the measure of the consistency for that test.

For the determination of the California bearing ratio (CBR) described in *ASTM 1883* use laboratory compacted samples. The test apparatus consists of a penetration piston and loading machine. Measuring of curves of load-penetration-relation and determination of the water content is performed.

For measuring the consistency with the (standard cone) penetrometer partly described in *ASTM D217, ASTM D937, BS 2000-49, BS 3712, prEN 13880-2, DIN 51580, DIN EN 1426, ISO/DIS 13765-1 and ISO 2137*, determine the depth, in tenth of a millimetre, that the needle or cone (in part several cone tips of different sizes) penetrates the sample under specific conditions of weight/load (~150mg-150g depending on the analysed material), time (fixed duration of ~5s), and temperature (~25°C); mostly classification of penetration range, e.g. 500x0.1mm.

The method for yield stress measurement of heterogeneous propellant makes use of a standard magnesium cone penetrometer described in *ASTM D2884*. This method is similar to the previous described methods. The penetration is determined at 25°C by releasing the cone-test

rod assembly from the penetrometer and allowing the assembly to drop for 5s. The cone will essentially be at the rest in less than this time, so the exact timing is not critical.
The yield stress is the measure of the maximum shear stress that can be applied without causing permanent deformation and is expressed in Pa. This value is calculated by measuring the cone penetration depth and by using a proper equation that takes into consideration the balance of involved forces.

In the standard test method for deep, quasi-static, cone and friction-cone penetration tests of soil described in *ASTM D3441* the end bearing and side friction component penetration resistance is measured, which are developed during the steady slow penetration of a pointed rod into soil. The apparatus uses both cone and friction-cone tips and may be mechanical or electric type. The mechanical penetrometer uses a set of inner rods to operate a telescoping penetrometer tips and to transmit the components of penetration resistance to the surface for measurements. The electric penetrometer uses electric-force transducers built into a non-telescoping penetrometer tip for measuring the components of penetration resistance. The results are reported as cone and friction-cone resistance expressed in 100 kPa with depth in metres.

In the same way operates the standard test method for performing electronic friction cone and piezocone penetration testing of soils described in *ASTM D5778*: A penetrometer tip with a conical point having a 60° apex angle and a cone base area of 10 or 15 cm² is advanced though the soil at a constant rate of 20mm/s. The force on the conical point (cone) required to penetrate the soil is measured by electrical methods, at a minimum of every 50mm of penetration. Stress is calculated by dividing the measured force (total cone force) by the cone base area to obtain cone resistance. A friction sleeve is present on the penetrometer immediately behind the cone tip, and the force exerted on the friction sleeve is measured by electrical methods at a minimum of every 50 mm of penetration. Stress is calculated by dividing the measured force by the surface area of the friction sleeve to determinate friction sleeve resistance.

The pocket penetrometer after Neuschäfer (CT-421) described in the *ATV-Arbeitsbericht (1989)* [23] has a diameter of ca. 2cm, a length of ca. 18cm and a weight of ca. 200g. Manually a force will be put via a spring on the sample. The penetration resistance can be read directly from the scale. For an exact determination several cones (adapters) according to the consistency of the investigated materials exist. The adapters have a relation diameter to height of 1:1. For determination of consistency three penetrations in the same sample are necessary. Then the penetrometer bearing is determined by a nomogram; the number of the cone size and the indicated value from scale are the input values. The penetration bearing is converted in this case by empirical regression line into a vane shearing strength.

The pocket cylinder penetrometer (Geotester) is originally capable for measuring the unconfined compression strength (cp. *ASTM D2166* and *ASTM D5102*), angle of internal friction ϕ and the cohesion C.
The sample is loaded in compression to failure: The force required for shearing the material is measured, it could be read directly from the scale. Stress is calculated by dividing the measured force by the surface area of the cylinder (plunger) to determinate penetration resistance. Like the penetrometer after Neuschäfer there do exist several cylinders of different sizes according to the consistency of the materials.

3.1.3.5 Material to be examined

The tests are mainly employed for the following materials
- Thermal insulating cements
- Hydraulic cement (mortar)
- Building plasters
- Refractory mortars
- Soil material (soil and soft rocks)
- Heterogeneous propellants (gel and emulsion type)

- Lubricating greases and petroleum
- Petrolatum
- Petroleum waxes
- Bitumen and bituminous binders
- Semi-solid and solid bituminous material
- Hot applied joint sealants
- Sewage sludges
- Waterwork sludges

3.1.3.6 Feasibility of the methods to the materials for the Horizontal project

The penetrometers and Vicat apparatuses designed to test the consistency can be used to test the solidity of substances like concentrated sludge, sludges at higher dry content or other materials as they may assume a paste-like or solid consistency.

The Penetration tester and the CBR method are not as suitable as the methods described before. The apparatus are specialised for the investigated materials like cement and soil respectively, therefore a modification for determination the consistency of the Horizontal materials could be much more complicated.

The cone and friction-cone penetration tests of described in *ASTM D3441* and *ASTM D5778* provide a good test method for determining the bearing capacity of soils. Most of the friction-cone apparatuses request electrical power and are due to their sizes not easy to handle. Therefore these test methods won't be further investigated.

3.2 Thixotropic behaviour of solid materials

For the determination of the thixotropic behaviour of solid materials especially for the Horizontal materials a standard method does not exist. From there it should be investigated a combination of methods for determination of the solidity like penetration, etc. and an energy-input in terms of "flow" apparatus to simulate the shear stress.

3.2.1 Standards analysed

The examined standard methods for the determination of thixotropic behaviour of different substances are reported in Table 10:

Method	**Material**	**Para-meter**	**Appara-tus**	**Standard range**	**Physical meaning/purpose**	**Utility / field**	**Evaluation**
ASTM D 2196 - 81 Rheological Properties of Non-Newtonian Materials by Rotational Viscometer	Non-Newtonian liquids	Rheological properties	Met. A: Brookfield viscometer Met. B: Brookfield viscometer Met. C: Brookfield viscometer	Shear rate 0.1-50 s^{-1} Shear rate 0.1-50 s^{-1} Shear rate 0.1-50 s^{-1}	Apparent viscosity Shear thinning and thixotropy Shear thinning of sheared mat.	-	Considered and found not appropriate
BS EN 12350-3:2000 Testing fresh concrete. Vebe test	Fresh concrete	Consistency	Vebe meter/ Consistometer (container, mould, disc, vibrating table, etc.)	Max. particle size 63mm; Vebe time: 5-30s. Moving assembly (rod, disc, weight) 2750±50g	Measure of the time taken for the surface of a disc to be fully in contact with the grout (Vebe time)	-	Considered and found not appropriate
BS EN 12350-4:2000 Testing fresh concrete. Degree of compactibility	Fresh concrete	Consistency (Degree of Compactibility)	Container, means of compacting the concrete (internal vibrator, vibrating table), etc.	Max. particle size 63mm; Degree of Compactibility: 1,04-1,46	The concrete is compacted by vibration and the distance from the surface of the compacted concrete to the upper edge of the container is used to determine the degree of compactibility.	-	Considered and found not appropriate
BS EN 12350-5:2000 Testing fresh concrete –Part 5: Flow table test	Fresh concrete	Consistency	Flow table, mould, Compacting bar, etc.	Not applicable to foamed concrete or no-fines concrete, max. aggregate size 63 mm	Measuring the spread of concrete (diameter) on a flat plate, which is subjected to jolting.	-	Considered and found not appropriate
BS EN 13395-1:2002 Products and systems for the protection and repair of concrete structures. Test methods. Determination of workability. Test for flow of thixotropic mortars	Trowel-grade hydraulic cement mortars CC, polymer modified hydraulic cement mortars PCC, polymer bound mortars PC	Workability (consistence)	Mortar mixer or concrete mixer, flow table and truncated conical mould, etc.	-	Measure of the spread (diameter) of a defined test sample when placed on a flow table, with the spread being achieved by a set number of jolts. *(EN 1015-3)*	Protection and repair of concrete	Considered and found not appropriate
CEN 00227124 prEN 13286-4 Unbound and hydraulically bound mixtures – Part 4:	Unbound and hydraulically bound mixtures	Laboratory reference density and	Mould, detachable baseplate and removable	Contain not more than 30% by mass retained on	Mixture in CBR-type mould using an electrically powered vibrating hammer over a range of water	Application to mixtures used in road construction	Considered for further investigation

