UNDP/UNCHS/Project VIE/86/020

Assistance to Human Settlements Planning & Development in Rural Areas

Soil Analysis Notes, 1

Field testing techniques

DW/GRET - CERPAD

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Soil Analysis Notes, 2

Laboratory testing procedures for soil

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Soil Analysis, 2

Laboratory testing procedures for soil

Source 1 : MUDH/REXCOOP Addis Ababa Project
Laboratory programme on soil / Technical Reports;
de Lauriers T., GRET 1984, 247p

Source 2: British Standard Methods
of Test for Soils for Civil Engineering Purposes,
BS. 1377,

Compiled by: DW/GRET for CERPAD

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1, DESCRIPTION OF THE BUILDING TECHNICS TO BE TESTED

1.1 ADOBES [4]

Adobe is a soil molded brick which dries naturally under sun .

Adobe is a technic used for several thousand years. It is one of the first building material technic used by man kind .

The word "ADOBE" , Spanish word, comes from the Egyptian word " THOBE" (brick) which is translated by "OTTOB" in Arabic .

The standard production of adobes is manual, but USA adobes factories presently use mechanical means: five men can produce several ten thousand adobes per day .

Adobe has a large choice of production technics, and is easy to use for building .

Use black cotton soil (swelling clay) to make adobes is very difficult because of the swelling and the big drying shrinkage , Anyway, we shall try to test the following means :

- To mix swelling clay with sand to get a good granular curve (swelling clay is very fine).
- To use straw to avoid big cracks ,

. Such an Adobe made with swelling clay will need a good archirecture design and a good plastering .

1.2 COMPRESSED BRICKS [4]

To make compressed bricks, slightly wet soil is introduced in the mold of a press-machine . One high force is applied on the soil by levels,cams, rods or hydraulic jacks, The soil is compressed and its volume is divided by two . After demold - ing , we get a compact block which has a fare finish- ing, which seems like burnt brick and which has the same building advantages as burnt brick .

Compressed soil bricks are used since a recent time . For 30 years, this technic has been the most studied among soil construction, and has got many improvements .

The press - machine problems have been the most studied until now . But the other steps of the brick abrication also need machines to be studied and designed : crushers , pulverisers, sifters , mixers . These machines increase the quality of the bricks and decrease the energy request (especially by decreasing the binding agents quantity) .

Compressed bricks stabilized with cement may use 35 to 60 % energy less than burnt bricks .

Use black cotton soil (swelling clay) to make compressed bricks is not an easy task . To achieve such an aim , we shall test the following means :

- To mix swelling clay with sand to get a good granular curve (swelling clay is very fine) .
- To use lime :
  1, To help crushing of the dry lumps of clay.
  2, To avoid further swelling of the clay .
- To press at high pressure to avoid water capillary absorption , (swelling of the clay is c sed by water absorp.tion) .

2 , MAKING OF THE SAMPLES

2.1 ADOBES

2.1.1 SOIL EXTRACTION

1, Extract the earth which would be used in a further experiment .

2, Do not take the above lay of soil which contains much organic materials, roots grass and soon this lay is about 20 to 50 cm thick .

3, Be careful to sample a representative quality and quantity of soil .

4, Needs for making tests about 60 to 120kg (one to three volumes of a cement bag of 50 kg) . But it depends on the adobe samples to do .

5, Measure the natural water content and fill the sampling chart .

6, If the experiment is not done immediately store the soil in closed plastic bags .

2,1,2 WET MIXING

2,1,2,1 Manual Mixing

1, Prepare the right amount of every component of the mixture (soil, water, straw, cement, lime)

REMARK 1 Percentage definition of "Y" = $\frac{\text{Quantity of "y" in Kg}}{\text{Quantity of soil in Kg}}$

, For Example : adobe with 30% of water and 5% of lime means that you will prepare

Soil = 10 kg
Water = 3 kg (3 l)
Lime = 0,5 Kg

REMARK 2 For the straw, the quantity are given by Kg/m^3 of adobe .

, Calculate the volume of adobes , you will make V .

, Then get the straw weight you need .

, For Example : Volume of one adobe = 10^{-3} m^3
required quantity = $30 Kg/m^3$

, V : volume of 10 adobes = $10 \times 10^{-3} = 10^{-2}$ m^3

, M_s : needed straw weight = $30 \times V$ = 30.10^{-2} Kg,

M_S = 0,300 kg

REMARK 3 Be careful : The quantity of water is given for a dry soil .

If the soil is wet, you must correct the needed water quantity .

- Wanted water content = W_w
- Natural water content = W_n
- Needed water quantity = Q_w

$$W_w = \frac{\text{Weight of water in the mixture}}{\text{Weight of dry soil}} = \frac{P_1}{P_d}$$

$$W_n = \frac{\text{Weight of water in the natural soil}}{\text{Weight of dry soil}} = \frac{P_2}{P_d}$$

$$Q_w = P_1 - P_2$$

$$Q_w = Pd\ (W_w - W_n)$$

, For example

W_w = [illegible] %

W_n = 10 %

P_d = Weight of soil = 10 Kg

Q_w = 10 (0,30 - 0, 10) = 10 x 0 , 20

Q_w = 2 Kg water (therefore 2 liters .)

2, Put every component in a big tank except the water .

3, Mix first without water (dry mixing)

4, Add water little by little and every where .

5, Mix with trowels, hands or feets until you obtain an homogeneous mixture (wet mixing).

Be careful ! Do not let some of the material components in the corner of the tank .

6, If necessary (for lime for instance), let the mixture in the tank for a few days ; sprinkle water on it every day before molding and cover it with a plastic sheet .

2,1,2,2 Mechanical mixing the process of the mixing depends on the mixture.

2,1,3 MOLDING

1, Measure the water content of the used soil mixture (see 31) .

2, Dive the adobe mold in water .

3, Fill the mold with the soil mixture by throwing it in the mold

- First, fill the corner .
- Then , the middle .

4, By shearing with a wet ruler laid on the edge of the mold , level the adobe .

5, If common adobe mold

- Strip off the adobe by flashing it on a weight Known test ply wood .

- clean the mold and begin again .

if ASTM 14.14.14 cm mold (weight Known) strip off the adobe to 14 days after drying.

6, Weight and measure the dimensions of the adobe immediately (see 32 and 33) .

7, Label the adobe for further experiments and measurements .

2,1,4 DRYING

1, Dry during 3 days under straw .

2, Dry during 11 days without handling the adobe except on the test ply wood .

3, Dry during 14 days on the short side of the adobe ,

4, Measure weight and dimensions when it is required (see 3) .

