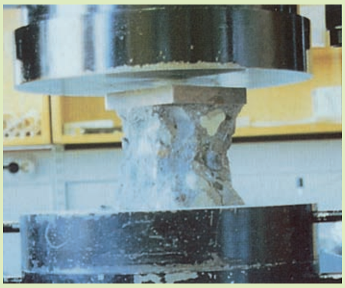
THE UNITED REPUBLIC OF TANZANIA
MINISTRY OF WORKS



CML
CENTRAL MATERIALS LABORATORY

Laboratory Testing manual

2000

THE UNITED REPUBLIC OF TANZANIA
MINISTRY OF WORKS

Laboratory Testing Manual 2000

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Preface

The importance of standardized and consistent test procedures in road construction in order to establish quality can not be over emphasized.

This Manual describes the procedures for laboratory testing of road construction and building materials carried out at the Central Materials Laboratory (CML). The test procedures are in essence based on British Standard (BS) for testing of soils, aggregates and concrete. American Society for Testing and Materials (ASTM) have been used for asphalt testing. These procedures are in accordance with the requirements referred to in the Ministry of Works, Pavement and Materials Design Manual of 1999 and Standard Specifications for Road Works of 2000.

It has been said that, " One test result is worth a hundred expert opinions", but this is only true if such a result is truly accurate and relevant for its application. In practice, it is essential that test procedures are clearly specified and that their fields of application and limitations are clearly understood. It is in this context this Manual has been compiled, although simplified to a more practical approach to make it easier to do the tests. However, after saying so the performances of the tests are in accordance with the relevant standards i.e. BS and ASTM.

The described test procedures are standards for testing of road construction materials and shall under no circumstances be diverted from. Hence, consistent and high quality laboratory routines are essential, so are the quality assurance of test results and test equipment. Only these can produce reliable results, which can be used to predict and explain the performance of road construction materials.

Preparation of this Manual has been a component under the Institutional Co-operation between the Ministry of Works and the Norwegian Public Roads Administration (NPRA) to support and improve the capacity at the Central Materials Laboratory (CML). The Government of Tanzania and the Norwegian Agency for International Development (NORAD) have jointly financed the project.

Central Materials Laboratory, Dar es Salaam June, 2000

Danford. J. Mariki

Ag. Chief Engineer/CML

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This Laboratory Testing Manual – 1999 has been prepared as a component under the Institutional Co-operation between Ministry of Works (MoW), Central Materials Laboratory (CML) and the Norwegian Public Roads Administration (NPRA). The Government of Tanzania and the Norwegian Agency for International Development (NORAD) have jointly financed the project, which forms part of a programme to establish technical standards and guidelines for highway engineering.

This Manual has been prepared by a number of peoples, under the project management by the two project engineers:

Mr. S.S. Rutajama, CML

Mr. C. Overby, NPRA

The following persons have contributed to this Laboratory Testing Manual:

Mr. J. Y. Mrema, CML
Mr. A. Mtola, CML
Mr. O. Mtavangu, CML
Mr. H. Kapombe, CML
Mr. P. Mazzuki, CML
Mr. B. Mariki, CML
Mr. T. Lyanga, CML
Mr. O. Salehe, CML
Ms. N. Bugenyi, CML
Mr. S. Nergaard, NOTEBY
Mr. A. Soegaard, NOTEBY
Mr. E. O. Andersen, SINTEF
Mr. S. Hoseth, SINTEF
Mr. R. Johansen, ViaNova

The project management wish to acknowledge the significant contribution from all people involved giving critical comments during various phases in compiling this report.

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Conversion Table

Example: to convert 10 miles to kilometres, find 1 mile in the 'length' table.
Numbers on that same horizontal are equal units to 1 mile, therefore 1 mile = 1.6094 km; 10 miles = 16.094 km.

Length

km	**m**	**mm**	**mile**	**yard**	**ft**	**in**	**10^{-3} in**
1	1000	10^{6}	0.6214	1094	3281	3.937×10^{4}	3.937×10^{7}
10^{-3}	1	1000	6.214×10^{-4}	1.0936	3.281	39.370	3.937×10^{4}
10^{-6}	10^{-3}	1	6.214×10^{-7}	1.094×10^{-3}	3.281×10^{-3}	3.937×10^{-2}	39.37
1.6094	1609.4	1.609×10^{6}	1	1760	5280	63360	6.336×10^{7}
9.144×10^{-4}	0.9144	914.41	5.682×10^{-4}	1	3	36	36000
3.048×10^{-4}	0.3048	304.8	1.894×10^{-4}	0.3333	1	12	12000
2.54×10^{-5}	0.0254	25.4	1.578×10^{-5}	2.778×10^{-2}	8.333×10^{-2}	1	1000
2.54×10^{-8}	2.54×10^{-5}	0.0254	1.578×10^{-8}	2.778×10^{-5}	8.333×10^{-5}	10^{-3}	1

Area

km²	**m²**	**cm²**	**mm²**	**sq. mile**	**acre**	**yd²**	**ft²**	**in²**
1	10^{-6}	10^{10}	10^{12}	0.38612	247.11	1.196×10^{6}	1.076×10^{7}	1.550×10^{9}
10^{-6}	1	10^{4}	10^{6}	3.86×10^{-7}	2.471×10^{-4}	1.1960	10.764	1550
10^{-10}	10^{-4}	1	100	3.86×10^{-11}	2.471×10^{-8}	1.196×10^{-4}	1.076×10^{-3}	0.1550
10^{-12}	10^{-6}	10^{-2}	1	3.86×10^{-13}	2.47×10^{-10}	1.196×10^{-6}	1.076×10^{-5}	1.550×10^{-3}
2.590	2.59×10^{6}	2.59×10^{10}	2.59×10^{12}	1	639.96	3.097×10^{6}	2.788×10^{7}	4.01×10^{8}
4.047×10^{-3}	4047	4.047×10^{7}	4.047×10^{9}	1.563×10^{-3}	1	4840	43560	6.273×10^{6}
8.36×10^{-7}	0.8361	8361	8.36×10^{5}	3.228×10^{-7}	2.066×10^{-4}	1	9	1296
9.29×10^{-8}	9.29×10^{-2}	929	92900	3.587×10^{-8}	2.296×10^{-5}	0.1111	1	144
6.45×10^{-10}	6.45×10^{-4}	6.4516	645.16	2.491×10^{-10}	1.594×10^{-7}	7.716×10^{-4}	6.944×10^{-3}	1

Volume

m³	**dm³ (litre)**	**cm³ (ml)**	**yd³**	**ft³**	**in³**	**UK gallon**	**US gallon**
1	10^{-3}	10^{6}	1.3079	35.311	6102	219.97	264.17
10^{-3}	1	10^{3}	1.308×10^{-3}	3.531×10^{-2}	61.02	0.2200	0.2642
10^{-6}	10^{-3}	1	1.308×10^{-6}	3.531×10^{-5}	6.102×10^{-2}	2.199×10^{-4}	2.642×10^{-4}
0.7646	764.6	7.646×10^{5}	1	27	46650	168.19	201.99
2.832×10^{-2}	28.32	2.832×10^{-4}	3.704×10^{-2}	1	1728	6.229	7.481
1.639×10^{-5}	1.639×10^{-2}	16.387	2.144×10^{-5}	5.787×10^{-4}	1	3.605×10^{-3}	4.329×10^{-3}
4.546×10^{-3}	4.546	4.546×10^{3}	5.946×10^{-3}	0.1605	277.42	1	1.2008
3.785×10^{-3}	3.785	3.785×10^{3}	4.951×10^{-3}	0.1337	231	0.8327	1

Mass

Tonne (Mg)	**kg**	**g**	**UK ton**	**US ton**	**cwt**	**lb**	**oz**
1	1000	10^{6}	0.9842	1.1011	19.66	2.205×10^{3}	3.527×10^{4}
10^{-3}	1	1000	9.842×10^{-4}	1.101×10^{-3}	1.966×10^{-2}	2.2046	35.274
10^{-6}	10^{-3}	1	9.842×10^{-7}	1.101×10^{-6}	1.966×10^{-5}	2.204×10^{-3}	3.527×10^{-2}
1.016	1016	1.016×10^{6}	1	1.12	20	2240	35840
0.9081	908.1	9.081×10^{5}	0.8928	1	17.856	2000	32000
5.085×10^{-2}	50.85	5.085×10^{4}	0.05	0.0560	1	112	1792
4.536×10^{-4}	0.4536	453.6	4.46×10^{-4}	5×10^{-4}	8.92×10^{-3}	1	16
2.835×10^{-5}	2.835×10^{-2}	28.349	2.79×10^{-5}	3.125×10^{-5}	5.580×10^{-4}	6.25×10^{-2}	1

Density

Tonne/m^3 Mg/m^3 g/cm^3	kg/m^3	lb/in^3	UK ton/yd^3	US ton/yd^3	lb/ft^3
1	1000	0.03613	0.75247	0.8428	62.43
10^{-3}	1	3.613×10^{-5}	7.525×10^{-4}	8.428×10^{-4}	6.243×10^{-2}
27.680	27680	1	20.828	23.328	1.728×10^{3}
1.3289	1.328×10^{3}	4.801×10^{-2}	1	1.12	82.955
1.1865	1.186×10^{3}	4.287×10^{-2}	0.8929	1	74.074
1.602×10^{-2}	16.019	5.787×10^{-4}	1.205×10^{-2}	1.35×10^{-2}	1

Force and weight

MN	kN	N	kgf	tonf	lbf
1	1000	10^{6}	1.0196×10^{5}	100.4	2.248×10^{5}
10^{-3}	1	10^{3}	101.96	0.1004	224.82
10^{-6}	10^{-3}	1	0.10196	1.004×10^{-4}	0.2248
9.807×10^{-6}	9.807×10^{-3}	9.807	1	9.842×10^{-4}	2.2048
9.964×10^{-3}	9.964	9964	1016	1	2240
4.448×10^{-6}	4.448×10^{-3}	4.448	0.45455	4.464×10^{-4}	1

The Greek Alphabet

Capital	***Small***	***Name***
Α	α	alpha
Β	β	beta
Γ	γ	gamma
Δ	δ	delta
Ε	ε	epsilon
Ζ	ζ	zeta
Η	η	eta
Θ	θ	theta
Ι	ι	iota
Κ	ϰ	kappa
Λ	λ	lambda
Μ	μ	mu
Ν	ν	nu
Ξ	ξ	xi
Ο	ο	omicron
Π	π	pi
Ρ	ϱ	rho
Σ	σ	sigma
Τ	τ	tau
Υ	υ	upsilon
Φ	ϕ	phi
Χ	χ	chi
Ψ	ψ	psi
Ω	ω	omega

Pressure, stress and modulus of elasticity

MN/m^2 MPa	kN/m^2 kPa	kp kgf/cm^2	bar	atm	m H_2O	ft H_2O	mm Hg	Ton/ft^2	psi lbf/in^2	lbf/ft^2
1	1000	10.197	10	9.869	102.2	355.2	7500.6	9.320	145.04	20886
0.001	1	1.019×10^{-2}	0.0100	9.87×10^{-3}	0.1022	0.3352	7.5006	0.0093	0.14504	20.886
9.807×10^{-2}	98.07	1	0.9807	0.9678	10.017	32.866	735.56	0.9139	14.223	2048.1
0.100	100	1.0197	1	0.9869	10.215	33.515	750.06	0.9320	14.504	2088.6
0.1013	101.33	1.0332	1.0132	1	10.351	33.959	760.02	0.9444	14.696	2116.2
9.788×10^{-3}	9.7885	9.983×10^{-2}	9.789×10^{-2}	9.661×10^{-2}	1	3.2808	73.424	9.124×10^{-2}	1.4198	204.45
2.983×10^{-3}	2.9835	3.043×10^{-2}	2.984×10^{-2}	2.945×10^{-2}	0.3048	1	22.377	2.781×10^{-2}	0.43275	62.316
1.333×10^{-4}	0.1333	1.3595×10^{-3}	1.333×10^{-3}	1.315×10^{-3}	1.362×10^{-2}	4.469×10^{-2}	1	1.243×10^{-3}	1.934×10^{-2}	2.7846
0.1073	107.3	1.0942	1.0730	1.0589	10.960	35.960	804.78	1	15.562	2240
6.895×10^{-3}	6.895	7.031×10^{-2}	6.895×10^{-2}	6.805×10^{-2}	0.7043	2.3108	51.714	6.426×10^{-2}	1	144
4.788×10^{-5}	4.788×10^{-2}	4.883×10^{-4}	4.788×10^{-4}	4.725×10^{-4}	4.891×10^{-3}	1.605×10^{-2}	0.3591	4.464×10^{-4}	6.944×10^{-3}	1

Permeability

m/s	cm/s	m/year	Darcy	ft/yr	ft/day
1	100	3.156×10^{7}	1.04×10^{5}	1.035×10^{8}	2.835×10^{5}
0.01	1	3.156×10^{5}	1.04×10^{3}	1.035×10^{6}	2.834×10^{3}
3.169×10^{-8}	3.169×10^{-6}	1	3.28×10^{3}	3.281	8.982×10^{-3}
9.66×10^{-6}	9.66×10^{-4}	304	1	1000	2.74
9.658×10^{-9}	9.659×10^{-7}	0.3048	10^{-3}	1	2.738×10^{-3}
3.527×10^{-6}	3.527×10^{-4}	111.33	0.365	365.25	1

Densities (at 20 °C) g/cm^3

Pure Water	0.99820	Kerosene (approx)	0.80
Sea Water	1.04	Paraffin wax (m.p. 52-52 °C)	0.912
Mercury	13.546	Microcrystalline wax (m.p. 60-63 °C)	0.915

Multiplying Prefixes

Prefix symbol	***Name***	***Multiplying factor***
G	giga	1 000 000 000 = 10^{9}
M	mega	1 000 000 = 10^{6}
k	kilo	1 000 = 10^{3}
h	hecto*	100 = 10^{2}
da	deca*	10
d	deci*	10^{-1} = 0.1
c	centi*	10^{-2} = 0.01
m	milli	10^{-3} = 0.001
μ	micro	10^{-6} = 0.000 001
n	nano	10^{-9} = 0.000 000 01

*** Not recommended in SI***

Soil Mechanics Testing

CML test method, reference number	Name of test	Reference to test methods
Tests on Soils and Gravels		
1.1	Moisture Content	BS1377:Part 2:1990
1.2	Liquid Limit (Cone Penetrometer)	BS1377:Part 2:1990
1.3	Plastic Limit & Plasticity Index	BS1377:Part 2:1990
1.4	Linear Shrinkage	BS1377:Part 2:1990
1.5	Particle Density Determination - Pyknometer	BS1377:Part 2:1990
1.6	Bulk Density for undisturbed samples	BS1377:Part 2:1990
1.7	Particle Size Distribution - Wet sieving	BS1377:Part 2:1990
1.8	Particle Size Distribution - Hydrometer Method	BS1377:Part 2:1990
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1.10	CBR Test - One point method	BS1377:Part 4:1990
1.11	CBR Test - Three point method	BS1377:Part 4:1990 and TMH1:method A8:1986
1.12	Consolidation Test - Oedometer	BS1377:Part 5:1990
1.13	Triaxial Test	BS1377:Part 7:1990
1.14	Shear Box Test	BS1377:Part 7:1990
1.15	Permeability Test - Constant Head	BS1377:Part 5:1990
1.16	Organic Content - Ignition Loss Method	BS1377:Part 3:1990 and NPRA 014 test 14.445
1.17	Crumb Test	BS1377:Part 5:1990
1.18	pH Value (pH meter)	BS1377:Part 3:1990
1.19	Preparation of Stabilised Samples for UCS	TMH1:method A14:1986 and BS1924:Part 2:1990
1.20	Compaction Test - Stabilised Materials	TMH1:method A14:1986 and BS1924:Part 2:1990
1.21	UCS of Stabilised Materials	TMH1:method A14:1986
1.22	Initial Consumption of Lime - ICL	BS1924:Part 2:1990

TEST NO. 1.1

Moisture Content

Objective

To determine the amount of water present in a soil expressed as a percentage of the mass of dry soil. This is termed the moisture content of the soil.

Main Principles

The moisture content of a soil is assumed to be the amount of water within the pore space between the soil grains which is removable by oven-drying at a temperature not exceeding 110 °C. The moisture content has a profound effect on soil behaviour.

The oven-drying method is regarded as standard laboratory practice.

References

BS 1377 : Part 2 : 1990.

Required equipment

- a drying oven with temperature of 105 °C to 110 °C
- a balance readable to 0,1 g
- a metal container
- a desiccator

Test Procedure

Step 1: Clean and dry the container, then weigh it to the nearest 0.1 g (m_1)

Step 2: A representative sample shall be crumbled and loosely placed in the container.
- For fine-grained soils the sample weight shall be min. 30 g.
- For medium-grained soils the sample weight shall be min. 300 g.
- For coarse-grained soils the sample weight shall be min. 3 kg.

Step 3: The container with sample shall immediately be weighed (m_2) and placed in the oven to dry at 105 °C for minimum 12 hours.

Step 4: After drying, weigh the container and the contents (m_3)

Notes

The actual drying time necessary will depend on of the type of soil, but 12 hours will be adequate for most soils.

*For **calcrete and coral rock** materials the drying temperature shall be limited to 60 °C.*

Calculations

Calculate the Moisture Content of the soil specimen, w, as a percentage of the dry soil mass to the nearest 0.1%, from the equation:

$$W = \left(\frac{m2 - m3}{m3 - m1}\right) \text{x } 100 \ (\%)$$

where

m_1 is the mass of the container (in g)
m_2 is the mass of the container and wet soil (in g)
m_3 is the mass of the container and dry soil (in g)

Moisture Content

Notes

Report

The test report shall include the following:

a) Type of material and sample identification
b) Reference to this procedure
c) Test results, individual values and average value
d) The final moisture content (w) is reported to two significant figures.

Form for the test

The enclosed form “Moisture Content” shall be used.

Practical Considerations

One may control that the material is completely dry by holding a beaker with cold water directly above the sample. If the sample is not dry, moisture will condense on the outside of the glass.

Maintenance

The balance and the drying oven shall be checked and calibrated regularly (every month) with respect to weight and temperature.

It is important that the containers are kept clean and dry.

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WORKING SHEET

Moisture Content

Project	**Location**	**Depth**
Client	**Lab.no**	**Date**
Responsible Technician	**Checked**	**Approved**

TEST METHOD	CML TEST 1.1, ref. BS 1377 : Part 2 : 1990							
Specimen reference								
Container no.								
Mass of wet soil + container (m_2)	g							
Mass of dry soil + container (m_3)	g							
Mass of container (m_1)	g							
Mass of moisture (m_2 - m_3)	g							
Mass of dry soil (m_3 - m_1)	g							
Moisture Content $w = \left(\frac{m_2 - m_3}{m_3 - m_1}\right) 100$	%							

TEST NO. 1.2

Liquid Limit (Cone penetrometer method)

Notes

Objective

The liquid limit is the empirically established moisture content at which a soil passes from the liquid state to the plastic state.

The liquid limit provides a means of identifying and classifying fine-grained cohesive soils especially when also the plastic limit is known. Variations in the moisture content in a soil may have significant effect on its shear strength, especially on fine-grained soils.

Main Principles

The cone penetrometer method is the preferred method to the Casagrande test as it is essentially a static test depending on soil shear strength.

This method covers the determination of the liquid limit of a sample in its natural state, or a sample from which material retained on a 425 mm test sieve has been removed. It is based on the measurement of penetration into the soil of a standardised cone.

BS 1377 also describes a one-point cone penetrometer method.

References

BS 1377 : Part 2 : 1990.

Required equipment

- Test sieves of sizes 425 µm
- An airtight container
- A flat glass plate
- Two palette knives or spatulas
- A penetrometer
- A cone of stainless steel, 35 mm long with a smooth, polished surface and an angle of 30 ° having a mass of 80 g.
- A metal cup 55 mm in diameter and 40 mm deep with the rim parallel to the flat base
- An evaporating dish or a damp cloth
- Apparatus for moisture content determination
- A wash bottle containing clean water
- A metal straight edge
- A stopwatch

Sample preparation

Step 1: Take a sample of the soil of sufficient size to give a test specimen weighing about 400 g which passes the 425 µm sieve. This should be enough material for both Plastic Limit and Linear Shrinkage tests in addition to the Liquid Limit test.

Step 2: Transfer the soil to a glass plate. Add water and mix thoroughly with two palette knives until the mass becomes a thick homogeneous paste.

Step 3: Place the paste in an airtight container and allow to stand for 16 - 24 hours to enable the water to permeate through the soil.

If the soil in the natural state contains little or no material retaining larger than 425 µm, sieving is not necessary, eg. black cotton soil and red coffee soil. Any coarse particles can be removed by hand.
The sample material must not be oven dried prior to testing.

It is necessary to prepare the material one day in advance.

TEST NO.1.2

Liquid Limit (Cone penetrometer method)

Notes

The sequence of the testing must be with increasing moisture content.

If the soil has to be left for a while on the glass plate during the procedure, cover the soil with a damp cloth or the evaporating dish to prevent the soil from drying out When the penetration value is about 20 mm, set aside about 150 g of the sample for Linear Shrinkage and 50 g for Plastic Limit tests.

The drying temperature for moisture content determination is generally 105 °C to 110 °C. However, for calcrete and coral rock materials the drying temperature shall be 60 °C.

Test Procedure

Step 1: Take the 400 g soil sample and place it on a glass plate. Mix the paste for at least 10 minutes using the two palette knives. Add more distilled water if necessary so that the first cone penetro meter reading is about 15 mm.

Step 2: Push a portion of the mixed soil into the cup with a palette knife, taking care not to trap air, gently tapping the cup against a firm surface if necessary. Strike off excess soil with the straightedge to give a smooth level surface.

Step 3: With the penetration cone locked in the raised position lower the cone so that it just touches the surface of the soil. When the cone is in the correct position, a slight movement of cup will just mark the soil surface. Lower the dial gauge to contact the cone shaft and record the reading of the dial gauge to the nearest 0.1 mm.

Step 4: Release the cone for a period of 5 ± 1 sec. After locking the cone in position, lower the dial gauge to contact the cone shaft and record the reading of the dial gauge to the nearest 0.1 mm. Record the difference between the readings as the “cone penetration”.

Step 5: Lift out the cone and clean it carefully.

Step 6: A little more wet soil shall be added to the cup and the process repeated. If the difference between the first and second penetration readings is less than 0.5 mm, the average of the two penetrations shall be recorded. If the second penetration is more than 0.5 mm and less than 1 mm different from the first, a third test shall be carried out. If the overall range is then not more than 1 mm, record the average of the 3 penetrations. If the overall range is more than 1 mm, the soil shall be removed from the cup, remixed and the test repeated until consistent results are obtained.

Step 7: Take a moisture content sample of about 20 g from the area penetrated by the cone and determine the moisture content.

Step 8: The penetration test shall be repeated at least three more times using the same sample of soil to which further increments of water have been added. The amount of water added shall be such that a range of penetration values of approximately 15 mm to 25 mm is covered by the four test runs.

Step 9: Each time soil is removed from the cup for the addition of water, wash and dry the cup.

TEST NO. 1.2

Liquid Limit (Cone penetrometer method)

Notes

1. Calculations

Calculate the moisture content of each specimen.

$$w = \left(\frac{m2 - m3}{m3 - m1}\right) \times 100\ (\%)$$

where

m_1 is the mass of the container (in g)
m_2 is the mass of the container and wet soil (in g)
m_3 is the mass of the container and dry soil (in g)

2. Plot the relationship between the moisture content and cone penetration with the moisture content as the abscissae and the cone penetration as ordinates, both on linear scales.

3. Draw the best straight line fitting the points.

4. The Liquid Limit (w_L) of the soil sample is the moisture content corresponding to a cone penetration of 20 mm and shall be expressed to the nearest whole number.

Report

The test report shall include the following:

a) Type of material and sample identification
b) Reference to this procedure
c) Test result, i.e. the Liquid Limit of the soil sample
d) Whether the material was tested in the natural state or after sieving

Form for the test

The enclosed form shall be used.

Practical Considerations

Take care not to damage the point of the cone by accidentally dropping the cone on the base plate.

To avoid corrosion on the cone, it must be kept clean at all times. The cone corrodes easily, and rust could appear after just a few hours if it is left unclean.

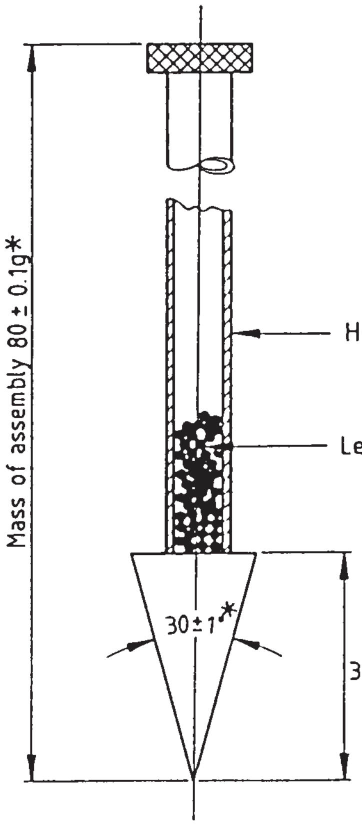
Maintenance

Check the condition of the cone point with the test gauge.

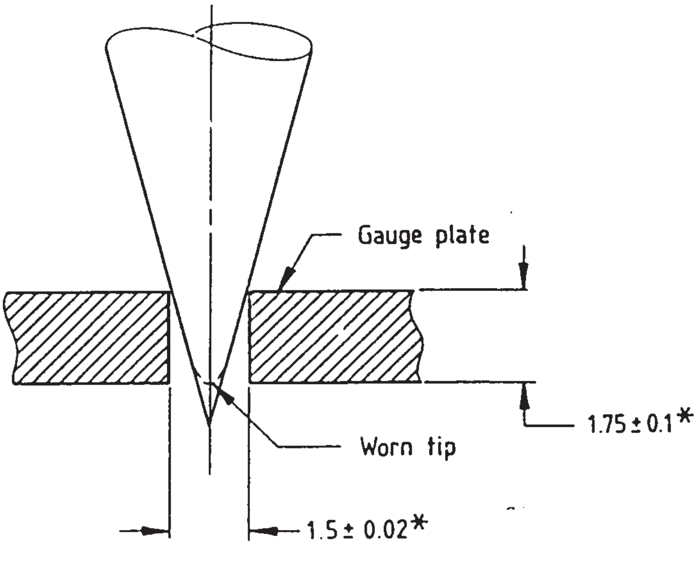
Check that the cone is falling freely without friction when released.

Check the weight of the cone.

Keep the equipment clean at all times.



(a) cone assembly



(b) tip gauge

All dimensions are in millimetres.

* See **4.1.3.1.1** of BS 1377 : Part 1 : 1990.

Figure 1. Details of cone forliquid limit test

TEST NO. 1.3

Plastic Limit and Plasticity Index

Notes

Objective

The Plastic Limit is the empirically established moisture content at which a soil becomes too dry to be plastic.

It is used together with the Liquid Limit to determine the Plasticity Index which when plotted against the Liquid Limit on the plasticity chart provides a means of classifying cohesive soils. The Plasticity Index is the difference between the Liquid Limit and the Plastic Limit. The Plasticity Index is the range of moisture content in which a soil is plastic; the finer the soil, the greater the Plasticity Index.

Main Principles

This method covers the determination of the liquid limit of a sample in its natural state, or a sample from which material retained on a 425 µm test sieve has been removed.

References

BS 1377 : Part 2 : 1990.

Required equipment

- Two flat glass plates, one for mixing soil and one for rolling threads
- Two palette knives or spatulas
- Apparatus for moisture content determination
- Clean water
- A length of rod, 3 mm in diameter and 100 mm long

Sample preparation

This test commonly is performed as a continuance of the Liquid Limit test, and material for the test could conveniently be prepared as part of the Liquid Limit test.

Otherwise a 40 g sample should be prepared in the same way as specified for the Liquid Limit test.

Test Procedure

Step 1: Take the 40 g soil paste sample and place it on a glass plate.

Step 2: Allow the soil to dry partially until it becomes plastic enough to be shaped into a ball.

The sample may be put out in the sun for a short period to speed up the drying process. A hairdryer may also be used. Alternatively a drying oven at a low temperature may be used.

Step 3: Mould the ball of soil between the fingers and roll it between the palms of the hands until the heat of the hands has dried the soil sufficiently for slight cracks to appear on its surface.

Step 4: Divide this sample into 2 sub-samples of about 20 g each and carry out separate determination on each portion. (Divide each of the 2 sub-samples into 4 more or less equal parts).

Step 5: Mould the soil in the fingers to equalize the distribution of moisture. Then form the soil into a thread about 6 mm diameter between the first finger and thumb of each hand.

Step 6: Roll the thread between the fingers, from finger-tip to the second joint, of one hand and the surface of the glass plate. Use enough pressure to reduce the diameter of the thread to about 3 mm in 5 to 10 complete, forward and back, movements of the hand.

Step 7: Pick up the soil, mould it between the fingers to dry it further, form it into a thread and roll it out again as specified above.

Step 8: The procedure shall be repeated until the thread shears both longitudinally and transversely when rolled to about 3 mm diameter. The metal rod may be used to gauge the diameter. The first crumbling point is the Plastic Limit.

Step 9: Gather together the pieces of crumbled soil thread and transfer them to a suitable container for determination of the moisture content and replace the lid immediately.

Step 10: Repeat the rolling procedure on the other 3 portions of the sub-sample, placing them all in the same container for determination of the moisture content.

Step 11: Repeat the rolling procedure on the 2nd sub-sample as described above so that 2 completely separate determinations are made.

Notes

Do not gather the pieces of soil together in order to reform the thread after it has crumbled.

The drying temperature for moisture content determination is generally 105 °C to 110 °C. However, for calcrete and coral rock materials the drying temperature shall be 60 °C.

It is important to perform 2 separate tests and achieve 2 separate moisture content determinations.

Calculations

1) Calculate the moisture content of both samples. If the 2 results differ by more than 0.5 % moisture content, repeat the whole test.
2) Calculate the average of the 2 moisture content values and express the value to the nearest whole number. This is the Plastic Limit (w_p).

Report

The test report shall include the following:

a) Type of material and sample identification
b) Reference to this procedure
c) Test result, i.e. the Plastic Limit of the soil sample
d) Whether the material was tested in the natural state or after sieving

If it is not possible to perform the Plastic Limit, the soil is reported as non-plastic (NP).

Plastic Limit and Plasticity Index

Notes

Derivation of Plasticity Index

The Plasticity Index (I_P) is defined as the difference between the Liquid Limit (w_L) and the Plastic Limit (w_P), and is calculated from the equation:

$I_P = w_L - w_P$

This value is also reported to the nearest whole number.

Form for the test

The enclosed form shall be used.

Practical Considerations

The hands of the operator should be clean and dry when performing the test.

Maintenance

The equipment shall be kept clean at all times.

TEST NO. 1.4

Linear Shrinkage

Notes

The Linear Shrinkage test offers a convenient method to confirm that the test results for the Plasticity Index are reasonable. Most types of soil exhibit a relationship between the Plasticity Index and the Linear Shrinkage of the material. The Linear Shrinkage is considered a more reliable indicator than the Plasticity Index for materials with very low plasticity (i.e. ≤ 6 %)

Objective

Shrinkage due to drying is significant in clays, but less so in silts and sands. If the drying process is prolonged after the plastic limit has been reached, the soil will continue to decrease in volume, which is also relevant to the converse condition of expansion due to wetting.

The Linear Shrinkage value is a way of quantifying the amount of shrinkage likely to be experienced by clayey material. Such a value is also relevant to the converse condition of expansion due to wetting.

Main Principles

Linear Shrinkage method covers the determination of the total linear shrinkage from linear measurements on a bar of soil of the fraction of a soil sample passing a 425 µm test sieve, originally having the moisture content of the Liquid Limit.

References

BS 1377 : Part 2 : 1990.

Required equipment

- A flat glass plate
- Two palette knives or spatulas
- A drying oven capable of maintaining temperature of 105 °C - 110 °C
- Clean water
- A brass mould for Linear Shrinkage test
- Silicone grease or petroleum jelly
- Vernier callipers or steel rule with accuracy 0.5 mm

Sample preparation

It is recommended that this test always is conducted as part of the Liquid Limit testing as a check on the PI result.

This test commonly is performed as a continuance of the Liquid Limit and Plastic Limit tests, and material for the test could therefore conveniently be prepared as part of the Liquid Limit test.

The maisture content must be to within 1% of Liquid Limit.

Otherwise a 150 g sample should be prepared in the same way as specified for the Liquid Limit test. A sample of material passing through a 425 µm sieve, or alternatively a sample of natural soil without coarse particles, shall be thoroughly mixed with distilled water until the mass becomes a smooth homogeneous paste with a moisture content at about the Liquid Limit of the soil.

Test Procedure

Step 1: Clean the mould thoroughly and apply a thin film of silicone grease or petroleum jelly to its inner faces to prevent the soil adhering to the mould.

Step 2: Take the 150 g soil paste sample at approximately the Liquid Limit.

Linear Shrinkage

Notes

For highly plastic material even 3 days of airdrying may be deemed necessary. Do not be tempted to put the sample too early in the oven.

Should the specimen crack or warp badly, or curve such that the measurements are impossible, the test should be repeated at a slower drying rate.

Step 3: Place the soil/water mixture in the mould such that it is slightly proud of the sides of the mould. Gently jar the mould, or carefully tap the mould against a firm surface, to remove any air pockets in the mixture.

Step 4: Level the soil along the top of the mould with the palette knife and remove all soil adhering to the rim of the mould by wiping with a damp cloth.

Step 5: Place the mould where the paste can air dry slowly for 1 – 2 days until the soil has shrunk away from the walls of the mould.

Step 6: Then complete the drying at 105 °C to 110 °C.

Step 7: Cool the mould and measure the mean length of the soil bar by pressing it against the end of the mould where there is a better fit, while measuring the distance between the opposite side of the mould and the soil bar.

Calculations

1) Calculate the Linear Shrinkage of the soil as a percentage of the original length of the specimen, L_0 (in mm), from the equation :

$$\text{Percentage of Linear Shrinkage} = \left(1-\frac{L_D}{L_0}\right)100$$

where

L_D is the length of the oven-dry specimen (in mm).

Report the Linear Shrinkage of the soil to the nearest whole percentage.

Report

The test report shall include the following:

a) Type of material and sample identification
b) Reference to this procedure
c) Test result, i.e. the Linear Shrinkage of the soil sample
d) Whether the material was tested in the natural state or after sieving

Form for the test

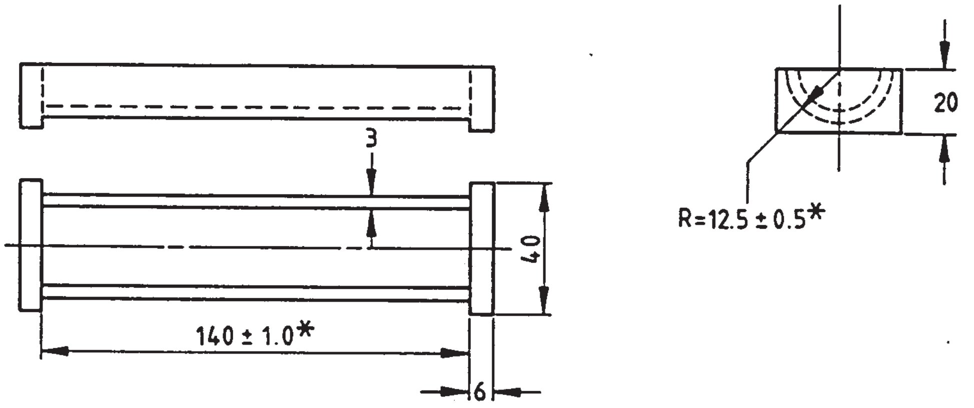
The enclosed form shall be used.

Practical Considerations

Due to the long time required for air drying, Linear Shrinkage is a time consuming test. However, it is important to take the time required in order to produce reliable results.

Maintenance

The equipment shall be kept clean at all times.



All dimensions are in millimetres.

NOTE. This design has been found satisfactory, but alternative designs may be used provided that the essential requirements are fulfilled.

Figure 2. Mould for linear shrinkage test

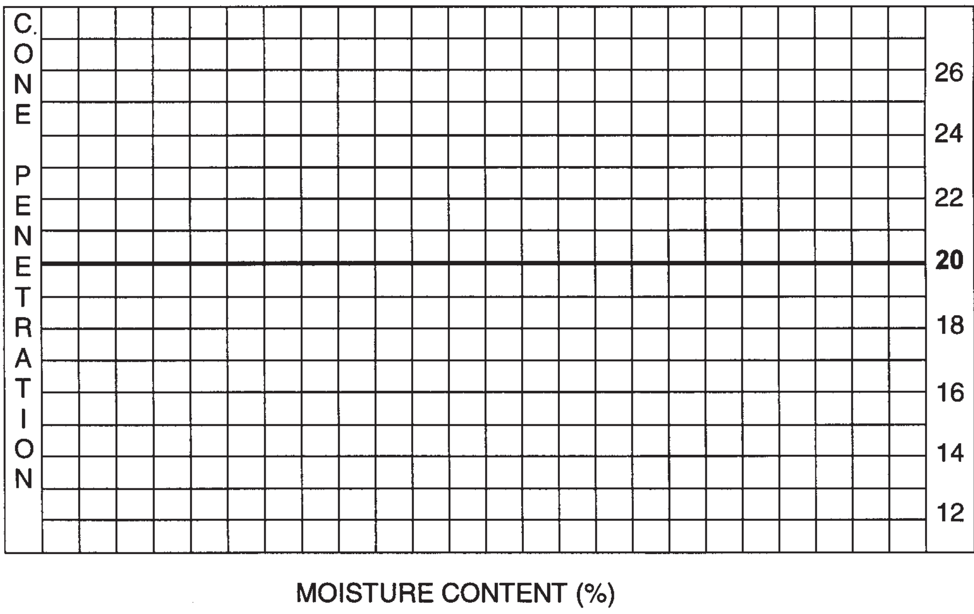
CML
CENTRAL MATERIALS LABORATORY

WORKING SHEET

Liquid and Plastic Limits
Linear Shrinkage and Shrinkage Product

Project	**Location**	**Depth**
Client	**Lab.no**	**Date**
Responsible Technician	**Checked**	**Approved**

TEST METHOD	CML TESTS 1.2, 1.3 and 1.4, ref. BS 1377 : Part 2 : 1990							
		LIQUID LIMIT				**PLASTIC LIMIT**		
TEST NO.		1	2	3	4	1	2	Average
Initial gauge reading	mm							
Final gauge reading	mm							
Average penetration	mm							
Container no.								
Mass of wet soil + container	g							
Mass of dry soil + container	g							
Mass of container	g							
Mass of moisture	g							
Mass of dry soil	g							
Moisture content	%							



Sample preparation:
a) As received
b) Airdried: °C
c) Washed on 425 µm
d) Oven dried: °C
e) Not known
Proportion retained on 425 µm sieve: %
LIQUID LIMIT **LL = %**
PLASTIC LIMIT **PL = %**
PLASTICITY INDEX **PI = %**

LINEAR SHRINKAGE and SHRINKAGE PRODUCT							
Specimen reference							
Initial length	L_0	mm					
Oven-dried length	L_D	mm					
Linear Shrinkage, **LS** = $100\,(1 - \frac{L_D}{L_0})$		%					
Shrinkage Product, **SP** = LS x % < 425µm							

TEST NO.1.5

Partice Density Determination - Small Pyknometer Method

Notes

Objective

Particle density is the term used instead of Specific Gravity of particles. Knowledge of the particle density is essential in relation to other tests, especially for calculating porosity and voids and for computation of particle size analysis from a sedimentation procedure (Hydrometer analysis). It is also important when compaction and consolidation properties are considered.

Main Principles

The small pyknometer method is suitable for soils consisting of particles finer than 2 mm. Larger particles may be ground down to smaller than 2 mm before testing.

References

BS 1377 : Part 2 : 1990.

Required equipment

- 2 nos. 50 mL density bottles (pyknometers) with stoppers
- Constant temperature water bath
- Vacuum desiccator
- Vacuum pump and suitable rubber tubing
- Drying oven capable of maintaining temperature of 105 °C - 110 °C
- Distilled water in a wash bottle
- Test sieve 2 mm
- Balance readable to 0.01 g
- Mortar and piston.

Sample preparation

Oven-drying of the material is required, sun-drying is not sufficient.

An oven-dried soil sample of about 100 g shall be prepared. Large particles shall be ground to pass a 2 mm sieve.

Two specimens, each between 5 g and 10 g shall be obtained by riffling and stored in airtight containers.

Test Procedure

Step 1: A density bottle with stopper shall be dried with a cloth and weighed to the nearest 0.01 g (m_1).

Step 2: The first soil specimen shall be transferred to the density bottle direct from the sealed container. The weight of the bottle with soil sample and stopper shall be recorded to the nearest 0.01 g (m_2).

Boiled water will be almost air-free and may be used.

Step 3: Air-free distilled water shall be added so that the soil in the bottle is just covered.

Take care during this operation to ensure that air trapped in the soil does not bubble too violently.

Step 4: Place the bottle containing soil and water, without the stopper, in the vacuum desiccator. Evacuate the desiccator gradually. The bottle shall be allowed to remain in the desiccator for at least one hour until no further loss of air is apparent.

Partice Density Determination - Small Pyknometer Method

Notes

Remember to check that there are no airbubbles in the Pyknometer. Tap the Pyknometer carefully to release any entrapped air.

Many soils have substantial proportions of heavier or lighter particles. Such soils will give erratic density values, and a number of repeat tests may be required to obtain a good average value.

Step 5: Release the vacuum and remove the lid of the desiccator. Vibrate the bottle till no more air is released. Replace the lid and evacuate again as specified above.

Step 6: Remove the bottle from the desiccator and add air-free water until the bottle is full. Insert the stopper and immerse the bottle up to neck in the water bath for at least 1 hour.

Step 7: If there is an apparent decrease in volume of water, remove the stopper, add water to fill the bottle and replace the stopper. Return the bottle to the bath and again allow the contents to attain the constant temperature.

Step 8: The stoppered bottle shall then be taken out of the bath, wiped dry carefully, and weighed to the nearest 0.01 g (m_3).

Step 9: Clean out the bottle, fill it completely with air-free water, insert the stopper and immerse in constant temperature water bath for 1 hour. If required, top up the bottle as described in step 7.

Step 10: Take the stoppered bottle out of the bath, carefully wipe it dry and weigh it to the nearest 0.01 g (m_4).

Step 11: The steps 1 – 10 shall be repeated using the second specimen of the same soil so that two values of particle density can be obtaied. If the results differ by more than 30 kg/m^3, the test shall be repeated.

Calculations

1. Calculate the Particle Density, ρ_s (in kg/m^3), from the equation:

$$\rho_s = \frac{m_2 - m_1}{(m_4 - m_1) - (m_3 - m_2)} \times 1000$$

where

m_1 is the mass of density bottle (in g)
m_2 is the mass of bottle and dry soil (in g)
m_3 is the mass of bottle, soil and water (in g)
m_4 is the mass of bottle full of water only (in g).

2. Calculate the average of the two results if they differ by no more than 30 kg/m3.

Express the average value of the Particle Density to the nearest 1 kg/m^3.

Report

The test report shall include the following:

a) Type of material and sample identification
b) Reference to this procedure
c) The average value of the Particle density of the soil specimen.

Partice Density Determination - Small Pyknometer Method

Notes

Form for the test

The enclosed form shall be used.

Practical Considerations

The Pyknometers may be calibrated once and for all to obtain fixed values for volume and mass of the Pyknometers.

Maintenance

Cleaning of the Pyknometers are important, and the material must not be left standing in the Pyknometers longer than necessary.

WORKING SHEET

Particle Density

Small Pyknometer

Project	**Location**	**Depth**
Client	**Lab.no**	**Date**
Responsible Technician	**Checked**	**Approved**

TEST METHOD	CML TEST 1.5, ref. BS 1377 : Part 2 : 1990							
Specimen reference								
Pyknometer number								
Mass of bottle + soil + water	m_3	g						
Mass of bottle + soil	m_2	g						
Mass of bottle full of water	m_4	g						
Mass of density bottle	m_1	g						
Mass of soil	$m_2 - m_1$	g						
Mass of water in full bottle	$m_4 - m_1$	g						
Mass of water used	$m_3 - m_2$	g						
Volume of soil particles	$(m_4 - m_1) - (m_3 - m_2)$	mL						
Particle Density	$\rho_s = 1000 \times \dfrac{m_2 - m_1}{(m_4 - m_1) - (m_3 - m_2)}$	kg/m^3						
Average Value	ρ_s	kg/m^3						

TEST NO. 1.6

Bulk Density and Unit Weight for undisturbed samples

Notes

Objective

From the Bulk Density of a soil, the Unit Weight of the soil may easily be derived. The Unit Weight of a soil is an essential parameter in most geotechnical engineering analyses, e.g. stability of slopes, consolidation settlement, earth pressure and bearing capacity analyses.

Main Principles

The Bulk Density of a soil is the ratio of the total mass to the total volume. The Unit Weight of the soil is the ratio of the total weight (*a force*) to the total volume.

This procedure describes a practical way of determining the Bulk Density and Unit Weight on undisturbed samples obtained by means of a U-100 sampling tube, a 54 mm sampling tube or from a block sample.

It may be convenient to include the determination of several other parameters when determining the Bulk Density of a sample, i.e. the Dry Density, the Void Ratio, the Degree of Saturation and the Unit Weight.

The described method is a "Linear Measurement Method". An alternative method is the "Immersion in Water Method", as described in BS 1377.

References

BS 1377 : Part 2 : 1990.

Required equipment

- Balance readable to 1 g
- Sample extruder
- Apparatus and equipment for moisture content determination (optional)

Test Procedure - cylindrical tube sample

Step 1: After registration cylindrical tube sample, the lids shall be unscrewed and the wax removed.

Step 2: Weigh the cylinder with the sample inside. The mass shall be recorded to the nearest 1 g (m_T).

Step 3: The length of the sample in the cylinder is determined by measuring the length of the cylinder (l_1) and the depths from both ends of the cylinder (l_2 and l_3). The average depths to the sample is recorded since the sample surface is never even.

Step 4: Extrude the sample by following relevant procedures for further tests to be carried out on the sample.

Step 5: When the sample has been extruded, weigh clean and dry the cylinder and record its mass (m_C).

To be decided by the Engineer.

Step 6: (Optional) The moisture content shall be determined on three different specimens from the sample, in order to achieve the average condition of the sample. Ref. CML test procedure no. 1.1.

TEST NO. 1.6

Bulk Density and Unit Weight for undisturbed samples

Notes

Test Procedure - Block sample

Step 1: Depending on the soil, the sample is cut to either a rectangular prism form or a cylindrical form, preferably by a cylindrical or rectangular tube which is pushed into the soil.

Step 2: Trim the ends of the sample.

Step 3: Weigh the tube with the sample inside. The mass shall be recorded to the nearest 1 g (m_T).

Step 4: Record the internal dimensions of the tube, or the dimensions of the sample if no tube is used.

Step 5: Extrude the sample by following relevant procedures for further tests to be carried out on the sample.

Step 6: When the sample has been extruded, weigh clean and dry the tube and record its mass (m_C).

To be decided by the Engineer

Step 7: (Optional) The moisture content shall be determined on three different specimens from the sample, in order to achieve the average condition of the sample. Ref. CML test procedure no. 1.1.

Calculations

1. The Bulk Density of the sample, ρ (in kg/m^3), is calculated from the equation:

$$\rho = \frac{M}{V} = \frac{m_T - m_c}{V} \text{ x } 1000$$

where

m_T is the mass of the cylinder/container + sample (in g)
m_C is the mass of the empty cylinder/container (in g)
V is the volume of the sample (in cm^3)

2. The Unit Weight of the sample, γ (in kN/m^3), is derived from the equation:

$$\gamma = \frac{W}{V} = \frac{Mg}{V} = \rho \text{ x } g = \rho \text{ x } 9{,}81 \text{ x } 10^{-3}$$

where

g is the acceleration due to gravity (= 9,81 m/s^3)

The value of the Bulk Density shall be expressed to the nearest 1 kg/m^3, and the Unit Weight to the nearest 0.01 kN/m^3.

TEST NO. 1.6

Bulk Density and Unit Weight for undisturbed samples

Notes

Report

The test report shall include the following:

a) Type of material and sample identification
b) Reference to this procedure
c) The value of the Bulk Density of the soil sample
d) The value of the Unit Weight of the soil sample
e) The Dry Density, Void Ratio and Degree of Saturation (if required).

Form for the test

The enclosed form shall be used.

Example

U-100 tube:

Length of cylinder	l_1	cm	100
Sample to edge	l_2	cm	10
Sample to edge	l_3	cm	15
Length of sample	$L = l_1 - l_2 - l_3$	cm	75
Internal diameter	D	cm	10,2
Area of sample	$A = \pi/4 \times D^2$	cm^2	81,67
Volume of sample	$V = L \times A$	cm^3	6 125
Mass of cylinder + sample	m_T	g	22 028
Mass of cylinder	m_C	g	10 850
Mass of sample	$M = m_T - m_C$	g	11 1782
Bulk Density	$\rho = \frac{M}{V} \times 1000$	kg/m^3	1825
Unit Weight	$\gamma = \rho \times 9{,}81 \times 10^{-3}$	kN/m^3	17,90

For a rectangular prism specimen the Bulk Density is calculated from:

$$\rho = \frac{M}{LBH} \times 1000$$

where L, B and H are the dimensions of the trimmed specimen.

CML CENTRAL MATERIALS LABORATORY	**WORKING SHEET** **Bulk Density and Unit Weight**

Project	**Location**	**Depth**
Client	**Lab.no**	**Date**
Responsible Technician	**Checked**	**Approved**

TEST METHOD	CML TEST 1.6, ref. BS 1377 : Part 2 : 1990							
Specimen reference								
Container no.		g						
Mass of wet soil + container		g						
Mass of dry soil + container		g						
Mass of container		g						
Mass of moisture		g						
Mass of dry soil		g						
Moisture Content	w	%						
Average Moisture Content	w	%						
Particle Density (assumed or determined from CML test 1.5)	ρ_S	kg/m^3						
Length of cylinder	l_1	cm						
Sample to edge	l_2	cm						
Sample to edge	l_3	cm						
Length of sample	$L = l_1 - l_2 - l_3$	cm						
Internal diameter	D	cm						
Area of sample	$A = \frac{\pi}{4} x D^2$	cm^2						
Volume of sample	$V = L x A$	cm^3						
Mass of cylinder + sample	m_T	g						
Mass of cylinder	m_C	g						
Mass of sample	$M = m_T - m_C$	g						
BULK DENSITY	$\rho = \frac{M}{V} x 1000$	kg/m^3						
DRY DENSITY	$\rho_d = \frac{100\rho}{100+w}$	kg/m^3						
VOID RATIO	$e = \frac{\rho_S}{\rho_d} - 1$							
DEGREE OF SATURATION	$S = \frac{w\rho_S}{e} x 10^{-3}$	%						
BULK UNIT WEIGHT	$\gamma = \rho x 9{,}81 x 10^{-3}$	kN/m^3						

For a rectangular prism specimen the Bulk Density is calculated from: $\rho = \frac{M}{LBH} x 1000$

where L, B and H are the dimensions of the trimmed sample.

TEST NO. 1.7

Particle Size Distribution- Wet Sieving

Notes

Objective

A particle size distribution analysis is a necessary classification test for soils, especially coarse soils, in that it presents the relative portions of different sizes of particles. From this it is possible to determine whether the soil consists of predominantly gravel, sand, silt or clay sizes and, to a limited extent, which of these sizeranges is likely to control the engineering properties of the soil.

Main Principles

If the material do not contain silt or clay particles, the sample may be dry sieved only.

The procedure given involves preparation of the sample by wet sieving to remove silt and clay sized particles. Followed by dry sieving of the remaining coarse material.

This method covers the quantitative determination of particle size distribution in an essentially cohesionless soil, down to fine sand size. The combined silt clay can be obtained by difference. If the soil does not contain particles retained on a 2 mm test sieve in significant quantity, the hydrometer method shall be used.

References

BS 1377 : Part 2 : 1990.

Required equipment

The aperture sizes of the test sieves should adequately cover the range for the particular soil being tested, but it will not be necessary to use every size for every test.

Test sieve 63 μm may be used if 75 μm test sieve is not available.

- Test sieves: 75 mm, 63 mm, 50 mm, 37.5 mm, 28 mm, 20 mm, 14 mm, 10 mm, 6.3 mm, 5 mm, 3.35 mm, 2 mm, 1.18 mm, 600 μm, 425 μm, 300 μm, 212 μm, 150 μm, 75 μm.
- Lid and receiver.
- A balance readable and accurate to 0.5 g.
- Riffle boxes.
- A drying oven capable of maintaining a temperature of 105°C to 110°C.
- Evaporating dishes.
- Metal trays.
- Scoop.
- Sieve brushes.
- Sodium hexametaphosphate.
- Rubber tubing about 6mm bore.
- Mechanical sieve shaker (optional).

Sample preparation

Under damp conditions (eg. rainy seasons), it may be required to oven-dry the sample for min. 12 hours at 60°C.

The test sample shall be obtained by air-drying for at least 12 hours depending on the type of the sample.

A representative sample shall be obtained by riffling or quartering to give a minimum mass of about 2.5 kg.

TEST NO. 1.7

Particle Size Distribution- Wet Sieving

Test procedure

Step 1: Weigh the air-dried (or oven dried) test sample to 0.1 % of its total mass (m_1).

Step 2: Place the sample and sieve through a 20 mm sieve size, brush any particles too coarse to pass through the sieve with wirebrush until the individual particles are clean of any finer material.

Step 3: Sieve the fraction retained on the 20 mm test sieve on the appropriate larger test sieves and weigh the amount retained on each test sieve.

Step 4: Weigh the material passing a 20 mm test sieve (m_2).

Step 5: Riffle the sample to get a convenient fraction of about 0.5 kg and weigh that fraction (m_3).

Step 6: Spread the riffled fraction in the large tray or bucket and cover with water.

Step 7: If the soil is cohesive add sodium hexametaphosphate to the water first, at a concentration of 2 g/litre. Stir the mixture well to wet the soil, allow the soil to stand for at least 1hour in this solution stirring frequently.

Step 8: Wash the material through a 75 µm sieve, allowing the material passing sieve 75 µm to run to waste. Ensure that neither test sieve is overloaded in the process, either with material or with water.

Step 9: Transfer all the material retained on the sieve into a tray or evaporating dish and dry in an oven at 105°C to 110°C. Allow it to cool and weigh (m_4).

Step 10: Sieve the dried fractions through the appropriate sieves down to the 75 µm test sieve. Weigh the amount retained on each sieve and any fines passing the 75 µm test sieve and record.

Notes

If the particle size distribution is to be extended below 75 µm (i.e. a Hydrometer analysis is to be performed), the fines must be collected in a tray and not run to waste.

Calculations

1. For samples containing particles larger than 20 mm in size, calculate the proportion by mass of material retained on each of the coarse sieves as a percentage of m_1.

For example:

Percentage retained on 28 mm sieve

$$= \left[\frac{m_{(28\text{mm})}}{m_1}\right] 100$$

2. Calculate the corrected mass of material retained on each of the sieves between 20 mm and 75 µm by multiplying by $\frac{m_2}{m_3}$,then calculate this mass as a percentage of m_1.

For example:

Percentage retained on 10 mm sieve

$$= m_{(10\text{mm})} \left(\frac{m_2}{m_3}\right) \left(\frac{100}{m_1}\right)$$

Notes

3. Calculate the cumulative percentage by mass of the sample passing each of the sieves, from the general relationship:

   (% passing this sieve) = (% passing previous sieve) – (% retained on this sieve).

4. Calculate the fraction passing the 75 µm test sieve by difference. The mass of the fines lost by washing equals ($m_3 – m_4$). To this is added the mass of any fine material (m_F) passing the 75 µm when dry sieved, and the percentage finer than 75 µm is equal to:

$$\left\{\frac{(m_3 - m_4) + m_F}{m_3}\right\} \text{x} \left(\frac{m_2}{m_1}\right) \text{x}100$$

5. Plot the grading as a curve on a semi-logarithmic chart.

Report

The test report shall include the following information:

a) Type of material and sample identification
b) Reference to this procedure
c) The particle size distribution curve

Form for the test

The enclosed form shall be used.

Practical considerations

Take care to ensure that sieving is complete, the minimum period of shaking should be 10 minutes.

Never put a sieve in the drying oven for drying the material, as this will destroy the sieve.

Maintenance

Test sieves should be inspected for defects before each use. A more detailed examination should be made at regular intervals to discover signs of wear, warping, tears, splits holes, blockages and any other defects in the mesh.

Bibliography

Manual of Soil Laboratory Testing, Vol. 1, Second edition by K. H. Head.

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CENTRAL MATERIALS LABORATORY

WORKING SHEET

Sieve Analysis

Grading Modulus and Grading Coefficient

Project	**Location**	**Depth**
Client	**Lab.no**	**Date**
Responsible Technician	**Checked**	**Approved**

TEST METHOD CML TEST 1.7, ref. BS 1377 : Part 2 : 1990

Initial Dry Mass	m_1	g			
BS test sieve		Mass retained (g)		Percentage retained	Cumulative percentage passing
		Actual	Corrected m	$(\frac{m}{m_1}) \times 100$	
75 mm					
63 mm					
50 mm					
37.5 mm					
28 mm					
20 mm					
Passing 20 mm	m_2				
total (checked with m_1)					
riffled	m_3				
riffled and washed	m_4				
Correction factor	$\frac{m_2}{m_3}$				
14 mm					
10 mm					
(6.3 mm)					
5 mm					
(3.35 mm)					
2 mm					
1.18 mm					
600 µm					
(425 µm)					
300 µm					
(212 µm)					
150 µm					
75 µm (63 µm)					
Passing 75 µm (63 µm)	m_F				
Total (check with m_4)			(m_1)		
Grading Modulus : GM = (300 - %<2mm - %<0,425mm - %<0,075mm)/100	GM				
Grading Coefficient : GC = ((%<28mm - %<0,425mm) x (%<5mm))/100	GC				

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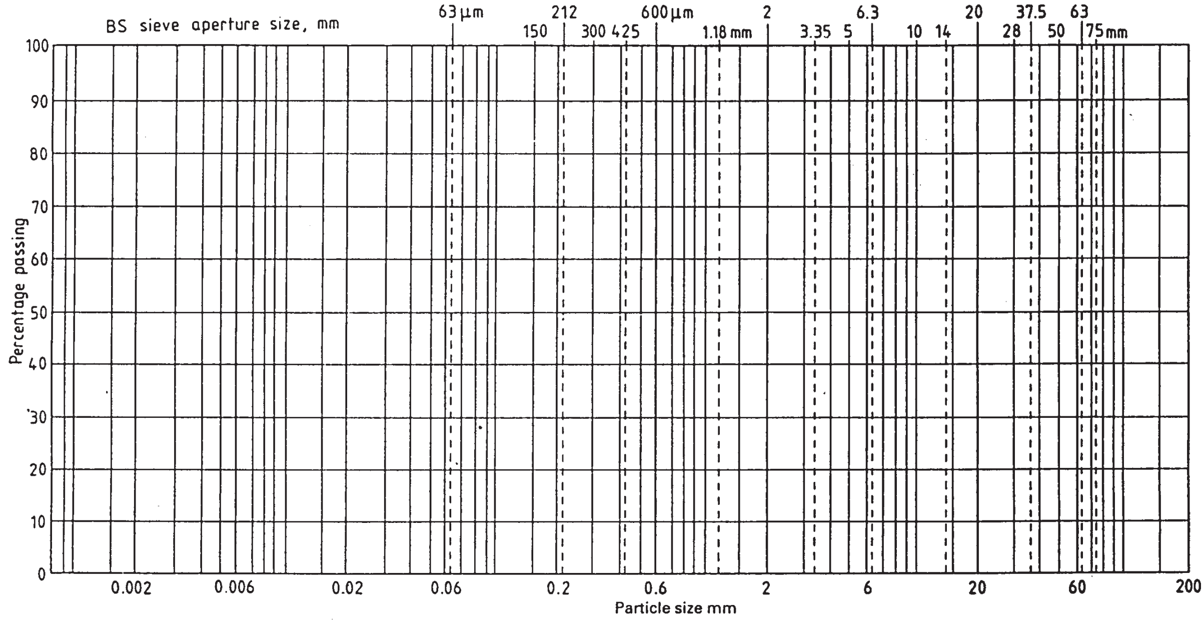
Sieve Analysis
Particle Size Distribution Chart

Project	**Location**	**Depth**
Client	**Lab.no**	**Date**
Responsible Technician	**Checked**	**Approved**

TEST METHOD CML TEST 1.7, ref. BS 1377 : Part 2 : 1990



CLAY	Fine	Medium	Coarse	Fine	Medium	Coarse	Fine	Medium	Coarse	COBBLES	BOULDERS
	SILT			SAND			GRAVEL				

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Central Materials Laboratory
Ministry of Works

1 Soil Mechanics

TEST NO. 1.8

Particle Size Distribution- Hydrometer Method

Notes

In an ordinary Wet sieving analysis, however, the material finer than 0.075 mm is washed to waste.

Objective

Hydrometer method combined with wet or dry sieving enable a continuous particle size distribution curve of a soil to be plotted from the size of the coarsest particles down to clay sizes.

Main Principles

The Hydrometer method covers the quantitative determination of the particle size distribution in a soil from the coarse sand size to the clay size by means of sedimentation. The test is normally not required if less than 10 % of the material passes the 75 µm test sieve in a wet or dry sieving analysis.

A double hydrometer test is recommended as indicative laboratory testing for identification of dispersive soils. This involves testing on two identical portions of the soil sample, one with and one without the use of dispersing agent. The ratio between the measured clay fractions provides a measure of the dispersability of the material, ref. Appendix A6.2 of the Pavement and Materials Design Manual and BS1377:Part 5.

The analysis requires that the particle density of the soil specimen is known or can be assumed.

References

BS 1377 : Part 2 : 1990

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Required equipment

- Hydrometer
- 2 nos. 1L graduated measuring glass cylinders of about 60 mm diameter
- Thermometer readable to 0.5 °C
- Mixer
- Drying oven capable of maintaining temperature of 105 °C - 110 °C
- Distilled water
- Test sieves comprising at least 2 mm, 600 µm, 212 µm, 75 µm and receiver.
- A balance readable to 0.1 g.
- Stopwatch
- Plastic wash bottle
- Evaporating dish
- Dispersing agent, Sodium Hexametaphosphate solution
- Nomographic Chart (ref. Stoke's law).

A 63 µm test sieve may be used if a 75 µm test sieve is not available.

Dissolve 33 g of sodium hexametaphosphate and 7 g of sodium carbonate in distilled water to make 1 L solution.

Sample preparation

The dry mass of soil required depends on the type of soil. Appropriate quantities are about 100 g for a sandy soil and 50 g for a clay or silt.

The required amount of material for the Hydrometer test is about 40 – 50 g (passing 75 µm).

Test Procedure

Step 1: Weigh the sample to 0.1 g to obtain its initial dry mass, m_1.

Step 2: Place the sample in a wide-mouthed conical flask.

If organic matter is present in the soil in significant quantity, pretreatment with hydrogen peroxide is required, ref. BS.

Notes

Dispersion

Step 3: Add 100 mL of the dispersant solution to the soil. Shake the mixture thoroughly until all the soil is in suspension.

Step 4: Mix the suspension in the mixing machine for about 5 minutes until the soil is broken down to individual particles.

The longer you mix, the finer the material becomes.
Check that all clay particles (lumps) are dissolved.

Step 5: Transfer the suspension from the flask to the 75 µm sieve placed on the receiver, and wash the soil using a jet of distilled water from the wash bottle. The amount of water used shall not exceed 500 mL.

Step 6: Transfer the suspension that has passed through the sieve to the 1 L measuring cylinder, and make up to the 1 L graduation mark. This suspension shall be used for the sedimentation analysis.

Step 7: The material retained on the 75 µm sieve shall be transferred to an evaporating dish and oven-dried.

Step 8: When cool, resieve this material on relevant sieves down to 75 µm. Weigh the material retained on each sieve to 0.1 g.

Step 9: Add any material passing the 75 µm sieve to the measuring cylinder.

The total amount of material for the sedimentation analysis should be 40 – 50 g.

Sedimentation

Step 10: Make a separate solution in a 1 L measuring cylinder consisting of 100 mL of the dispersant solution and dilute with distilled water to the 1 L mark. This cylinder shall be placed alongside the cylinder with the soil suspension to achieve the same temperature.

Step 11: Mix the soil suspension in the measuring cylinder by placing the palm of one hand over the open end and turn it vigorously end-over-end about 60 times in 2 minutes.

When the cylinder is upside down, make certain that no soil is stuck to the bottom of the cylinder.

If there is a lot of froth forming on top of the suspension, this may be removed by adding a small amount of pure alcohol from a wash bottle.

Step 12: Place the cylinder quickly on a table and start the timer.

Step 13: Immerse the Hydrometer in the suspension and allow it to float freely.

Step 14: Take hydrometer readings at the upper ring of the meniscus after periods of approximately ½ min, 1 min, 2 min and 4 min. without removing the Hydrometer.

The times indicated may be deviated from if required. This will be taken into account in the subsequent calculations.

Step 15: Remove the Hydrometer slowly, and rinse it in distilled water and place it in the other cylinder with the dispersant solution. Record the top of the meniscus reading, R_0.

Step 16: Reinsert the hydrometer in the soil suspension and record readings after periods of approximately 8 min., 15 min, 30 min, 1 h, 2 h, 4 h, and 24 h from the start of sedimentation. Insert and withdraw the hydrometer after each reading.

Step 17: Observe and record the temperature of the suspension once during the first 15 min and then after each subsequent reading.

Particle Size Distribution- Hydrometer Method

Notes

Calculations

Fine sieving

1. Calculate the proportion of soil retained on each sieve as a percentage of the dry mass of soil used, *m* (in g),

   For example:
   Percentage retained on the 600 µm sieve:

   $= (\frac{m_{(600\ \mu m)}}{m}) \times 100$

2. Calculate the cumulative percentages by mass passing each of the sieves from the general relationship:

   (Cumulative % passing this sieve) = (cumulative % passing previous sieve) – (% retained on this sieve)

Sedimentation

3. Calculate the true hydrometer reading, R_h (in mm), from the equation:

   $R_h = R_h' + C_m$

   where C_m is the meniscus correction. $C_m = 0.5$.

   R_h' is the observed hydrometer reading.

   Enter the values in Table 1.

A description of how to calibrate a Hydrometer is given in BS 1377 : Part 2 : 1990.

4. Obtain the effective depth, H_r (in mm), corresponding to the reading, R_h, from the Hydrometer scale calibration curve. Enter the value of H_r in Table 1.

The equivalent particle diameter, D, can also be calculated mathematically, ref. BS 1377.

5. The equivalent particle diameter, D (in mm), shall be determined by using the nomographic chart for the application of Stoke's law. Each Hydrometer has its own calibrated nomographic chart.

6. Calculate the modified hydrometer reading, R_d, from the equation:

   $R_d = R_h' - R_0'$

   where

   R_0' is the hydrometer reading at the upper rim of the meniscus in the dispersant solution. $R_0' = 1.9$ for 100 mL dispersant solution.

   Enter the value of R_d in Table 1.

Notes

7. Calculate the percentage by mass, K, of particles smaller than the corresponding equivalent particle diameter, D (in mm) from the equation:

$$K = \left(\frac{100\,\rho s}{m(\rho s - 1)}\right) R_d$$

where

The total dry mass of the sample used for the test is inserted here, whether or not any particles were retained on the 75 μm sieve.

m is the mass of the dry soil used (in g)
ρ_s is the particle density (in $Mg/m^3 = ton/m^3$).

Enter the value of K corresponding to each value of D as shown in Table 1.

Report

The test report shall include the following:

a) Type of material and sample identification
b) Reference to this procedure
c) Results of the sedimentation analysis shall be reported and plotted on a semi-logarithmic chart.
d) Results of the sieve analysis (if appropriate)

Form for the test

The enclosed form shall be used.

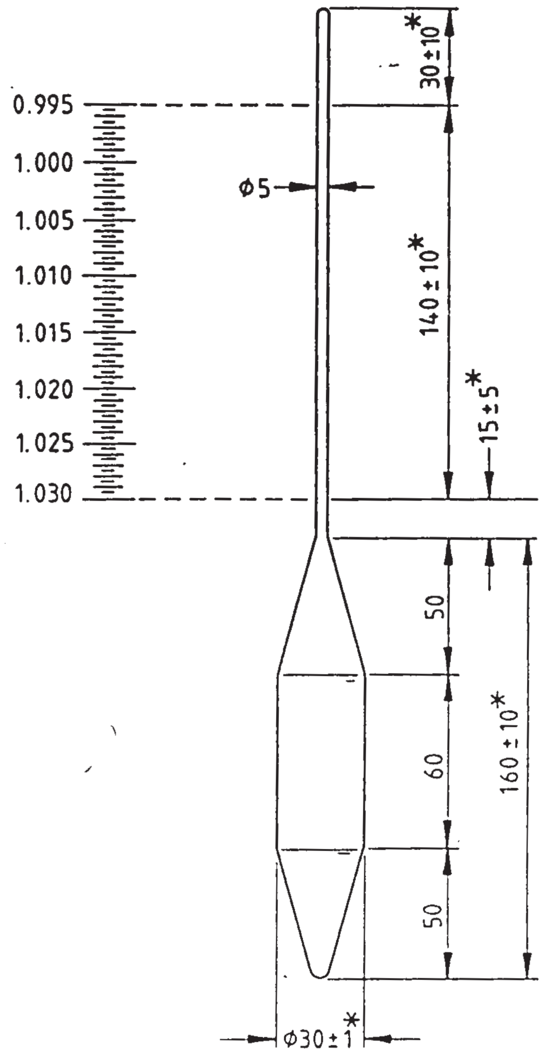
Practical Considerations

The sodium hexametaphosphate solution is unstable and shall be freshly prepared (not older than 1 month). The date of preparation shall be written on the bottle.

1	2	3	4	5	6	7	8	9	10
Date	Time	Elapsed time, t (min)	Temperature T (°C)	Reading R_h'	$R_h' + C_m = R_h$	H_r (mm)	D (mm)	$R_h' - R_0' = R_d$	K %

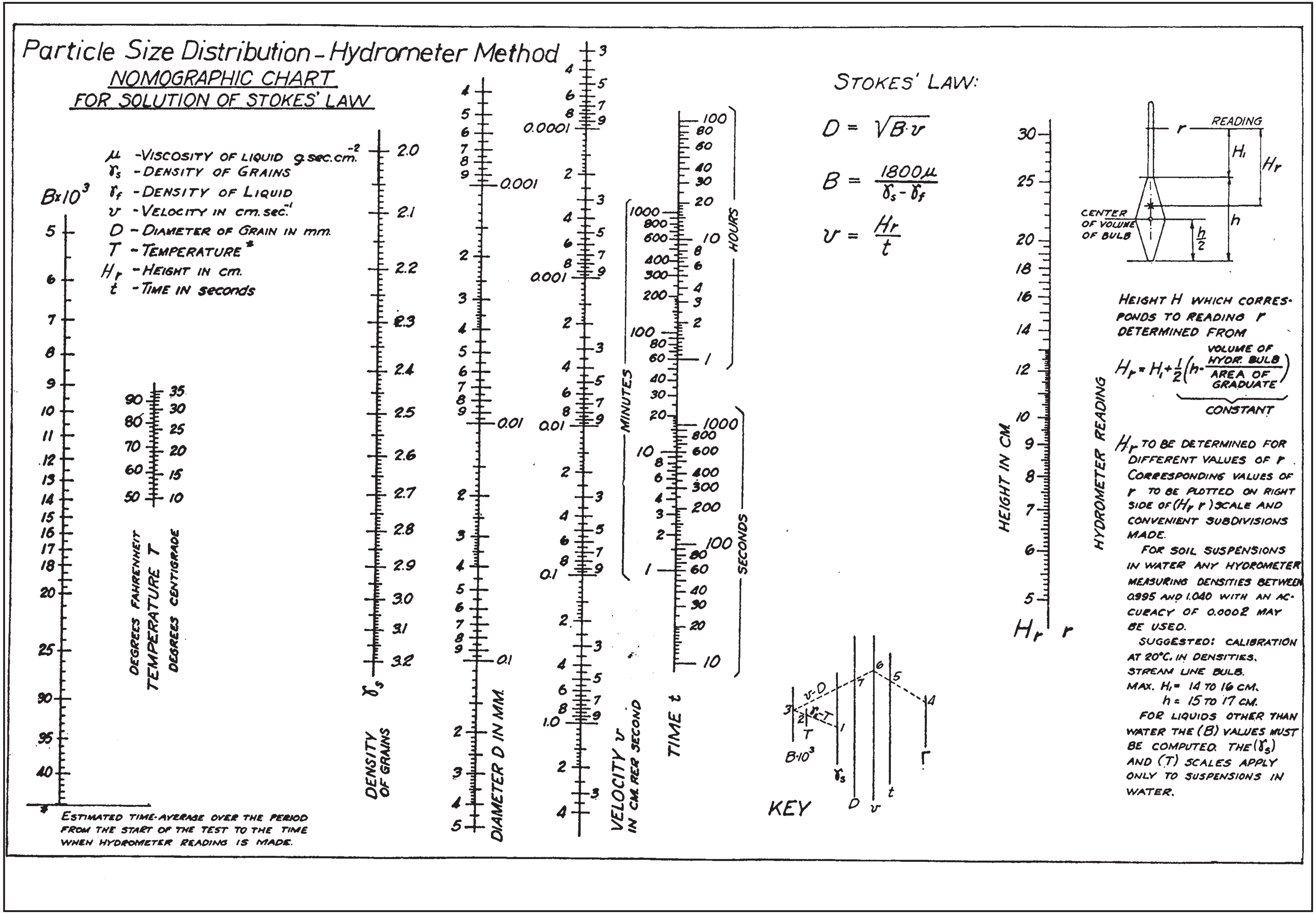
Table 1 Hydrometer Test Data

t	is the elapsed time from start of sedimentation
T	is the temperature at that time
R_h'	is the hydrometer reading at the upper rim of the meniscus, consisting of the decimal part only (eg. a hydrometer reading of 1.0325 would be recorded as a value of 32.5)
C_m	is the meniscus correction
H_r	is the effective depth corresponding to R_h, obtained from the calibration curve
D	is the equivalent particle diameter
R_0'	is the Hydrometer reading at the upper rim of the meniscus in the dispers ant solution
R_d	is the modified Hydrometer reading
K	is the percentage by mass of particles less than D



NOTE. Calibrations in g/ml at 20°C
All dimensions are in millimetres.
* See **4.1.3.1.1** of BS 1377 : Part 1 : 1990.