Test methods for laboratory reference density and water content - Vibrating hammer		water content (+relationship)	extension piece, Vibrating hammer (elec.),	the 20 mm sieve; not more than 10% by mass of the mixture retained on the 40 mm test sieve.	contents. The range includes the optimum water content at which the maximum dry density for the specified degree of compaction is obtained.		
CEN 00227125 prEN 13286-5 Unbound and hydraulically bound mixtures – Part 5: Test methods for laboratory reference density and water content - Vibrating table	Unbound and hydraulically bound mixtures (cohesionless material)	Max. dry density and water content	Vibrating table, moulds, Surcharge base plate, etc.	Up to 12% mass fines (< 0.063 mm), max. particle size of the materials to be tested is 80 mm.	The mixture is compacted in a mould by means of a load on the top of the mixture. The laboratory dry density and corresponding water content are determined.	Application to mixtures used in road material.	Considered for further investigation
DIN 1168-2:1975-07 Building Plasters, Requirements, Testing, Control	Building Plasters	Among other things: Water-gypsum-value	Mixer, table, table, etc.	Temperature: 18-25°C;	Measure of the diameter of the water-building plaster-mixture after it has been spread by operation (several impacts) of the table.	-	Considered and found not appropriate
ISO 13765-2:2001-12 Refractory mortars - Part 2: Determination of consistency using the reciprocating flow table	Refractory mortars	Consistency	Flow tables and mould, mixer, etc.	-	The consistency of a refractory mortar is assessed by the increase in diameter of a sample, when subject to mechanical agitation using a reciprocating flow table	-	Considered and found not appropriate

Table 10: Standards for thixotropic behaviour

3.2.2 Laboratory or field test feasibility

Due to the fact that many methods require large space and electrical power, the test methods have to be generally simulated in the laboratory. The energy-input resp. the vibration of the described apparatus mimics the transport conditions. For simple field test methods could be created a small-sized robust design of the laboratory method, which is driven electrically, if electric power is available, or manually by a hammer e.g.

3.2.3 Apparatus

The tests examined use the following types of apparatus:

- Vebe meter (Consistometer) (Fig. 19)
- Flow table (Fig. 20; Fig. 21)
- Vibrating table (Fig. 22)
- Vibrating hammer (Fig. 23)

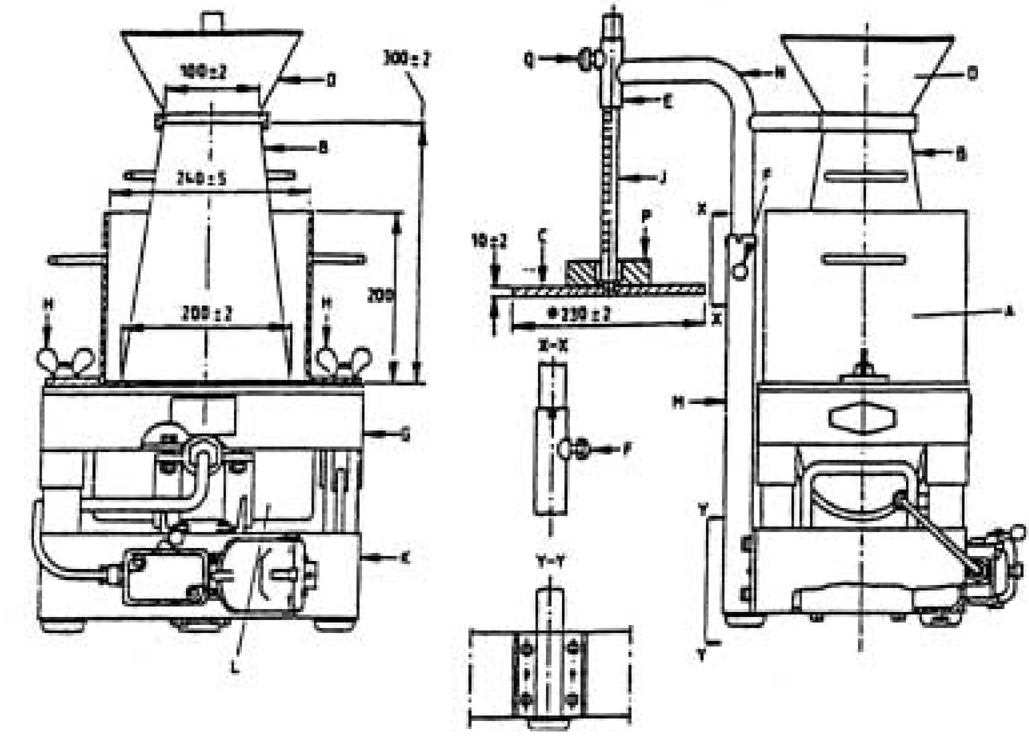


Fig. 19: Consistometer (Vebe meter, dimensions in mm) [43]

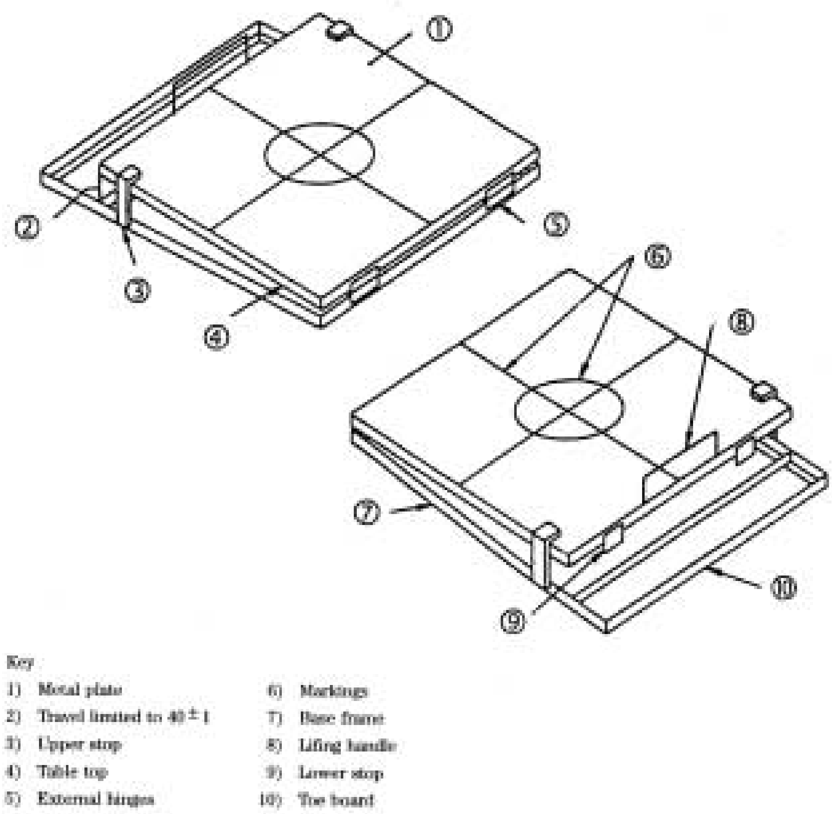
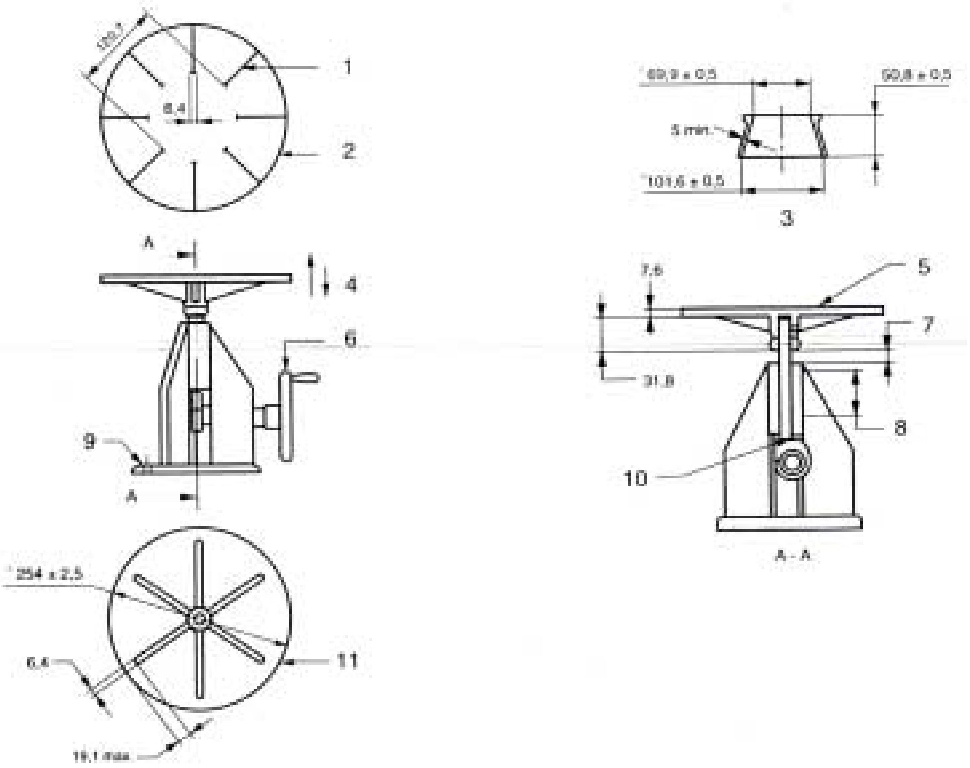