2, MAKING OF THE SAMPLES

2,2 COMPRESSED BRICKS

2,2,1 SOIL EXTRACTION

2,2,2 SOIL DRYING

For making a pressed bricks, we need a dry soil that means less than 12%

- Therefore spread the soil on plastic sheet for several days in the laboratory, if it is possible, in a sunny part of the laboratory
- When the water content seems low, control it by measuring the water content .

2,2,3 GRINDING

1, pass the soil through the sieve of 6 mm (AFNOR N° 38 or 39) .

2, Grind the lumps of soil which do not pass through the sieve with a trowel.

OR 1' - Grind manually with a small rammer the big lumps of soil up to a 2cm diameter .

2' - Mix the soil with 2 to 6% of lime (dry mixing) .

3' - Let soil and lime settle for 24 hours .

2,2,4 DRY MIXING

1, Prepare the right amount of every component of the mixture (soil, cement lime ,,,) (see REMARKS 1 - 3 of 2,1,2,1) .

2, The mixture is mechanically prepared by quantity of about 1,5 Kg .

For Example

If you need 1.3 Kg of the following soil mixture ,

8 % lime

12 % water

You prepared 10 times of the following soil mixture,

Soil	=	1,200	kg
Lime	=	0,096	"
Total	=	1,296	"
(Water	=	0,144	" Wet mixing)

3, Put the different components into the bowl of the mortar mixer except water (dry mixing)

4, Mix at low speed with the mortar mixer for 2 mn .

2,2,5 WET MIXING

1- Add the water into the bowl, and sprinkle the dry soil mixture every where.

2- Mix at low speed with the mortar mixer for 2 mn

3- Scrape the soil which sticks to the edges of the bowl with the paddle.

4- Mix at low speed 3 mn again ,

5- If necessary (for lime for instance) store the mixture in a tank for a few days sprinkle water on it every day before molding.

2,2,6 MOLDING PRESSING

(Numbers between brackets refer to the scheme of the 2500 KN compressive tester(§ 345) [3])

1- Prepare the equipment

- MODIFIED PROCTOR MOLD (with collar extension)
  - Lubricate the inside of the mold to get an easy stripping .
  - Put in the bottom of the mold a round sheet of paper to get an easy stripping .
  - Check all the screws .

- **COMPRESSIVE TESTER**

  - It is used as an experimental bricks-press machine .
  - Lower down the screw ram (see § 345 - 12)
  - Check all the tester (see § 345 - 3)

- **CONCRETE CYLINDER**

  - This mortar cylinder has been molded before in a modified PROCTOR mold . But the volume of the mold has been reduced by 1 mm thickness sheet of paper round the mold .
  - Mortar is prepared with the mortar mixer and the following co ponent ,

    - Cement = 1,500 Kg (3 x 0,500 Kg)
    - Sand = 3,000 Kg (3 x 1,000 ")
    - Water = 0,660 " (3 x 0,220 l)

    i.e Three mixings with the mortar mixer .

2, Fill the modified PROCTOR mold with 3 Kg soil mixture . Full carefully the mold not to get empty spaces , but do not compact with hands or trowel .

3, Put the concrete cylinder above the soil mixture filling .

4, Drive it into the mold and begin to compact the soil mixture manually .

5, Put the modified PROCTOR mold full of soil with the concrete cylinder on the center of the lower platen (7).

6, Work up the screw ram (8) and compact the more it is possible by this mean .

7, Check if the ball mounted top platen (1) is well arranged ,

8, Switch ON (12)

9, Look at the black needle on the low pressure gauge scale (4) ,

10, When the needle reaches the required compressed force, switch OFF (12) , Normally this force will not be more than 500 kN . Therefore the 2500 KN pressure gauge scale is not used . If it is needed to go over 500 bN, refer to § 345 - 7 .

Never Move the loading ajustment device (11), and let it in lower sp ed ,

Calculation of the required com pressed for , F .

P = wanted compressive strength.

S = area of the upon side of the brick .

F = P x S

<u>For Example</u>

P = 60 bars = 6000 KN / m^2

S = $\frac{(0,15)^2}{4}$ = 0,01771 m^2 (area for modified PROCTOR mold)

F = 6000 x 0,0177

F = 106 KN

11, Turn on the unloading device (13)

12, Lower down the lower platen(7) by turning down the screw ram (8) .

13, Take the mold out the compressive tester .

14, Take out the concrete cylinder .

15, Dismount the mold and strip off the compressed brick

16, Weight and measure the compressed brick immediately.

17 , Label the compressed brick for further experiments and measurements .

18 , Clean and lubricate the modified PROCTOR mold .

19 , Clean the lower platen (7) and the debris-tray (10) of the compressive tester .

20 , To mold a new brick , go back to 1 .

2.2.7 BRICKS DRYING

- Dry in the laboratory on flat grates during 28 days (cement stabilization) , or 90 days (lime stabilization)

- Measure weight and dimentions when it is required (§ 3) ,

3 . MEASUREMENTS AND TESTS

3.1 MOLDING WATER CONTENT

1 INTRODUCTION

1.1 AIM

To control if the wanted water content is right .

1.2 PRINCIPLE

Measure of the water content by sampling a few quantity (about 50 g) of the soil mixture which is prepared to be molded .

2 TEST METHOD

2.1 EQUIPMENT

- Cup
- Stove
- Automatic Scales

2.2 CHEMICALS AND OTHER

2.3 PREPARATION

2.4 TEST DESCRIPTION

1, Weight the cup : P1

2, Weight the cup full of the wet soil mixture P2

3, Put the cup full of the soil mixture in the stove for about 24 hours .

4, When the soil mixture is dry, weight the cup full of the dry soil mixture.

2.5 CALCULATIONS AND RESULTS

P1 = Weight of the cup.

P2 = Weight of the cup full of the wet soil mixture.

P3 = Weight of the cup full of the dry soil mixture.

P2 - P3 = Weight of the water contained in wet soil mixture.

P3 - P1 = Weight of the dry soil mixture.

W = water content.

$$W = \frac{P2 - P3}{P3 - P1}$$

Accuracy = P $\pm$ 0,5 gramme W = 0,1 %

2.6 POSSIBLE TEST MISTAKES

- e cup is not dry when P1 is measured.
- .e drying of the soil mixture is not finished when P3 is measured.
- Lost of soil mixture during the experiment.

2.7 OTHER REMARKS

Do not forget that water content is changing at every time !

3. EXPLANATION AND INTERPRETATION

- Compare the measured water content (Wm) with the wanted water content (W_w)

If $W_w > W_m$ = Add more water in the soil mixture

If $W_w = W_m$ = It is good

If $W_w < W_m$ = Add less water in the soil mixture,

- A bad water content at the molding of the brick may have an effect on its further comportment .