Figure 3 Hydrometer for determination of fine particle size


Particle Size Distribution - Hydrometer Method

NOMOGRAPHIC CHART FOR SOLUTION OF STOKES' LAW

μ - Viscosity of liquid $g.sec.cm.^{-2}$
γ_s - Density of grains
γ_f - Density of liquid
v - Velocity in $cm.sec.^{-1}$
D - Diameter of grain in mm.
T - Temperature *
H_r - Height in cm.
t - Time in seconds

STOKES' LAW:

$$D = \sqrt{B \cdot v}$$

$$B = \frac{1800\mu}{\gamma_s - \gamma_f}$$

$$v = \frac{H_r}{t}$$

Height H which corresponds to reading r determined from

$$H_r = H_1 + \frac{1}{2}\underbrace{\left(h - \frac{\text{volume of hydr. bulb}}{\text{area of graduate}}\right)}_{\text{constant}}$$

H_r to be determined for different values of r. Corresponding values of r to be plotted on right side of (H_r r) scale and convenient subdivisions made.

For soil suspensions in water any hydrometer measuring densities between 0.995 and 1.040 with an accuracy of 0.0002 may be used.

Suggested: calibration at 20°C. in densities. Stream line bulb. Max. H_1 = 14 to 16 cm. h = 15 to 17 cm.

For liquids other than water the (B) values must be computed. The (γ_s) and (T) scales apply only to suspensions in water.

* Estimated time-average over the period from the start of the test to the time when hydrometer reading is made.

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WORKING SHEET

Particle Size Distribution

Hydrometer method

Project	**Location**	**Depth**
Client	**Lab.no**	**Date**
Responsible Technician	**Checked**	**Approved**

TEST METHOD	CML TEST 1.8, ref. BS 1377 : Part 2 : 1990		
Hydrometer no.		Dispersing agent	
Meniscus correction C_m	0,5	Particle Density ρ_s	Mg/m^3
Dry mass of sample m_0	g		
Dry mass after pretreatment m	g		
Dry mass passing 75 µm sieve m_s	g		

Date	Time	Time elapsed t	Hydrometer reading $R_{h'}$	Temperature T °C	$R_{h'} + C_m = R_h$	H_r (from chart)	D (mm) (from chart)	K (in %) = $\frac{100\rho_s R_h}{m_s(1-\rho_s)}$	K' = $K\frac{m_s}{m}$ %
		½ min.							
		1 min.							
		2 min.							
		4 min.							
		8 min.							
		15 min.							
		30 min.							
		1 hour							
		2 hours							
		4 hours							
		24 hours							

t	is the elapsed time from start of sedimentation
T	is the temperature at that time
R_h'	is the hydrometer reading at the upper rim of the meniscus, consisting of the decimal part only (eg. a hydrometer reading of 1.0265 would be recorded as a value of 26.5)
R_h	is the true Hydrometer reading
C_m	is the meniscus correction
H_r	is the effective depth corresponding to R_h, obtained from the calibration curve
D	is the equivalent particle diameter
K	is the percentage by mass of particles less than D

TEST NO. 1.9

Dry Density - Moisture Content Relationship (BS Light & BS Heavy)

Notes

There is a similar third type of test which makes use of a Vibrating Hammer for the compaction effort.(There is also a static compaction method).

For coarser material this type of test is generally not considered applicable.

Objective

The objective of this test is to obtain relationships between compacted dry density and soil moisture content, using two magnitudes of manual compactive effort. The test is used to provide a guide for specifications on field compaction.

The first is a light compaction test using a 2.5 kg rammer (Standard Proctor). The second is a heavy compaction test using a 4.5 kg rammer with a greater drop on thinner layers of soil (Modified Proctor). For both tests a compaction mould of 1 litre internal volume is used for soil in which all particles pass a 20 mm test sieve.

For soils containing up to 10 % material coarser than 37.5 mm and up to 30 % material coarser than 20 mm, equivalent tests are carried out in the larger CBR mould.

Main Principles

The dry density which can be achieved for a soil depends on the degree of compaction applied and the moisture content.

The moisture content which gives the highest dry density is called the optimum moisture content for that type of compaction. In general the optimum moisture content is less than the Plastic Limit.

References

BS 1377 : Part 4 : 1990.

Method using 2.5 Kg rammer (BS Light)

Required equipment

- A cylindrical compaction mould with internal diameter of 105 mm and internal height of 115 mm and a volume of 1.0 L (1000 cm3). The mould shall be fitted with a detachable baseplate and a removable extension (collar) approximately 50 mm height.
- Subsidiary mould (CBR mould), diameter 152 mm, height 127 mm.
- A metal rammer having a 50 mm diameter circular face and weighing 2.5 kg. The rammer shall be equipped with an arrangement for controlling the height of drop to 300 mm.
- A balance readable to 1 g.
- Palette knives or spatulas
- A straightedge, e.g. a steel strip
- A 20 mm and 37.5 mm test sieves and receiver
- A container suitable for mixing the quantity of material to be used
- Water proof containers and scoop
- A large metal tray
- Measuring cylinder, 200 ml or 500 ml
- Suitable tools for extracting specimen from mould
- Apparatus for moisture content determination

TEST NO. 1.9

Dry Density - Moisture Content Relationship (BS Light & BS Heavy)

Sample preparation

Prepare 5 representative samples each of about 3 kg of material passing the 20 mm test sieve. (For the use of the 1 litre mould). Break up lumps of fine material by rolling on a flat surface.

Notes

Increments of water content of about 2 % are suitable for sandy and gravelly soils and about 3 % for cohesive soils.

For coarser material where max. 10 % is retained on the 37.5 mm sieve and max. 30 % is retained on the 20 mm sieve, a CBR mould shall be used. The material coarser than 37.5 mm shall be removed and weighed, and replaced by the same quantity of material of the fraction 20 mm - 37.5 mm. In this case, each of the 5 samples should be of about 6 kg.

Mix each sample thoroughly with different amounts of water to give a suitable range of moisture contents. The range of moisture contents shall be such that at least 2 values lie either side of the optimum moisture content.

It is advised to turn the container upside down at suitable intervals.

Seal each of the 5 portions in an airtight container and allow to cure for a minimum of 4 hours.

The finer the material, the longer curing time is required.
On coarse material 1 batch only may be used. Water is then added for each individual point.

Test Procedure - 1 litre mould

Step 1: The mould with the base plate attached shall be weighed to the nearest 1 g (m_1).

Step 2: Attach the extension collar and place the mould on a solid base, e.g. a concrete floor.

Step 3: Place a quantity of moist soil in the mould such that when compacted it occupies a little over 1/3 of the height of the mould body.

If it is difficult to evaluate the required heights, 3 equal portions could be weighed by assuming a reasonable density. Remember to use the collar even for the first layer, to avoid damaging the edge of the mould.

Step 4: Place the rammer with guide on the material in the mould. Lift the rammer handle until it reaches the top of the guide, then release handle allowing to drop freely on the sample.

Step 5: Change position of guide and again drop rammer. Repeat the process, systematically covering entire surface of sample. A total of 27 blows shall be applied.

For coarser material when a CBR mould is used, 62 blows shall be applied to each layer.

Step 6: Remove rammer and fill next layer of soil in the mould, and repeat the above process twice more by applying 27 blows to both the second and the third layer. The mould should be filled, but surface should not be more than 6 mm proud of the upper edge of the mould body.

Step 7: When all three layers are compacted, remove the extension collar, strike off excess soil and level the surface of the compacted soil to the top of the mould using the straightedge. Replace any coarse particles removed in the levelling process by finer material from the sample well pressed in.

Step 8: Weigh the soil and the mould with baseplate attached to 1 g (m_2).

Step 9: Remove the compacted sample from the mould. Take a representative sample of min. 300 g of the soil for determination of its moisture content.

Sample for moisture content may not be taken before compaction.

Step 10: Discard the remainder of the sample. (The sample must not be re-used in a later test).

Dry Density - Moisture Content Relationship (BS Light & BS Heavy)

Notes

When the weight of sample in the mould decreases, you may stop the test.

Step 11: This whole process shall be carried out for all 5 portions of the sample.

Calculations

1. Calculate the Bulk Density of each compacted specimen from the equation:

Bulk Density, $\rho = \frac{m_2 - m_1}{V} \times 1000$ (in kg/m³)

where

m_1 is the mass of mould and baseplate (in g)
m_2 is the mass of mould, baseplate and compacted soil (in g)
V is the volume of the mould (in cm3)

2. Calculate the Dry Density, ρ_d (in kg/m^3), of each

Dry Density, $\rho_\mathbf{d} = \frac{100\,\rho}{100 + w}$

where

w is the moisture content of the soil (in %)

The maximum may lie between two observed points, but when drawing the curve care should be taken not to exaggerate its peak.

3. Plot the Dry Densities obtained from a series of determinations as ordinates against the corresponding Moisture Contents as abscissae. Draw a curve of best fit to the plotted points and identify the position of the maximum on this curve. Read off the values of dry density and moisture content, to three significant figures, corresponding to that point, see figure 1.

4. On the same graph, plot the curves corresponding to the 0 %, 5 % and 10 % air voids, calculated from the equation:

$$\rho_d = \frac{1 - \frac{V_a}{100}}{\frac{1}{\rho_s} + \frac{w}{100\,\rho_w}}$$

where

$\rho_\mathbf{d}$ is the dry density (in kg/m^3)
ρ_s is the particle density (in kg/m^3)
ρ_w is the density of water (in kg/m^3)
V_a is the volume of air voids in the soil, expressed as a percentage of the total volume of soil
w is the moisture content (in %)

Dry Density - Moisture Content Relationship (BS Light & BS Heavy)

Notes

Report

The test report shall include the following:

a) Type of material and sample identification

b) Reference to this procedure

c) The experimental points and the smooth curve drawn through them showing the relationship between Moisture Content and Dry Density.

d) The Dry Density corresponding to the maximum Dry Density on the curve, reported as the Maximum Dry Density to the nearest whole number (in kg/m3).

e) The corresponding Moisture Content reported as the Optimum moisture Content to two significant figures (in %).

f) The amount of material (stone) retained on the 20 mm and 37.5 mm sieves reported to nearest 1 % by dry mass.

g) The particle density and whether measured or assumed

Form for the test

The enclosed form shall be used.

Method using 4.5 kg rammer (BS Heavy)

In this test the compactive effort is greater than described in the above test. The mass of the rammer is increased to 4.5 kg, the height of the drop to 450 mm, and the number of compacted layers are increased from three to five.

For the coarser material where max. 10 % is retained on the 37.5 mm sieve and max. 30 % is retained on the 20 mm sieve, the material coarser than 37.5 mm shall be removed and weighed, and replaced by the same quantity of material of the fraction 20 mm - 37.5 mm.

The test is performed on material passing the 20 mm test sieve using the 1 L mould, or on material passing 37.5 mm test sieve using the CBR mould as described above.

The sample preparation and the testing procedure is identical to the above test with the exception of:

- The rammer used is 4.5 kg in weight with a drop of 450 mm.
- The moist soil shall be compacted in 5 equal layers into the mould

For coarser material when a CBR mould is used, 62 blows shall be applied to each layer.

The number of blows applied to each layer shall be 27, i.e. the same as for the above described test.

Calculations, plotting of curves and expression of results including the test report are the same as for the above test.

Practical Considerations

Preferably use a jack to remove the sample from the mould. Do <u>not</u> use a metal hammer/mallet as this will destroy the mould.

It should be emphasized that material must not be re-used in the compaction test by adding more water to the same sample and obtaining the DD/MC curve in such a manner.

Notes

Maintenance

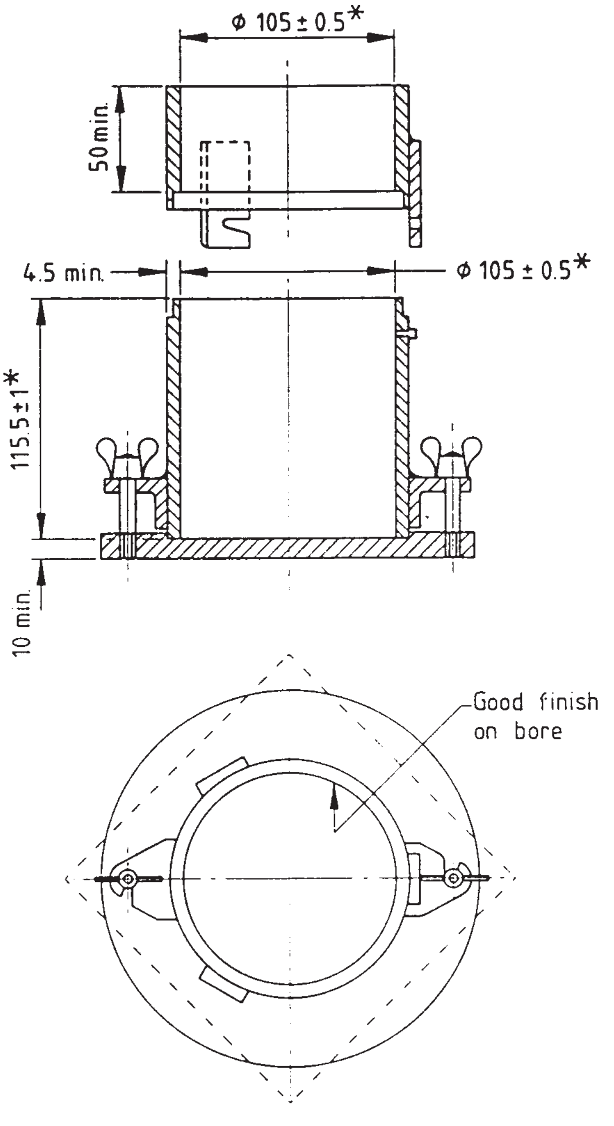
The moulds must be kept clean with smooth inside walls.

The rammer must always be free of material sticking to its face. Also the inside of the guide must be checked regularly such that the rammer always falls freely inside the guide.

Precision

For some highly permeable soils such as clean gravels, uniformly graded and coarse clean sands, the results of the laboratory compaction test may provide only a poor guide for specification of field compaction.

For these soils one of the maximum dry density tests described in clause 4 in BS 1377:Part 4:1990 would be more appropriate.

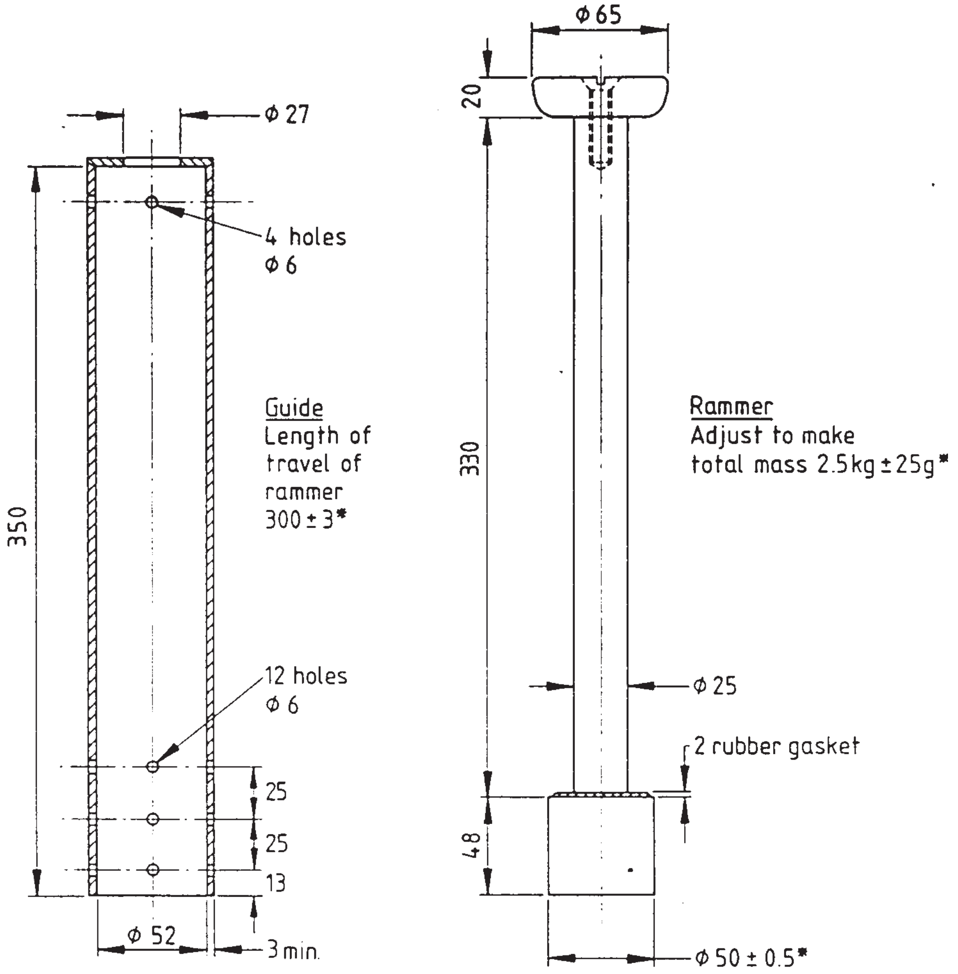


All dimensions shown are in millimetres.

This design has been found satisfactory, but alternative designs may be used provided that the essential requirements are fulfilled.

*See **4.1.3.1.1** of BS 1377 : Part 1 : 1990.

Figure 4 Mould for compaction test (1L mould)

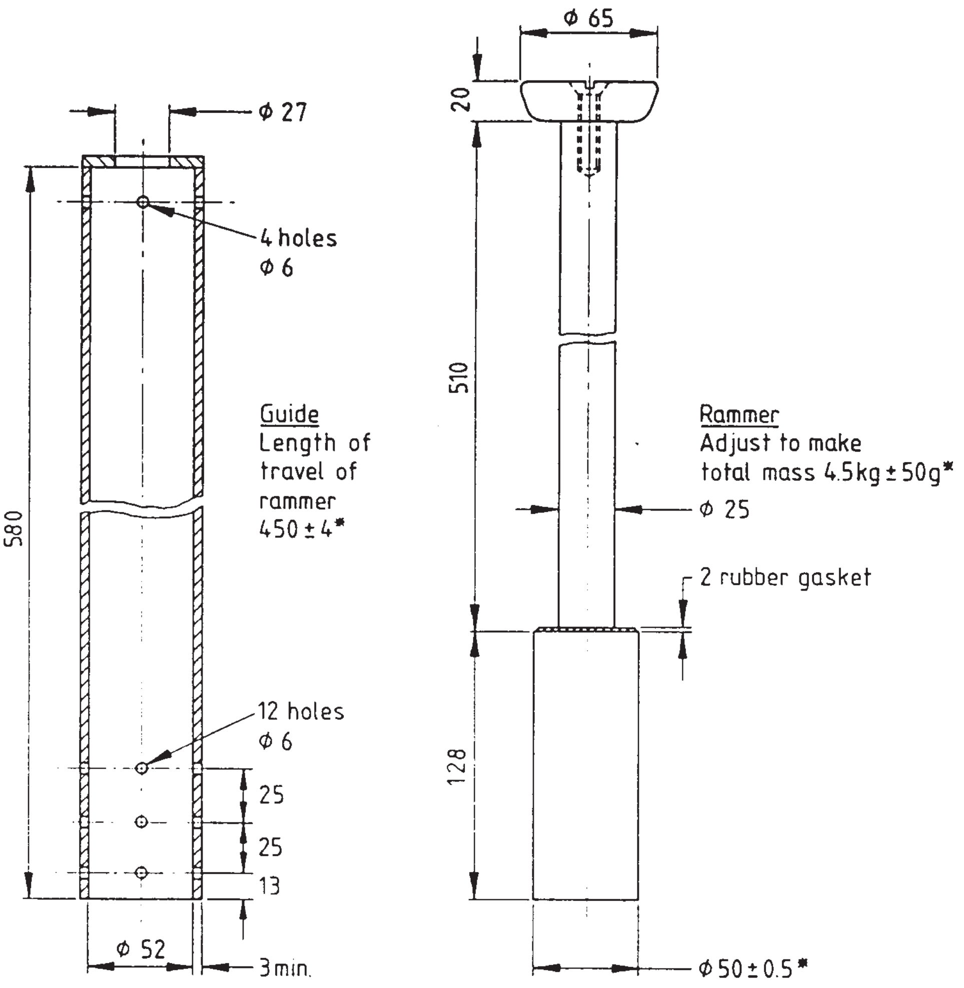


All dimensions shown are in millimetres.

This design has been found satisfactory, but alternative designs may be used provided that the essential requirements are fulfilled.

*See **4.1.3.1.1** of BS 1377 : Part 1 : 1990.

Figure 5 2.5 kg rammer for compaction test



This design has been found satisfactory, but alternative designs may be used provided that the essential requirements are fulfilled.

*See **4.1.3.1.1** of BS 1377 : Part 1 : 1990.

Figure 6 4.5 kg rammer for compaction test

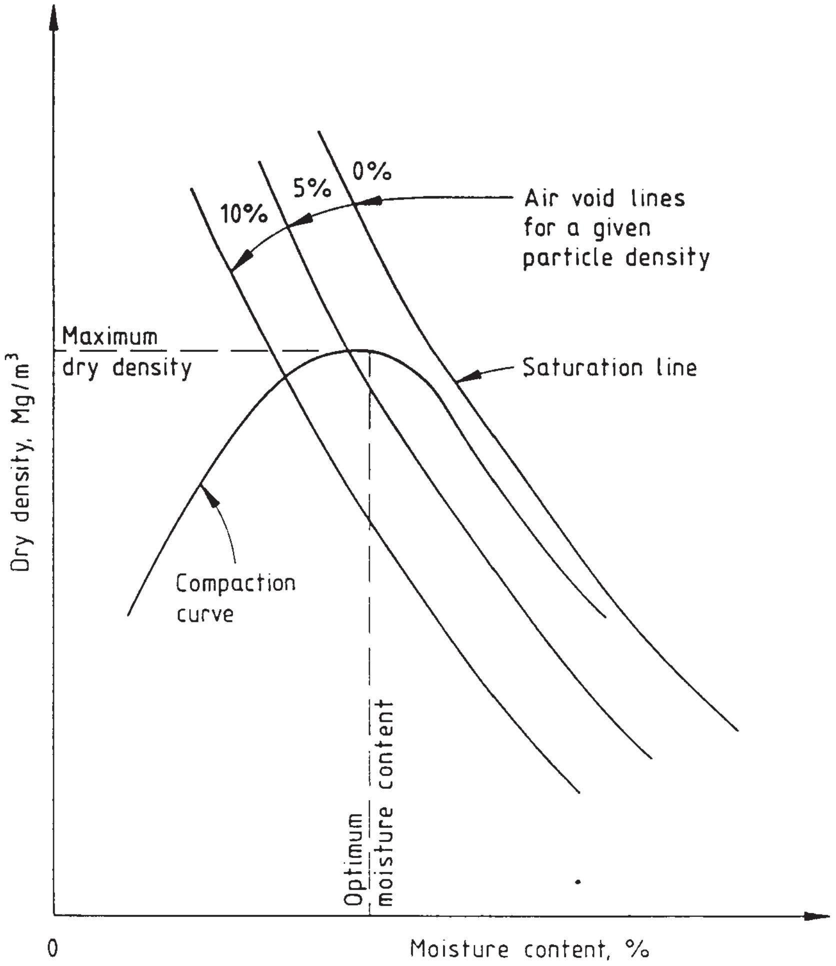


Figure 6 Dry density/moisture content relationship curve

CML
CENTRAL MATERIALS LABORATORY

WORKING SHEET

Compaction Test

Project	**Location**	**Depth**
Client	**Lab.no**	**Date**
Responsible Technician	**Checked**	**Approved**

TEST METHOD CML TEST 1.9, ref. BS 1377 : Part 4 : 1990

METHOD:	TEST NO.	1	2	3	4	5	6	7
WEIGHT OF SAMPLE	(g)							
WATER ADDED	(cc)							
WEIGHT OF MOULD + SAMPLE	(g)							
WEIGHT OF MOULD	(g)							
WEIGHT OF SAMPLE	(g)							
WET DENSITY	(kg/m³)							
DRY DENSITY	(kg/m³)							
FACTOR OF MOULD:								
MOISTURE CONTAINER NO.								
WEIGHT OF WET SOIL + CONTAINER	(g)							
WEIGHT OF DRIED SOIL + CONTAINER	(g)							
WEIGHT OF CONTAINER	(g)							
WEIGHT OF WATER	(g)							
WEIGHT OF DRY SOIL	(g)							
MOISTURE CONTENT	(%)							

DRY DENSITY (kg/m³)

MOISTURE CONTENT %

NMC %	OMC %	MDD -Kg/m³

TEST NO. 1.10

CBR - California Bearing Ratio Test - One Point Method

Notes

The preferred test method in the Pavement and Materials Manual is the 3-point method, ref. CML test 1.11.
The one point method could be used as an indicator of CBR in "emergencies" of insufficient sample size. It should not be used in compliance control for road projects.

The method described here is for a material compacted to 100 % of MDD for BS Heavy compaction or 100 % of MDD for BS Light compaction.

Static compaction or dynamic compaction by vibrating hammer can also be used, to achieve any specified density, ref. BS 1377.

Choice of rammer depends on the required degree of compaction, i.e. BS Light or BS Heavy.

Objective

The strength of the subgrade is the main factor in determining the required thickness of flexible pavements for roads and airfields. The strength of a subgrade, subbase and base course materials are expressed in terms of their California Bearing Ratio (CBR) value.

The CBR-value is a requirement in design for pavement materials of natural gravel.

Main Principles

This method covers the laboratory determination of the California Bearing Ration (CBR) of a compacted sample of soil dynamically compacted by metal rammers – one point method.

The CBR value is the resistance to a penetration of 2.5 mm of a standard cylindrical plunger of 50 mm diameter, expressed as a percentage of the known resistance of the plunger to 2.5 mm in penetration in crushed aggregate, (taken as 13.2 kN).

References

BS 1377 : Part 4 : 1990

Required equipment

- Test sieves, sizes 20 mm and 5 mm.
- A cylindrical metal mould, i.e. the CBR mould, having a nominal internal diameter of 152 mm and a height of 127 mm. The mould shall be fitted with a detachable baseplate and a removable extension. The internal face shall be smooth, clean and dry before use.
- A metal rammer of either 2,5 kg or 4,5 kg
- A steel rod
- A steel straightedge
- A spatula
- A balance, capable of weighing up to 25 kg readable to 5 g.
- Apparatus for moisture content determination.
- Filter papers 150 mm in diameter.

Sample preparation

The CBR test shall be carried out on material passing the 20 mm test sieve. If the soil contains particles larger than this, the fraction retained on the 20 mm test sieve shall be removed and weighed before preparing the test sample. If this fraction is greater than 25 %, the test is not applicable.

The moisture content of the soil shall be chosen to represent the design condition for which the test results are required.

TEST NO.1.10

CBR - California Bearing Ratio Test - One Point Method

Notes

The Optimum Moisture Content (OMC) is normally required.

A coarse material may be tested at once without curing.

Three portions for the 2.5 kg method and five portions for the 4.5 kg method.

One-third for the 2.5 kg method and one-fifth for the 4.5 kg method.

Take a portion of material large enough to provide about 6 kg of material passing a 20 mm sieve.

Bring the sample to the required moisture content. The soil shall be thoroughly mixed and shall normally be sealed and stored for at last 24 h before compacting into the mould.

The specified effort of compaction shall correspond to the 2.5 kg rammer method - BS Light or the 4.5 kg rammer method - BS Heavy (or to an intermediate value).

Test procedure

Step 1: Divide the prepared quantity of soil into three (or five) portions equal to within 50 g and seal each portion in an airtight container until required for use, to prevent loss of moisture.

Step 2: Stand the mould assembly on a solid base, e.g. a concrete floor or plinth.

Step 3: Place the first portion of soil into the mould and compact it, so that after 62 blows of the appropriate rammer the layer occupies about or a little more than one-third (or one-fifth) of the height of the mould. Ensure that the blows are evenly distributed over the surface.

Step 4: Repeat using the other two (or four) portions of soil in turn, so that the final level of the soil surface is not more than 6 mm above the top of the mould body.

Step 5: Remove the collar and trim the soil flush with the top of the mould with the scraper, checking with the steel straightedge.

Step 6: Weigh the mould, soil and baseplate to the nearest 5 g (m_3).

Soaking

Required equipment

- A perforated baseplate, fitted to the CBR mould in place of the normal baseplate (see figure 8).
- A perforated swell plate, with an adjustable stem to provide a seating for a dial gauge. (see figure 9).
- Tripod, mounting to support the dial gauge.
- A dial gauge, having a travel of 25 mm and reading to 0,01 mm.
- A soaking tank, large enough to allow the CBR mould with baseplate to be submerged, preferably supported on an open mesh platform.
- Annular surcharge discs, each having a mass known to + 50 g. Halfcircular segments may be used.
- Petroleum jelly.

TEST NO. 1.10

CBR - California Bearing Ratio Test - One Point Method

Notes

At CML all baseplates are perforated.

One surcharge disc of 2 kg simulates the effect of approximately 70 mm of superimposed construction on the formation being tested.

Record the time taken for water to appear at the top of the sample. If this has not occurred in three days, flood the top of the sample and leave to soak for a further day giving the normal soaking period of 4 days.

Soaking procedure

Step 1: If a solid baseplate have been used, this shall be removed from the mould and replaced with a perforated baseplate.

Step 2: Fit the collar to the other end of the mould, packing the screw threads with petroleum jelly to obtain a watertight joint.

Step 3: Place the mould assembly in the empty soaking tank. Place a filterpaper on top of the sample followed by the perforated swell plate. Fit the required number of annular surcharge discs around the stem on the perforated plate.

Step 4: Mount the dial gauge support on top of the extension collar, secure the dial gauge in place and adjust the stem on the perforated plate to give a convenient zero reading.

Step 5: Fill the soaking tank with water to just below the top of the mould extension collar. Start the timer when the water has just covered the baseplate.

Step 6: Record readings of the dial gauge each day.

Step 7: Take off the dial gauge and its support, remove the mould assembly from the soaking tank and allow the sample to drain for 15 min.

Step 8: Remove the surcharge discs, perforated plate and extension collar. Remove the perforated baseplate and refit the solid baseplate if available.

Step 9: If the sample has swollen, trim it level with the end of the mould.

The sample is then ready for test in the soaked condition.

Penetration test procedure

Required equipment

- A cylindrical metal plunger.
- A CBR compression machine. The machine shall be capable of applying at least 45 kN at a rate of penetration of the plunger of 1 mm/min to within ± 0,2 mm/min.
- A loading ring.
- A dial gauge with 25 mm travel, reading to 0,01 mm for measuring the penetration of the plunger into the specimen.
- A stopwatch
- The CBR mould
- Surcharge discs

TEST NO.1.10

CBR - California Bearing Ratio Test - One Point Method

Notes

Procedure

Step 1: Place the mould with baseplate containing the sample, with the top face of the sample exposed, centrally on the lower platen of the testing machine.

Step 2: Place the appropriate annular surcharge discs on top of the sample

Step 3: Fit into place the cylindrical plunger on the surface of the sample.

Step 4: Apply a seating force to the plunger, depending on the expected CBR value as follows:

For CBR value up to 5% apply 10 N
For CBR value from 5% to 30% apply 50 N
For CBR value above 30% apply 250 N

The seating force is not taken into account during the test.

Step 5: Record the reading of the loading ring as the initial zero reading (or reset the loading ring to read zero).

Step 6: Secure the penetration dial gauge in position. Record its initial zero reading, or reset it to zero.

Step 7: Start the test so that the plunger penetrates the sample at a uniform rate 1mm/min.

Step 8: Record readings of the force gauge at intervals of penetration of 0,25 mm, to a total penetration not exceeding 7,5 mm (see form F).

Step 9: If a test is to be carried out on both ends of the sample, raise the plunger and level the surface of the sample by filling in the depression left by the plunger. Check for flatness with the straightedge.

Step 10: Remove the baseplate from the lower end of the mould, fit it securely on the top end and invert the mould. Trim the exposed surface if necessary.

Step 11: Carry out the test on the base by repeating steps 1 – 8.

If the sample has been soaked the moisture content after soaking will generally exceed the initial moisture content.

Step 12: After completing the penetration test or tests, determine the moisture content of the test sample.

Calculation and plotting

Force-penetration curve (see form 4.F and 4.G)

1) Calculate the force applied to the plunger from each reading of the loading ring observed during the penetration test.
2) Plot each value of force as ordinate against the corresponding penetration as abscissa and draw a smooth curve through the points.

The normal curve is convex upwards as shown in figure 12, test 1, and needs no correction.

If the initial part of the curve is concave as for test 2 in figure 12, a correction is necessary. Draw a tangent at the point of the steepest slope, and produce it to intersect the abscissa. This is the corrected zero point.

CBR - California Bearing Ratio Test - One Point Method

Notes

If the curve continues to curve upwards as for test 3 in figure 12, it is considered that the penetration of the plunger is increasing the soil density and subsequently its strength. No correction is necessary.

Calculation of California Bearing Ratio (CBR)

Penetrations of 2.5 mm and 5.0 mm are used for calculating the CBR value.

1. Record the plunger force value at 2.5 mm penetration from the (corrected) force-penetration curve.
2. Calculate the corresponding CBR value from the equation:

$$\text{CBR value (in \%)} = P \times \frac{100}{13.2}$$

where

P is the plunger force (in kN) at 2.5 mm penetration.

3. Record the plunger force value at 5.0 mm penetration from the (corrected) force-penetration curve.
4. Calculate the corresponding CBR value from the equation:

$$\text{CBR value (in \%)} = P \times \frac{100}{20.0}$$

where

P is the plunger force (in kN) at 5.0 mm penetration.

4. The higher of these two values is taken as the CBR value.
5. If a test is carried out on both ends of the sample, the above calculation procedure, steps 1 – 5, is repeated.

Density Calculations

1) Calculate the internal volume of the mould, V_m (in cm^3).

2) *Bulk density*. The initial bulk density, ρ (in kg/m^3), of the sample, is calculated from the equation:

$$\rho = \frac{m_3 - m_2}{V_m} \times 1000$$

where

m_3 is the mass of soil, mould and baseplate (in g)
m_2 is the mass of the mould and baseplate (in g)
V_m is the volume of the mould body (in cm^3).

3) *Dry density*. The initial dry density, ρ_d (in kg/m^3), of the sample is calculated from the equation:

CBR - California Bearing Ratio Test - One Point Method

Notes

$$\rho_d = \left(\frac{100}{100 + w}\right) \rho$$

where

w is the moisture content of the soil (in %).

4) If the dry density of the soaked soil is required, calculate it from the equation:

$$\rho_{ds} = \frac{\rho_d}{1 + \frac{Ax}{1000V_m}}$$

where

A is the area of cross section of the mould (in mm^2)
x is the increase in sample height after swelling (in mm).

Report

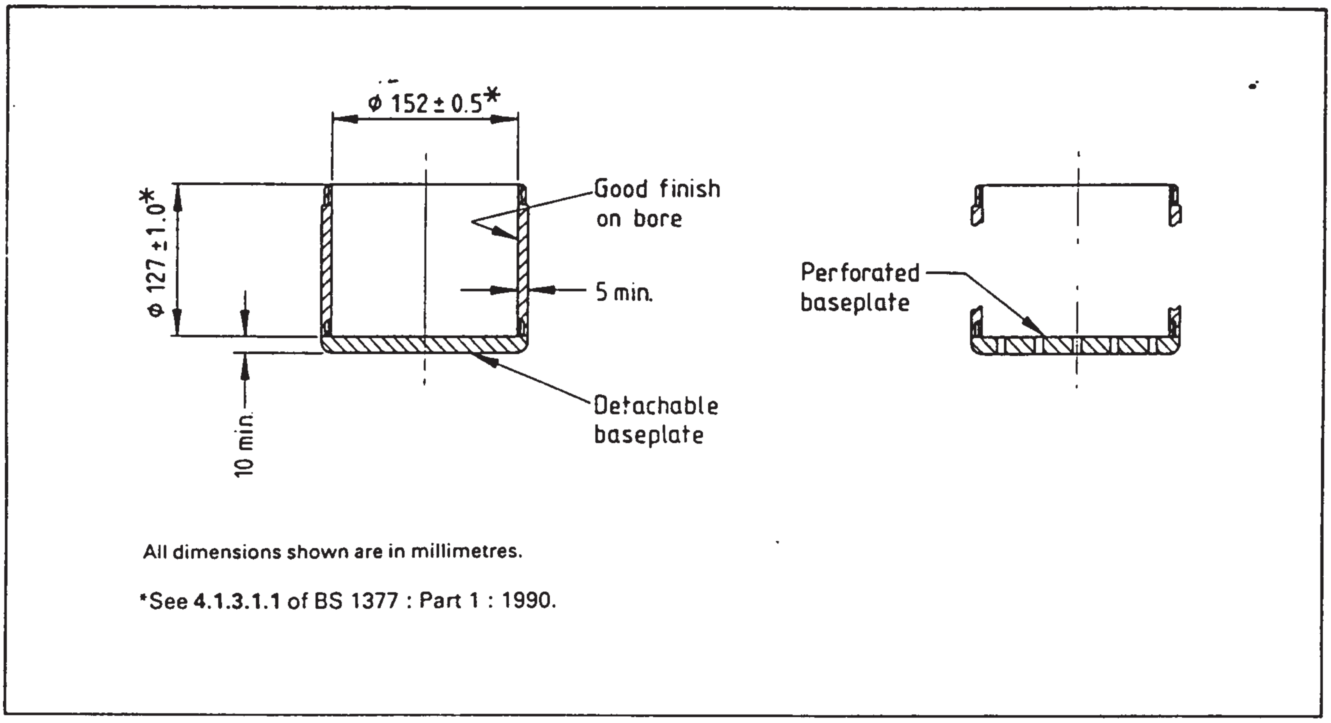
The test report shall include the following:

1. Type of material and sample identification
2. Reference to this procedure
3. Force-penetration curves, showing corrections if appropriate
4. The CBR values (from top and bottom), to the nearest whole num ber. If the result from each end of the sample are within ± 10 % of the mean value, the average result may be reported.
5. The initial sample density and the moisture content and dry density if required
6. The final moisture contents below the plunger after testing
7. (Whether soaked or not)
8. Period of soaking and amount of swell
9. The proportion by dry mass of any over-size material removed from the original soil sample before testing.

Practical Considerations

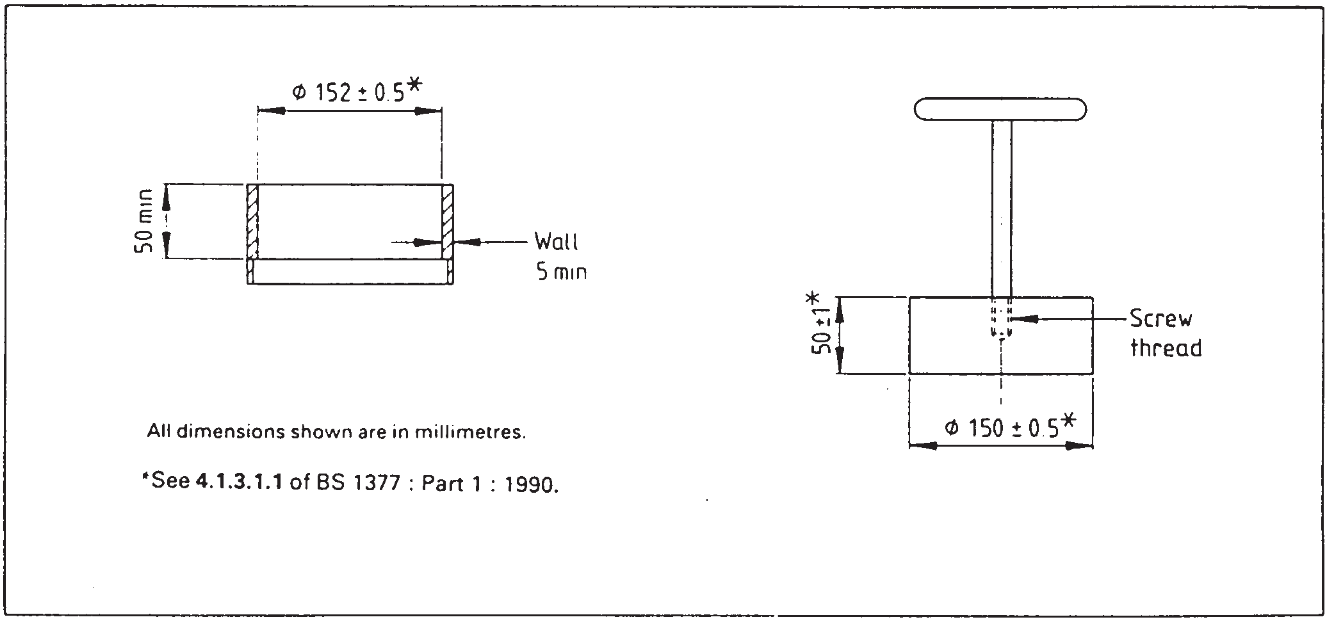
Use an extruder for removing the sample (no hammering).

Make certain that the mould is fastened tightly to the baseplate.



All dimensions shown are in millimetres.

*See **4.1.3.1.1** of BS 1377 : Part 1 : 1990.



All dimensions shown are in millimetres.

*See **4.1.3.1.1** of BS 1377 : Part 1 : 1990.

Figure 9 Plug and collar extension for use with cylindrical mould for the determination of the California Bearing Ratio

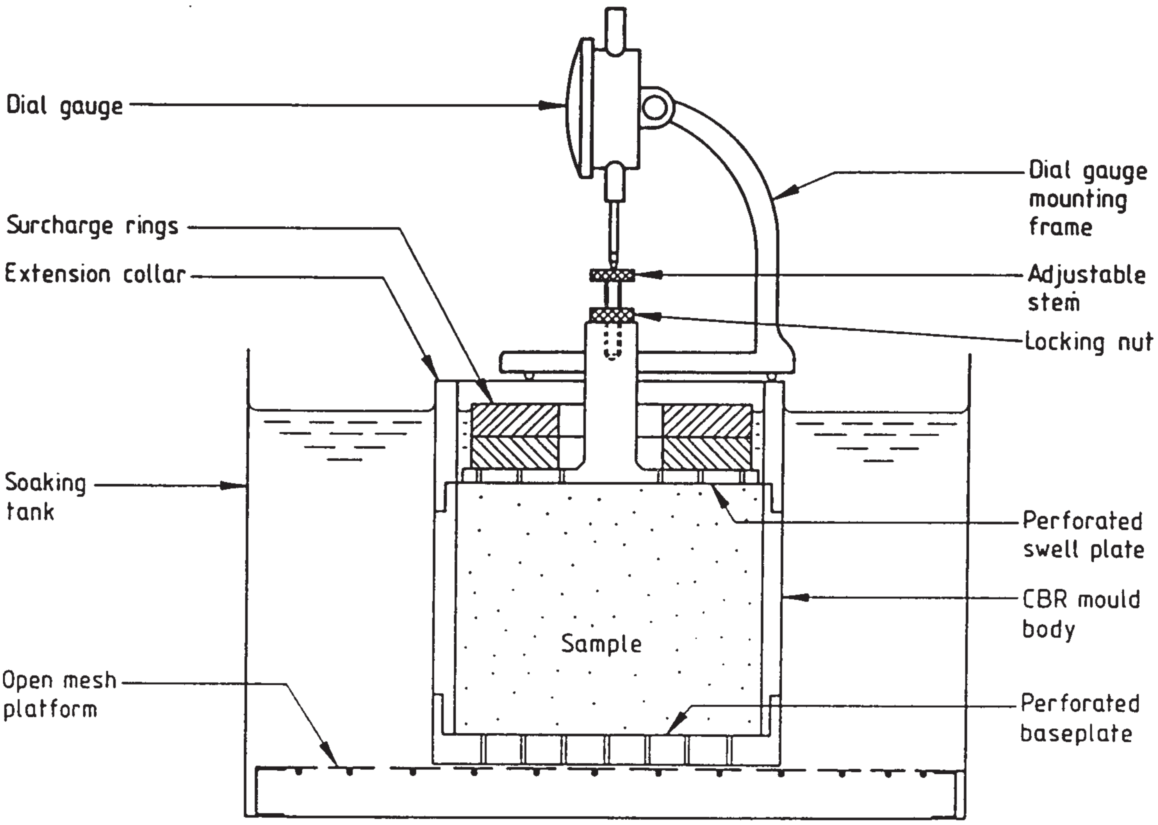
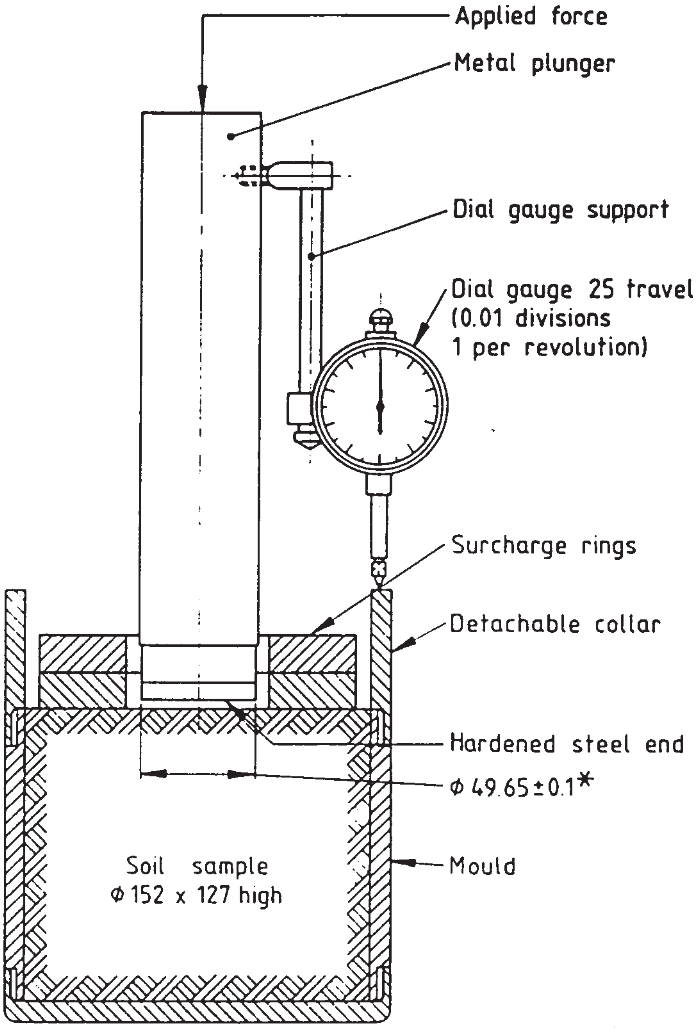


Figure 10 Apparatus for measuring the swelling of a sample during soaking for the CBR test

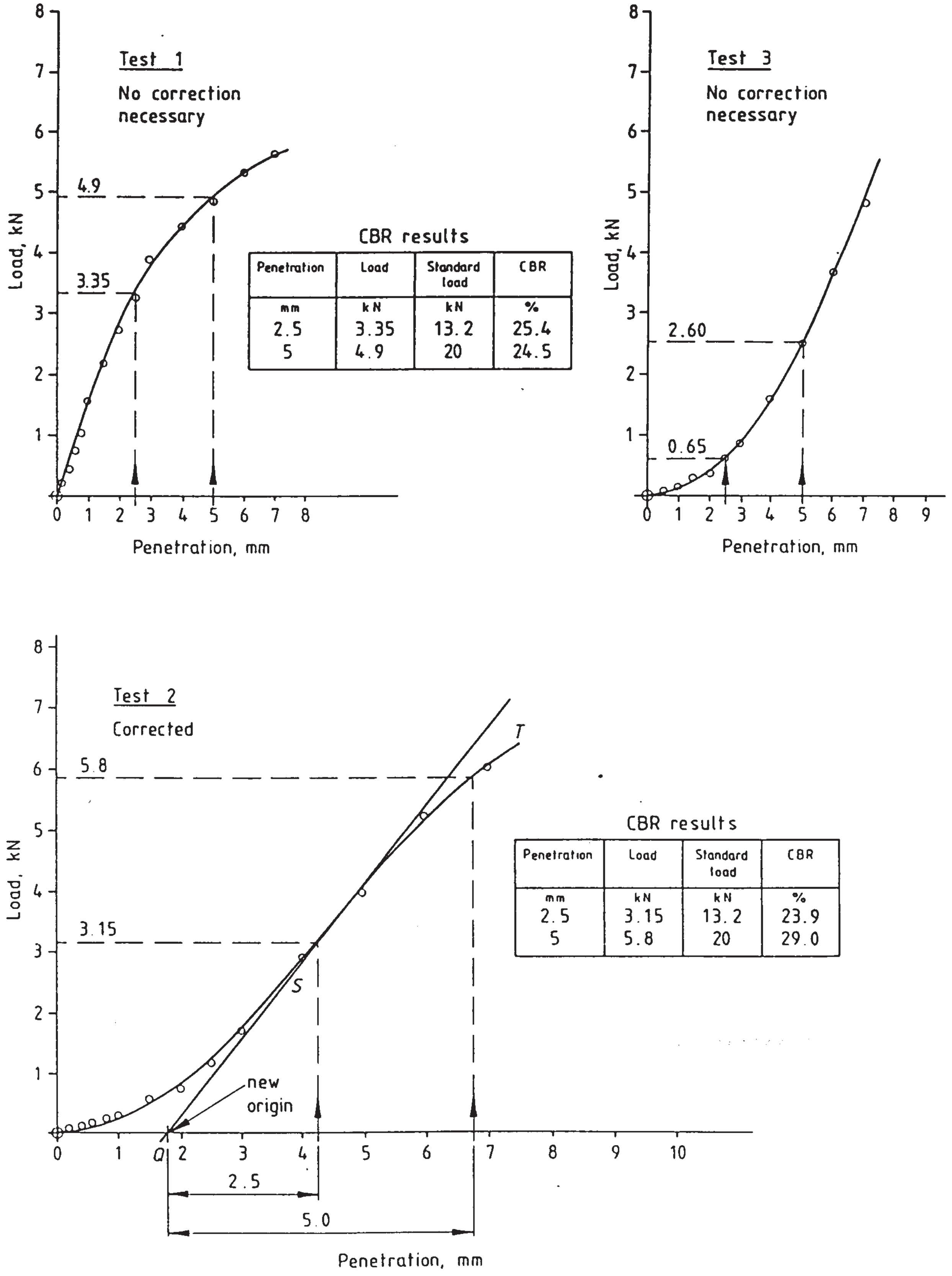


All dimensions shown are in millimetres.

This design has been found satisfactory, but alternative designs may be used provided that the essential requirements are fulfilled.

*See **4.1.3.1.1** of BS 1377 : Part 1 : 1990.

Figure 11 General arrangement of apparatus for the CBR test



CBR results

Penetration	Load	Standard load	CBR
mm	kN	kN	%
2.5	3.35	13.2	25.4
5	4.9	20	24.5

CBR results

Penetration	Load	Standard load	CBR
mm	kN	kN	%
2.5	3.15	13.2	23.9
5	5.8	20	29.0

Figure 12 Typical CBR test result curves

CENTRAL MATERIALS LABORATORY

WORKING SHEET

CBR Test

Project	**Location**	**Depth**
Client	**Lab.no**	**Date**
Responsible Technician	**Checked**	**Approved**

TEST METHOD	CML TEST 1.10, ref. BS 1377:Part 4:1990						
Compaction Method:		Density in % of MDD:	%	Soaking Days:		**ACTUAL**	
Proving Ring no.:		Target MDD	kg/m^3	Target OMC	%	DD	kg/m^3
Present MC Values		Mean Present MC		Difference in MC		MC	%
%	%		%		%	**CBR at :**	
Mass of water to be added (ml) = Mass of soil (g) / (100 + present MC) x Diff. in MC (%) = ... ml						2.5 mm	%
						5.0 mm	%
						SWELL	%

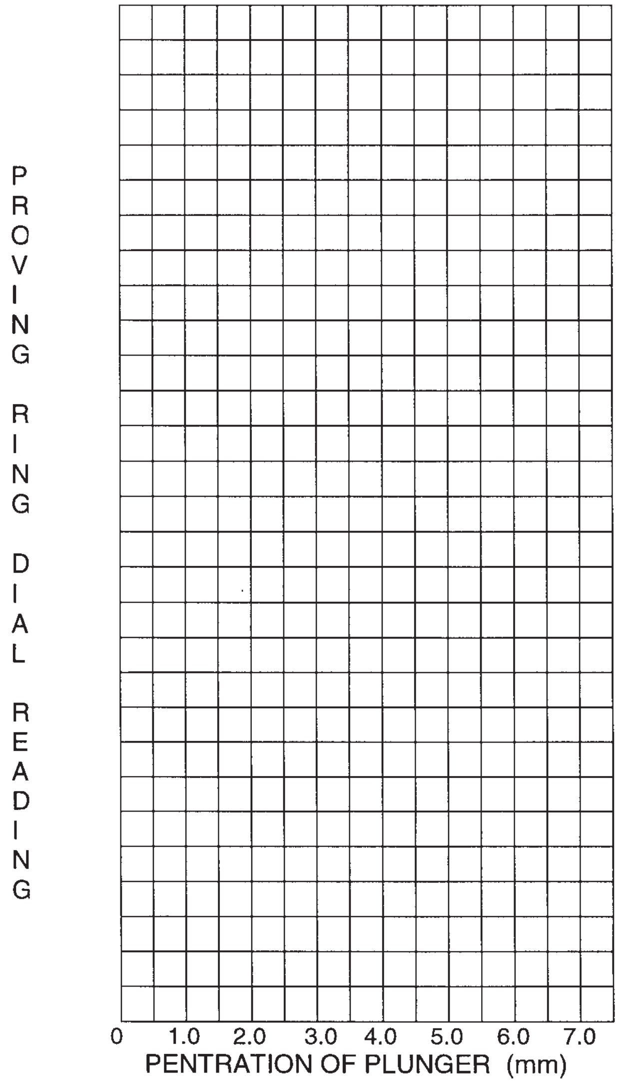
SWELL	
Initial Dial Gauge setting	
Final Dial Gauge setting	
Difference (swell)	
Percentage Swell	

TESTING

Penetration of Plunger (mm)	Dial Gauge Reading		Penetration of Plunger (mm)	Dial Gauge Reading	
	Top	Bottom		Top	Bottom
0.5			4.5		
1.0			5.0		
1.5			5.5		
2.0			6.0		
2.5			6.5		
3.0			7.0		
3.5			7.5		
4.0			8.0		

CALCULATION OF CBR %

PENETRATION	2.5 mm		5.0 mm	
	Top	Bottom	Top	Bottom
Proving Ring Dial Reading				
Equivalent kN				
	x $\frac{100}{13.2}$		x $\frac{100}{20.0}$	
CBR %				



TEST NO. 1.11

CBR - California Bearing Ratio test - Three Point Method

Notes

Objective

The strength of the subgrade is the main factor in determining the required thickness of flexible pavements for roads and airfields. The strength of subgrade, subbase and base course materials are expressed in terms of their California Bearing Ratio (CBR) value.

The CBR-value is a requirement in design for pavement materials of natural gravel.

Main Principles

This method covers the laboratory determination of the California Bearing Ratio (CBR) of a compacted sample of soil - three point method, which is the prescribed method in the Pavement and Materials Design Manual.

The CBR value is the resistance to a penetration of 2.5 mm of a standard cylindrical plunger of 50 mm diameter, expressed as a percentage of the known resistance of the plunger to 2.5 mm in penetration in crushed aggregate, (taken as 13.2 kN).

References

BS 1377 : Part 4 : 1990 and TMH 1 : 1986 : A8

Required equipment

- Test sieves, sizes 20 mm and 5 mm.
- Three cylindrical metal moulds, i.e. CBR moulds, having a nominal internal diameter of 152 mm and a height of 127 mm. The moulds shall be fitted with a detachable baseplate and a removable extension. The internal face shall be smooth, clean and dry before use.
- Two metal rammers of weights 2,5 kg and 4,5 kg.
- A steel rod
- A steel straightedge
- A spatula
- A balance, capable of weighing up to 25 kg readable to 5 g.
- Apparatus for moisture content determination.
- Filter papers 150 mm in diameter.
- Perforated baseplates, fitted to the CBR moulds in place of the normal baseplate (see figure 8).
- Perforated swell plates, with an adjustable stem to provide a seating for a dial gauge. (see figure 9).
- Tripod, mounting to support the dial gauge.
- A dial gauge, having a travel of 25 mm and reading to 0,01 mm to be fitted to the tripod for measuring swell.

All moulds at CML are fitted with perforated baseplates instead of solid baseplates which is the normal BS standard. However, the use of perforated baseplates is quite allright.

CBR - California Bearing Ratio test - Three Point Method

Notes

- A soaking tank, large enough to allow the CBR mould with base plate to be submerged, preferably supported on an open mesh platform.
- Annular surcharge discs for soaking, each having a mass known to + 50 g. Halfcircular segments may be used. Combined weight 4,5 kg.
- Petroleum jelly.
- A cylindrical metal plunger/piston with diameter 49,65 mm.
- A CBR compression machine. The machine shall be capable of applying at least 45 kN at a rate of penetration of the plunger of 1 mm/min to within ± 0,2 mm/min.
- A loading ring.
- A dial gauge with 25 mm travel, reading to 0,01 mm for measuring the penetration of the plunger into the specimen.
- A stopwatch
- Annular surcharge discs for penetration test. Combined weight 5.5 kg.

Sample preparation

The particles retained on the 20 mm sieve may be crushed lightly to pass that sieve.

If the fraction retained on the 20 mm test sieve is > 25 %, the test is likely to give a conservative impression of the strength of the material.

The CBR test shall be carried out on material passing the 20 mm test sieve. If the soil contains particles larger than this, the fraction retained on the 20 mm test sieve shall be removed and weighed before preparing the test sample. If this fraction is greater than 25 %, the test is generally considered unreliable in emulating site conditions, and such test results must consequently be treated with care.

Take a portion of material large enough to provide about 25 kg of material passing a 20 mm sieve.

Bring the sample to the optimum moisture content (OMC ± 0,3 %) according to the BS Heavy compaction test. The soil shall be thoroughly mixed and shall normally be sealed and stored for at last 24 h before compacting into the moulds.

Test Procedure – Moulding

Step 1: Weigh the moulds with baseplates attached to the nearest 5 g (m_2).

Step 2: Measure the internal dimensions of the moulds to 0,5 mm.

Step 3: Attach the extension collar to the moulds and cover the baseplates with a filter paper.

Step 4: The moist material (at OMC) is transferred to a mixing tray. It is thoroughly but rapidly mixed and then covered by a damp sack which should be kept over the material until compaction is completed so as to keep the moisture content as constant as possible.

Step 5: Stand the mould assemblies on a solid base, e.g. a concrete floor or plinth.

CBR - California Bearing Ratio test - Three Point Method

Notes

Step 6: The first mould is now tamped full of material using the 4,5 kg rammer, five layers and 62 blows per layer. Each layer should occupy about or a little more than one-fifth of the height of the mould. Ensure that the blows are evenly distributed over the surface. The final level of the soil surface should be about 5 – 10 mm above the top of the mould body.

Step 7: Remove the collar and trim the soil flush with the top of the mould with the scraper, checking with the steel straightedge.

Step 8: Weigh the mould, soil and baseplate to the nearest 5 g (m_3).

Step 9: A representative sample for moisture content is now taken from the mixing tray.

Step 10: The second mould is then tamped full of material using the 4,5 kg rammer, five layers and 30 blows per layer. The moulded material is trimmed off, weighed and another representative sample for moisture content is taken from the mixing tray.

Step 11: The third mould is then tamped full of material, but in this case only three layers of material are compacted and on each layer 62 blows of the 2,5 kg rammer is applied. The moulded material is again trimmed off and weighed.

The compactive effort used for the three moulds is summarized below:

(a) 4,5 kg rammer, five layers and 62 blows per layer.

(b) 4,5 kg rammer, five layers and 30 blows per layer.

(c) 2,5 kg rammer, three layers and 62 blows per layer.

The average of the two moisture content determinations taken after the compaction of the first and second moulds, is taken as the moulding moisture content for all three moulds.

Test Procedure - Soaking

Make certain that the baseplate is tightly screwed on, so that there is no gap between the baseplate and the sample.

Step 1: Place a filter paper on top of each sample and fit perforated baseplates on top of the moulds and invert the moulds.

Step 2: Remove the baseplates from the moulds. Fit the collar to the end of the mould, packing the screw threads with petroleum jelly to obtain a watertight joint.

To ensure that that the water has free access to the bottom of the material in the mould, suitable means must be fitted to the bottom of the soaking tank.

One surcharge disc of 2 kg simulates the effect of approximately 70 mm of superimposed construction on the formation being tested.

Step 3: Place the mould assembly in the empty soaking tank. The surface of the moulded material which was against the base plate should now be facing upwards. Place a filterpaper on top of the sample followed by the perforated swell plate. Fit annular surcharge discs weighing 4.5 kg around the stem on the perforated swell plate.

Step 4: Mount the dial gauge support on top of the extension collar, secure the dial gauge in place and adjust the stem on the perforated plate to give a convenient zero reading.

CBR - California Bearing Ratio test - Three Point Method

Notes

Record the time taken for water to appear at the top of the sample. If this has not occurred in three days, flood the top of the sample and leave to soak for a further day giving the normal soaking period of 4 days.

The normal soaking period is 4 days.

In all handling of the moulded material care should be taken not to jar the material.

Step 5: Fill the soaking tank with water to just below the top of the mould extension collar. Start the timer when the water has just covered the baseplate.

Step 6: Record readings of the dial gauge each day.

Step 7: After 4 days of soaking, take off the dial gauge and its support, remove the mould assembly from the soaking tank and allow the sample to drain for 15 min.

Step 8: Carefully remove the surcharge discs, perforated swell plate and extension collar.

Step 9: If the sample has swollen, trim it level with the end of the mould.

The sample is then ready for testing.

Test Procedure - Penetration

Step 1: Place the mould containing the sample, with the top face (originally the bottom face) of the sample exposed, centrally on the lower platen of the testing machine.

Step 2: Place annular surcharge discs weighing 5,5 kg carefully on top of the sample.

Step 3: Fit into place the cylindrical plunger on the surface of the sample.

Step 4: Apply a seating force to the plunger, depending on the expected CBR value as follows:

For CBR value up to 5% apply 10 N
For CBR value from 5% to 30% apply 50 N
For CBR value above 30% apply 250 N

Step 5: Record the reading of the loading ring as the initial zero reading (or reset the loading ring to read zero).

Step 6: Secure the penetration dial gauge in position. Record its initial zero reading, or reset it to zero.

Step 7: Start the test so that the plunger penetrates the sample at a uniform rate 1mm/min.

Step 8: Record readings of the force gauge at intervals of penetration of 0,25 mm, to a total penetration not exceeding 7,5 mm (see form F).

Step 9: Perform the penetration test on all three samples.

Calculation and plotting

Force-penetration curve (see form 4.F and 4.G)

1) Calculate the force applied to the plunger from each reading of the loading ring observed during the penetration test.

2) Plot each value of force as ordinate against the corresponding penetration as abscissa and draw a smooth curve through the points.

CBR - California Bearing Ratio test - Three Point Method

Notes

The normal curve is convex upwards as shown in figure 5, test 1, and needs no correction.

If the initial part of the curve is concave as for test 2 in figure 5, a correction is necessary. Draw a tangent at the point of the steepest slope, and produce it to intersect the abscissa. This is the corrected zero point.

If the curve continues to curve upwards as for test 3 in figure 5, it is considered that the penetration of the plunger is increasing the soil density and subsequently its strength. No correction is necessary.

Density Calculations

1) Calculate the internal volume of the mould, V_m (in cm^3).

2) *Bulk density*. The initial bulk density, ρ (in kg/m^3), of the sample, is calculated from the equation:

$$\rho = \frac{m_3 - m_2}{V_m} \times 1000$$

where

m_3 is the mass of soil, mould and baseplate (in g)
m_2 is the mass of the mould and baseplate (in g)
V_m is the volume of the mould body (in cm^3).

3) *Dry density*. The moulded dry density, ρ_d (in kg/m^3), of the samples is calculated from the equation:

$$\rho_d = \left(\frac{100}{100 + w}\right) \rho$$

where

w is the moisture content of the soil (in %).

Swell calculation

The Swell (in %) is calculated from the equation:

$$S = \frac{(k - L)}{127} \times 100$$

where

S is the swell expressed as a percentage of the height of the moulded material before soaking, i.e. 127 mm.

k is the dial gauge reading after 4 days' soaking

L is the dial gauge reading before soaking.

TEST NO. 1.11

CBR - California Bearing Ratio test - Three Point Method

Notes

Calculation of California Bearing Ratio (CBR)

Penetrations of 2.5 mm and 5.0 mm may be used for calculating the CBR value. However, the CBR at 2.5 mm penetration is generally used for assessing the quality of the material.

1. Record the plunger force value at 2.5 mm penetration from the (corrected) force-penetration curve for each of the three specimens.
2. Calculate the corresponding CBR values from the equation:

   $$\text{CBR value (in \%)} = P \times \frac{100}{13.2}$$

   where

   P is the plunger force (in kN) at 2.5 mm penetration.
3. Record the plunger force values at 5.0 mm penetration from the (corrected) force-penetration curves.
4. Calculate the corresponding CBR values from the equation:

   $$\text{CBR value (in \%)} = P \times \frac{100}{20.0}$$

   where

   P is the plunger force (in kN) at 5.0 mm penetration.

The CBR at 2.5 mm penetration is generally used for assessing the quality of the material.

CBR-Density Relationship

1) In order to obtain the relationship between CBR and Dry Density, the CBR at 2,5 mm penetration is plotted on a logarithmic scale against the Dry Density on a natural scale for the three compactive efforts used.
2) The points are connected to each other to indicate the CBR-Density relationship. The design CBR can thus be obtained at the desired percentage of the maximum Dry Density- normally the specified minimum percentage compaction.

Report

The test report shall include the following:

1. Type of material and sample identification
2. Reference to this procedure
3. Force-penetration curves, showing corrections if appropriate
4. The CBR values to the nearest whole number
5. The CBR-Density relationship as a curve with the CBR value plotted on a logarithmic scale and the density on a natural scale

CBR - California Bearing Ratio test - Three Point Method

Notes

The tripod should be kept by the senior laboratory technician for safe keeping when not in use.

6. The moulded sample density and the moisture content and dry density
7. Period of soaking and amount of swell
8. The proportion by dry mass of any over-size material removed from the original soil sample before testing.

Practical considerations

It is possible to measure swell using only one tripod (with one gauge) for all moulds in a test series:

Step 1: Make 3 paint marks on all mould collars to guide the position of the tripod.

Step 2: Take the measurement by placing the tripod in the position of the paint marks and move the tripod around so the tip of the gauge moves around on the little area on top of the stem, until the *highest reading* is found.

Step 3: Record this reading as the "zero" reading, i.e. do not attempt to make a zero, or any specific figure for the reading by adjustments.

Step 4: Move the tripod over to the next mould and repeat Step 2 and 3.

Step 5: All subsequent readings are carried out in the same manner (i.e. by positioning the tripod and moving it around until the *highest reading* is found) and calculate swell from the records.

For figure references see Figures 9-12 at pages 53-56.

Maintenance

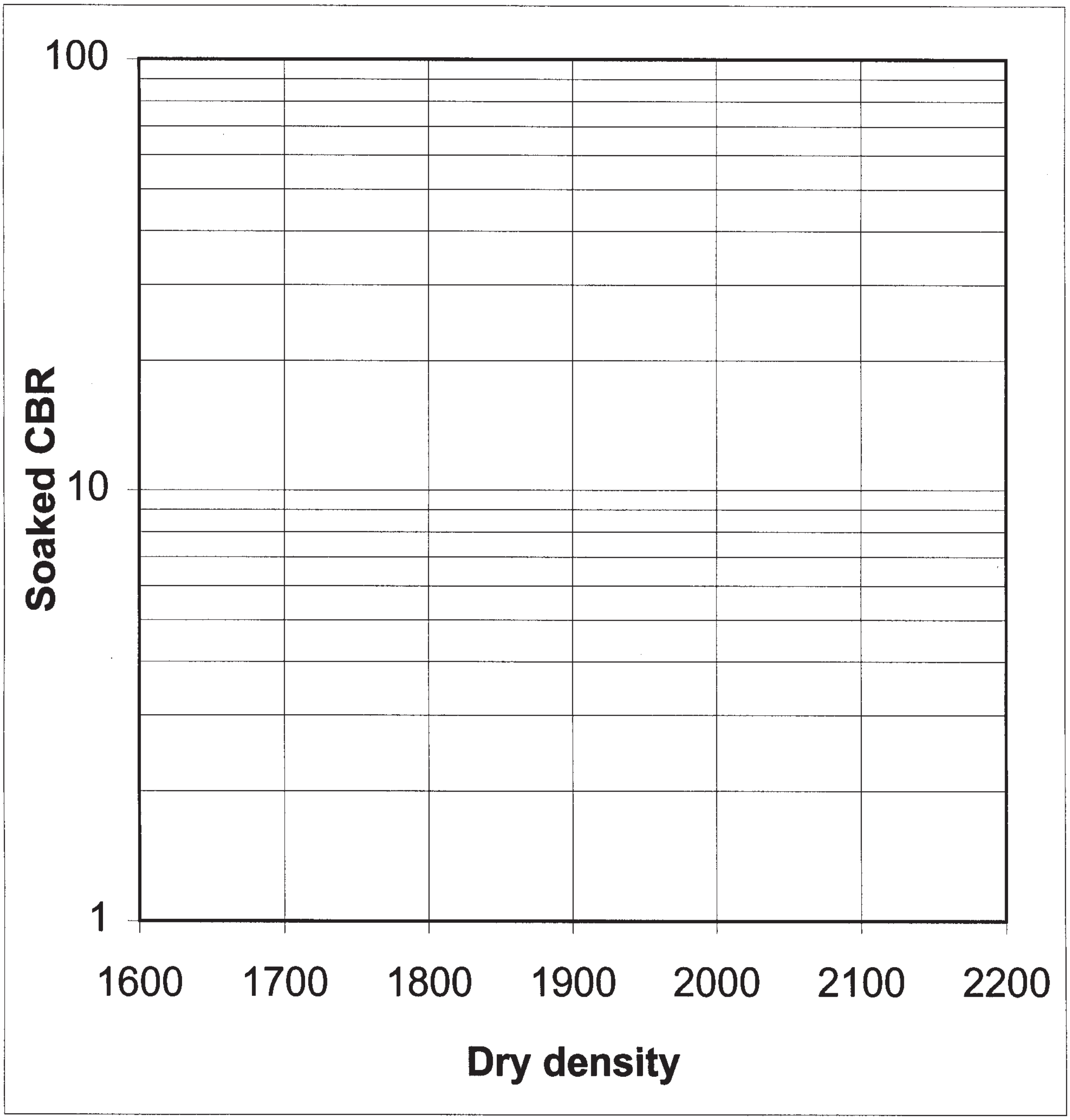
Check and clean the perforated baseplates regularly to make sure that the holes are open and not clogged.

CENTRAL MATERIALS LABORATORY

WORKING SHEET

CBR Test

Project	**Location**	**Depth**
Client	**Lab.no**	**Date**
Responsible Technician	**Checked**	**Approved**



	A	B	C
Rammer	2.5 kg	4.5 kg	4.5 kg
Layers	3	5	5
Blows	62	30	62

CENTRAL MATERIALS LABORATORY

WORKING SHEET

CBR Test

Project	**Location**	**Depth**
Client	**Lab.no**	**Date**
Responsible Technician	**Checked**	**Approved**

TEST METHOD	CML TEST 1.11, ref. BS 1377:Part 4:1990 and TMH:1986:A8						
Compaction Method:		Density in % of MDD:	%	Soaking Days:		**ACTUAL**	
Proving Ring no.:		Target MDD	kg/m^3	Target OMC	%	DD	kg/m^3
Present MC Values		Mean Present MC		Difference in MC		MC	%
%	%	%		%		**CBR at :**	
Mass of water to be added (ml) = $\frac{\text{Mass of soil (g)}}{(100 + \text{present MC})} \times \frac{\text{Diff. in MC (\%)}}{} =$ .... ml						2.5 mm	%
						5.0 mm	%
						SWELL	%

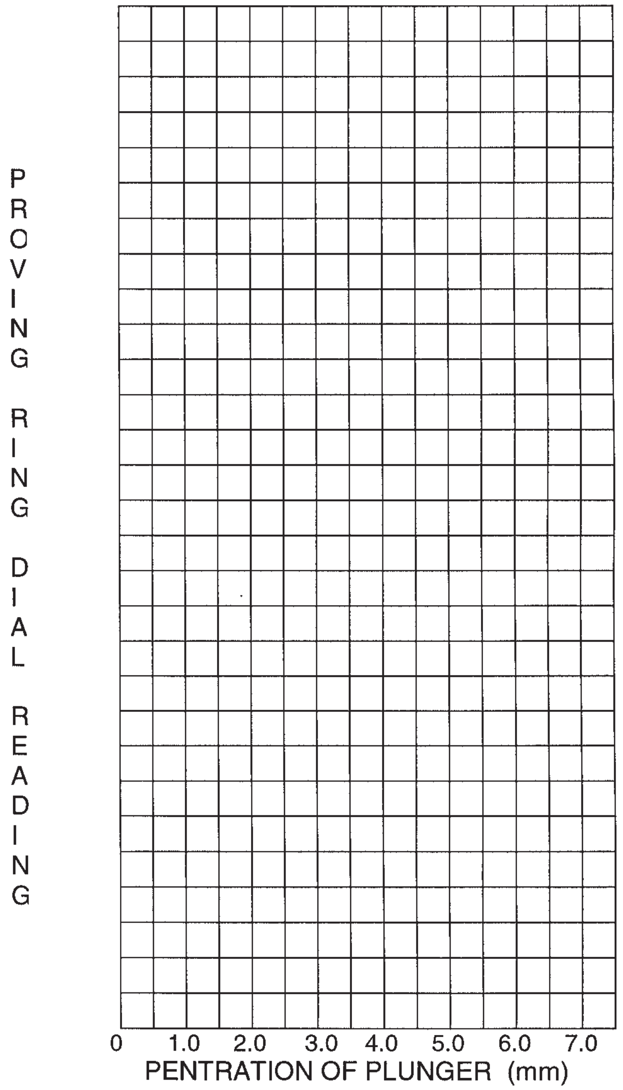
SWELL	
Initial Dial Gauge setting	
Final Dial Gauge setting	
Difference (swell)	
Percentage Swell	

TESTING

Penetration of Plunger (mm)	Dial Gauge Reading	Penetration of Plunger (mm)	Dial Gauge Reading
0.5		4.5	
1.0		5.0	
1.5		5.5	
2.0		6.0	
2.5		6.5	
3.0		7.0	
3.5		7.5	
4.0		8.0	

CALCULATION OF CBR %

PENETRATION	2.5 mm	5.0 mm
Proving Ring Dial Reading		
Equivalent kN		
	$\times \frac{100}{13.2}$	$\times \frac{100}{20.0}$
CBR %		



TEST NO. 1.12

Consolidation - One Dimensional Properties (Oedomenter)

Notes

Objective

The oedometer consolidation test is used for the determination of consolidation characteristics of low-permeability soils when subjected to vertical loads. The results may be used to calculate and estimate settlements of structural foundations when placed on the ground. The two parameters normally required are:

- The compressibility of the soil: *Coefficient of volume compressibility,* m_v
- The time related parameter: *Coefficient of consolidation,* C_v

When structures are built on saturated soils, the load is presumed to be carried initially by incompressible water within the soil voids. Due to the additional load on the soil, water will tend to be squeezed out from the voids causing a reduction in void volume and consequently settlement of the structure.