Fig. 20: Flow table [44]



Key

1 Lines to be scribed on face of table

2 Table (brass or bronze)

3 Conical mould

4 Movement of the flow table: up and down

5 Table to be fixed to shaft and total mass to be 4,1± 0,5 kg

6 Handle, or alternatively, motor drive through flexible shaft

7 Drop

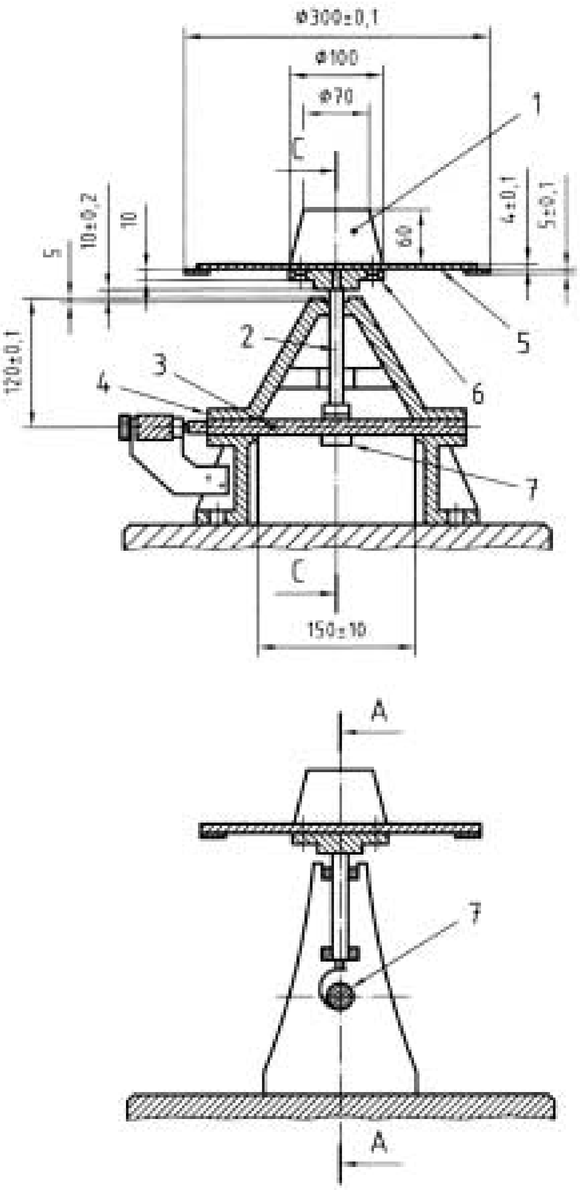
8 Machined to give a drop of 12,7± 0,1

9 Fixing holes

10 Hardened contact faces

11 View on underside of table

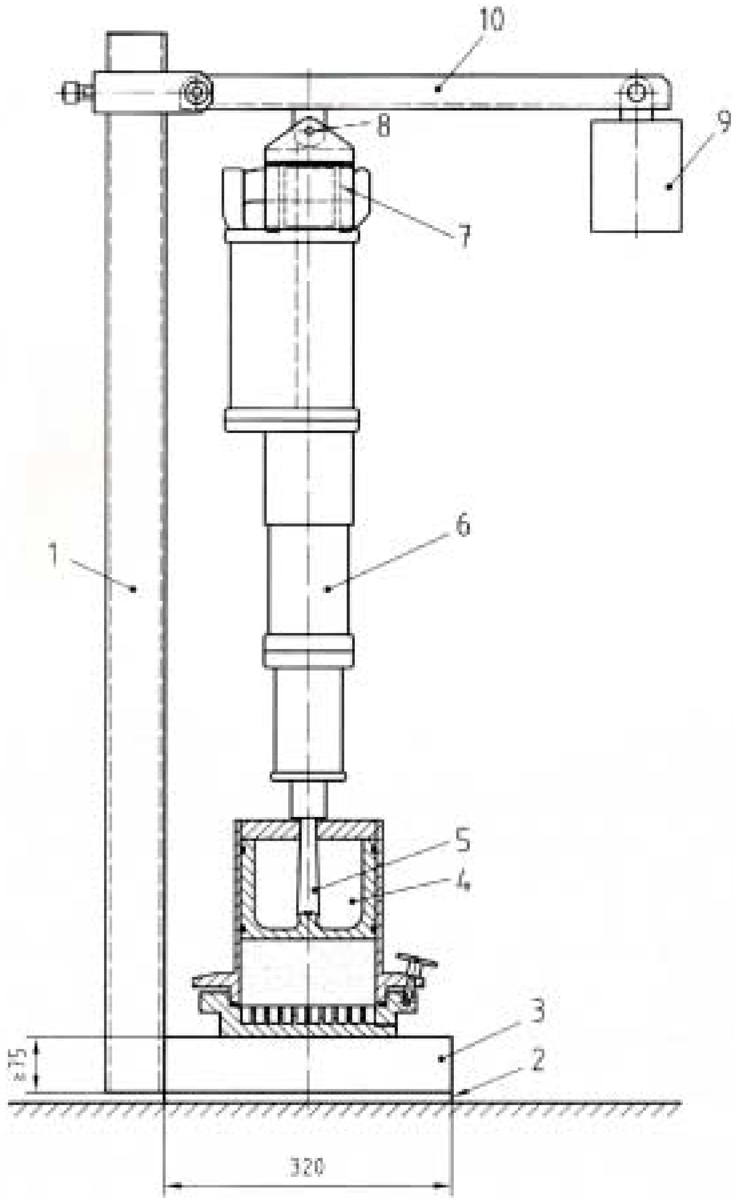
Fig. 21: Flow table and conical mould (dimensions in mm) [45]



Key

1 Truncated conical mould
2 Disc
3 Rigid table plate
4 Lifting cam
5 Stand
6 Horizontal shaft
7 Lifting spindle

Fig. 22:Vibrating table (dimensions in millimetre) [46]



Key

1	Support frame	6	Vibrating hammer
2	Rubber mat	7	Hammer grip assembly
3	Steel base, minimum area 0,1 m^2	8	Securing pin to allow hammer to hang vertically
4	Compaction mould and anvil	9	Surcharge mass
5	Shank	10	Lever arm

Fig. 23: Compaction rig assembly with vibrating hammer (dimensions mm) [47]

3.2.4 What is measured and how

For testing fresh concrete with the Vebe meter described in *BS EN 12350-3* the time taken for the surface of a disc to be fully in contact with the grout is measured (Vebe time). This time should be in the range of 5 to 30s. For determination of the degree of compactibility described in *BS EN 12350-4* the concrete is compacted by vibration. The distance from the surface of the compacted concrete to the upper edge of the container is used to determine the degree of compactibility. For determination of the consistency of concrete with the aid of a flow table described in *BS EN 12350-5* the spread of concrete (diameter) on a flat plate, which is subjected to jolting, is measured. In a similar way the standard *BS EN 13395-1* operates with mortars (cp. also *EN 1015-3*).

For determination of the density and water content of unbound and hydraulically bound mixtures samples in a CBR-type mould using an electrical powered vibrating hammer described in *prEN 13286-4* including a range of water contents have to be create of. The range includes the optimum water content at which the maximum dry density for the specified degree of compaction is obtained. Another apparatus for compaction is a Vibrating table described in *prEN 13286-5:* The mixture is compacted in a mould by means of a load on the top of the mixture. Then the laboratory dry density and corresponding water content are determined.

For the method described in *DIN 1168-2* the diameter of the water-building plaster-mixture is measured after it has been spread by operation (several hubs) of the table.

In the method described in *ISO 13765-2* the consistency of a refractory mortar is assessed by the increase of the diameter of a sample, when it is subjected to mechanical agitation using a reciprocating flow table.

3.2.5 Material to be examined

The tests are mainly employed for the following materials

- Fresh concrete
- Hydraulic cement mortars
- Unbound and bound mixtures
- Building plasters
- Refractory mortars

3.2.6 Feasibility of the methods to the materials for the Horizontal project

Important for the feasibility of methods for determination of the thixotropic behaviour for all materials of interest is the combination of penetration tests and energy input. This input can be applied electrically by vibrating apparatus or manually by hubs or knocks. For Horizontal project in general all energy-input-apparatus are suitable. To simulate transport conditions the vibrating apparatuses are well appropriate, whereby especially the external apparatuses like vibrating table are rather suitable than the internal apparatuses like vibrating hammer. Also the handling with the test samples is important (preparation, size of moulds, etc.). These items have to be determined in further investigations.