3, MEASUREMENTS AND TESTS

3,2 SIZE MEASUREMENTS

1 INTRODUCTION

1,1 AIM

Control the right ini ial dimension of the bricks, follow and know the shrinkage or the swelling of the bricks according to the age and the condition of storage.

1,2 PRINCIPLE

Length, breadth, thickness, diameter are measured just after the molding, 7,14,28 and 90 days after the molding.

2 TEST METHOD

2,1 EQUIPMENT

ruler.

2,2 CHEMICALS AND OTHER PRODUCTS

none.

2,3 PREPARATION

none.

2,4 TEST DESCRIPTION

- For every dimension, at the required time(0,7,14,28,90 days).
- Measure it on different places of the brick (3 or more and calculate the average).

2.5 CALCULATIONS AND RESULTS

D finition of shrinkage or swelling of the dimension

d_i
- d : the initial of the measured dimension
- i : number of days after molding for the measurement .

S(d) = shrinkage or swelling after i day for the dimension d ,

$$Si(d) = \frac{di - do}{d\ dry_{(28\ \text{or}\ 90\ \text{days})}} \quad [\%]$$

- d could be also a volume .

Accuracy

[m] - $S_i(d)$: ± 0,01 %

d : ± 1mm = ± 0,001 m

[m^3] - S_i (V) : ±0,1 %

V: ± $3{,}10^{-5}$ m^3

d : ± 10^{-3} m^3

2. POSSIBLE TEST MISTAKES

- Bad choice of the measurement places; they have to be placed all around the brick .
- bad measurements .

3, EXPLANATION AND INTERPRETATION

- $S_i > 0$ = swelling

  $S_i < 0$ = shrinkage

- a good linear shrinkage during drying is less than 0,2 % (2mm /m) [1]

3, MEASUREMENTS AND TESTS

3 3 WEIGHT MEASUREMENTS

1, INTRODUCTION

1,1 AIM

- To know the final weight of brick ,
- To know the quickness of the drying or of absorption and the final water content of the brick after natural drying ,
- To know the final volumic mass of the brick .

1,2 PRINCIPLE

- To measure the weight after 0 , 3 , 7 , 14 , 28, 90 days ,

2, TEST METHOD

2,1 EQUIPMENT

Automatic scales (accuracy ± 0,1 gramme) ,

2,2 CHEMICALS AND OTHER PRODUCTS

2,3 PREPARATION

None, except for adobe .

At 0 day , the adobe is muddy , Therefore it must be molded on a weight Known ply wood, and be weighed with this ply wood . The adobe weight will be calculated by substraction .

2.4 TEST DESCRIPTION

Put the brick on the automatic scales .

Read the weight .

Write it on the results chart .

2.5 CALCULATIONS AND RESULTS

2.5.1 Percentage of drying

Wi = water content after i days of drying

P di .= percentage of drying after i days of drying ,

$$P_{di} = \frac{WO - W_i}{W} \quad (I)$$

Initial datas = Wo : molding water content

P_i : weight after i days of drying

$$W_i = \frac{P\ water}{P\ dry} = \frac{P_i - P\ dry}{P\ dry} \quad ; (1)$$

$$Wo = \frac{Po - P\ dry}{P\ dry} \longrightarrow P\ dry = \frac{P_o}{I + W_o} \quad (2)$$

- (1) and (2) give

$$W_i = \frac{P_i - \frac{P_o}{1 + W_o}}{\frac{P_o}{1 + W_o}} = \frac{P_i (1 + W_o) - P_o}{P_o}$$

Therefore (I) becomes :

$$P_{di} = \frac{W_o - \frac{P_i (1 + W_o) - P_o}{P_o}}{W_o}$$

$$P_{di} = \frac{P_o W_o - P_i (1 + W_o) + P_o}{W_o}$$

$$\boxed{P_{d_i} = (P_o - P_i) \frac{(1 + W_o)}{W_o}}$$

Accuracy

P_i : $\pm$ 10^{-1} g

W_o : $\pm$ 10^{-1} %

P_{di} : $\pm$ 2 %

2,5,2 Final Water Content

The final water content is the water content after 28 (or 90) days of drying or absorption .

$$W_i = \frac{P_i}{P_o} \times (1 + W_o) - 1$$

Accuracy : P_i : $\pm$ 0, 1_g

Wo : $\pm$ 0, 1%

W_i : $\pm$ 0, 1%

2,5,3 Final Volumic Mass

The final volumic mass is the volumic mass after 28 (or 90) days of drying or absorption ,

M_i = Mass of the brick after i days , [kg]

V_i = Volume of the brick after i days [m^3]

ρ_i = Volumic mass of the brick after i days , [Kg / m^3]

$$\rho_i = \frac{Mi}{Vi}$$

Accuracy:- M_i : $\pm$ 10^{-4} kg ,

V : $\pm$ $3{,}10^{-5}$ m^3

P : $\pm$ 100 kg / m^3

2,6 POSSIBLE TEST MISTAKES

Bad handling of the brick which damages it , therefore its weight changes. Be careful when you handle the brick !

3, EXPLANATION AND INTERPRETATION

$P_{di} > 0$: drying

$P_{di} < 0$: absorption

Absorption for stabilized adobes [1]

$|P_{d7}|$ 2, 5 %

$|P_{d7}|$

2%	:	very good quality
2% to 3%	:	good quality
3% to 4%	:	poor quality
4%	:	bad quality

, Final water content after drying < 4% :
good stabilized adobe [1]

, Volumic mass [4]

VOLUMIC MASS		COMPRESSED BRICKS	ADOBES
Wet(after) Molding)	Minimum	1870 kg/m^3	-
	Recommended	2200 kg/m^3	-
Dry	Minimum	1700 kg/m^3	1400 kg/m^3
	Recommended	2000 kg/m^3	-

3, MEASUREMENTS AND TESTS

3.4 DRY AND WET COMPRESSIVE STRENGTHS

1, INTRODUCTION

1,1 AIM

To know the mechanical comportment of the brick after drying (dry compressive strength) and after 28 days of absorption (wet compressive strength).

1,2 PRINCIPLE

Compressive strength test used for concrete sample .