In soils of high permeability (coarse grained soils), this process takes a relatively short time for completion, with the result that almost all of the settlement will occur during the construction period. These rarely cause major problems. In low permeability soils (clays), this process takes place slowly and continuously over a long period of time - months, years and even decades - after completion of construction.

Main Principles

The method described covers the procedure and technique for consolidation tests on naturally deposited soils taken undisturbed from the ground in the form of cores or blocks.

The commonly used U-100 tube sampler does, however, not yield undisturbed samples, and the test results from tests on such samples must be used with care.

This method covers the determination of the magnitude and rate of the consolidation of a saturated or near-saturated specimen of soil in the form of a disc confined laterally, subjected to vertical axial pressure, and allowed to drain freely from the top and bottom surfaces. The method is concerned mainly with the primary consolidation phase, but it can also be used to determine secondary compression characteristics.

In this test the soil specimen is loaded axially in increments of applied stress. Each stress increment is held constant until the primary consolidation has ceased. During this process water drains out of the specimen, resulting in a decrease in height which is measured at suitable intervals. These measurements are used for the determination of the relationship between compression (or strain) or voids ratio and effective stress, and for the calculation of parameters which describes the amount of compression and the rate at which it takes place.

References

BS 1377 : Part 5 : 1990.

Apparatus

The consolidation apparatus, known as the oedometer, shall be of the fixed ring type.

TEST NO. 1.12

Consolidation - One Dimensional Properties (Oedomenter)

Notes

A consolidation ring which shall completely and rigidly support and confine the soil specimen laterally. The ring shall be of corrosion-resistant metal.

The ring shall be provided with a cutting edge to facilitate the preparation of the specimen. The inner surface of the ring shall be smooth.

Deformation of the apparatus may be significant when testing stiff soils, but can often be ignored for soft soil.

The diameter of the consolidation ring shall be determined primarily by the nominal sizes of undisturbed tube samples received for test but also with regard to the character of the soil and the maximum size of particles present in the sample. The inside diameter of the ring used for fine silts and clay soils shall be at least 6 mm smaller than the undisturbed tube sample to permit trimming off no less than 3 mm of soil all around which may have been disturbed during the sampling operation.

Preparation of sample

The sample may be built in (extruded into the consolidation ring) from the following type of samples:

- Cylinder samples, U100 or 54 mm samples
- Block samples cut from test pits
- In-situ specimen built in directly from the bottom of test pits.

The soil is carefully trimmed away outside the consolidation ring. Check that there is no gap between the ring and the sample. If there is, a new sample should be prepared.

Specimen measurements

Step 1: Measure the height of the specimen to 0,05 mm (H_0) in its ring.

A suitable form for recording these data is shown on form "Specimen Details".

Step 2: Place the specimen in its ring on the watch glass or tray and weigh immediately to 0.1 g, m_1. Determine the initial mass of the specimen, m_0 $\quad m_0 = m_1 - m_{ring} - m_{tray}$

Step 3: Take a sample of soil similar to that in the ring for the determination of initial moisture content, and if required, the particle density. The trimmings from the sample preparation are suitable.

Preparation and assembly of apparatus

Porous plates. Before using the porous plates in a test they shall be prepared as follows.

To prevent clogging the pores, filter papers should be used at the top and bottom of the specimen.

Step 1: Clean the surface using natural bristle or nylon brush.

Step 2: Ensure that the pores are not clogged by fine soil particles, and that the plates are readily permeable to water.

Step 3: Saturate the pores by boiling in distilled water for at least 20 min, either over heat at atmospheric pressure, or in a vacuum desiccator in which the pressure has been reduced to about 20 mm of mercury.

Notes

Step 4: For saturated soils, or for soils that do no exhibit a high affinity for water, keep the plates saturated in de-aerated water until required for use. Immediately before assembly in the consolidation cell remove free surface water with a tissue, ensuring that the pores remain saturated.

Step 5: For soils that readily absorb water, allow the plates to air dry.

Assembly of consolidation cell

Step 1: Place the bottom porous plate centrally in the consolidation cell.

Step 2: Place the specimen contained in its ring centrally on top of the porous plate.

Step 3: Assemble the cell components so that the consolidation ring is laterally confined and in correct alignment.

Step 4: Place the top porous plate and loading cap centrally on top of the specimen.

Assembly in load frame

Step 1: Place the consolidation cell in position on the bed of the loading apparatus.

Step 2: Adjust the counterbalanced loading beam so that when the load-transmitting members just make contact with the loading cap the beam is slightly above horizontal position.

Step 3: Add a small weight to the beam hangar, sufficient to maintain contact between the load-transmitting members while final adjustments are made. The resulting seating pressure on the specimen shall not exceed 2 kN/m^2 (kPa).

Step 4: Clamp the compression gauge securely into position so that it can measure the relative movement between the loading cap and the base of the cell. Arrange the gauge to allow for measurement of a small amount of swelling of the specimen, while the greater part of the range of travel allows for compression. Record the initial reading of the gauge.

Test procedure

Additional loading steps should be considered near the value for p_0 and p_c.

Loading sequence. A range of pressures selected from the following sequence has been found to be satisfactory.

6, 12, 25, 50, 100, 200, 400, 800, 1600, 3200 kN/m^2 (kPa).

The loadings of 1600 and 3200 kN/m^2 should be considered only for stiff and overconsolidated clays.

The Engineer shall decide.

A typical test comprises four to six increments of loading, each held constant for 1 h, and each applied stress being double that of the previous stage. The last increment of loading shall be held for 24 hours.

TEST NO. 1.12

Consolidation - One Dimensional Properties (Oedomenter)

Notes

The Engineer shall decide the initial pressure to be applied.

Table 1. Suggested initial pressures for consolidation test

Soil Consistency	Initial pressure
Stiff	Equal to p'_o or the next higher recommended pressure if p'_o is less than p_s.
Firm	Somewhat less than p'_o preferably using the next lower recommended pressure.
Soft	Appreciably less than p'_o usually 25 kN/m^2 (kPa) or less.
Very soft	Very low, typically 6 kN/m^2 (kPa) or 12 kN/m^2 (kPa). Initial consolidation under a small load will give added strength to prevent squeezing out under next load increment.

p'_o represents the estimated present vertical effective stress in situ at the horizon from which the specimen was taken.

p_s represents the swelling pressure.

Application of pressure

Step 1: Record the compression gauge reading as the initial reading for the load increment stage d_1.

Step 2: Apply the required pressure to the specimen at a convenient moment (zero time) by adding the appropriate weights to the beam hanger without jolting. Remove the weight used for the seating load.

Step 3: Fill the consolidation cell with water after applying the pressure. If the specimen begins to swell, or if the compression virtually ceases within a short time, proceed to the next higher pressure. Alternatively, if required, determine the swelling pressure.

Step 4: Take readings of the compression gauge at suitable intervals of time. The following periods of elapsed time from zero are convenient. A suitable form for recording the readings is shown as form “Settlement Readings”.

0, 8, 15, 30 seconds
1, 2, 4, 8, 15, 30 minutes and 1 hour
(2, 4 and 24 hours for the last load increment)

The readings are stopped when the primary consolidation is completed. Usually t_{90} is achieved in less than 1 hour. A complete consolidation test could then be run in one day.

Step 5: Plot the compression gauge readings against square root time, while the test is in progress, either manually or by an automatic recorder.

Plot against logarithm of time may also be used, ref. BS1377.

Step 6: Maintain the pressure for 1 hour and plot the readings to con firm that t_{90} have been reached.

For some types of soil, readings have to be taken over a longer period than 1 hour.

Step 7: Record the time and compression gauge reading at the termination of the load increment stage d_1. This reading becomes the initial reading for the next stage.

Consolidation - One Dimensional Properties (Oedomenter)

Notes

Step 8: Increase the pressure to the next value in the selected sequence.

Step 9: Repeat further stages of the sequence of loading, making at least four stages in all. The maximum pressure applied to the specimen shall be greater than the effective pressure which will occur in situ due to the overburden and proposed construction.

The last stage of load increment shall stay on for 24 hours, and readings be taken at suitable intervals including 2, 4 and 24 hours.

Unloading

Normally unloading is done in one step (to p'_0 or to the initial applied pressure). Record and plot the final reading, and proceed to "Dismantling".

The Engineer shall decide if the unloading curve is required.

The unloading portion of the log pressure/ voids ratio curve is required in some methods of analysis for estimating the preconsolidation pressure for the soil. Normally the number of unloading stages should be at least half the number of loading stages, and should provide reasonably equally spaced points on a log pressure scale.

If the unloading curve is required, the specimen shall be unloaded from the maximum pressure in steps as follows:

Step 1: Reduce the pressure to a value not less than the last but one value of the loading sequence at a convenient moment (zero time).

Step 2: Record reading of the compression gauge at convenient intervals.

Step 3: Plot the reading so that the completion of swelling can be identified.

Step 4: Record the final reading of the compression gauge.

Step 5: Repeat point 1 to 4 at least twice more, finishing with an applied pressure equal to the swelling pressure (if applicable) or to the initial applied pressure.

Step 6: When the compression gauge indicates that equilibrium under the final pressure has been reached, proceed to "Dismantling".

Dismantling

Step 1: Drain off the water from the cell. Allow to stand for 15 min to enable free water to drain from the porous plates.

Step 2: Mop up any excess water from within the cell.

Step 3: Remove the load from the specimen and remove the consolidation cell from the apparatus.

Step 4: Dismantle the cell, and weigh the specimen in its ring on the weighed watch glass or tray.

Step 5: Transfer the specimen and ring on the watch glass or tray to the oven maintained at 105^o C to 110^o C, dry the specimen to constant mass and determine the dry mass of the specimen to 0.1 g (m_d).

Calculations and plotting

General data. (See form "Specimen Details").

1) Calculate the initial moisture content, w_0 (in %), from the specimen trimmings.

$$w_0 = \frac{m_0 - m_d}{m_d} \text{ x } 100\ \%$$

2) Calculate the initial bulk density, ρ (in Mg/m^3 = ton/m^3), from the equation

$$\rho = \frac{m_o 1000}{AH_0} \qquad [1\ \text{Mg/m}^3 = 1000\ \text{kg/m}^3 = 1\ \text{ton/m}^3]$$

where

m_0 is the initial mass of the specimen (in g):
A is the area of the specimen (in mm^2):
H_0 is the initial height of the specimen (in mm).

3) Calculate the initial dry density, ρ_d (in Mg/m^3), from the equation

$$\rho_d = \frac{100\ \rho}{100 + w_0}$$

4) If it is required to plot void ratio against pressure calculate the initial voids ratio e_0 from the equation

$$e_0 = \frac{\rho s}{\rho d} - 1$$

where

ρ_s is the particle density (in Mg/m^3).

5) The initial degree of saturation S_0 may be calculated as a percent age from the equation

$$S_0 = \frac{w_0 - \rho s}{e_0} [\text{ in } \%]$$

This value can be used to indicate whether the test specimen is fully saturated initially.

Compressibility characteristics

The compressibility characteristics may be illustrated by plotting the compression of the specimen as ordinate on a linear scale against the corresponding applied pressure p (in kPa), as abscissa on a logarithmic scale (see form 5.C). Compression is usually indicated in terms of voids ratio, but the actual thickness of the specimen or the strain expressed as a percentage reduction in thickness referred to the initial thickness, may be used as alternatives.

Notes

1) Calculate the equivalent height of solid particles, H_s (in mm), from the equation:

$$H_s = \frac{H_0}{1 + e_0}$$

The correction for deformation of the apparatus under loading is ignored.

2) Calculate the height of the specimen, H (in mm), at the end of each loading or unloading stage from the equation

$$H = H_0 - \Delta H$$

where

ΔH is the cumulative compression of the specimen (reduction in height) from the initial height as recorded by the compression gauge:

3) Calculate the Voids ratio, *e*, at the end of each loading or unloading stage, if required, from the equation

$$e = \left(\frac{H - H_s}{H_s}\right)$$

The Coefficient of volume compressibility may also be calculated in terms of the Voids ratio from the equation

$$m_v = \frac{1000}{1 + e_1} \left(\frac{e_1 - e_2}{p_2 - p_1}\right)$$

e_1 is the Voids ratio of the specimen at the start of the load increment

e_2 is the Voids ratio of the specimen at the end of that increment

Values of m_v is often in the range 0.1 - 1.5 m^2/MN.

4) Calculate the *Coefficient of volume compressibility*, m_v (in m^2/MN), for each loading increment from the equation

$$m_v = \frac{(H_1 - H_2)}{H_1} \cdot \frac{1000}{(p_2 - p_1)} \qquad [1\ MN = 1000\ kN]$$

where

H_1 is the height of the specimen at the start of a loading increment (in mm):
H_2 is the height of the specimen at the end of that increment (in mm):
p_1 is the pressure applied to the specimen for the previous loading stage (in kN/m^2 = kPa).
p_2 is the pressure applied to the specimen for the loading stage being considered (in kN/m^2 = kPa).

5) If required plot values of voids ratio as ordinate against applied pressure on a logarithmic scale as abscissa (see form 5.C). Draw smooth curves through the points for both the loading and the unloading portions. If the swelling pressure was measured, the curves will start and terminate at the swelling pressure. Indicate the value of the initial voids ratio, e_0, on the vertical axis.

Coefficient of consolidation (see form “Calculations”).

General. Two curve fitting methods are recognized for evaluating the *Coefficient of consolidation*, C_v, namely

For the logarithm-of-time curve-fitting method, ref. BS1377:Part 5:1990.

- The logarithm-of-time curve-fitting method, and
- The square root time curve-fitting method.

Consolidation - One Dimensional Properties (Oedomenter)

Notes

The two fitting methods generally show reasonable agreement. In this procedure only the *Square root time curve-fitting method* is included.

Square root time curve-fitting method (See figure 14.)

1. Draw the straight line of best fit to the early portion of curve (usually within the first 50% of compression) and extend it to intersect the ordinate of zero time. This intersection represent the corrected zero point, denoted by d_0.
2. Draw the straight line through the d_0 point which at all points has abscissae 1.15 times as great as those on the best fit line. The intersection of this line with the laboratory curve gives the 90% compression point d_{90}.
3. Read off the value of t_{90} from the laboratory curve corresponding to the d_{90} point and calculate the value of C_v (in m²/year), from the equation

$$C_v = 0.112\,\bar{H}^2 / t_{90} \qquad \text{[in m}^2\text{/year]}$$

where

$\bar{H}$ is the average specimen thickness for the relevant load increment (in mm), i.e.

$$\bar{H} = \frac{H_1 + H_2}{2}$$

t_{90} is expressed in minutes.

C_v may also be calculated from t_{50} rather than t_{90} because the middle of the laboratory settlement curve is the portion which agrees most closely with the theoretical curve, i.e.:

$C_v = 0.026 / \bar{H}^2 t_{50}$ *[m²/year]*

Values of C_v is often in the range 0,1 - 1000 m²/year

Coefficient of secondary compression

The *Coefficient of secondary compression, C_{sec}*, may be derived from the laboratory logarithmic of time curve. The duration of the load increments may have to be extended to up to 1 week, however. The derivation is not included in this procedure, ref. BS1377 for description.

Secondary compression is normally disregarded for inorganic materials, as the primary consolidation is the major contributor to the settlement.

Reporting results

a) Reference to this procedure

b) The initial dimensions of the specimen

c) The initial moisture content, bulk density and dry density

d) The particle density whether measured or assumed

e) The initial void ratio and degree of saturation (if required)

f) A plot of the voids ratio or the vertical compression against the logarithm of applied pressure for the complete load-unload cycle

g) Plots of compression against time (log time or square root time or both as appropriate), for each load increment, if required

Notes

h) the calculated values of the *Coefficient of volume compressibility,* m_v (in m^2/MN), and *Coefficient of consolidation*, C_v (in m^2/year), to two significant figures, for each load increment, in the form of a table

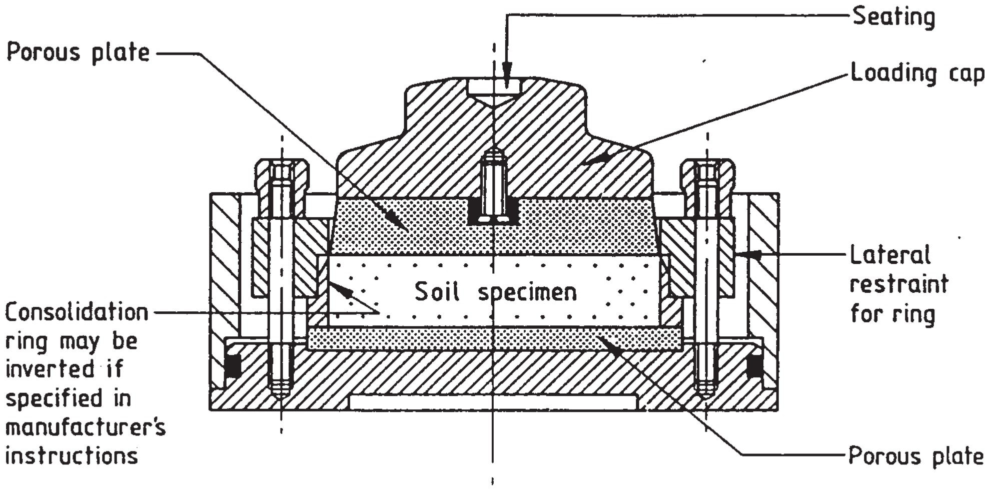
i) the location and depth of the test specimen within the original sample.

Practical considerations

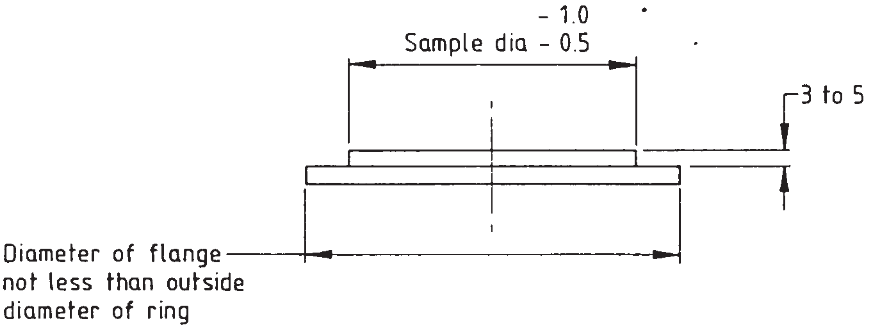
The consolidation apparatus must be firmly fixed to the concrete table.

Maintenance

The consolidation ring must be regularly inspected for cuts.
The weight of the weights must be checked regularly.
The dial gauge must be checked regularly to control that the needle runs freely.



(a) Section of a typical consolidation cell



(b) Flanged disc

All dimensions are in millimetres.
See **4.1.3.1.1** of BS 1377 : Part 1 : 1990.

Figure 13 Section of a typical consolidation cell

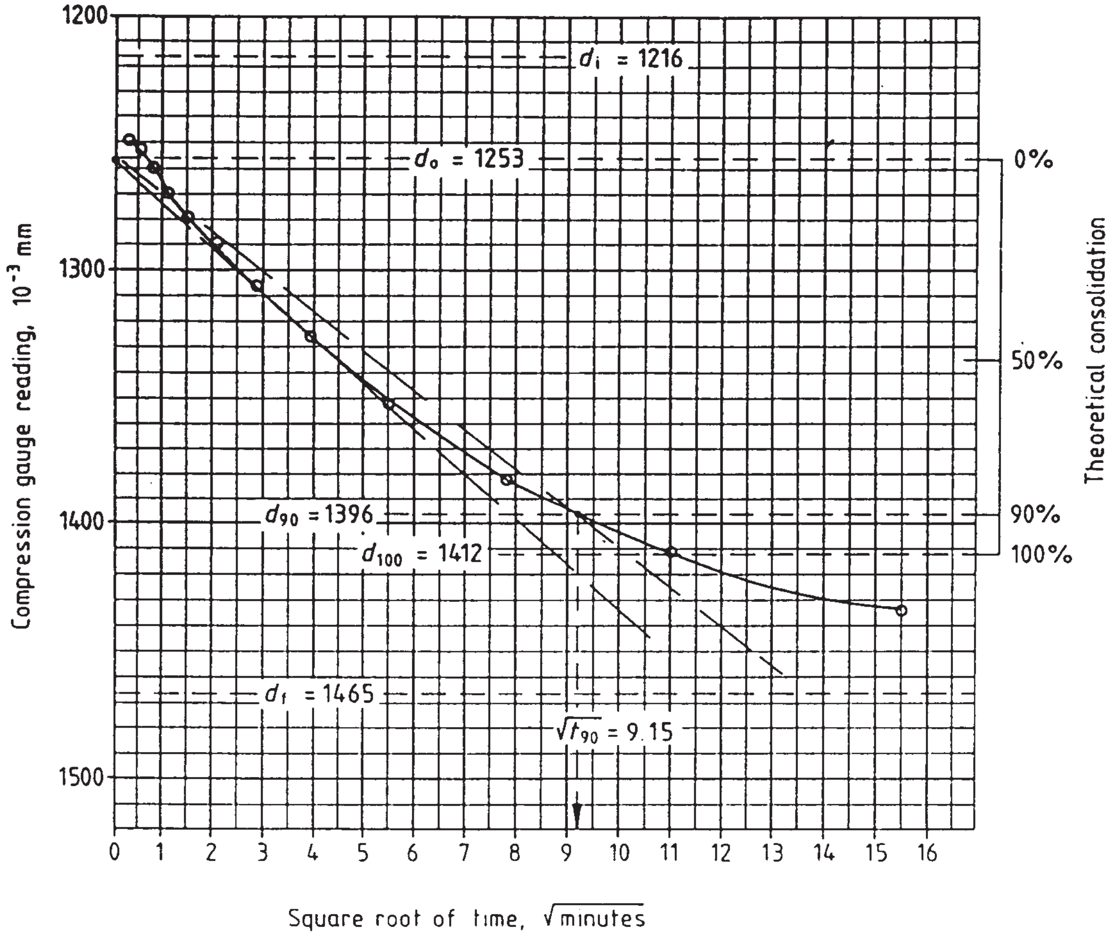
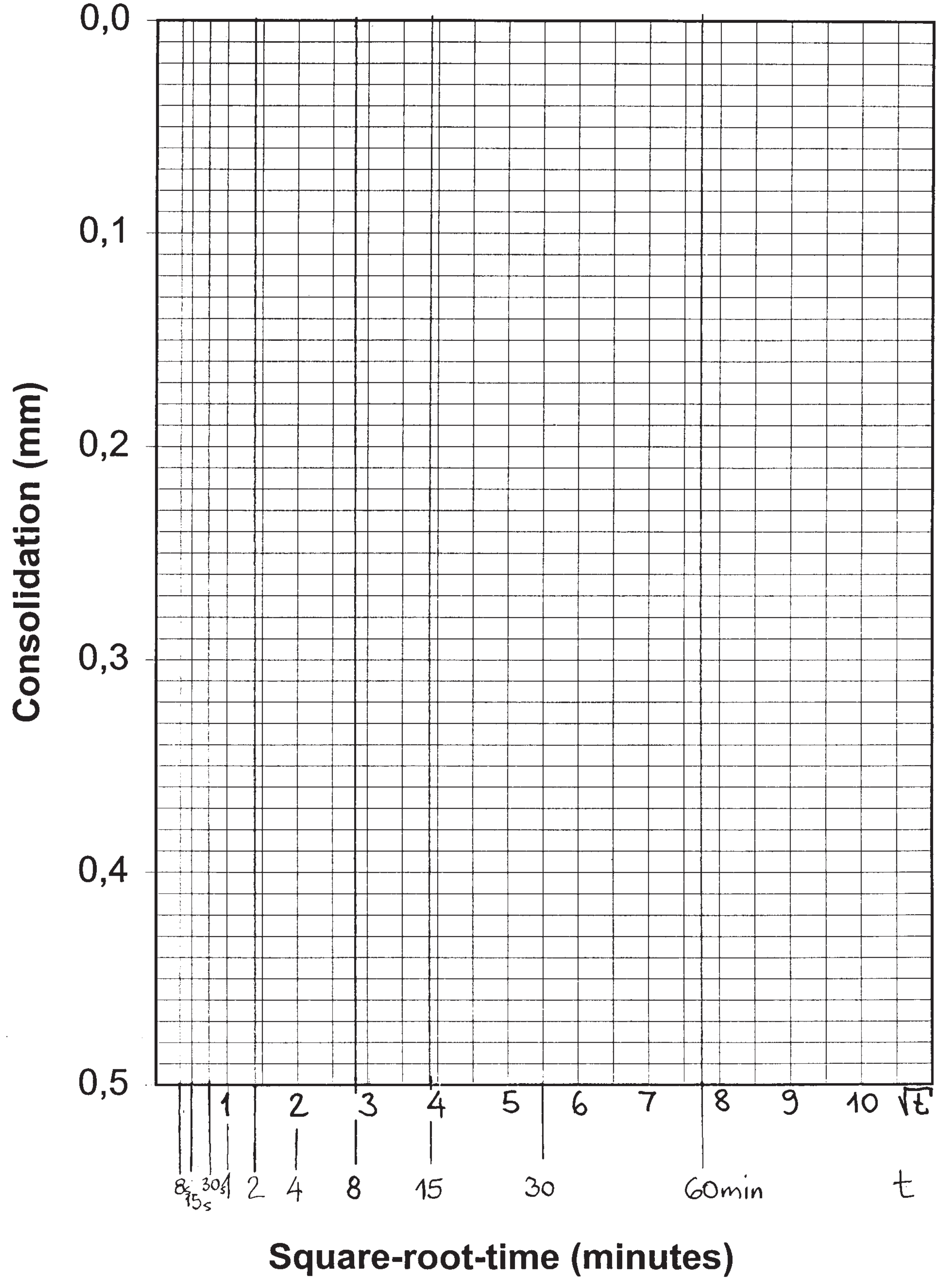


Figure 14 Laboratory consolidation curve: square root of time fitting method


Consolidation (mm)
0,0
0,1
0,2
0,3
0,4
0,5
1
2
3
4
5
6
7
8
9
10 √t
8s
15s
30s
1
2
4
8
15
30
60min
t
Square-root-time (minutes)

CML
CENTRAL MATERIALS LABORATORY

WORKING SHEET

Consolidation Test

Specimen Details

Project	**Location**	**Depth**
Client	**Lab.no**	**Date**
Responsible Technician	**Checked**	**Approved**

TEST METHOD	CML TEST 1.12, ref. BS 1377 : Part 5 : 1990			
Cell no:	Ring no:	Particle density, ρ_s measured/assumed: ton/m^3 (Mg/m^3)		
DIMENSIONS	Initial specimen	Overall change	Final specimen	Specimen preparation method
Diameter D (mm)		X		
Area A (mm^2)		X		
Height H (mm)	H_0			
Volume V (cm^3)				

WEIGHINGS	Initial specimen		Final specimen
	(a) Using moisture content from trimmings	(b) Using data from (a) and (c)	(c) Data from specimen after test
Wet soil + ring + tray g		X	
Dry soil + ring + tray g	X	X	
Ring + tray g		X	
Wet soil g	m_0	m_0	
Dry soil g	X	m_d	m_d
Water g	X		
Moisture content (measured) %	X		
Moisture content (from trimming) %	w_0	X	X
Density ton/m^3 (Mg/m^3)			
Voids ratio	e		
Degree of Saturation %	S_0		
Height of solids H_s mm			

MOISTURE CONTENT OF TRIMMINGS - ref. CML TEST 1.1								
Specimen reference								
Container no.								
Mass of wet soil + container (m_2)	g							
Mass of dry soil + container (m_3)	g							
Mass of container (m_1)	g							
Mass of moisture ($m_2 - m_3$)	g							
Mass of dry soil ($m_3 - m_1$)	g							
Moisture Content $w_0 = \left(\frac{m_2 - m_3}{m_3 - m_1}\right) 100$	%							

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WORKING SHEET

Consolidation Test

Settlement Readings

Project	**Location**	**Depth**
Client	**Lab.no**	**Date**
Responsible Technician	**Checked**	**Approved**

TEST METHOD CML TEST 1.12, ref. BS 1377 : Part 5 : 1990

Machine no.	Specimen diameter: mm	Height: mm
Cell no.	Lever ratio:	Area mm^2
Ring no.	1 kg on hanger gives pressure of: kN/m^2 (kPa)	

Load & Pressure			kg		kN/m^2	kg		kN/m^2	kg		kN/m^2
Time elapsed	t min	$\sqrt{t}$	Clock time	Gauge reading	ΔH mm	Clock time	Gauge reading	ΔH mm	Clock time	Gauge reading	ΔH mm
0	0	0									
8 sec	0.13	0.36									
15 sec	0.25	0.50									
30 sec	0.5	0.71									
1 min	1	1.0									
2 min	2	1.41									
4 min	4	2.0									
8 min	8	2.83									
15 min	15	3.9									
30 min	30	5.5									
1 hour	60	7.75									

Load & Pressure			kg		kN/m^2	kg		kN/m^2	kg		kN/m^2
Time elapsed	t min	$\sqrt{t}$	Clock time	Gauge reading	ΔH mm	Clock time	Gauge reading	ΔH mm	Clock time	Gauge reading	ΔH mm
0	0	0									
8 sec	0.13	0.36									
15 sec	0.25	0.50									
30 sec	0.5	0.71									
1 min	1	1.0									
2 min	2	1.41									
4 min	4	2.0									
8 min	8	2.83									
15 min	15	3.9									
30 min	30	5.5									
1 hour	60	7.75									

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WORKING SHEET

Consolidation Test
Calculations

Project	**Location**	**Depth**
Client	**Lab.no**	**Date**
Responsible Technician	**Checked**	**Approved**

TEST METHOD CML TEST 1.12, ref. BS 1377 : Part 5 : 1990

Machine no.	Specimen diameter: mm	Height H_0: mm
Cell no.	Height of solids H_s :	
Ring no.	Initial voids ratio e_0:	

VOIDS RATIO					COMPRESSIBILITY			COEFFICIENT OF CONSOLIDATION				
					Incremental						C_v =	
Increment no.	Pressure P (kN/m^2)	Cum. compr. ΔH (mm)	Consolidated height $H = H_0 - \Delta H$ (mm)	Voids ratio $e = \frac{H - H_s}{H_s}$	Height change δH (mm)	Pressure change δP (kN/m^2)	$m_v = \delta H/H_1 \times 1000/\delta P$ (m^2/MN)	t_{50} min	t_{90} min	$\overline{H} = ½ (H_1 + H_2)$ (mm)	$0.026\ \overline{H}^2/t_{50}$ (m^2/year)	$0.112\ \overline{H}^2/t_{90}$ (m^2/year)
0		0		0	0	0	-	-	-	-	-	-

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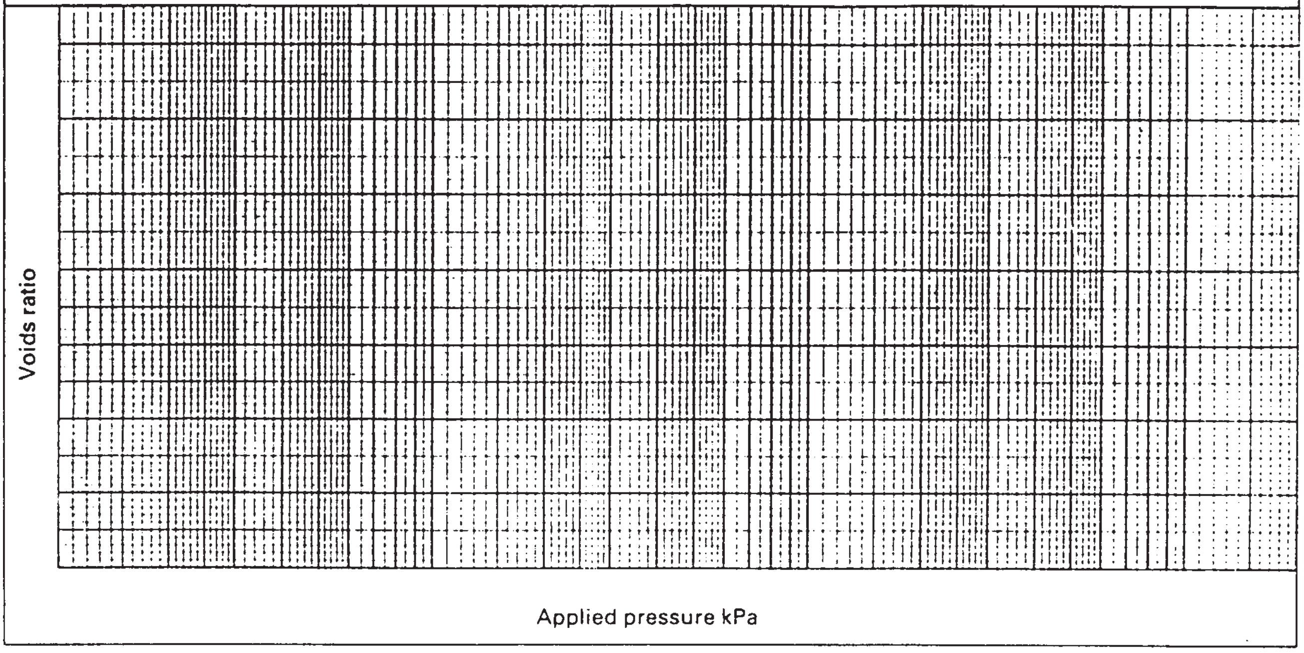
WORKING SHEET

Consolidation Test

Log pressure/voids ratio curve

Project	**Location**	**Depth**
Client	**Lab.no**	**Date**
Responsible Technician	**Checked**	**Approved**

Test method BS 1377 : Part 5 : 1990



SPECIMEN INITIALLY	
Diameter mm	Density Mg/m^3
Height mm	Moisture content %
Voids ratio	Dry density Mg/m^3
Saturation %	Particle density Mg/m^3 measured/assumed
Depth below surface m	
Swelling pressure kPa	
REMARKS	

Pressure stage kPa	Laboratory coefficients of	
	Compressibility m^2/MN	Consolidation m^2/year

	Operator .	Checked	Approved

TEST NO. 1.13

Triaxial test - Undrained Shear Strength (total stress)

Notes

Objective

The Triaxial test is primarily designed to determine the shear strength parameters of a soil sample either in terms of *total stresses*, i.e. the angle of shear resistance (φ), the cohesion (*c*) and the undrained shear strength (c_u). Or in terms of *effective stresses*, i.e. the angle of shear resistance (φ') and the cohesion (*c*').
These values may be used to calculate the bearing capacity of a soil and the stability of slopes.

The test is intended mainly for fine grained homogenous soils.

The described test is an undrained test without measurement of pore pressure. This method covers the determination of the Undrained Shear Strength (c_u), the Cohesion (*c*) and the Angle of internal friction (φ) of a specimen of *cohesive soil* when it is subjected to a constant confining pressure and to straincontrolled axial loading, when no change in total moisture content is allowed. Tests are usually carried out on a set of 3 similar specimens, subjected to different confining pressures.

Main Principles

This test is carried out in the Triaxial apparatus on specimens in the form of cylinders of height approximately equal to twice the diameter. Specimens diameter range from 38 mm to about 110 mm.

In this test the specimen is confined in an impervious membrane between impervious end caps in a triaxial cell which can be pressurized by water. The axial load is increased by applying a constant rate of strain until the specimen fails, normally within a period of 5 min. to 15 min.

References

BS 1377 : Part 7 : 1990. In addition to the derivation only of the Undrained shear strength, c_u, the derivation of φ and *c* have also been included.

For a set of tests on three similar specimens of undisturbed normally consolidated soil, cell pressure of about 0.5 σ_v, σ_v and 2 σ_v might be appropriate, where s_v is the total vertical in-situ stress. The pressure used should cover the range of vertical stress likely to be experienced by the soil in-situ. For compacted soils the cell pressures should be related in a similar manner to the estimated total stresses likely to occur in the field conditions.

Test Conditions

The following test conditions shall be specified by the Engineer before starting a series of tests:

(a) Size of test specimen
(b) Number of specimens to be tested (minimum 2 - 3)
(c) Cell confining pressures (se note)
(d) Whether undisturbed or remoulded specimens are to be tested
(e) For remoulded specimens the moisture content, and either the dry density to be achieved or the compactive effort to be applied.

Required equipment

- *Triaxial cell*, of dimensions appropriate to the size of the test specimen, suitable for use with water at internal working pressures required to perform the test. (A gas shall not be used for pressurizing the cell.)

Triaxial test - Undrained Shear Strength (total stress)

Notes

The main features of the cell are shown in figure 1 and are as follows:

(a) Cell top plate of corrosion resistant material fitted with an air bleed plug and close-fitting piston guide bushing.

The piston should be perfectly clean and lightly oiled.

(b) Loading piston for applying axial compressive force to the specimen. Lateral bending of the piston during a test shall be negligible. Friction between the piston or seal and its bushing shall be small enough to allow the piston to slide freely under its own weight when the cell is empty. The clearance between the piston and its bushing or seal shall minimize leakage from the cell.

(c) Cylindrical cell body which shall be removable for inserting the specimen, and shall be adequately sealed to the top plate and base plate.

(d) Cell base of corrosion resistant rigid material incorporating a connection port as shown.

- *Apparatus for applying and maintaining the desired pressure* on water within the cell to an accuracy of ± 5 kPa with a gauge of test grade for measuring the pressure. CML is using Controls pressure system. Oil and water pressure range is 0 – 1.700 kPa.
- *Machine capable of applying axial compression at a uniform rate* to the specimen at a convenient speed within the range 0.05 mm/min to 4 mm/min. The machine shall be capable of applying an axial deformation of about one-third the height of the specimen tested.
- *Means of measuring the axial deformation of the specimen,* readable to 0.01 mm.
- *Calibrated loading ring*, supported by the crosshead of the compression machine so as to prevent its own weight being transferred to the test specimen.
- *Rigid corrosion resistant or plastic end caps* of the same diameter as the test specimen. A self-aligning seating shall be provided between the top end cap and the loading ram.

Before use the membrane shall be checked for imperfections by blowing it up (as a balloon). Faulty membranes shall be discarded.

- *Tubular membrane* of high density latex to enclose the specimen and provide protection against leakage from the cell fluid.
- *Membrane stretcher,* to suit the size of the specimen.
- *Two rubber O-rings*, for sealing each end of the membrane on to the top cap and base pedestal.
- *Extruder* for vertical extrusion of sample from U-100 tubes
- *Sample tubes* 38 mm internal diameter and about 230 mm long, with sharp cutting edge and cap
- *Trimming knife, wire saw, spatula*
- *Steel rule*
- *Vernier calipers*
- *Apparatus for Moisture Content determination*.

Triaxial test - Undrained Shear Strength (total stress)

Notes

Specimens may be of undisturbed soil, or of compacted soil prepared by compaction into a mould. The degree of compaction should relate to field conditions.

Common practice is to extrude 38 mm samples from a U-100 tube or a piston sample tube.

Sample preparation

The specimen shall have a height equal to about twice the diameter, with plane ends normal to the axis. The size of the largest soil particle shall not be greater than one-fifth of the specimen diameter.

Step 1: Remove the soil from its sampling tube or container and make a careful inspection to ascertain the condition. Report any indication of local softening, disturbance, presence of large particles, or other non-uniformity. If these features cannot be avoided use an alternative sample for preparing the test specimens.

Step 2: Protect the soil from loss of moisture during preparation.

Step 3: When a set of specimens is required for testing at different confining pressures, select the specimens so that they are similar. Record the location and orientation of each specimen within the block sample.

Step 4: Measure the length L_0 (in mm), diameter D_0 (in mm) and mass m (in g) of each prepared specimen with sufficient accuracy to enable the bulk density to be calculated to an accuracy of ± 1 -2%**.**

Step 5: Place the specimen that is to be tested first between end caps in the membrane as quickly as possible to prevent loss of moisture. Seal the specimens that are not to be tested immediately to prevent loss of moisture.

Step 6: After preparing the test specimens, break open the remainder of the sample and record a detailed description of the soil fabric.

Test Procedure

Step 1: Place the specimen on the base end cap and place the top cap on the specimen. Filter stones may be used on top and bottom of the specimen.

Step 2: Fit the membrane evenly on the stretcher.

It is advisable to use a small suction to get rid of any air. Leakages will then also be detected.

Step 3: Place the membrane around the specimen while applying suction to the stretcher.

Step 4: Seal the membrane to the end caps by means of rubber O-rings (or the stretcher), without entrapping air.

Step 5: Place the specimen centrally on the base pedestal of the triaxial cell, ensuring that it is in correct vertical alignment.

Step 6: Assemble the cell body with the loading piston well clear of the specimen top cap. Check alignment by allowing the piston to slide down slowly until it makes contact with the bearing surface on the top cap, then retract the piston. If necessary remove the cell body and correct any eccentricity.

Step 7: Fill the triaxial cell with water, ensuring that all the air is displaced through the air vent. Add some oil on top.

Step 8: Pressurize the triaxial cell and make final adjustments.

TEST NO. 1.13

Triaxial test - Undrained Shear Strength (total stress)

Notes

Step 9: Raise the water pressure in the cell to the desired value with the loading piston restrained by the load frame or force-measuring device. The pressure should be kept on for about ½ hour before proceeding with the test. The cell pressure shall be determined by the Engineer.

Step 10: Adjust the loading machine to bring the loading piston to within a few mm of its seating on the specimen top cap. Record the reading of the force-measuring device during steady motion as the initial reading.

Step 11: Adjust the machine further to bring the loading piston just in contact with the seating of the top cap. Record the reading of the axial deformation gauge.

A suitable rate of strain is 2 % per min, which equals 1,5 mm per min. for a 76 mm long specimen.

Step 12: Select a rate of axial deformation such that failure is produced within a period of 5 min to 15 min. Engage the appropriate gear on the compression machine. The rate of axial deformation shall be decided by the Engineer.

Suitable reading intervals for a soil of medium compressibility are typically 0.25 % strain up to 1 % strain, and 0.5 % strain thereafter. For a very stiff soil which is likely to fail suddenly at a small strain, readings should be taken at frequent intervals of force rather than of strain to obtain the required number of readings.

Step 13: Start the test by switching on the machine.

Step 14: Record readings of the force-measuring device and the deformation gauge at regular intervals of the latter, so that at least 15 sets of readings are recorded up to the point of failure.

Step 15: Verify that the cell pressure remains constant.

Approximately 15 mm which corresponds to 15 rounds on the deflection dial gauge.

Step 16: Continue the test until the maximum value of the axial stress has been passed and the peak is clearly defined, or until an axial strain of 20 % has been reached.

Step 17: Stop the test and remove the axial force.

Step 18: Drain the water from the cell, dismantle the cell and remove the specimen.

These actions should be completed without delay to avoid loss of moisture from the specimen.

Step 19: Remove the rubber membrane from the specimen and record the mode of failure with the aid of a sketch.

Step 20: Break open the specimen and record a description of the soil including its fabric.

Step 21: Determine the moisture content of the whole specimen, or of representative portions. If there are surfaces of failure, moisture content specimens should be taken from zones adjacent to them.

Plotting and Calculations

1) From each set of readings calculate the axial force, P (N), applied to the specimen by multiplying the difference between that reading and the initial reading of the gauge on the force-measuring device by its calibration factor (in N per divisions).

2) Calculate the cross-sectional area, A (mm), of the specimen, on the assumption that it deforms as a right cylinder, from the equation:

$$A = \frac{A_0}{1 - \varepsilon}$$

where

Notes

A_0 is the initial cross-sectional area of the specimen (in mm^2) calculated from the initial diameter D_0

ε is the axial strain, equal to $\frac{\Delta L}{L_0}$

where

L_0 is the initial length of the specimen (in mm)
ΔL is the change in length measured by the axial deformation gauge (in mm).

3) Calculate the Principal Stress difference, i.e. the Deviator Stress (in kPa = kN/m^2): $(\sigma_1 - \sigma_3) = \frac{P}{A} \text{x } 1000$ [kPa = N/mm^2 x 1000 = kN/m^2]
4) Plot the stress-strain relationship for each specimen, i.e. the deviator stress against axial strain. Curves for all three specimens may be plotted on the same graph.
5) The values at failure should be tabulated as shown below:

Specimen no.	Deviator stress $(\sigma_1 - \sigma_3)$	Cell pressure σ_3	σ_1 $= (\sigma_1 - \sigma_3) + \sigma_3$
A			
B			
C			

6) Using these values of σ_3 and σ_1, the Mohr circle at failure for each specimen can be drawn on the same graphical plot. The scale on the vertical axis (shear stress axis) and the horizontal axis (principal stress axis) must be the same. Draw the best line fit to touch the circles. This tangential line is the Mohr-Coulomb envelope representing failure. The angle of inclination (φ degrees) of the envelope to the horizontal is measured, and the intercept (c) on the shear stress axis is read off.
7) Calculate the value of the Undrained Shear Strength, c_u (in kPa), from the equation:

$$c_u = \frac{1}{2}(\sigma_1 - \sigma_3)$$

8) Calculate the Bulk Density of the specimen ρ (in Mg/m^3), from the equation:

$$\rho = \frac{1000 m_0}{A_0 L_0} \quad [\text{ Mg/m}^3 = 1000 \text{ g/mm}^3 = \text{tonne/m}^3 \text{ }]$$

where

m_0 is the mass of the specimen (in g).

Triaxial test - Undrained Shear Strength (total stress)

Notes

Report

The test report shall include the following:

a) Type of material and sample identification
b) Reference to this procedure
c) Initial specimen dimensions
d) Whether undisturbed or remoulded specimens, and method of specimen preparation
e) Initial moisture content, bulk density and dry density of the specimen
f) Set of stress-strain curves for the three specimens
g) Tabulated values of σ_1 , σ_2 and $(\sigma_1 - \sigma_3)$
h) Mohr circle diagrams
i) Angle of shear resistance, φ (to the nearest 0,5°)
j) Cohesion intercept, c (to the nearest 1 kPa = 1 kN/m^2)
k) The Undrained Shear Strength value, $c_u = ½ (\sigma_1 - \sigma_3)_f$ (to the nearest 1 kPa = 1 kN/m^2)
l) Strain at failure (in %) for each specimen
m) Depth and orientation of test specimen within the original sample
n) Rate of strain (in %/min) applied during the test
o) Mode of failure

A suitable form for reporting data is shown below:

UNDRAINED TRIAXIAL TEST								
Specimen diameter = mm				Rate of strain = % per minute				
Spec. no	Bulk density	Moisture content	Cell pressure	AT FAILURE		SHEAR STRENGTH		Shear strength at failure c_u
				Compr. stress	Strain	c	φ	

Form for the test

The enclosed forms shall be used.

Practical considerations

Use dry filter stones. The use of filter stones is not mandatory, but it makes the handling of the samples easier.

Maintenance

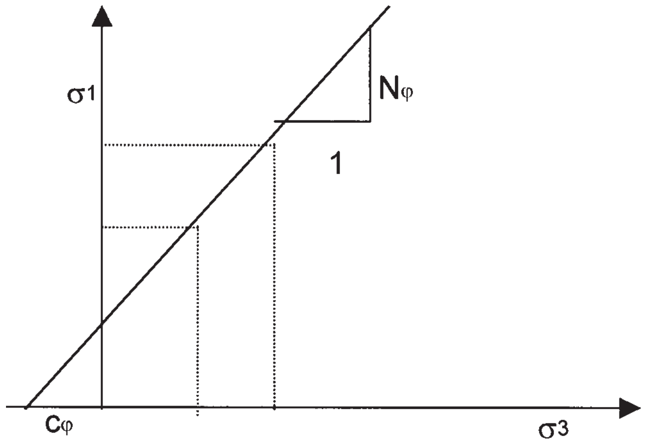
Clean the cell after running the test.
Wash and powder the rubber membrane.
Clean the filter stones.

Notes

Appendix

An alternative method of calculating the Angle of shear resistance, φ and the Cohesion intercept, c, is shown below.

The cell pressure, σ_3 is plotted against $\sigma_1 = \sigma_3 + (\sigma_1 - \sigma_3)$ at failure for the performed tests (i.e. minimum 2 tests).



The Angle of shear resistance is calculated from:

$$\tan \varphi = \frac{N\varphi - 1}{2\sqrt{N\varphi}} \quad \text{and} \quad \varphi = \arctan \varphi$$

The Cohesion intercept is calculated from:

$$c = \frac{C\varphi}{2\sqrt{N\varphi}}$$

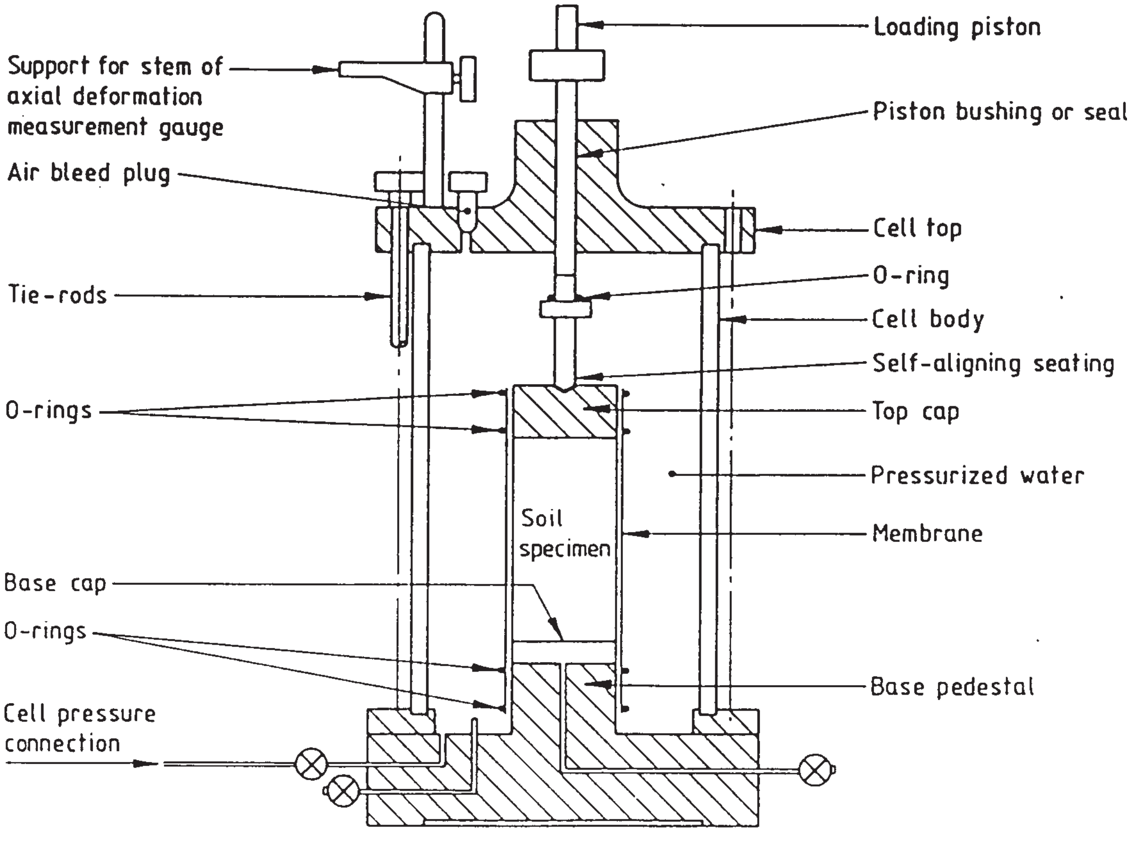


Figure 15 Typical details of triaxial cell

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WORKING SHEET

Triaxial Test

Undrained Shear Strength

Project	**Location**	**Depth**
Client	**Lab.no**	**Date**
Responsible Technician	**Checked**	**Approved**

TEST METHOD CML TEST 1.13, ref. BS 1377 : Part 7 : 1990

Type of specimen Undisturbed / compacted *	Nominal diameter mm

Preparation procedure

Specimen details	Initially	After test		Sketch showing specimen location in original sample
Diameter D mm		Mass g		
Area A_0 mm^2		Dry mass g		
Length L_0 mm		Moisture content %		
Volume cm^3				
Mass g				
Density Mg/m^3				

Compression test Single stage / Multistage, Stage*

Machine no.	Rate of deformation mm/min	Cell pressure kPa

Membrane thickness mm	Force device no.	Mean calibration N/division	Stress factor kPa/division

Deformation gauge reading	Compression of specimen ΔL mm	Strain $\epsilon = \frac{\Delta L}{L_0}$	Force gauge reading	Axial force P N	Corrected area $A = \frac{A_0}{1-\epsilon}$ mm^2	Measured deviator stress $(\sigma_1 - \sigma_3) = \frac{1000\,P}{A}$ kPa

Sketch of failure conditions

Inclination of shear surface

Measured deviator stress	kPa
Membrane correction	kPa
Corrected deviator stress	kPa
Axial strain	%
Shear strength c_u	kPa

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WORKING SHEET (II)

Triaxial Test

Undrained Shear Strength

Project	**Location**	**Depth**
Client	**Lab.no**	**Date**
Responsible Technician	**Checked**	**Approved**

TEST METHOD CML TEST 1.13, ref. BS 1377 : Part 7 : 1990

Deformation gauge reading	Compression of specimen ΔL (mm)	Strain $\varepsilon = \frac{\Delta L}{L_0}$	Force gauge reading	Axial force P (N)	Corrected area $A = \frac{A_0}{1-\varepsilon}$ (mm)	Measured deviator stress $(\sigma_1 - \sigma_3) = \frac{1000P}{A}$ (kPa)

TEST NO. 1.14

Shearbox Test - Drained Shear Strength

Notes

The rate of displacement may vary from 1 mm/min for a free-draining sand to less than 0,001 mm/min for a silty or clayey material.

The "quick" test is best suited to determine the value of φ for free-draining sands

The matters listed under points b) - d) are to be decided by the Engineer.

Objective

The Shear Box allows a direct shear test to be made by relating the shear stress at failure to the applied normal stress. The objective of the test is to determine the effective shear strength parameters of the soil, the cohesion (c') and the angle of internal friction (φ'). These values may be used for calculating the bearing capacity of a soil and the stability of slopes.

Main Principles

In the direct shear test a square prism of soil is laterally restrained and sheared along a mechanically induced horizontal plane while subjected to a pressure applied normal to that plane. The shearing resistance offered by the soil as one portion is made to slide on the other is measured at regular intervals of displacement. Failure occurs when the shearing resistance reaches the maximum value which the soil can sustain.

By carrying out tests on a set of (usually three) similar specimens of the same soil under different normal pressures, the relationship between measured shear stress at failure and normal applied stress is obtained.

The shearbox apparatus can be used only for carrying out drained tests for the determination of effective shear strength parameters. There is no control of drainage, and the procedure cannot be used for undrained tests.

The test specimen is consolidated under a vertical nomal load until the primary consolidation is completed. It is then sheared at a rate of displacement that is slow enough to prevent development of excess pore pressures. Test data enable the effective shear strength parameters *c' and* φ' to be derived.

Reference

BS 1377 : Part 7 : 1990

Test conditions

The following test conditions shall be specified before a series of tests is started:

a) Size of test specimen
b) Whether undisturbed or remoulded specimens are to be tested:
- For undisturbed specimens, the orientation of the specimens relative to the plane of shear
- For remoulded specimens the moisture content, and either the dry density to be achieved or the compactive effort to be applied

c) Number of test specimens to be tested as a set
d) The normal pressures to be applied

TEST NO. 1.14

Shearbox Test - Drained Shear Strength

Notes

Required equipment

- *Shearbox apparatus* for carrying out tests on soil specimens of 60 mm square and 30 mm high divided horizontally into two halves. Details of the shearbox is shown in figure 1, and a typical arrangement of the shearbox apparatus assembly in figure 2.
- Two porous plates of corrosion-resistant material.
- Two perforated grid plates of about the same size in plan as the porous plates, if necessary.
- A loading cap to cover the top grid plate or porous plate.
- A calibrated means of applying a vertical force to the loading cap such as a loading yoke.
- A motorized loading device capable of applying horizontal shear to the vertically loaded specimen at constant rates of displacement from which a rate to suit the soil being tested can be selected.
- A shear load measuring device (loading ring)
- Dial gauge for measuring the relative horizontal displacement of the two halves of the shearbox.
- Dial gauge for measuring the vertical deformation of the specimen during the test.
- Specimen cutter.
- Tool for removing the specimen from the cutter.
- Levelling template for trimming the surface of the specimen in the shearbox to a known level.
- Calibrated vernier external/internal caliper for measuring the internal dimensions and height of the cutting ring or test specimen to 0.1 mm.
- Stopclock, readable to 1 sec.
- Balance, readable to 0.1 g.
- Apparatus for determining moisture content.
- Silicone grease or petroleum jelly.

Preparation and assembly of shearbox

Step 1: Apply a thin coating of silicon grease or petroleum jelly to the inside faces of the shearbox and to the surfaces of contact between the two halves of the box.

Step 2: Assemble the shearbox with two halves securely clamped together, fit the baseplate and place it securely in position in the carriage.

Step 3: Place a grid plate on the base of the box if necessary, followed by a porous plate.

TEST NO.1.14

Shearbox Test - Drained Shear Strength

Notes

Preparation of specimen

Specimen of either cohesive or non-cohesive soil may be tested in the shearbox. Preparation procedures depend on the type of soil, as indicated below. The size of the largest particle shall not exceed one tenth of the height of the specimen.

Normally three similar specimens are prepared from an undisturbed or remoulded cohesive sample, for testing under three different normal pressures. A non-cohesive sample shall be large enough to provide three separate specimens to avoid having to re-use the same material.

Undisturbed specimens are built into the shearbox by the use of the specimen cutter.

Remoulded specimens shall be compacted into an e.g. Proctor mould given sufficient compactive effort to achieve the desired density. The specimens are then built into the shearbox by the use of the specimen cutter.

Test procedure

Initial adjustments

Step 1: Position the carriage (on its bearings) on the machine bed, and adjust the drive unit to the correct starting point of the shear test. Secure the horizontal displacement gauge in position.

Step 2: Assemble the loading system so that the loading yoke is supported by the ball seating on top of the load cap.

Remember to include the weight of the yoke and topcap when calculating the consolidation pressure.

Step 3: Secure the vertical deformation gauge in position so that it can measure the vertical movement of the centre of the loading cap, ensuring that it allows enough movement in either direction. Record the initial zero reading.

Consolidation

The applied force must be decided by the Engineer. Normally values of 50%, 100% and 150% of the stress likely to occur in the ground will be appropriate.

Step 1: Apply a normal force to the specimen, to give the desired vertical stress, σ_n (in kPa), smoothly and as rapidly as possible without jolting. Start the clock at the same instant if consolidation readings are significant.

*The Engineer must decide whether to test in **soaked** or **dry** condition.*

Step 2: Except when testing dry soils, as soon as possible after applying the normal force fill the carriage with water to a level just above the top of the specimen, and maintain it at that level throughout the test.

The time required to shear the sample to failure may be obtained from the consolidation graph:
$t_f = 12{,}7 \times t_{100}$ *(min)*

Step 3: Record readings of the vertical deformation gauge and elapsed time at suitable intervals to allow a graph to be drawn of vertical deformation as ordinate, against square-root of elapsed time as abscissa. A plot of vertical deformation against time to a logarithmic scale may also be made. Continue until the plotted readings indicate that primary consolidation is complete.
Form 7 (b) is suitable for recording and plotting these data.

TEST NO. 1.14

Shearbox Test - Drained Shear Strength

Notes

Final adjustments

On completion of the consolidation stage and before shearing make the following checks and adjustments:

Step 4: Ensure that all adjacent components from the constant rate of displacement device through to the load measuring device and its point of restraint are properly in contact, but under zero horizontal load.

Step 5: *Remove the clamping screws which lock the two halves of the shearbox together.*

Step 6: Raise the upper half of the box, keeping it level, by turning the lifting screws *(1/4 to 1/2 turn).* The amount of clearance between the two halves should be enough to prevent them coming together during the test, but shall not permit extrusion of the soil between them. Retract the lifting screws.

Step 7: Record the initial readings of the horizontal displacement gauge, the vertical deformation gauge and the force measuring device.

Remember to remove the clamping screws before the shearing starts. If this is forgotten the equipment will be destroyed.

Recommended speed
For a free-draining sand a rate of 1 mm/min will be suitable. The time to failure should, however, be determined from the consolidation graph (7b).
$t_f = 12{,}7 \times t_{100}$ (min),
where; $t_{100} = \sqrt{t_{100}{}^2}$

Shearing

Shear the specimen to failure:

Step 8: Start the test and at the same instant start the timer. Record readings of the force measuring device, the horizontal displacement gauge, the vertical deformation gauge and elapsed time, at regular intervals of horizontal displacement such that at least 20 readings are taken up to the maximum load ('peak' shear strength).

Step 9: Take additional readings as the maximum horizontal force is approached, so that if the 'peak' occurs it can be clearly defined.

Step 10: Continue shearing and taking readings beyond the maximum force, or until the full travel of the apparatus has been reached if there is no defined peak, then stop the test.

Step 11: Reverse the direction of travel of the carriage and return the two halves of the shearbox to their original alignment.

Step 12: If the specimen was sheared under water, siphon off the water from around the specimen and allow to stand for about 10 min to enable free water to drain from the porous plates.

Step 13: Remove the vertical force and loading yoke from the specimen.

Step 14: Transfer the specimen from the shearbox to a small tray, taking care not to lose any soil. Remove any free water with a tissue.

Step 15: Weigh the specimen on the tray to 0.1 g.

Step 16: Dry the soil in an oven at 105°C to 110°C and determine its dry mass (m_d) to 0.1 g, and its final moisture content.

Shearbox Test - Drained Shear Strength

Notes

Calculations and plotting

General data

See form 7 a).

1) Calculate the initial Moisture Content, w_0 (in %), from the equation:

$$w_0 = \frac{m_0 - m_d}{m_d} \times 100$$

where

m_0 is the initial mass of the specimen (in g):

m_d is the final dry mass of the specimen (in g).

1 Mg = 1000 kg (= 1 tonne)

2) Calculate the initial Dry Density, ρ_d (in Mg/m^3) from the equation:

$$\rho_d = \frac{m_d \times 1000}{AH_o}$$

where

For an undisturbed specimen trimmed in the specimen cutter, H_0 is equal to the height of the cutter.

For a disturbed specimen formed in the shearbox, H_0 is calculated from h_1, h_2 and the appropriate plate thickness t_p.

A is the plan area of the specimen (in mm^2):

H_0 is the initial height of the specimen (in mm).

3) Calculate the initial Bulk Density, ρ (in Mg/m^3) from the equation:

$$\rho = \frac{m_o \times 1000}{AH_o}$$

4) Calculate the initial Void Ratio, e_0 (if required) from the equation:

$$e_0 = \frac{\rho_s}{\rho_d} - 1$$

where

ρ_s is the particle density (in Mg/m^3) (which may be measured, or assumed).

5) Calculate the initial degree of saturation, S_0 (if required) as percentage from the equation:

$$S_0 = \frac{w_0 \rho_s}{e_0}$$

6) Calculate the Voids Ratio, e, at the end of the consolidation stage, and at the end of shearing (if required) from the equation:

$$e = e_0 - \left[\frac{\Delta H}{H_0}(1 + e_0)\right]$$

where

ΔH is the calculated change in height (vertical deformation) of the specimen (in mm) from the initial zero reading.

Shearbox Test - Drained Shear Strength

Notes

See form (7c).

Stresses and displacements

From each set of data obtained during the shear test calculate the horizontal shear force, P (in N), applied to the specimen.

7) Calculate the Shear Stress on the surface of shear, τ (in kPa) for each set of readings from the equation:

$$\tau = \frac{P}{A} \text{x } 1000$$

where

A is the initial plan area of the specimen (in mm^2).

8) The normal stress σ_n (in kPa), applied to the specimen is given by the equation

kPa = kN/m^2

$$\sigma_n = \frac{1000\text{x}9.81m}{A} \qquad [1\text{ kg}_{\text{force}} = 9.81\text{ N}]$$

The continual change in the area of contact is not normally taken into account.

where

m is the mass of the hanger and hanger weights (or equivalent mass if a lever-arm loading system is used) applied to the loading cap (in kg).

9) Calculate the cumulative vertical deformation for each set of readings relative to the datum corresponding to the initial specimen height.

See form 7 (e).

Graphical plots, single stage tests

For each specimen of a set of single-stage tests, plot the following graphs:

a) Shear stress (in kPa) as ordinates against horizontal displacement (in mm) as abscissae

b) Change in height (vertical deformation) of the specimen (in mm) as ordinates against horizontal displacement (in mm) as abscissae, if required. If preferred the changes in height may be plotted in terms of voids ratio by using the equation given in point 6 above.

c) From each stress-displacement graph read off the value of the maximum shear stress (the ‘peak’ strength) and the corresponding horizontal displacement and change in specimen height.

d) Plot each value of peak strength τ_f (in kPa), as ordinates against the corresponding vertical normal stress σ_n (in kPa) applied for that test as abscissae, both to the same linear scale.

e) If it can be assumed that the relationship is linear, the slope of the line and its intercept with the shear strength axis can be derived from the line of best fit through the plotted points. The slope gives the angle of shearing resistance φ’ (in degrees), and the intercept gives the apparent cohesion c’ (in kPa), both in terms of effective stress.

Shearbox Test - Drained Shear Strength

Notes

Test report

The test report shall contain the following:

a) Reference of this procedure

b) Statement of the method used

c) Initial dimensions of the specimens

d) Initial moisture content, bulk density, and dry density

e) Particle density, indicating whether measured or assumed

f) Initial voids ratio and degree of saturation, if required

g) Tabulated values for each specimen of the applied normal stress, maximum shear stress and corresponding horizontal relative displacement

h) Rate of horizontal displacement

i) Whether the specimen were tested dry or submerged

j) Graphical plots of settlement against square-root time for each specimen, if relevant

k) Graphical plots of shear stress, and if required, the change in specimen thickness, against cumulative horizontal displacement for each specimen

l) Graphical plots of maximum shear stress against normal applied stress, showing the derivation of c’, φ’.
The horizontal and vertical scale must be the same. Draw the line of best fit through the 3 points. This line is the failure envelope or the Coulomb envelope. If the soil is granular and non-cohesive, the line should pass through the origin (c’ = 0).

m) (Only if the plotted relationship are linear) Angle of shearing resistance φ’, to the nearest 1/2^o, and cohesion intercept c’ (in kPa) to two significant figures, for the maximum condition.

Checking and preparation of the apparatus

Measurements

See form 7 a).

- Ensure that the specimen cutter is clean and dry, and that the cutting edge is in good condition.
- Determine and record the mass of the cutter to 0.1 g.
- Determine the mass of the tray or watch glass to 0.1 g.
- Verify and record the mean internal dimensions of the cutter to 0.1 mm.
- Ensure that the shearbox components are clean and dry. Clamp the two halves of the box securely together with the clamping screws, fit the baseplate and assemble the shearbox securely in the carriage.
- Determine the internal plan dimensions (L_1 x L_2) of the shearbox to 0.1 mm, and calculate the plan area A (in mm^2) Determine the mean depth from the top surface of the upper half to the top of the base plate (h_1) to 0.1 mm.

Notes

- Measure and record the thickness of each porous plate and grid plate to 0.1 mm. Determine the combined thickness of plates to be used for the test (t_p).

Maintenance

- The equipment shall be kept clean, dry and calibrated.