3.3 Piling behaviour

- Slump test apparatus
- Compacting apparatus (e.g. Oedometer)
- CPB- Cubic piling box (after E. Pasqualini [48])
- "Turned Box"

3.3.1 Standards and non-standardised methods analysed

The examined methods for the determination of piling behaviour of different substances are reported in Table 11:

Method	Material	Para-meter	Appara-tus	Standard range	Physical meaning/purpose	Utility/ field	Evaluation
ASTM C143/C143M-00 Standard Test Method for Slump of Hydraulic-Cement Concrete *ASTM C143-74 (-78)*	Hydraulic cement concrete	Consistency (slump)	Mould	Up to 37,5 mm in size, not applicable to non-plastic and non-cohesive concrete	Concrete is placed and compacted in a mould. The mould is raised, and the concrete allowed subsiding. The vertical distance between the original and displaced position of the centre of the top surface of the concrete is measured and reported as the slump of the concrete.	Laboratory and field method to test the consistency of hydraulic cement concrete	Considered and found not appropriate
BS 1881-102:1983 Testing Concrete – Part 102: Method for determination of slump	Concrete	Slump (Consistency),	Mould, etc.	Slump 5-175 mm, max. particle size 40mm	Filling the mould in three layers, tamping each layer, raising the mould vertically. Measuring the slump: determination of the difference between the height of the mould and the highest point of the sample being tested	Classification of the workability (table)	Considered and found not appropriate
BS 1881-103:1993 Testing Concrete – Part 103: Method for determination of compacting factor	Concrete	Compacting factor (Consistency),	Sampling tray, Compacting factor apparatus, etc.	Max. particle size 40mm, compacting factor: 0.70-0.98; > 30 strokes per layer	After preparation weigh the cylinder and its contents. Mixing with concrete of the same sample, place in a cylinder and compact each layer by using compacting apparatus; weigh the cylinder. Compact the sample once more. Calculate the ratio: mass of the partially-compacted concrete / mass of the fully compacted concrete.	Classification of the workability (table)	Considered and found not appropriate
BS EN 1170-1:1998 Precast concrete products – Test method for glass-fibre reinforced cement. Part 1: Measuring the consistency of the matrix – "Slump test" method	Glass-fibre reinforced cement	Consistency,	Plastic or metallic tube, flat plate with nine numbered concentric circles etc.		Sample (200cm³) is filled in the tube, lift the tube vertically; after 30s read the number of the circle reached by the spreading matrix	water-cement ratio (suitability for pumping and compaction)	Considered and found not appropriate
ASTM D2435-96 Standard test method for one-dimensional	Soil	Compression index, Young	Oedometer	Minimum sample diameter-to-height ratio =	Soil is placed into a mould and then subjected to incrementally applied	Compressibility and settlement evaluation /	Considered for further investigation

consolidation properties of soils		modulus		2.5 Minimum diameter = 5 cm	controlled-stress vertical loading. Settlements are measured. Primary and secondary compressibility is determined, as well as rate of consolidation.	in the laboratory	
CPB test: Cubic piling box [48]	Particular and lightly compacted materials (soil, waste, etc.)	Piling behaviour	Cubic piling box	Minimum dimensions are related to the grain size of the material to be tested	Material is placed into the box and then the sidewalls are overturned. The natural slope angle of the remaining material is assessed	Determination of the piling angle of loose materials	Considered for further investigation
"Turned Box" [Method in France]		Piling behaviour	Rectangular Box		*Comment: Further informations are necessary.*		

Table 11: Standards and non-standardised methods for piling behaviour

3.3.2 Laboratory or field test feasibility

These test methods are mostly performed in the laboratory, because they require a lot of preparation. Special field test methods for determination of the piling behaviour don't exist so far. But for some apparatuses it is possible to create for simple field tests a small-sized robust design of the laboratory apparatus according to the analysed material.

3.3.3 Apparatus

The tests examined use the following types of apparatus:

- Moulds, if needed: laboratory tools (results: Fig. 24)
- Compacting apparatus (e.g. Oedometer) (Fig. 25; Fig. 26; Fig. 27)
- Plastic or metallic tube, flat plate

Besides these apparatuses another types of apparatuses, which are not reported in the standards, but may be considered as a promising tool to test the piling behaviour of the analysed materials, are the following apparatuses:

- Cubic Piling Box (CPB) (Fig. 28; Fig. 29)
- "Turned Box"

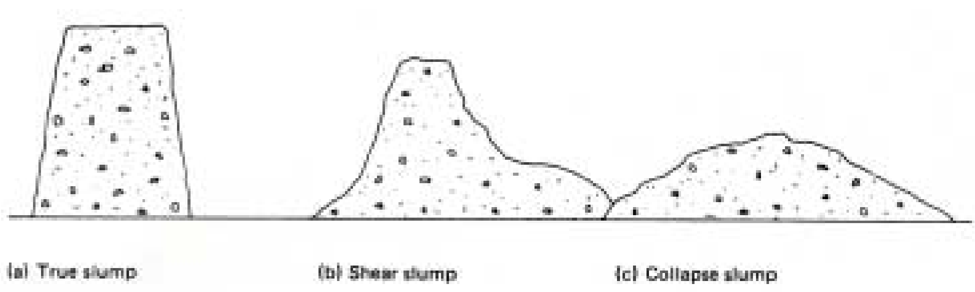


Fig. 24: Forms of slump [49]

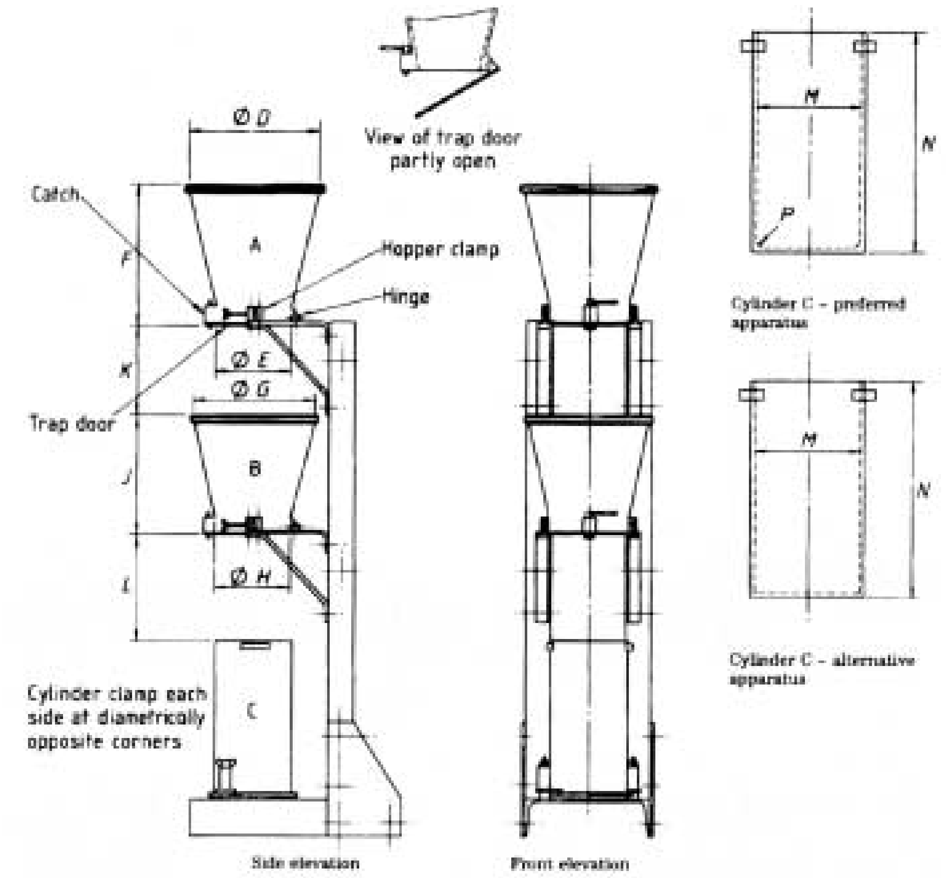


Fig. 25: Compacting factor apparatus [50]

A special form of compacting apparatus is the Oedometer

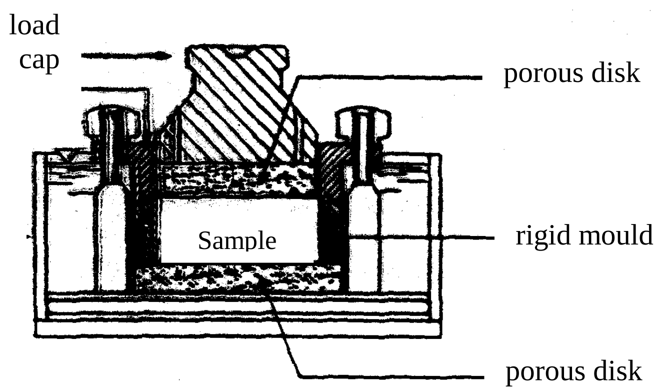


Fig. 26: Oedometer [48]