2, TEST METHOD

2,1 EQUIPMENT

2500 KN Compressive Tester .

2,2 CHEMICALS AND OTHER PRODUCTS

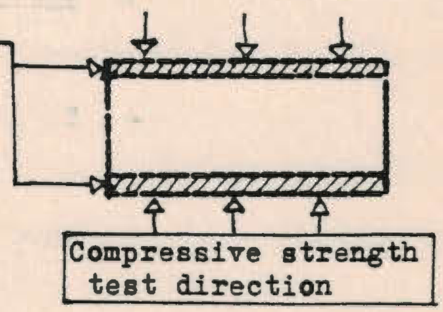
2,3 PREPARATION OF THE TEST

If the side of the brick in the compressive strength direction are not flat and smooth, they must be planed and smoothed ,

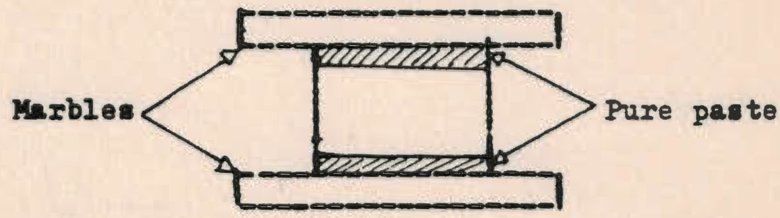
- Prepare for that aim a pure paste of lime

  lime /water: 2 / 1

  Put the paste on the two sides of the brick ,



- Cure the paste by putting the brick between two heavy and smooth surfaces (marbles for instance)



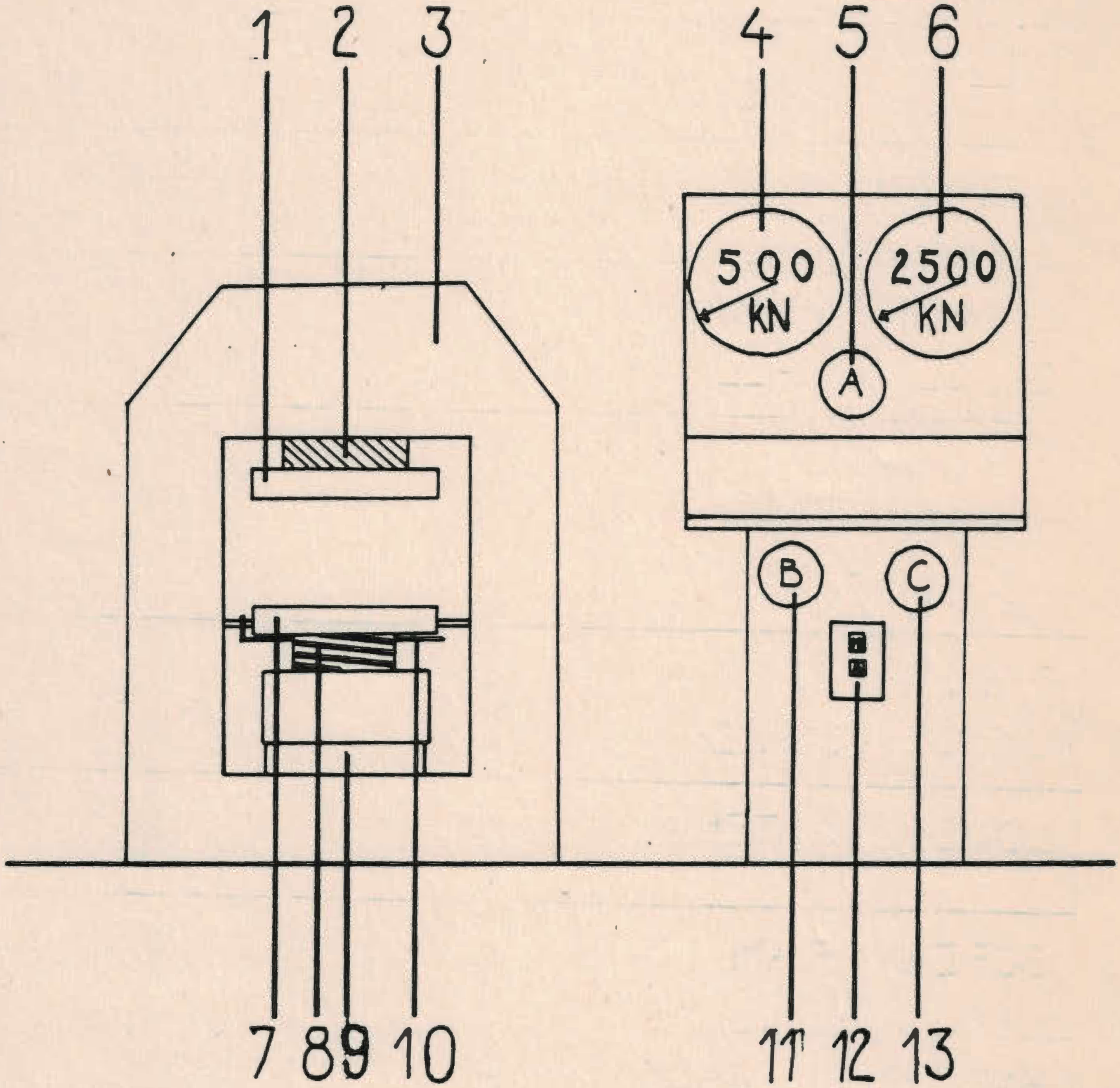
2,4. TEST DESCRIPTION [3]

Numbers between brackets refer to the scheme of the 2500 compressive tester

1- Put on the center of the lower platen (7) the well prepared brick.

2- Adjust to the ball mounted top platen (1) against the upper side of the brick by working up the screw ram (8) . If it is needed to rise up the brick more than 6cm, put thick iron tray on the lower platen(7) before putting the brick .

3- Check - The unloading device (13) put it to zero .
- The loading adjustment device (11) put it at the lower speed .
- The automatic isolation value and cock of (4) (5) : the low pressure gauge scale must work at the beginning of the experiment.



2500KN COMPRESSIVE TESTER

2500 KN COMPRESSIVE TESTER		
BALL MOUNTED TOP PLATEN	1	
TOP PLATEN WEDGING DEVICE	2	
WELDED FRAMEWORK	3	
LOW PRESSURE GAUGE SCALE	4	
AUTOMATIC ISOLATION VALVE AND COCK OF 4	5	
PRESSURE GAUGE SCALE	6	
LOWER PLATEN	7	
SCREW RAM	8	
HYDRAULIC JACK	9	
DEBRIS TRAY	10	
LOADING ADJUSTMENT DEVICE	11	

2500 KN COMPRESSIVE TESTER		
SWITCH ON/OFF	12	
UNLOADING DEVICE	13	

- The zero of the two pressure gauge scales (4 and 6) by putting the zero of the scale in front of the black pointer .
- Adjust the red pointer just above the black pointer ,

4 - Switch ON (12)

5 - Check at every time ,

- The pressure gauge scale (4 and 6)
- The testing sample = be careful not to be hurt by a violent crushing of the sample .

6 - If the pressure rises up too slowly, increase the speed by turning of the loading adjustment device (11) .