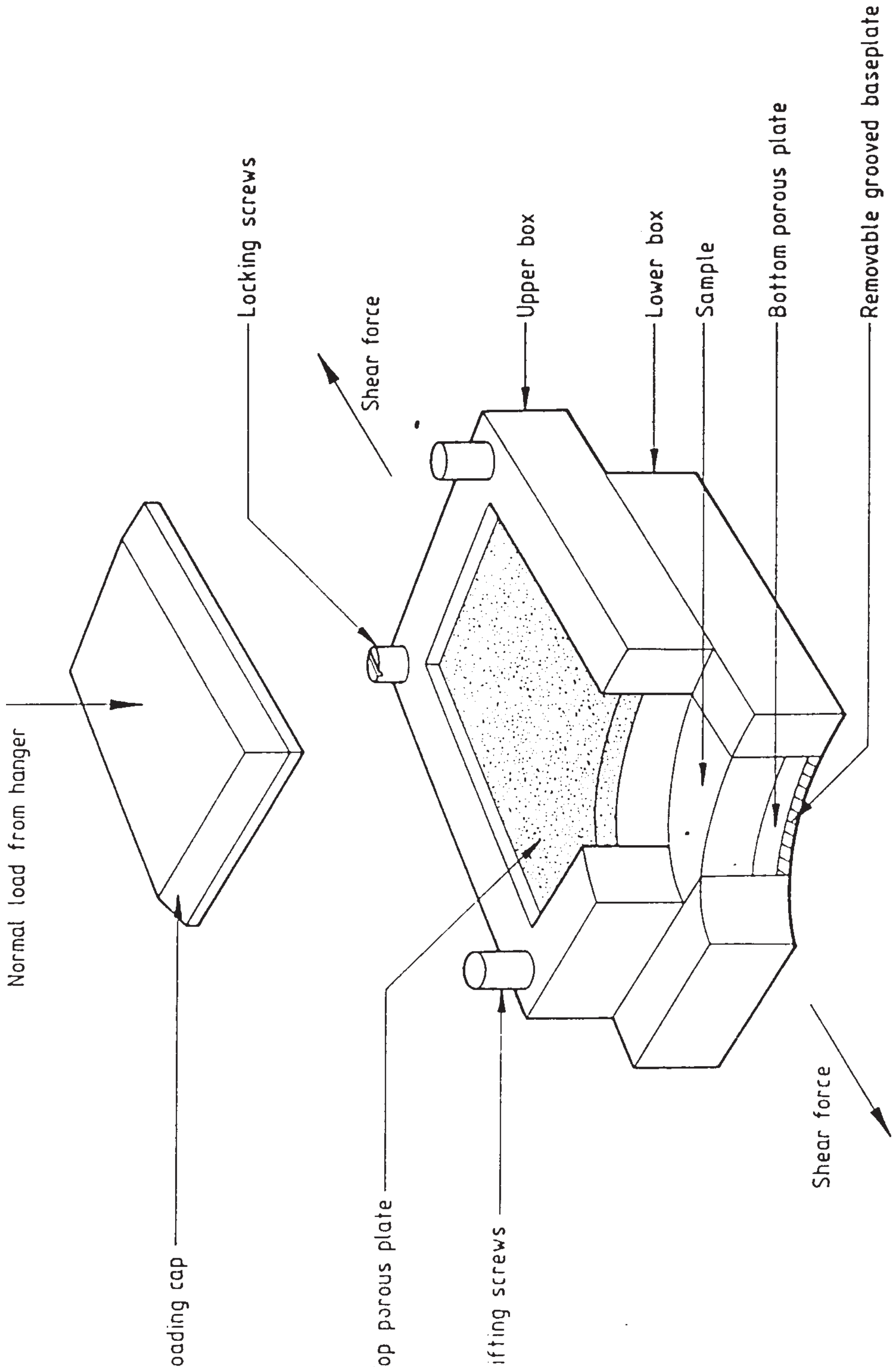

Figure 16 Details of shearbox

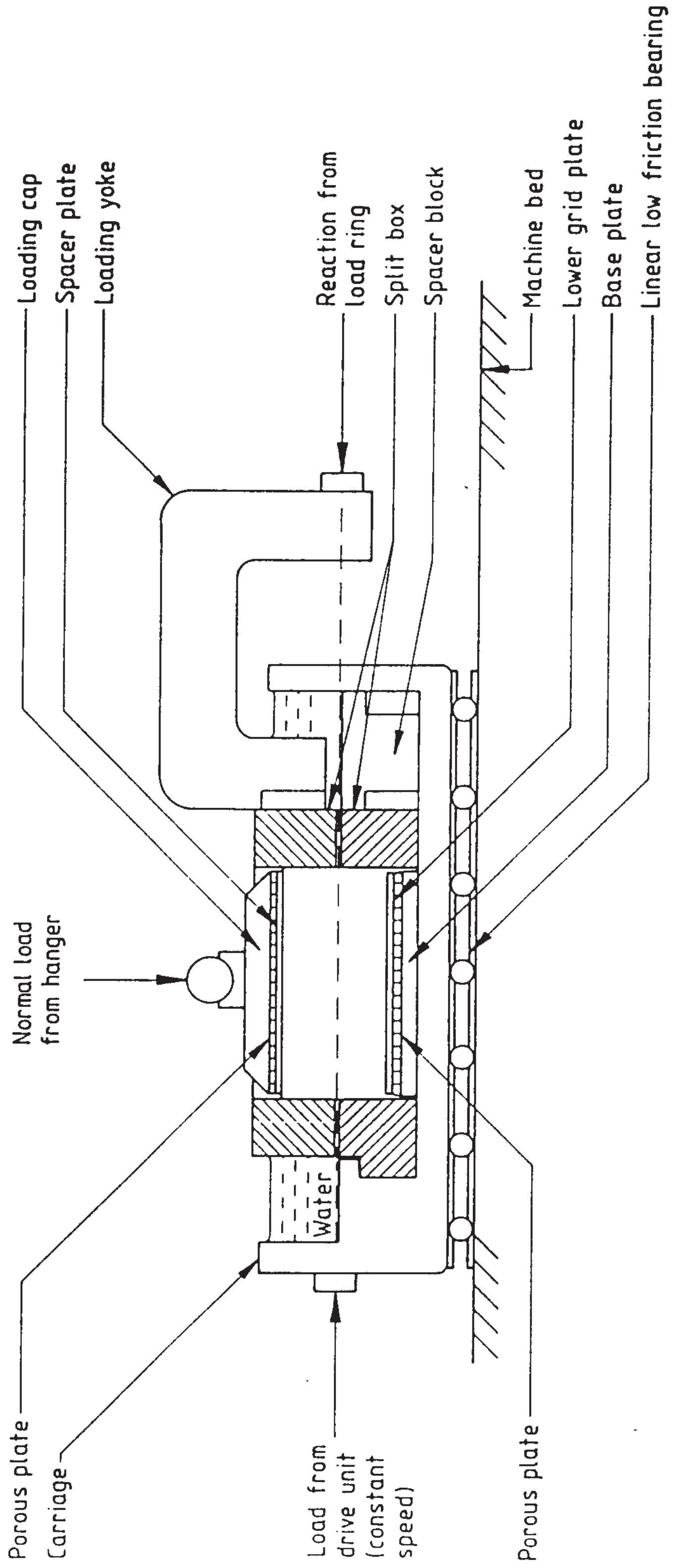

Figure 17 Typical general arrangement of shearbox apparatus

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WORKING SHEET

Shearbox Test

Consolidation - Form a

Project	**Location**	**Depth**
Client	**Lab.no**	**Date**
Responsible Technician	**Checked**	**Approved**

TEST METHOD CML TEST 1.14, ref. BS 1377 : Part 7 : 1990
Soil Description:

Machine no.	Type of specimen undisturbed / compacted / loosely deposited*
Preparation procedure	

Weighings		Initially	After test	**Nominal dimensions**		
Wet soil + cutter + tray*	g			Length	L_1 mm	
Dry soil + cutter + tray*	g				L_2 mm	
Cutter + tray	g			Area	A mm^2	
Wet soil	g			Height	H mm	
Dry soil	g			Volume	V cm^3	
Water	g			Particle density	ρ_s Mg/m^3	
Moisture content: measured	%			Sketch showing specimen location in original sample		
trimmings	%					
Density	Mg/m^3					
Dry density	Mg/m^3					
Voids ratio	e					
Degree of saturation	%					
Initial mass of disturbed soil *	g					
Mass of soil remaining	g					
Mass of specimen	g					

Shearbox details and setting up

Top of box to top of baseplate	h_1 mm			
Top of box to top porous plate	h_2 mm			
Combined thickness of plates	t_p mm			
Sample thickness $H_0 = h_1 - (h_2 + t_p)$	mm			
Mass of load hanger	m_1 kg			
Lever ratio	r		$r \times m_2 =$ kg	
Mass on hanger m_2		kg		
Total mass on specimen	m kg			
Normal stress $\sigma_n = \frac{9810m}{A} =$				kPa

Top of load cap above top of box, unloaded	h_3 mm	
Top of load cap above top of box, with yoke	h_4 mm	
Settlement under loading yoke	mm	
Initial reading of vertical deformation gauge	R_1	
Zero reading of gauge $R_0 = R_1 \pm (h_3 - h_4)$		

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WORKING SHEET

Shearbox Test

Consolidation - Form b

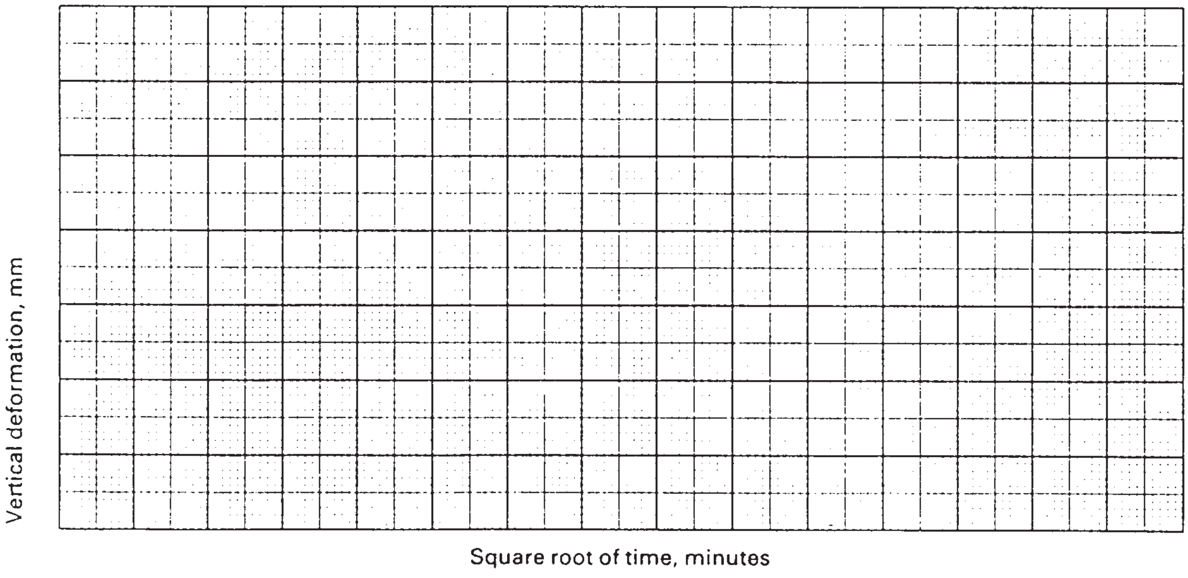
Project	**Location**	**Depth**
Client	**Lab.no**	**Date**
Responsible Technician	**Checked**	**Approved**

TEST METHOD CML TEST 1.14, ref. BS 1377 : Part 7 : 1990

Soil Description:

Machine no.	Date started	Normal stress kPa

Clock time	Elapsed time				$\sqrt{t}$	Gauge reading	Deformation ΔH mm	
	h	min	s	t min				
				0	0		(zero reading)	
								From graph, $\sqrt{t_{100}}$ =
								t_{100} = min
								$t_f = 12.7 \times t_{100}$ = min
								Estimated displacement at failure = mm
								Calculated rate of displacement = mm/min
								At end of consolidation $e = e_0 - \frac{\Delta H}{H_0}(1 + e_0)$ =



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WORKING SHEET

Shearbox Test

Shearing - Form c

Project	**Location**	**Depth**
Client	**Lab.no**	**Date**
Responsible Technician	**Checked**	**Approved**

TEST METHOD CML TEST 1.14, ref. BS 1377 : Part 7 : 1990

Soil Description:

Type of test	Single stage / Multiple reversals*		Run no.
Force device no.	Mean calibration N/division	Specimen size x mm	Stress factor kPa/division
Machine no.	Rate of displacement mm/min	Normal stress kPa	

Time	Elapsed time min	Force gauge reading	Shear stress kPa	Horizontal displacement		Vertical deformation	
				measured mm	cumulative mm	gauge reading	cumulative mm

Remarks	Sketches of shear surfaces at failure

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WORKING SHEET

Shearbox Test

Graphical Data - Form d

Project	**Location**	**Depth**
Client	**Lab.no**	**Date**
Responsible Technician	**Checked**	**Approved**

TEST METHOD CML TEST 1.14, ref. BS 1377 : Part 7 : 1990

Soil description:

Test reference

Normal stress		kPa						
Rate of displacement		mm/min						
Peak	Shear stress	kPa						
	Displacement	mm						
Residual	Shear stress	kPa						
	No. of travels							
	Displacement	mm						

Shear Strength Parameters

Maximum	c'	kPa	
	φ'	deg	
Residual	c'_R	kPa	
	φ_R'	deg	

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WORKING SHEET

Shearbox Test

Graphical Plot - Form e

Project	**Location**	**Depth**
Client	**Lab.no**	**Date**
Responsible Technician	**Checked**	**Approved**

Shear stress, kPa

Normal stress, kPa

Vertical deformation, mm

Shear stress, kPa

Horizontal displacement, mm

TEST NO. 1.15

Permeability Test - Constant Head

Notes

The Constant Head permeameter is best suitable for relatively coarse grained soils such as sands and gravels.
The Falling Head permeameter is more appropriate for fine-grained soils such as silty and clay-like soils.

Objective

The fundamental soil property involved in water flow is permeability. The permeability is especially relevant for engineering problems like determination of rate of leakage through an earth dam.

It depends mainly on the particle size, void ratio, density and degree of saturation.

Main Principles

The permeability of a soil is a measure of its capacity to allow the flow of water through the pore spaces between solid particles. The degree of permeability is determined by applying a hydraulic pressure gradient in a sample of saturated soil and measuring the consequent rate of flow. The coefficient of permeability is expressed as a velocity.

The specimens are formed in a permeability cell and water is passed through it from a constant level tank. Pressure take-off points located along the sides of the permeability cell are connected to 3 manometer tubes. Water passing through the specimen is collected and measured.

References

BS 1377 : Part 5 : 1990.

Required equipment

The permeability of the discs shall be greater than that of the soil sample.

The grading of the filter material depends on the particle size distribution of the test sample. The filter material grading limits should lie between 4 x the 15 % passing size and 4 x the 85 % passing size of the test sample. The material should be well graded between those limits.

- Permeameter cell
- Two discs of wire gauze (or porous disc) with a diameter equal to the internal diameter of the cell body
- A vertical adjustable reservoir tank
- A supply of clean water (preferably de-aerated)
- A discharge reservoir with overflow to maintain a constant level
- A set of transparent manometer tubes
- A pinch cock for each manometer tube
- Filter material of suitable grading for placing adjacent to the perforated plates at each end of the permeameter
- Measuring cylinders of 100 ml, 500 ml and 1.000 ml
- A scoop
- A flatended tamping rod
- A thermometer
- A stopclock
- A balance readable to 1 g

Sample Preparation

This test is not suitable for soils containing more than 10 % of material passing the 63 µm sieve.

If a number of tests are to be performed at different densities to establish a relationship between permeability and voids ratio, prepare several samples.

Step 1: Remove oversize particles larger than 8 mm in diameter. The volume of the sample shall be about twice that required to fill the permeameter cell. The sample shall not be dried.

Step 2: Take two ore more representative samples from the prepared material for the determination of Moisture Content and Particle Density.

Permeability Test - Constant Head

Notes

Step 3: Weigh the remainder of the prepared sample to 1 g (m_1).

Test Procedure

Step 1: Assemble the base plate, with perforated base, to the permeameter cell body.

Step 2: Place the graded filter material in the bottom of the cell to a depth of about 50 mm. Level the surface and place a wire gauze (or porous disc) on top.

Place the soil to be tested into the permeameter in such a way as to give a homogenous deposit at the required density or voids ratio. The final height:diameter ratio of the test sample shall not be less than 2:1.

Step 3: Place the soil in the permeameter in at least 4 layers, each of which is of a thickness about equal to half the diameter.

Step 4: Tamp each layer with a controlled number of standard blows with the tamping rod. Level the surface of each layer before adding the next.

Step 5: Place the upper wire gauze (or porous disc) on top of the sample.

Step 6: Place the graded filter material on top of the disc to a depth of minimum 50 mm.

Step 7: Release the piston in the top plate and withdraw it to its fullest extent.

Step 8: Fit the top plate to the permeameter cell and tighten it down in position.

Step 9: Lower the piston carefully and bed the perforated plate on to the filter material. Hold the piston down firmly and tighten the locking collar in this position.

Measurements

Step 10: Determine the mean length of the test sample, L_1 (in cm), to 1 mm, by measuring at three locations around the perimeter.

Step 11: Dry the soil left over and weigh it to 1 g (m_2), so that the dry mass of the test sample can be obtained by difference

Saturation

Step 12: Connect the control valve on the base of the permeameter to the water supply. Open the top connection and the air bleed to atmosphere, and close the connection to the manometer tubes.

Step 13: Allow water to enter the cell and slowly percolate upwards through the sample until it emerges first from the air bleed, which is then closed, and then from the top connection.

The water level shall rise slowly enough not to cause disturbance of the sample, or piping

Step 14: Measure the length of the sample again (L_2) and record the average measurement, L (in cm) = ½ ($L_1 + L_2$).

Step 15: Close the control valve. Connect the water supply to the permeameter top connection, and connect the control valve at the base to the discharge reservoir, without entrapping air.

Permeability Test - Constant Head

Notes

Step 16: Set the inlet reservoir at a level a little above the top of the permeameter cell and open the supply valve. Open the manometer pinch cocks one by one and ensure that no air is trapped in the flexible tubing as water flows into the manometer tubes. The water in all tubes shall reach the level of the reservoir surface.

Step 17: The permeameter cell is now ready for test under the normal condition of downward flow. *If a test with upward flow is required, e.g. for investigating piping effects, fit the control valve, connected to the discharge reservoir, to the top of the cell and connect the water supply to the base.*

Downward water flow

An initial hydraulic gradient of 0.2 is often suitable, although a slightly higher value may be more appropriate for finergrained or more dense samples.

Step 18: Adjust the height of the inlet reservoir to a suitable level with regard to the hydraulic gradient to be imposed on the sample.

Step 19: Open the control valve at the base to produce flow through the sample under a hydraulic gradient appreciably less than unity (1.0). Allow the water levels in the manometer tubes to become stable before starting test measurements.

Step 20: Place a measuring cylinder of suitable capacity under the outlet from the discharge reservoir and simultaneously start the timer.

Step 21: Measure the quantity of water collected in the cylinder during a given time interval. Alternatively record the time required to fill the cylinder up to a given volume.

Step 22: Record the water levels in the manometer tubes.

If the three levels indicate significant non-uniformity of the hydraulic gradient, remo

Step 23: Record the temperature of the water in the discharge reservoir.

Step 24: Repeat steps 19 to 23 four more times, or until consistent readings are obtained.

Calculations

1) Calculate the rate of flow, q_1, q_2 etc. (in ml/s) during the period of each observation of flow from the equation:

$$q_1 = \frac{Q_1}{t} \text{ etc.} \qquad \text{where}$$

Q_1, Q_2 etc. (in ml) is the volume of water collected from the outlet reservoir during each time period, t (in s).

Calculate the average rate of flow, q, for the set of readings at one hydraulic gradient.

2) Calculate the hydraulic gradient, i, between the uppermost and lower manometer gland points from the equation:

$$i = \frac{h}{y} \qquad \text{where}$$

The intermediate manometer point is used to provide a check on the uniformity of the hydraulic gradient between the outer points, $y = x_1 + x_2$, see figure 19.

h is the difference between the two manometer levels (in cm);

Notes

The permeability of clean sands and gravels will normally be in the range from k= 0,0001 cm/s to k=100 cm/s.

Table 1 is on the enclosed working sheet.

y is the difference between the corresponding glandpoints (in cm).

3) Calculate the coefficient of permeability, k (in cm/s), for one set of readings from the equation:

$$k = \frac{q}{i}\frac{R_t}{A} \qquad \text{where}$$

A is the area of cross section of the sample (in cm^2);

R_t is the temperature de correction factor for the viscosity of water, derived from Table 1, to standardize the permeability to 20 °C.

4) Calculate the Dry Mass, m_3 (in g), of the initial sample from the equation:

$$m_3 = m_1 \frac{100}{100 + w} \qquad \text{where}$$

m_1 is the initial mass of the sample (in g)

w is the moisture content (in %)

5) Calculate the Dry Density, ρ_d (in kg/m^3), of the test sample from the equation:

$$\rho_d = \frac{4\ (m_3 - m_2)}{\Pi\ \ DDL} \text{x } 1000 \qquad \text{where}$$

m_2 is the mass of dry soil remaining after setting up the test sample (g)

D is the sample diameter (in cm)

L is the overall length of the sample (in cm).

6) Calculate the Void Ratio, e, of the test sample (if required) from the equation:

$$e = \frac{\rho_s}{\rho_d} - 1 \qquad \text{where}$$

ρ_s is the Particle Density (in kg/m^3)

Additional more extensive testing (if applicable)

If a series of tests at different hydraulic gradients is required, then Steps 19 to 24 above shall be repeated under progressively increasing hydraulic gradients. This can be achieved by increasing the height of the inlet reservoir, or by opening the control valve further as necessary.

Laminar flow is indicated when the relationship between rate of flow and hydraulic gradient is linear. Deviation from the straight line at high gradients indicate turbulent flow.

The hydraulic gradients shall cover the range of interest within the range of laminar flow.

If a relationship between Coefficient of Permeability and Voids Ratio over a range of void ratios is required, the whole test shall be repeated using

Notes

different portions of the same soil, but placed and compacted to different densities.

Calculations

If tests have been carried out at different hydraulic gradients, plot the calculated Rate of Flow, q, against the Hydraulic Gradient, i.

Draw the straight line of best fit through the plotted points and determine its slope which is:

$$\frac{\Delta q}{\Delta i}$$

When a range of Hydraulic Gradients is used, the Coefficient of Permeability of the sample may be calculated from the equation:

$$k = \frac{\Delta q}{\Delta \mathrm{i}} \frac{R_t}{A}$$

If the Coefficient of Permeability is determined at several densities, plot the calculated values of k as ordinates, to logarithmic scale, against Density or Voids Ratio, e, as abscissae, to linear scale.

Report

The test report shall include the following:

a) Type of material and sample identification
b) Reference to this procedure
c) Whether or not de-aerated water was used
d) The Particle Size Distribution curve for the original sample (if appropriate)
e) The proportion and size of oversize material removed before preparing the test sample
f) Method of placing and compacting the test sample
g) The dimensions of permeameter cell
h) The Dry Density
i) The Voids ratio (if required)
j) Then Coefficient of Permeability, k (in cm/s), to two significant figures, for the condition of laminar flow, corrected to 20 °C.
k) A plot of Coefficient of Permeability, k (log scale) against Density or Voids Ratio, e, if appropriate.

Form for the test

The enclosed form shall be used.

Maintenance

Ensure that the permeameter cell, gauze, perforated plates, glands and joints are clean and free from blockage.

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WORKING SHEET

Permeability
Constant Head

Project	**Location**	**Contractor**
Client	**Lab.no**	**Date**
Responsible Technician	**Checked**	**Approved**

TEST METHOD CML TEST 1.15, ref. BS 1377 : Part 5: 1990

Length of sample (before saturation)	L_1 (cm)		Mass of prepared sample	m_1 (g)	
Length of sample (after saturation)	L_2 (cm)		Dry mass of remainder of sample	m_2 (g)	
Average length of sample	$L = ½ (L_1 + L_2)$		Moisture content of initial sample	w (%)	
Diameter of sample	D (cm)		Particle density	ρ_s (kg/m^3)	
Area of sample	A (cm^2)		Dry mass (g)	$m_3 = m_1 \frac{100}{100+w}$	
Dry density, $\rho_d = \frac{4(m_3 - m_2)}{\pi DDL} 1000$	(kg/m^3)		Void ratio	$e = \frac{\rho_s}{\rho_d} - 1$	

Test no.	Time interval t (sec)	h	y	Hydraulic gradient i = h/y	Flow Q	Rate of flow q = Q/t	Tempe-rature T	Corr. factor R_t	**Permeability** $k = \frac{qR_t}{iA}$
	(s)	(cm)	(cm)		(ml)	(ml/s)	°C		(cm/s)

Table 1. Temperature correction factors for permeability

Tempe-rature	°C	20	21	22	23	24	25	26	27	28	29	30	31	32
Correction factor	R_t	1.00	0.975	0.95	0.925	0.905	0.88	0.86	0.845	0.83	0.815	0.80	0.785	0.77

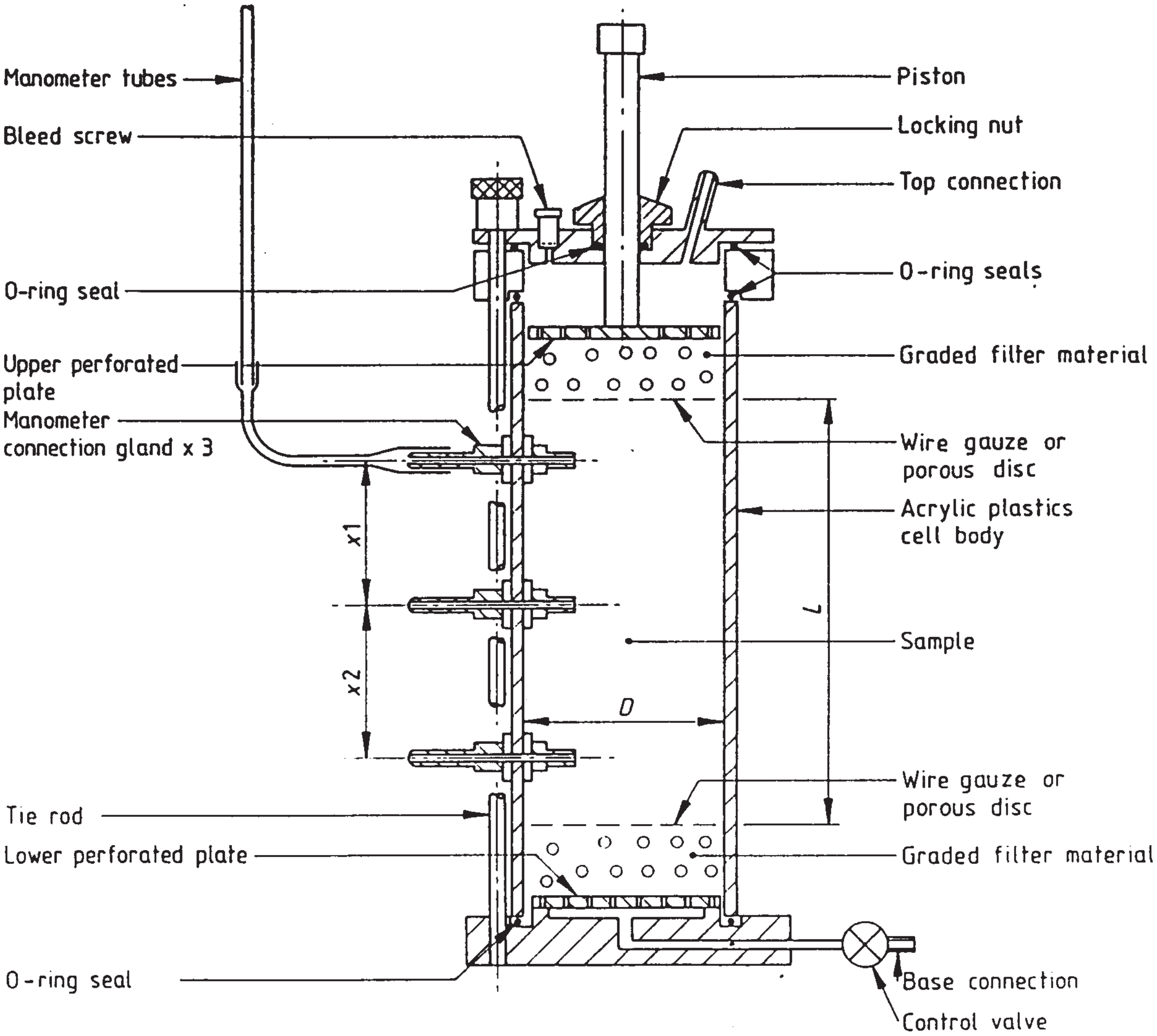

Figure 18 Section of a typical constant-head permeability cell

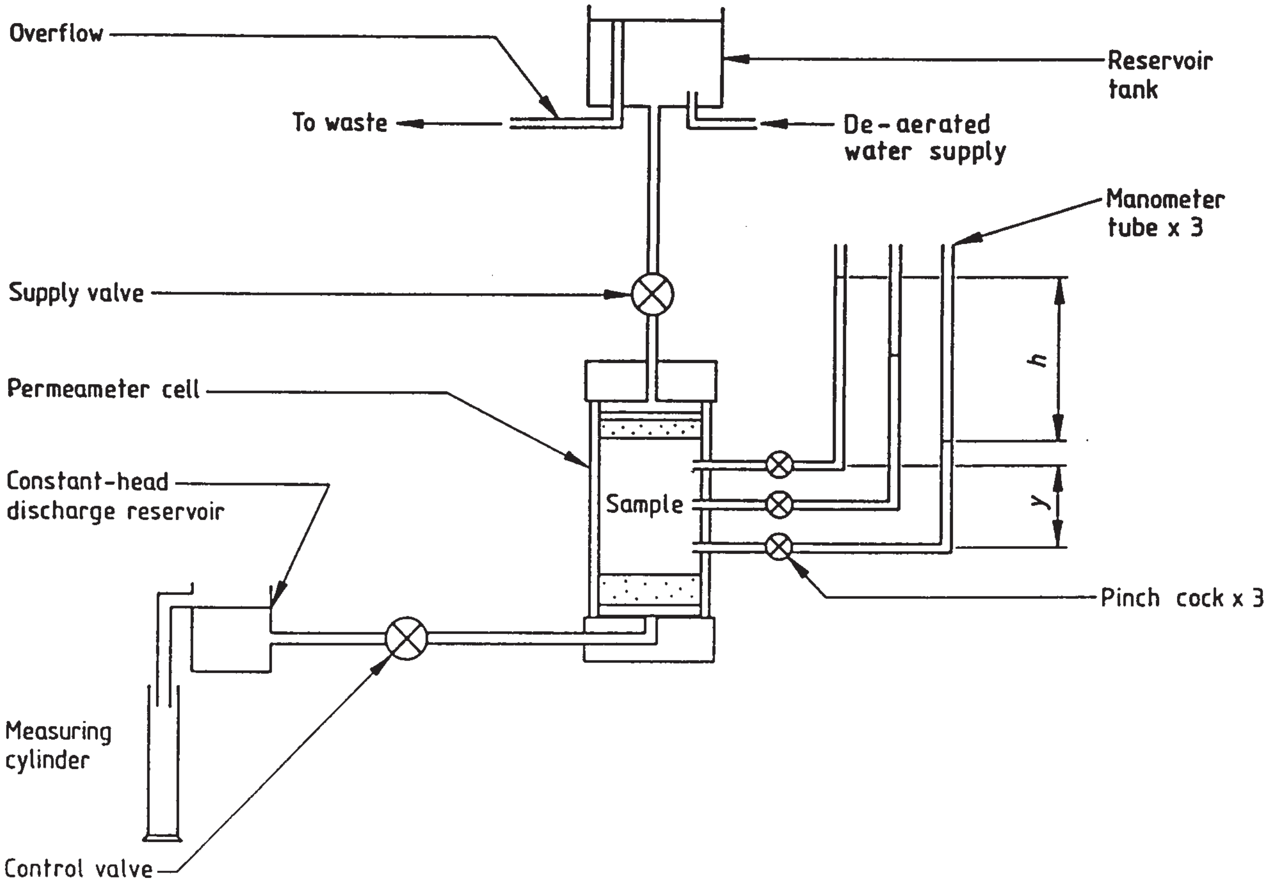

Figure 19 Arrangement of apparatus for constant-head permeability test

TEST NO. 1.16

Organic Content - Loss on Ignition (LOI) method

Notes

The described method of ignition loss is not considered an accurate method for determining the Organic Content. However, the method is considered adequate for the majority of ordinary geotechnical investigations.

Objective

The described test is a method for quantitative determination of the Organic Content in a soil sample by ignition of a dry test sample. The method is suitable for fine-grained soils (sands and silts) with relatively high organic content, but containing little chalky material.

The method may also be applied for gravels for subbase and base materials in road construction. For gravels only a small part of the sample will be less than 425 µm. However, the finely distributed organic material in a gravelly material is considered the most significant factor regarding the material's ability to bind and retain water.

Main Principles

The dried sample is combusted at 440 °C and Organic Content of the sample is taken as the percentage loss in weight.

The organic content is determined of the material less than 425 µm of the test sample.

References

BS 1377 : Part 3 : 1990 (NPRA 014 : 14.445 : 12.97)

Required equipment

- Balance, readable to 0.01 g
- Metal container
- Desiccator containing anhydrous silica gel
- Pestle and mortar
- Muffle furnace with capacity of 440 ± 25 °C
- 2 Quartzite dishes (crucibles), (e.g. 70 mm diameter)
- Test sieves of aperture 2 mm and 425 µm
- Drying oven with temperature of 50 C ± 2.5 °

Test Procedure

Step 1: Weigh the 2 quartzite dishes/crucibles after heating to 440 ± 25 °C for 1 hour and after allowing to cool in a desiccator to the nearest 0.01 g (m_c).

Step 2: A representative test sample of about 300 g shall be taken from the main sample and placed in the container.

Step 3: Place the test sample in the oven to dry at 50 ± 2.5 °C for minimum 12 hours. After drying, weigh the sample to the nearest 0.1 g (m_1).

Step 4: Sieve the material on a 2 mm test sieve, and crush retained particles other than stones to pass the 2 mm sieve. Reject the stones ensuring that no fine material adheres to them, e.g. by brushing. Record the mass of the material passing 2 mm test sieve, m_2, to 0.1 g.

Step 5: Divide the material passing the 2 mm sieve to produce a sample weighing 10, - 15 g.

Organic Content - Loss on Ignition (LOI) method

Notes

Step 6: Pulverize this sample so that it passes a 425 µm test sieve.

Step 7: Subdivide the sample to obtain 2 test specimens each weighing about 5 g.

Step 8: Place each specimen in a prepared dish/crucible and dry in the oven at a temperature of 50 C ± 2.5 ° for about 4 hours more, and weigh each of the 2 crucibles with soil to 0.01 g (m_3).

Step 9: Place the crucibles with the soil in the unheated muffle furnace, heat to 440 ± 25 °C, and maintain this temperature for minimum 12 hours.

Step 10: Remove the sample from the furnace and place in a desiccator to cool. Record the weight of the crucibles with the samples to 0.01 g (m_4).

Calculations

1) The Organic Content (or Loss of Ignition) of the material is taken as the loss in mass, and is reported as the percentage loss in mass from the equation:

$$\text{Organic Content (\%)} = \left(\frac{m_3 - m_4}{m_3 - m_c}\right) \times 100 \quad \text{where}$$

m_3 is the mass of the crucible and oven-dry soil specimen (in g)

m_4 is the mass of the crucible and specimen after ignition (in g)

m_c is the mass of the crucible (in g)

2) The percentage of the original soil sample passing the 2 mm test sieve is calculated from the equation:

$$\text{Fraction finer than 2 mm} = \frac{m_2}{m_1} \times 100 \quad \text{where}$$

m_1 is the original dry mass of the sample (in g)

m_2 is the mass of sample passing the 2 mm sieve (in g)

Report

The test report shall include the following:

a) Type of material and sample identification

b) Reference to this procedure

c) The Organic Content (or Loss on Ignition) as a percentage of the material less than 2 mm (425 µm) to 2 significant figures

d) The percentage by dry mass of the original sample passing the 2 mm test sieve (425 µm), to the nearest 1 %.

The accuracy of the test depends amongst other on the content of chalky material in the sample. Mass loss can also result from release of crystalline water.

Form for the test

The enclosed form shall be used.

CML
CENTRAL MATERIALS LABORATORY

WORKING SHEET

Organic Content
Loss on Ignition

Project	**Location**	**Depth**
Client	**Lab.no**	**Date**
Responsible Technician	**Checked**	**Approved**

TEST METHOD CML TEST 1.16, ref. BS 1377 : Part 3 : 1990

Specimen reference						
Mass of initial sample	m_1	g				
Mass of soil passing 2 mm test sieve	m_2	g				
Crucible no.						
Mass of crucible	m_c	g				
Mass of crucible + dry soil	m_3	g				
Mass of crucible + soil after ignition	m_4					
Organic Content, as percentage of soil finer than 2 mm (or 425 µm)	$\frac{m_3 - m_4}{m_3 - m_c} \times 100$	%				
Percentage finer than 2 mm (or 425 µm) in original sample	$\frac{m_2}{m_1} \times 100$	%				

TEST NO.1.17

Crumb Test

Notes

For some soils, a dilute solution of sodium hydroxide is required instead of water. (Dissolve 0.04 g of anhydrous sodium hydroxide in distilled water to make 1 litre of solution).

Objective

The Crumb test is a simple indicator test that is recommended for initial field identification of dispersive soils.

Main Principles

Dispersive clay soils are identified by observing the behaviour of a few crumbs of soil placed in distilled water. The dispersion is classified depending on the degree of muddiness of the water.

References

BS 1377 : Part 5 : 1990.

Required equipment

- a 100 ml glass beaker
- distilled water

Test Procedure

Step 1: Prepare a few crumbs, each about 6 mm to 10 mm diameter, from representative portions of the soil at the natural moisture content.

Step 2: Drop the crumbs in the beaker about one-third full of distilled water.

Step 3: Observe the reaction after allowing to stand for 5 to 10 min.

Observations

Observe the behaviour of the crumbs, and classify in accordance with the following guidelines:

Grade 1: No reaction. Crumbs may slake or run out to form a shallow heap on the bottom of the beaker, but there is no sign of cloudiness caused by colloids in suspension.

Grade 2: Slight reaction. A very slight cloudiness can be seen in the water at the surface of a crumb.

Grade 3: Moderate reaction. There is an easily recognizable cloud of colloids in suspension, usually spreading out in thin streaks at the bottom of the beaker.

Grade 4: Strong reaction. A colloidal cloud covers most of the bottom of the beaker, usually as a thin skin. In extreme cases all the water becomes cloudy.

Grades 1 and 2 represent a non-dispersive reaction, and grades 3 and 4 a dispersive reaction.

Crumb Test

Notes

Report

The test report shall include the following:

a) Type of material and sample identification
b) Reference to this procedure
c) Whether the soil is classified as ***non-dispersive or dispersive,*** and the relevant Grade from the observation guideline above.
d) Details of reagent used, if any

Form for the test

The enclosed form shall be used.

CML
CENTRAL MATERIALS LABORATORY

WORKING SHEET

Crumb Test

Project	**Location**	**Depth**
Client	**Lab.no**	**Date**
Responsible Technician	**Checked**	**Approved**

TEST METHOD CML TEST 1.17, ref. BS 1377 : Part 5 : 1990

Specimen reference	Soil description	Reagent used (if any)	Classification (Grade 1 - 4)	Classification* Non-dispersive/Dispersive

* Grades 1 and 2 represent a **non-dispersive** reaction
* Grades 3 and 4 represent a **dispersive** reaction

TEST NO. 1.18

Determination of the pH value - Electrometric method

Notes

Objective

The method can be used for determining the pH value of a sample of ground water.

Main Principles

This is the procedure for determining the pH value by the electrometric method, which gives a direct reading of the pH value of a soil suspension in water.

References

BS 1377 : Part 3 : 1990.

Required equipment

For the Initial Consumption of Lime (ICL) test, different electrodes are required.

- A balance readable to 0.01 g.
- A pestle and mortar
- Non-corrodible tray
- A 2 mm test sieve with receiver
- A pH meter, fitted with a glass electrode and a calomel reference electrode covering the range pH 3.0 to pH 10.0 readable to 0.05 pH units.
- 3 nos. 100 ml glass or plastic beakers with cover glasses and stirring rods
- 2 nos. 500 ml volumetric flasks
- A wash bottle containing distilled water

Reagents

Buffer solution pH 4.00. Dissolve 5.11 g of potassium hydrogen phthalate in distilled water and dilute to 500 ml, using a volumetric flask.

Buffer solution pH 9.20. Dissolve 9.54 g of sodium tetraborate (borax) in distilled water and dilute to 500 ml, using a volumetric flask.

Potassium chloride. Prepare a saturated solution and use to maintain the calomel electrode of the pH meter in accordance with the manufacturer’s instructions.

Sample preparation

Step 1: Allow the initial soil sample to air-dry or sun-dry by spreading out on a tray.

Use an appropriate guard sieve.

Step 2: Sieve the sample on a 2 mm test sieve and crush retained particles other than stones to pass the sieve.

Step 3: Reject the stones, ensuring that no finer material adheres to them, e.g. by brushing. Throughout these and subsequent operations, ensure that there is no loss of fines.

TEST NO. 1.18

Determination of the pH value - Electrometric method

Notes

Step 4: Reduce the material passing the 2 mm test sieve by successive riffling through a 15 mm divider to produce a representative test sample of 30 g to 35 g.

Test Procedure – Electrometric method of pH determination

Step 1: Weigh out 30 ± 0.1 g from the sample and place in a 100 ml beaker.

The pH value of a soil suspension varies with the ratio of soil to water. An increase in water will bring the pH closer to 7 (neutral).

Step 2: Add 75 ml of distilled water to the beaker, stir the suspension for a few minutes, cover with a cover glass and allow to stand for at least 8 h.

Step 3: Stir the suspension again immediately before testing.

Step 4: Calibrate the pH meter by using standard buffer solutions, following the procedure recommended by the manufacturer.

The pH readings of the suspension should reach a constant value in about 1 min after immersion. No readings should be taken until the pH meter has reached equilibrium.

Step 5: Wash the electrode with distilled water and immerse in the soil suspension. Take two or more readings of the pH of the suspension with brief stirring between each reading. These readings shall agree to within 0.05 pH units before being accepted.

Step 6: Remove the electrodes from the suspension and wash them with distilled water. Re-check the calibration of the pH meter against one of the standard buffer solutions.

When not in use, leave the electrode standing in a beaker of distilled water .

Step 7: If the instrument is out of adjustment by more than 0.05 pH units, set it to the correct adjustment and repeat Steps 5 and 6 until consistent readings are obtained.

Report

A minimum of two specimens of the same sample should be tested in order to obtain a mean value and an indication of the reliability of the results.

The test report shall include the following:

a) Type of material and sample identification
b) Reference to this procedure
c) The ***pH value*** of the soil suspension to the nearest 0.1 pH unit. Both individual test results and mean values shall be reported.

Practical Considerations

pH meter electrodes are extremely fragile, and great care should therefore be taken with their use.

TEST NO. 1.19

Preparation of Stabilized Samples for UCS

Notes

Objective

This is a procedure for the making of specimens for the determination of the Unconfined Compressive Strength (UCS) of stabilised soils, gravels and sands.

References

TMH1 - 1986 : A14 and (BS 1924 : Part 2 : 1990).

Required equipment

- CBR compaction mould, split type, 152.4 mm in diameter and 152.4 mm high with a detachable collar and base plate and a 25.4 mm thick spacer plate fixed to the base plate.
- A metal rammer having a 50 mm diameter circular face and weighing 4.5 kg. The rammer shall be equipped with an arrangement for controlling the height of drop to 450 mm.
- A balance readable to 5 g.
- A palette knife or spatula
- A straightedge, e.g. a steel strip
- A 20 mm and a 37.5 mm test sieves and receiver
- A large metal tray
- Suitable tools for extracting specimen from mould
- Apparatus for moisture content determination
- Galvanized iron mixing baths 450 x 650 x 200 mm deep (at least 3).
- Suitable carrier plates to hold specimens.
- Airtight containers with lids, about 20 litres in capacity (at least 4).

Sample preparation

Prepare an adequate quantity (approximately 150 kg) of the air-dried material passing the 20 mm test sieve. Break up lumps of fine material by rolling on a flat surface to pass the 20 mm test sieve and add to the portion passing the sieve. Mix the material thoroughly and quarter out a specimen of about 35 kg. This is in turn divided into 5 equal parts of about 7 kg each.

These 5 specimens shall be used in the determination of the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) of stabilized material, ref. CML Test 1.20.

Determination of moisture content

Step 1: Take two representative samples of between 500 g and 1000 g each of the remaining material.

Step 2: Place them in suitable containers to determine the moisture content.

Step 3: Weigh the samples immediately to the nearest 0.1 g.

Step 4: Dry the samples in an oven at 105 ^{o}C to 110 ^{o}C to constant mass.

Transfer the remaining material to the airtight tins.

Preparation of Stabilized Samples for UCS

Notes

Making specimens for the determination of compressive strength

Step 1: Using the remaining air-dry material in the air-tight tins, divide out three similar lots of material of approximately 21 kg (oven-dry weight) each. Calculate the mass of air-dry material required for each lot by taking into account the moisture content of the air-dry material as determined on the samples above.

2 % means 2 parts stabilizer to 100 parts oven-dry raw materia by weight.

Step 2: Select three different stabilizer contents at which the specimens for compressive strength determination are to be made. These are usually in increments of 2 %, e.g. 2 %, 4 % and 6 % by mass of oven-dry material.

Step 3: Calculate and weigh out the three quantities of stabilizer required for the above three lots of raw material.

In calculating the required amount of water to be admixed, it is advicable to allow for evaporation by adding 0.3 - 0.5 % depending on weather.

Step 4: Calculate and measure out the required quantity of water to bring each lot to OMC. The quantity of water required is the difference between the quantity of water present in the air-dry material and the quantity of water required to obtain OMC as determined in *CML Test 1.20 "Dry Density - Moisture Content relation for Stabilized Material"*.

Step 5: Mix in the stabilizer and then the water and treat for 4 hours covering the samples with damp cloths (sample bags), and mixing every half hour.

Step 6: Compact three specimens from each of the three lots, altogether 9 specimens with 3 different stabilizer contents. The compaction procedure is outlined in CML Test 1.20, i.e. using a 4.5 kg rammer with a drop of 450 mm, applying 62 evenly distributed blows to each of the 5 equally thick layers.

Step 7: Weigh the moulds with compacted specimens.

With certain materials lacking cohesion it may be necessary to leave the samples in their moulds for 24 hours to develop some strength before the moulds are removed. If this is necessary, the specimens should be covered with damp cloths for 24 hours.

Step 8: Remove the specimens from the moulds by dismantling the split moulds.

Step 9: The specimens are now placed on the carrier plates and are ready for curing, *ref. CML Test 1.21 " Unconfined Compressive Strength of Stabilized Materials".*

Calculations

1. *Moisture Content, w, as a percentage of the dry soil mass to the nearest 0.1%:*

$$w = \left(\frac{m_2 - m_3}{m_3 - m_1}\right) \times 100\ (\%)$$

where

Notes

m_1 is the mass of the container (in g)
m_2 is the mass of the container and wet soil (in g)
m_3 is the mass of the container and dry soil (in g)

2. *Quantity of Stabilizer to be added for specimens*

$$C = \frac{YW}{100}$$

where

C = mass of stabilizer required (g)
Y = percentage of stabilizer required
W = mass of oven-dry material (g)

3. *Quantity of water to be admixed with the material for specimens*

$$V = \frac{Q(P + C)}{100} - (M - P)$$

where

V = volume of water (ml)
Q = optimum moisture content
P = mass of material (oven-dry) to be used (g)
C = mass of stabilizer to be added (g)
M = mass of material (air-dry) (g)

4. *Percentage of stabilizer by volume*

$$v = \frac{100(Am)}{B(100 + A)}$$

where

v = % of stabilizer by volume of the total stabilized material
A = % of stabilizer by mass of the total raw material (as obtainedfrom graph of stabilizer content against strength)
m = maximum dry density (kg/m^3)
B = density of stabilizer (kg/m^3)

5. *Dry density of UCS specimens*

$$D = \left(\frac{W}{d + 100}\right) \text{x} \; \frac{100}{V} \; \text{x} \; 1000$$

where

D = dry density (kg/m^3)
W = mass of wet specimen immediately after compaction (g)
V = volume of mould (cm^3)
d = moulding moisture content expressed as a percentage of the dry stabilized material.

Preparation of Stabilized Samples for UCS

Notes

Report

The test report shall include the following:

a) Type of material and sample identification
b) Reference to this procedure
c) Quantities of stabilizer for UCS specimens
d) Moisture content of UCS specimens
e) Dry Density of UCS specimens

Form for the test

The results shall be compiled as applicable in the form for Test 1.20, “Dry Density -Moisture Content Relation for Stabilized Material” and in form for Test 1.21, “Unconfined Compressive Strength (UCS) of Stabilized Materials”.

TEST NO. 1.20

Dry Density - Moisture Content Relationship for Stabilized Material

Notes

Objective

Compaction of stabilized material is the process by which the solid particles are packed more closely together by mechanical means, thereby increasing the dry density of the material.

This method covers the determination of dry density when a stabilized material is compacted in a specified manner over a range of moisture contents. The range includes the Optimum Moisture Content (OMC) at which the Maximum Dry Density (MDD) for this degree of compaction is obtained.

Main Principles

A 4.5 kg rammer with a 450 mm drop compacting material in a CBR mould in 5 equal layers (Modified Proctor) is used as the compactive effort. The test is used for soil in which all particles pass a 20 mm test sieve. It is also used for coarser soils containing up to 15 % material coarser than 37.5 mm.

References

BS 1924 : Part 2 : 1990 and TMH1 : 1986 : A14

Required equipment

- CBR moulds with internal diameter of 152 mm and internal height of 127 mm. The moulds shall be fitted with a detachable baseplate and a removable extension (collar).
- A metal rammer weighing 4.5 kg. The rammer shall be equipped with an arrangement for controlling the height of drop to 450 mm.
- A balance readable to 5 g.
- Palette knives or spatulas
- A straightedge, e.g. a steel strip
- A 20 mm and a 37.5 mm test sieves and receiver
- Water proof containers and scoop
- A large metal tray
- A garden trowel
- Measuring cylinder 200 ml or 500 ml
- Suitable tools for extracting specimen from mould
- Apparatus for moisture content determination

Sample preparation

Step 1: Prepare 5 representative samples each of about 7 - 8 kg of air-dried material passing the 20 mm test sieve. Break up lumps of fine material by rolling on a flat surface. (Taken from sample prepared in CML Test 1.19 “Preparation of Stabilized Samples”.

Step 2: Weigh out 4 % of stabilizer by mass of the air-dried material for each of the 5 samples. *(The amount of stabilizer required have not been determined at this stage. 4 % is an estimated amount, and the test should be repeated with the required amount of stabilizer if found to be significantly different).*

Dry Density - Moisture Content Relationship for Stabilized Material

Notes

The choice of the range of moisture contents to use is one of trial-and-error and could lead to a large number of test portions being required. One should therefore be prepared to produce a larger number than 5 test portion.

Step 3: Mix each sample thoroughly with the stabilizer and the different required amounts of water to give a suitable range of moisture contents. The range of moisture contents shall be such that the Optimum Moisture Content, at which the Maximum Dry Density occurs, is within the range. *(For non-cohesive sandy and gravelly materials a minimum moisture content of 4 - 6 % would be suitable, with additional increments of 1 - 2 % for each successive test portion tested).*

The stabilizer should be admixed with the raw material immediately before the admixing of water. In order to simulate conditions on the road, compaction of the stabilized material is delayed for about 4 hours after the mixing-in of the stabilizer and water. The moist material is covered by damp cloths, e.g. sample bags. Every half hour it is thoroughly mixed with a trowel.

Compaction procedure

Step 1: The mould with the base plate attached shall be weighed to the nearest 5 g (m_1).

Step 2: Attach the extension collar and place the mould on a solid base, e.g. a concrete floor.

If it is difficult to evaluate the required heights, 3 equal portions could be weighed by assuming a reasonable density. Remember to use the collar even for the first layer, to avoid damaging the edge of the mould.

Step 3: Place a quantity of the first test portion in the mould such that when compacted it occupies a little over 1/5 of the height of the mould body.

Step 4: Apply 62 blows from the rammer dropped from a height of 450 mm to the layer. Distribute the blows uniformly over the surface.

Step 5: Remove rammer and fill next layer of soil in the mould, and repeat the above process 4 more times by applying 62 blows to all layers. The mould should be filled, but surface should not be more than 6 mm proud of the upper edge of the mould body.

Step 6: When all five layers are compacted, remove the extension collar, strike off excess soil and level the surface of the compacted material to the top of the mould using the straight-edge. Replace any coarse particles removed in the levelling process by finer material from the sample well pressed in.

Step 7: Weigh the soil and the mould with baseplate attached to 5 g (m_2).

Sample for moisture content may <u>not</u> be taken before compaction.

Step 8: Remove the compacted sample from the mould. Take a represen tative sample of min. 300 g of the material for determination of its moisture content, ref. CML Test 1.1.

Step 9: Discard the remainder of the sample. (The sample must <u>not</u> be re-used in a later test).

TEST NO. 1.20

Dry Density - Moisture Content Relationship for Stabilized Material

Notes

When the weight of sample in the mould decreases, you may stop the test.

The maximum may lie between two observed points, but when drawing the curve care should be taken not to exaggerate its peak.

Step 10: This whole process shall be carried out for all 5 portions of the sample.

Calculations

1. Calculate the Bulk Density of each compacted specimen from the equation:

   Bulk Density, $\rho = \frac{m_2 - m_1}{V} \times 1000$ (in kg/m³)

   where

   m_1 is the mass of mould and baseplate (in g)
   m_2 is the mass of mould, baseplate and compacted soil (in g)
   V is the volume of the mould (in cm3)
   $V = 2305$ cm^3 for a BS standard CBR mould.

2. Calculate the Dry Density, ρ_d (in kg/m^3), of each compacted specimen from the equation:

   Dry Density, $\rho_d = \frac{100\,\rho}{100 + w}$

   where

   w is the moisture content of the relevant test portion (in %)

3. Plot the Dry Densities, obtained from a series of determinations, as ordinates against the corresponding Moisture Contents as abscissae. Draw a curve of best fit to the plotted points and identify the position of the maximum on this curve. Read off the values of dry density and moisture content, to three significant figures, corresponding to that point.

Report

The test report shall include the following:

a) Type of material and sample identification
b) Reference to this procedure
c) The experimental points and the smooth curve drawn through them showing the relationship between Moisture Content and Dry Density.
d) The Dry Density corresponding to the maximum Dry Density on the curve, reported as the Maximum Dry Density to the nearest whole number (in kg/m3).
e) The corresponding Moisture Content reported as the Optimum Moisture Content to two significant figures (in %).
f) The amount of material (stone) retained on the 20 mm and 37.5 mm sieves reported to nearest 1 % by dry mass.

TEST NO.1.20

Dry Density - Moisture Content Relationship for Stabilized Material

Notes

Form for the test

The enclosed form shall be used.

Practical Considerations

Preferably use a jack to remove the sample from the mould. Do not use a metal hammer/mallet as this will destroy the mould.

It should be emphasized that material must not be re-used in the compaction test by adding more water to the same sample and obtaining the DD/MC curve in such a manner.

Maintenance

The moulds must be kept clean with smooth inside walls.

The rammer must always be free of material sticking to its face. Also the inside of the guide must be checked regularly such that the rammer always falls freely inside the guide.

Precision

For some highly permeable soils such as clean gravels, uniformly graded and coarse clean sands, the results of the laboratory compaction test may provide only a poor guide for specification of field compaction.

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WORKING SHEET

Compaction Test

Project	**Location**	**Depth**
Client	**Lab.no**	**Date**
Responsible Technician	**Checked**	**Approved**

TEST METHOD CML TEST 1.9, ref. BS 1377 : Part 4 : 1990

METHOD:	TEST NO.	1	2	3	4	5	6	7
WEIGHT OF SAMPLE	(g)							
WATER ADDED	(cc)							
WEIGHT OF MOULD + SAMPLE	(g)							
WEIGHT OF MOULD	(g)							
WEIGHT OF SAMPLE	(g)							
WET DENSITY	(kg/m³)							
DRY DENSITY	(kg/m³)							
FACTOR OF MOULD:								
MOISTURE CONTAINER NO.								
WEIGHT OF WET SOIL + CONTAINER	(g)							
WEIGHT OF DRIED SOIL + CONTAINER	(g)							
WEIGHT OF CONTAINER	(g)							
WEIGHT OF WATER	(g)							
WEIGHT OF DRY SOIL	(g)							
MOISTURE CONTENT	(%)							

DRY DENSITY (kg/m³)

MOISTURE CONTENT %

NMC %	OMC %	MDD -Kg/m³

TEST NO. 1.21

Unconfined Compressive Strength (UCS) of Stabilized Materials

Notes

Objective

In this method the Unconfined compressive Strength of stabilized material is determined by subjecting prepared specimens (mixed, compacted and cured) to an increasing load until failure.

Main Principles

The Unconfined Compressive Strength (UCS) of a stabilized material is the load in kN/m^2 (kPa) required to crush a cylindrical specimen 127 mm high and 152.4 mm in diameter to total failure at a rate of application of load of 140 kN/m^2 per second (140 kPa/s).

References

TMH1 - 1986, Method A14

Required equipment

- Suitable plastic bags to hold specimens and carriers in an airtight condition in a water bath as described below.
- A water bath preferably maintaining temperatures of about 25 ^{o}C.
- A compression testing machine capable of applying a rate of loading of 140 kN/m^2 per second (kPa/s) and capable of measuring a load of 200 kN accurately to 1 kN.

Sample preparation

Specimens shall be prepared in split type CBR moulds in accordance with the procedure described in CML test 1.20.

In order to establish the required stabilizer content to produce a mixture conforming to a specified UCS, three specimens are necessary for each stabilizer content.

In the case of samples for field control, one specimen per field sample is sufficient.

Curing of specimens

The actual ambient temperature will determine the curing conditions. However, exposure of the specimens or water bath to direct sunlight must be avoided.

Step 1: The specimens shall be cured for seven days in plastic bags immersed in a water bath at a maintained temperature preferably about 25 ^{o}C.

Step 2: After seven days, remove the specimens from the plastic bags and submerge them in water for 4 hours. The temperature of the water should preferably be about 25 ^{o}C.

Compressive strength determination

Step 1: Remove the specimens from the water.

Step 2: Crush each specimen to total failure in the compression testing machine. The load must be applied to the flat face of the specimen and the rate of application of the load shall be 140 kPa/s. This is equivalent to a rate of 153 kH/min for 152 mm diameter specimens.

Step 3: Record the load to the nearest 1 kN.

TEST NO. 1.21

Unconfined Compressive Strength (UCS) of Stabilized Materials

Notes

Calculations

1. Calculate the Unconfined Compressive Strength to the nearest 10 kN/m^2 (kPa) as follows:

$$\text{UCS} = \frac{(load)kN}{0.01824} \text{ (in kN/m}^2\text{)}$$

Report

The test report shall include the following:

a) Type of material and sample identification
b) Reference to this procedure
c) The amount of stabilizer (in %)
d) The Moisture Content - OMC (in %)
e) The Dry Density - MDD (in kg/m^3)
f) The amount of material retained on the 20 mm and 37.5 mm sieves reported to nearest 1 % by dry mass.
g) The temerature of the curing conditions.
h) The Unconfined Compressive Strength to the nearest 10 kN/m^2 (kPa)

Form for the test

The enclosed form shall be used.

Practical Considerations

To establish the required stabilizer content to produce a mixture conforming to a specified strength, the UCS results should be recorded and a graph of stabilizer content against strength should be plotted. For the graph the average UCS of three specimens of each stabilizer content should be used. However, an obviously incorrect result, due to possible damage to a specimen before testing, should be ignored.

Mixtures of cement, milled blastfurnace slag, lime or other additives usually take longer to reach the same strength as that of ordinary Portland cement. To achieve comparable strengths it is therefore necessary to determine the hardening time that gives equivalent cement strength for each mixture, and to adopt the procedure accordingly. Thus, for example, it has been found that some lime/cement mixtures achieve equivalent strength after eleven days. However, the actual hardening time has to be determined in each case. If a hardening time other than seven days is used, this must be stated on the report sheet.

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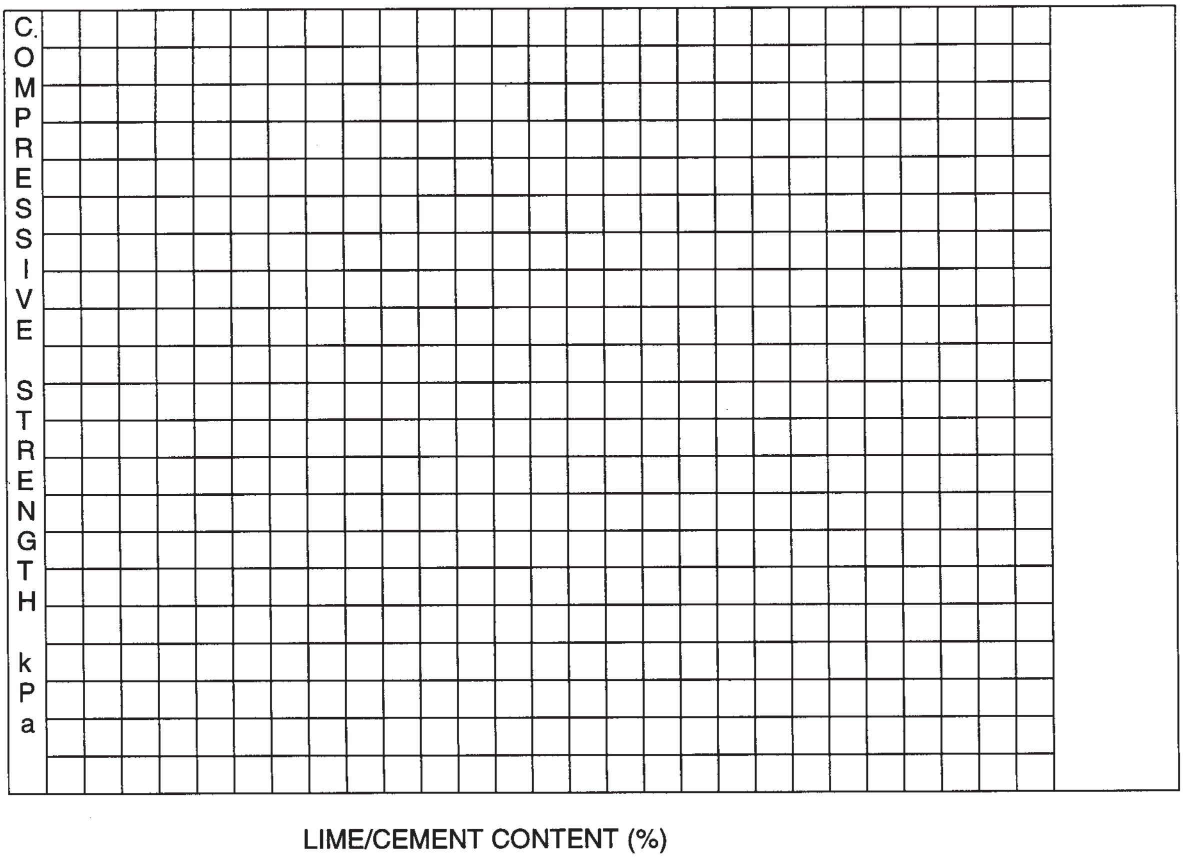
WORKING SHEET

Unconfined Compressive Strength
UCS

Project	**Location**	**Depth**
Client	**Lab.no**	**Date**
Responsible Technician	**Checked**	**Approved**

TEST METHOD CML TESTS 1.21, ref. TMH1 - 1986 - A14

		COMPACTION DATA		SPECIMEN DATA			
Specimen reference	CEMENT/ LIME CONTENT (%)	Maximum Dry Density (kg/m^3)	Optimum Moisture Content (%)	Dry Density (kg/m^3)	Moisture Content (%)	7 Day Compressive Strength	
						Individual (kPa)	Average (kPa)



THE UNITED REPUBLIC
OF TANZANIA
MINISTRY OF WORKS

SUMMARY SHEET

Stabilized Materials

CML
CENTRAL MATERIALS LABORATORY

Project	**Date**	**Date**
Client	**Checked**	**Approved**

Location									
Lab. no									
Depth									
Before Stabilization									
Soil Classification	BSSC								
Grading	d_{max} mm								
	37,5 mm								
	20 mm								
	10 mm								
	5 mm								
	2 mm								
	425 µm								
	75 µm								
Grading Modulus	GM								
Organic Content	%								
Atterberg Limits	LL (%)								
	PL (%)								
	PI (%)								
	LS (%)								
Compaction	MDD (kg/m^3)								
	OMC (%)								
CBR_{soaked} (%)	at 95% of MDD BS-Heavy								
	Swell (%)								
Aggregate Strength - TVF_{dry}	kN								
Initial Consumption of Lime - ICL	%								
After Stabilization									
Stabilizer Content Cement/Lime	%								
Atterberg Limits	LL (%)								
	PL (%)								
	PI (%)								
	LS (%)								
UCS	MPa								
Material Class	CM-C1-C2-C3								
Field Density	FDD (kg/m^3)								
	FMC (%)								

TEST NO.1.22

Initial Consumption of Lime (ICL)

Notes

The method does not dispense with the need to establish necessary lime content to achieve design strength or required reduction in plasticity, but rather gives the lowest threshold value to achieve a permanent stabilizing effect. Until further, the method is used also when cement is the intended stabilizer for the material, awaiting test methods to be developed for the initial consumption of cement.

Objective

The Initial Consumption of Lime (ICL) is the amount of lime consumed in the initial ion exchange reaction, and is the required minimum content to achieve a permanent gain in strength of the material.

Main Principles

A saturated solution of lime (calcium hydroxide) in distilled water completely free of carbon dioxide has a pH value of 12.40 at 25 °C. This pH is required to maintain reaction between the lime and any reactive components in the material to be stabilized. Samples of the material are therefore mixed with water and different proportions of the lime being used, and the minimum amount of lime needed to give a pH of 12.40 is expressed as the ICL of the material.

References

BS 1924 : Part 2 : 1990.

It is essential to use electrodes that are suitable for highly alkaline solutions.

Required equipment

- A pH meter, fitted with a suitable glass electrode system for use up to pH values of 13.0 readable to 0.05 pH unit.
- A balance, of 250 g minimum capacity readable to 0.01 g.
- A drying oven capable of maintaining a temperature of 105 ± 5 °C.
- 6 nos. of glass or plastic bottles of 250 ml capacity fitted with watertight stoppers
- A 425 µm test sieve
- A thermometer with range 15 °C to 25 °C readable to 0.5 °C
- 2 nos. airtight containers for storing lime (e.g. 1 l preserving jars)
- A 100 ml measuring cylinder
- A wash bottle
- A beaker of 50 ml to 100 ml capacity
- Soft paper tissue

The buffer solution should not be kept for more than 7 days.

Reagents

Buffer solution pH 4.00. Dissolve 2.55 g of potassium hydrogen phthalate in distilled water and dilute to 350 ml, using a volumetric flask.

Buffer solution pH 9.20. Dissolve 4.99 g of disodium tetraborate (borax) in distilled water and dilute to 250 ml, using a volumetric flask.

Potassium chloride. Prepare a saturated solution and use to maintain the calomel electrode of the pH meter in accordance with the manufacturer's instructions.

Dilute hydrochloric acid. Dilute 100 ml of the concentrated acid to 500 ml with distilled water.

Distilled water, free of CO_2. Gently boil the required quantity of distilled water for one hour and allow to cool to room temperature without access to air before use. Use this water within 24 hours.

Notes

Calcium hydroxide of laboratory grade. Store in airtight container.

Lime, for the stabilization work. Store in airtight container.

Determination of the suitability of the lime

Prepare a saturated solution of the lime to be used by placing 5 g of lime in one of the bottles. Add 100 ml of CO_2-free distilled water. Shake the bottle for 30 s every 10 min. for the first hour and then every hour for 4 hours. Leave the suspension in the tightly stoppered bottle for 24 h before use. Pour the suspension into a beaker and determine its pH to the nearest 0.05 pH unit, and record its temperature to the nearest 0.5 °C.

Calculate the pH value of the solution at 25 °C (pH_{25}) from the equation:

$$pH_{25} = pH_T + 0.03\,(T - 25) \qquad \text{where}$$

pH_T is the pH at the measured temperature T °C.

If the pH value at 25 °C is in the range 12.35 to 12.45 the lime is suitable for use. If it is not, the quality of the lime for the purpose of lime-stabilization is suspect, and the results of any ICL test carried out with it are meaningless.

However, a soil's potential for lime-stabilization may be determined by carrying out the ICL test with Calcium Hydroxide of laboratory grade.

Sample preparation

It is assumed in this test that the lime-reactive fraction of the material is concentrated in the fraction finer than 425 mm in particle size.

Reduce the laboratory sample to produce a test portion which after being dried at 105 ± 5 °C and sieved on a 425 µm test sieve has a mass of about 200 g.

Test Procedure

Step 1: Take the dried and sieved portion and subdivide it into two representative halves, each weighing about 100 g. Take one of these to provide 5 test specimens each with a mass of about 20 g weighed to the nearest 0.1 g.

The proportions chosen will ensure that in most cases the percentage of lime required will be included in the first trial.

Step 2: Place each test specimen into each of the 5 bottles and weigh out to the nearest 0.01 g the lime to be used in the test in the proportions 2.0 %, 3.0 %, 4.0 %, 5.0 % and 6.0 %. Add the lime to the bottles to mix the lime with the dry material.

Step 3: Add 100 ± 2 ml of CO_2 – free distilled water to each bottle. Shake the bottle and contents until there is no evidence of dry material on the bottom.

Step 4: Shake the bottles for 30 s every 10 min. for 1 hour. After 1 hour ± 5 min. determine the pH values of the suspensions. Wash the electrodes in distilled water, and dry them, between each insertion.

Initial Consumption of Lime (ICL)

Notes

Step 5: If none of the suspensions reaches a pH value above 12.30 (corrected to 25 °C), but this value is obtained for the 2 % lime content, carry out additional tests with lower values of lime addition.

If the pH values go up to 12.40, but this value is not reached until 5 or 6 % lime content, additional tests with higher values of lime addition might be considered.

An assessment should be made whether or not it will be economic to add lime in proportions higher than 6 %.

If a pH value of 12.4 is achieved with as little as 3 % lime content, repeat the test using additional lime contents of 0.5 %, 1.0 %, 1.5 % and 2.5 %.

Calculations

1. Plot the percentage of lime added to the material against the pH (corrected to 25 °C) and read off, by interpolation, the proportion of lime required to give pH values of 12.30 to 12.40.
2. If the pH readings go to 12.40, record to the nearest 0.1 % the lowest percentage of lime that gives this value as the ICL of the material.
3. If the pH readings do not go beyond 12.30, but this value is obtained from 2 % lime content (or less), record to the nearest 0.1 % the lowest percentage of lime that gives this value as the ICL of the material.

When using the ICL values in further work, remember that the values refer only to the fraction of material finer than 425 mm in particle size, and make due allowance for this.

If quicklime is to be used in the field, then the hydrated lime percentage obtained should be multiplied by 0.75 to give the quicklime equivalent.

Report

The test report shall include the following:

a) Type of material and sample identification
b) Reference to this procedure
c) Details of the lime used for the test
d) The graph showing the relationship between pH and lime content
e) The ***ICL value*** to the nearest 0.1 % in those cases where it can be derived
f) The proportion of the material passing the 425 µm test sieve.

Laboratory tests for establishing the relation between lime content and strength or plasticity on full samples are the natural continuation of the ICL test.

Test form

The enclosed form “Initial consumption of lime” shall be used.

Practical Considerations

pH meter electrodes are extremely fragile and great care should therefore be taken with their use.

Notes

If the instrument is out of adjustment by more than 0.05 unit, the results shall be discarded and the test repeated

APPENDIX to test 1.22 Initial Consumption of Lime

Calibration and use of the pH meter

The pH-system should be checked before first use and every time a new electrode is used. But once it has been found to be suitable, no further test with calcium hydroxide need to be made.

Step 1: Calibrate the pH meter with the standard buffer solutions following the manufacturer's recommended procedure. Check the calibration with the standard pH 9.2 buffer solution a few minutes before and after each set of determinations.

Step 2: When using pH meters not fitted with automatic temperature compensation, adjust the instrument correctly according to the temperatures of the solutions before taking a reading. Before insertion into any solution, wash the electrodes with distilled water and clean with soft paper tissue. Also wash electrodes with distilled water immediately after removal from any solution. When not in use, keep the electrodes in distilled water.

Step 3: Prepare a saturated solution of the calcium hydroxide by placing 5 g of calcium hydroxide in one of the bottles. Add 100 ml of CO_2-free distilled water. Shake the bottle for 30 s every 10 min. for the first hour and then every hour for 4 hours. Leave the suspension in the tightly stoppered bottle for 24 h before use. Pour the suspension into a beaker and determine its pH to the nearest 0.05 pH unit, and record its temperature to the nearest 0.5 °C.

Step 4: Calculate the pH value of the solution at 25 °C (pH_{25}) from the equation:

$$pH_{25} = pH_T + 0.03\,(T - 25) \qquad \text{where}$$

pH_T is the pH at the measured temperature T °C.

Step 5: If the pH value at 25 °C is in the range 12.35 to 12.45 the pH meter and electrode system is suitable for the test. If not, check that the lime is of good quality grade before investigating any possible defects in the pH meter and/or electrodes.

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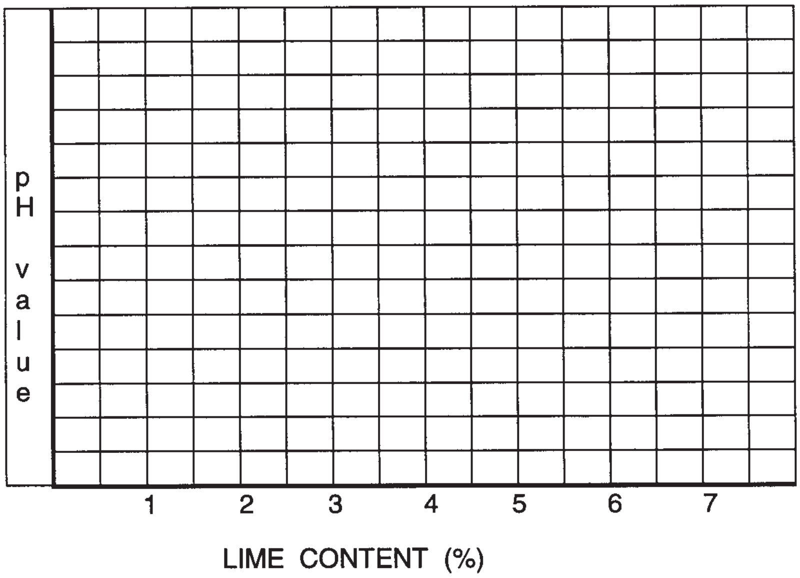
WORKING SHEET

Initial Consumption of Lime (ICL)

Project	**Location**	**Depth**
Client	**Lab.no**	**Date**
Responsible Technician	**Checked**	**Approved**

TEST METHOD	CML TEST 1.22, ref. BS 1924 : Part 2 : 1990		
		Calcium hydroxide	Lime used in test
pH of saturated solution			
Temperature	°C		
pH corrected to 25 °C			

Lime content	%									
pH value of suspension										
Temperature	°C									
pH corrected to 25 °C										



Proportion of material < 425 µm	%
Initial consumption of Lime (ICL)	%

THE UNITED REPUBLIC
OF TANZANIA
MINISTRY OF WORKS

SUMMARY SHEET (I)

SOIL TESTS

CML
CENTRAL MATERIALS LABORATORY

Project	**Date**	**Date**
Client	**Checked**	**Approved**

Location									
Lab. no									
Depth									
Grading	75 mm								
	63 mm								
	50 mm								
	37,5 mm								
	20 mm								
	10 mm								
	5 mm								
	2 mm								
	1,18 mm								
	600 µm								
	425 µm								
	212 µm								
	150 µm								
	75 µm								
Atterberg Limits	LL (%)								
	PL (%)								
	PI (%)								
	LS (%)								
Moisture Content	%								
Particle Density	kg/m^3								
Bulk Density	kg/m^3								
Soil Classification	BSCS								
Compaction BS Light / Heavy	MDD (kg/m^3)								
	OMC (%)								
Field Density	FDD (kg/m^3)								
	FMC (%)								
CBR (%) unsoaked	95% heavy DD								
	98% heavy DD								
CBR (%) (4 days soaked)	100% light DD								
	Swell %								
	95% heavy DD								
	100% heavy DD								
	Swell (%)								

THE UNITED REPUBLIC
OF TANZANIA
MINISTRY OF WORKS

SUMMARY SHEET (II)

SOIL TESTS

CML
CENTRAL MATERIALS LABORATORY

Project	**Date**	**Date**
Client	**Checked**	**Approved**

Location									
Lab. no									
Depth									
Grading Modulus	GM								
Grading Coefficient	GC								
Shrinkage Product	SP								
Organic Content	%								
Soluble Salts									
Triaxial test results Shear strength parameters	c (kN/m^2)								
	φ (°)								
	c_u (kN/m^2)								

Test on Aggregates and Concrete

Tests on Aggregates and Concrete		
2.1	Moisture Content of Aggregates	BS812:Part 109:1990
2.2	Relative Density and Water Absorption	BS812:Part 2:1975
2.3	Sieve Tests on Aggregates	BS812:Part 103.1:1985
2.4	Flakiness Index (FI) and Average Least Dimension (ALD)	BS812:Section 105.1:1989
2.5	Elongation Index	BS812:Section 105.2:1990
2.6	Aggregate Crushing Value (ACV)	BS812:Part 110:1990
2.7	Ten Percent Fines Value (TFV)	BS812:Part 111:1990
2.8	Aggregate Impact Value (AIV)	BS812:Part 112:1990
2.9	Los Angeles Abrasion Test (LAA)	ASTM C535-89
2.10	Sodium Soundness Test (SSS)	ASTM C88-90
2.11	Slump Test	BS1881:Part 102:1983
2.12	Making of Concrete Test Cubes	BS1881:Part 108:1983
2.13	Concrete Cube Strength	BS1881:Part 116:1983

TEST NO. 2.1

Moisture Content of Aggregates

Notes

Objective

To determine the amount of total water present in a sample of aggregate expressed as a percentage of the dry mass. This is termed the moisture content of the aggregate.

Main Principles

The oven-drying method provides a measure of the total water present in a sample of aggregate and is the definitive procedure, and is regarded as standard laboratory practice.

References

BS 812 : Part 109 : 1990.

Required equipment

- a drying oven with temperature of 105 ± 5°C
- a balance readable to 0.5 g
- a metal container
- a scoop
- a riffle box

Some loss of water by evaporation is inevitable during sampling and sample reduction. Precautions should be taken to minimize evaporation losses by carrying out all operations as quickly as possible and by adequate storing of the samples.

Sample Preparation

Reduce the laboratory sample to produce a test portion complying with Table 1 below appropriate to the nominal size of the aggregate.

Nominal size of aggregate mm	Minimum mass of test portion kg
63	15
50	10
40 to 20	5
20 to 10	2
10 to 5	1
less than 5	0.5

Table 1.Minimum mass of test portion for moisture content determination

The actual drying time necessary will depend on the amount of fines in the aggregate, but 12 hours will normally be adequate.
*For **calcrete** and **coral rock** materials the drying temperature shall be limited to 60 °C.*

Test Procedure

Step 1: Clean and dry the container, then weigh it to the nearest 0.1 g (m_1)
Step 2: Place the sample in the container using the scoop and weigh the whole (m_2).
Step 3: Place container with the test portion in the oven to dry at 105 °C for minimum 12 hours.
Step 4: After drying, weigh the container and the contents (m_3)

Calculations

Calculate the Moisture Content of the aggregate, w, as a percentage of the dry soil mass to the nearest 0.1%, from the equation:

Moisture Content of Aggregates

Notes

$$w = \frac{m_2 - m_3}{m_3 - m_1} \times 100\ (\%)$$

where

m_1 is the mass of the container (in g)
m_2 is the mass of the container and wet test portion (in g)
m_3 is the mass of the container and dry test portion (in g)

Report

The test report shall include the following:

a) Type of material and sample identification
b) Reference to this procedure
c) Test results, individual values and average value
d) The final moisture content (*w*) is reported to the nearest 0.1 %.

Form for the test

The enclosed form shall be used.

Practical Considerations

One may control that the material is completely dry by holding a beaker with cold water directly above the sample. If the sample is not dry, moisture will condense on the outside of the glass.

Maintenance

The balance and the drying oven shall be checked and calibrated regularly (every month) with respect to weight and temperature.

It is important that the containers are kept clean and dry.

WORKING SHEET

Moisture Content
of Aggregates

Project	**Location**	**Depth**
Client	**Lab.no**	**Date**
Responsible Technician	**Checked**	**Approved**

TEST METHOD CML TEST 2.1, ref. BS 812 : Part 109 : 1990

Specimen reference								
Container no.								
Mass of wet test portion + container (m_2)	g							
Mass of dry test portion + container (m_3)	g							
Mass of container (m_1)	g							
Mass of moisture ($m_2 - m_3$)	g							
Mass of dry test portion ($m_3 - m_1$)	g							
Moisture Content $w = \left(\frac{m_2 - m_3}{m_3 - m_1}\right) 100$	%							

TEST NO. 2.2

Relative Density and Water Absorption of Aggregates

Notes

Objective

This procedure specifies two methods for the determination of the relative density and water absorption of aggregates. The methods are used for aggregates intended for road construction or concrete mixes.