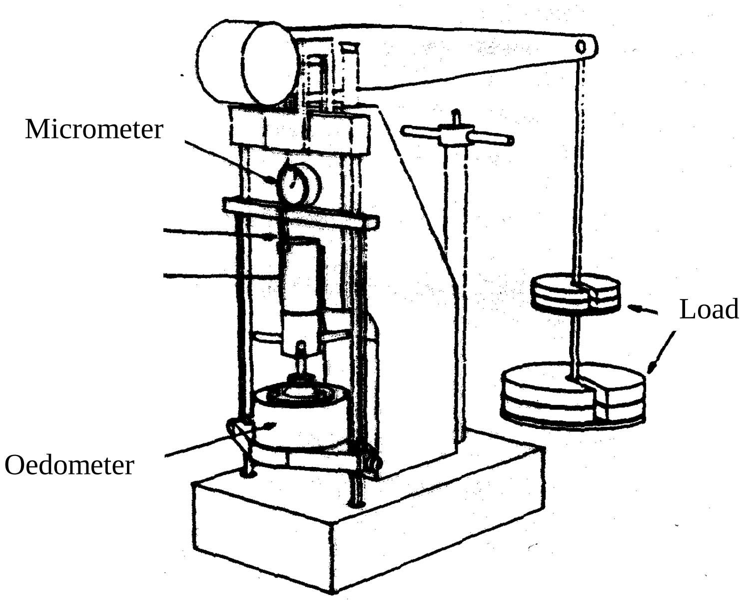


Fig. 27: Device for loading [48]

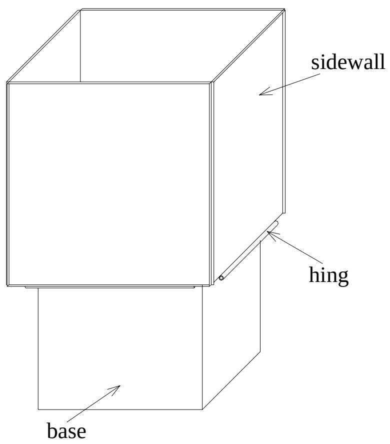


Fig. 28: Cubic Piling Box at start of test (closed sidewalls) [48]

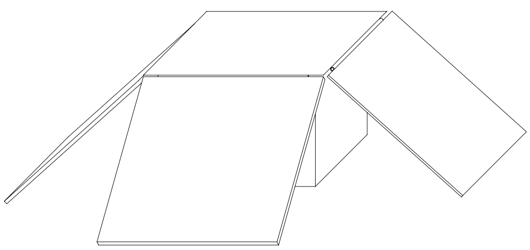


Fig. 29: Cubic Piling Box at the end of test (opened sidewalls) [48]

3.3.4 What is measured and how

For the determination of the slump of hydraulic cement and concrete the sample is placed and compacted in a mould. The mould is raised, and the concrete allowed subsiding. The vertical distance between the original and displaced position of the centre of the top surface of the concrete is measured and reported as the slump of the concrete.

For the determination of the Compacting factor within 150s of placing the sample in the upper hopper from the compacting apparatus the cylinder and its contents are weighted. After that, the concrete in the upper hopper is mixed with concrete of the same sample, place in a cylinder in six layers and compact each layer by using either the compacting bar or the vibrator (hammer); weight the cylinder again. Stroking with the compacting bar or use Vibrating hammer/ table. Calculate the ratio of the mass of partially compacted concrete dividing by the mass of fully compacted concrete.

Another variant to determine the slump is following method: The sample (200cm^3) is filled in a tube placed on a table with several circles, then the tube is lifted vertically; after 30s read the number of the circle reached by the spreading matrix. This test method needs a special flow table with some circles; due to the spreading the slump is determined “horizontally”, not “vertically” like the other slump test methods.

The Oedometer test method covers procedures for determining the magnitude and rate of consolidation of soils when it is restrained laterally and drained axially while subjected to incrementally applied controlled stress loading. According to the standard procedure, the test is performed with constant load increment duration of 24 h. The specific loading schedule will depend on the purpose of the test. Each stress increment is maintained until excess pore water pressure is completely dissipated. During the consolidation process, measurements are made of change in the sample height and these data are used to determine the relationship between the effective stress and void ratio or strain, and the rate at which consolidation can occur by evaluating the coefficient of consolidation. The data from the consolidation test are used to estimate the magnitude and the rate of settlement of structures and embankments.

The test method with the aid of the Cubic Piling Box (CPB) can be used for determining the piling angle (angle of rest) of pieces. The particular material is placed into the box and, if necessary, it can be compacted. Then the sidewalls are suddenly overturned and the stable final configuration is surveyed. The natural slope angle of the remaining material can be measured on each side of the sample remaining on the box base.

3.3.5 Material to be examined

The tests are mainly employed for the following materials

- Hydraulic cement (concrete)
- Concrete
- Glass-fibre reinforced cement
- (Fine-grained) soils
- (Solid) waste

3.3.6 Feasibility of the methods to the materials for the Horizontal project

The standardised methods like slump tests require a certain threshold of consistency of the materials of interest. For determination of the piling behaviour new methods were developed, for example the "Turned Box" and the "Cubic Piling Box", which were created in France and Italy [48] respectively.

As far as piling behaviour is concerned, the Oedometer test can be used to characterize the compressibility of the material and to have an indication of how much a stratum of piled material can settle due to the loading of the material placed above. For piling behaviour, the selection of the loading schedule (maximum value, load increments and the duration of each increment) will be defined on the basis of the total height of piling and of the piling sequence. In particular, the maximum load will be necessarily lower that that used according to the standard for soils. The size of the mould that contains the sample can vary on the basis of the maximum grain size of the material to be tested.

The CPB test [48] can be easily performed on particular pieces like dewatered sludges, waste and soils, etc. as well as on cohesive materials e.g. compacted materials. As far as piling behaviour is concerned, the CPB can be used to immediately and easily assess the natural slope angle of a material.

4. CRITICAL POINT AND RECOMMENDATIONS

In this section mainly the methods with the expression “Considered for further investigation” in the column “Evaluation” in chapter 3 are discussed.

Standardisation procedures for Horizontal material examination will consist of

- Sampling, transport, preservation, storage
- Pre-treatment
- Measurement and evaluation of results.

4.1 Solidity

4.1.1 Comparison (discussion: pro/contra)

Laboratory vane shear apparatus

In general the “Vane shear strength” is one of the most commonly used parameter in the field of soil mechanics. There do exist a lot of standards. In Germany e.g. also exists such a parameter in the field of waste disposal / landfilling: For landfilling of wastes the *TA Siedlungsabfall (1993)* [14] gives a minimum value for the solidity of 25 kN/m². The vane shear strength of sewage sludge depends in some extent on the dry solid content, but there does exist no good correlation for different sludges. For the laboratory method there are two similar apparatus described in *ASTM D4648* and *ATV-Arbeitsbericht* [35, 23].

Contra: For reliable measurements of the vane shear strength the investigated materials have to be cohesive. Therefore the vane testing apparatus can't be applied for non-cohesive materials like coarse-grained soils.

Pro: Due to the fact that some investigations with sewage and waterworks sludges made by the laboratory vane shear apparatus (*ATV-Arbeitsbericht* and *Wichmann et al.* [23, 15]), this method should be preferred as the laboratory reference method. The calculation of the shear strength - after sample preparation and measurement -consists of the following equations after *Zweck 1969* [51]):

$$\tau_v = \frac{M}{K}[kN / m^2] \qquad \text{(Eq. 4)}$$

where M: max. torque in [kN m],

K: $$\frac{\pi}{2} \cdot d^2 \cdot h \cdot (1 + \frac{d}{3h})[m^3] \qquad \text{(Eq. 5)}$$

where d: diameter of the sheared cylinder = width of the vane,

h: height of the vane.

The shear strength τ_v is equal to the cohesion c_u of the undrained soil by (fast) shearing. For h = d:

$$\tau_v = \frac{3 \cdot M}{2 \cdot \pi \cdot d^3} \qquad \text{(Eq. 6)}$$

For a constant shear rate the vane should be driven electrically e.g. with a velocity of 10 degree per minute, because the measured shear strength is influenced by the shear rate.

The characteristics of this apparatus are [16]:

- length of time: ca. 60 minutes (for 3 measurements)
- good handling (motorised test procedure)
- reproducibility of test values (average +/- 10 %)
- measuring range: 1- 180 kN/m^2.

Another investigated vane testing apparatus - pocket vane shear apparatus - with several vanes of different sizes was not as suitable as other methods for determining the shear strength of materials with lower dry solids content. This aspect was pointed out by investigations performed with waterwork sludges (*Wichmann et al.* [15]).

<u>Penetrometer</u>
The described apparatuses are suitable to obtain reliable results of the measurements in both laboratory and field.

Contra: The procedures with penetrometers are time-dependent. The measurement has to be carrying out within a fixed duration of e.g. 5 seconds. This aspect affords a precise test execution.