7 - When the low pressure gauge scale (4) is reaching 450 KN , turn off quickly the automatic isolation value and cock (5).

8 - When the sample is crushed:

- The black pointer falls down.
- The red pointer indicates the crushing compressive force F .
- Turn on the unloading device (13)
- Switch OFF (12)

9 - Down the lower platen (7) by turning down The screw raw (8).

10 - Take the crushed brick out the compressive tester .

11 - Clean the lower platen (7) and the debris tray(10).

12 - If necessary for further experiments, lower down the hydraulic jack (9) with the car lifting jack placed betwen the lower platen (7) and the ball mounted top platen (1).

2.5 CALCULATIONS AND RESULTS

F = crushing compressive force [KN]

P = crushing compressive pressure [bar]

S = horizontal area of the brick $[m^2]$

$$P = \frac{F}{S} \times 10^{-2}$$

$(1bar \sim 1Kg/cm^2)$

Accuracy F = $\pm$ 5 KN

S = $\pm 2.10^{-4}$ m^2

P = $\pm$ 3 bars

To convert to another unit pressure use the figure on the following page .

For every type of brick, measure the compressive strength for 3 samples .

2.6 POSSIBLE TEST MISTAKES

- Not flat and smooth horizantal sides of the brick
- bad place of the brick on the lower platen (7)
- bad making of the brick (especially bad mixing of the soil)

1 U → VAUT ↓	$N/m^2 = Pa$ (S.I.)	$kN/m^2 = kPa$	$MN/m^2 = MPa$	Kg/cm^2	p.s.i.	bar	atm	mm Hg
$N/m^2 = Pa$ (S.I.)	1	10^3	10^6	$9.81.10^4$	$6.89.10^3$	10^5	$1.013.10^5$	133.2
$kN/m^2 = kPa$	10^{-3}	1	10^3	98.1	6.89	10^2	101.3	0.1332
$MN/m^2 = MPa$	10^{-6}	10^{-3}	1	0.0981	$6.89.10^{-3}$	10^{-1}	0.1013	$0.1332.10^{-3}$
Kg/cm^2	$10.19.10^{-6}$	$10.19.10^{-3}$	10.19	1	0.0703	1.02	1.033	$1.358.10^{-3}$
p.s.i.	$0.1451.10^{-3}$	0.1451	145.1	14.22	1	14.51	14.726	$19.3.10^{-3}$
bar	10^{-5}	10^{-2}	10	0.981	0.0689	1	1.013	$1.332.10^{-3}$
atm	$0.987.10^{-5}$	$0.987.10^{-2}$	9.87	0.967	$6.79.10^{-2}$	0.987	1	$1.315.10^{-3}$
mmHg	$7.507.10^{-3}$	7.507.	7507	736.4	51.77	750.7	760	1

3. EXPLANATION AND INTERPRETATIONS

- Minimum wet compressive strength SW = 10 bar
- " dry " " SD = 40 "
- Max wet/dry " " Ratio $\frac{SD}{SW} < 4$

Mean of stabilizing	Dry compressive Strength
Cement	50 to 100 bar
Lime	30 to 80 "
Bitcume	15 to 60 "
Fibre	5 to 20 "
Chemicals	20 to 40 "
Strong chemicals	150 to 400 "
Reference [1]	

- Stabilised adobes [1]:

. USA : dry compressive strengh > 24 bar

. PERU : dry compressive strength > 17,6 bar: good quality
14 to 17,6 bar: medium "
< 14 bar: bad "

- Compressed brick (CINVA) [1]

ONU : wet compressive strength > 14 bar .

3, MEASUREMENTS AND TESTS

3,5 WATER ABSORPTION

1, INTRODUCTION

1,1 AIM

To know the capillary water absorption of a molded and dry brick.

To study the comportment of the brick against water .

1,2 PRINCIPLE

Measure of the weight increasing when the bottom of the bricks is in contact with water during 28 days .

2 TEST METHOD

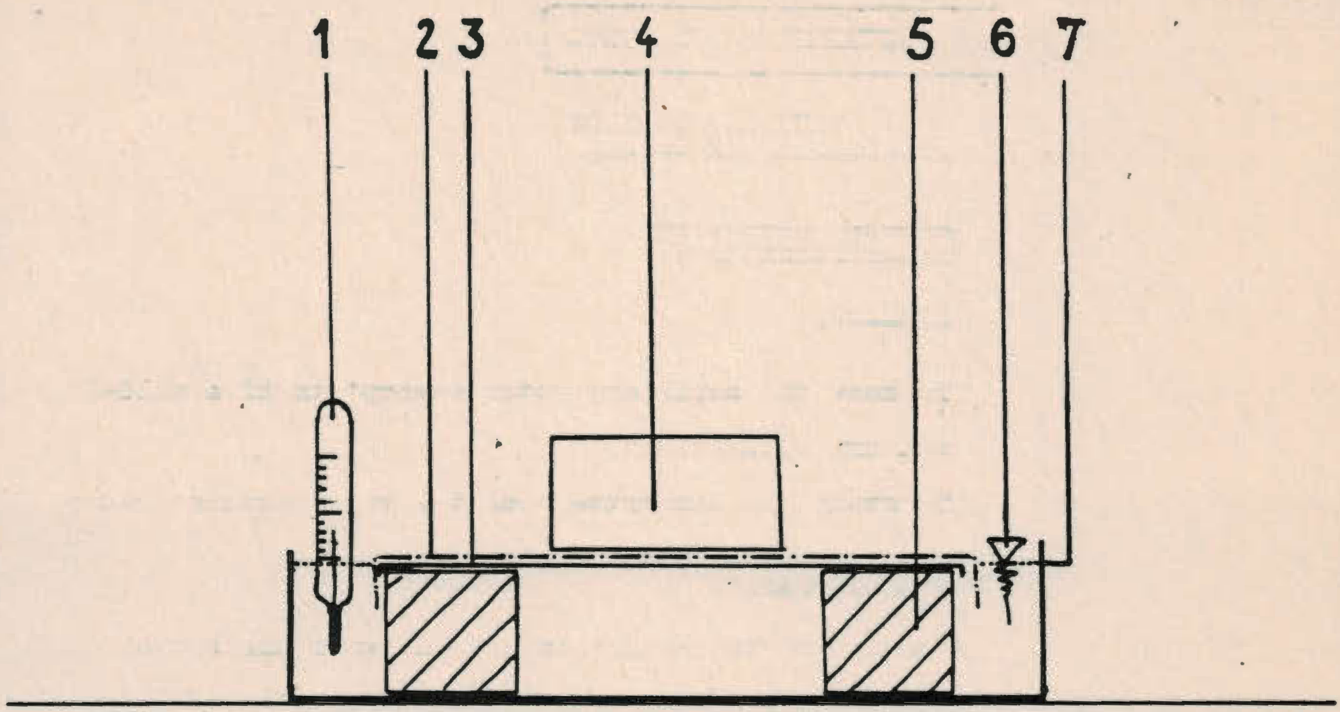
2,1 EQUIPMENT

- A tank.
- Supports .
- One stainless grate .
- Blotting or filter paper .
- Thermometer.