Relative density on a saturated surface-dry basis, ρ_s, are used for pavement materials to be tested for mechanical properties and for calculations in concrete mix design.

Water absorption, w_{abs}, is used for calculations in concrete mix design.

Apparent relative density, ρ_a, may be used in production control to check if the density of the aggregate varies.

Main Principles

For methods for aggregates of 10 mm nominal size and smaller and for fillers, reference is made to BS 812 : Part 2 : 1975.

The preferred method described is a glass vessel method for aggregates between 5 mm and 40 mm size.
A subsidiary wire basket method for aggregates larger than 10 mm is also described.

References

BS 812 : Part 2 : 1975.

Method for aggregates between 5 mm and 40 mm

Preferred method

Required equipment

- A drying oven with temperature of 105 ± 5°C
- A balance readable to 0.5 g
- A wide mouthed glass vessel of 1.0 litres to 1.5 litres capacity, with A flat ground lip and a plane ground glass disc to cover it giving a watertight fit.
- Two dry soft absorbent cloths
- A shallow tray
- An airtight container large enough to take the sample
- A 5 mm test sieve
- Water free of impurities (e.g. dissolved air). Freshly boiled tap water cooled to room temperature may be used.

Sample Preparation

Aggregates which have been artificially heated shall not normally be used.

A sample of about 1 kg of the aggregate shall be used. The sample shall be thoroughly washed on the 5 mm test sieve to remove finer particles, e.g. clay, silt and dust and drained.

Two tests shall be made.

Relative Density and Water Absorption of Aggregates

Notes

The difference in the temperature of the water used for the first and second weighing shall not exceed 2°C.

Test Procedure

Step 1: Immerse the test sample in water in the glass vessel/jar for 24 ± 0,5 hours. The vessel shall be gently agitated to remove entrapped air. This may be achieved by rapid clockwise and anticlockwise rotation of the vessel between the operator's hands.

Overfill the vessel by adding water and slide the plane ground glass disc over the mouth so as to ensure that no air is trapped in the vessel. Then dry the vessel and weigh it (mass *B*).

Step 2: Empty the vessel and allow the aggregate to drain while the vessel is refilled with water, sliding the glass disc into position as in Step 1. Then dry the vessel and weigh it (mass *C*).

Step 3: Place the aggregate on a dry cloth and gently surface-dry it with the cloth.

Step 4: Spread the aggregates out not more than one stone deep on the second dry cloth and leave it exposed to air away from direct sunlight until all visible films of water are removed, but the aggregate still have a damp appearance. Then weigh the aggregates (mass *A*).

Step 5: Place the aggregates in the shallow tray in the oven to dry at 105°C for 24 ± 0,5 hours.

Step 6: Cool the sample in the airtight container and weigh it (mass *D*).

Calculations

1. Relative Density on an oven-dry basis (in ton/m^3) :

$$\rho_d = \frac{D}{A - (B - C)}$$

2. Relative Density on a saturated and surface-dry basis (in ton/m^3):

$$\rho_s = \frac{A}{A - (B - C)}$$

3. Apparent Relative Density (in ton/m^3):

$$\rho_a = \frac{D}{D - (B - C)}$$

4. Water absorption (in % of dry mass):

$$w_{abs} = \frac{100\,(A - D)}{D}$$

where

A is the mass of the saturated surface-dry aggregate in air (in g)
B is the mass of vessel containing sample and filled with water (in g)
C is the mass of vessel filled with water only (in g)
D is the mass of the oven-dry aggregate in air (in g)

Relative Density and Water Absorption of Aggregates

Notes

Method for aggregates all larger than 10 mm

Subsidiary method

Required equipment

- A drying oven with temperature of 105 ± 5°C
- A balance readable to 0.5 g, and of a type to permit the basket containing the sample to be suspended from the beam and weighed in water.
- A wire mesh basket having apertures not larger than 6.5 mm, with wire hangers suspending it from the balance.
- A watertight container in which the basket may be freely suspended
- Two dry soft absorbent cloths
- A shallow tray
- An airtight container large enough to take the sample
- A 10 mm test sieve
- Water free of impurities (e.g. dissolved air). Freshly boiled tap water cooled to room temperature may be used.

Sample Preparation

A sample of about 2 - 2.5 kg of the aggregate shall be used. The sample shall be thoroughly washed on the 10 mm test sieve to remove finer particles, e.g. clay, silt and dust and drained.

Two tests shall be made.

Test Procedure

Step 1: Place the sample in the wire basket and immerse it in water for 24 ± 0,5 hours. The water level shall be minimum 5 cm above the top of the basket. Remove the entrapped air from the sample by lifting the basket slightly up and down under water with gentle agitation to remove entrapped air.

Step 2: Weigh the basket with the sample in water. If it is necessary to transfer them to a different tank for weighing, remove any entrapped air as described in Step 1 before weighing (mass B).

Step 3: Remove the basket and sample from the water and allow them to drain for a couple of minutes.

Step 4: Empty the aggregate on a dry cloth, and return the empty basket to the water. Jolt it to remove entrapped air and weigh it in water (mass C).

Step 5: Gently surface-dry the aggregate placed on the dry cloth.

Step 6: Spread the aggregates out not more than one stone deep on the second dry cloth and leave it exposed to air away from direct sunlight until all visible films of water are removed, but the aggregate still have a damp appearance. Then weigh the aggregates (mass A).

Notes

Step 7: Place the aggregates in the shallow tray in the oven to dry at 105 °C for 24 ± 0,5 hours.

Step 8: Cool the sample in the airtight container and weigh it (mass *D*).

Calculations

1. Relative Density on an oven-dry basis (in ton/m^3) :

$$\rho_d = \frac{D}{A - (B - C)}$$

2. Relative Density on a saturated and surface-dry basis (in ton/m^3):

$$\rho_s = \frac{A}{A - (B - C)}$$

3. Apparent Relative Density (in ton/m^3):

$$\rho_a = \frac{D}{D - (B - C)}$$

4. Water absorption (in % of dry mass):

$$w_{abs} = \frac{100\,(A - D)}{D}$$

where

A is the mass of the saturated surface-dry aggregate in air (in g)
B is the apparent mass in water of the basket + the sample of saturated aggregate (in g)
C is the apparent mass in water of the empty basket (in g)
D is the mass of the oven-dry aggregate in air (in g)

Report

The test report shall include the following:

a) Type of material and sample identification
b) Reference to this procedure and the method used
c) The title of each form of Relative Density determined shall be quoted
d) The mean values of Relative Density is reported to the nearest 0.01 ton/m^3
e) The mean value of Water Absorption is reported to the nearest 0.1 %.

Form for the test

The enclosed form shall be used.

Practical Considerations

As with any porous material, the value obtained for the relative density of an aggregate depends on the details of the method of test. Furthermore, different sizes of the same aggregate often have different values of relative

Relative Density and Water Absorption of Aggregates

Notes

density and water absorption. Therefore, when comparing different aggregates it is essential that the test is made on samples sensibly of the same grading.

Air bubbles in the sample or in the water may lead to significant errors when the volume of the sample shall be determined.

For any material the following relationship is valid: $\rho_a > \rho_s > \rho_d$

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WORKING SHEET

Relative Density and Water Absorption

Project	**Location**	**Depth**
Client	**Lab.no**	**Date**
Responsible Technician	**Checked**	**Approved**

TEST METHOD CML TEST 2.2, ref. BS 812 : Part 2 : 1975

Specimen reference			A	B	Mean
Mass of saturated surface-dry aggregate in air	*A*	g			
Mass of vessel + sample filled with water	*B*	g			
Mass of vessel filled with water only	*C*	g			
Mass of oven-dry aggregate in air	*D*	g			
Relative density on an oven-dry basis	$\rho_d = \frac{D}{A-(B-C)}$	t/m^3			
Relative density on a saturated and surface-dry basis	$\rho_s = \frac{A}{A-(B-C)}$	t/m^3			
Apparent relative density	$\rho_a = \frac{D}{D-(B-C)}$	t/m^3			
Water Absorption	$w_{abs} = (\frac{A-D}{D})\ 100$	%			

Specimen reference			A	B	Mean
Mass of saturated surface dry aggregate in air	*A*	g			
Mass of basket + sample in water	*B*	g			
Mass of empty basket in water	*C*	g			
Mass of oven-dry aggregate in air	*D*	g			
Relative density on an oven-dry basis	$\rho_d = \frac{D}{A-(B-C)}$	t/m^3			
Relative density on a saturated and surface-dry basis	$\rho_s = \frac{A}{A-(B-C)}$	t/m^3			
Apparent relative density	$\rho_a = \frac{D}{D-(B-C)}$	t/m^3			
Water Absorption	$w_{abs} = (\frac{A-D}{D})\ 100$	%			

TEST NO. 2.3

Sieve Tests on Aggregates

Notes

Objective

The particle size distribution of samples of aggregates and fillers are determined by sieving.

Main Principles

For coarse and fine aggregates free from particles which cause agglomeration, ***Dry Sieving*** may be performed.

For aggregates which may contain clay or other materials likely to cause agglomeration, preliminary separation by washing through a fine sieve is required before dry sieving, ie. ***Washing and Sieving.***

References

BS 812 : Part 103.1 : 1985.

Required equipment

All these sieves should not be used at the same time. Make an appropriate selection fitting to the material to be tested.

- Test sieves with diameter 450 mm or 300 mm : 75 mm, 63 mm, 50 mm, 37.5 mm, 28 mm, 20 mm, 14 mm, 10 mm, 6.3 mm, 5 mm,
  Test sieves with diameter 300 mm or 200 mm: 3.35 mm, 2.36 mm, 1.70 mm, 1.18 mm, 825 μm, 600 μm, 425 μm, 300 μm, 212 μm, 150 μm, 75 μm.
- Lids and receivers.
- A balance readable and accurate to 0.5 g.
- Riffle boxes.
- A drying oven capable of maintaining a temperature of 105 °C ± 5 °C.
- Metal containers.
- Metal trays.
- Scoop.
- Sieve brushes.
- Mechanical sieve shaker (optional).

Sample preparation

Step 1: Reduce the sample to produce a test portion complying with Table 1 below appropriate to the maximum size of the material.

Step 2: Dry the test portion by heating at a temperature of 105 °C ± 5 °C for minimum 12 hours. Allow to cool, weigh and record as M_1.

DRY SIEVING METHOD - Test procedure

Step 1: Assemble appropriate sieves with a receiver at the bottom in increasing aperture size from bottom to top. Place the oven dried sample on top of the coarsest sieve and cover with a lid.

Step 2: Either by hand or using the mechanical sieve shaker, shake the sieves for a sufficient time to separate the sample into the different size fractions.

Sieve Tests on Aggregates

Notes

Maximum particle size mm	Minimum mass of test portion kg
63	20
50	15
0	10
28	5
20	2
14	1
10	0.5
5	0.2
3	0.2
< 3	0.1

Table 2. Minimum mass of test portion for sieve analysis

*2 minutes per sieve is considered appropriate.
Do not force material material through the mesh by hand pressure.
Light brushing may be used on the 150 µm and 75 µm sieves.*

Step 3: When the mechanical shaker is used, check that separation is complete by briefly hand sieving.

When sieving is done by hand alone, start with the coarsest sieve and shake each sieve over a clean tray or receiver until no more material passes.

If the sieves are blinded by overloading, an intermediate sieve may be introduced.

Step 4: Weigh the material retained on each sieve, together with any material cleaned/picked from the mesh, on completion of sieving on that sieve.

WASHING and SIEVING METHOD - Test procedure

Step 1: Wet both sides of a 75 µm test sieve, reserved for use in this type of test only, and fit a guard sieve 1.18 mm or 2.36 mm on top.

Step 2: Place the weighed oven dried sample (M_1) in a container and add sufficient water to half fill the container. Agitate the contents so that the fines are completely separated from coarser particles.

Step 3: Pour the suspension of fine solids on to the guarded 75 µm test sieve. Continue washing the coarse residue until the water passing the test sieve is clear.

Step 4: Wash all residues from the container and sieves into the tray. Remove excess free water by careful decantation through the 75 µm sieve, and dry the total residue in the oven 105 °C ± 5 °C for minimum 12 hours. Allow to cool, weigh and record as M_2.

Step 5: Determine the mass of material passing the 75 µm sieve as: $M_1 - M_2$.

Step 6: Continue with dry sieving as outlined in the chapter above, steps 1 – 4.

Sieve Tests on Aggregates

Notes

Calculations

1. Calculate the mass retained on each sieve as a percentage of the original dry mass (M_1). For the mass of material passing the finest sieve, add that passing during washing ($M_1 - M_2$) to that found during the dry sieving.

   For example:
   Percentage retained on 10 mm sieve

   $$= M_{(10\ mm)} \left(\frac{100}{M_1} \right)$$

2. Calculate the mass of the sample passing each sieve as a cumulative percentage, from the general relationship:

   (% passing this sieve) = (%passing previous sieve) – (% retained on this sieve).

3. Plot the grading as a curve on a semi-logarithmic chart.

Report

The test report shall include the following information:

a) Type of material and sample identification
b) Reference to this procedure
c) The particle size distribution curve

Form for the test

The enclosed form shall be used.

Practical considerations

Take care to ensure that sieving is complete, the minimum period of mechanical shaking should be 10 min.

Never put a sieve in the drying oven for drying the material, as this will destroy the sieve.

Maintenance

Test sieves should be inspected for defects before each use. A more detailed examination should be made at reqular intervals to discover signs of wear, warping, tears, splits holes, blockages and any other defects in the mesh.

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WORKING SHEET

Sieve Analysis
Dry Sieving

Project	**Location**	**Depth**
Client	**Lab.no**	**Date**
Responsible Technician	**Checked**	**Approved**

TEST METHOD	CML TEST 2.3, ref. BS 812 : Part 103.1 : 1985			
Initial Dry Mass	M_1	g		
Mass after washing on 75 µm (63 µm) sieve (if required)	M_2	g	If not washed, then $M_2 = M_1$	
BS test sieve		Mass retained (g)	Percentage retained $\left(\frac{M}{M_1}\right) \times 100$	Cumulative percentage passing
75 mm				
63 mm				
50 mm				
37.5 mm				
28 mm				
20 mm				
14 mm				
10 mm				
(6.3 mm)				
5 mm				
(3.35 mm)				
2 mm				
1.18 mm				
600 µm				
(425 µm)				
300 µm				
(212 µm)				
150 µm				
75 µm (63 µm)				
Passing 75 µm (63 µm) M_F		x		
Add washed material $(M_1 - M_2)$		x		
Total mass passing 75 µm (63 µm)	$(M_1 - M_2) + M_F$			
Total	(check with M_1)			

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PARTICLE SIZE DISTRIBUTION

SITE:
OR
PROJECT:

DATE: - - - - -

OPERATOR: _ _ _ _ _ _ _ _ _ _ _ _ _ _

ENGINEER: _ _ _ _ _ _ _ _ _ _ _ _ _ _

LOCATION: (Km/MS NO.) _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

SAMPLE/LAB.NO.: _ _ _ _ _ _ DEPTH (cm): _ _ _ _ _ _ _ _ _

SIEVING METHOD: ☐ WET ☐ DRY

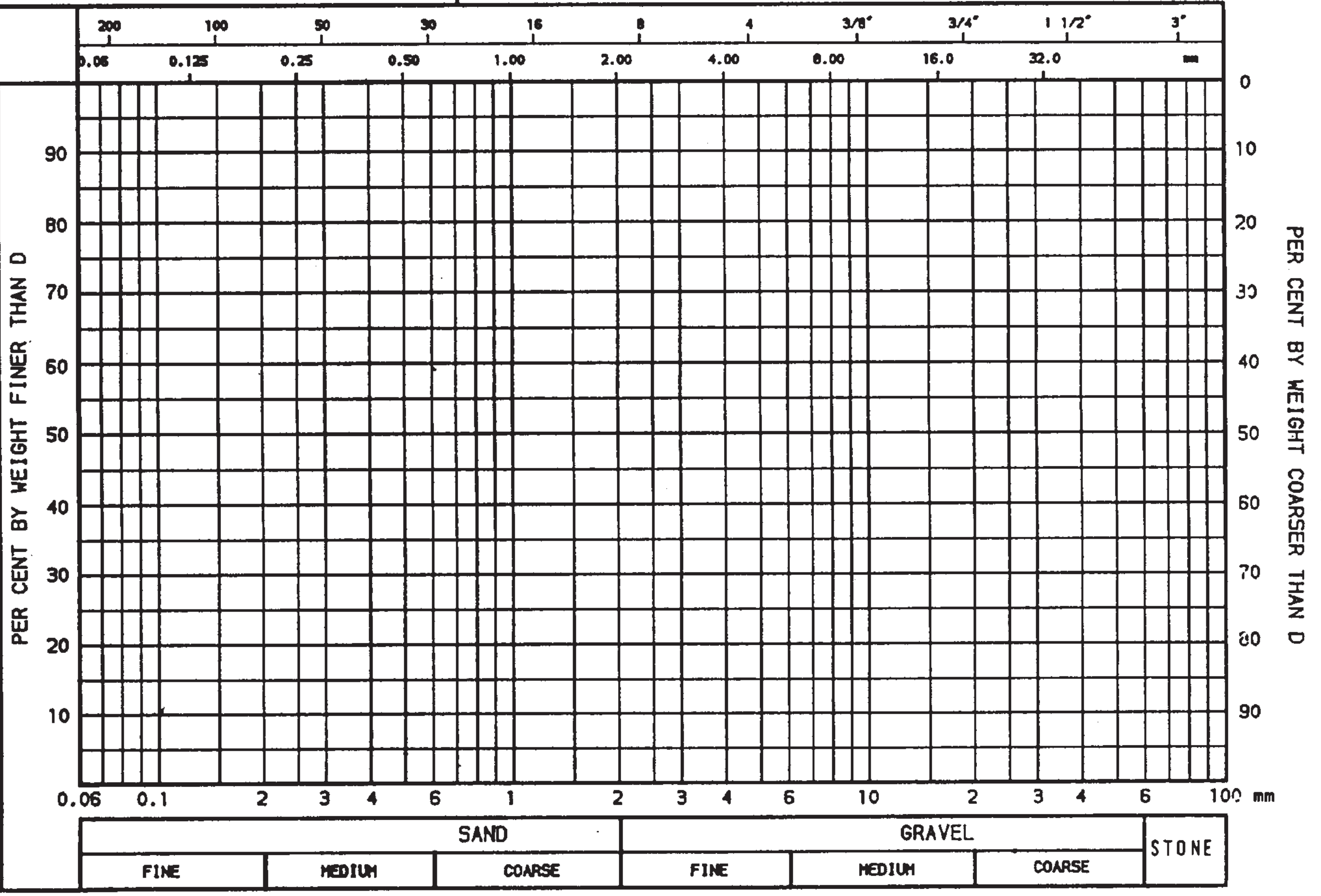
☐ ASTM ☐ BS ☐ DIN ☐ ISO

MASS OF DRY SAMPLE..........grams

SIEVE SIZE mm	MASS RETAINED (grams)	PERCENTAGE OF TOTAL RETAINED	PERCENTAGE OF TOTAL PASSING	ROUNDED % OF TOTAL PASSING

SPLITTING OF SAMPLE PASSING 5.0 mm _ _ _ _ _ _ _ _ _ _
WEIGHT OF DRY SAMPLE: grams

2.0				
1.0				
0.600				
0.425				
0.300				
0.150				
0.075				
TOTAL				



GRADING MODULE: _ _ _ _ _ _

METERIALS DESCRIPTION:

TEST NO. 2.4

Flakiness Index (FI) and Average Least Dimension (ALD)

Notes

Objective

Flakiness Index is one of the tests used to classify aggregates and stones. In Pavement Design there are specific requirements regarding the Flakiness Index of materials.

For base course and wearing course aggregates the presence of flaky particles are considered undesirable as they may cause inherent weakness with possibilities of breaking down under heavy loads.

Aggregates are classified as flaky when they have a thickness of less than 60 % of their mean sieve size.

The objective of the test is to determine the Flakiness Index of coarse aggregates.

Main Principles

The Flakiness Index of a an aggregate sample is found by separating the flaky particles and expressing their mass as a percentage of the mass of the sample. The test is applicable to material passing a 63 mm sieve and retained on a 6.3 mm sieve.

References

BS 812 : Section 105.1 : 1989

Required equipment

- *A sample divider, e.g. a riffle box*
- *Drying oven* - with temperature of 105 °C ± 5 °C.
- *Balance* - readable to 1.0 g.
- *Test sieves* – Ref. Table 1
- *A sieve shaker (*optional)
- *Metal trays*
- *A Metal thickness Gauge,* of a pattern shown in Figure 1.

Nominal aperture size (square hole perforated plate 450 mm or 300 mm diameter) mm
63
50
37.5
28
20
14
10
6.3

Table 3. Particulars of sieves

TEST NO. 2.4

Flakiness Index (FI) and Average Least Dimension (ALD)

Notes

Sample preparation

Step 1: Reduce the sample to produce a test portion complying with Table 2 below.
Step 2: The test sample shall be washed, if necessary, and oven-dried at 105 °C to 110 °C to substantially constant weight.
Step 3: Allow the sample to cool and weigh the sample to the nearest 1g.

Nominal size of material mm	Minimum mass of test portion after rejection of oversize and undersize particles kg
50	35
40	15
28	5
20	2
14	1
10	0.5

Table 4. Minimum mass of test portion

Test Procedure

Step 1: Carry out a sieve analysis using the sieves given in Table 1.
Step 2: Discard all aggregates retained on the 63 mm sieve and all aggregate passing the 6.3 mm sieve.
Step 3: Weigh each of the individual size-fractions retained on the sieves, and store them in trays with their size marked on the trays.
Step 4: From the sums of masses of the fractions in the trays (M_1), calculate the individual percentage retained on each of the various sieves. Discard any fraction whose mass is 5 % or less of mass M_1. Record the mass remaining (M_2).
Step 5: Gauge each fraction using the thickness gauge. Select the gauge appropriate to the size-fraction under test and gauge each particle of that size-fraction separately by hand.
Step 6: Combine and weigh all the particles passing each of the gauges. (M_3).

If required, a Flakiness Index may be determined separately for individual size fractions by recording separately the masses of the individual size-fractions and the mass of each size-fraction passing the appropriate gauges.

Calculations

The value of the Flakiness Index is calculated from the expression:

$$\text{Flakiness Index, FI} = \frac{M_3}{M_2} \times 100$$

Flakiness Index (FI) and Average Least Dimension (ALD)

Notes

Report

The test report shall include the following:

a) Type of material and sample identification
b) Reference to this procedure
c) Test result, i.e. the Flakiness Index of the test sample. The Flakiness Index shall be expressed to the nearest whole number.
d) Whether the material was tested in the natural state or after sieving
e) Sieve analysis obtained from this test.

Form for the test

The enclosed form shall be used.

Average Least Dimension (ALD)

Objective

Further adjustments of the bitumen spray rate may be carried out as outlined in the Pavement and Materials Design Manual. This will depend on site conditions such as type of surface, type of chipping including their dust content and absorbency or optional use of pre-coating, varying proportions of heavy vehicles and special traffic conditions like climbing lanes.

The average least dimension (ALD) is a useful parameter to describe the available voids in a layer of chipping for surface dressing. The required basic spray rate of bitumen to hold the chipping in place is determined in the surface design (Pavement and Materials Design Manual) as a function of the ALD and traffic loading.

Main principles

The average least dimension (ALD) of chipping can be determined by directly measuring the smallest size of 200 particles in a representative sample using callipers and calculating the average. However, a more practical method is the one described below, whereby ALD is estimated as a function of the average size of the chipping, as determined by normal square mesh sieves, and the degree of flakiness. Such estimates using established relationships expressed in the enclosed nomograph are considered sufficiently accurate for the purpose of surface design.

Test Procedure

A grading analysis is performed on a representative sample of the chipping in accordance with CML test 2.3 (BS 812 : 1985).

Determination of the Median Size

The sieve size through which 50 % of the chipping pass is determined (known as the “median size”).

Determination of the Average Least Dimension

The Flakiness Index is determined in accordance with the procedure outlined above. The ALD is read off from the enclosed nomograph by joining the scale for the Median Size to the scale for Flakiness Index.

The Average Least Dimension (ALD) is reported in mm with one decimal.

Form for the test

The enclosed form shall be used.

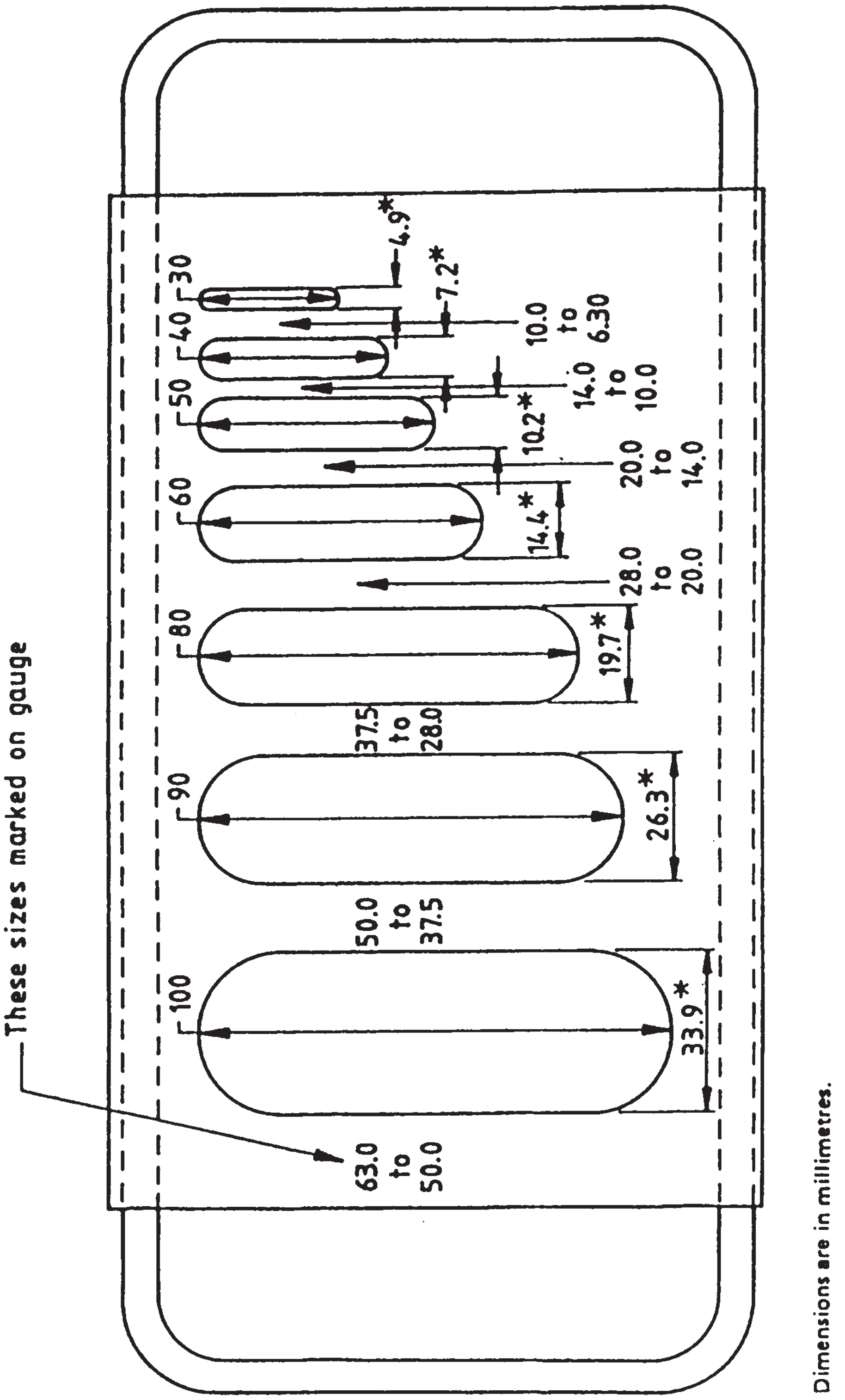
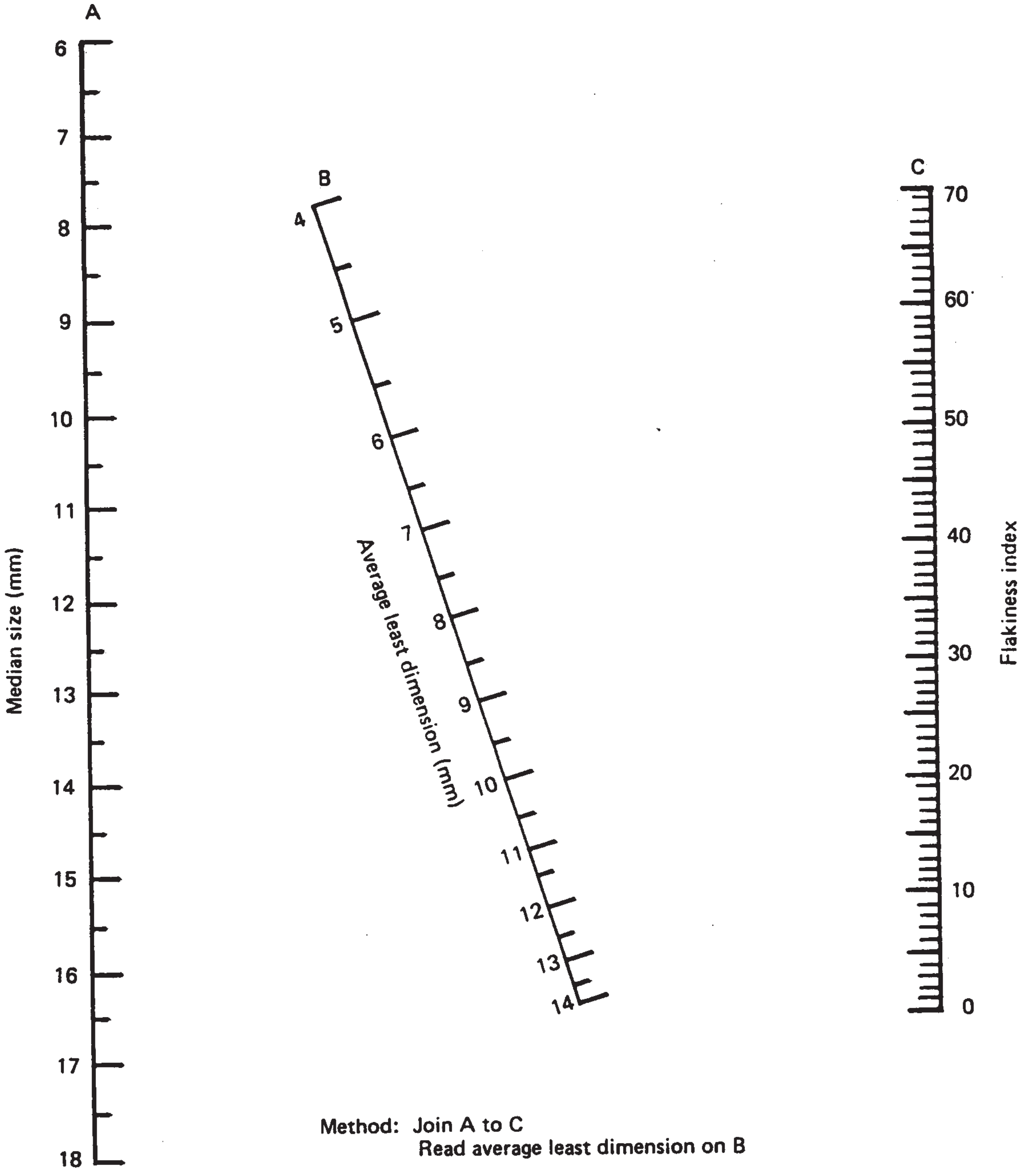


Figure 1 Thickness gauge



Method: Join A to C
Read average least dimension on B

Figure 2 Determination of average least dimension

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WORKING SHEET

Flakiness Index - FI
Average Least Dimension - ALD

Project	**Location**	**Depth**
Client	**Lab.no**	**Date**
Responsible Technician	**Checked**	**Approved**

TEST METHOD CML TEST 2.4, ref. BS 812 : Section 105.1 : 1989

		Fraction Gauged						
Passing sieve	mm	63	50	37,5	28	20	14	10
Retained on sieve	mm	50	37,5	28	20	14	10	6,3
Slots width	mm	33.9	26.3	19.7	14.4	10.2	7.2	4.9
Fraction Gauged	x							
Before Gauging								
Mass of tray + Aggregate farction	g							
Mass of tray	g							
Mass of Aggregate fraction **M_0**	g							
Individual percentage **M_0/M_1 x 100**	%							
Sum of Aggregate mass **M_1**	g							
Sum of fractions less than 5% of M_1	g							
Remaining sum of Aggregate mass **M_2**	g							

After Gauging		
Mass of tray + Sum of Aggregate passing slots	g	
Mass of tray	g	
Sum of Aggregate mass passing slots **M_3**	g	
Flakiness Index **FI = M_3/M_2 x 100**	%	

Average Least Dimension		
Median size (the sieve size through which 50% pass)	mm	
Average Least Dimension - ALD (determined from nomograph)	mm	

TEST NO. 2.5

Elongation Index

Notes

Example: Aggregates passing 14 mm and retained on 10 mm are classified as elongated when:
L > ½ (14 + 10) x 1.8 = 21.6 mm

Objective

Elongation is a means of classifying coarse aggregates.

Aggregate particles are classified as elongated when they have a length (greatest dimension) of more than 1.8 of their mean sieve size.

The objective of the test is to determine the Elongation Index of coarse aggregates.

For base course and wearing course aggregates the presence of elongated particles are considered undesirable as they may cause inherent weakness with possibilities of breaking down under heavy loads.

Main Principles

The Elongation Index of an aggregate sample is found by separating the elongated particles and expressing their mass as a percentage of the mass of the sample. The test is applicable to material passing a 50 mm sieve and retained on a 6.3 mm sieve.

References

BS 812 : Section 105.2 : 1990

Required equipment

- *A sample divider, e.g. a riffle box*
- *Drying oven* - with temperature of 105 ± 5 °C.
- *Balance* - readable to 1.0 g.
- *Test sieves* – Ref. Table 1
- *A sieve shaker (*optional)
- *Metal trays*
- *A Metal Length Gauge,* of a pattern shown in Figure 3.

Nominal aperture size (square hole perforated plate 450 mm or 300 mm) mm
50
37.5
28
20
14
10
6.3

Table 5. Particulars of sieves

TEST NO. 2.5

Elongation Index

Notes

Sample preparation

Step 1: Reduce the sample to produce a test portion complying with Table 2 below.
Step 2: The test sample shall be washed, if necessary, and oven-dried at 105 ± 5 °C to substantially constant weight.
Step 3: Allow the sample to cool and weigh the sample to the nearest 1g.

Nominal size of material mm	Minimum mass of test portion after rejection of oversize and undersize particles kg
40	15
28	5
20	2
14	1
10	0.5

Table 6. Minimum mass of test portion

Test Procedure

Step 1: Carry out a sieve analysis using the sieves given in Table 1.
Step 2: Discard all aggregates retained on the 50 mm sieve and all aggregate passing the 6.3 mm sieve.
Step 3: Weigh each of the individual size-fractions retained on the sieves, and store them in trays with their size marked on the trays.
Step 4: From the sums of masses of the fractions in the trays (M_1), calculate the individual percentage retained on each of the various sieves. Discard any fraction whose mass is 5 % or less of mass M_1. Record the mass remaining (M_2).
Step 5: Gauge each fraction using the length gauge. Select the gauge appropriate to the size-fraction under test (see Table 3) and gauge each particle of that size-fraction separately by hand. Elongated particles are those whose greatest dimension prevents them from passing through the gauge, and these are placed to one side.
Step 6: Combine and weigh all the elongated particles. (M_3).

If required, an Elongation Index may be determined separately for individual size fractions by recording separately the masses of each of the individual size-fractions and the masses of elongated particles in each size-fraction.

Aggregate size fraction		Gap between pins of length gauge	Minimum mass for subdivision
Test sieve			
100 % passing	100% retained		
mm	mm	mm	kg
50	37.5	78.7	35
37.5	28	59.0	15
28	20	43.2	5
20	14	30.6	2
14	10	21.6	1
10	6.3	14.7	0.5

Table 7. Data for determination of Elongation Index

Elongation Index

Notes

Calculations

The value of the Elongation Index is calculated from the expression:

$$\text{Elongation Index, EI} = \frac{M_3}{M_2} \times 100$$

where

M_2 is the sum of the masses of fractions that have a mass greater than 5 % of the total mass.
M_3 is the mass of all the elongated particles

Report

The test report shall include the following:

a) Type of material and sample identification
b) Reference to this procedure
c) Test result, i.e. the *Elongation Index* of the test sample. The *Elongation Index* shall be expressed to the nearest whole number.
d) Whether the material was tested in the natural state or after sieving
e) Sieve analysis obtained from this test.

Form for the test

The enclosed form shall be used.

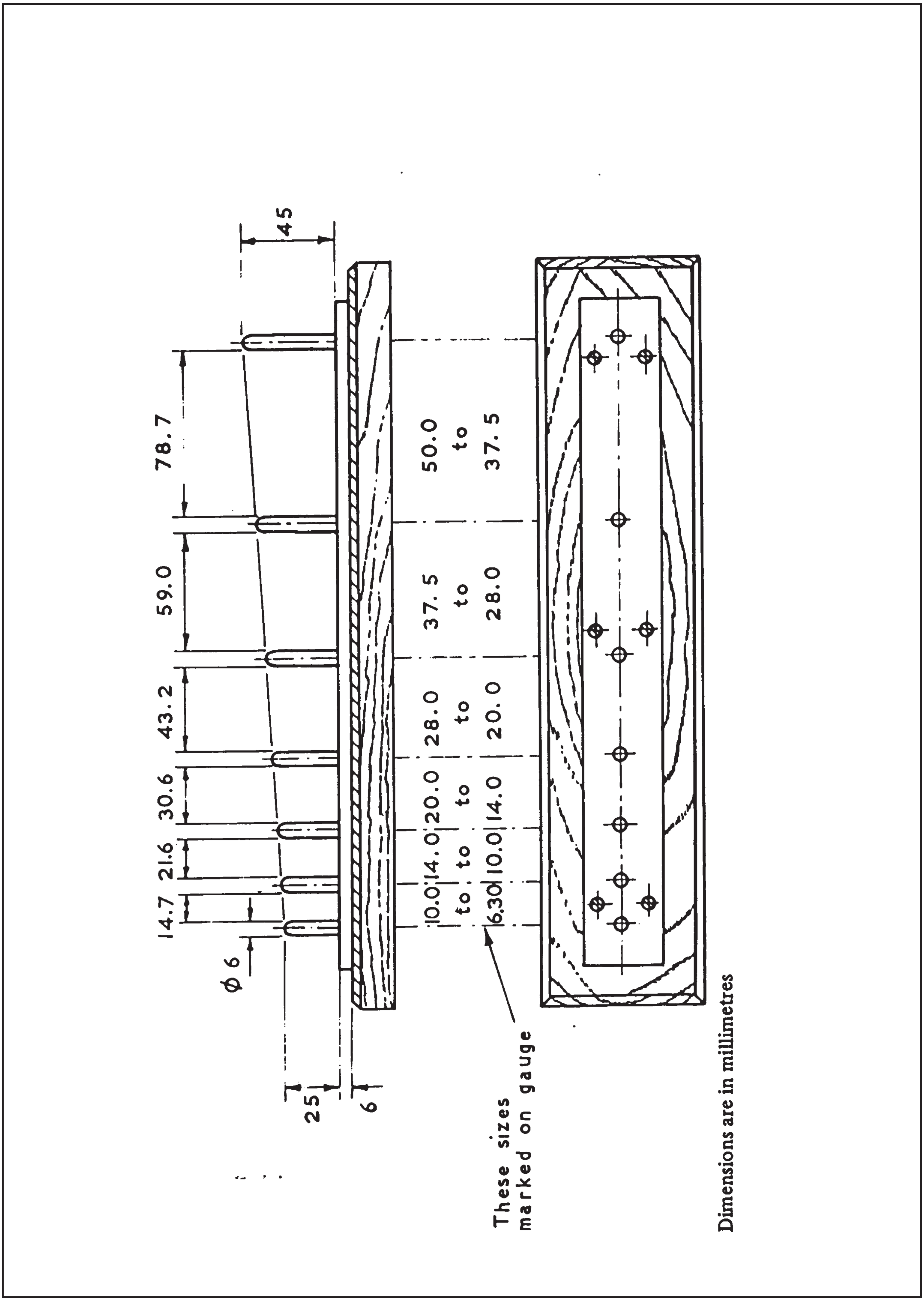

Figure 3 Lenght gauge

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WORKING SHEET

Elongation Index - EI

Project	**Location**	**Depth**
Client	**Lab.no**	**Date**
Responsible Technician	**Checked**	**Approved**

TEST METHOD CML TEST 2.5, ref. BS 812 : Section 105.2 : 1990

		Fraction Gauged					
Passing sieve	mm	50	37,5	28	20	14	10
Retained on sieve	mm	37,5	28	20	14	10	6,3
Gaps between pins	mm	78.7	59.0	43.2	30.6	21.6	14.7
Fraction Gauged	x						
Before Gauging							
Mass of tray + Aggregate farction	g						
Mass of tray	g						
Mass of Aggregate fraction **M_0**	g						
Individual percentage **M_0/M_1 x 100**	%						
Sum of Aggregate mass **M_1**	g						
Sum of fractions less than 5% of M_1	g						
Remaining sum of Aggregate mass **M_2**	g						

After Gauging		
Mass of tray + Sum of Aggregate <u>not</u> passing gaps	g	
Mass of tray	g	
Sum of Aggregate mass not passing gaps **M_3**	g	
Elongation Index **EI = M_3/M_2 x 100**	%	

TEST NO. 2.6

Aggregate Crushing Value - ACV

Notes

Objective

Aggregates used in road construction should be strong enough to resist crushing under traffic wheel loads. If the aggregates are weak, the integrity of the pavement structure is likely to be adversely affected. The strength of coarse aggregates may be measured by the Aggregate Crushing test.

The Aggregate Crushing Value (ACV) gives a relative measure of the resistance of an aggregate to crushing under a gradually applied load.
Main Principles
The Aggregate Crushing Value (ACV) is determined by measuring the material passing a specified sieve after crushing under a load of 400 kN.

The test is applicable to a standard fraction aggregates passing a 14 mm sieve and retained on a 10 mm sieve.

If the standard size fraction 14 - 10 mm is not available, tests may be performed on other size fractions between 2.36 mm and 28 mm, ref. BS 812, and table below:

Fraction	*Separating sieve*
28 - 20 mm	*5.0 mm*
20 - 14 mm	*3.35 mm*
14 - 10 mm	***2.36 mm***
10 - 6.3 mm	*1.70 mm*
6.3 - 5.0 mm	*1.18 mm*
5.0 - 3.35 mm	*850 μm*
3.35 - 2.36mm	*600 μm*

For the sizes smaller than 10mm a smaller apparatus may be used, i.e. cylinder diameter 75 mm, mould size 57 mm x 90 mm, tamping rod diameter 8 mm, and applied force 100 kN.

The method is not suitable for testing soft aggregates with an ACV higher than 30. In such cases the method for Ten Percent Fines Value (TFV) is applicable, ref. CML Test no. 2.7.

References

BS 812 : Part 110 : 1990

Required equipment

- *A Steel Cylinder*, open ended of nominal 150 mm internal diameter with *Plunger* and *Baseplate*, ref. figure 1.
- *Test sieves* – square-hole perforated-plate type of sizes 14 mm and 10 mm, and a woven wire 2.36 mm sieve.
- *Tamping rod*, steel bar 16 mm diameter and 600 mm long with both ends hemispherical
- *Compression Testing Machine,* 500 kN capacity
- *Cylindrical Metal Measure,* with internal diameter of 115 mm and internal depth of 180 mm
- *A sample divider, e.g. a riffle box*
- *Drying oven* - with temperature of 105 °C ± 5 °C.
- *Balance* – min. 3 kg capacity readable to 1 g.
- *Rubber mallet*
- *Metal tray* of known mass
- *Brush* with stiff bristles.

Sample preparation

If the material is dusty, it should be washed before testing. It is not to be washed after testing.

Step 1: Reduce the sample to produce a test portion of sufficient mass to produce three test specimens of 14 mm to 10 mm size fraction, ref. Table 1 below.

Notes

Grade of the aggregate mm	Minimum mass of the test portion * kg
All-in aggregate 40 max. size	60
All-in aggregate 20 max. size	45
Graded aggregate 40 to 5	40
Graded aggregate 20 to 5	25
Graded aggregate 14 to 5	15

* For normal density aggregate

Table 8. Guide to minimum mass of test portions required to obtain a suitable mass of material to determine the ACV.

Step 2: Sieve the entire surface dry test portion on the 14 mm and 10 mm sieves to remove the oversize and undersize fractions.

The appropriate quantity of aggregate may be found conveniently by filling the cylindrical measure in three layers of approximately equal depth. Tamp each layer 25 times, from a height of about 50 mm above the surface of the aggregate. Level off using the tamping rod.

Step 3: Divide the resulting 14 mm – 10 mm fraction to produce three test specimens each of sufficient mass such that the depth of the material in the Cylinder is approximately 100 mm after tamping.

Step 4: The test specimens shall be oven-dried at 105 ± 5°C for not more than 4 hours. Allow to cool before testing. Record the mass of material comprising the test specimens.

Test Procedure

Step 1: Place the cylinder of the test apparatus in position on the baseplate. Place the test specimen in it in thirds, each third being compacted by 25 strokes of the tamping rod evenly distributed over the surface of the layer. The tamping rod shall be dropped from a height of about 50 mm above the surface of the aggregate.

Take care to ensure that the plunger does not jam in the cylinder.

Step 2: Carefully level the surface of the aggregate and insert the plunger so that it rests horizontally on this surface.

During the early stages of the test, there is a significant deformation, and it may not be possible to maintain the required loading rate and variations will occur. These variations should be kept to a minimum with the principal object to complete the test in 10 min.

Step 3: Place the apparatus with the specimen and plunger in position, between the platens of the compression testing machine. Apply force at a uniform rate so that the required force of 400 kN is reached in 10 min ± 30 s:

If this fails to remove the compacted aggregate, other methods should be used taking care not to crush the particles.

Step 4: Release the force and remove the crushed material aggregate by holding the cylinder over a clean tray of known mass and hammering on the outside with the rubber mallet until the particles are sufficiently loose to enable the specimen to fall freely on to the tray. Use a brush to remove the fine particles adhering to the inside of the cylinder, the baseplate and the underside of the plunger.

Step 5: Weigh the tray and the aggregate and record the mass of aggregate used (M_1) to the nearest 1 g.

Step 6: Sieve the whole specimen in the tray on the 2.36 mm sieve until no further significant amount passes. Weigh and record the

Aggregate Crushing Value - ACV

Notes

masses of the fraction passing and retained on the sieve to the nearest 1 g ($M_2 + M_3$ respectively). If the total mass ($M_2 + M_3$) differs from the initial mass (M_1) by more than 10 g, discard the result and test a further specimen.

Step 7: Repeat the complete test procedure using a second specimen of the same mass as the first specimen.

Calculations

1) Calculate the Aggregate Crushing Value (ACV) expressed as a percentage to the first decimal place for each test specimen from the following equation:

$$ACV = \frac{M_2}{M_1} \text{ x } 100$$

where

M_1 is the mass of the test specimen (in g)
M_2 is the mass of the material passing the 2.36 mm sieve (in g).

2) Calculate the mean of the two results to the nearest whole number.

3) Report the mean as the Aggregate Crushing Value (ACV).

The median of 4 results is calculated by disregarding the highest and lowest result and averaging the two middle results.

If the individual results differ by more than 7 % of the mean value, the test shall be repeated for two further specimens. The median value shall be reported as the ACV.

Report

The test report shall include the following:

a) Type of material and sample identification
b) Reference to this procedure
c) The Aggregate Crushing Value (ACV)

Form for the test

The enclosed form shall be used.

Practical Considerations

Knock on the cylinder with a rubber mallet to remove the material. Do not knock on the material itself.

Maintenance

Calibration of the compression testing machine should be performed once a year.

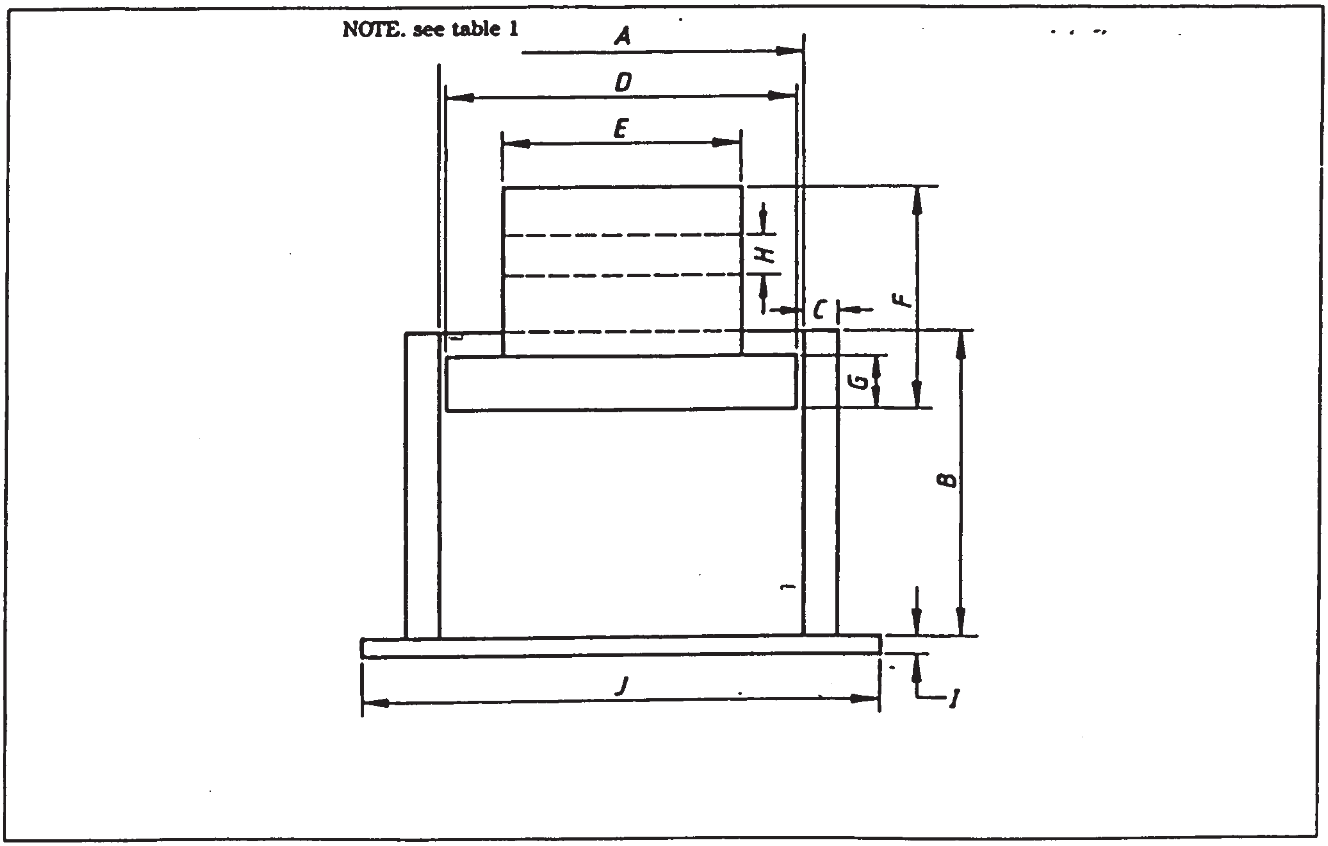

Figure 4 Outline form of cylinder and plunger apparatus for the aggregate crushing value

Table 7 Principal dimensions of cylinder and plunger apparatus

Component	**Dimensions (see figure 1)**	**Nominal 150 mm internal diameter of cylinder**	**Nominal 75 mm internal diameter of cylinder (see appendix A)**
		mm	mm
Cylinder	Internal diameter, *A*	154 ± 0.5	78.0 ± 0.5
	Internal depth, *B*	125 to 140	70.0 to 85.0
	Minimum wall thickness, *C*	16.0	8.0
Plunger	Diameter of piston, *D*	152 ± 0.5	76.0 ± 0.5
	Diameter of stem, *E*	> 95 to ≤ *D*	> 45.0 to ≤ *D*
	Overall length of piston plus stem, *F*	100 to 115	60.0 to 80.0
	Minimum depth of piston, *G*	not less than 25.0	not less than 19.0
	Diameter of hole, *H*	20.0 ± 0.1	10.0 ± 0.1
Baseplate	Minimum thickness, *I*	10	10
	Length of each side of square, *J*	200 to 230	110 to 115

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WORKING SHEET

Aggregate Crushing Value
ACV

Project	**Location**	**Depth**
Client	**Lab.nr**	**Date**
Responsible Technician	**Checked**	**Approved**

TEST METHOD CML TEST 2.6, ref. BS 812 : Part 110 : 1990

Fraction tested	Separating sieve		
28 - 20 mm	5.0 mm		
20 - 14 mm	3.35 mm		
14 - 10 mm	**2.36 mm**		**STANDARD**
		Standard or Smaller apparatus	
10 - 6.3 mm	1.70 mm		
6.3 - 5.0 mm	1.18 mm		
5.0 - 3.35 mm	850 µm		
3.35 mm - 2.36 mm	600 µm		

Specimen reference					
Mass of tray + test specimen (g)					
Mass of tray alone (g)					
Mass of original test specimen (g)	M_1				
Mass of tray + material passing separating sieve (g)					
Mass of tray alone (g)					
Mass of material passing separating sieve (g)	M_2				
Mass of tray + material retained on separating sieve					
Mass of tray alone (g)					
Mass of material retained on separating sieve (g)	M_3				
Mass passing and retained on separating sieve - check versus M_1	$M_2 + M_3$				
Aggregate Crushing Value (in %)	$\frac{M_2}{M_1} \times 100$				
ACV - mean value	%				
ACV - median value	%				

TEST NO. 2.7

Ten Percent Fines Value - TFV (10% FACT)

Notes

The apparatus, method and materials used are similar to the determination of the Aggregate Crushing Value (ACV).

*If the standard size fraction **14 - 10 mm** is not available, tests may be performed on other size fractions between 2.36 mm and 28 mm, ref. BS 812, and table below:*

Fraction	Separating sieve
28 - 20 mm	*5.0 mm*
20 - 14 mm	*3.35 mm*
14 - 10 mm	***2.36 mm***
10 - 6.3 mm	*1.70 mm*
6.3 - 5.0 mm	*1.18 mm*
5.0 - 3.35 mm	*850 µm*
3.35 - 2.36mm	*600 µm*

For the sizes smaller than 10mm a smaller apparatus may be used, i.e. cylinder diameter 75 mm, mould size 57 mm x 90 mm, tamping rod diameter 8 mm, and applied force up to 100 kN.

Objective

Aggregates used in road construction should be strong enough to resist crushing under traffic wheel loads. If the aggregates are weak, the integrity of the pavement structure may be adversely affected.

The strength of the aggregates may be measured in a crushing test. The Ten Percent Fines Value (TFV) gives a relative measure of the resistance of an aggregate to crushing under a gradually applied load. In Pavement design there are specific requirements for the TFV of materials, tested both dry and soaked.

Main Principles

The 10 % Fines Value (TFV) is determined by measuring the load required to crush a prepared aggregate sample to give 10 % material passing a specified sieve after crushing. The test is also known as the 10% Fines Aggregate Crushing Test - 10 % FACT.

The test can be performed in both a dry condition and in a soaked condition.

The test is applicable to both weak and strong aggregates. The standard size fraction is passing a 14 mm sieve and retained on a 10 mm sieve.

(The TFV test resembles the determination of the Aggregate Crushing Value (ACV), which requires a force equal to 400 kN to be applied on the test sample).

References

BS 812 : Part 111 : 1990

Required equipment

- *A Steel Cylinder*, open ended of nominal 150 mm internal diameter with *Plunger* and *Baseplate*, ref. figure 1.
- *Test sieves* – square-hole perforated-plate type of sizes 14 mm and 10 mm, and a woven wire 2.36 mm sieve.
- *Tamping rod*, steel bar 16 mm diameter and 600 mm long with both ends hemispherical
- *Compression Testing Machine,* 500 kN capacity
- *Cylindrical Metal Measure,* with internal diameter of 115 mm and internal depth of 180 mm
- *A sample divider, e.g. a riffle box*
- *Drying oven* - with temperature of 105 °C ± 5 °C.
- *Balance* – min. 3 kg capacity readable to 1 g.
- *Rubber mallet*
- *Metal tray* of known mass
- *Brush* with stiff bristles.

Ten Percent Fines Value - TFV (10% FACT)

Notes

Additional for testing in a soaked condition

- *Drying cloths (two hand towels)*
- *3 no. Wire mesh baskets*
- *Watertight container*
- *Supply of clean water*

Sample preparation

If the material is dusty, it should be washed before testing.

Step 1: Reduce the sample to produce a test portion of sufficient mass to produce three test specimens of 14 mm to 10 mm size fraction, ref. Table 1 below.

Table 9. Guide to minimum mass of test portions required to obtain a suitable mass of material to determine the TFV.

Grade of the aggregate mm	Minimum mass of the test portion * kg
All-in aggregate 0-40 mm max. size	60
All-in aggregate 0-20 mm max. size	45
Graded aggregate 40 to 5 mm	40
Graded aggregate 20 to 5 mm	25
Graded aggregate 14 to 5 mm	15

* For normal density aggregate

The appropriate quantity of aggregate may be found conveniently by filling the cylindrical measure in three layers of approximately equal depth. Tamp each layer 25 times, from a height of about 50 mm above the surface of the aggregate. Level off using the tamping rod.

Step 2: Sieve the entire surface dry test portion on the 14 mm and 10 mm sieves to remove the oversize and undersize fractions.

Step 3: Divide the resulting 14 mm – 10 mm fraction to produce three test specimens each of sufficient mass such that the depth of the material in the Cylinder is approximately 100 mm after tamping.

Step 4: The test specimens shall be oven-dried at 105 ± 5°C for not more than 4 hours. Allow to cool before testing. Record the mass of material comprising the test specimens.

For soaked condition

Step 5: Each of the three test specimens shall be placed in the wire basket and immersed in water. The water level in the container shall be at least 50 mm above the top of the baskets. Immediately after immersion remove entrapped air by lifting the baskets 25 mm above the base of the container and allowing it to drop 25 times. Keep the baskets immersed for 24 ± 2 hours.

Step 6: After soaking, remove the specimen of aggregate from the basket and dry the free water from the surface. Carry out the test procedure immediately after this operation.

Ten Percent Fines Value - TFV (10% FACT)

Notes

Test Procedure

Dry condition

Step 1: Place the cylinder of the test apparatus in position on the baseplate. Place the test specimen in it in thirds, each third being compacted by 25 strokes of the tamping rod evenly distributed over the surface of the layer. The tamping rod shall be dropped from a height of about 50 mm above the surface of the aggregate.

Take care to ensure that the plunger does not jam in the cylinder.

Step 2: Carefully level the surface of the aggregate and insert the plunger so that it rests horizontally on this surface.

During the early stages of the test, there is a significant deformation, and it may not be possible to maintain the required loading rate and variations will occur. These variations should be kept to a minimum with the principal object to complete the test in 10 min.

Step 3: Place the apparatus with the specimen and plunger in position, between the platens of the compression testing machine. Apply force at a uniform rate so as to cause a total penetration of the plunger in 10 min ± 30 s of approximately:

a) 15 mm for rounded or partially rounded aggregates, e.g. uncrushed grave
b) 20 mm for normal crushed aggregates
c) 24 mm for honeycombed aggregates, e.g. some slags

Step 4: Record the maximum force (f) applied to produce the required penetration. Release the force and remove the crushed material aggregate by holding the cylinder over a clean tray of known mass and hammering on the outside with the rubber mallet until the particles are sufficiently loose to enable the specimen to fall freely on to the tray. Use a brush to remove the fine particles adhering to the inside of the cylinder, the baseplate and the underside of the plunger.

If this fails to remove the compacted aggregate, other methods should be used taking care not to crush the particles.

Step 5: Weigh the tray and the aggregate and record the mass of aggregate used (M_1) to the nearest 1 g.

Step 6: Sieve the whole specimen in the tray on the 2.36 mm sieve until no further significant amount passes. Weigh and record the masses of the fraction passing and retained on the sieve to the nearest 1 g ($M_2 + M_3$ respectively). If the total mass ($M_2 + M_3$) differs from the initial mass (M_1) by more than 10 g, discard the result and test a further specimen.

If the percentage of the material (m) passing the sieve calculated from

$$m = \frac{M_2}{M_1} \times 100$$

does not fall within the range 7.5 % - 12.5 %, test a further specimen using an adjusted maximum test loading to bring the percentage of fines within the range and record the value of (m) obtained.

A suitable force will typically vary from 50 kN for weak gravels to more than 200 kN for good quality aggregates.

Ten Percent Fines Value - TFV (10% FACT)

Notes

Step 7: Repeat the complete test procedure using a second specimen of the same mass as the first specimen at the same force that gave a percentage fines value within the range 7.5 % - 12.5 %.

Soaked Condition

Follow the test procedure described above, step 1 – 4, except that after the specimen has been removed from the cylinder, it shall be oven-dried at a temperature of 105 ± 5°C for at least 12 hours. Allow the material to cool and weigh to the nearest 1 g and record the mass of the test specimen (M_1). Complete the procedure as described in steps 6 and 7 above.

Calculations

1) Calculate the force F (in kN), to the nearest whole number, required to produce 10 % fines for each test specimen, with the percentage of material passing in the range 7.5 % - 12.5 %, from the following equation:

$$F = \frac{14\ f}{m+4}$$

where

f is the maximum force (in kN)
m is the percentage of material passing the 2.36 mm sieve at the maximum force

2) Calculate the mean of the two results to the nearest 10 kN for forces of 100 kN or more, or to the nearest 5 kN for forces less than 100 kN.

Report the mean as the Ten Percent Fines Value (TFV).

The median of 4 results is calculated by disregarding the highest and lowest result and averaging the two middle results.

If the individual results differ by more than 10 kN and by more than 10 % of the mean value, the test shall be repeated for two more specimens. The median value shall be reported as the TFV.

The Preferred test method

The preferred optional testing method is to combine the TFV test with the ACV test.

4 test specimens are prepared as described above. The 4 specimens are subjected to 50 kN – 100 kN – 150 kN and 400 kN respectively.

The 4 results are plotted on a chart with the applied load as the abscissae and the percentage fines (passing 2.36 mm) as the ordinate. A curve is drawn through the plotted points. The force F (in kN) corresponding to 10 % fines is reported as the Ten Percent Fines Value (TVF).

Notes

It is recommended to prepare a control specimen to which the reported force (in kN) is applied and the fines (passing 2.36 mm) after crushing are measured as described above. This percentage of fines should be near 10 %.

Report

The test report shall include the following:

a) Type of material and sample identification
b) Reference to this procedure
c) The test condition of the aggregates, i.e. dry or soaked condition
d) The Ten Percent Fines Value (TFV) of the dry aggregate; and/or
e) The Ten Percent Fines Value (TFV) of the soaked aggregate

Form for the test

The enclosed test form shall be used.

Practial Considerations

Knock on the cylinder with a rubber mallet to remove the material. Do not knock on the material itself.

Maintenance

Calibration of the compression machine should be performed once a year.

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WORKING SHEET

Ten Percent Fines Value (TFV)
10% FACT

Project	**Location**	**Depth**
Client	**Lab.nr**	**Date**
Responsible Technician	**Checked**	**Approved**

TEST METHOD CML TEST 2.7, ref. BS 812 : Part 111 : 1990

Fraction tested	Separating sieve		
28 - 20 mm	5.0 mm		
20 - 14 mm	3.35 mm		
14 - 10 mm	**2.36 mm**		**STANDARD**
		Standard or Smaller apparatus	
10 - 6.3 mm	1.70 mm		
6.3 - 5.0 mm	1.18 mm		
5.0 - 3.35 mm	850 μm		
3.35 mm - 2.36 mm	600 μm		

Specimen reference						Control Test
Applied Force	F	**50 kN**	**100 kN**	**150 kN**	**400 kN**	
Mass of tray + test specimen (g)						
Mass of tray alone (g)						
Mass of original test specimen (g)	M_1					
Mass of tray + material passing separating sieve (g)						
Mass of tray alone (g)						
Mass of material passing separating sieve (g)	M_2					
Mass of tray + material retained on separating sieve						
Mass of tray alone (g)						
Mass of material retained on separating sieve (g)	M_3					
Mass passing and retained on separating sieve - check versus M_1	$M_2 + M_3$					
Percentage Fines (in %)	$\frac{M_2}{M_1} \times 100$					
ACV (for F = 400 kN)	%	X	X	X		X
10 % Fines Value (from chart) (kN)	F					X

TEST NO. 2.8

Aggregate Impact Value - AIV

Notes

Objective

Aggregates used in road construction should be strong enough to resist crushing under traffic wheel loads.

The strength of the aggregates may be measured in crushing or impact tests. The Aggregate Impact Value (AIV) gives a relative measure of the resistance of an aggregate to sudden shock or impact.

Main Principles

The Engineer shall decide whether to test in dry or soaked condition.

*If the standard size fraction **14 - 10 mm** is not available, tests may be performed on smaller size fractions down to 2.36 mm, ref. BS 812, and table below*

Fraction	*Separating sieve*
14 - 10 mm	***2.36 mm***
10 - 6.3 mm	*1.70 mm*
6.3 - 5.0 mm	*1.18 mm*
5.0 - 3.35 mm	*850 µm*
3.35 - 2.36mm	*600 µm*

The test can be performed in either a dry condition or in a soaked condition.

The test is applicable to a standard fraction aggregates passing a 14 mm sieve and retained on a 10 mm sieve.

References

BS 812 : Part 112 : 1990

Required equipment

- *Aggregate Impact Testing Machine*, ref. figure 1.
- *Test sieves* – square-hole perforated-plate type of sizes 14 mm and 10 mm, and a wovenwire 2.36 mm sieve.
- *Cylindrical metal measure* with an internal diameter of 75 mm and an internal depth of 50 mm.
- *Tamping rod*, steel bar 16 mm diameter and 600 mm long with both ends hemispherical
- *A sample divider, eg. a riffle box*
- *Drying oven* - with temperature of 105 °C ± 5 °C.
- *Balance* - readable to 0.1 g.
- *Rubber mallet*
- *Metal tray* of known mass
- *Brush* with stiff bristles.

Additional for testing in a soaked condition

- *Drying cloths (towels)*
- *3 no. Wire mesh basket*
- *Watertight container*
- *Supply of clean water*

Sample preparation

If the material is dusty, it should be washed before testing.

Step 1: Reduce the sample to produce a test portion of sufficient mass to produce three test specimens of 14 mm to 10 mm size fraction, ref. Table 1 below.

Aggregate Impact Value - AIV

Notes

Table 10. Guide to minimum mass of test portions required to obtain a suitable mass of material to determine the AIV

Grade of the aggregate mm	Minimum mass of the test portion * kg
All-in aggregate 0-40 mm max. size	20
All-in aggregate 0-20 mm max. size	15
Graded aggregate 40 to 5 mm	12
Graded aggregate 20 to 5 mm	8
Graded aggregate 14 to 5 mm	5

* For normal density aggregate

Step 2: Sieve the entire dried test portion on the 14 mm and 10 mm sieves to remove the oversize and undersize fractions.

Step 3: Divide the resulting 14 mm – 10 mm fraction to produce three test specimens each of sufficient mass to fill the entire Cylindrical Metal Measure.

Step 4: The test specimens shall be oven-dried at 105 ± 5°C for not more than 4 hours. Allow to cool before testing.

Step 5: Fill the measure to overflowing with the aggregate. Tamp the aggregate with 25 evenly distributed blows of the rounded end of the tamping rod, each blow letting the tamping rod fall freely from about 50 mm above the surface of the aggregate.

Step 6: Remove surplus aggregate by rolling the tamping rod across the container. Remove by hand any aggregate which impedes its progress, and fill any obvious depressions with added aggregate. Record the net mass of aggregate in the measure and use the same mass for the second test specimen.

For soaked condition

Step 7: Each of the three test specimens shall be placed in the wire basket and immersed in water. The water level in the container shall be at least 50 mm above the top of the baskets. Immediately after immersion remove entrapped air by lifting the baskets 25 mm above the base of the container and allowing it to drop 25 times. Keep the baskets immersed for 24 ± 2 hours.

Step 8: After soaking, remove the specimen of aggregate from the basket and dry the free water from the surface.

TEST NO. 2.8

Aggregate Impact Value - AIV

Test Procedure

Dry condition

Step 1: Place the impact machine upon the level plate, block or floor, so that it is rigid and the hammer guide columns are vertical. Fix the cup in position and place the test specimen in it and compact by 25 strokes of the tamping rod. Adjust the height of the hammer so that it is 380 ± 5 mm above the upper surface of the aggregate in the cup.

Step 2: Let the hammer fall freely on to the aggregate to achieve a total of 15 blows at intervals of not less than 1 s.

Notes

No further adjustment for hammer height is required during the test.

If this fails to remove the compacted aggregate, other methods should be used taking care not to crush the particles.

Step 3: Remove the crushed aggregate by holding the cup over a clean tray and hammering on the outside with the rubber mallet until the particles are sufficiently loose to enable the specimen to fall freely on to the tray. Use a brush to remove the fine particles adhering to the inside of the cup and the underside of the hammer.

Step 4: Weigh the tray and the aggregate and record the mass of aggregate used (M_1) to the nearest 0.1 g.

Step 5: Sieve the whole specimen in the tray on the 2.36 mm sieve until no further significant amount passes. Weigh and record the masses of the fraction passing and retained on the sieve to the nearest 0.1 g ($M_2 + M_3$ respectively). If the total mass ($M_2 + M_3$) differs from the initial mass M_1 by more than 1 g, discard the result and test a further specimen.

Step 6: Repeat the procedure using a second specimen of the same mass as the first specimen.

Soaked Condition

The number of blows will usually be less than 15, but the actual number has to be determined by trial and error. Therefore more than two test specimens will usually be required. Once the number of blows has been determined, the procedure is repeated on a second test specimen using the same number of blows.

Step 7: Follow the test procedure described above in Steps 1 and 2, except that the number of blows of the hammer is the number of blows that yield between 5 % and 20 % fines. However, 15 blows may also be used for the soaked condition

Step 8: Remove the crushed specimen from the cup and dry it in the oven at a temperature of 105 ± 5°C for at least 12 hours. Allow the material to cool and weigh to the nearest 0.1 g and record the mass of the test specimen (M_1). Complete the procedure as described in Steps 5 and 6 above.

Notes

Calculations

Dry Condition

Calculate the Aggregate Impact Value (AIV) expressed as a percentage to the first decimal place for each test specimen from the following equation:

$$AIV = \frac{M_2}{M_1} \times 100$$

where

M_1 is the mass of the test specimen (in g)
M_2 is the mass of the material passing the 2.36 mm sieve (in g).

Soaked Condition

Calculate the mass of the fines m expressed as a percentage of the total mass for each test specimen from the following equation:

$$m = \frac{M_2}{M_1} \times 100$$

where

M_1 is the mass of the oven-dried test specimen (in g)
M_2 is the mass of the oven-dried material passing the 2.36 mm sieve (in g).

Calculate the Aggregate Impact Value (AIV) expressed as a percentage to the first decimal place for each test specimen from the equation:

$$AIV = \frac{15\,m}{n}$$

where

n is the number of hammer blows to which the specimen is subjected.

If 15 blows were used:

$$AIV = m = \frac{M_2}{M_1} \times 100$$

The ratio between dry and soaked AIV may then be regarded as an indication of durability for soft aggregates.

For both the Dry condition and the Soaked condition the mean of the two values shall be determined to the nearest whole number. The mean is reported as the Aggregate Impact Value, unless the individual results differ by more than 15 % of the mean value. In this case the test shall be repeated for two more specimens. The median value shall be reported as the AIV.

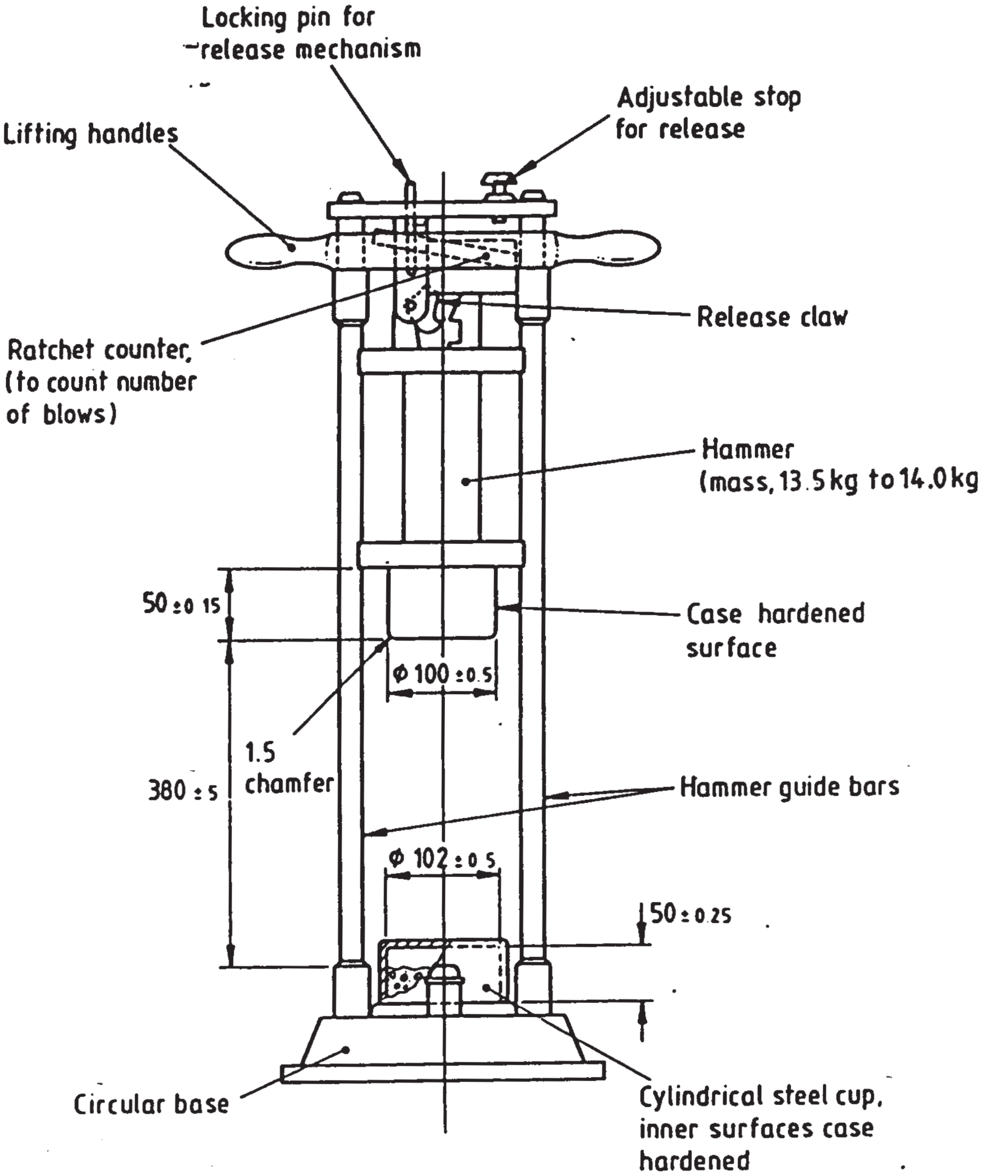
The median of 4 results is calculated by disregarding the highest and lowest result and averaging the two middle results.