Pro: The advantage is the great variation of the penetrometer tip according to the investigated material. There does exist a range of different tips in form of a plunger, a cone or a needle. That is why several methods are considered for further investigations. Explicit determinations, what kind of tip for a special material is the best, have to be investigated in further experiments. The procedure of calculation is quite simple: According to *Hansbo (1957)* [55] the sludge cohesion (undrained shear strength c_u) can be derived from the cone penetration depth using the empirical equation:

$$c_u = \frac{K \cdot m \cdot g}{i^2} \cdot \left(1 + \frac{h}{i}\right) \qquad \text{(Eq. 7)}$$

where m: mass of the cone,
g: acceleration of gravity,
i: depth of penetration (indentation),
h: distance between cone apex and soil surface when the cone is dropped (normally h = 0),
K: function of the apex angle of the cone (Fig. 30).

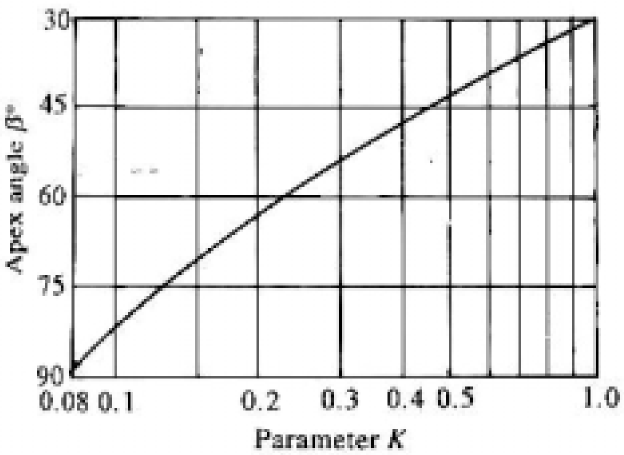


Fig. 30: Relation between the parameter K and the apex angle β of the cone

Further advantages are[16]:

- length of time: ca. 5 minutes (for 3 measurements)
- very good handling
- reproducibility of test values (average +/- 10 %)
- costs: ca. 40 % of the Laboratory Vane Shear Apparatus

Vicat apparatus

The Vicat apparatus is a special kind of a penetration apparatus and has a tip in terms of a needle. In particular the beginning and end of solidification is measured, that means it could be verify shear strength. This aspect has to be developed in further investigations; it is one part of research needs in the field of determining solidity.

Contra: Because of the shape of the penetration tip this apparatus could be only suitable for solid materials like dewatered sludges, particular treated bio-waste and soil. In further investigations this assumption has to be confirmed.

Pro: The Vicat apparatus is a special penetration apparatus, which operates time-independent. For the measuring procedure there is a fixed depth, which the needle has to be reached. For determining the consistency of materials this aspect could be much more comfortable during the measurements.

Pocket penetrometer

Pro: A promising tool for simple field tests – determination of the penetrometer bearing capacity p_P – is the pocket penetrometer after Neuschäfer. After sample preparation and performance the value of penetration resistance can be read directly on the scale of the penetrometer. The penetrometer bearing capacity is determined with the aid of a nomogram, whereby the average of the values, which are indicated by the scale within three measurements, and the factor of the cone tip (see Fig. 17) are the input values. Furthermore the obtained value can be converted to the parameter "vane shear strength τ_v" by a regression line e.g. for waterworks sludges (Fig. 31). In general the equation for the regression line [23] is determined as

$$\tau_v = (-0,56) + 0,156 \cdot p_P \qquad \text{(Eq. 8)}$$

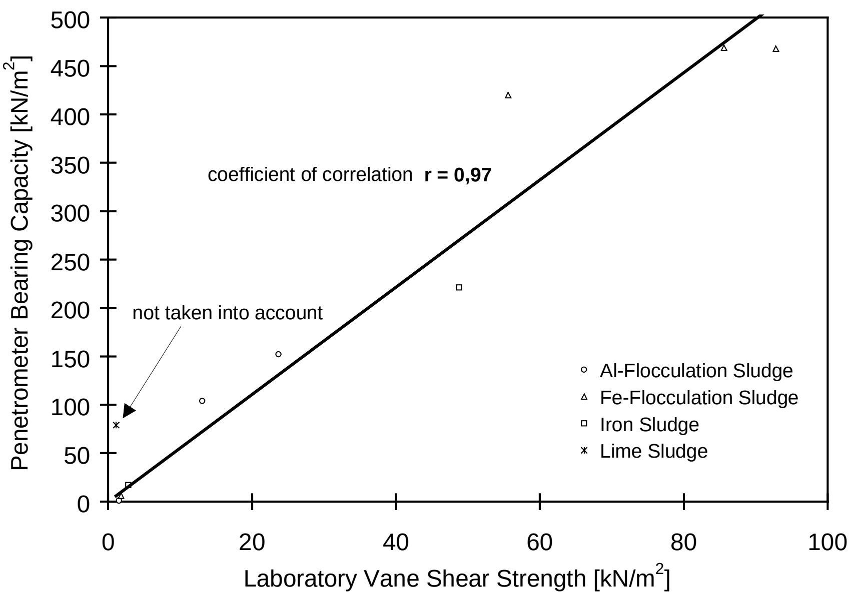


Fig. 31: Comparison penetrometer bearing capacity vs. laboratory vane shear strength [16]

Further advantages of this method are [16]:

- consisting several cone tips for a wide range of materials
- length of time: ca. 5 minutes (for 3 measurements)
- good handling
- reproducibility of test values (average +/- 8 %)
- measuring range: 0 - ca. 90 kN/m^2 (Vane Shear Strength)
- low costs: ca. 8 % of the Laboratory Vane Shear Apparatus.

<u>Pocket cylinder penetrometer</u>
Contra: Only a few investigations were carried out in the past. For certain conclusions further investigations will be necessary.

Pro: However, this penetrometer can be also a capable apparatus for field tests, in this case for measuring the unconfined compression strength q_u. The *TA Siedlungsabfall (1993)* [14] gives for landfilling of wastes a minimum value for the unconfined compression strength of 50 kN/m^2 with an axial deformation of max. 20%. It could be a helpful tool for the choice of the best suitable instrument, that there do exist such default values. The unconfined compression strength is related to the undrained shear strength c_u in terms of Eq. 3 (compare chapter 1.6.1): $q_u = 2 \cdot c_u$.

Further characteristics are [16]:

- length of time: ca. 5 minutes (for 3 measurements)
- very good handling
- reproducibility of test values (average +/- 8 %)
- low costs: ca. 6 % of the Laboratory Vane Shear Apparatus

4.1.2 Recommendations

For the determination of the shear strength it is recommended that the triaxial test should be the absolute laboratory reference method (e.g. after *DIN 18137-2* [52]).

4.1.2.1 Laboratory reference method

Method 1: Laboratory vane shear apparatus (ATV-Arbeitsbericht 1989)
Method 2: Penetrometer (cone or needle)
Method 3: Vicat apparatus

4.1.2.2 Field test

Method 1: Pocket penetrometer after Neuschäfer
Method 2: Pocket cylinder penetrometer

4.2 Thixotropic behaviour of solid materials

4.2.1 Comparison (discussion: pro/contra)

For standardisation of the thixotropic behaviour of solid materials a combination of standardised methods will be determined. Because of the experiences of the experts committee the combination "Penetrometer + energy-input" will be preferred. The advantage of penetrometers was already explicated in section 4.1.1. The energy input can be applied electrically by vibrating apparatus or manually by hubs or knocks. In the following only the apparatuses for the energy-input are described:

Contra: Vibrating hammer
The vibrating hammer is an internal apparatus. During the measurement of the thixotropic behaviour this instrument could influence the procedure and therefore the results would be not certain.

Pro: Vibrating table
To simulate transport conditions the vibrating apparatuses, especially external apparatuses, are rather suitable than the internal apparatuses or the hand-made methods. For laboratory reference the apparatus can be more exact and thus more complex than a simple field method.

For simple field test methods could be create a small-sized robust design of the laboratory method, which is driven electrically, if electric power is available, or manually by a hammer e.g.

4.2.2 Recommendations

4.2.2.1 Laboratory reference method

Method 1: Penetrometers + energy-input (e.g. vibrating table)

4.2.2.2 Field test

Method 1: Penetrometers + energy-input (e.g. vibrating table: small-sized apparatus, which should be easy to operate)
Method 2: Penetrometers + energy input (e.g. by a hammer, if electric power is not available; adequate mould)

4.3 Piling behaviour

4.3.1 Comparison (discussion: pro/contra)

Oedometer
The strain condition of a material due to piling are different from those in the Oedometer, where lateral strain are prevented. Nevertheless, if the material is piled in lifts that are large enough in comparison with their height (three times at least), oedometic strains can be considered as representative. The settlement of the lower portion of the material can be evaluated.
The minimum sample diameter and height should be 20 cm in order to test a representative volume of material. To avoid or reduce the friction at the interface between the material and the ring as negligible a film of grease should be placed on the internal wall of the mould before placing the sample. A compaction mould for Proctor compaction (ASTM D698-91 [53]) can be used as well.