2,2 CHEMICALS AND OTHER PRODUCTS

- Water.

2,3 PREPARATION OF THE TEST



THERMOMETER	1	
BLOTTING OR FILTER PAPER	2	
STAINLESS GRATE	3	
BRICK UNDER STUDY	4	
SUPPORT	5	
WATER LEVEL	6	
TANK	7	
ABSORPTION TEST		

EXCOOP - MUD.H.
LABORATOIRE DE L'E.T.S.M
DOSSIER ____________

Pourcentage de la chaux ____________
Presence de la paille -AVEC ______
Serie ____________ -SANS ______

Manipulateur:
Nom ____________
Signature ____________
Date ____________

N° de briques		1	2	3	4	5	6	7	8	9	10
Date de fabrication											
Hauteur (cm)	0 jours										
	14 jours										
	28 jours										
Diametre (cm)	0 j										
	14 j										
	28 j										
Poids (kg)	0 j										
	14 j										
	28 j										
W% à la date de fabrication											
γ_d											
Resistance à la compression à 28 j											
0 jour											
1 jour											
2 jours											
3 "											
7 "											
14 "											
28 "											
Resistance à la compression											
0 jour											
1 jour											
2 jours											
3 "											
7 "											
14 "											
28 "											
Resistance à la compression											

Observations ____

2.4 TEST DESCRIPTION

- Weight the grate recovered of paper: m.
- Weight at 0 , 1 , 3 , 7 , 14 , 28 days the brick put on the grate: m_1 Check the temperature and note it on the chart .
- The weight of the brick is $M_1 = m_1 - m$.
- Fill the tank with water up to the right level every day .

2.5 CALCULATIONS AND RESULTS

- See 33 : WEIGHT MEASUREMENTS.
- Report the result on a graph.

2.6 POSSIBLE TEST MISTAKES

- Bad handling of the wet brick .
- Too much over water on the grate when mass is measured.

3. EXPLANATIONS AND INTERPRETATIONS

- See 33 WEIGHT MEASUREMENTS .

3 , MEASUREMENTS AND TESTS

3,6 EROSION TEST

1, INTRODUCTION

1,1 AIM

To know the comportment of the brick against the fall of the rain .

1,2 PRINCIPLE

Water drips from a pipette and falls down regularly on the tested brick .

2, TEST METHOD

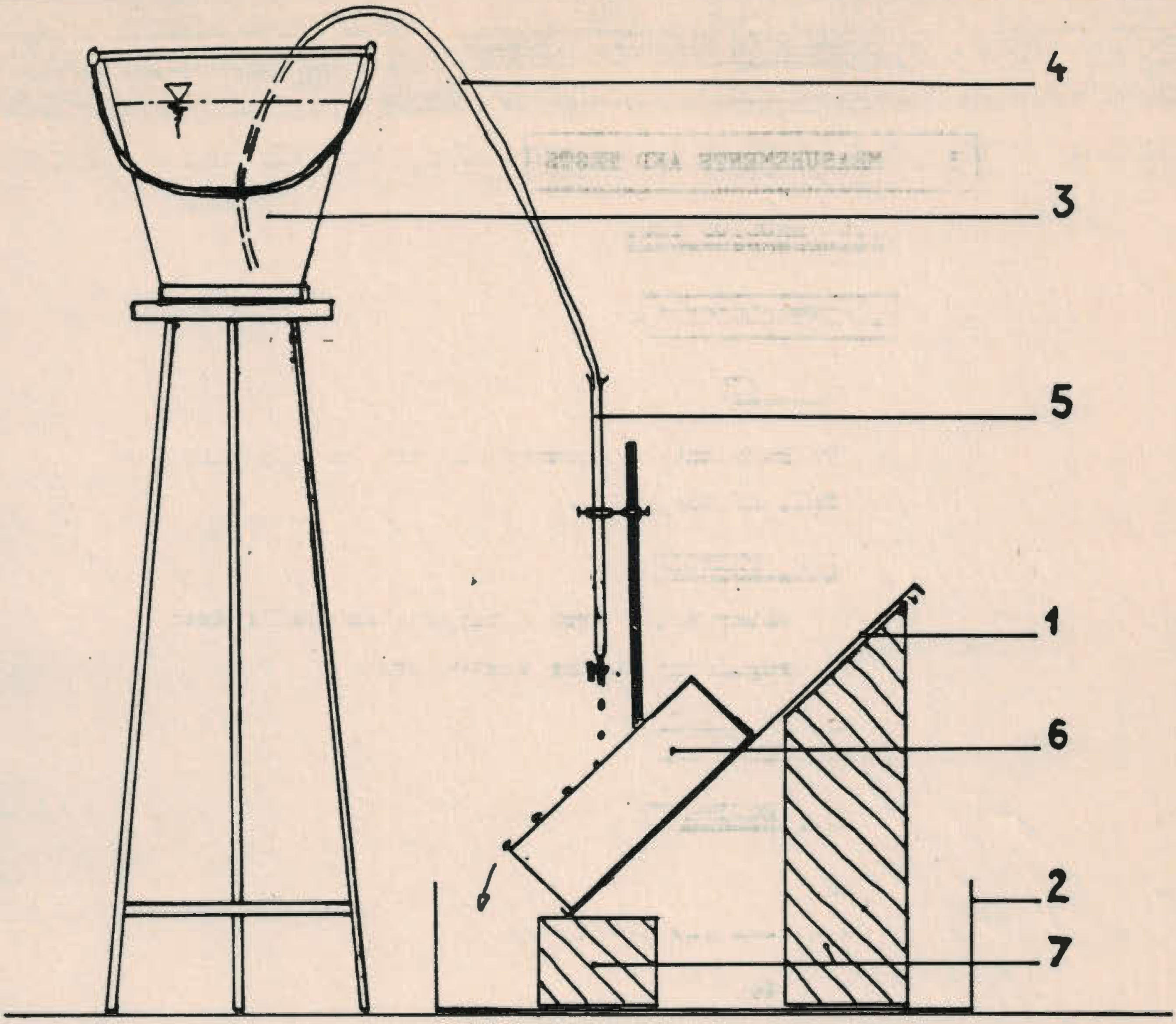
2,1 EQUIPMENT

- Tank.
- Supports and wedges.
- Pipette.
- Bucket.
- A pipe.