Report

The test report shall include the following:

a) Type of material and sample identification
b) Reference to this procedure
c) The test condition of the aggregates, i.e. dry or soaked condition
d) The AIV of the dry aggregate
e) The AIV of the soaked aggregate, stating the number of blows of the hammer that was used in the test
f) Ratio between dry and soaked AIV (if required)

If the AIV is greater than 30 % the test result should be treated with caution.



All linear dimensions are in millimetres.

Figure 5 Aggregate Impact Value Apparatus

CENTRAL MATERIALS LABORATORY

WORKING SHEET

Aggregate Impact Value
AIV

Project	**Location**	**Depth**
Client	**Lab.nr**	**Date**
Responsible Technician	**Checked**	**Approved**

TEST METHOD CML TEST 2.8, ref. BS 812 : Part 112 : 1990

TEST CONDITION	
DRY	
SOAKED	

Fraction tested	Separating sieve		
14 - 10 mm	**2.36 mm**		**STANDARD**
10 - 6.3 mm	1.70 mm		
6.3 - 5.0 mm	1.18 mm		
5.0 - 3.35 mm	850 µm		
3.35 mm - 2.36 mm	600 µm		

Specimen reference					
Number of blows (normally 15 blows)	n				
Mass of tray + test specimen (g)					
Mass of tray alone (g)					
Mass of original test specimen (g)	M_1				
Mass of tray + material passing separating sieve (g)					
Mass of tray alone (g)					
Mass of material passing separating sieve (g)	M_2				
Mass of tray + material retained on separating sieve					
Mass of tray alone (g)					
Mass of material retained on separating sieve (g)	M_3				
Mass passing and retained on separating sieve - check versus M_1	$M_2 + M_3$				
Aggregate Impact Value (in %) - DRY	$\frac{M_2}{M_1} \times 100$				
Aggregate Impact Value (in %) - SOAKED	$\frac{M_2}{M_1} \times \frac{15}{n} \times 100$				
AIV - mean value	%				
AIV - median value	%				

TEST NO. 2.9

Los Angeles Abrasion test - LAA

Notes

A procedure for testing coarse aggregates larger than 19 mm is covered in Test Method ASTM C 535 – 89 using the same equipment.

Backlash or slip in the driving mechanism is very likely to furnish test results which are not duplicated by other LA machines producing constant peripheral speed.

Objective

The objective of the test is to assess the hardness of coarse aggregates used in pavement construction. Due to the movement of traffic, the road stones used in the surface course are subjected to wearing action at the top. Resistance to wear or hardness is hence an essential property for road aggregates, especially when used in wearing course.

This test method covers a procedure for testing sizes of coarse aggregates, e.g. for surface dressing, smaller than 37.5 mm for resistance to degradation using the Los Angeles testing machine.

Main Principles

The Los Angeles test is a measure of degradation of mineral aggregates of standard gradings resulting from a combination of actions including abrasion, impact and grinding in a rotating steel drum containing a specified number of steel spheres. As the drum rotates, a shelf plate picks up the sample and the steel spheres, carrying them around until they are dropped to the opposite side of the drum, creating an impact/crushing effect. The contents then roll within the drum with an abrading and grinding action until the shelf plate impacts and the cycle is repeated.

After the prescribed number of resolutions, the contents are removed from the drum and the aggregate portion is sieved to measure the degradation as a percent loss.

References

ASTM C 131 - 89

Required equipment

- *Los Angeles Testing Machine* – The machine consists of a hollow rotating steel cylinder, closed at both ends, with an inside diameter of 711 mm and an inside length of 508 mm. An opening with a dust tight cover are provided for the introduction of the test sample. A steel shelf is extending the full length of the cylinder and projecting inward 89mm.
- The machine shall be so driven and counterbalanced as to maintain a substantially uniform peripheral speed.
- *Test sieves* - sizes 1.70 mm, 2.36 mm, 4.75 mm, 6.3 mm, 9.5 mm, 12.5 mm, 19.0 mm, 25.0 mm and 37.5 mm.
- *Drying oven* - with temperature of 105 °C to 110 °C
- *Balance* - readable to 1.0 g.
- *Charge* - The charge shall consist of steel spheres averaging approximately 46.8 mm (46.0 – 47.6 mm) in diameter and with mass between 390 g and 445 g.
- The charge, depending on the grading of the sample as described in *Table 12* shall be as follows:

TEST NO. 2.9

Los Angeles Abrasion test - LAA

Notes

Grading	Number of Spheres	Mass of Charge, g
A	12	5000 ± 25
B	11	4584 ± 25
C	8	3330 ± 20
D	6	2500 ± 15

Table 11

Sample preparation

Step 1: The test sample shall be washed and oven-dried at 105 °C to 110 °C to substantially constant mass.

Step 2: The sample shall be separated into individual size fractions and recombined to the grading of *Table 12* most nearly corresponding to the range of sizes in the aggregate as furnished for the work.

Step 3: The mass of the sample shall prior to test shall be recorded to the nearest 1 g (m_1).

Test Procedure

The material must be allowed to cool down before it is transferred to the Los Angeles drum.

If the aggregate is essentially free of adherent coatings and dust, the requirements for washing before and after the test may be waived.

Step 1: Place the test sample and the charge in the Los Angeles testing machine and rotate the machine at a speed of 30 to 33 rpm for 500 revolutions.

Step 2: After the 500 revolutions, discharge the material from the machine and make a preliminary separation of the sample in a sieve coarser than the 1.70 mm sieve. Sieve the finer portion on a 1.70 mm sieve.

Step 3: Wash the material coarser than 1.70 mm sieve.

Step 4: Oven-dry at 105 °C to 110 °C to substantially constant mass, and weigh to the nearest 1 g (m_2).

Calculations

1) Express the loss (difference between the original mass (m_1) and the final mass (m_2) of the test sample as a percentage of the original mass of the test sample, from the equation:

$$\text{LAA value} = \left(\frac{m_1 - m_2}{m_1}\right) \times 100\ (\%)$$

Report

The test report shall include the following:

a) Type of material and sample identification
b) Reference to this procedure
c) Test result, i.e. the *LAA value* of the test sample. Report the value as the percentage loss.
d) Whether the material was tested in the natural state or after sieving.

Form for the test

The enclosed form shall be used.

Los Angeles Abrasion test - LAA

Notes

Precision

The Los Angeles test has been widely used as an indicator of the relative quality of various sources of aggregate having similar mineral compositions. The results do not automatically permit valid comparisons to be made between sources distinctly different in origin, composition or structure. Specifications limits based on this test should be assigned with extreme care in consideration of available aggregate types and their performance history in specific end uses.

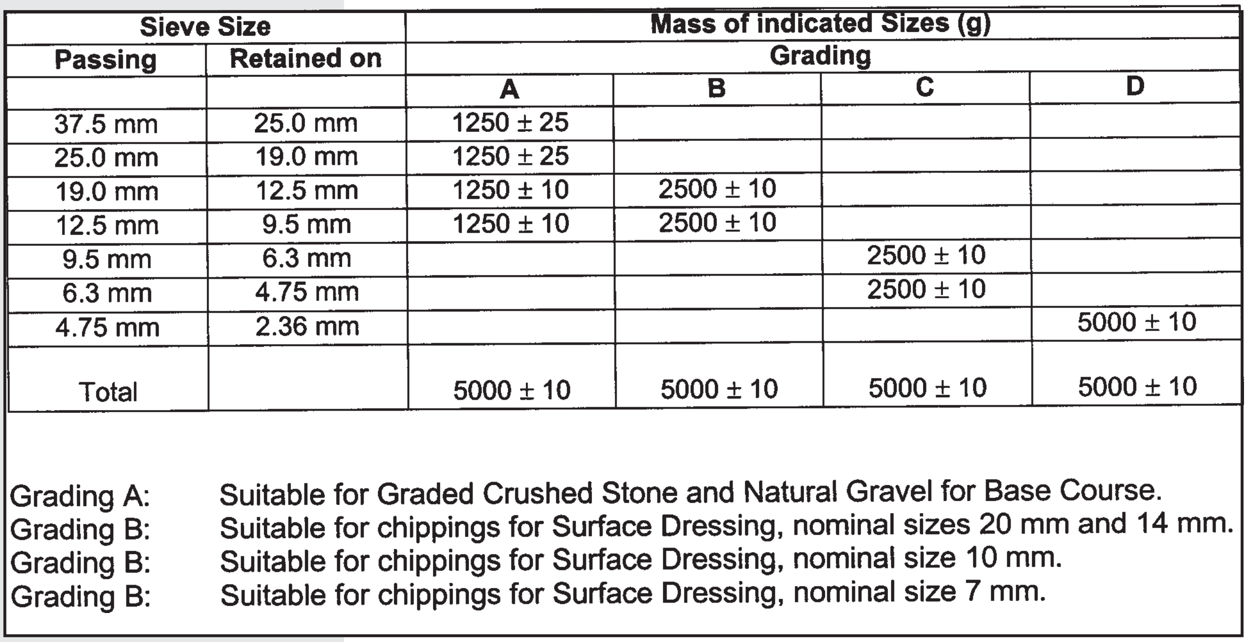
Practical Considerations

As the test is extremely noisy, hearing protection is strongly recommended for the operators.

Rusty spares should not be used.

Maintenance

The steel spheres are subject to heavy wear, and their mass must be checked regularly.



Sieve Size		Mass of indicated Sizes (g)			
Passing	Retained on	Grading			
		A	B	C	D
37.5 mm	25.0 mm	1250 ± 25			
25.0 mm	19.0 mm	1250 ± 25			
19.0 mm	12.5 mm	1250 ± 10	2500 ± 10		
12.5 mm	9.5 mm	1250 ± 10	2500 ± 10		
9.5 mm	6.3 mm			2500 ± 10	
6.3 mm	4.75 mm			2500 ± 10	
4.75 mm	2.36 mm				5000 ± 10
Total		5000 ± 10	5000 ± 10	5000 ± 10	5000 ± 10

Grading A: Suitable for Graded Crushed Stone and Natural Gravel for Base Course.
Grading B: Suitable for chippings for Surface Dressing, nominal sizes 20 mm and 14 mm.
Grading B: Suitable for chippings for Surface Dressing, nominal size 10 mm.
Grading B: Suitable for chippings for Surface Dressing, nominal size 7 mm.

Table 12 Grading of theTest Samples

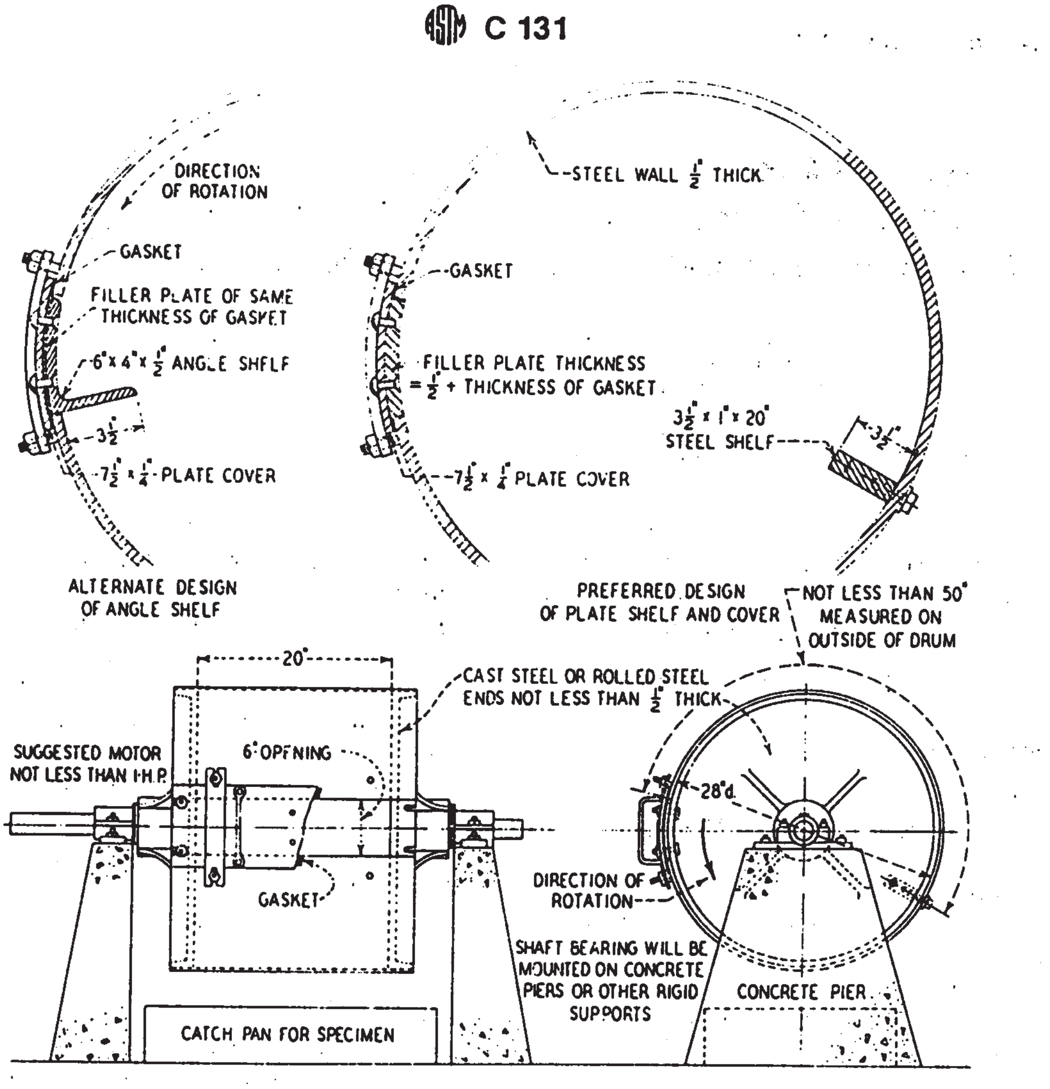


Figure 6 Los Angeles Testing Machine

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WORKING SHEET

Los Angeles Abrasion Test (LAA)

Project	**Location**	**Depth**
Client	**Lab.no**	**Date**
Responsible Technician	**Checked**	**Approved**

TEST METHOD CML TEST 2.9, ref. ASTM C 539 - 89

Sieve Size		Mass of indicated Sizes (g)			
Passing	Retained on	Grading			
		A	**B**	**C**	**D**
37.5 mm	25.0 mm	1250 ± 25			
25.0 mm	19.0 mm	1250 ± 25			
19.0 mm	12.5 mm	1250 ± 10	2500 ± 10		
12.5 mm	9.5 mm	1250 ± 10	2500 ± 10		
9.5 mm	6.3 mm			2500 ± 10	
6.3 mm	4.75 mm			2500 ± 10	
4.75 mm	2.36 mm				5000 ± 10
Total		5000 ± 10	5000 ± 10	5000 ± 10	5000 ± 10

Sample reference					
Sample description					
Grading used					
Mass of sample before test (m_1)	g				
Mass retained on sieve size 1.70 mm (m_2)	g				
Mass passing sieve size 1.70 mm $(m_1 - m_2)$	g				
LAA Value $\left(\frac{m_1 - m_2}{m_1}\right) \times 100$	%				

TEST NO. 2.10

Soundness of Aggregates by use of Sodium Sulphate

Notes

Objective

The objective of the test is to provide a procedure for making a preliminary estimate of the soundness of aggregates subject to weathering action for use in concrete and road pavements.

Main Principles

The Soundness test by use of Sodium Sulphate covers the testing of aggregates to estimate their soundness when subjected to weathering. This is accomplished by repeated immersion in saturated solutions of sodium sulphate followed by oven drying to partially or completely dehydrate the salt precipitated in permeable pore spaces. The internal expansive force, derived from the rehydration of the salt upon re-immersion, simulates the expansion of water on freezing. The test method furnishes information helpful in judging the soundness of aggregates when adequate information is not available from service records of the material exposed to actual weathering conditions.

References

ASTM C 88 - 90

Required equipment

ASTM sieves must be used for this test.

- *Test sieves* - sizes 150 µm, 300 µm, 600 µm, 1.18 mm, 2.36 mm, 4.00 mm, 4,75 mm, 8,0 mm, 9,5 mm, 12.5 mm, 16,0 mm, 19.0 mm, 25.0 mm, 31,5 mm, 37.5 mm, 50 mm, and 63 mm.
- *Drying oven* - with temperature of 110 ± 5 °C.
- *Balance* - for fine aggregate, readable to 0.1 g and for coarse aggregate readable to 1.0 g.
- *Containers* - for immersing the samples of aggregate in solution. The containers shall be perforated to permit free access of the solution to the sample and drainage from the sample without loss of aggregate, e.g. baskets made of wire mesh or sieves with suitable apertures.
- *Specific Gravity Measurement* - Hydrometers or a suitable combination of graduates glassware and balance, capable of measuring the solution specific gravity within ± 0.001.

Special Solution Required

A solution of *Sodium Sulphate* for the immersion of test samples is required.

The use not less than 350 g of the anhydrous salt or 750 g of the decahydrate salt per litre of water is recommended.

Step 1: Prepare a saturation solution of sodium sulphate by dissolving USP or equal grade of salt in water at a temperature of 25 to 30 °C. Add sufficient salt of either the anhydrous salt (Na_2SO_4) or the crystalline decahydrate salt ($Na_2SO_4 \cdot 10H_2O$) to ensure not only saturation but also the presence of excess crystals when the solution is ready for use in the tests.

Notes

Step 2: Thoroughly stir the mixture during the addition of the salt and stir the solution at frequent intervals until used. To reduce evaporation and prevent contamination, keep the solution covered at all times when not in use.

Store in the cold room with air conditioning.

Step 3: Allow the solution to cool to 21 ± 1 °C. Again stir, and allow the solution to remain at the designated temperature for at least 48 hours before use. Prior to each use, break up the salt cake, if any, in the container. Stir the solution thoroughly and determine the specific gravity of the solution. When used, the solution shall have a specific gravity between 1.151 and 1.174. Discard a discoloured solution, or filter it and check for specific gravity.

Samples

Fine Aggregate - Fine aggregate for the test shall be passed through a 9.5 mm sieve. The sample shall be of such size that it will yield not less than 100 g of each of the following fractions, which shall be available in amount of 5 % or more each.

Passing sieve	Retained on sieve
600 μm	300 μm
1.18 mm	600 μm
2.36 mm	1.18 mm
4.75 mm	2.36 mm
9.5 mm	4.75 mm

Table 13

Coarse Aggregate - Coarse aggregate for the test shall consist of material from which material finer than 4.75 m have been removed. The sample shall be of such a size that it will yield the following amounts of the indicated fractions that are available in 5 % or more:

Passing sieve	Retained on sieve	Mass (in g)
9.5 mm	4.75 mm	300 ± 5
19.0 mm	9.5 mm	1000 ± 10
Consisting of:		
12.5 mm	9.5 mm	330 ± 5
19.0 mm	12.5 mm	670 ± 10
37.5 mm	19.0 mm	1500 ± 50
Consisting of:		
25.0 mm	19.0 mm	500 ± 30
37.5 mm	25.0 mm	1000 ± 50
63 mm	37.5 mm	5000 ± 300
Consisting of:		
50 mm	37.5 mm	2000 ± 200
63 mm	50 mm	3000 ± 300

Table 14

TEST NO. 2.10

Soundness of Aggregates by use of Sodium Sulphate

Notes

When an aggregate to be tested contains appreciable amounts of both fine and coarse aggregate, i.e. more than 10 % mass coarser than 9.5 mm and 10 % mass finer than 4.75 mm, Test separate samples of the minus 4.75 mm fraction and the plus 4.75 mm fraction. Report the test results separately for the fine-aggregate fraction and the coarseaggregate fraction, giving the percentages of the coarse- and fine-size fractions in the initial grading.

Preparation of Test Sample

Fine Aggregate

Step 1: Thoroughly wash the sample on a 300 μm sieve.

Step 2: Dry to constant weight at 110 ± 5 °C.

Do not use fine aggregates sticking in the meshes of the sieves in preparing the samples.

Step 3: Separate into the different fractions as follows:
Make a rough separation of the graded sample by means of a nest of the standard sieves specified in Table 1. From the fractions obtained in this manner, select samples of sufficient size to yield 100 g after sieving to refusal.

Step 4: Weigh samples consisting of 100 ± 0.1 g out of each separate fractions, and place in separate containers for the test.

Coarse Aggregate

Step 1: Thoroughly wash and dry the sample of coarse aggregate to constant mass at 110 ± 5 °C.

Step 2: Separate into the different fractions shown in Table 2.

Step 3: Weigh out quantities of the different fractions within the tolerances of Table 2. Where the test portion consists of two fractions, combine them to the designated total mass. Record the mass of the test samples and their fractional components.

Step 4: In the case of sizes larger than 19.0 mm, record the number of particles in the test samples.

Test Procedure

Cover the container to reduce evaporation.

Step 1: Immerse the samples in the prepared solution of *Sodium Sulphate* for 16 – 18 hours, in such a manner that the solution covers them to a depth of at least 15 mm. The temperature of the solution should be kept at 21 ± 1 °C.

Step 2: After the immersion period, remove the aggregate sample from the solution, permit to drain for 15 ± 5 min., and place in the drying oven.

TEST NO. 2.10

Soundness of Aggregates by use of Sodium Sulphate

Notes

Check the losses in mass of the test samples by removing and weighing them without cooling at intervals of 2 to 4 hours.

Step 3: Dry the samples at the temperature of 110 ± 5 °C until constant mass has been achieved.

Step 4: After constant mass has been achieved, allow the samples to cool to room temperature, when they shall again be immersed in the prepared solution.

The number of cycles shall be decided by the Engineer.

Step 5: Repeat the process of alternative immersion and drying until the required number of cycles is obtained.

Quantitative Examination

Step 1: After completion of the final cycle and after the sample has cooled, wash the sample free from the *Sodium Sulphate* as determined by the reaction of the wash water with *Barium Chloride* ($BaCl_2$). Wash by circulating water at 43 ± 6 °C through the samples in their containers. This may be done by placing them in a tank where the hot water can be introduced near the bottom and allowed to overflow.

During washing the samples shall not be subjected to impact or abrasion that may tend to break up particles.

Step 2: After the Sodium Sulphate has been removed, dry each fraction of the sample to constant mass at 110 ± 5 °C.

Step 3: Sieve the fine aggregate over the same sieve on which it was retained before the test. The method and duration of sieving shall be the same as were used when preparing the samples.

No extra manipulation shall be employed to break up particles.

Step 4: Sieve the coarse aggregate over the sieve shown below for the appropriate size of particle. Sieving shall be by hand, with agitation sufficient only to assure that all the undersize material passes the designated sieve.

Aggregate Passing	Aggregate Retained	Sieve to be used to Determine Loss
63 mm	37.5 mm	31.5 mm
37.5 mm	19.0 mm	16.0 mm
19.0 mm	9.5 mm	8.0 mm
9.5 mm	4.75 mm	4.0 mm

Table 15

Step 5: Weigh the material retained on each sieve and record each amount. The difference between each of these amounts and the initial mass of the fraction of the sample tested is the loss in the test, and is to be expressed as a percentage of the initial mass for use in Table 3.

Qualitative Examination

Step 1: For the test samples coarser than 19.0 mm, separate the particles of each test sample into groups according to the action produced by the test, refer to Table 4.

Notes

Step 2: Record the number of particles showing each type of distress.

Report

The test report shall include the following:

a) Type of material and sample identification
b) Reference to this procedure
c) Mass of each fraction of each sample before the test.
d) Material from each fraction of the sample finer than the sieve designated for sieving after the test, expressed as a percentage of the original mass of the fraction.
e) Weighted average calculated from the percentage loss of each fraction, based on the grading of the sample as received for examination, except that:
f) for *Fine Aggregates* assume sizes finer than the 300 µm sieve to have 0 % loss and sizes coarser than the 9.5 mm sieve to have the same loss as the next smaller size for which test data is available.
g) for *Coarse Aggregates* assume sizes finer than the 4.75 mm sieve to have the same loss as the next larger size for which test data are available.
h) For an aggregate containing appreciable amounts of both fine and coarse material tested as two separate samples, compute the weighted average losses separately for the minus 4.75 mm and plus 4.75 mm fractions based on recomputed gradings considering the fine fraction as 100 % and the coarse fraction as 100 %. Report the results separately giving the percentage of the minus 4.75 mm and plus 4.75 mm material in the initial grading.
i) For the purpose of calculating the weighted average, consider any sizes that contain less than 5 % of the sample to have the same loss as the average of the next smaller and the next larger size. If one of these sizes is absent, the size shall have the same loss as the next larger or smaller size, whichever is present.
j) Report the weighted percentage loss to the nearest whole number.
k) In the case of particles coarser than 19.0 mm before the test: The number of particles in each fraction before the test and the number of particles affected, classified as to number disintegrating, splitting, crumbling, cracking, flaking, etc., as shown in Table 4.
l) Whether the solution was freshly prepared or previously used.

Form for the test

The enclosed form shall be used.

Practical considerations

Proper and adequate safety precautions must be applied when working with chemicals.

Table 16 Form for Recording Test Data (with illustrative Test Values)

Sieve Size			Grading of original sample (in %)	Mass of test fractions before test (in g)	% passing designated sieve after test	**Weighted percentage loss**
SOUNDNESS TEST ON FINE AGGREGATE						
Passing	Retained on	**Mass (g)**				
< 150 µm			6			
300 µm	150 µm		11			
600 µm	300 µm		26	100	4.2	1.1
1.18 mm	600 µm		25	100	4.8	1.2
2.36 mm	1.18 mm		17	100	8.0	1.4
4.75 mm	2.36 mm		11	100	11.2	1.2
9.5 mm	4.75 mm		4		11.2*	0.4
TOTALS			**100**			**5**
SOUNDNESS TEST ON COARSE AGGREGATE						
63 mm	50 mm	2825 g	20			
50 mm	37.5 mm	1958 g		4783	4.8	1.0
37.5 mm	25.0 mm	1012 g	45			
25.0 mm	19.0 mm	513 g		1525	8.0	3.6
19.0 mm	12.5 mm	675 g	23			
12.5 mm	9.5 mm	333 g		1008	9.6	2.2
9.5 mm	4.75 mm	298 g	12	298	11.2	1.3
TOTALS			**100**			**8**

* The percentage loss (11.2 %) of the next smaller size is used, since this size contains less than 5 % of the original sample as received.

Table 17 Form for Qualitative Examination (with illustrative Test Values)

QUALITATIVE EXAMINATION OF COARSE SIZES										
Particles Exhibiting Distress										
Sieve Size		Splitting		Crumbling		Cracking		Flaking		Total no. of particles before test
Passing	Retained	No.	%	No.	%	No.	%	No.	%	
63 mm	37.5 mm	2	7	0	0	2	7	0	0	29
37.5 mm	19.0 mm	5	10	1	2	4	8	0	0	50

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WORKING SHEET

Sodium Sulphate Soundness
SSS

Project	**Location**	**Depth**
Client	**Lab.no**	**Date**
Responsible Technician	**Checked**	**Approved**

TEST METHOD CML TEST 2.10, ref. ASTM C88 - 90

Sieve Size			Grading of original sample (in %)	Mass of test fractions before test (in g)	Passing designated sieve after test (in %)	**Weighted Percentage Loss**
SOUNDNESS TEST ON FINE AGGREGATE						
Passing	Retained on					
< 150 µm						
300 µm	150 µm					
600 µm	300 µm					
1.18 mm	600 µm					
2.36 mm	1.18 mm					
4.75 mm	2.36 mm					
9.5 mm	4.75 mm					
TOTAL			**100**			
SOUNDNESS TEST ON COARSE AGGREGATE						
Passing	Retained on	Mass (in g)	%			
63 mm	50 mm					
50 mm	37.5 mm					
37.5 mm	25.0 mm					
25.0 mm	19.0 mm					
19.0 mm	12.5 mm					
12.5 mm	9.5 mm					
9.5 mm	4.75 mm					
TOTAL			**100**			

Number of immersion/drying cycles* * normally 5 cycles	

QUALITATIVE EXAMINATION OF COARSE SIZES

Particles Exhibiting Distress

Sieve Size		Splitting		Crumbling		Cracking		Flaking		Total no. of particles before test
Passing	Retained	No.	%	No.	%	No.	%	No.	%	
63 mm	37.5 mm									
37.5 mm	19.0 mm									

TEST NO. 2.11

Slump Test

Notes

Objective

The Slump Test is one of several method for determining the workability of fresh concrete.

Main Principles

The slump test is carried out by filling a specified mould with freshly mixed concrete and measuring the slump after removal of the mould.

The method applies to cohesive concrete of medium to high workability, and with maximum aggregate size of 40 mm.

References

BS 1881 : Part 102 : 1983.

Required equipment

- A slump mould of galvanized iron or steel. The mould shall be in the form of a cut-off cone with the following internal dimensions:
  - diameter of base: 200 ± 2 mm
  - diameter of top: 100 ± 2 mm
  - height: 300 ± 2 mm
- Scoop
- Sampling tray
- Shovel
- Tamping rod, made out of straight steel bar, 16 mm diameter and 600 mm long.
- Rule, graduated from 0 mm to 300 mm at 5 mm intervals, the zero point being at one end of the rule.

Sampling

The sample can be taken from a laboratory mix maximum 2 minutes after mixing, and determination of slump should commence instantly.

If the concrete is delivered in a mixing truck, the slump may be measured using a sample from the initial discharge.

Test Procedure

The test should be carried out at a location free from vibration and shocks.

Step 1: Ensure that the inner surface of the mould is clean and damp or dry. Place the bottom of the mould on a clean, smooth, horizontal, firm an non-absorbent surface (e.g. a steel plate.

Step 2: While firmly holding the mould, fill it with fresh concrete within 2 minutes after mixing. The mould shall be filled in three layers, each approximately one-third of the height of the mould when tamped.

Be careful not to tamp the base under the mould forcibly.

Step 3: Tamp each layer with 25 strokes of the tamping rod, the strokes being distributed uniformly over the cross-section of the layer. Tamp each layer to its full depth.

Slump Test

Notes

Step 4: Heap the concrete above the mould before the top layer is tamped. After the top layer have been tamped, strike off the concrete level with the top of the mould with a sawing motion of the tamping rod.

Step 5: With the mould still held down, clean away excess concrete found the outside of the mould.

Step 6: Remove the mould from the concrete by raising it vertically, slowly and carefully, in 5 to 10 seconds. The entire operation from the start of filling to the removal of the mould shall be carried out without interruption and shall be completed within 2 ½ minutes.

The workability of a concrete mix changes with time due to the hydration of the cement and loss of moisture. Tests on different samples should, therefore, be carried out at a constant time interval after mixing if strictly comparable results are to be obtained.

Step 7: Immediately after the mould is removed, measure the slump to the nearest 5 mm by using the rule to determine the difference between the height of the mould and of the highest point of the specimen being tested.

Expression of results

The test is only valid if it yields a true slump. This being a slump in which the concrete remains substantially intact and symmetrical as shown in Figure 1(a).

If the specimen shears, as shown in Figure 1(b), or collapses, as shown in Figure 1(c), take another sample and repeat the procedure.

Normal concrete may be expected to have a slump of 80 - 150 mm.

Record the slump to the nearest 5 mm.

Report

The test report shall include the following information:

TMH1 performs the test in triplicate and reports the Slump as the mean result of three tests.

a) Reference to this procedure
b) Date, time and place of sampling and sample identification
c) Time and place of test
d) Time lapse from sampling to commencement of test
e) Form of slump, whether ***true*, *shear*** or ***collapse***
f) Measured true ***Slump***

Form for the test

The enclosed form shall be used.

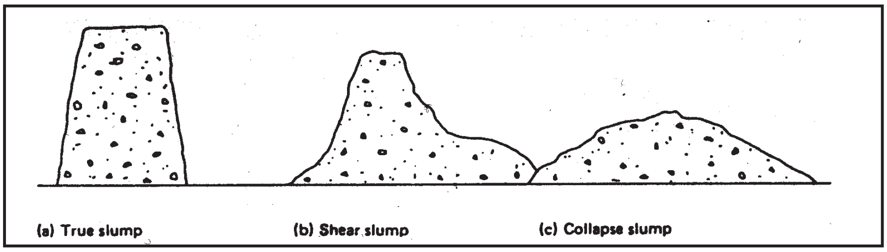

Figure 1 Forms of slump

CENTRAL MATERIALS LABORATORY

WORKING SHEET

Slump Test

Project	**Location**	**Contractor**
Client	**Lab.no**	**Date**
Responsible Technician	**Checked**	**Approved**

TEST METHOD CML TEST 2.11, ref. BS 1881 : Part 102 : 1983

Construction part:	Concrete Class:

Sampling

Time	Date	Operator

Time lapse from sampling to testing: .... minutes

Sample ID	Pore Volume (%)	Air Temp. (°C)	Concrete Temp. (°C)	Form of Slump	SLUMP	
				True, Shear or Collapse	Measured (cm)	Design (cm)

TEST NO. 2.12

Making Test Cubes from Fresh Concrete

Notes

Objective

This method describes the making of concrete test cubes for testing for compressive strength.

Main Principles

The test cubes shall have nominal sizes of 100 mm or 150 mm. The maximum size of aggregate is 20 mm for 100 mm cubes and 40 mm for 150 mm cubes.

References

BS 1881 : Part 108 : 1983.

Required equipment

For further details of tolerances, ref. BS 1881:Part 108.

- Mould of cast iron or steel, with removable base plate.
  The depth of the mould and the distance between the two pairs of opposite internal side faces, shall be the nominal size of 100 ± 0.15 mm or 150 ± 0.15 mm .
- Scoop
- Vibrating table or steel compacting bar weighing 1.8 kg, 380 mm long and having a ramming face 25 mm square.
- Plasterer’s steel float
- Sampling tray
- Shovel

Mixing

The actual ambient temperature will determine the mixing and curing conditions. However, exposure to direct sunlight must be avoided.

Step 1: Air-dry the aggregate to be used and bring it to temperature preferably about 25 °C. Mix the cement thoroughly and bring it to a temperature preferably about 25 °C. Portion the material by mass to the nearest 0.5 %.

If hand mixing: mix the dry cement and fine aggregate before adding the coarse aggregate and finally the water in increments.

Step 2: Mix the concrete in a mixing machine. Load the mixing drum with coarse aggregate, fine aggregate, cement and add water slowly. Continue mixing until the concrete is uniform in appearance, but not for less than 2 minutes after all material is in the drum.

Sampling

Obtain a sample of fresh concrete either from the laboratory made batch or from a mix at a building site. The sample shall be thoroughly mixed just before it is moulded.

From each sample of fresh concrete there shall be made 2 test cubes specimens.

Moulding

Step 1: Place the moulds on a rigid horizontal surface or on the vibrating table. Fill with concrete in layers of approximately 50 mm deep and compact each layer by the compacting bar or the vibrating table.

Making Test Cubes from Fresh Concrete

Notes

When the slump is less than about 100 mm, the compacting bar is not suitable. The use of the vibrating table is then recommended.

Over-compaction may cause unwanted excessive segregation.

If the cubes are made on Site, the specimens should be stored at Site at as optimum conditions as possible for 24 hours. Then mark them and take them to the laboratory. Remove the specimens from their moulds and immerse them in water.

The normal curing period is 28 days.

When compacting with a ***compacting bar,*** distribute the strokes evenly over the cross-section of the mould without penetrating any previous layer significantly. Use 35 strokes per layer for 150 mm cubes or 25 strokes per layer for 100 mm cubes.

When using a ***vibrating table,*** compact until the surface of the concrete becomes relatively smooth and has aglazed appearance.

Curing

Step 1: Cover the test cubes (in the moulds) with an impervious sheet and store them in a place free from vibrations. The room shall have a relative humidity preferably of min. 90 % and a temperature preferably about 25 °C.

Step 2: After an initial curing period of 24 hours, mark each cube so that it can clearly be identified, and remove it carefully from the mould.

Step 3: Submerge the cubes immediately in water at a temperature preferably of about 25 °C

Report

The test report shall include the following information:

a) Reference to this procedure
b) Date, time and place of sampling and sample identification
c) Time and place of making cubes
d) Temerature of mixing and curing conditions
e) Number and nominal size of cubes
f) Method of compaction

Form for the test

The enclosed form shall be used.

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WORKING SHEET

Making of Concrete Cubes

Project	**Location**	**Contractor**
Client	**Lab.no**	**Date**
Responsible Technician	**Checked**	**Approved**

TEST METHOD	CML TEST 2.12, ref. BS 1881 : Part 108 : 1983		
Construction part:			
Conditions of curing: Soaked / Air dry	Sampling		
Condition at testing: Saturated / Air dry	Time:	Date:	Operator:
Cement Type:	Concrete Class:		
Additive:	Aggregate:		
Metod of Compaction:			

Cube marking	Cube Size W x D x H (mm x mm x mm)	Mass of Cube (g)	Density (g/dm^3)	Test Load (kN)	Date made	Date tested	Age of Cube (Days)	Cube Strength MPa	Type of failure

TEST NO. 2.13

Concrete Cube Strength

Objective

All concrete design is based on a specific strength of concrete. This may vary from project to project, but is usually in the range from 15 MPa – 50 MPa.

This procedure describes the method for determining the compressive strength of concrete cubes. The Concrete Strength is normally tested at an age of 28 days.

Main Principles

Test specimens shall be concrete cubes made, cured and stored in accordance with BS 1881. Do not test cubes which have been made in badly assembled moulds or which are clearly misshapen. State the reasons in the test report. Remove any projecting fins.

References

BS 1881 : Part 116 : 1983.

Required equipment

- Compression Testing Machine.
- Auxiliary platens. When auxiliary platens are used, the top auxiliary platen shall rest on and be aligned with the cube.
- A balance with min. 10 kg capacity, readable and accurate to 1 g.

Notes

One test sample shall consist of two specimens of the same form and dimensions, made of one sample of fresh concrete.

Test Procedure

Step 1: Weigh each specimen, as-received or saturated.

Step 2: Check the nominal dimensions and take measured dimensions of each specimen.

Step 3: Determine the density of each specimen.

Step 4: Immerse in water, for a minimum of 5 minutes, those cubes which have not been cured in water or where the surfaces have been allowed to dry. Remove the cubes from the curing or density water tank and test while they are still wet.

Step 5: Carefully centre the cube on the lower platen and ensure that the load will be applied to two opposite cast faces of the cube.

Step 6: Without shock, apply and increase the load continuously at a nominal rate within the range 12 MPa/min. to 24 MPa/min. until no greater load can be sustained. Record the maximum load applied to the cube.

Unsatisfactory failures are usually caused by insufficient attention to the detail of the various procedures that have to be followed to make and test specimens

Type of Failure

Record any unusual features in the type of failure. Refer to figure 1 for examples of satisfactory failure and to figure 2 for examples of some unsatisfactory failures.

Calculations

Notes

1. Calculate the cross-sectional area of the cube face from the checked nominal dimensions or from measured dimensions. Calculate the compressive strength of each cube by dividing the maximum load by the cross-sectional area. Express the result to the nearest 0.5 MPa (N/mm^2).
2. Calculate the average of the test results for the two specimens of the same size and dimension, made from the same sample of fresh concrete. This is reported as the Compressive Strength of the test sample.

Report

The test report shall include the following information:

a) Reference to this procedure
b) Date, time and place of sampling and sample identification
c) Time and place of making cubes
d) Number and nominal size of cubes
e) Age of specimen at the time of testing
f) Conditions of curing and at testing (saturated or not)
g) Density of specimen
h) Compressive strength of each specimen and the Compressive strength of the test sample (i.e. the mean value of two specimens from the same sample)
i) Type of failure

Form for the test

The enclosed form shall be used.

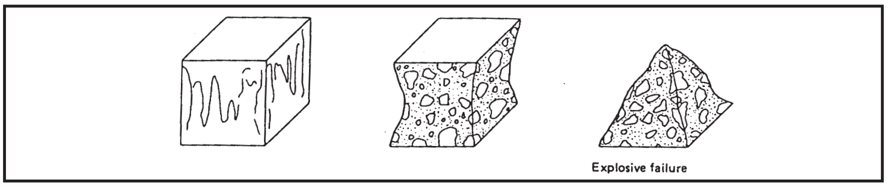
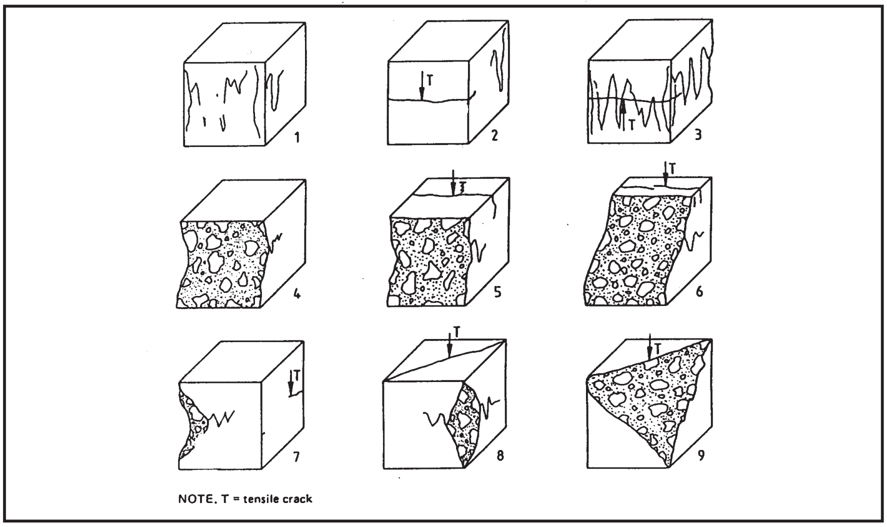


Figure 1 Satisfactory failures



NOTE. T = tensile crack

Figure 2 Some unsatisfactory failures

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WORKING SHEET

Compressive Strength
of Concrete Cubes

Project	**Location**	**Contractor**
Client	**Lab.no**	**Date**
Responsible Technician	**Checked**	**Approved**

TEST METHOD CML TEST 2.13, ref. BS 1881 : Part 116 : 1983			
Construction part:			
Conditions of curing: Soaked / Air dry	Sampling		
Condition at testing: Saturated / Air dry	Time:	Date:	Operator:
Cement Type:	Concrete Class:		
Additive:	Aggregate:		
Metod of Compaction:			

Cube marking	Cube Size W x D x H (mm x mm x mm)	Mass of Cube (g)	Density (g/dm^3)	Test Load (kN)	Date made	Date tested	Age of Cube (Days)	Cube Strength MPa	Type of failure

THE UNITED REPUBLIC OF TANZANIA MINISTRY OF WORKS	SUMMARY SHEET **CONCRETE TESTING**	CML CENTRAL MATERIALS LABORATORY

Project	**Date**	**Date**
Client	**Checked**	**Approved**

Contractor:				Construction part:		
SLUMP		Pore Volume (%)	Air Temp. (°C)	Concrete Temp (°C)	Sampling	
Measured (cm)	Design (cm)				Date:	Operator:
		Additive:			Concrete Class:	
Cement Type:				Aggregate:		

Lab. no.	Marking	Cube Dimensions W x D x H (mm x mm x mm)	Density (g/dm^3)	Date made	Date tested	Age of Cube (Days)	Compressive Strength	
							Individual (MPa)	Average (MPa)

THE UNITED REPUBLIC
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MINISTRY OF WORKS

SUMMARY SHEET

AGGREGATE TESTS

CML
CENTRAL MATERIALS LABORATORY

Project	**Date**	**Date**
Client	**Checked**	**Approved**

Location									
Lab. no									
Type of Rock									
Grading	75 mm								
	50 mm								
	28 mm								
	20 mm								
	14 mm								
	10 mm								
	5 mm								
	2 mm								
	1,18 mm								
	600 µm								
	425 µm								
	75 µm								
Dust Content	< 425 µm (%)								
Filler Content	< 75 µm (%)								
Moisture Content	%								
Plasticity Index	PI								
Specific Gravity	%								
Relative Density	ρ_d - ρ_s - ρ_a								
Water Absorption	%								
Flakiness Index	%								
ALD	mm								
Elongation Index	%								
ACV	%								
TFV (10% FACT) (soaked)	kN								
TFV (10% FACT) (dry)	kN								
AIV	%								
LAA - Los Angeles Abrasion value	% Grading:								
SSS	% loss								

Asphalt Testing

Tests on Asphalt and Bituminous Materials		
3.1	Pre-conditioning of Bitumen Samples Prior to Mixing or Testing	NPRA 014 test 14.511
3.2	Density of Bituminous Binders	ASTM D70-97
3.3	Flash and Fire Point by Cleveland Open Cup	ASTM D92-90
3.4	Thin-Film Oven Test (TFOT)	ASTM D1754-87
3.5	Penetration of Bituminous Materials	ASTM D5-86
3.6	Softening Point Test	ASTM D36-70
3.7	Ductility	ASTM D113-86
3.8	Viscosity Determination using the Brookfield Thermosel Apparatus	ASTM D4402-91
3.9	Density and Water Absorption of Aggregates Retrieved on a 4.75 mm Sieve	ASTM C127-88
3.10	Density and Water Absorption of Aggregates Passing the 4.75 mm Sieve	ASTM C128-88
3.11	Calibration of Glass Pycnometers (0.5-1 litre)	NPRA 014 test 14.5922
3.12	Mixing of Test Specimens; Hot Bituminous Mixes	NPRA 014 test 14.5532
3.13	Determination of Maximum Theoretical Density of Asphalt Mixes and Absorption of Binder into Aggregates	ASTM D2041-95 and D4469-85
3.14	Bulk Density of Saturated Surface Dry Asphalt Mix Samples	ASTM D2726-96
3.15	Bulk Density of Paraffin-Coated Asphalt Mix Samples	ASTM D1188-89
3.16	Bulk Density of Asphalt Mix Samples, Calliper Measurements	NPRA 014 test 14.5622
3.17	Calculation of Void Content in Bituminous Mixes	ASTM D3203 and AASHTO pp19-93
3.18	Marshall Test	ASTM D1559-89
3.19	Marshall Mix Design	ASTM D1559-89
3.20	Refusal Density Mix Design	TRL Overseas Road Note 31, app. D:1990
3.21	Indirect Tensile Strength Test	ASTM D3967 and NPRA 014 test 14.554
3.22	Determination of Binder Content and Aggregate Grading by Extraction	ASTM D2172-88, method B
3.23	Effect of Water on Bituminous Coated Aggregates, Boiling Test	ASTM D3625-96

TEST NO. 3.1

Preconditioning of Bitumen Samples prior to Mixing or Testing

Notes

Objective

This method describes how bituminous binders are sampled and preconditioned (prepared for testing). This includes heating, homogenizing and removal of any impurities from the bitumen.

This method does not apply to bitumen emulsion.

Main principles

Bitumen must always be heated as gently as possible. Excessive heating and heating time will change the material properties.

Heating of bituminous materials will always change the material properties to some extent. Impurities or oxidized material must be removed from the surface of the sample before heating to prepare test samples. The heating should always be minimized to prepare a representative sample.

Definitions

Laboratory sample: sample to be tested according to one or more test procedures.

Test sample: an individual test sample is obtained after preparing and splitting a laboratory sample.

References

Norwegian Public Roads Administration's guidelines for laboratory investigations, Handbook 014. Test no. 14.511.

European standard prEN12594, "*Bitumen and bituminous binders – Preparation of test samples*".

Required equipment

- Heating oven with temperature control ± 5°C or better.
- Spoon, spatula or knife
- Stirring device.
- Aluminum foil, metal lids or similar to cover sample containers and test specimens.
- Sample containers: buckets or cans with a metal lid (containers of glass can also be used)

Test procedure

General considerations

- Test samples for several tests must be prepared at the same time.
- The homogenized material must be prepared as described in each specific test procedure. All heating of bituminous materials will change the properties of the material. Test samples should for this reason never be heated more than once.
- Homogenized material prepared for later testing should be stored in full containers covered by a lid or aluminum foil. The containers should be clearly marked for later identification.
  Test samples of fresh bitumen normally do not have to be homogenized. In this case, samples can be taken out directly using a hot knife, spatula or similar. The spatula or knife should

Samples of bitumen must be covered to avoid pollution of the sample surface.

Preconditioning of Bitumen Samples prior to Mixing or Testing

Notes

not be overheated so that smoke is emitted from the material during sampling. Utilize only the quantity needed for the specific test to be performed.

Remove oxidized or polluted material.

- If the surface of the material is oxidized or polluted (dust) this must be removed. Use a hot knife or spatula that is not overheated.

Homogenizing and splitting of laboratory samples

Step 1: Oxidized or polluted surface is removed.

Heating temperature and time must be adjusted for the type of material and sample size.

Step 2: The tin/box containing the bituminous material is placed with the lid loosely fitted in an oven at a temperature of 80-90°C over the estimated softening point. Table 3.1-1 contains recommended heating temperatures for different types of bituminous materials. Maximum heating time for samples up to 1 liter is 60 minutes (120 minutes for polymer modified bitumen). Larger samples need longer heating times (e.g. a sample of 3 liters is heated for a maximum of 3.5 hours).

Take care never to incorporate water into bitumen samples. Small amounts of water may cause uncontrollable volume-expansion during heating

Step 3: Remove the tin/box from the oven and stir carefully to avoid incorporating air bubbles into the bitumen. Modified bitumen must be stirred extra thoroughly, preferably with a mechanical stirring device.

Step 4: After homogenizing, the bitumen is transferred directly to the test sample containers or molds. The test sample must never be reheated more than once.

Report

The test report shall include the following:

a) Reference to this procedure
b) Type and identification of the test sample
c) Date of conditioning
d) Heating temperature and time
e) Description of any deviations from this procedure

Practical considerations

Binder properties are to some extent affected by heating. The heating time and temperature should always be kept to a minimum to avoid excessive aging of the material. If not, the results from following tests will not be representative.

Type of binder	Temperature (°C)
Polymer modified	150-170
Bitumen < 100 pen	130-150
Bitumen 100-430 pen	115-130

Soft bitumen and Cutback bitumen	Temperature (°C)
Viscosity, 60 °C: 6000 - 20000 mm^2/s	80-100
Viscosity, 60 °C: 1000 - 6000 mm^2/s	60
Viscosity, 60 °C: < 1000 mm^2/s	20-30

Table 3.1-1 Recommended heating temperatures for different types of bituminous materials.

TEST NO. 3.2

Density of Bituminous Binders

Notes

Objective

The objective of this method is to determine the relative density and density of semi-solid bituminous materials such as bitumen.

Main principles

A sample of bituminous material is filled into a calibrated pycnometer (with known mass and volume) and weighed. The pycnometer is filled with distilled water, tempered to 25 °C and weighed. This data is used to calculate the relative density and density of the material.

Definitions

Relative density: the ratio of the mass of a given volume of material to that of an equal volume of water at the same temperature.

Density: The mass per unit volume expressed as typically g/cm^3.

References

ASTM D70-97

Required equipment

- Balance accurate to 0.01 grams (A balance accurate to 0.001 grams is required in ASTM D70. A somewhat less accurate balance will not affect the results significantly).
- Standardized pycnometers for bituminous binders, see the reference document.
- Water bath, accurate to ± 0.1 °C.
- Thermometer, accurate to ± 0.1 °C.
- Glass beaker, 600 ml low form.
- Distilled water.

Test procedure

Calibration of pycnometers

Always use distilled water.

Step 1: Fill the beaker partially with distilled water, so the pycnometer can be immersed to a depth (from water surface to top pycnometer) of minimum 40 mm.

Step 2: Place the beaker (with water) into the water bath. The distance from the bottom of the beaker to the surface of the water in the bath shall be minimum 100 mm. The top of the beaker must be above the water level in the bath. Clamp the beaker if necessary. The water bath shall hold a temperature of 25 ± 0.1 °C.

Step 3: Clean and dry the pycnometer. Weigh to the nearest 0.01 gram (including the pycnometer top). Designate this mass as *"Mass A"*.

Step 4: Fill the pycnometer with distilled water. Place the top loosely on the pycnometer and place in the beaker (standing in the water bath) at 25 ± 0.1 °C for at least 30 minutes. The water level inside the beaker must be above the top of the pycnometer.

Density of Bituminous Binders

Notes

Note: Do not remove the water droplet which may form due to expansion.

Fill pycnometer ¾ full.

Step 5 Pick up the pycnometer from the beaker, dry and weigh to the nearest 0.01 gram. Designate the mass of pycnometer and water as *"Mass B". (Note: The pycnometer top must be dried with one stroke only using a dry towel. Do not remove the water droplet which may form due to expansion).*

Determination of relative density and density

Step 6: Melt the bituminous sample until sufficiently fluid to pour. Stir gently, without incorporating air bubbles, to prevent local over heating. The heating temperature should not exceed 110 °C above the expected softening point. The heating time should not exceed 30 minutes.

Step 7: A clean, dry and preheated pycnometer is filled with the material to approximately ¾ of its capacity. Cool the pycnometer in room temperature for 40 minutes. Weigh the pycnometer, top and sample to the nearest 0.01 gram. Designate this mass as *"Mass C"*.

Step 8: Fill the pycnometer with distilled water and place in the beaker standing in the water bath. Temperate at 25 ± 0.1 °C for a minimum of 30 minutes. Dry the pycnometer (as described earlier) and weigh to the nearest 0.01 gram. Designate this mass as *"Mass D"*.

Results

Calculate the relative density to the nearest 0.001 using the following equation:

$$Relative\ density = \frac{C - A}{(B - A) - (D - C)}$$

where:

A: mass of pycnometer and top
B: mass of pycnometer filled with distilled water
C: mass of pycnometer partially filled with sample
D: mass of pycnometer plus sample plus water

Calculate the density to the nearest 0.001 using the following equation:

$$\text{Density} = \text{relative density} \times \rho_{water}$$

where:

Relative density: as determined previously
ρ_{water}: density of water at the test temperature in desired units (0.997 g/cm^3 at 25°C).

Measurements of relative density and density should be performed on two parallel samples.

Density of Bituminous Binders

Notes

Test precision

Duplicate determinations of relative density and density shall not be considered suspect unless they differ by more than the limits given in table 3.2-1.

Table 3.2-1 Test precision (based on determination of mass accurate to 0.001 g)

	One operator	Two laboratories
Relative density	0.002	0.005

Report

The test report shall include the following:

a) Reference to this procedure.
b) Type and identification of the test sample.
c) Calculated relative density and/or density to three decimal points and test temperature.
d) Test date.

e) Description of any deviations from this procedure

Maintenance

Always clean the pycnometers immediately after use.

Clean the pycnometers after use. Heat the pycnometer and pour out the sample. While still hot, clean out as much material as possible using paper tissue. Cool to room temperature and clean the remaining using solvent.

Example:

The following illustrates the determination of relative density and density of a bituminous binder at 25 °C.

Mass of empty pycnometer including top:	Mass A = 38.302 g
Mass of pycnometer (and top) filled with distilled water:	Mass B = 64.276 g
Mass of pycnometer (and top) partially filled with sample:	Mass C = 58.037 g
Mass of pycnometer (and top), sample and water:	Mass D = 64.531 g

Calculation of relative density:

$$Relative\ density = \frac{58.037 - 38.302}{(64.276 - 38.302) - (64.531 - 58.037)} = 1.013$$

Calculation of density:

$$Density = 1.013 \times 0.997 g/cm^3 = 1.010\ g/cm^3$$

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WORKING SHEET

Density of Bituminous Binders

Project	**Location**	**Depth**
Client	**Lab.no**	**Date**
Responsible Technician	**Checked**	**Approved**

Test temperature: °C

Pycnometer no.			
Mass A	Mass of pycnometer and top (grams)		
Mass B	Mass of pycnometer filled with distilled water (grams)		
Mass C	Mass of pycnometer partially filled with sample (grams)		
Mass D	Mass of pycnometer plus sample plus water (grams)		

$Relative\ density = \frac{C-A}{(B-A)-(D-C)}$		
$Density = Relative\ density \cdot \rho_{water}$ (g/cm^3)		

Average relative density	
Average density (g/cm^3)	

Comments:

TEST NO. 3.3

Flash and Fire Point by Cleveland Open Cup

Notes

This method is used to determine flash and fire points for petroleum products with flash point 79°C and above.

Objective

This method is used to determine the flash and fire points of all petroleum products, except fuel oils and those having an open cup flash below 79 °C. The flash and fire points indicate the materials combustibility. The fumes from the material at the flash point temperature are explosive.

Main principles

The test cup is filled to a specific level. The sample is heated at a specified rate. At specified intervals, a small flame is passed over the sample. The lowest temperature that causes the vapours to ignite is taken as the flash point. When determining the fire point, the test is continued until the test flame causes the sample to ignite and burn for at least 5 seconds.

Definitions

The flash point is defined as the lowest temperature at which the vapour from the liquid is ignited by an open flame.

The fire point is defined as the lowest temperature at which the liquid will continue to burn without further heat supply. The fire point temperature will always be significantly above the flash point temperature.

References

ASTM D92-90

Required equipment

- Cleveland Open Cup apparatus.
- Square shield, 460 mm wide by 610 mm tall, with open front (recommended only).
- Thermometer ASTM 11C or similar (- 6 to 400 °C).
- Gas supply for test flame.
- Barometer

Test procedure

Preparation of apparatus

The apparatus and sample must be shielded from draft as this will affect the test results.

Step 1: Place the apparatus level in a draft-free room. Shield from strong light to determine the flash point with accuracy.

Step 2: Clean the test cup, see maintenance. If the test cup was heated to dry after cleaning, cool to minimum 56 °C below the expected flash point

Step 3: Place the thermometer in a vertical position with the bulb 6.4 mm above the bottom of the cup and located at a point half between the center and the side of the cup on a diameter perpendicular to the arc of the sweep of the test flame. The thermometer should be placed on the opposite side of the test flame burner arm.

Flash and Fire Point by Cleveland Open Cup

Notes

Sample preparation

Step 4: Fill the sample cup to the filling line. The temperature of the material should be as low as possible, and maximum 56 °C below the expected flash point temperature. Air bubbles on the sample surface must be destroyed.

Procedure

Step 5: Light the test flame and adjust it to a diameter of 3.2 to 4.8 mm. The center of the flame should be maximum 2 mm above the edge of the test cup.

Control the temperature rise closely.

Step 6: Apply heat and adjust the temperature rise of the sample to 14-17 °C/min. When the temperature of the sample is approximately 56 °C below the expected flash point, decrease the heat to a temperature rise of 5-6 °C/min. This constant temperature rise should be attained during the last 28 °C before the flash point.

Step 7: Starting at minimum 28 °C below the flash point, apply one sweep of the test flame for every 2 °C rise on the thermometer (in opposite directions each time). The time for the test flame to cross the test cup should be approximately 1 second.

Step 8: The flash point is recorded as the reading on the thermometer when the first flash appears on the sample surface. Do not confuse the true flash with the bluish halo that sometimes surrounds the test flame.

Step 9: To determine the fire point, continue heating at the specified rate of 5-6 °C and apply the test flame for each 2 °C rise in temperature. The fire point is recorded as the thermometer reading when the samples ignites and continues to burn for at least 5 seconds.

Results

Calculations

Correct measured flash and fire point values for barometric pressure.

Observe and record the barometric pressure at the time of the test. When the pressure differs from 760 mm Hg, correct the flash point and fire point temperatures using the following equation:

$$\text{Corrected value} = C + 0.03 \times (760 - P)$$

where:

C = observed flash point / fire point temperature to the nearest 2 °C
P = barometric pressure in mm Hg

Report the recorded and corrected flash point and / or fire point temperature to the nearest 2 °C as the *COC Flash Point* or *Fire Point*.

Flash and Fire Point by Cleveland Open Cup

Notes

Deposits of carbon must regularly be removed from the test cup.

Test precision

Duplicate flash and fire point determinations shall not be considered suspect unless they differ by more than the limits given in table 3.3-1.

Table 3.3-1 Test precision

	One operator	2 laboratories
Flash point	< 8 °C	< 17 °C
Fire point	< 8 °C	< 14 °C

Report

The test report shall include the following:

a) Reference to this procedure
b) Type and identification of the test sample
c) Test results
d) Date
e) Description of any deviations from this procedure

Maintenance

Wash the test cup with solvent to remove all traces of material from previous tests. If any deposits of carbon are present, steel wool should be used. Rinse with clean water.

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WORKING SHEET

Flash and Fire Point by Cleveland Open Cup

Project	**Location**	**Depth**
Client	**Lab.nr**	**Date**
Responsible Technician	**Checked**	**Approved**

Measured flash point (°C)	
Measured fire point (°C)	
Measured barometric pressure (mm Hg)	

Correction of measured flash/fire point for barometric pressure:

$$\textit{Corrected Value} = C + 0.03 \cdot (760 - P)$$

where:
C = observed flash point / fire point temperature to nearest 2 °C
P = barometric pressure in mmHg

COC Flash point (°C)	
COC Fire point (°C)	

Comments:

Thin-Film Oven Test (TFOT)

Notes

The TFOT-procedure causes changes in material properties similar to that of a hot-mixing process.

Determination of change in mass is optional.

Pour samples to measure original material properties.

Objective

This method determines the effect of heat and air on a film of bituminous material under specified conditions. It indicates changes in properties during conventional hot mixing and thus yields a residue that approximates the binder condition in a newly constructed pavement.

Main principles

A thin film of bituminous material is heated in an oven at 163 °C for 5 hours. The effects of heat and air on material properties can be determined by selected tests before and after the oven treatment. A procedure for determining the change in mass is also provided.

The effect of this treatment is determined from measurements of selected material properties before and after the test.

References

ASTM D 1754-87 *"Standard Test Method for Effect of Heat and Air on Asphaltic Materials (Thin-Film Oven Test)*

Required equipment

- Standardized oven, see reference document.
- Balance accurate to 0.1g
- Optional: Balance accurate to 0.01g if determination of change in mass is required (ASTM D1754 requires a balance accurate to 0.001g for this purpose. However, use of a slightly less accurate balance will not affect the results significantly).
- Sample containers (TFOT-pans), diameter 140 mm, height 9.5 mm (see reference document).
- ASTM 13C thermometer, 155-170°C, or similar.
- Container of glass or metal, approx. 0.25 liters.

Test procedure

Preparation of test specimens

Step 1: Place a sufficient amount of bitumen in a suitable container and heat to a fluid condition. Extreme care should be taken not to overheat the bitumen. The temperature should be at least 10°C lower than the testing temperature. Stir the bitumen with a general-purpose thermometer occasionally during the heating period, but avoid incorporating air bubbles in the sample.

Step 2: If determination of change in mass is required, weigh the empty TFOT-pans to the nearest 0.01g.

Step 3: Weigh 50 ± 0.5g of liquid bitumen into each of two or more TFOT-pans.

Step 4: At the same time, pour a portion of the sample into the required containers for measurement of original material properties. Complete the appropriate tests.

Thin-Film Oven Test (TFOT)

Notes

Step 5: If determination of change in mass is required, cool the test containers to room temperature and weigh them to the nearest 0.01g. If determination of change in mass is not required, allow the samples to cool to approximately room temperature before placing in the oven.

Procedure

Step 6: Check that the rotating shelf is in the correct position. The maximum tilt of the rotating plate shall not be more than 3 degrees from the horizontal. Check that the speed of the rotating shelf is 5.5 ± 1 rpm.

Step 7: Determine the temperature in the oven by means of the specified thermometer. It should be placed at a distance equal from the center and the edge of the rotating shelf and with the bottom of the thermometer bulb about 6 mm above the top of the shelf.

Step 8: When the oven has reached a temperature of 163 ± 1°C quickly place the test containers onto the rotating shelf. Immediately close the door, and start rotating the shelf.

Only one material may be tested at once.

Step 9: Leave the test containers in the oven for 5 hours at constant test temperature. The 5-hour period starts when the temperature reaches 162°C. The total time in the oven shall in no case exceed 5 hours and 15 minutes. Under no circumstances shall bitumen of different grades be tested in the oven at the same time.

Step 10: At the end of the heating period, if determination of change in mass is required, the test containers are removed from the oven and cooled to room temperature. If not, proceed directly to the following step. Weigh the cooled test containers to the nearest 0.01g. Place the test containers on the rotating shelf in the oven for another 15 minutes at the same temperature as during the test before proceeding.

Scrape out the material from the TFOT-pans using a spatula.

Step 11: Remove the TFOT-pans from the oven and pour the bitumen into one single glass or metal container. Use a spatula or knife to scrape all the material from the test containers.

Step 12: Stir the bitumen in the glass or metal container well. Heat gently if necessary to keep the bitumen liquid.

Step 13: Proceed with the appropriate tests within 72 hours after completing the TFOT-procedure.

Always cover the container if stored for later testing.

Step 14: If further testing is not to be performed immediately, the bitumen must be stored in the container and covered to prevent accumulation of dust.

Thin-Film Oven Test (TFOT)

Notes

Use the correct sign for loss of mass (-) and gain of mass (+).

Results

Calculations

When change in mass is required, calculate the average change in mass for the specimens as mass percent of the original material to the nearest 0.01%.

Loss of mass is denoted as negative values, while gain of mass is denoted as positive values.

Test precision

Determination of material properties before and after the TFOT procedure shall not be considered suspect unless they differ by more than the limits given in table 3.4-1. For more detailed information, see the reference document.

Report

The test report shall include the following:

a) Reference to this procedure
b) Type and identification of the test sample
c) Testing temperature and results of all tests performed
d) Date
e) Description of any deviations from this procedure

Maintenance

Clean TFOT-pans after use. If any spill of material occurs inside the TFOT-oven, this should be cleaned. Regularly check the speed of the rotating shelf and the oven temperature.

Table 3.4-1 Test precision

Properties	Single operator	Two laboratories
$\text{Retained penetration} = \frac{\text{Pen. after TFOT}}{\text{Pen. before TFOT}}$, %	4	8
Change in mass (< minus 0.4%)	0.04	0.16
Change in mass (> minus 0.4%)	8% of the average of the two	40% of the average of the two
Viscosity at 60 °C	9.3% of the average of the two	33% of the average of the two

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WORKING SHEET

Thin-Film Oven Test (TFOT)

Project	**Location**	**Depth**
Client	**Lab.no**	**Date**
Responsible Technician	**Checked**	**Approved**

Pan no.	A Mass of TFOT-pan grams	B Mass of sample + pan before TFOT, grams	C Mass of sample + pan after TFOT, grams	Change in mass [1] $\frac{C-B}{B-A} \cdot 100\ \%$
			Average:	

[1] Correct use of sign: *Loss of mass (-), Gain of mass (+)*

Elapsed time from when the TFOT-pans were placed into the chamber to the chamber temperature again reaches 162 °C: minutes

Comments:

CML test 3.4, ref: ASTM D1754-87

TEST NO. 3.5

Penetration of Bituminous Materials

Notes

Objective

The penetration test is used to measure consistency of bituminous materials expressed as the distance in tenths of a millimeter that a standard needle vertically penetrates a sample of the material under known conditions of loading, loading time and temperature.

Main principles

A needle of specified dimensions is allowed to penetrate vertically into a bituminous material under specified load, temperature and time conditions. The distance the needle penetrates in units of 1/10 mm is termed the penetration value. This method is valid for penetration values in the range 2-500.

References

ASTM D 5-86: *"Penetration of Bituminous Materials"*.

Required equipment

- Standardized penetrometer
- Standardized penetration needles (2.5 g)
- Needle holder (47.50 g) and weight (50.00 g)
- Stop watch with accuracy 0.1 sec. or better (only in case of manual penetrometers)
- Penetration tins, minimum 55 mm diameter and 35 mm deep for materials with penetration 200 or less.
- Penetration tins, 60-70 mm diameter and 45-60 mm deep for materials with penetration between 200-500.
- Water bath with preferably deionized or distilled water, minimum 10 liters, with temperature control of ± 0.1 °C.
- Perforated plate supported minimum 50 mm above the bottom of the bath and minimum 100 mm below the water surface.
- Transfer container of minimum 350 ml with sufficient depth to cover the penetration tins.
- Certified or calibrated thermometers to calibrate the water bath.
- Source of light (table lamp, flash light or similar)

Test procedure

Preparation of test specimen

Prepare 2 parallel samples.

Step 1: Heated bitumen is poured into 2 penetration tins. The tins must be filled at least 10 mm above the expected penetration depth. One penetration tin is stored for later analysis if required.

Cover the penetration tins to protect from dust

Step 2: Immediately after pouring the samples, the tins must be covered to protect from dust. Glass lids, aluminum foil or similar can be used. The samples are then allowed to cool off at room temperature, 1-1.5 hours for small tins and 1.5-2 hours for the bigger tins.

Penetration of Bituminous Materials

Notes

Step 3: After cooling, transfer one tin to the water bath. The required temperature equilibration time is 1-1.5 hours for small tins and 1.5-2 hours for the larger tins. The transfer container is placed in the water bath along with the penetration tin.

Typical test conditions: 25°C, 100g and 5 s loading time.

Test conditions

Typical test conditions for temperature, load and time are 25 °C, 100 g and 5 s. Other test conditions may also be used for special testing. See the reference document.

Procedure

Step 4: Control that the penetrometer is level and correctly set up. Control that the needle holder can move unobstructed when released.

Step 5: Clean the penetration needle with a suitable solvent (toluene, trichloroethane or trichloroethylene) and dry with a clean cloth, paper or cotton.

Step 6: The sample is transferred to the transfer container under water, transfer container and sample is then placed on the penetrometer base plate. The sample must be covered by water.

Using a source of light, lower the needle until the needle tip touches the reflected image on the sample surface.

Step 7: Bring the penetrometer dial to zero. Lower the needle until it barely touches the surface of the sample. Lowering the needle down to the surface of the sample may often be tricky because of reflections of light from the water. To solve this, a source of light (flashlight or similar) must be used. Place the light so that a reflection of the needle is seen on the sample surface. Lower the needle until the needle tip barely comes into contact with the reflected image.

Step 8: Double-check and adjust the dial reading if necessary. Release the needle for the specified period of time. If the sample tin moves during loading, the measurement must be rejected.

Step 9: Read the penetration depth off the penetrometer dial.

Perform 3 parallel measurements per sample.

Perform a minimum of 3 valid measurements. The locations on the sample surface must be minimum 10 mm apart and away from the container side. If the penetration depth is larger than 100, the needles must be left standing in the sample to avoid deformation of the sample surface. The 3 measurements can be performed continuously within 2 minutes. If more time is needed (to clean the needle between measurements if only one is used), the transfer container and sample must be placed back into the water bath for a conditioning time of minimum 10 minutes between each measurement.

Notes

Clean the needles with paper, cotton etc. and solvent. Store the needles in a safe place protected from corrosion and other damage.

The conditions and procedures described provide for determinations of penetrations up to 350. However, the method may also be used for direct determinations up to 500. This will require the larger penetration tin and specialized needles. See the reference document.

An approximation of penetration values above 350 can be obtained by using a standard penetration needle, a large penetration tin and 50 g loading (remove the 50 g weight on the needle holder). The penetration is then calculated by multiplying the measured value by $\sqrt{2}$ (»1.414).

Results

Assessment of results

If the deviation between highest and lowest value of the 3 parallel measurements exceeds the values in table 3.5-1, the measurement must be rejected. Repeat the test using the second sample.

If the second sample does not meet the criteria in table 3.5-1, ignore all results and repeat the test completely.

Calculations

When the requirements in table 3.5-1 are met, calculate the average value to the nearest whole unit (1/10-mm).

Test precision

Although a test is properly conducted and meets the requirements in table 3.5-1, the test result may for various reasons be questioned. In table 3.5-2, the maximum limits for difference between 2 properly conducted tests are given.

Report

The test report shall include the following:

a) Type of material and sample identification
b) Reference to this procedure
c) Test results, individual values and average value
d) Test date
e) Description of any deviations from this procedure

Practical considerations

It is VERY important to follow the outlined time schedule closely.

- It is very important that the time schedule from preparation of samples to measurements is followed closely. When bitumen is left standing in room temperature, its stiffness will gradually increase due to formation of molecular structures within the material. This is called "structural hardening". If a sample is prepared one day and penetration measured the next day, the measured penetration value may be significantly lower than if the measurement was performed according to the specified procedure.

Notes

Stored samples must be reheated before measuring penetration.

- The “structural hardening” will be removed if the sample is reheated. The material will then go back to its original condition. If penetration is to be measured on samples that have been stored, they must first be reheated and stirred gently to avoid incorporating air. The standard procedure is then followed. Reheating a sample may also change the material properties slightly. A sample must never be reheated more than once to measure penetration.

A poor accomplished test may greatly affect the results and indirectly affect the performance on the road.

- It is essential that the test method be followed precisely, as even a slight variation can cause large differences in results. The most common errors are; poor sampling and sample preparation, badly maintained apparatus and needles, incorrect timing and temperature. A wrong result may lead to incorrect classification or approval of materials. This may indirectly lead to rutting or cracking problems on the road.

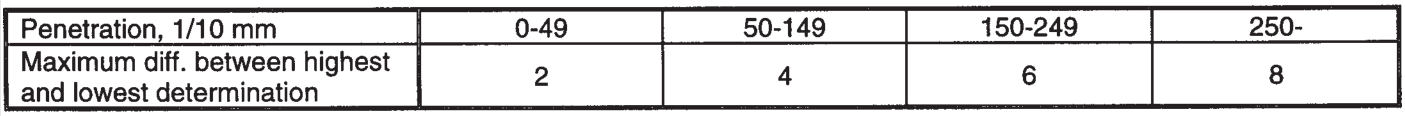
Maintenance

Never use corroded or damaged needles

The mass of the penetration needle (2.50 g), needle holder (47.50 g) and weight (50.00 g) must be regularly checked. Needles must regularly be checked with respects to shape and corrosion (check needle tip closely).

The condition of the needles is very important. Rusty or damaged needles must never be used. To avoid corrosion of needles, they must be stored in small airtight containers. Needles, which will not be used for a long time, can be covered by Vaseline, grease or similar. Before using, they must then be carefully cleaned with solvent.