Pro: Important advantages of this method are that the procedure is well known – it is a Standard in France and USA and an overall method in practise in many other countries - and it is easy to handle. From there this method should be preferred as an additional laboratory reference method.

Cubic Piling Box (CPB)
The Cubic Piling Box should be preferable to the French method (No ref. 256, cp. Annex 1) because the friction between the sidewalls and the material to be tested does not affect the final result in terms of slope angle. The influence of the CPB dimension on the slope angle should be negligible provided that the side of the box is much greater of the maximum grain size of the sample. This method was originally proposed for solid waste materials having a maximum grain size of about 5 cm (Pasqualini et al., 2003 [48]). In that case, the sides of the cubic box were equal to 60 cm. For other materials a minimum of 30 cm x 30 cm should be considered in order to test a representative volume of material. The dimension of the cubic box should be at least 5

times greater than the maximum grain size of the sample to be tested. For detailed results of other materials for Horizontal project further investigations are necessary.

Pro: Important advantages of this method are the very simple handling, the feasibility to both in the laboratory and in situ, no specialised personnel and the great variability due to the different sizes of the Cubic Piling Box related to the grain size of the material.

4.3.2 Recommendation

4.3.2.1 Laboratory reference method

Method 1: Cubic Piling box (CPB)
Method 2: Oedometer

4.3.2.2 Field test

Method 1: Cubic Piling Box (CPB)

4.4 Summary of recommended methods

The following Table 12 gives an overview of the recommended apparatuses and methods for determination of the solidity, thixotropic behaviour and piling behaviour.

Method (Apparatus)	**Solidity**	**Thixotropic behaviour of solid materials**	**Piling behaviour**
Penetrometer	***Shear strength*** **(Lab / field)**	***Shear strength*** **(Lab*/field$^{+/**}$)**	
Vicat apparatus	***Shear strength*** **(Lab)**		
Laboratory vane shear apparatus	***Vane shear strength*** **(Lab)**		
Pocket penetrometer (Neuschäfer)	***Bearing capacity*** [1] **(Field)**		
Pocket cylinder penetrometer	***Unconfined compression strength*** [2] **(Field)**		
Vibrating table		***Shear strength*** **(Lab*/ field^{+})**	
Hammer (manual)		***Shear strength*** **(Field**)**	
Cubic piling box (CPB)			***Piling angle*** **(Lab/field)**
Oedometer			***Compactibility*** **(Lab)**

Combinations for thixotropic behaviour: *+*; $^{+}$+$^{+}$; **+**
[1] Conversion into shear strength is possible
[2] Conversion into undrained shear strength is possible.

Table 12: Summary of the recommended apparatuses

4.5 Research needs

4.5.1 Basics of methods

The mechanical property "solidity" can be determined directly by the shear strength or by the penetration bearing capacity resp. the unconfined compression strength, which could be both converted into shear strength. The measure of the shear strength during an energy-input in terms of vibration should describe the “thixotropic behaviour”. For the “piling behaviour” it is recommended to measure the compactibility and/or piling angle.

The proposed methods for determining the parameters mentioned above are either existing standards, methods used in practise or methods, which are still in a development stage. However, for improvement of the methodologies most of the procedures and used apparatuses have to be optimised by further examinations, especially for the materials, which are discussed in the Horizontal project. For all parameter do exist methods for both laboratory and field, whereby the field test results will be compared with laboratory ones used as reference.

4.5.2 Applicability of methods to Horizontal materials

Within the scope of this project the proposed methods should be applicable to the whole range of Horizontal materials (sludge, treated bio-waste and soil). Investigations in the past were often carried out only for several materials like sewage sludge or waterworks sludges for the parameter solidity or solid, particular bio-wastes for the parameter piling behaviour e.g.. But during these performed tests the influences of the material properties (grain size and shape, dry solids, etc.) were exhibit. By means of this knowledge it is possible to assume behaviour in general by using a special method.

For adaptation of methods for all materials mentioned above or for a more exact measure it is possible to vary the dimensions of the apparatuses: For example the cone size and shape or weight of the penetrometer tip according to the consistency of the investigated sample. Another example is to vary the size of the sidewalls of the Cubic Piling Box (CPB) according to the grain size of the investigated material. These variations are promising tools for optimisation the measuring procedures. Further examinations of the proposed methods, which have to be carried out in the future, should confirm the theoretical considerations.

Another item is the pre-treatment of the samples before carrying out the investigations. Especially a rough determination of the consistency before application of a special method could be advantageous for the measurement. Different types of sampling and pre-treatment are required for each method. Important for the pre-treatment are the parameters:

- particle size of the material,
- dimensions of the mould,
- compaction of the materials,
- moreover the density of the sample.

For example the pre-treatment for measuring the vane shear strength is explained as follows [23]:

(1) The material – if needed, dewatered – is reduced to small pieces with particle sizes of about 10 mm
(2) The mould – in this case the small Proctor vessel – has an internal diameter of 100 mm und a height of 120 mm.
(3) The material is filled into the Proctor vessel in three equal portions (each about 100 mm before compaction) and is compressed with ten knocks by the small Proctor hammer (falling weight of 2.5 kg, height of falling 300 mm, diameter of the plunger 50 mm, diameter of compensating plate 99,5 mm, compare *DIN 18127* [31]).

(4) After finishing emplacement and before test performance the density have to determined for a uniform starting position.

The procedure mentioned above could be transmitted to the pre-treatment of measuring the shear strength or related parameters - penetration bearing capacity and unconfined compression strength – in common and also for examination of the thixotropic behaviour, whereby the shear strength is measured during shear stress. For determination of the piling behaviour (piling angle) a pre-treatment in terms of reducing to small pieces with a uniform particle size - regarding the size of the sidewalls of the Cubic Piling Box (CPB) – is proposed. It should be a similar pre-treatment like the method for the shear strength, but instead of the Proctor vessel and hammer the CPB and, if needed, according compaction apparatuses are used. For further considerations it could be helpful to cooperate with the WP 2 "Sampling".

4.5.3 Questions to be answered

Research must define through interlaboratory tests precision, repeatability and reliability of methods proposed, where:

- *Repeatability* is defined as the ability of a method to reproduce a measurement while being tested under an unchanging set of conditions. This does not imply that the obtained value is correct, but rather that it is the same every time;
- *Reproducibility* is the same as repeatability, but at a different set of conditions. It is therefore a more realistic indication of a method to reproduce a measurement, whenever a predefined set of conditions is recreated.

However, as far as these methods are concerned the use of *fresh sludge* could be required, so the following problems arise:

- the sludge characteristics change with time of storage, also considered that any preservation practice (e.g. freezing) makes things worse;
- the sludge characteristics are strongly affected by transport and handling;
- fresh sludge requires particular precautions and authorization for transport by ordinary delivering systems.

4.5.4 Route, how to answer them

A protocol of validation of physical parameters will be prepared (Protocol for validation of physical parameter methods – CEN/TC308/WG1/TG3 – N29 (ref. [54] to be followed).

4.5.5 Steps to be taken

- ➢ Laboratory tests (cp. 4.5.4)
- ➢ Evaluation (cp. 4.5.4)
- ➢ Final proposal methods to be standardised (Research Report, Version 1)
- ➢ Consulting with CEN/TC's/WG's, etc.
- ➢ Revision of proposal for methods to be standardised (Research Report, Version 2)
- ➢ Interlaboratory tests included evaluation
- ➢ Final draft for methods to be standardised

4.6 Contacts with CEN/TC's/WG's

4.6.1 Actions

- 01.08.2003: Circulation of the first draft of "*Physical Properties – Solidity, Thixotropic Behaviour and Piling Behaviour – Desk Study"* (Horizontal report No. 22) with the list of standards researched (see Annex 1), proposals for draft standards (see Annex 2 – 12) and a cover letter (see Annex 13) to the members of
  - CEN/TC308/WG1,
  - CEN/TC308/WG1/TG3 and
  - Aldo Giove (member of the CEN/TC292/WG2).

  The comments, which were received until 08/20/2003, listed in Annex 14 with according comments from our side.

- 29.08.2003: Discussion of the first draft of Horizontal reports No. 21 and No. 22 during the CEN/TC308/WG1/TG's-meeting resp. the final CEN/TC308/WG1-meeting in Hamburg. Releasing the final versions of the first drafts of Horizontal reports No. 21 and No. 22; they will be circulated in professional groups and available for comments until 10/17/2003.