2,2 CHEMICALS AND OTHER PRODUCTS

- Water.

2,3 PREPARATION



GRATE	1	
TANK	2	
BUCKET WITH WATER	3	
WATER-PIPE	4	
PIPETTE	5	
BRICK UNDER STUDY	6	
SUPPORTS AND WEDGES	7	
EROSION TEST		

2,4 TEST DESCRIPTION

- Weight the brick before the experiment : M_0.
- Measure the thickness of the brick : e_0.
- Check regularly the level of water in the bucket.
- Be careful that the bottom of the brick is not in water.
- After 28 days, dry the brick in the stove during 48 hours.
- Weight the brick = M'_0.
- Measure the thickness of the brick = e'_0, where the drops fall.

2,5 CALCULATIONS AND RESULTS

- $$\text{Lost of weight} = \frac{M_0 - M'_0}{M_0} \; [\%]$$

accuracy: M_0: $\pm 10^{-4}$ kg

$\frac{M_0 - M'_0}{M_0}$: $\pm$ 10-2 %

- $$\text{Lost of thickness} = \frac{e_0 - e'_0}{e_0} \; [\%]$$

accuracy: e_0 : $\pm 10^{-3}$ m

$\frac{e_0 - e'_0}{e_0}$: $\pm 10^{-1}$ %

- writing notes

2.6 POSSIBLE TEST MISTAKES

- The drops fall down on a part cular point of the brick.
- Irregular cadence of dripping.
- Bad measure of e'_o.
- It is a not precised test .

4 , REFERENCES

[1] CONSTRUIRE EN TERRE, par le Craterre, P.Doat , A. Hays , H.Houben, S.Matuk , F.Vitoux , Editions alternatives, collection An Architecture .

[2] PERRIER, Notice BM 32 D , MORTAR MIXER. RILEM cemburean Method , Complying with AFNOR P15-411 .

[3] PERIER , Notice LJ 374 , 2000 AND 3000 KN TEST PRESSES Measurement according to AFNOR 18-411 .

[4] Recommandations pour la conception des batiments du QUARTIER EN TERRE DE L'ISLE D' ABEAU, PLAN CONSTRUCTION , Secretariat permanent ministere de l'Urbamisme et du Logement .

Part 2.
British Standard soil testing proceudres (extract)

British Standard Methods of test for

Soils for civil engineering purposes

1. General

1.1 Scope

This British Standard specifies methods of test for soils for civil engineering purposes.

NOTE. The titles of the British Standards referred to in this standard are listed on the inside back cover.

1.2 Definitions and symbols

1.2.1 Definitions. For the purposes of this British Standard the following definitions and those given in BS 892 apply:

(1) *Liquid limit (LL).* The moisture content at which a soil passes from the plastic to the liquid state, as determined by the liquid limit test.

(2) *Plastic limit (PL).* The moisture content at which a soil becomes too dry to be in a plastic condition, as determined by the plastic limit test.

(3) *Plasticity index (PI).* The numerical difference between the liquid limit and the plastic limit of a soil.

(4) *Non-plastic.* A soil with a plasticity index of zero or one on which the plastic limit cannot be determined.

(5) *Particle size distribution.* The percentages of the various grain sizes present in a soil as determined by sieving and sedimentation.

(6) *Cobbles.* Rounded or sub-angular stones of sizes between 200 mm and 60 mm.

(7) *Gravel fraction.* The fraction of a soil composed of particles between the sizes of 60 mm and 2 mm. The gravel fraction may be subdivided as follows:

		BS test sieve sizes to be used for separation*
Coarse gravel	60 mm to 20 mm	63 mm to 20 mm
Medium gravel	20 mm to 6 mm	20 mm to 6.3 mm
Fine gravel	6 mm to 2 mm	6.3 mm to 2 mm

(8) *Sand fraction.* The fraction of a soil composed of particles between the sizes 2.0 mm and 0.06 mm. The sand fraction may be subdivided as follows:

		BS test sieve sizes to be used for separation*
Coarse sand	2.0 mm to 0.6 mm	2.0 mm to 600 μm
Medium sand	0.6 mm to 0.2 mm	600 μm to 212 μm
Fine sand	0.2 mm to 0.06 mm	212 μm to 63 μm

(9) *Silt fraction:* The fraction of a soil composed of particles between the sizes 0.06 mm and 0.002 mm. The silt fraction may be subdivided as follows:

Coarse silt	0.06 mm to 0.02 mm
Medium silt	0.02 mm to 0.006 mm
Fine silt	0.006 mm to 0.002 mm

(10) *Clay fraction.* The fraction of a soil composed of particles smaller in size than 0.002 mm.

(11) *Cohesive soil.* A soil which, by virtue of its clay content, will form a coherent mass.

(12) *Non-cohesive soil. Granular soil.* A soil which will not form a coherent mass.

(13) *Sampling.* The selection of a representative portion of a material.

*These are the test sieve sizes nearest to the theoretical sizes. When the 2.0 mm and 63 μm sieves are not available the 2.36 mm (No. 7) and 75 μm (No. 200) sieves may be used without seriously affecting the result.

(14) *Quartering.* The reduction in quantity of a large sample of material by dividing a circular heap, by diameters at right angles, into four approximately equal parts, removing two diagonally opposite quarters, and mixing the two remaining quarters intimately together so as to obtain a truly representative half of the original mass. The process is repeated until a sample of the required size is obtained.

(15) *Riffling.* The reduction in quantity of a large sample of material by dividing the mass into two approximately equal halves by passing the sample through an appropriately sized riffle (or riffle box). The process is repeated until a sample of the required size is obtained.

(16) *Compaction.* The process of packing soil particles more closely together by rolling or other mechanical means, thus increasing the dry density of the soil.

(17) *Consolidation.* The process whereby soil particles are packed more closely together over a period of time by application of continued pressure.

(18) *Bulk density.* The mass of a material (including solid particles and any contained water) per unit volume including voids.

(19) *Dry density.* The mass of the dry material, after drying to constant mass at 105 °C, contained in unit volume of undried material.

(20) *Moisture content*.* The mass of water which can be removed from the soil, usually by heating at 105 °C, expressed as a percentage of the dry mass.

(21) *Optimum moisture content.* The moisture content at which a specified amount of compaction will produce the maximum dry density (see Fig. 1).

(22) *Maximum dry density.* The dry density obtained using a specified amount of compaction at the optimum moisture content (see Fig. 1).

(23) *Relative compaction.* The percentage ratio of the dry density of the soil to the maximum dry density of that soil, as determined by a specified laboratory compaction test.