Table 3.5-1 Acceptable differences between 3 parallel measurements



Penetration, 1/10 mm	0-49	50-149	150-249	250-
Maximum diff. between highest and lowest determination	2	4	6	8

Table 3.5-2 Test precisiŏn

Penetration 25 °C, 100 g, 5 s	Acceptable difference, 2 results	
	One operator	Two laboratories
Bitumen < 50 pen., units (1/10 mm)	< 1	< 4
Bitumen > 50 pen., % of mean value	< 3	< 8

CENTRAL MATERIALS LABORATORY

WORKING SHEET

Penetration of Bituminous Materials

Project	**Location**	**Depth**
Client	**Lab.no**	**Date**
Responsible Technician	**Checked**	**Approved**

Tin Number 1

Measurement no.	1	2	3	Average value
Penetration 1/10 mm				

Tin Number 2

Measurement no.	1	2	3	Average value
Penetration 1/10 mm				

Comments:

TEST NO. 3.6

Softening Point Test

Notes

The softening point represents a state of a certain consistency.

Objective

The softening point test is used to measure and specify the temperature at which bituminous binders begin to show fluidity. The softening point is also useful in evaluating the uniformity of shipments or sources of supply. The softening point is also an indicative of the tendency of the material to flow at elevated temperatures encountered in service.

Main principles

The temperature of a sample is raised at a constant rate and read when the binder has undergone a specified deformation.

A steel ball of 3.5 g is placed on a sample of binder contained in a brass ring which is suspended in a water or glycerin bath. Water is used for softening points of 80 °C and below, and glycerin is used for softening points greater than 80 °C. The bath temperature is raised at 5 °C per minute, the binder gradually softens and eventually deforms slowly as the ball falls through the ring. At the moment the bitumen and steel ball touches a base plate 25 mm below the ring, the temperature of the water/ glycerin is recorded.

This test is used to determine the softening point of bituminous binders in the temperature range 30°C - 200°C.

References

ASTM D 36-70

Required equipment

- Boiled distilled or de-ionized water (the water must not contain bubbles of air).
- Glycerol (99% pure).
- Talcum powder.
- Metal plate with a smooth surface.
- Glass container, 600ml low type, suitable for the ring holder to be used.
- Rings and steel balls (3.5 g) as specified in the reference document.
- Ring holder for 2 rings and a thermometer.
- Heating unit (e.g. gas flame or thermostatically controlled heating unit) to produce the specified heating rate.
- ASTM 15C (or similar) Low Softening Point Thermometer, having a range from –2 to +80 °C.
- ASTM 16C or 16F (or similar) High Softening Point Thermometer, having a range from 30°C to 300 °C.
- Forceps.

Test procedure

Preparation of test specimens

Step 1: Heat the sample to a temperature that does not exceed the expected softening point by more than 110°C. The heating time must not exceed 2 hours.

Softening Point Test

Notes

Step 2: Heat the rings to approximately the same temperature as the binder sample. Place the rings on a metal plate (not preheated) with a thin coating of a mixture of glycerol and talcum powder (1:1).

Step 3: Fill 2 rings.

Step 4: Cool for at least 30 minutes at room temperature. For very soft samples (soft at room temperature), see the reference document.

Complete the test within 4 hours from preparing the samples.

Step 5: After cooling, cut of the surplus bitumen with a heated spatula.

Step 6: The total time involved to complete the test (from pouring the test specimens) must not exceed 4 hours.

Procedure A (for materials with Softening Points 80°C or below)

Use distilled water only.

Step 7: Fill freshly distilled/de-ionized water holding 5±1 °C in the glass container containing the ring holder, rings and thermometer. Fill to a depth between 101.6 to 108 mm.

Step 8: Put the steel balls at the bottom of the container or in another small container with water (at 5 ± 1°C). Maintain the whole assembly at 5°C for 15 min.

Step 9: Place the balls onto the samples in the centering guide using forceps.

Step 10: Immediately place the container with the assembly onto the heating unit.

Apply heat at a constant rate of 5°C per minute.

Step 11: Apply heat to obtain a constant temperature raise of 5 ± 0.5°C per minute. The rate of temperature raise shall *not* be averaged over the period of the test. The temperature shall be recorded every minute. After the first three minutes, the rate of rise must be within ± 0.5 °C for every minute period. Reject all tests that do not fall within these limits and repeat the test.

Step 12: Record the temperature reading for each ring and ball when the sample touches the bottom plate. If the softening point temperature for the 2 parallel samples differs by more than 1 °C, repeat the test.

Procedure B (for materials with Softening Points 80°C and above)

Use glycerin instead of water for softening points exceeding 80°C

Use procedure A with the following exceptions:

- Use glycerin instead of water.
- Use an ASTM 16C or 16F thermometer or similar.
- The starting temperature of the glycerin bath shall be 32 °C.

Softening Point Test

Notes

Results

Measurements

Report the average temperature of two recorded softening points to the nearest 0.5 °C.

Softening point determinations in glycerin will approximately be 4 °C above a similar determination in water. For materials with softening points around 80 °C, the type of heating fluid must therefore be reported.

Test precision

Duplicate softening point determinations shall not be considered suspect unless they differ by more than the limits given in table 3.6-1.

Table 3.6-1 Test precision

One operator	Two laboratories
1.1°C	2.0°C

Report

The test report shall include the following:

a) Reference to this procedure
b) Test date
c) Type and identification of the test sample
d) Type of bath fluid used
e) All measured values and average value
f) Description of any deviations from this procedure

Maintenance

Never use corroded rings or balls.

The mass and condition of the balls must be checked regularly. Balls with corrosion must not be used. To avoid corrosion the balls should be stored in small airtight containers, or covered by Vaseline, grease or similar.

Balls and rings must always be cleaned thoroughly after use.

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WORKING SHEET

Softening Point Test

Project	**Location**	**Depth**
Client	**Lab.no**	**Date**
Responsible Technician	**Checked**	**Approved**

Time (minutes)	Temp. (°C)	Temp. rise (°C)
0		
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		

Time (minutes)	Temp. (°C)	Temp. rise (°C)
12		
13		
14		
15		
16		
17		
18		
19		
20		
21		
22		
23		
24		

	Ring 1	Ring 2	Average
Softening point (°C)			

Bath Fluid:

Water ☐
Glycerin ☐

Comments:

TEST NO. 3.7

Ductility

Notes

Typical test conditions: 25°C and 50 mm/min elongation rate.

Be careful not to use too much glycerol and talcum when coating the mold. Apply in a thin uniform layer.

Objective

The ductility test is used to describe the ductile and tensile behavior of bituminous binders. The test, which is normally performed at ambient temperatures, is believed to reflect the homogeneity of the binder and its ability to flow. The test may be used to measure ductility for specification requirements.

Main principles

A dumbbell-shaped specimen is placed in a water bath and allowed to equilibrate. The sample is stretched at 50 mm/min until it breaks. The distance at rupture in centimeters is reported as the ductility. Normal conditions are 25 °C and 50 mm/min. If other conditions are used, this must be reported along with the test result.

References

ASTM D 113-86 *"Standard Test Method for Ductility of Bituminous Materials"*

Required equipment

- 3 standardized brass molds, see the reference document.
- Water Bath, minimum 10 liters, with a thermostat to maintain the temperature within ± 0.1°C of the testing temperature. Other requirements, see the reference document. Floating plastic balls may be placed in the water bath for extra insulation and to improve temperature control if needed.
- Testing Machine for pulling the test specimens apart. The machine must be able to pull the test specimens at least 100 cm apart at the specified speed without undue vibration.
- Thermometer, -8 to +32°C, accuracy 0.1°C. Type ASTM 63C or similar.
- Straight edged knife or spatula.
- Mixture of glycerol and talcum powder (1:1).

Test procedure

Preparation of test specimens

Step 1: Assemble the molds and place them on the brass plate. The brass plate is previously coated with a thin uniform layer of a glycerol and talcum powder mixture (1:1) to prevent the material from sticking to the plate. Also coat the interior side surfaces of the mold itself.

Step 2: Carefully heat the sample (avoid overheating) until it has become sufficiently fluid to pour. If the bitumen is not homogeneous, strain it through a heated 300 mm sieve.

Step 3: Stir carefully to avoid incorporating air bubbles.

Step 4: Pour melted bitumen into the mold in a thin stream back and forth from end to end until it is just more than level full.

Ductility

Notes

Step 5: Cool at room temperature for about 30-40 minutes. Cover the samples to protect against dust.

Step 6: Place the plate with the molds in the water bath at the specified testing temperature. Leave them on the perforated plate in the water bath for 30 minutes.

Be cautious when cutting off excess material. The finished cut sample must not have visible marks that can lead to premature crack initiation.

Step 7: Remove the samples from the bath and cut of the excess bitumen with a hot straight edged knife or spatula to make the mold just level full.

Step 8: Place the plate with the molds back into the water bath for 90 ± 5 minutes.

Test conditions

Normal testing conditions are 25 °C and elongation rate of 50 mm/min. A variation of ± 5% in the elongation rate is permissible. If other testing temperatures or speeds are used, it must be explicitly stated in the test report.

Procedure

Step 9: After storage in the water bath, remove the brass plate and sidepieces. Immediately place the samples in the testing machine.

Do not stop the test until it is finished.

Step 10: Stop the stirrer in the ductility bath. Pull the test specimens apart at the specified speed. The specimens must be covered both below and above by at least 2.5 cm of water. The temperature should be kept within ± 0.5°C of the testing temperature at all times.

Step 11: Record the distance in cm when each of the 3 specimens breaks.

If the material sinks or floats as it is pulled into a thin thread, the bath fluid's density may have to be adjusted.

Step 12: As the material is being stretched into a thin thread, one may observe that the material floats to the surface or sinks to the bottom of the bath. If this is the case, the test shall not be considered normal. The density of the bath fluid must in these cases be adjusted by addition of either methyl alcohol or sodium chloride so that the specimens neither touch the surface or the bottom of the bath during the test. Repeat the test.

Results

Measurements

The following shall be recorded during the test:

- The distance between the end clips in cm when the test specimens break.
- If a normal test is not obtainable for three tests, report the ductility as being unobtainable under the conditions of the test.

Ductility

Notes

Test precision

Duplicate ductility determinations shall not be considered suspect unless they differ by more than the limits given in table 3.7-1.

Table 3.7-1 Test precision

Ductility at 7-25°C	One operator	Two laboratories
< 7 cm	1 cm	2 cm
> 7 cm	15% of the average	30% of the average

Report

The test report shall include the following:

a) Reference to this procedure
b) Type and identification of the test sample
c) Testing temperature and pulling speed
d) Measured ductility, individual values and average of three samples
e) Test date
f) Description of any deviations from this procedure

Use distilled water if buildup of algae is a problem.

Maintenance

The molds must be cleaned thoroughly after use. The water bath must be emptied and cleaned regularly to avoid buildup of algae.

CENTRAL MATERIALS LABORATORY

WORKING SHEET

Ductility

Project	**Location**	**Depth**
Client	**Lab.no**	**Date**
Responsible Technician	**Checked**	**Approved**

Sample no.	1	2	3	Average
Initial reading (mm)				
Final reading (mm)				
Normal rupture (Yes/No) [1]				
Ductility (mm)				

[1] *Normal rupture: rupture occurring at the point where the thread has practically no cross-section*

Comments:

TEST NO. 3.8

Viscosity determination using the Brookfield Thermosel Apparatus

Notes

Measurements performed at temperatures or shear rates where the material exhibits non-Newtonian behavior may not always predict performance in the field.

Objective

This method outlines a procedure for measuring the apparent viscosity (dynamic viscosity) of bitumen from 38 to 260 °C using the Brookfield Thermosel apparatus.

Main principles

The torque of a spindle rotating in a sample container with bitumen is measured. Given the dimensions of the spindle and sample container, the shear rate and shear stress applied to the material is calculated. The viscosity of the material is calculated as the ratio of the shear stress to the shear strain. This method is especially useful to measure viscosity at application temperatures. Note that the viscosity measured on materials exhibiting non-Newtonian behavior is not a true material property. Such viscosity values reflect the behavior of the fluid only under the specific measuring conditions, and may therefor not reflect the performance of the material under the conditions in field.

Definitions

Apparent viscosity, also called dynamic viscosity, is defined as the ratio of shear stress to shear rate for a Newtonian or non-Newtonian liquid. The SI-unit for viscosity is Pascal seconds (Pa×s). Frequently, viscosity is also denoted as Poise (0.1 Pa×s) or centiPoise (mPa×s).

Newtonian and non-Newtonian liquids: A Newtonian liquid is a liquid for which the rate of shear is proportional to the shearing stress. If the ratio between shearing stress and shear rate (=viscosity) is not constant, the material is non-Newtonian. Many materials, such as bitumen, may exhibit both Newtonian and non-Newtonian behavior depending on the shear rate and temperature.

References

ASTM D 4402-91, *"Standard Test Method for Viscosity Determinations of Unfilled Asphalts Using the Brookfield Thermosel Apparatus"*

Required equipment

- Brookfield Thermosel high temperature viscosity unit.
- Spindles for Brookfield Thermosel viscometer.
- Thermosel system including thermo container, temperature con troller, sample chamber and extraction tool.
- Heating oven.
- Balance with accuracy 0.01 g.

Test procedure

Step 1: Turn on the Thermosel power. Set the temperature controller to the desired temperature.

Step 2: Select the appropriate spindle and speed from table 3.8-2 and 3.8-3 to match the expected viscosity of the material.

Viscosity determination using the Brookfield Thermosel Apparatus

Notes

Select the appropriate spindle and speed to match the expected viscosity

At temperatures above 60-70 °C, the measured viscosity for unmodified bitumens will not significantly be affected by the speed. Select any speed which matches the required viscosity range.

The amount of required material varies with the testing temperature. For this reason, prepare a new sample

Step 3: Place the sample container into the temperature chamber. Attach the selected spindle to the viscometer and lower the spindle into the sample container. Wait for 1.5 h or until temperature equilibrium is obtained.

Step 4: Set the sample container holder on a balance. Rise the viscometer and take out the sample container using the extraction tool. Place the sample container into the sample holder on the balance. Tare the balance.

Step 5: Weigh in (pour) the right amount of preheated material. The right amount is specified in terms of volume and varies with the spindle to be used. Use density data for the bitumen to calculate the mass required. Add the right amount of bitumen into the sample container. Approximately 8-10 ml is required. The required mass for some selected temperatures is given in table 3.8-4.

Step 6: Using the extraction tool, place the loaded sample container back into the thermo-container.

Step 7: Lower the viscometer placing the spindle into the sample. Align the thermo-container.

Step 8: Allow the bitumen to reach equilibrium temperature. This normally will take approximately 15 minutes.

Ensure that the spindle does not “stick” to the sample container sidewall during measurements.

Step 9: When using large spindles, one may observe during measurements that the spindle “sticks” to the sample container sidewall. This will incorrectly increase the measured viscosity. To avoid this problem, gently move the spindle by hand and ensure that there is no direct contact between spindle and sample container before starting the measurement.

Step 10: Start the measurement at the selected speed. If no error message is displayed, record three readings 60 s apart. Stop the test.

Step 11: The viscometer will display an error message if the measured viscosity is outside the viscosity range for the selected spindle-speed combination. If an error message is displayed, select a lower (or higher) speed. Record three readings 60 s apart. Stop the test.

Step 12: If a correct measurement cannot be obtained using the selected spindle, select a new spindle and repeat the whole procedure.

Step 13: Do not change the speed during a measurement as this will change the shear rate and may affect the test results.

Viscosity determination using the Brookfield Thermosel Apparatus

Notes

Results

Measurements

The following shall be recorded during the test:

- Measured viscosity in centiPoise (mPa×s) after 1, 2 and 3 minutes.
- Spindle number and speed (rpm) used for the measurement.

Calculations

If desired, the measured dynamic viscosity in centiPoise (mPa×s) can be converted to kinematic viscosity in centiStokes (mm^2/s) by dividing by the density of the binder in g/cm^3.

$$v = \frac{\eta}{\rho}$$

where:
ν = kinematic viscosity (mm^2/s)
η = dynamic viscosity (mPa×s)
ρ = density of binder at testing temperature (g/cm^3)

Test precision

Duplicate viscosity determinations shall not be considered suspect unless they differ by more than the limits given in table 3.8-1.

Table 9 Test precision

One operator	Two laboratories
3.5%	14.5 %

Report

The test report shall include the following:

a) Reference to this procedure
b) Type and identification of the test sample
c) Testing temperature, spindle number and speed
d) Measured viscosity
e) Test date
f) Description of any deviations from this procedure

Always try to use as large a spindle as possible. This will improve the accuracy of the measurement.

Practical considerations

The equipment computes a shear rate, which depends on the spindle and speed used for the measurement. This shear rate is then used to calculate the viscosity displayed by the equipment. The accuracy of the calculated shear rate, and thus the measured viscosity, improves with increasing spindle size. For this reason, always try to select as large a spindle as possible.

Verify the equipment using certified viscosity standards.

Maintenance

Clean all equipment used. To calibrate/verify the equipment, measurements should regularly (minimum once a year) be performed on certified viscosity standards (silicon oils) available from Brookfield or Cannon.

Notes

Table 3.8-2 Typical viscosity values for bitumen at 60, 90 and 135°C in centiPoise (mPa×s)

Temperature Bitumen	60°C	90°C	135°C
Pen40	700 000	13 500	500
Pen60	290 000	9 000	370
Pen85	170 000	6 000	270
Pen180	37 000	2 200	160
Pen250	35 000	2 100	150
Pen370	30 000	1 800	135

Table 3.8-3 Viscosity range in centiPoise (mPa×s) for different spindle / speed combinations

Spindle number Speed (rpm)	21	27	28	29
0.5	20 000 – 200 000	100 000 – 1 000 000	200 000 – 2 000 000	400 000 – 4 000 000
1.0	10 000 – 100 000	50 000 – 500 000	100 000 – 1 000 000	200 000 – 2 000 000
2.5	4 000 – 40 000	20 000 – 200 000	40 000 – 400 000	80 000 – 800 000
5.0	2 000 – 20 000	10 000 – 100 000	20 000 – 200 000	40 000 – 400 000
10	1 000 – 10 000	5 000 – 50 000	10 000 – 100 000	20 000 – 200 000
20	500 – 5 000	2 500 – 25 000	5 000 – 50 000	10 000 – 100 000
50	200 – 2 000	1 000 – 10 000	2 000 – 20 000	4 000 – 40 000
100	100 – 1 000	500 – 5 000	1 000 – 10 000	2 000 – 20 000

Table 3.8-4 Required mass (grams) for different spindle/temperature combinations (based on typical density data)

Temperature Spindle	60°C	90°C	135°C
21	7.95	7.80	7.58
27	10.44	10.24	9.95
28	11.43	11.21	10.90
29	12.92	12.68	12.32

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WORKING SHEET

Brookfield Viscosity

Project	**Location**	**Depth**
Client	**Lab.no**	**Date**
Responsible Technician	**Checked**	**Approved**

Testing temp. °C		Spindle number		Spindle speed (rpm)	

Time	1 minute	2 minutes	3 minutes	Average
Viscosity (centiPoise)				

Testing temp. °C		Spindle number		Spindle speed (rpm)	

Time	1 minute	2 minutes	3 minutes	Average
Viscosity (centiPoise)				

Testing temp. °C		Spindle number		Spindle speed (rpm)	

Time	1 minute	2 minutes	3 minutes	Average
Viscosity (centiPoise)				

Comments:

TEST NO. 3.9

Density and Water Absorption of Aggregates Retrieved on a 4.75 mm Sieve

Notes

Objective

This method is used to determine the dry density (ς_d) of aggregates retrieved on a 4.75 mm sieve. The density of aggregates is used for various calculations of mix characteristics and in mix design. This method may also be used to determine the water absorption of the aggregates.

Main principles

The dry bulk density and apparent density of aggregates retained on a 4.75 mm sieve are calculated from the loss in mass of saturated surface dry aggregates when submerged in water.

The water absorption is determined by calculating the mass of water absorbed after a 24 hour immersion in percentage of the oven dried material.

Definitions

Density (ς_d) is defined as the mass per unit volume of a material at a given temperature.

Bulk density (ς_{bd}) is defined as the mass per unit volume (including permeable and inpermeable voids) of a material at a given temperature.

Apparent density (ς_{ad}) is defined as the mass per unit volume (excluding permeable voids but including impermeable voids) of a material at a given temperature.

References

ASTM C127-88¨

Required equipment

- Thermometer with accuracy 0.1°C
- Balance with accuracy 0.01g
- Sample container (wire cloth basket)
- Water bath and device to suspend the sample container into the bath
- Heating oven which can maintain a temperature of 110 ± 5 °C.
- Distilled water.

Test procedure

Number of samples

Always measure on a minimum of two parallel samples.

The test procedure involves weighing the material several times. To attain the desired accuracy in determination of the density, this procedure should be carried out on at least two parallel samples for each material.

Preparation of test sample

Step 1: Sieve the material on a 4.75-mm sieve to obtain samples. The mass of the sample should be adjusted according to the nominal maximum aggregate size, see table 3.9-1.

TEST NO. 3.9

Density and Water Absorption of Aggregates Retrieved on a 4.75 mm Sieve

Notes

Adjust the mass of the sample according to maximum aggregate size

Table 13 Sample size

Nominal maximum aggregate size, mm	Minimum mass of test sample, kg
12.5	2
19.0	3
25.0	4
37.5	5

Step 2: Wash the sample thoroughly to remove dust from the surfaces.

Step 3: Cover the sample with water in a suitable container and soak for 24 ± 4 hours.

Determination of saturated surface dry condition

Step 4: After soaking the sample, drain off free water and transfer the sample to a large absorbent cloth. To obtain the saturated surface dry condition, roll the sample in the cloth until all visible water has been absorbed. The surfaces of the aggregates should still appear damp.

Step 5: As soon as the saturated surface dry condition has been reached, determine the weight of the sample and transfer it to a wire cloth basket that previously has been tared in water.

Shake the basket under water to remove entrapped air before weighing

Step 6: Weigh the basket with sample in water, normally at 25°C. Take care that no air is entrapped.

Determination of dry weight

Step 7: Pour off the water without loosing any material. Dry the sample to constant mass in an oven at 105-110°C. Record the mass of the oven-dried sample.

Results

Calculations

Calculate the bulk density and apparent density to the nearest 0.001 g/cm^3 and the water absorption to the nearest 0.01% by using the following equations:

$$\text{Bulk density, } \rho_{bd} = \frac{A}{\frac{(B - C)}{0.997}} \ (g/cm^3)$$

$$\text{Apparent density, } \rho_{bd} = \frac{A}{\frac{(A - C)}{0.997}} \ (g/cm^3)$$

$$\text{Water absorption} = \frac{B - A}{A} \cdot 100\ \%$$

Density and Water Absorption of Aggregates Retrieved on a 4.75 mm Sieve

Notes

where:
A = mass of oven dry sample in air, grams
B = mass of saturated surface dry sample in air, grams
C = mass of saturated sample in water at 25°C, grams

The average density for samples containing material passing and retained on the 4.75 mm sieve is calculated using the following equation:

$$\text{Averange density} = \frac{100}{\frac{P_1}{\rho_1} + \frac{P_2}{\rho_2}}$$

where:
P_1 = percentage of material passing the 4.75 mm sieve
P_2 = percentage of material retained on the 4.75 mm sieve
ρ_1 = density of the material passing the 4.75 mm sieve
ρ_2 = density of the material retained on the 4.75 mm sieve

See the following example.

Test precision

Among the largest sources of error when determining the density are air bubbles in the water and sample when weighing and the determination of the saturated surface dry condition.

Duplicate measurements shall not be considered suspect unless they differ by more than the limits give in table 3.9-2.

Table 3.9-2 Test precision

	One operator	Two laboratories
Bulk density	0.025 g/cm^3	0.038 g/cm^3
Apparent density	0.020 g/cm^3	0.032 g/cm^3
Water absorption	0.25 %	0.41 %

Report

The test report shall include the following:

a) Type of material and identification of the test sample.
b) Test date.
c) Reference to this procedure.
d) Results of weighing.
e) Calculated bulk and apparent density to the nearest 0.001 g/cm^3.
f) Water absorption to the nearest 0.01 %.
g) Description of any deviations from this procedure.

Note: Density (ς_d) may also be expressed as: t/m^3, kg/m^3, kg/dm^3 or kg/l

TEST NO. 3.9

Density and Water Absorption of Aggregates Retrieved on a 4.75 mm Sieve

Notes

It is necessary to recognize the importance of accurate values for the density in mix design.

Inaccurate values for the density may seriously affect the performance of an asphalt mix in the field.

Practical considerations

The density of aggregates is a very important parameter in asphalt mix design and analyses. Binder content, which normally is expressed as weight-%, must always be considered in proportion to the density of the aggregates. The density is also used to calculate void contents in asphalt mixes, a very important parameter in mix design and mix evaluation.

In all, it is very important that the density is determined with high accuracy. If not, the results from mix design and mix analyses will be misleading. Wrong measurements of density may very well lead to rutting, aging or cracking problems in the field

Maintenance

Clean all equipment after use.

Example

A: Mass of oven dried sample in air =2120.0 g
B: Mass of saturated surface dry sample in air =2190.3 g
C: Mass of saturated sample in water =1368.2 g

$$\text{Bulk density, } \rho_{bd} = \frac{A}{\dfrac{(B - C)}{0.997}} = \frac{2120}{\dfrac{(2190.3 - 1368.2)}{0.997}} = 2.571 \ g/cm^3$$

$$\text{Apparent density, } \rho_{ad} = \frac{A}{\dfrac{(A - C)}{0.997}} = \frac{2120}{\dfrac{(2120 - 1368.2)}{0.997}} = 2.811 \ g/cm^3$$

$$\text{Water absorption} = \frac{B - A}{A} \cdot 100\ \% = \frac{2190.3 - 2120.0}{2120.0} \cdot 100\% = 3.32\%$$

The total sample consists of 64% material retained on the 4.75 mm sieve and 36% passing the 4.75 mm sieve
The bulk and apparent densities of the material passing the 4.75 mm sieve have also been determined to be:

$\rho_{bd} = 2.562 \text{ g/cm}^3$
$\rho_{ad} = 2.701 \text{ g/cm}^3$

$$\text{Average bulk density, } \rho_{bd} = \frac{100}{\dfrac{64}{2.571} + \dfrac{36}{2.562}} = 2.568 \ g/cm^3$$

$$\text{Average apparent density, } \rho_{ad} = \frac{100}{\dfrac{64}{2.811} + \dfrac{36}{2.701}} = 2.770 \ g/cm^3$$

CENTRAL MATERIALS LABORATORY

WORKING SHEET

Density and Water Absorption of Aggregates Retained on a 4.75 mm Sieve

Project	**Location**	**Depth**
Client	**Lab.no**	**Date**
Responsible Technician	**Checked**	**Approved**

Material:			Sample 1	Sample 2
Mass A	Mass of oven dry sample	grams		
Mass B	Mass of saturated surface dry sample in air	grams		
Mass C	Mass of saturated sample in water	grams		

Bulk density, $\rho_{bd} = \dfrac{A}{\dfrac{(B-C)}{0.997}}$	g/cm^3		
Apparent density, $\rho_{ad} = \dfrac{A}{\dfrac{(A-C)}{0.997}}$	g/cm^3		
Water absorption, $w_{abs} = \dfrac{B-A}{A} \cdot 100\%$	%		

Average bulk density, ρ_{bd}	g/cm^3	
Average apparent density, ρ_{ad}	g/cm^3	
Average water absorption, w_{abs}	%	

$$\text{Combined density} = \frac{100}{\dfrac{P_1}{\rho_1} + \dfrac{P_2}{\rho_2}}$$

where:
P_1 = percentage of material passing the 4.75 mm sieve
P_2 = percentage of material retained on the 4.75 mm sieve
ρ_1 = density of the material passing the 4.75 mm sieve
ρ_2 = density of the material retained on the 4.75 mm sieve

Combined bulk density, ρ_{bd}	g/cm^3	
Combined apparent density, ρ_{ad}	g/cm^3	

Comments:

CML test 3.9, ref: ASTM C127-88

TEST NO. 3.10

Density and Water Absorption of Aggregates Passing the 4.75 mm Sieve

Notes

Objective

This method is used to determine the density (ς_d) of aggregates passing a 4.75 mm sieve. The density of aggregates is used for various calculations of mix characteristics and in mix design. This method may also be used to determine the water absorption of the aggregates.

Main principles

A material sample in saturated surface-dry state is weighed into a calibrated pycnometer with known volume. The pycnometer is then filled with distilled water and entrapped air is removed. The pycnometer is tempered to 25 °C and weighed. This data is used to calculate the bulk and apparent densities and the water absorption of the aggregates.

Definitions

Density (ς_d) is defined as the mass per unit volume of a material at a given temperature.

Bulk density (ς_{bd}) is defined as the mass per unit volume (including permeable and inpermeable voids) of a material at a given temperature.

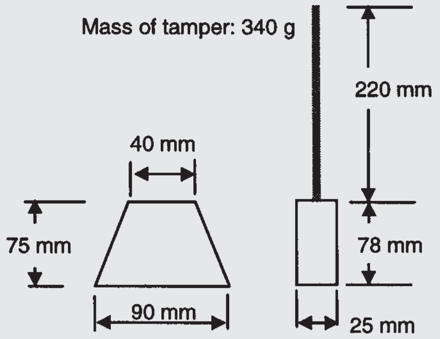
Apparent density (ς_{ad}) is defined as the mass per unit volume (excluding permeable voids but including impermeable voids) of a material at a given temperature.

References

ASTM C128-88 and ASTM D854

Required equipment

- Pycnometer, large enough to test representative samples.
- Thermometer with accuracy 0.1°C
- Vacuum type dessicator.
- Vacuum pump or other arrangement to create suction within the dessicator.
- Balance with accuracy 0.01g
- Water bath with a constant temperature of 25 ± 0.1°C
- Heating oven which can maintain a temperature of 110 ± 5 °C.
- Distilled water.
- Metal mould in the form of a frustum of a cone with dimension as follows: 40 ± 3 mm inside diameter at the top, 90 ± 3 mm inside diameter at the bottom, 75 ± 3 mm height and the metal having a minimum thickness of 0.8 mm.
- Metal tamper weighing 340 ± 15 g and having a flat circular tamping face 25 ± 3 mm in diameter.



Metal mould and tamping rod needed for determination of saturated surface dry condition

Test procedure

Number of samples

The test procedure involves weighing the material several times. To attain the desired accuracy in determination of the density, this procedure should be carried out on at least two parallel samples for each material.

Always measure on a minimum of two parallel samples.

TEST NO. 3.10

Density and Water Absorption of Aggregates Passing the 4.75 mm Sieve

Preparation of test sample

Step 1: Sieve the material on a 4.75-mm sieve to obtain samples. One sample should weigh approximately 500 grams.

The sample size may be reduced to 300 grams for single-sized aggregates

Step 2: Cover the sample with water in a suitable container and soak for 24 ± 4 hours.

Determination of saturated surface dry condition

Step 3: After soaking the sample, decant excess water (without loosing fines) and spread the sample onto flat non-absorbent surface. Expose the sample to a moving current of hot air. Stir the sample frequently to ensure uniform drying. Continue until the material approaches a free-flowing condition.

Step 4: Place the conical mould on a flat non-absorbent surface with the smaller opening facing upward. Fill it loosely to overflowing with the partially dried material. Tamp the surface of the material lightly 25 times with the tamping rod. Each drop should start approximately 5 mm above the surface. Do not add additional material during or after the tamping.

Use the cone test to determine the saturated surface dry condition

Step 5: Lift the mould vertically. If the material retains it conical shape, free water is still present. Continue to dry the material and repeat the cone test until the material slumps slightly on removal of the mould. This indicates that the saturated surface dry condition has been reached. If the material slumps on the first trial, it may have been dried past the saturated surface dry condition. In this case, add a few ml of water in the sample and permit it to stand in a covered container for 30 minutes. Continue the process of drying and testing until the saturated surface dry condition has been reached.

For some materials, the saturated surface dry condition may be difficult to determine

For materials that do not readily slump, see alternative procedures in ASTM C128.

Filling of pycnometer and removal of entrapped air

Step 6: Transfer the material to a pycnometer. The pycnometer should not be filled more than half full. Weigh the pycnometer and sample to the nearest 0.01 grams.

Step 7: Fill the pycnometer with distilled water until approximately 2/3 full. Roll, invert and agitate the pycnometer to eliminate air bubbles.

Step 8: Place the pycnometer in the vacuum dessicator. Apply suction to the dessicator (below 100 mm Hg) by using a vacuum pump. Maintain the reduced pressure for approximately 1 hour.

Notes

Step 9: The pycnometer is carefully filled with distilled water and plugged. Place in a water bath at 25°C for 1 hour.

Step 10: Adjust the water level in the pycnometer with a pipette to the filling line on the glass top. Remove the pycnometer from the bath, dry off water on the outside and weigh with contents.

Do not dry the material in the pycnometer

Step 11: Transfer the contents of the pycnometer to a container for drying. Pour off as much water as possible without loosing any material. Dry to constant weight and record the mass of oven dry material.

Results

Calculations

Calculate the bulk density and apparent density to the nearest 0.001 g/cm^3 and the water absorption to the nearest 0.01% by using the following equations:

$$\text{Bulk density, } \rho_{bd} = \frac{A}{D - \frac{(C - B)}{0.997}} \ (g/cm^3)$$

$$\text{Apparent density, } \rho_{bd} = \frac{A}{D - \frac{(C - A - E)}{0.997}} \ (g/cm^3)$$

$$\text{Water absorption} = \frac{B - E - A}{A} \cdot 100\ \%$$

where:
A = mass of oven dry sample, grams
B = mass of saturated surface dry sample + pycnometer, grams
C = mass of saturated sample + pycnometer filled with water, grams
D = volume of pycnometer, cm^3
E = mass of clean dry pycnometer, grams

See the following example.

Test precision

Among the largest sources of error when determining the density are air bubbles in the water and sample when weighing and the determination of the saturated surface dry condition.

Duplicate measurements shall not be considered suspect unless they differ by more than the limits give in table 3.10-1.

Table 3.10-1 Test precision

	One operator	Two laboratories
Bulk density	0.027 g/cm^3	0.056 g/cm^3
Apparent density	0.027 g/cm^3	0.056 g/cm^3
Water absorption	0.31 %	0.66 %

Density and Water Absorption of Aggregates Passing the 4.75 mm Sieve

Notes

Report

The test report shall include the following:

a) Type of material and identification of the test sample.
b) Test date.
c) Reference to this procedure.
d) Results of weighing.
e) Calculated bulk and apparent density to the nearest 0.001 g/cm^3.
f) Water absorption to the nearest 0.01 %.
g) Description of any deviations from this procedure.

Note: Density (ρ_d) may also be expressed as: t/m^3, kg/m^3, kg/dm^3 or kg/l

Practical considerations

It is necessary to recognize the importance of accurate values for the density in mix design.

The density of aggregates is a very important parameter in asphalt mix design and analyses. Binder content, which normally is expressed as weight-%, must always be considered in proportion to the density of the aggregates. The density is also used to calculate void contents in asphalt mixes, a very important parameter in mix design and mix evaluation.

Inaccurate values for the density may seriously affect the performance of an asphalt mix in the field.

In all, it is very important that the density is determined with high accuracy. If not, the results from mix design and mix analyses will be misleading. Wrong measurements of density may very well lead to rutting, aging or cracking problems in the field. The entire mix design and various mix investigations rely on highly accurate values for the density.

Maintenance

The pycnometers must be emptied and cleaned carefully immediately after use. Store the pycnometers properly, protected from dust.

Pycnometers should be calibrated according to test 3.11 regularly, minimum once a year. A new calibration is also required whenever small pieces of glass are broken from the pycnometer or glass top. Seriously damaged pycnometers, with cracks or large pieces missing, must never be used and should be discarded immediately.

TEST NO. 3.10

Density and Water Absorption of Aggregates Passing the 4.75 mm Sieve

Notes

Example

A:	Mass of dry sample	=56.30	g
B:	Mass of saturated surface dry sample + pycnometer	=101.56	g
C:	Mass of saturated sample + pycnometer + water	=186.12	g
D:	Volume of pycnometer	=106.79	cm^3
E:	Mass of clean dry pycnometer	= 44.13	g

$$Bulk\ density, \rho_{bd} = \frac{A}{D - \frac{(C - B)}{0.997}} = \frac{56.30}{106.79 - \frac{(186.12 - 101.56)}{0.997}} = 2.562\ g/cm^3$$

$$Apparent\ density, \rho_{ad} = \frac{A}{D - \frac{(C - A - E)}{0.997}} = \frac{56.30}{106.79 - \frac{(186.12 - 56.30 - 44.13)}{0.997}} = 2.701\ g/cm^3$$

$$Water\ absorption = \frac{B - E - A}{A} \cdot 100\ \% = \frac{101.56 - 44.13 - 56.30}{56.30} \cdot 100\% = 2.01\%$$

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WORKING SHEET

Density and Water Absorption of Aggregates Passing the 4.75 mm Sieve

Project	**Location**	**Depth**
Client	**Lab.no**	**Date**
Responsible Technician	**Checked**	**Approved**

Material:			Sample no 1	Sample no 2
	Pycnometer no			
A	Mass of oven dry sample	grams		
B	Mass of saturated surface dry sample + pycnometer	grams		
C	Mass of saturated sample + pycnometer + water	grams		
D	Volume of pycnometer	grams		
E	Mass of clean dry pycnometer	grams		

Bulk density, $\rho_{bd} = \dfrac{A}{D - \dfrac{(C-B)}{0.997}}$	g/cm^3		
Apparent density, $\rho_{ad} = \dfrac{A}{D - \dfrac{(C-A-E)}{0.997}}$	g/cm^3		
Water absorption, $w_{abs} = \dfrac{B-E-A}{A} \cdot 100\%$	%		

Average bulk density, ρ_{bd}	g/cm^3	
Average apparent density, ρ_{ad}	g/cm^3	
Average water absorption, w_{abs}	%	

Comments:

CML test 3.10, ref: ASTM C128-88 and ASTM D854

TEST NO. 3.11

Calibration of glass pycnometers (0.5 - 1 liter)

Notes

Objective

The objective of this method is to calibrate the glass pycnometers used to determine density of aggregates for bituminous mixes.

Main principles

Clean and dry pycnometers are weighed. The volume of the pycnometers are then determined by filling and weighing the pycnometers with distilled water holding a temperature of 25 °C.

References

Norwegian Public Roads Administration's guidelines for laboratory investigations, Handbook 014. Test no. 14.5922.

Required equipment

- Balance accurate to 0.01 grams.
- Water bath, accurate to ± 0.1 °C.
- Thermometer, accurate to ± 0.1 °C.
- Distilled water.
- Water bottle.

Test procedure

Always clean and dry the pycnometers before performing the calibration.

Step 1: Pycnometers and their corresponding tops are cleaned and dried. Cool to room temperature.

Step 2: Add silicon grease to the ground surface on the pycnometer tops. Avoid excessive use of grease.

Step 3: Pycnometer including top is weighed to the nearest 0.01 gram. Note the mass (m_1).

Step 4: The pycnometer is filled with distilled water to the line/ mark on the pycnometer top.

Step 5: Place the pycnometer in the water bath. The water should fully cover the main body of the pycnometers.

Adjust the water level in the pycnometers as the temperature changes.

Step 6: Leave the pycnometers standing in the water bath at temperature 25 ± 0.1 °C for 1 hour. The water level in the pycnometer top must be adjusted up to the mark/line as the temperature changes.

Step 7: The pycnometers are then dried and weighed to the nearest 0.01 gram. Note the mass (m_2).

Two parallel calibrations should be performed on each pycnometer.

A minimum of two parallel calibrations should be performed on each pycnometer.

Notes

Results

Calculations

Mass of distilled water = $m_2 - m_1$

The volume of the pycnometers are calculated using the following equation:

$$\text{Volume pycnometer, } 25\ ^oC = \frac{m_2 - m_1}{\rho_{\text{distilled water}}} = \frac{m_2 - m_1}{0.997}$$

where:
m_1 = mass of pycnometer.
m_2 = mass of pycnometer plus water.
$\rho_{\text{distilled water}}$ = density of distilled water at 25 °C.

Prepare a list of pycnometer mass and volume after calibration.

Report

After calibrating the pycnometers, prepare a list of pycnometer mass and volume (determined from calibration) as shown in table 3.11-1. This list should be updated every time the calibration routine is performed.

Table 3.11-1 Pycnometer calibration data

Pycnometer no.	Mass	Volume
1	m_1	V_1
2	m_2	V_2
3	m_3	V_3

Never use seriously damaged pycnometers.

Practical considerations

Pycnometers need not be calibrated every time they are used, but as a minimum once a year. A new calibration is also required whenever small pieces of glass are broken from the pycnometer or glass top. Seriously damaged pycnometers, with cracks or large pieces missing, must never be used and should be discarded immediately.

CENTRAL MATERIALS LABORATORY

WORKING SHEET

Calibration of Glass Pycnometers

Project	**Location**	**Depth**
Client	**Lab.no**	**Date**
Responsible Technician	**Checked**	**Approved**

Calibration temperature: 25 °C

Pycnometer no.	m_1 = mass of empty pycnometer incl. top (grams)	m_2 = mass of pycnometer incl. water (grams)	Volume pycnometer $= \frac{m_2 - m_1}{0.997}$ (cm^3)

Comments:

TEST NO. 3.12

Mixing of Test Specimens; Hot Bituminous Mixes

Notes

Objective

The objective of this procedure is to produce hot bituminous mixes in the laboratory. The conditions are chosen to produce as closely as possible a mix with characteristics similar to plant-mixed asphalt.

Main principles

Combine the different aggregate fractions to obtain the correct aggregate grading.

If various aggregate fractions are used, they must be prepared and mixed to produce a final aggregate grading identical to the mix-specification or mix-formulation. Aggregates and bitumen are preheated and blended at recommended mixing times and mixing temperatures.

References

Norwegian Public Roads Administration's guidelines for laboratory investigations, Handbook 014, Test no. 14.5532.

Required equipment

- Heating oven
- Balance with accuracy of 1g with ample capacity for the quantity of mix to be made, including the mixing container.
- Balance with accuracy of 0.01g for weighing binder additives.
- Equipment for manual or mechanical mixing.
- Suitable containers for heating the aggregates.

Test procedure

Preparation of aggregates

The correct quantity of each fraction must be calculated or taken from the mix formulation.

Step 1: The aggregate grading may be obtained by combining several fractions. The right proportions of each fraction must first be calculated to get the right grain size distribution for the hot mix. These fractions must then be split down to the required quantities to avoid segregation problems. The different fractions are then mixed to produce the final correct aggregate grading in the correct amount required for the specimens that will be made.

Step 2: Heat the aggregates in a suitable container to maximum 10°C above the mixing temperature given in Table 3.12-1. Keep the aggregates at this temperature for min. 2 hours.

Preheat bitumen and aggregates separately.

Step 3: Additives (if used) must be added to the aggregate before heating if they can withstand the heat. It is important that the additives are mixed evenly with the aggregates.¨

Preparing the binder

Step 4: The binder is heated gently in a container suitable for pouring to the mixing temperature found in Table 3.12-1. The binder is kept at this temperature for maximum 2 hours in a covered container. Overheating, in temperature or time, will affect the binder properties and must not occur.

Mixing of Test Specimens; Hot Bituminous Mixes

Notes

Step 5: Any additives to the binder are weighed on a balance with accuracy 0.01g or better. If no other information is given, the additives are added to the binder maximum 30 minutes before mixing with the aggregate.

Table 3.12-1 Mixing and compaction temperatures

Binder	Mixing temperature (°C)	Compaction temperature (°C)
Pen 40	145 - 155	135 – 145
Pen 60	142 - 152	132 – 142
Pen 85	138 - 148	129 – 139
Pen 180	130 - 140	122 – 132
Pen 250	126 - 136	117 – 127
Pen 370	121 - 131	112 – 122

Always adjust the mixing and compaction temperature to the type of binder used.

The values given in Table 3.12-1 are based on a mixing temperature at which the binder has a viscosity of 170 ± 20 mm^2/s and a compaction temperature at which the binder has a viscosity of 280 ± 30 mm^2/s. The temperature ranges given are approximate. If more detailed information about the temperature-viscosity relationship for the binder is known, more exact temperatures may be determined. When using polymer modified binders the recommended mixing and compaction temperatures given by the supplier should be used.

Mixing of binder and aggregates

The mixing may be done either manually or mechanically.

Step 6: The container to be used for mixing of binder and aggregate must be heated to the mixing temperature. It may be practical to heat the aggregates in the same container that is to be used for mixing of aggregate and binder.

Mix until all the aggregates are fully coated with binder.

Step 7: After the aggregate (with any additives) has been placed in the mixing container, the exact right amount of binder is added. The materials are mixed until the binder coats the aggregates completely. To avoid a large drop in temperature during mixing, the time used for mixing should be kept to a minimum.

Step 8: The procedure from here will depend on which type of specimens that will be made or which tests that will be performed. If the mix-temperature drops below the compaction temperature, the mix should be put back into the heating oven. The mix should in these cases be covered to avoid excessive ageing.

TEST NO. 3.12

Mixing of Test Specimens; Hot Bituminous Mixes

Notes

Important: ***The reliability of results from asphalt mix testing is very much dependent on representative samples. Mixing must for this reason be performed with great care and accuracy.***

Report

The test report shall include the following:

a) Type of material and sample identification
b) Reference to this procedure
c) Any special observations
d) Mixing temperature
e) Description of any deviations from this procedure

Practical considerations

The reliability of test results performed on laboratory mixed asphalt samples depends on preparation of the samples with great accuracy. Variations in binder content, aggregate grading or binder properties will affect the test results and wrong or misleading conclusions may be drawn. Consequences of this may be shortened pavement life due to rutting, cracking or ageing.

Maintenance

Clean all equipment used.

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WORKING SHEET

Mixing of Test Specimens
Hot Bituminous Mixes

Project	**Location**	**Depth**
Client	**Lab.no**	**Date**
Responsible Technician	**Checked**	**Approved**

A = total weight of aggregates: grams

Fraction name	B = % by weight of A	Mass = $\frac{A}{100}$xB (grams)
Sum:		

Type of bituminous binder:

C = binder in % by weight of total mix	Mass = $\frac{A \times C}{100 - C}$ (grams)

Heating temperatures, °C

Aggregates	
Binder	

Comments:

TEST NO. 3.13

Determination of Max. Theoretical Density of Asphalt Mixes and Absorption of Binder into Aggregates

Notes

Objective

This method (Rice's method) is used to determine the maximum theoretical density, also called the void-free density, of asphalt mixes. The maximum theoretical density is used to calculate the void content of asphalt mixes.

This method is also used to determine the amount of binder absorbed by the aggregates in an asphalt mix.

Main principles

A weighed sample of oven-dry asphalt mixture in loose condition is placed in a tared container/bowl. Water holding a temperature of 25°C is added to completely submerge the sample. Vacuum is applied to remove entrapped air within the sample. The void-free volume of the sample is measured by weighing the container (with sample) immersed in water.

The binder absorption is calculated from the difference between the total volume of all mix components (calculated from mass and densities) and the void-free volume of the mix determined in this procedure. The binder absorption is expressed as percentage of the mass of dry aggregates in the mix.

References

ASTM D2041-95, D4469-85
AASHTO T209-94

Required equipment

Different types of bowls, containers or pycnometers may be used

- Thermometer with accuracy 0.1°C.
- Glass, plastic or metal bowl/container with a capacity of approximately 2000 ml. Other types of containers may also be used, see the reference documents.
- Balance with minimum accuracy of 0.1 g.
- Water bath capable of holding a temperature of 25°C.
- Vacuum type dessicator.
- Vacuum pump or other arrangement to create suction within the vacuum dessicator.

Test procedure

Perform the required tests in advance

Step 1: To calculate the absorption of binder into aggregates, the bulk density of the aggregate blend (test 3.9 and 3.10) and the density of the binder (test 3.2) must be determined in advance. If the binder content of the mix is unknown, this must be determined by extraction (test 3.21).

Step 2: Obtain a sample from an existing mixture or prepare a mixture in the laboratory. Samples prepared in the laboratory must be identical (in terms of types and grading of aggregates and binder content) to the mix being investigated. The size of the sample shall be governed by the maximum nominal aggregate size according to table 3.13-1.

Determination of Max. Theoretical Density of Asphalt Mixes and Absorption of Binder into Aggregates

Notes

Table 3.13-1 Sample size

Nominal maximum aggregate size, mm	Minimum mass of test sample, kg
25.0	2.5
19.0	2.0
12.5	1.5
9.5	1.0
4.75	0.5

IMPORTANT: separate the particles manually

Step 3: Separate the particles of the sample without fracturing the mineral particles. Particles of the fine aggregate portion should not be larger than 6.5 mm. If the mixture is not sufficiently soft to separate the particles manually, place it in a large flat pan and warm in an oven until it can be handled. The sample must be dry before proceeding.

Step 4: Weigh and determine the mass of the bowl/container in air and immersed in water.

Step 5: Place the sample in the bowl/container (must be dry) and determine its mass. The sample must at this time be cooled down to room temperature.

Add a wetting agent to facilitate the removal of air

Step 6: Add water to the bowl/container until the sample is completely covered. Add a wetting agent to facilitate the removal of entrapped air in the sample. 2 drops of a 10% solution of Teenol or similar detergent is suitable.

Step 7: Place the bowl/container in the vacuum dessicator and reduce the pressure to 30 mm Hg. Shake the sample at 2-minute inter vals to facilitate the removal of air. Maintain the reduced pres sure for 15 ± 2 minutes followed by a gradual pressure equalizing to atmospheric pressure.

Step 8: Suspend the bowl/container and contents in water at 25 ± 1°C and determine its mass after 10 ± 1 minute immersion. The bowl/container should be immersed to a depth sufficient to cover it completely during weighing.

Supplemental procedure for mixtures with porous aggregates not completely coated with bitumen

If the pores of the aggregates are not completely sealed by a bituminous film, they may become saturated with water during the evacuation process. To determine if this has occurred, proceed with the following. If this is not considered to be a problem, proceed directly to the calculations.

Step 9: Drain water from the sample. Loss of particles must not occur.

Notes

The drying procedure normally takes about 2 hours

Step 10: Spread the sample in front of an electric fan to remove surface moisture. Break conglomeration of the mixture by hand and stir the sample at regular intervals. Weigh the sample at 10-minute intervals. When the loss in mass is less than 0.5 grams after an interval, consider the sample to be surface dry. Record the mass of the surface dry sample.

Step 11: Calculate the maximum theoretical density by replacing the dry mass of the material with the mass of the surface dry material in the denominator of the equation.

Results

Calculation of maximum theoretical density

Calculate the maximum theoretical density of the mixture to the nearest 0.001 g/cm^3 from the following equation:

$$\text{Maximum theoretical density, } \rho_{d\,max} = \frac{A}{\dfrac{A - (B - C)}{\rho_{water}}} \quad (g / cm^3)$$

where:
A = mass of dry sample in air (or surface dry, in denominator only), grams
B = mass of bowl/container and sample immersed in water, grams
C = mass of bowl/container immersed in water, grams
ρ_{water} = density of water (0.997 g/cm^3 at 25°C)

Calculation of binder absorption

To calculate the binder absorption, the total volume of the aggregates (use the bulk density) and binder must be calculated. From this value, subtract the volume of the void-free sample found in this procedure. The difference between the two is the binder absorbed by the aggregates. Convert this to mass of binder. Report the binder absorption to the nearest 0.1%.

Step 1: Determine the mass of binder in the sample:

$$D = \frac{p \text{ x } A}{100}, \text{ grams}$$

where:
A = mass of dry sample in air, grams
D = mass of binder in the sample, grams
p = percentage of binder in the mixture, %

Step 2: Determine the mass of aggregates in the sample:

$$E = \frac{(100 - p) \text{ x } A}{100}, \text{ grams}$$

where:
A = mass of dry sample in air, grams
E = mass of aggregates in the sample, grams
p = percentage of binder in the mixture. %

Notes

Step 3: Determine bulk volume of aggregates and binder in the sample

$$Vol_{bulk} = \frac{E}{\rho_{bd}} + \frac{D}{\rho_{bit}} \text{ , cm}^3$$

where:
Vol_{bulk} = bulk volume of aggregates and binder in the sample, cm^3
D = mass of binder in the sample, grams
E = mass of aggregates in the sample, grams
ρ_{bd} = bulk density of the aggregates, g/cm^3
ρ_{bit} = density of the binder, g/cm^3

The difference between the bulk volume of the constituent parts of the sample and the volume of the void-free sample is equal to the volume of absorbed binder

Step 4: Determine the volume of void-free sample:

$$Vol_{voidfree} = \frac{A - (B - C)}{\rho_{water}} \text{ , } cm^3$$

where:
$Vol_{void\text{-}free}$ = void-free volume of the sample, cm^3
A = mass of dry sample in air (or surface dry), grams
B = mass of bowl/container and sample immersed in water, grams
C = mass of bowl/container immersed in water, grams
ρ_{water} = density of water (0.997 g/cm^3 at 25°C)

Express the absorbed binder as a percentage of the mass of aggregates in the sample

Step 5: Percentage of binder absorbed by the aggregates:

$$Pabs = \frac{(Vol_{bulk} - Vol_{voidfree}) \ x \ \rho_{bit}}{E} \cdot 100 \ \%$$

where:
Vol_{bulk} = calculated bulk volume of aggregates and binder in the sample, cm^3
$Vol_{void\text{-}free}$ = void-free volume of the sample, cm^3
E = mass of aggregates in the sample, grams

Test precision

Duplicate measurements shall not be considered suspect unless they differ more than the limits given in table 3.13-2.

Table 3.13-2 Test precision (for bowl determination only)

	One operator	Two laboratories
Maximum theoretical density, g/cm^3	0.018	0.055

Report

The test report shall include the following:

a) Reference to this procedure
b) Type and identification of the test sample

Notes

c) Maximum theoretical density to the nearest 0.001 g/cm^3 and absorbed binder to the nearest 0.1 %
d) Date
e) Description of any deviations from this procedure

Practical consideration

The void content is a very important parameter in mix design and mix evaluation. The void content is calculated directly from the maximum theoretical density of the mix, which consequently must be determined with high accuracy. Wrong or inaccurate measurements of maximum theoretical density may indirectly lead to rutting, aging or cracking problems in the field. Wrong conclusions may also be drawn in the laboratory when investigating the causes for poor mix performance in the field.

Maintenance

Clean all equipment after use.

Example:

The maximum theoretical density of a bituminous mixture is to be measured at 25°C. The following data for the mix are given:

Binder content: 5.0 %
Average bulk density of aggregates (at 25°C): 2.492 g/cm^3
Density of bitumen (at 25°C): 1.011 g/cm^3

The mixture contains porous aggregates, which are not all fully coated by bitumen in the mixture.

Results of weighing:

Mass of bowl in air:	463.1 grams
Mass of bowl immersed in water at 25°C:	402.2 grams
Mass of dry sample + bowl in air:	2464.1grams
Mass of dry sample (calculated):	2001.0grams
Mass of sample + bowl immersed in water at 25°C:	1558.7 grams
Mass of surface dry sample:	2004.3 grams

Calculation of maximum theoretical density:

Alternative 1: Do not consider absorption of water into the aggregates (not the correct procedure for this mix)

$$Maximum\ \ theoretical\ \ density,\ \rho_{d\,max} = \frac{2001.0}{\dfrac{2001.0-(1558.7-402.2)}{0.997}} = 2.362\ \ g/cm^3$$

Alternative 2: Do consider absorption of water into the aggregates (correct procedure for this mix)

$$Maximum\ \ theoretical\ \ density,\ \rho_{d\,max} = \frac{2001.0}{\dfrac{2004.3-(1558.7-402.2)}{0.997}} = 2.353\ \ g/cm^3$$

From this it can be seen that water absorption into porous aggregates may effect the maximum theoretical density significantly and therefor should be accounted for.

Calculation of binder absorption:

Mass of binder in the sample: $$D = \frac{5 \times 2001.0}{100} = 100.05 \text{ grams}$$

Mass of aggregates in the sample: $$E = \frac{95 \times 2001.0}{100} = 1900.95 \text{ grams}$$

Bulk volume of aggregates and binder in the sample: $$Vol_{bulk} = \frac{1900.95}{2.492} + \frac{100.05}{1.011} = 861.78 \text{ cm}^3$$

Volume of void-free mixture sample: $$Vol_{voidfree} = \frac{2004.3 - (1558.7 - 402.2)}{0.997} = 850.35 \text{ cm}^3$$

Binder absorption: $$p_{abs} = \frac{(861.78 - 850.35) \times 1.011}{1900.95} \cdot 100\ \% = 0.6\ \%$$

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WORKING SHEET

Maximum Theoretical Density of Asphalt Mixes, Absorption of Binder into Aggregates

Project	**Location**	**Depth**
Client	**Lab.no**	**Date**
Responsible Technician	**Checked**	**Approved**

Aggregates:
Fully coated ☐
Porous, not fully coated ☐

Predetermined input data:

$\rho_{bd\,agg}$	Bulk density of the total aggregate blend (test 3.9 and 3.10)				g/cm^3
ρ_{bit}	Density of binder (test 3.2)				g/cm^3
p	Binder content in the asphalt mix				%

Results of weighing:

m_1	Mass of container/bowl in air				grams
C	Mass of container/bowl in water				grams
m_2	Mass of container/bowl and dry sample in air				grams
B	Mass of container/bowl and saturated sample in water				grams
A_s	Mass of surface dry sample in air				grams
A_d	Mass of dry sample in air (calculate) = $m_2 - m_1$				grams

Calculations:

$\rho_{d\,max}$ [1]	Maximum theoretical density = $\dfrac{A_d}{\dfrac{A_d-(B-C)}{0.997}}$				g/cm^3
$\rho_{d\,max}$ [2]	Maximum theoretical density = $\dfrac{A_d}{\dfrac{A_s-(B-C)}{0.997}}$				g/cm^3
D	Mass of binder in the asphalt sample = $0.01 \cdot p \cdot A_d$				grams
E	Mass of aggregates in the asphalt sample = $0.01 \cdot (100-p) \cdot A_d$				grams
V_{bulk}	Bulk volume of aggregates and binder in the sample = $\dfrac{E}{\rho_{bdagg}}+\dfrac{D}{\rho_{bit}}$				cm^3
$V_{void\,free}$ [3]	Void-free volume asphalt sample = $\dfrac{A_{d/s}-(B-C)}{0.997}$				cm^3
p_{abs}	Binder absorbed by the aggregates = $\dfrac{(V_{bulk}-V_{voidfree})\cdot\rho_{bit}}{E}\cdot 100\%$				%

[1] Equation for aggregates fully coated with binder, where absorption of water is not a problem
[2] Equation for porous aggregates, not fully coated with binder, where absorption of water may be a problem
[3] Use A_d for fully coated aggregates, use A_s for aggregates which are not fully coated and may absorb water

CML test 3.13, ref: ASTM D2041-95 and D4469-85, AASHTO T209-94

TEST NO. 3.14

Bulk Density of Saturated Surface Dry Asphalt Mix Samples

Notes

Objective

This method is used to determine the bulk density of hot mixed asphalt mix samples. The test specimens may be core-drilled from existing pavements or made in the laboratory. The samples must not have an exposed open air void system or large cavities in the end faces.

Main principles

The volume of a sample is found by determining its buoyancy in water. Density is calculated from the sample's dry mass, saturated surface dry mass and measured volume.

References

ASTM D2726-96

Required equipment

- Saw for cutting core samples.
- Steel brush.
- Balance, minimum 1200g, with accuracy ± 0.01g.
- Sample container (wire cloth basket) for weighing asphalt samples immersed n water.
- Water bath 15 liters, thermostatically regulated with an accuracy of ± 0.1°C.
- Distilled water
- Heating oven

Test procedure

Preparation of test specimens from the field

Pavement samples:

Step 1A: Cut two square specimens from the pavement with a cutting saw. The samples shall not have cracks or other distresses. All cut surfaces must be made using the cutting saw.

Core-drilled samples:

Step 1B: If the samples consist of one asphalt layer, the surface facing the sub-base must be cleaned with a steel brush and water or cut. All samples must be completely clean of particles from other layers.

The pretreatment of the samples depends on type of sample

Step 1C: If the samples consist of two or more asphalt layers, the layer to be investigated (normally the top layer) is cut of.

The top of samples taken from pavements that have been blinded off with fine crushed aggregates or sand must be cut. Failing to do so will give inaccurate results. Do not cut of more than required.

The sample thickness should preferably be over 1.5x the largest nominal aggregate size.

The thickness of prepared/cut samples should at least be 1.5 times the largest nominal aggregate size in the asphalt layer, with a minimum thickness of 20 mm. For square pavement samples, the length of the sides

Notes

should also be at least 4 times the largest nominal aggregate size. If this requirement is not met, the test results may become inaccurate.

Procedure
Bulk density should always be determined for a minimum of two parallel test samples.

Constant mass is defined as the mass at which further drying (at 52°C) does not alter the mass by more than 0.05%.

Step 2: The samples should be dried to constant mass at room temperature or in a heating oven at low temperature (the samples must not deform) before determining their volume. Recently molded laboratory samples need not be dried if they have not been exposed to moisture.

Step 3: Record the dry mass.

Step 4: Immerse each specimen in water at 25 ± 1.0°C for 4±1 minutes and record the immersed mass.

Any water that seeps from the specimen during the weighing operation is considered part of the saturated surface dry specimen.

Step 5: Remove the specimen from the water, damp dry the specimen by blotting with a damp dry towel as quickly as possible. Determine the surface dry mass immediately.

Results

Calculation of bulk density
The bulk density is calculated as follows:

Mass in air (dry specimen): m_1
Mass submerged in water: m_2
Mass of saturated surface dry specimen: m_3

Volume of test sample: $V_1 = \dfrac{m_3 - m_2}{\rho_{water}}$

Bulk density of specimen: $\rho_{bd} = \dfrac{m_1}{V_1}$

where $\rho_{\mathbf{water}}$ = density of water at 25°C, set to be 0.9970 g/cm^3.

Calculation of water absorption

Determine the percentage of absorbed water by volume as:

$$\text{Water absorption} = \frac{m_3 - m_1}{V_1} \cdot 100\ \%$$

If the water absorption exceeds 2 percent, this test method is not suitable to determine the bulk density. Use test 3.15 or 3.16 instead.

Test precision
Duplicate measurements shall not be considered suspect unless they differ more than the limits given in table 3.14-1.

TEST NO. 3.14

Bulk Density of Saturated Surface Dry Asphalt Mix Samples

Notes

Table 3.14-1 Test precision

	One operator	Two laboratories
Bulk density, g/cm^3	0.035	0.076

Report

The test report shall include the following:

a) Reference to this procedure.
b) Type and identification of the test sample.
c) Calculated density to three decimal points and absorbed water to the nearest 0.1%.
d) Test date.
e) Description of any deviations from this procedure.

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WORKING SHEET

Bulk Density of Saturated Surface Dry Asphalt Mix Samples

Project	**Location**	**Depth**
Client	**Lab.no**	**Date**
Responsible Technician	**Checked**	**Approved**

Specimen no.	Binder content, %	Mass of specimens			Volume (cm^3)	Bulk density (g/cm^3)	Water absorption, %
		m_1 Dry, grams	m_2 Immersed in water, grams	m_3 Surface dry, grams	$V_1 = \frac{m_3 - m_2}{0.997}$	$\rho_{bd} = \frac{m_1}{V_1}$	$\frac{m_3 - m_1}{V_1} \cdot 100\%$

Comments:

TEST NO. 3.15

Bulk Density of Paraffin-Coated Asphalt Mix Samples

Notes

Do not use this method for samples with large open visible voids. If this is the case (void content > approximately 12%), use test 3.16 to determine the bulk density.

Objective

This method is used to determine the bulk density of asphalt mix samples. The test specimens may be core-drilled from existing pavements or made in the laboratory. This method is suitable for samples that contain open or interconnected voids and/or absorb more than 2 percent water as determined in test 3.14.

Main principles

The volume of a paraffin-coated sample is found by determining its buoyancy in water. Density is calculated from the sample's dry mass, mass of paraffin on the sample and measured volume of the paraffin-coated sample.

References

ASTM D1188-89
AASHTO T275-91

Required equipment

- Saw for cutting the samples.
- Steel brush.
- Balance, minimum 1200g, with accuracy ± 0.01g.
- Sample container (wire cloth basket) for weighing asphalt samples immersed n water.
- Water bath 15 liters, thermostatically regulated with an accuracy of ± 0.1°C.
- Distilled water
- Paraffin
- Heating oven

Test procedure

Preparation of test specimens from the field

Pavement samples:

Step 1A: Cut two square specimens from the pavement with a cutting saw. The samples shall not have cracks or other distresses. All cut surfaces must be made using the cutting saw.

Core-drilled samples:

Step 1B: If the samples consist of one asphalt layer, the surface facing the sub-base must be cleaned with a steel brush and water or cut. All samples must be completely clean of particles from other layers.

The pretreatment of the samples depends on type of sample

Step 1C: If the samples consist of two or more asphalt layers, the layer to be investigated (normally the top layer) is cut of.

The top of samples taken from pavements that have been blinded off with fine crushed aggregates or sand must be cut. Failing to do so will give inaccurate results. Do not cut of more than required.

Bulk Density of Paraffin-Coated Asphalt Mix Samples

Notes

The sample thickness should preferably be over 1.5x the largest nominal aggregate size.

The thickness of prepared/cut samples should at least be 1.5 times the largest nominal aggregate size in the asphalt layer, with a minimum thickness of 20 mm. For square pavement samples, the length of the sides should also be at least 4 times the largest nominal aggregate size. If this requirement is not met, the test results may become inaccurate.

Procedure

Bulk density should always be determined for a minimum of two parallel test samples.

Constant mass is defined as the mass at which further drying (at 52°C) does not alter the mass by more than 0.05%.

Step 2: The samples should be dried to constant mass at room temperature or in a heating oven at low temperature (the samples must not deform) before determining their volume. Recently molded laboratory samples need not be dried if they have not been exposed to moisture.

Step 3: Record the dry mass.

The temperature of the melted paraffin should be approximately 5°C above the melting point.

Step 4: Coat the sample with melted paraffin sufficiently thick to seal all voids. Allow the sample to cool at room temperature for 30 minutes.

Step 5: Record the mass of the paraffin-coated sample.

If the samples will be used for further testing, the samples should be dusted with talc prior to coating. This will ease the removal of paraffin from the samples.

Step 6: Immerse each specimen in water at 25 ± 1.0°C for 4±1 minutes and record the immersed mass.

Step 7: Determine the density of paraffin at 25°C, if this is unknown. The density of paraffin is approximately 0.90 g/cm^3.

Results

Calculation of bulk density

The bulk density is calculated as follows:

Mass of sample in air (dry specimen): m_1
Mass of paraffin-coated sample in air: m_2
Mass of coated sample in water: m_3
Density of paraffin: ρ_p

Volume of test sample: $V_1 = \left(\frac{m_2 - m_3}{\rho_{water}}\right) - \left(\frac{m_2 - m_1}{\rho_p}\right)$

Bulk density of specimen: $\rho_{bd} = \frac{m_1}{V_1}$

where:
ρ_{water} = density of water at 25°C, set to be 0.9970 g/cm^3
ρ_p = density of paraffin at 25°C, set to be 0.90 g/cm^3 if not measured

Test precision

Duplicate measurements of bulk density by the same operator shall not be considered suspect unless they differ more than 0.02 g/cm^3.

Bulk Density of Paraffin-Coated Asphalt Mix Samples

Notes

Report

The test report shall include the following:

a) Reference to this procedure.
b) Type and identification of the test sample.
c) Calculated density to three decimal points.
d) Test date.
e) Description of any deviations from this procedure.

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WORKING SHEET

Bulk Density of Paraffin-Coated Asphalt Mix Samples

Project	**Location**	**Depth**
Client	**Lab.no**	**Date**
Responsible Technician	**Checked**	**Approved**

Density of paraffin (ρ_p) at 25°C: g/cm³

Specimen no.	Binder content, %	Mass of specimens			Volume (cm³)	Bulk density (g/cm³)
		m_1 Dry, grams	m_2 Paraffin-coated in air, grams	m_3 Paraffin-coated in water, grams	$V_1 = \frac{m_2 - m_3}{0.997} - \frac{m_2 - m_1}{\rho_p}$	$\rho_{bd} = \frac{m_1}{V_1}$

Comments:

TEST NO. 3.16

Bulk Density of Asphalt Mix Samples, Caliper Measurements

Notes

Objective

This method is used to determine the density of asphalt mix samples with interconnecting voids or open air void systems above approximately 12%.

Main principles

The volume of a sample is calculated from measurements of diameter and height using a caliper. Density is calculated from measured dry mass and volume.

References

Norwegian Public Roads Administration's guidelines for laboratory investigations, Handbook 014. Test no. 14.5622.

Required equipment

- Saw for cutting core samples.
- Steel brush.
- Balance, minimum 1200g, with accuracy ± 0.01g.
- Caliper

Test Procedure

Preparation of test specimens from the field

Pavement samples:

Step 1A: Cut two 100x100mm samples from the pavement with a cutting saw. The samples shall not have cracks or other distresses. All cut surfaces must be made using the cutting saw.

Core-drilled samples:

Step 1B: If the samples consist of one asphalt layer, the surface facing the sub-base must be cleaned with a steel brush and water or cut. All samples must be completely clean of particles from other layers.

Step 1C: If the samples consist of two or more asphalt layers, the layer to be investigated (normally the top layer) is cut of.

The pretreatment of the samples depends on type of sample

The top of samples taken from pavements that have been blinded off with fine crushed aggregates or sand must be cut. Failing to do so will give inaccurate results. Do not cut of more than required.

Do not include intended surface structure to the void content.

Any intended surface structure of the samples should not be included in the void content. Samples with this type of surface structure should be cut before the caliper measurements and weighing.

Procedure

Density should always be determined for a minimum of two parallel test samples.

TEST NO. 3.16

Bulk Density of Asphalt Mix Samples, Caliper Measurements

Notes

Use a caliper to measure height and diameter.

Step 2: The samples should be dried to constant mass at room temperature or in a heating oven at low temperature (the samples must not deform) before determining their volume.

Step 3: Measure the sample height in four locations and diameter in two locations

Results

Calculations

The density is calculated as follows:

$$\rho_d = \frac{m_1 \times 100}{\left(\frac{d}{2}\right)^2 \text{ x } \pi \text{ x } h}$$

where:

ρ_d = sample density, g/cm^3

m_1 = mass of dry sample accurate to 0.1 g

d = average diameter accurate to 0.1 mm

h = average height accurate to 0.1 mm

Report

The test report shall include the following:

a) Reference to this procedure.
b) Type and identification of the test sample.
c) Calculated density to two decimal points.
d) Test date.
e) Description of any deviations from this procedure.

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WORKING SHEET

Bulk Density of Asphalt Mix Samples Caliper Measurements

Project	**Location**	**Depth**
Client	**Lab.no**	**Date**
Responsible Technician	**Checked**	**Approved**

Spec. no.	m_1 mass of dry specimen grams	Height (mm)				Diameter (mm)			Bulk Density g/cm^3
		h_1	h_2	h_3	h_{mean}	d_1	d_2	d_{mean}	$\rho_d = \frac{m_1 \times 1000}{\left(\frac{d}{2}\right)^2 \times \pi \times h}$

Comments:

TEST NO. 3.17

Calculation of Void Content in Bituminous Mixes

Notes

Objective

This method is used to calculate the void content, voids filled with binder and voids in mineral aggregate for bituminous mixes. The density of the mix, which is used in the calculation, may be determined from analysis of core-drilled samples or samples made in the laboratory.

Main principles

The void content is calculated using the density and the maximum theoretical density of the samples. The voids in mineral aggregate are determined from the bulk volume of the asphalt mix sample and the bulk volume of aggregates in the mix. The voids filled with binder are determined from the volume of effective binder in the mix and the volume of voids in the aggregate.

Definitions

The *void content* is defined as the volumetric percentage of a sample that is not filled by aggregate or binder at 25°C.

The *voids in mineral aggregate (VMA)* is defined as the difference in bulk volume of the mix and mineral aggregates in the mix, expressed as a percentage of the bulk volume of the mix.

The *voids filled with binder* is defined as the volume of effective binder in the mix, expressed as a percentage of the volume of voids in the aggregates (VMA).

References

ASTM D3203
AASHTO Designation PP19-93

Test procedure

Density and maximum theoretical density of the asphalt mix and density of binder and aggregates must be known in advance.

The following data must be measured/calculated in advance:

- Maximum theoretical density of the samples (test 3.13).
- Bulk density of the asphalt mix samples (test 3.14, 3.15 or 3.16).
- Density of binder and aggregates in the mix (test 3.2, 3.9 and 3.10)

Results

Calculations

To determine the void content, voids in mineral aggregate and voids filled with binder, the following calculations must be made in advance. The basis of these calculations is 100 cm^3 of the mix.