4.6.2 Comments received and incorporated

- 05.08.2003: Comments received from J-C. Baudez: (see Annex 14, commented)
- 08.08.2003: Comments received from R. Thierbach (see Annex 14, commented)

4.6.3 Official meetings

WP7-Meetings
- 12.02.2003 in Bergamo
- 04.04.2003 in Ancona
- 03-06.07.2003 in Ancona
- 24-28.07.2003 in Bari

CEN/TC308/WG1 – Meetings
- 26-28.03.2003 in Oslo
- 29.08.2003 in Hamburg

CEN/TC308/WG1/TG3 – Meetings
- 26-28.03.2003 in Oslo
- 28.08.2003 in Hamburg

5. DRAFT STANDARD (CEN TEMPLATE)

Note: For writing horizontal standards the structure of p. 14 of the guideline was used.

5.1 Solidity

5.1.1 Laboratory reference method

5.1.1.1 Method 1

Physical properties – Determination of solidity – "Vane shear strength": Laboratory reference method by 'Laboratory vane shear apparatus'

The proposal for this standard is documented in Annex 2.

5.1.1.2 Method 2

Physical properties – Determination of solidity – "Shear strength": Laboratory reference method by 'Penetrometer'

The proposal for this standard is documented in Annex 3.

5.1.1.3 Method 3

Physical properties – Determination of solidity – “Shear strength”: Laboratory reference method by 'Vicat apparatus'

The proposal for this standard is documented in Annex 4.

5.1.2 Field test

5.1.2.1 Method 1

Physical properties – Determination of solidity – "Bearing capacity": Field test by 'Pocket penetrometer'

The proposal for this standard is documented in Annex 5.

5.1.2.2 Method 2

Physical properties – Determination of solidity – “Unconfined compression strength”: Field test by 'Pocket cylinder penetrometer'

The proposal for this standard is documented in Annex 6.

5.2 Thixotropic behaviour of solid materials

5.2.1 Laboratory reference method

5.2.1.1 Method 1

Physical properties – Determination of thixotropic behaviour – "Solid materials": Laboratory reference method by combination of 'Penetrometer and Vibrating table'

The proposal for this standard is documented in Annex 7.

5.2.2 Field test

5.2.2.1 Method 1

Physical properties – Determination of thixotropic behaviour – "Solid materials": Field test by combination of 'Penetrometer and Vibrating table'

The proposal for this standard is documented in Annex 8.

5.2.2.2 Method 2

Physical properties – Determination of thixotropic behaviour – "Solid materials": Field test by combination of 'Penetrometer and Hammer '

The proposal for this standard is documented in Annex 9.

5.3 Piling behaviour

5.3.1 Laboratory reference method

5.3.1.1 Method 1

Physical properties – Determination of piling behaviour – "Piling angle": Laboratory reference method by 'Cubic Piling Box (CPB)'

The proposal for this standard is documented in Annex 10.

5.3.1.2 Method 2

Physical properties – Determination of piling behaviour – "Compactibility": Laboratory reference method by 'Oedometer test'

The proposal for this standard is documented in Annex 11.

5.3.2 Field test

5.3.2.1 Method 1

Physical properties – Determination of piling behaviour – "Piling angle": Field test by 'Cubic Piling Box (CPB)'

The proposal for this standard is documented in Annex 12.

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ANNEX 1

ANNEX 2

ANNEX 3

ANNEX 4

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ANNEX 10

ANNEX 11

ANNEX 12

ANNEX 13

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ARBEITSBEREICH
WASSERWIRTSCHAFT UND
WASSERVERSORGUNG
PROF. DR.-ING. KNUT WICHMANN

CEN/TC308/WG1

CEN/TC308/WG1/TG3

M. Aldo Giove

Hamburg, 01.08.03
Th

Horizontal WP 7 "Physical Parameters"
1. Draft Report of Desk Study No. 22 "Solidity, Thixotropic Behaviour and Piling Behaviour"

Dear all,

in the annex "HorizontalNo22_010803.pdf" , "annex1_010803.pdf" and "annex2_010803.pdf" you will find the first draft of our desktop study report on "Solidity, Thixotropic Behaviour and Piling Behaviour". Please give us your comments until Wednesday, 20. August 2003 by email to below address.

All the comments received will be discussed at the Hamburg meeting of CEN/TC308/WG1/TG3 on 28.08.03 and of CEN/TC308/WG1 on 29.08.03.

The final version will be prepared at the end of the WG1 meeting in order to be sending to the coordinators on HORIZONTAL by 31. August 03 (absolute deadline).

Many thanks for your cooperation.

Kind regards,

K. Wichmann / C. Thormählen

ANNEX 14

08/05/2003: Jean-Christophe Baudez:

Dear Claudia,
I read your paper. My comments are below.

1- About thixotropy (p 20), I think there is a misunderstanding between thixotropy and viscoelasticity. You wrote "it changes from the liquid to the solid state and vice versa ... many polymers are thixotropic". Many polymers are viscoelastic, defined by three regions: first, a linear viscelastic behavior, then, a non-linear viscoelastic behavior, and finally, depending the structure, a viscous behavior or a rupure. (Pasty sewage sludge exhibits similar behavior, Baudez and Coussot, 2001, in Journal of Rheology).

Comment: I deleted the text passage about the polymers and added in chapter 1.6.2 some items about thixotropic behaviour resp. thixotropy in general (measuring procedures, etc.). Furthermore I integrated the material behaviour in stress-strain relationship in chapter 1.6.1 about solidity.

2- For the Vane Shear Strength, I think the strain (or rotation angle) should be recorder with time during each experiment. Some solid sludge must be elastic, and recording the shear strain during with the vane test is one of the methods to highlight this behaviour.

Comment: It's a good idea, for some operations like transportation or pumping it makes sense to integrate a time-measuring device to display the material behaviour during the shear period.

Proposal for incorporated text (p.54):
“Furthermore it is recommended (see comments from J-C. Baudez, Annex 14) to integrate a time-measuring device in the test procedure to record the strain (or rotation angle) depending on the time. This method can highlight the elastic behaviour, which is shown by some solid sludge.”

3- What do you mean by "flow table"? The inclined plane test? If so, you can read a paper written by P Coussot in Rheologica Acta, in 1995 (I think).

Comment:

4- About slump test, please, find in attached file a paper which summarize the principles and uses.

Comment: These aspects will be included in the Horizontal report No.21.

Sincerely yours,
____
Jean-Christophe Baudez
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F-03150 Montoldre
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Attached: 12_133.pdf

08/05/2003: Roland Thierbach:

In "HorizontalNo.22" wird unter 3.2 die Thixotropie behandelt, unter 3.2.4 "What is measured and how" wird jedoch mit keinem Wort darauf eingegangen wie ebendiese gemessen wird.

In "HorizontalNo. 22" the chapter 3.2 is about Thixotropy, but under 3.2.4 "What is measured and how" the measuring procedure of Thixotropy isn't explained in details.

Comment: In this report merely the thixotropic behaviour should be described. For this reason the measuring procedure of thixotropy generally needn't describe in details. In chapter 1.6.2 I specified the determination of the thixotropy resp. the hysteresis area, whose size display the degree of thixotropy.

Wäre es nicht sinnvoll, die Zahl der ausgewählten Messverfahren noch weiter zu begrenzen? (Generell würde ich immer Verfahren bevorzugen, die ein Ergebnis in einer SI-Einheit haben.)

Make it sense, to limit the number of the selected methods? (In general I 'd like preferring procedures with results in SI-unit).

Comment: In our opinion at the beginning of research it is important to consider a wide range of methods for further investigations. These further investigations including test series should confirm the theoretical considerations or not. In this stage it makes sense to limit the test methods.

Die Reporte 21 und 22 scheinen sich in weiten Teilen zu überschneiden. Wäre es nicht sinnvoll sie zusammenzufassen?

The reports No. 21 and 22 seem to be equal in some parts. Make it sense to summarise these reports?

Comment: Yes, some parts in both reports are equal. This aspect is mentioned in the last passage of chapter 1.2. But there are two different applications and it is reasonable to distinguish the mechanical properties on the one hand in flowability and on the other hand in solidity together with the thixotropic and piling behaviour. In addition a common report will be very extensive and consequently very large.

Es stecken einige grammatikalische Fehler drin; bei manchen Passagen merkt man deutlich, dass sie ein Deutscher geschrieben hat. D.h. es sollte noch mal ein "native speaker" drüberschauen.

There are some grammatical mistakes; in some text passage it is quite evident that a non-native speaker wrote this text. From there a native speaker should read it once more.

Comment: Yes, I agree with you.

Gibt es (neben der Viskosität) Korrelationen zwischen den behandelten Parametern und dem Druckverlust der bei der Förderung von Schlämmen in Rohrleitungen anfällt? Wenn ja, wäre es sinnvoll diese mit aufzunehmen?

Is there – beside the viscosity - any correlation between the examined parameters and the loss of pressure, which appears during the conveyance of sludges in pipes? If so, make it sense, to include these parameters in the report?

Comment: This is a question for the flowability-report (No.21), that's why I forwarded this item to the experts of flowability.

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