<u>Mass of aggregates in the sample:</u>

$$m_{agg} = \rho_{bd\,mix} \times (100 - p)$$

where:
m_{agg} = mass of aggregate in the mix, grams

Calculation of Void Content in Bituminous Mixes

Notes

$\rho_{bd\,mix}$ = bulk density of asphalt mix sample, g/cm^3
p = binder content i %

<u>Mass of binder in the sample:</u>

$$m_{bit} = \rho_{bd\,mix} \times p$$

where:
m_{bit} = mass of binder in the mix, grams
$\rho_{bd\,mix}$ = bulk density of asphalt mix sample, g/cm^3
p = binder content i %

<u>Mass of absorbed binder:</u>

$$m_{abs} = \frac{p_{abs} \times m_{agg}}{100}$$

where:
m_{abs} = mass of absorbed binder, grams
p_{abs} = binder absorbed by the aggregates (test 3.13), %
m_{agg} = mass of aggregate in the mix, grams

<u>Mass of effective binder:</u>

$$m_{eff} = m_{bit} - m_{abs}$$

where:
m_{eff} = mass of effective binder, grams
m_{abs} = mass of binder in the sample, grams
m_{abs} = mass of absorbed binder, grams

<u>Volume of aggregates:</u>

$$V_{agg} = \frac{m_{agg}}{\rho_{bd\,agg}}$$

where:
V_{agg} = volume of aggregates in the mix, cm^3
m_{agg} = mass of aggregates in the mix, grams
$\rho_{bd\,agg}$ = average bulk density of total aggregates (test 3.9), g/cm^3

Volume of effective binder:

$$V_{bit} = \frac{m_{eff}}{\rho_{bit}}$$

where:
$V_{\mathbf{bit}}$ = volume of effective binder in the mix, cm^3
m_{eff} = mass of effective binder in the mix, grams
ρ_{bit} = density of the binder (test 3.2), g/cm^3

Calculation of Void Content in Bituminous Mixes

Notes

Calculation of void content

The void content is calculated using the following equation:

$$V_0 = \frac{\rho_{d\,max} - \rho_{bd\,mix}}{\rho_{d\,max}} x100$$

where:

V_0 = void content in %
$\rho_{d\,max}$ = maximum theoretical density of sample, g/cm^3
$\rho_{bd\,mix}$ = bulk density of asphalt mix sample, g/cm^3

Calculation of voids in mineral aggregate

The voids in mineral aggregate is calculated using one of the following two equations:

$$VMA = 100 - V_{agg}$$

$$VMA = 100 - \frac{(100 - p) \times \rho_{bd\,mix}}{\rho_{bd\,aggr.}}$$

where:

VMA = voids in mineral aggregate, %
V_{agg} = volume of aggregates, cm^3
p = binder content in %
$\rho_{bd\,mix}$ = bulk density of asphalt mix sample, g/cm^3
$\rho_{bd\,aggr.}$ = average bulk density of total aggregates, g/cm^3

Calculation of voids filled with binder

The voids filled with binder is calculated using the following equation:

$$V_{fb} = \frac{V_{bit}}{VMA} \times 100\%$$

where:

V_{fb} = voids filled with binder, %
V_{bit} = volume of effective binder, cm^3
VMA = voids in mineral aggregate, %

Report

The test report shall include the following:

a) Reference to this procedure
b) Type and identification of the test sample
c) Calculated void content, voids in mineral aggregate (VMA) and voids filled with binder to the nearest 0.1 %
d) Date
e) Description of any deviations from this procedure

TEST NO. 3.17

Calculation of Void Content in Bituminous Mixes

Example:

Determine void content, voids in mineral aggregate (VMA) and voids filled with binder for the following asphalt mix:

- Binder content = 6.0 %
- The bulk density of the total aggregates has been determined to be $\rho_{bd\ agg} = 2.577$ g/cm^3
- The density of the binder has been determined to be $\rho_{bit} = 1.011$ g/cm^3
- The average bulk density of several core samples has been determined to be $\rho_{bd\ mix} = 2.214$ g/cm^3.
- The maximum theoretical density of these samples has been determined to be $\rho_{d\ max} = 2.360$ g/cm^3.
- The percentage of binder absorbed by the aggregates has been determined to be: $p_{abs} = 0.1$ %

Based on 100 cm^3 of asphalt mix (compacted mix):

Mass of aggregates: $m_{agg} = 2.214 \text{x} (100 - 6) = 208.11 \ grams$

Mass of binder in the sample: $m_{bit} = 2.214 \text{x} 6 = 13.28 \ grams$

Mass of absorbed binder: $m_{abs} = \frac{0.1 x 208.11}{100} = 0.21 \ grams$

Mass of effective binder: $m_{eff} = 13.28 - 0.21 = 13.07 \ grams$

Volume of aggregates: $V_{agg} = \frac{208.11}{2.577} = 80.76 \ cm^3$

Volume of effective binder: $V_{bit} = \frac{13.07}{1.011} = 12.93 \ cm^3$

The void content in the mix: $V_0 = \frac{2.360 - 2.214}{2.360} \text{x} 100\% = 6.2\%$

Voids in mineral aggregate, VMA: $VMA = 100 - 80.76 = 19.24\%$

(alternative calculation of VMA) $VMA = 100 - \frac{(100 - 6.0) x 2.214}{2.577} = 19.24 \ \%$

Void filled with binder: $V_{fb} = \frac{12.93}{19.24} \text{x} 100\% = 67.2 \ \%$

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WORKING SHEET

Calculation of Void Content in Bituminous Mixes

Project	**Location**	**Depth**
Client	**Lab.no**	**Date**
Responsible Technician	**Checked**	**Approved**

Predetermined data:		Series No. 1	Series No. 2
Maximum theoretical density of the mix (test 3.13), $\rho_{d\,max}$:	g/cm^3		
Percentage of binder absorbed by aggregates (test 3.13), p_{abs}:	%		
Density of the binder (test 3.2), ρ_{bit}:	g/cm^3		
Bulk density of the total aggregate blend (test 3.9 and 3.10), $\rho_{bd\,agg}$:	g/cm^3		
Binder content, p:	%		

Calculations are based on 100 cm^3 of compacted mix

Series No.								
Specimen No.								
Bulk density, $\rho_{bd\ mix}$ [1] g/cm^3								
Mass, grams	Aggregates	$m_{agg} = \rho_{bd\,mix} \cdot (100 - p)$						
	Binder	$m_{bit} = \rho_{bd\,mix} \cdot p$						
	Absorbed binder	$m_{abs} = \frac{p_{abs} \cdot m_{agg}}{100}$						
	Effective binder	$m_{eff} = m_{bit} - m_{abs}$						
Volume, cm^3	Aggregates	$V_{agg} = \frac{m_{agg}}{\rho_{bd\,agg}}$						
	Effective binder	$V_{bit} = \frac{m_{eff}}{\rho_{bit}}$						
Void content, %		$V_0 = \frac{\rho_{d\,max} - \rho_{bd\,mix}}{\rho_{d\,max}} \cdot 100$						
VMA, %		$VMA = 100 - V_{agg}$						
Voids filled with binder, %		$V_{fb} = \frac{V_{bit}}{VMA} \cdot 100\ \%$						

[1] of compacted specimen, predetermined in test 3.14, 3.15 or 3.16

Comments:

CML test 3.17, ref: ASTM D3203, AASHTO Designation PP19-93

TEST NO. 3.18

Marshall Test

Notes

Objective

The Marshall test is used to measure physical properties of asphalt specimens that relate to plastic deformation properties of asphalt mixes.

Main principles

The Marshall test can be used for mix samples with maximum aggregate size 25.4 mm or less.

The Marshall test is used for asphalt mixes containing bitumen or bitumen cutback where the maximum aggregate size is 25.4 mm or less. Asphalt specimens are loaded on their cylindrical side-edges with a Marshall loading head at specified loading rate and temperature. The resistance against plastic flow is measured.

References

ASTM D 1559-89

Required equipment

- 3 Specimen Molds – 101.6 mm in diameter by 76.2 mm high.
- Marshall Compaction Apparatus.
- Specimen Mold Holder.
- Marshall Test Apparatus with a load and deflection measuring device.
- Heating oven.
- Automatic or manuals mixing equipment for asphalt mix specimens.
- Water Bath and temperature control unit with minimum 1.0°C accuracy.
- Heating gloves.
- Slide caliper for measuring specimen thickness with an accuracy of ± 0.1 mm.

Test procedure

Preparation of test specimens

Prepare at least 3 parallel samples.

At least 3 parallel test specimens should be prepared. Each specimen requires approximately 1200 g of bituminous material. The mass required should be adjusted so that each test specimen has a height of 63.5 ± 1.3 mm after compaction. If necessary, a preliminary specimen should be made to find the right amount of material for the remaining specimens.

Step 1: Dried and preheated aggregate is mixed with preheated binder until a homogeneous mixture is achieved. For asphalt concrete specimens (AC-mixes) the mixing temperature should be equal to the temperature at which the binder has a viscosity of 170 ± 20 mm^2/s. See also test 3.12 *"Mixing of Test Specimens; Hot Bituminous Mixes"*.

Step 2: The specimen molds are preheated in an hot air oven to a temperature in the range 93-149°C. The bituminous material should have a temperature during compaction at which the binder has a viscosity of 280 ± 30 mm^2/s.

Marshall Test

Notes

Compact specimens with 75 blows to each side.

The testing temperature depends on the type of mix.

Step 3: The mixture is transferred into the specimen molds and the surface is leveled. The mold now containing asphalt mix is immediately placed into the Marshall compaction apparatus.

Step 4: The specimen is compacted with 75 blows to each side. Immediately after compaction, remove the compacted specimen from the mold and allow it to cool to room temperature.

Step 5: Measure the thickness of the specimen to the nearest 0.1 mm.

Step 6: Place the samples in a preheated water bath holding the correct temperature, see *Test conditions*.

Test conditions

The specimens are heated in the water bath to their testing temperature according to the type of binder:

Asphalt mixes containing bitumen
60 ± 1.0°C for 30-40 minutes

Asphalt mixes containing bitumen cutbacks
40 ± 1.0°C for 30-40 minutes

The load is applied with the Marshall breaking head at a constant rate of 50.8 mm/min. The Marshall breaking head should during testing be in the temperature range of 21-38°C. Do not preheat the breaking head to 60°C.

Procedure

Step 7: After the required temperature equilibration time, remove the specimen from the water bath and immediately place it in the testing-head of the Marshall Test apparatus.

Step 8: Apply the load to the specimen at the specified loading rate until the maximum load is reached and the load decreases. The flow value must be recorded from the micrometer at the exact time of maximum load. The elapsed time from removing the test specimen from the water bath to the maximum load is detected should not exceed 30 seconds.

Results

Measurements

The following should be recorded during the test:

- Mixing temperature (°C)
- Compacting temperature (°C)
- Number of blows during compaction
- Height of test specimen to the nearest 0.1 mm
- Temperature of test specimen at testing (°C)
- Flow value (1/10 mm)

Marshall Test

Notes

- Maximum load value (N), also called the Marshall stability value. This value must be corrected according to the specimen height (see *Calculations*).

Calculations

Measured stability values must be corrected for specimen height.

The Marshall stability is calculated by multiplying the maximum load value with a correction factor depending on the specimen height. Correction factors are given in Table 3.18-1.

Correction factors

Table 3.18-1 Correction factors according to specimen height

Specimen height (mm)	Correction factor	Specimen height (mm)	Correction factor
25	5.70	51	1.46
26	5.31	52	1.41
27	4.99	53	1.36
28	4.69	54	1.32
29	4.45	55	1.27
30	4.20	56	1.23
31	3.99	57	1.19
32	3.81	58	1.16
33	3.62	59	1.13
34	3.49	60	1.10
35	3.32	61	1.07
36	3.11	62	1.04
37	2.95	63	1.01
38	2.80	64	0.99
39	2.61	65	0.96
40	2.45	66	0.94
41	2.30	67	0.92
42	2.18	68	0.89
43	2.07	69	0.88
44	1.96	70	0.86
45	1.87	71	0.84
46	1.79	72	0.82
47	1.72	73	0.81
48	1.64	74	0.79
49	1.57	75	0.78
50	1.51		

Report

The test report shall include the following:

a) Reference to this procedure
b) All measured values including:
  - Corrected Marshall stability (N) as the average of at least 3 test specimens
  - Flow value (mm) to the nearest 0.1 mm as the average of at least 3 test specimens

Notes

c) Test date
d) Description of any deviations from this procedure

Practical considerations

Stability and flow will differ considerably on laboratory made specimens and core samples all though the mix is the same. The Marshall test should therefor always be performed on laboratory made samples, not on core samples.

Incorrect testing procedures may lead to poor performing mixes.

Testing performed at incorrect temperature or with badly maintained Marshall Test Apparatus may seriously affect the test results. In connection with Marshall Mix Design, this may lead to poorly performing mixes in the field. Typically, rutting problems may occur.

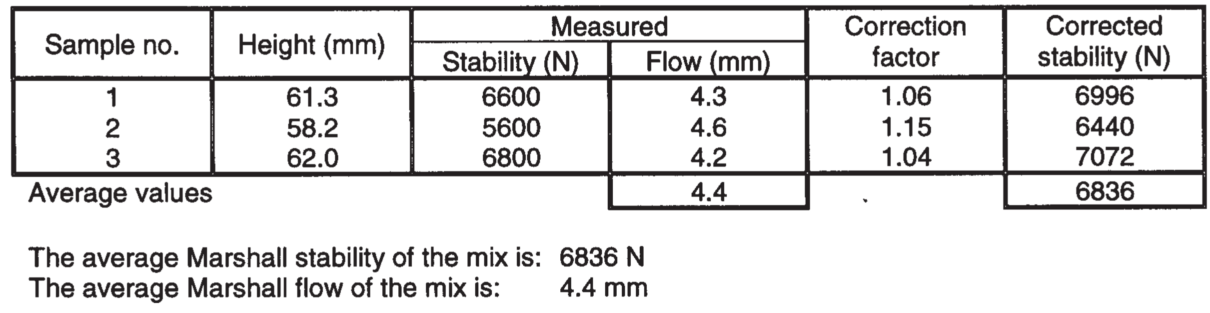
Maintenance

Check and calibrate the loading cell and deflection-measuring device every 6 months. Clean and lubricate the Marshall test apparatus and breaking head to prevent corrosion.

Example:

3 Marshall samples have been prepared in the laboratory to measure Marshall stability and flow. Sample height, measured stability and flow, correction values and corrected stability values are given in table 3.18-2.

Table 3.18-2 Sample data



Sample no.	Height (mm)	Measured		Correction factor	Corrected stability (N)
		Stability (N)	Flow (mm)		
1	61.3	6600	4.3	1.06	6996
2	58.2	5600	4.6	1.15	6440
3	62.0	6800	4.2	1.04	7072
Average values			4.4		6836

The average Marshall stability of the mix is: 6836 N
The average Marshall flow of the mix is: 4.4 mm

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Marshall Test

Project	**Location**	**Depth**
Client	**Lab.no**	**Date**
Responsible Technician	**Checked**	**Approved**

Sample No.	Binder content (%)	Height No.1 (mm)	Height No.1 (mm)	Height No.1 (mm)	Average height (mm)	Force Dial reading (mm)	Flow Dial reading (mm)	Stability (N)	Flow (mm)	Corrected stability (N)

Comments:

TEST NO. 3.19

Marshall Mix Design

Notes

Objective

The objective of the Marshall Mix Design procedure is to find the optimum binder content in a mix where the aggregate grading and type of bituminous binder is predetermined. The results from Marshall Mix Design are often used to set up asphalt mix formulation and specifications.

Main principles

The binder content is varied in steps of typically 0.5% around an assumed optimum binder content. The binder content is determined, which best complies with Marshall stability, flow, void content, voids filled with binder and density requirements for the mix being investigated.

References

ASTM D 1559-89: *"Standard Test for Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus".*

The Asphalt Institute, Maryland, USA, 1994: *"Mix Design Methods for Asphalt Concrete and other Hot-mix Types"*

Use at least 3 specimen mould to work effectively.

Required equipment

The same equipment as is used for the Marshall Test, see test 3.18. To work efficiently, it is recommended to have more than 3 specimen molds available.

Graphical method for blending aggregates

Step 1: As a starting point, a diagram is prepared for aggregate size distribution with percentage passing from 0-100% on the y-axis and sieve sizes on the x-axis. The x-axis is until further without a scale.

Step 2: Draw a diagonal from the origin of coordinates to the upper right corner of the diagram.

Step 3: From the specifications for the desired final aggregate distribution, determine the percentage passing each sieve size.

Determine the aggregate blend

Step 4: Draw a horizontal line from the percentage passing on the y-axis (determined in step 3) to the diagonal and down to the x-axis. Place the corresponding sieve size number on the x-axis at this location. Repeat this for all sieve sizes in step 3. A relative scale is now placed on the x-axis.

Step 5: Draw the sieve size distribution for all aggregate fractions into the diagram.

Step 6: Determine the percentage of each aggregate fraction in the final blend. Start from the right side of the diagram and draw a vertical line at the location where the distance "a" is equal for the 2 rightmost aggregate fractions. See figure 3.19-1.

Notes

Step 7: From the intersection between this vertical line and the diagonal, draw a horizontal line to the right. The distance from the top of the diagram down to the horizontal line gives the percentage of the rightmost of the two fractions. See example in figure 3.19-1.

Step 8: If only two aggregate fractions will be used, the percentage of the second fraction is the remaining. If 3 or more fractions will be used, repeat steps 6 and 7 for the remaining fractions and determine the final blend.

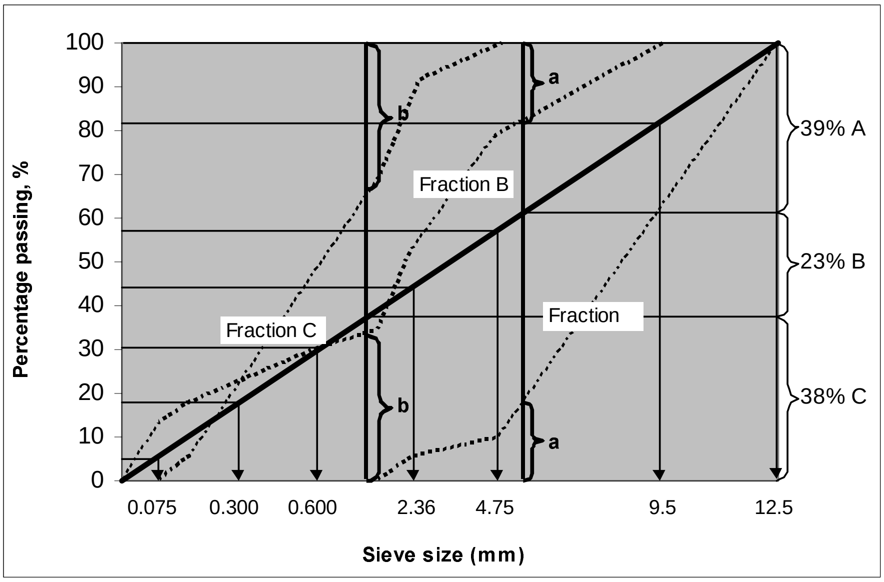


Figure 3.19-1 Graphical method for blending aggregates

Marshall mix design procedure

Step 1: The aggregate size distribution and type of binder is predetermined according to the type of bituminous mix that is being designed. The aggregate size distribution and type of binder must be the same for all asphalt specimens.

Calculate the combined bulk density of the aggregate blend

Step 2: If not known, determine the density of the binder r_{bit} and aggregates $r_{bd\ agg}$ according to test 3.2, 3.9 and 3.10. Step 1: Determine the combined density of the final aggregate blend by using the following equation:

$$\rho_{bd,combined} = \frac{100}{\frac{P_1}{\rho_1} + \frac{P_2}{\rho_2} + \frac{P_3}{\rho_3} + \ldots\ldots\ldots\ldots}$$

where:

$P_1, P_2, P_3 \ldots.$ = percentage of fractions in final aggregate blend
$r_1, r_2, r_3, \ldots.$ = bulk densities of the fractions

Prepare at minimum of 3 series of samples. 4-5 series will improve the overall quality of the mix design

Step 3: Prepare at least 3 series of 3 test specimens. Choose an assumed optimum binder content that is used for one series. Vary the binder content for the other series in 0.5% intervals around the assumed

Notes

optimum value. To obtain reliable results, 4-5 series with different binder contents is recommended. The variation in binder content may then be reduced to a somewhat lower value than 0.5 % (0.3-0.4%).

Preparation of test specimens

Step 4: Preparation of test specimens is carried out as described for the Marshall Test, see test 3.18. Also prepare a sufficient amount of mix to determine the maximum theoretical density.

Step 5: Determine the maximum theoretical density according to test 3.13

Step 6: Measure the thickness of the specimens (at room temperature) with a slide caliper to the nearest 0.1 mm.

Step 7: Determine the bulk density of the compacted specimens according to test 3.14, 3.15 or 3.16

Procedure

Step 8: The Marshall Test, test 3.18, is carried out on each test specimen.

Results

Measurements

The same measurements as described for the Marshall Test, test 3.18, shall be recorded during the testing of each individual sample.

Calculations

Calculate void content, VMA and voids filled with binder for all samples.

Determine the optimum binder content

· Calculate the corrected stability and determine the flow as described in test 3.18.
· Calculate the void content, voids in mineral aggregate (VMA) and voids filled with binder for all samples as described in test 3.17.
· Determine the optimum binder content as the average of:
- The binder content at maximum stability
- The binder content at maximum mix bulk density
- The binder content at which the void content is halfway between the upper and lower void requirements for the mix

Report

The test report shall include the following:

a) Reference to this procedure
b) From the Marshall Test for each test series:
    · thickness of test specimens to the nearest 0.1 mm
    · average corrected Marshall stability (N) of at least 3 test specimens
    · average flow value (mm) to the nearest 0.1 mm of at least 3 test specimens
    · testing temperature (°C)
c) In addition the following measurements for each test series:
    · maximum theoretical density ($\rho_{d\,max}$)
    · average bulk density (ρ_{bd})
    · average void content (V_0)
    · average voids filled with binder (V_{fb})

Notes

Put great effort into performing a high quality mix design. The performance of a mix in the field is highly dependent on this

d) Results presented in graphs as shown in figure 3.19-2.
e) Test date
f) Description of any deviations from this procedure.

Practical considerations

High quality mix design is required to optimize the properties of a mix with the given raw materials available. The sample preparation, as well as the measurements of stability, flow, void content etc., must be performed with high accuracy to ensure reliable results. A poor mix design will not utilize the potential of the materials, and will in many cases lead to shortened pavement life. Problems such as rutting, cracking or severe ageing may occur due to poor mix design.

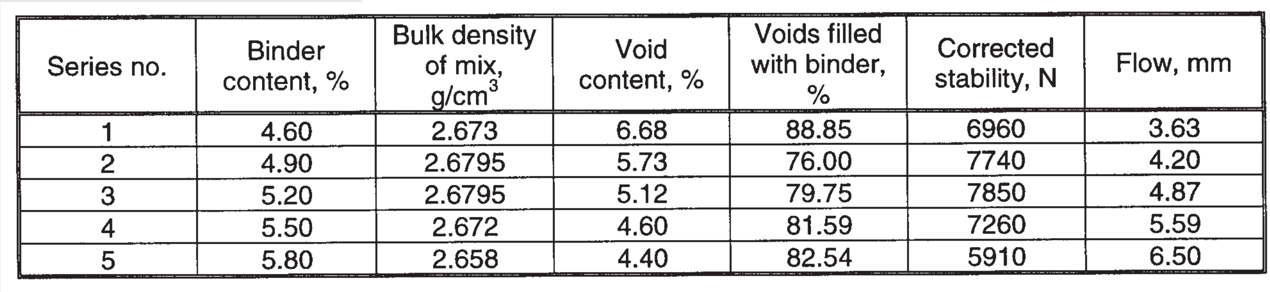
Maintenance

Check and calibrate the loading cell and deflection-measuring device every 6 months. Clean and lubricate the Marshall test apparatus, Marshall breaking head and molds to prevent corrosion.

Example:

5 series of 3 parallel test specimens (with varying binder content) have been prepared for Marshall Mix Design.
The following data for the mix (table 3.19-1) have been measured or calculated.

Table 3.19-1 Sample data, average of three samples



Series no.	Binder content, %	Bulk density of mix, g/cm^3	Void content, %	Voids filled with binder, %	Corrected stability, N	Flow, mm
1	4.60	2.673	6.68	88.85	6960	3.63
2	4.90	2.6795	5.73	76.00	7740	4.20
3	5.20	2.6795	5.12	79.75	7850	4.87
4	5.50	2.672	4.60	81.59	7260	5.59
5	5.80	2.658	4.40	82.54	5910	6.50

Sample density, voids, voids filled with binder, stability and flow are presented as functions of binder content as shown in figure 3.19-2.

The procedure from here is to determine the optimum binder content. The original Marshall procedure determines the optimum binder content as the average of the following three values:

1. Binder content at maximum stability (5.0% from figure 3.19-2).
2. Binder content at maximum mix density (5.0% from figure 3.19-2).
3. Binder content giving a void content halfway between the upper and lower requirements for the mix in consideration (5.1% from figure 3.19-2).

The optimum binder content in this example is 5.0% (the average of the three above values).

Notes

If requirements for Marshall stability, flow etc. are not met at this binder content, one should consider if a slightly higher or lower binder content would meet the requirements. If not, adjustments to the aggregate grading or binder stiffness may be required. In this case, a new full mix design may be required.

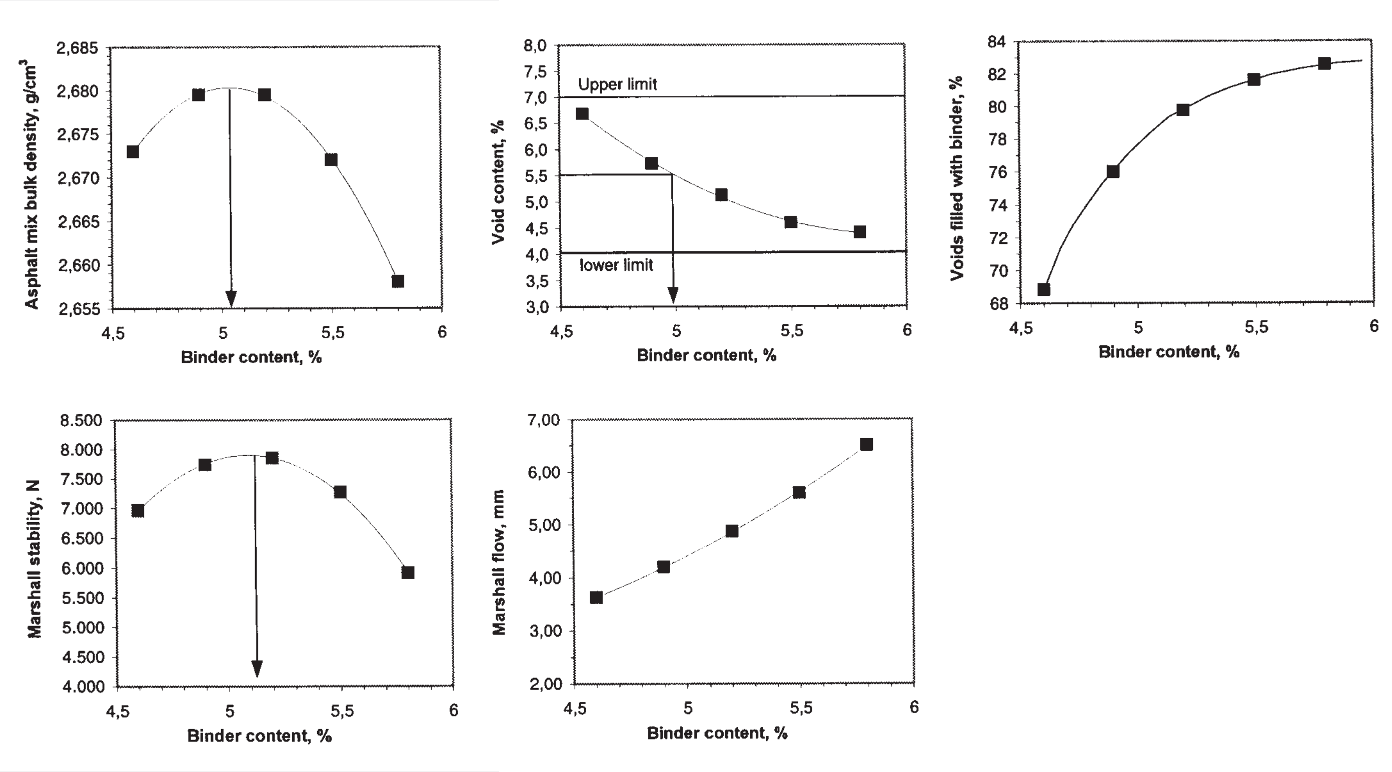


Figure 3.19-2 Presentation of Marshall Mix Design results

Marshall Mix Design Flowchart

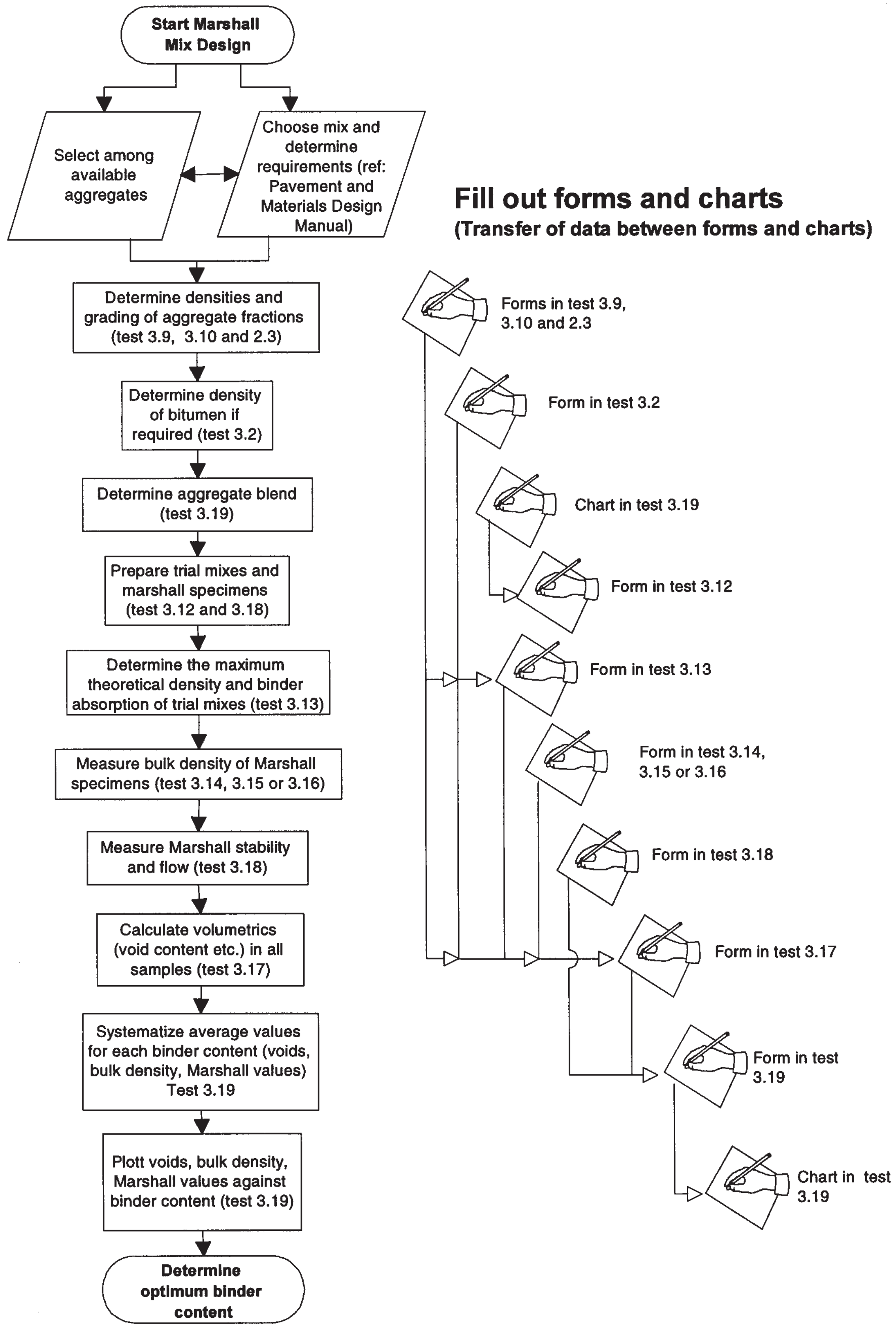
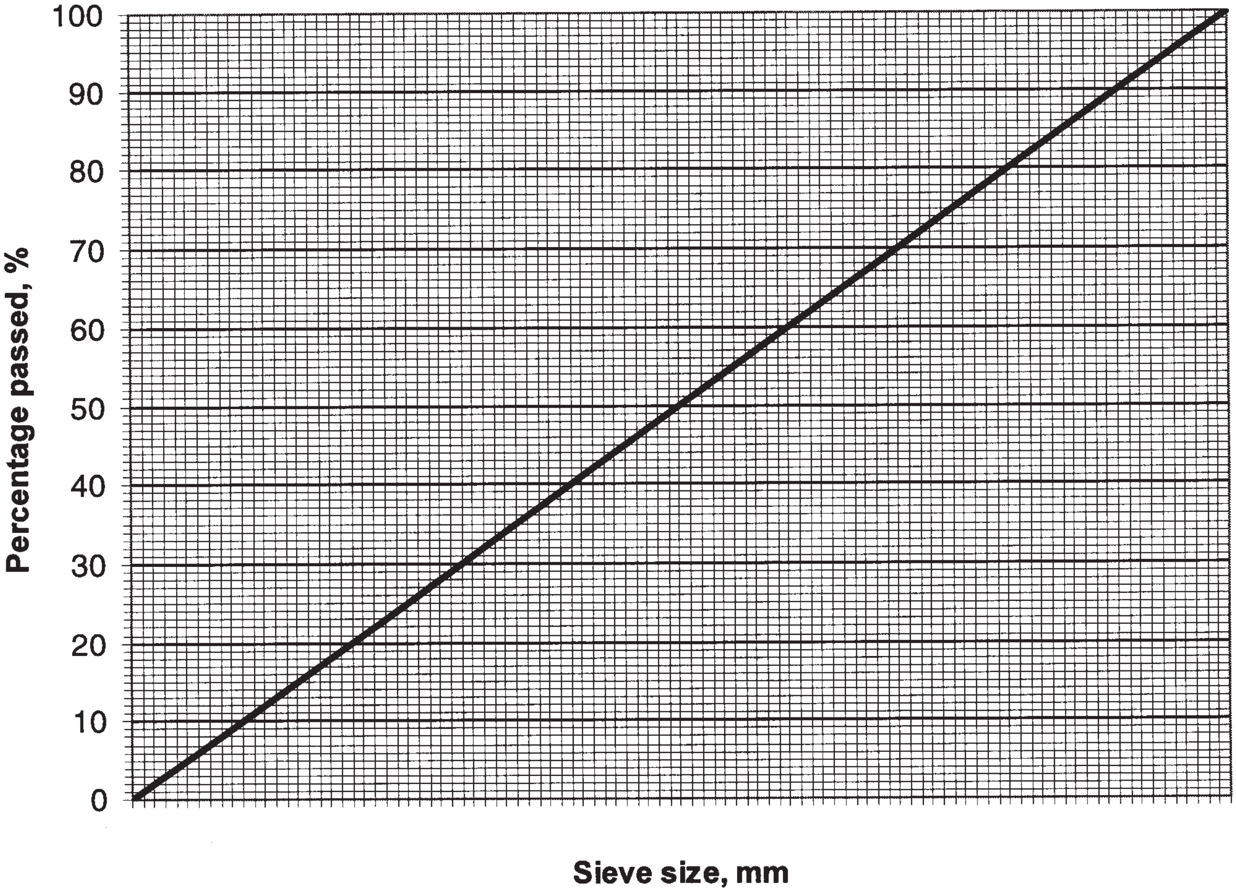


Figure 3.19-3 Marshall Mix Design flowchart

WORKING SHEET

Graphical Method for Blending Aggregates

Project	**Location**	**Depth**
Client	**Lab.no**	**Date**
Responsible Technician	**Checked**	**Approved**



Results:

Fraction	% by weight in final blend	Bulk density (test 3.9 and/or 3.10)

Combined density of final aggregate blend, g/cm^3 :

CML test 3.19

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Marshall Mix Design

Project	**Location**	**Depth**
Client	**Lab.no**	**Date**
Responsible Technician	**Checked**	**Approved**

Average values

Series No.	Binder content %	Bulk density g/cm^3	Void content %	VMA %	Voids filled with binder %	Corrected stability N	Flow mm
		test 3.14, 3.15, 3.16	test 3.17	test 3.17	test 3.17	test 3.18	test 3.18

Comments:

CML test 3.19, ref: ASTM D1559-89, Asphalt Institute 1994

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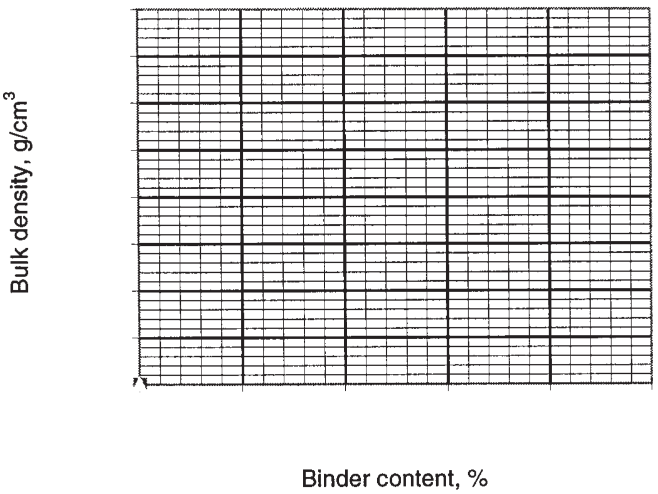
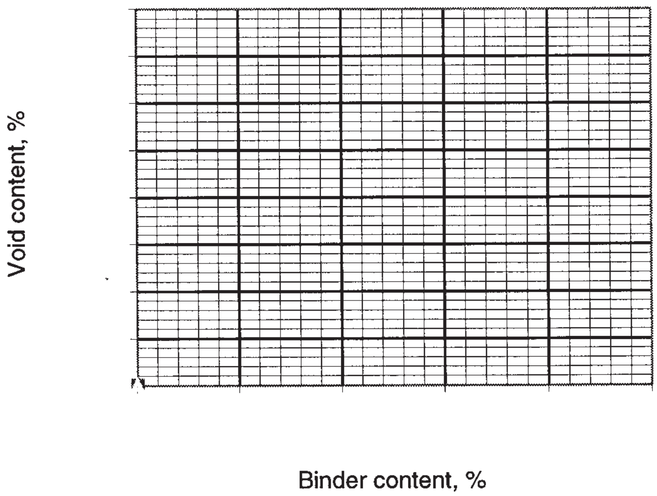
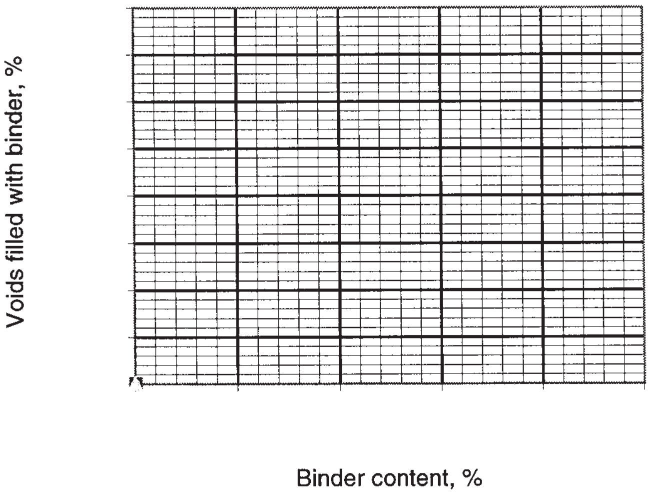
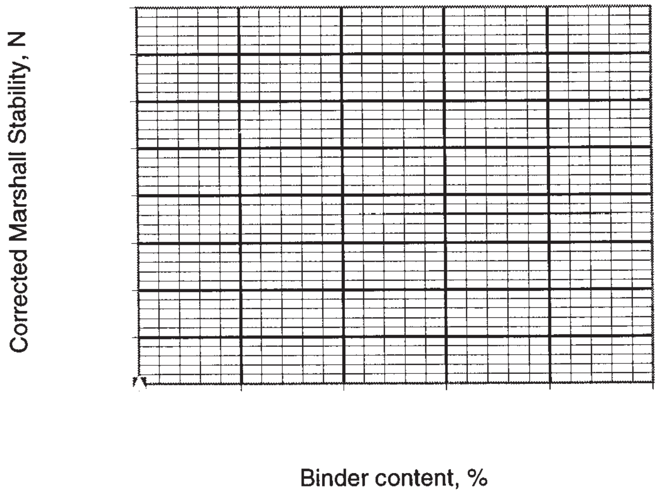
Marshall Mix Design

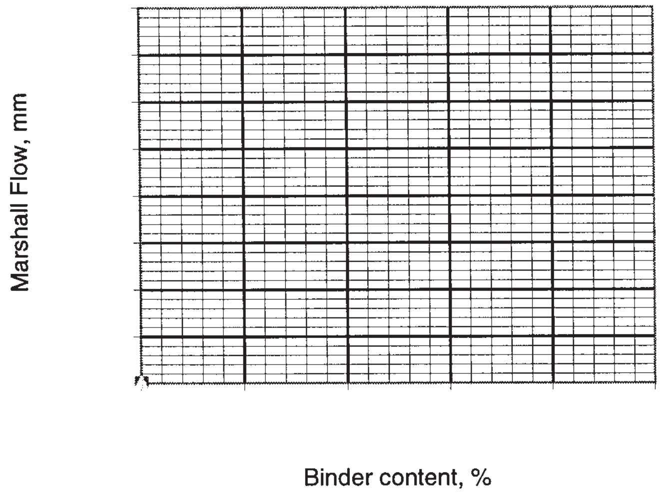
Project	**Location**	**Depth**
Client	**Lab.no**	**Date**
Responsible Technician	**Checked**	**Approved**











Optimum binder content: %

Comments:

TEST NO. 3.20

Refusal Density Mix Design

Notes

Objective

The refusal density procedure is used as a supplement to the standard Marshall mix design procedure. The objective of the refusal density procedure is to design asphalt mixes which will retain a required minimum air void content after secondary compaction by traffic.

Main principles

Trial mixtures with varying binder content are subjected to an extended Marshall compaction. The Marshall compaction is continued until no further densification of the samples is obtained. This state of maximum density is called the *refusal density*. The optimum binder content is determined as the binder content meeting the normal Marshall requirements and giving minimum 3% air voids at the refusal density.

An alternative procedure to the extended Marshall compaction called *"Extended Vibrating Hammer Compaction"* may also be used. See the reference document.

References

TRL Overseas Road Note 31, appendix D *"Refusal Density Design"*.

Required equipment

The same equipment as used for sample preparation in the Marshall test, see test 3.18.

Test procedure

Initial investigations

Step 1: The normal Marshall mix design procedure using 75 blows on each face should first be completed to check that Marshall requirements for the mix are met and to provide input to the refusal density procedure. See test 3.19. Prepare the graphs as shown in figure 3.19-2. Do not determine the optimum binder content for the mix yet.

Refusal density design procedure

Step 2: Determine the binder content corresponding to 6 % air voids from the Marshall mix design results.

Step 3: Prepare additional Marshall samples at three binder contents, namely the binder content giving 6 % air voids and at binder contents which are 0.5 % above and 0.5 % below this value. These samples must be compacted to their *refusal density* (maximum obtainable density using the Marshall compaction equipment).

Step 4: The number of blows required to produce the refusal density condition will vary from one mix to another. It is preferable to conduct a trial using the lowest binder content and compact

Notes

samples using an increasing number of blows, say 200, 300, 400, etc. until no further increase in density occurs. Usually 500 blows to each face is found to be sufficient.

Step 5: Plott a graph of air voids in the mix (at the refusal density) against binder content.

Step 6: From the plott prepared in step 5, determine the binder content which will give 3 % air voids at the refusal density. This value should be determined by interpolation, not by extrapolation. If necessary, extend the binder content range upwards or downwards to permit this.

Step 7: Check the results from the Marshall mix design (step 1) to ensure that the mix at this binder content meets the Marshall requirements. The final binder content should give a mix meeting the Marshall requirements and have minimum 3 % air voids at the refusal density.

Results

Test precision

No precision and bias statement has been prepared for this procedure.

Report

The test report shall include the following:

a) Reference to this procedure.
b) Type and identification of test material.
c) Void content at refusal density for all samples and the estimated binder content giving 3 % air voids in the mix at refusal density.
d) Test date.
e) Description of any deviations from this procedure.

Practical considerations

Multi-blow Marshall compaction may cause breakdown of aggregate particles. If this occurs to a significant extent, this procedure is not likely to be valid.

There are no national or international standards for this procedure. As experiences are gained, this procedure is likely to be subjected to further development.

Example:

From figure 3.19-2, the binder content corresponding to 6% air voids is 4.8 %. According to the refusal density procedure, additional samples have been prepared at binder contents of 4.3, 4.8 and 5.3 % and compacted to refusal density. Figure 3.20-1 shows the void content at refusal density plotted against the binder content.

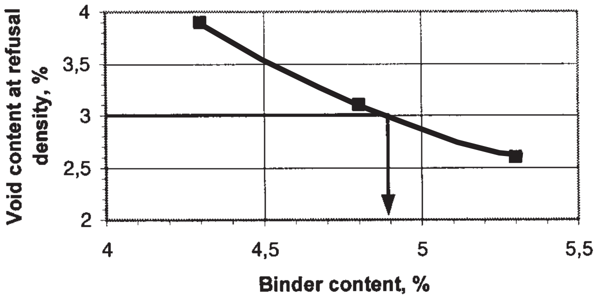


Figure 3.20-1 Void content at refusal density

As can be seen from figure 3.20-1, the binder content at 3% air voids is 4.9%. This is the maximum binder content for the mix. The procedure from here is to compare this binder content to the results from the Marshall mix design (figure 3.19-2) and determine a final binder content where all requirements are met.

The final binder content must meet the regular Marshall requirements for the mix *and* have a void content at refusal density of minimum 3%.

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Refusal Density Mix Design

Project	**Location**	**Depth**
Client	**Lab.no**	**Date**
Responsible Technician	**Checked**	**Approved**

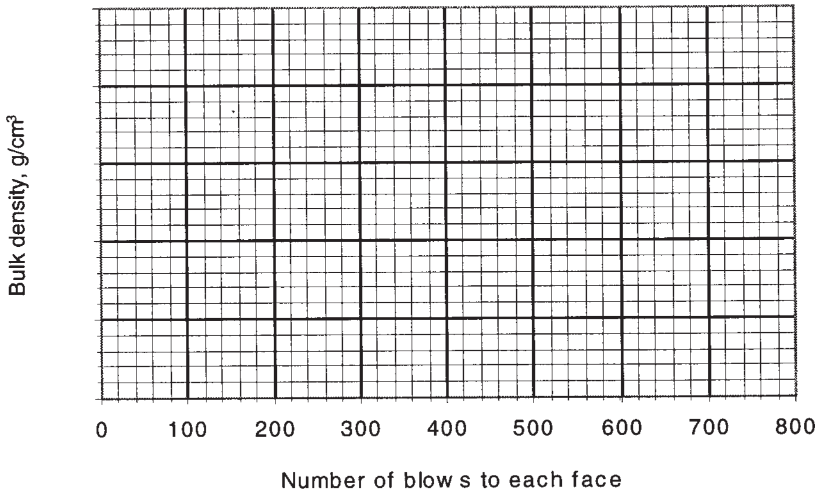
From Marshall mix design test results:

Binder content at 6% air voids: %

Trial to determine the number of blows required to obtain maximum (refusal) density

Binder content of trial mix:

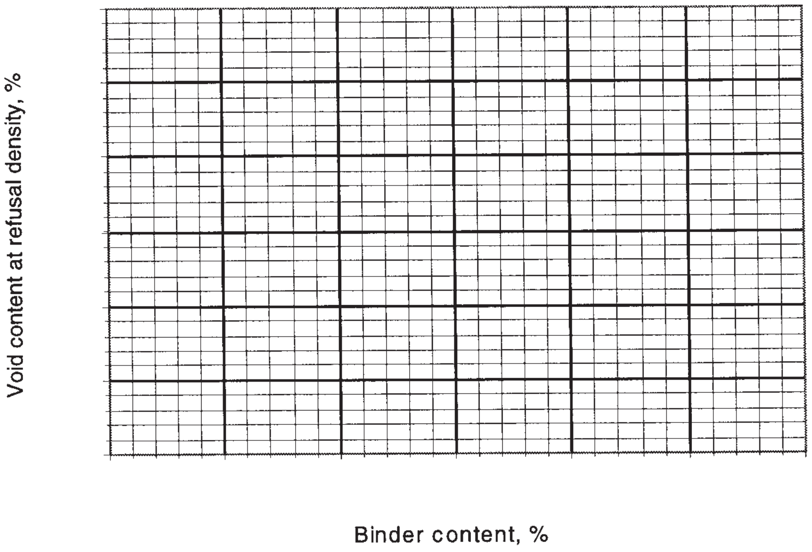
%



Binder content %	Void content at refusal density, %

Binder content at 3% air voids (at refusal density):

%



Optimum binder content determined from the Marshall mix design and refusal mix design procedures: %

Comments:

Indirect Tensile Strength Test

Notes

Objective

The test procedure is used to determine the indirect tensile strength and E-modulus of bituminous mixes. The results can be used to evaluate the relative quality/strength of materials as well as in pavement design, evaluation and analysis.

Main principles

A cylindrical test specimen is loaded on two diametrically opposite sides. This induces a tensile stress in the test specimen. The test is performed with a constant deformation speed until failure. The maximum load is recorded and is used to calculate the indirect tensile strength.

References

ASTM D3967
Norwegian Public Roads Administration's Handbook 014: "Guidelines for laboratory investigations", test No. 14.554.

Required equipment

- Testing machine, typically Marshall type test apparatus (loading speed of 2" / minute)
- An indirect tensile stress loading frame, figure 3.21-1.
- Water bath accurate to 1.0 °C.

The loading frame used consists of two parallel quadratic metal plates, 183 mm apart, held in place by stiff springs and metal rods in each of the four corners, as shown in Figure 3.21-1.

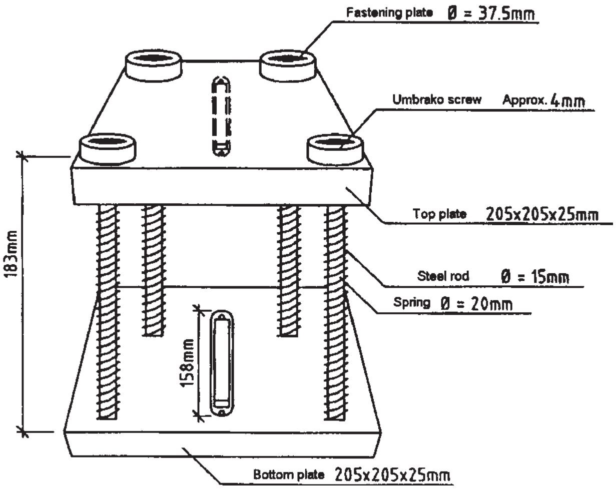


Figure 3.21-1 Typical loading frame for the indirect tensile strength test.

In the middle of each plate is a loading strip. These should be at least be of the same length as the test specimen height. The width of the loading strips should be 12.7 mm, with the same curvature as the test specimen.

Indirect Tensile Strength Test

Notes

Test procedure

Preparation of test specimens

The test specimens used in this test can either be core samples taken from road pavements or made in the laboratory. For further details about preparing test specimens, see test 3.12 and 3.18.

Minimum 3 samples are required to determine the indirect tensile strength.

Minimum 3 parallel tests are required to determine the indirect tensile strength. For core samples with uneven surfaces this should be increased to a minimum of 5 parallel tests.

Preparation of core samples is required before testing.

Step 1: Prepare test samples. When drilling cores from surface or base layer made from cold-mixed materials one should keep the use of water to a minimum, so that the specimens are not moistened unnecessarily. Before testing, the samples must have smooth, parallel surfaces. Cutting of core samples is therefor required. The height after cutting should be between 40 and 75 mm. The ideal height is in the range 50-60 mm. Laboratory made samples should in general not be cut.

Step 2: After preparing the test samples, the height should be measured in 3 places and the diameter in 2 places with a caliper.

Conditioning

Cold mixes must be dried before testing.

Cold mixes:
Step 3A: After cutting the specimens must be dried at room temperature for 24 hours. The cold mix samples are then placed inside watertight plastic bags and conditioned in a water bath at 29 °C for 3-4 hours. The samples must not be in direct contact with water during conditioning.

Other mixes:
Step 3B: The test specimens are conditioned by placing them directly into a water bath at 29°C for 30-40 minutes.

Test procedure

Step 4: The specimen is placed in the loading frame. The lateral surfaces of core samples are often uneven. If this is the case, a thin rubber tissue should be placed between the test specimen and the loading strips. Test the sample.

Store the samples after testing to determine their dry mass.

Step 5: Dry the specimens after testing in a heating oven at approximately 110°C. Weigh to the nearest 0.01 g.

The test must be completed within 3 minutes after removing the specimen from the water bath.

Indirect Tensile Strength Test

Notes

The E_{mod}- equation has been determined from measurements of E-modulus and indirect tensile strength on bituminous mixes in Norway.

Results

Measurements

Maximum load (N) is recorded.

Calculations

The indirect tensile strength is calculated as:

$$S_t = \frac{(636.62 \times P_{\max})}{(t \times D)}$$

where:
S_t = indirect tensile strength (kPa)
P_{max} = maximum load at failure (N)
t = height of specimen (mm)
D = diameter of specimen (mm)

The material's E-modulus is calculated using the following equation:

$$E_{mod} = 6.1 \times S_t + 100 \ (MPa)$$

Calculate the specimen dry bulk density based on registered dry mass and height/diameter measurements (mass/volume).

Report

The test report shall include the following:

a) Type of material and sample identification
b) Test date
c) Reference to this procedure
d) Description of any deviations from this procedure
e) Dry bulk density, indirect tensile strength and E-modulus for each individual test specimen.
f) Average dry bulk density, indirect tensile strength and E-modulus for all specimens.

Practical considerations

The E-modulus is often used for pavement design purposes. Incorrect measurements, due to poor measuring routines or sample preparation, may over- or underestimate the load distribution properties of the material. This may in the worst cases lead to under-dimensioning of the pavement structure and cause premature cracking and failure.

Maintenance

Check and calibrate the loading cell and deflection-measuring device every 6 months. Clean and lubricate the test apparatus and breaking head to prevent corrosion.

Indirect Tensile Strength Test

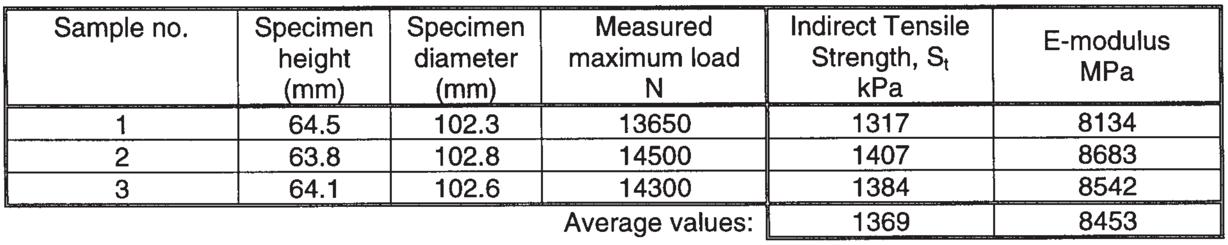
Notes

Example:

Three laboratory samples have been cored out from an existing pavement to determine indirect tensile strength and E-modulus for the mix.

Sample dimensions (height and diameter) and measured maximum load at failure from the indirect tensile test is given in table 3.21-1. The equations above have been used to calculate the material's indirect tensile strength and E-modulus.

Table 3.21-1 Calculations of indirect tensile strength and E-modulus.



Sample no.	Specimen height (mm)	Specimen diameter (mm)	Measured maximum load N	Indirect Tensile Strength, S_t kPa	E-modulus MPa
1	64.5	102.3	13650	1317	8134
2	63.8	102.8	14500	1407	8683
3	64.1	102.6	14300	1384	8542
			Average values:	1369	8453

The material's indirect tensile strength is: 1369 kPa
The material's E-modulus: 8453 MPa

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WORKING SHEET

Indirect Tensile Strength Test

Project	**Location**	**Depth**
Client	**Lab.no**	**Date**
Responsible Technician	**Checked**	**Approved**

Specimen No.	Average height (mm) test 3.16	Average diameter (mm) test 3.16	Max. load (KN)	Dry bulk density (g/cm^3) Test 3.14, 15 or 16	Indirect tensile strength (kPa)	E-modulus (Mpa)
			Average values:			

$$\text{Indirect Tensile Strength} = S_t = \frac{636620 \cdot P_{max}}{t \cdot D} \qquad E_{mod} = 6.1 \cdot S_t + 100$$

where:
S_t = indirect tensile strength (kPa)
P_{max} = maximum load at failure (KN)
E_{mod} = E-modulus (MPa)
t = average specimen height (mm)
D = average specimen diameter (mm)

Comments:

CML test 3.21, ref: ASTM D3967, NPRA HB014 test 14.554

TEST NO. 3.22

Determination of Binder Content and Aggregate Grading by Extraction

Notes

Objective

This method is used to determine the binder content in samples from all types of bituminous materials. The aggregates obtained by this method may later be sieved to determine the aggregate grading within the material.

Main principles

The bituminous mix is extracted with trichloroethylene, 1,1,1-trichloroethane or methylene chloride using an extraction unit similar to the one shown in figure 3.22-1. The binder content is determined as the difference in mass, between the original bituminous sample and the extracted binder-free aggregates, expressed as a percentage of the total mass.

Always use solvent proof gloves and gas masks when working with solvents.

Precautionary measures must be taken in all work involving use of solvents. Solvent proof gloves and gas masks must be used. Work involving solvents should be carried out in well-ventilated areas.

References

ASTM D 2172-88 Method B: *"Standard Test Methods for Quantitative Extraction of Bitumen from Bituminous Paving Materials".*

Norwegian Public Roads Administration's guidelines for laboratory investigations, Handbook 014. Test No. 14.5512.

Required equipment

- Suitable solvent (trichloroethylene, 1,1,1-trichloroethane or methylene chloride)
- Balance with accuracy 0.1g
- Extraction apparatus, see figure 3.22-1.
- Electric hot plate, thermostatically controlled
- Centrifuge with approx. 3500 rotations per minute
- Centrifuge cylinders
- Heating oven
- Water bottle
- Filter paper
- Steel rod for stirring
- Brush
- Large flat pan for splitting or quartering samples
- Heat insulated gloves
- Solvent proof gloves
- Gas masks

TEST NO. 3.22

Determination of Binder Content and Aggregate Grading by Extraction

Notes

Figure 3.22-1 Typical extraction apparatus

Test procedure

A) Extraction of bitumen from hot mixed bituminous materials

Heat up and split into representative samples.

Step 1: Hot mixed bituminous materials that have cooled off, must be reheated in a heating oven to obtain a plastic consistency before splitting or quartering into representative samples if required. The temperature in the heating oven should in this case not exceed the paving temperature for the specific mix.

For AC-mixes, the samples should preferably between 1.0-2.0 kg. Experience has shown that the sample size must be increased when extracting coarser mixes such as bituminous base courses. In some cases, it may be necessary to increase the sample size up to as much as 4 kg.

Perform two parallel extractions.

Two parallel extractions should always be performed.

Step 2: The empty wire cloth basket is weighed to an accuracy of 0.1g. The sample is then placed into the wire cloth basket, which is weighed again to the nearest 0.1g. The wire cloth basket, now including the sample, is placed in the extraction cylinder.

Be cautious and do not overheat. The solvent should boil gently.

Step 3: Approximately 500 ml of solvent is added and the metal condenser is placed on top. Turn on the water circulation through the condenser, and place the extraction unit on the electric hot plate. Adjust the temperature of the hot plate so that the solvent boils gently and condensed solvent flows through the wire cloth basket.

Step 4: The time required to complete an extraction will vary with size, binder and filler content of the sample. To check if the extraction is complete, remove the basket from the cylinder. Let the solution drip onto a filter paper. If the extraction process is completed, a

Notes

distinct clear ring is formed around an inner dark center of filler. If the outer ring is of a brownish color, the extraction process is not complete. The extraction process should then be continued until the outer ring becomes clear.

When extracting mixes with high binder and filler contents, the outer ring may be clear even if the extraction process is not completed. This is caused by the formation of a core of non-extracted material within the sample. For these materials, carefully stir the sample and add some additional solvent on the sample before dripping on the filter paper. Continue the extraction process if required.

Dry the aggregates when the extraction is completed.

Step 5: When the extraction is completed, the wire cloth basket containing the aggregates is placed in a heating oven at 110°C for drying. After drying and cooling the aggregates are weighed (and sieved if aggregate grading is required).

Step 6: After extraction, the solvent in the glass cylinder now contains the dissolved binder and some filler that has been washed through the wire cloth. This filler must be cleaned, dried and weighed to find the total mass of the aggregate within the sample. A centrifuge is used for this operation.

The filler is separated from the solvent by means of a centrifuge.

Transfer the solvent containing binder and filler into centrifuge cylinders. The cylinders can be filled up to 2/3 full and should after filling not differ more than maximum 1 g in mass. The centrifuge cylinders must be weighed in advance. The solution is centrifuged for 15-20 minutes at 3500 rpm. When completed, the solvent and binder can be poured out of the centrifuge cylinders, leaving the filler behind.

To clean the filler completely, the centrifuge procedure must be repeated several times until the solvent is clear (or slightly brown at the most) when pouring it from the centrifuge cylinder. The cleaned filler is dried in a heating oven at 110°C, cooled and weighed in the centrifuge cylinder.

When calculating the binder content and particle size distribution, this filler must be included.

Step 7: The binder content is calculated by finding the difference between initially weighed material and the sum of cleaned and dried aggregates (including the filler).

B) Extraction of bituminous materials containing water

In cold mixes, all traces of water must be removed from the sample before extraction.

Cold mixes may often due to use of emulsions or lack of heating in the mixing process contain some water. The same may also in some rare cases be for hot mixes *if the sampling and extraction analysis is performed*

Notes

immediately after mixing in the hot mix plant (water content of up to 0.2% may occur).

In cases where recovery of the bitumen is required, determination of water content and removal of water from the sample must be performed according to ASTM test method D 1461.

In cases where recovery of bitumen is not required, the entire test specimen may be dried to constant mass in an oven at 110 ± 5 °C prior to extraction. By weighing the sample before and after drying in the oven, water content may also be determined. The sample should be always be cooled down to room temperature before weighing.

Extraction of mixes containing absorptive aggregates

When absorptive aggregates are present, a modified extraction procedure must be used to extract all the bitumen and find the correct binder content.

Bitumen, which has been absorbed into the aggregates, may be very difficult to extract using the normal extraction procedure. This may be a significant source of error in the determination of binder content, even for moderately absorptive aggregates. Crushing the extracted aggregates in the laboratory followed by an additional extraction may solve this problem.

The following procedure can be used when absorptive aggregates are present in the mix. If the types of aggregates in the mix are unknown, a trial extraction should be performed to determine if adsorptive aggregates are present and thus choose the final extraction procedure.

Step 1: Perform a normal extraction. Determine visually when bitumen is no longer extracted from the aggregates. Stop the extraction.

The absorbed bitumen will in principle also affect the calculated aggregate grading. This effect is however very small and should be ignored.

Step 2: Determine binder content and aggregate grading according to the normal procedure. Take care to retain all the aggregates from the different sieves after the sieve-analysis.

Step 3: Crush all the aggregates using suitable laboratory equipment. Take care not to loose any material.

Step 4: Repeat the extraction procedure to determine the amount of absorbed bitumen.

Step 5: Add the mass of absorbed bitumen to the mass of bitumen found from the first extraction (step 1). Calculate the final binder content. See example.

Calculations

Calculate binder content and aggregate grading according to the following equations:

$$Binder\ content,\ \% = \left[\frac{(M_1 - M_2) - (M_3 + M_4)}{M_1 - M_2} \right] x 100\ \%$$

Notes

where:
M_1 = mass of test specimen
M_2 = mass of water in test specimen (if determined according to ASTM D1461)
M_3 = mass of extracted mineral aggregate
M_4 = mass of mineral filler in the centrifuged extract

$$Aggregate\ grading,\ \% = \frac{M_{sieve} \text{ x} 100\%}{M_3 + M_4}$$

where:
M_{sieve} = mass of mineral aggregate on the sieve of interest.

See also example of calculations

Test precision

Determination of binder content in two properly conducted tests on the same batch shall not vary by more than the values given in table 3.22-1. Note that this test precision data is not valid for the modified extraction procedure for absorptive aggregates.

Table 3.22-1 Test precision

Acceptable difference between 2 parallel results	
One operator	Two laboratories
0.52%	0.81%

Report

The test report shall include the following:
a) Type of material and sample identification
b) Test date
c) Reference to this procedure
d) Test results, individual values and average values to one decimal point
e) Description of any deviations from this procedure

Example:

An extraction has been performed to determine binder content and aggregate grading of an asphalt mix, in this case with absorptive aggregates. The procedure to determine binder content and aggregate grading is shown in tables 3.22-2 and 3.22-3 respectively. In the case of non-absorptive aggregates, the second extraction (absorption) should not be performed.

Determination of Binder Content and Aggregate Grading by Extraction

Notes

		Main extraction	Second extraction (absorption)
1	Wire cloth basket + sample	829.5 g	796.8 g
2	Wire cloth basket	224.3 g	224.3 g
3	Sample (1-2)	605.2 g	572.5 g
4	Wire cloth basket + aggregates	779.1 g	765.2 g
5	Wire cloth basket	224.3 g	224.3 g
6	Aggregates (4-5)	554.8 g	540.9 g
7	Centrifuge cylinders + extracted filler	298.3 g	308.5 g
8	Centrifuge cylinder	280.6 g	280.6 g
9	Extracted filler (7-8)	17.7 g	27.9 g
10	Sum aggregates after extraction (6+9)	572.5 g	568.8 g
11a	Binder content, mass (3-10+11b)	32.7 + 3.7g	-
11b	Absorbed binder (3-10)	-	3.7 g
12	**Binder content in % (11a/3)·100%**	**6.01 %**	

Table 3.22-2 Calculation of binder content (including absorbed binder)

Sieve size	grams		%
19.5 mm	75		13.1
12.5 mm	160		27.9
9.50 mm	226		39.5
5.00 mm	326		56.9
2.36 mm	383		66.9
1.18 mm	420		73.4
600 µm	459		80.2
425 µm	494		86.3
0.300 µm	509		88.9
0.150 µm	525		91.7
0.075 µm	535		93.4
Bottom pan	24.8	37.5	6.6
Extracted filler	12.7		
Sum aggregates	572.5		100

Table 3.22-3 Calculation of aggregate grading

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WORKING SHEET

Extraction
Binder content

Project	**Location**	**Depth**
Client	**Lab.no**	**Date**
Responsible Technician	**Checked**	**Approved**

DETERMINATION OF BINDER CONTENT			Main extraction		Second extraction (absorption)	
1	Wire cloth basket + sample	g				
2	Wire cloth basket	g				
3	Sample (1-2)	g				
4	Wire cloth basket + aggregates	g				
5	Wire cloth basket	g				
6	Aggregates (4-5)	g				
7	Centrifuge cylinder + extracted filler	g				
8	Centrifuge cylinder	g				
9	Extracted filler (7-8)	g				
10	Sum aggregates (6+9)	g				
11a	Binder content, mass (3-10+11b)	g			▨	
11b	Absorbed binder, mass (3-10)	g	▨			
12	Binder content (11a/3)·100%	%				

Comments:

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Extraction
Aggregate Grading

Project	**Location**	**Depth**
Client	**Lab.no**	**Date**
Responsible Technician	**Checked**	**Approved**

CALCULATION OF AGGREGATE GRADING

Sieve size mm	Aggregate grading sample A		Aggregate grading sample B		Average aggregate grading %
	grams	%	grams	%	
Bottom pan					
Extracted filler					
Sum aggregates					

Comments:

TEST NO. 3.23

Effect of Water on Bituminous Coated Aggregate

Notes

Objective

This test method covers a rapid procedure for visually observing the loss of adhesion in uncompacted bituminous-coated aggregate mixtures due to the action of boiling water. The test can be used to assess the water sensitivity of bituminous mixtures and effects of anti-stripping agents.

Main principles

A sample of bituminous mixture is placed into a glass beaker with boiling water. After a specified period of time, the retained coating on the aggregates is visually estimated.

References

ASTM D 3625-96 *"Effect of Water on Bituminous-Coated Aggregate Using Boiling Water".*

Required equipment

- Scoop, shovel or similar capable of removing a representative sample from a larger mass of bituminous coated aggregates.
- Two heat resistant glass beakers, 1500-2000 ml in size.
- Distilled water.
- Heating source, hot plate or similar.
- Thermometer
- Stop watch

Test procedure

Preparation of test sample

The temperature of hot-mix samples must be below the boiling temperature of water and above 85°C before placing in the boiling water. Cold mixes shall be at or above room temperature.

Step 1: Prepare an uncompacted bituminous-coated aggregate mixture, approximately 500 grams, following established laboratory procedures. See test 3.12. Alternatively, obtain a sample of plant-produced mixture, approximately 500 grams, using a scoop or similar.

Step 2: Split the 500-gram sample into two 250 gram samples.

Procedure

Step 3: Pour distilled water into a glass beaker such that the container is approximately half full and heat to boiling.

Avoid manipulation of the mix during handling after boiling

Step 4: Place the sample into the boiling water while the container is exposed to the heat source. Bring the water back to boiling and maintain boiling for 10 min ± 15 seconds. Avoid excessive manipulation of the mix during handling.

Step 5: After the 10-minute period, remove the container from the heat source.

Step 6: Skim off any free bitumen from the surface of the water. Cool to room temperature, decant the water and empty the wet mix onto a white paper towel.

Effect of Water on Bituminous Coated Aggregate

Notes

Step 7: For comparison, place a similar amount of fresh bituminous material into the second beaker and fill with unheated water. After a period of 10 minutes, decant the water and empty the wet mix onto a white paper towel

Estimate the coated area in percent immediately after the sample is placed on the white towel.

Step 8: Visually observe the aggregates (coarse and fine) for retained bitumen. Determine the coated area in percent. Any thin brownish, translucent areas shall be considered as fully coated. Make the visual observation immediately after the sample is placed on the white towel. Light and low magnification may aid in the observation

Results

Measurements

Report the estimated coated area in percent

Test precision

No precision and bias statement has been developed for this test.

Report

The test report shall include the following:

a) Reference to this procedure
b) Type and identification of the test material
c) Estimated coated area
d) Test date
e) Description of any deviations from this procedure

Practical considerations

The test is useful to identify possible problem materials but can not be expected to accurately predict field performance

This test method is useful as an indicator of the relative water susceptibility of bituminous-coated aggregates and to identify possible problem materials. However the test method can not be expected to accurately predict field performance as no such correlation has been established.

Maintenance

Clean all equipment used.

CENTRAL MATERIALS LABORATORY	WORKING SHEET **Effect of Water on Bituminous Coated Aggregate**	

WORKING SHEET

Effect of Water on Bituminous Coated Aggregate

Project	**Location**	**Depth**
Client	**Lab.no**	**Date**
Responsible Technician	**Checked**	**Approved**

Mixture identification:	
Binder type:	
Binder content, %:	
Aggregates:	

Laboratory prepared sample ☐
Plant-produced mixture ☐

Mix type: Hot mix ☐
Cold mix ☐

Estimated coated area after boiling: %

Comments:

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SUMMARY SHEET

Bituminous Binders

CENTRAL MATERIALS LABORATORY

Project	**Date**	**Date**
Client	**Checked**	**Approved**

Test name	**CML test**	**Ref.**	**Result**	**Unit**
Relative Density	3.2	ASTM D70-97		
Density	3.2	ASTM D70-97		g/cm^3
Cleveland Open Cup Flash Point	3.3	ASTM D92-90		°C
Cleveland Open Cup Fire Point	3.3	ASTM D92-90		°C
Change in mass after TFOT	3.4	ASTM D1754-87		%
Penetration	3.5	ASTM D5-86		1/10 mm
Softening Point	3.6	ASTM D36-70		°C
Ductility	3.7	ASTM D113-86		mm
Brookfield dynamic viscosity, °C	3.8	ASTM D4402-91		cPoise
Brookfield dynamic viscosity, °C	3.8	ASTM D4402-91		cPoise
Brookfield dynamic viscosity, °C	3.8	ASTM D4402-91		cPoise

Comments:

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SUMMARY SHEET

Aggregates

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Project	**Date**	**Date**
Client	**Checked**	**Approved**

Test name	**CML test**	**Ref.**	**Result**	**Unit**
Bulk density, aggregates > 4.75 mm	3.9	ASTM C127-88		g/cm^3
Apparent density, aggregates > 4.75 mm	3.9	ASTM C127-88		g/cm^3
Water absorption, aggregates > 4.75 mm	3.9	ASTM C127-88		%
Bulk density, aggregates < 4.75 mm	3.10	ASTM C128-88		g/cm^3
Apparent density, aggregates < 4.75 mm	3.10	ASTM C128-88		g/cm^3
Water absorption, aggregates < 4.75 mm	3.10	ASTM C128-88		%
Bulk density of combined aggregates	3.9	ASTM C127-88		g/cm^3
Apparent density of combined aggregates	3.9	ASTM C127-88		g/cm^3

Comments:

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SUMMARY SHEET

Bituminous Mixes

General Mix Investigations

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Project	**Date**	**Date**
Client	**Checked**	**Approved**

Material:

Test name	CML test	Ref.	Result	Unit
Maximum theoretical density	3.13	ASTM D2041-95		g/cm^3
Absorption of binder into aggregates	3.13	ASTM D4469-85		%
Bulk density of compacted saturated surface dry specimens	3.14	ASTM D2726-96		g/cm^3
Bulk density of paraffin-coated specimens	3.15	ASTM D1188-89		g/cm^3
Bulk density from caliper measurements	3.16	NPRA HB014 test 14.5622		g/cm^3
Void content	3.17	ASTM D3203		%
VMA	3.17	AASHTO PP19-93		%
Voids filled with binder	3.17	AASHTO PP19-93		%
Marshall stability	3.18	ASTM D1559-89		N
Marshall flow	3.18	ASTM D1559-89		mm
Indirect tensile strength	3.21	ASTM D3967, NPRA HB014 test 14.554		kPa
E-modulus	3.21	NPRA HB014 test 14.554		MPa
Binder content by extraction	3.22	ASTM D2172-88		%
Stripping test Estimated coated area after boiling	3.23	ASTM D3625-96		%

Comments:

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Bituminous Mixes

Mix Design

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Project	**Date**	**Date**
Client	**Checked**	**Approved**

Test name	**CML test**	**Ref.**	**Results**					**Unit**
			Binder content, %					
Maximum theoretical density	3.13	ASTM D2041-95						g/cm^3
Absorption of binder into aggregates	3.13	ASTM D4469-85						%
Bulk density of compacted saturated surface dry specimens	3.14	ASTM D2726-96						g/cm^3
Bulk density of paraffin-coated specimens	3.15	ASTM D1188-89						g/cm^3
Bulk density from caliper measurements	3.16	NPRA HB014 test 14.5622						g/cm^3
Air void content	3.17	ASTM D3203						%
VMA	3.17	AASHTO PP19-93						%
Voids filled with binder	3.17	AASHTO PP19-93						%
Marshall stability	3.18	ASTM D1559-89						N
Marshall flow	3.18	ASTM D1559-89						mm

Optimized mix

Optimum binder content from Marshall Mix Design	3.19	ASTM D1559-89 Asph. Inst. 1994		%
Optimum binder content from refusal density mix design	3.20	TRL Overseas Road Note 31		%
Air void content	3.19	ASTM D1559-89 Asph. Inst. 1994		%
Voids filled with binder	3.19	ASTM D1559-89 Asph. Inst. 1994		%
Marshall stability	3.19	ASTM D1559-89 Asph. Inst. 1994		N
Marshall flow	3.19	ASTM D1559-89 Asph. Inst. 1994		mm
Air voids at refusal density	3.20	TRL Overseas Road Note 31		%
Estimated coated area after boiling (at optimum binder content)	3.23	ASTM D3625-96		%

Comments:

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