(24) *Dry density/moisture content relationship.* The relationship between dry density and moisture content of a soil when a given compactive effort is employed.

(25) *Percentage air voids.* The volume of air voids in the soil expressed as a percentage of the total volume of the soil.

(26) *Air voids line.* A line showing the dry density/moisture content relationship for soil containing a constant percentage of air voids. (Air voids lines are shown in Fig. 1.) The line can be calculated from the equation:

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

where

ρ_d is the dry density of the soil (Mg/m^3);

ρ_w is the density of water (Mg/m^3);

V_a is the volume of air voids in the soil, expressed as a percentage of the total volume of the soil;

G_s is the specific gravity of the soil particles;

w is the moisture content, expressed as a percentage of the mass of dry soil.

(27) *Saturation line (zero air voids line).* A line showing the dry density/moisture content relationship for soil containing no air voids. The saturation line is also shown on Fig. 1. It is obtained by putting $V_a = 0$ in the equation given in definition (26).

*Although the term moisture content has been used throughout this standard, the term water content is also widely used and either may be employed.

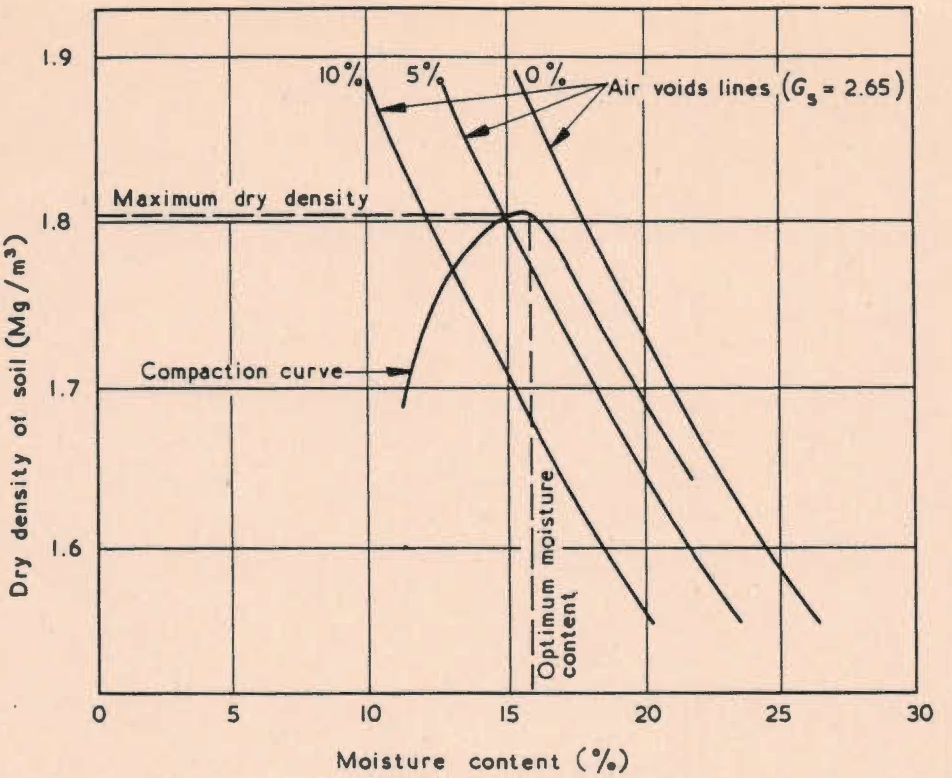


Fig. 1. Terms used in compaction tests

1.2.2 Symbols. For the purposes of this British Standard the following symbols and those given in BS 1991: Parts 1 and 4 and used:

Term	Symbol	Term	Symbol
Moisture content	w	Secondary compression ratio	r_s
Liquid limit	LL	Vane shear strength	S
Plastic limit	PL	Penetration resistance	N
Plasticity index	PI	Unconfined compression strength	σ_f
Non-plastic	NP	Maximum principal stress difference	$(\sigma_1 - \sigma_3)_f$
Linear shrinkage	LS	Specific gravity of soil particles	G_s
California Bearing Ratio	CBR	Bulk density of soil	ρ_d
Coefficient of volume compressibility (one dimensional)	m_v	Dry density of soil	ρ
Coefficient of consolidation	c_v	Density of water	ρ_w
Initial compression ratio	r_o	Percentage air voids	V_a
Primary compression ratio	r_p	Degree of saturation	Sr

1.3 Apparatus

Apparatus shall comply with the requirements of British Standards, where these are available. For example,

BS 410 Test sieves
BS 593 Laboratory thermometers
BS 604 Graduated measuring cylinders
BS 718 Density hydrometers and specific gravity hydrometers
BS 733 Density bottles
BS 846 Burettes and bulb burettes
BS 1583 One-mark pipettes
BS 1739 Filter flasks
BS 1752 Laboratory sintered or fritted filters
BS 1792 One-mark volumetric flasks
BS 1923 Glass filter funnels
BS 2648 Performance requirements for electrically-heated laboratory drying ovens
BS 3423 Recommendations for the design of glass vacuum desiccators

For the type of materials covered by this British Standard full tolerance sieves will be sufficiently accurate. Sieves with 5 mm aperture size and above shall be perforated plate square hole test sieves. Below that size they shall be woven wire test sieves.

The essential details of the equipment illustrated in this standard have been indicated by asterisks in the figures.

The manufacturing tolerances on the essential dimensions shall be as shown below unless other tolerances are shown in the figures.

(1) ± 1.0 mm on dimensions greater than 300 mm.
(2) ± 0.5 mm on dimensions between 100 mm and 300 mm as fractions.
(3) ± 0.15 mm on dimensions up to and including 100 mm.

Where mass is an essential requirement the tolerance on the mass is shown in the figure.

NOTE 1. The following range of balances covers the requirements of all the tests in this standard:

Capacity	100 g	250 g	1 kg	2 kg	5 kg	10 kg	25 kg
Accuracy	0.001 g	0.01 g	0.1 g	0.2 g	0.5 g	1 g	5 g

NOTE 2. The following palette knives cover the requirements of all the tests in this standard:

Length	100 mm	200 mm
Breadth	20 mm	30 mm

1.4 Grouping of soils

For the purposes of the tests described in this British Standard, soils shall be grouped as follows:

(1) *Fine-grained soils.* Soils containing not less than 90 % passing a 2 mm BS test sieve
(2) *Medium-grained soils.* Soils containing not less than 90 % passing a 20 mm BS test sieve.
(3) *Coarse-grained soils.* Soils containing not less than 90 % passing a 37.5 mm BS test sieve.

The grouping of a soil thus depends on the result of a sieve analysis. Any soil shall be regarded as belonging to the finest-grained group appropriate under the definitions given above.

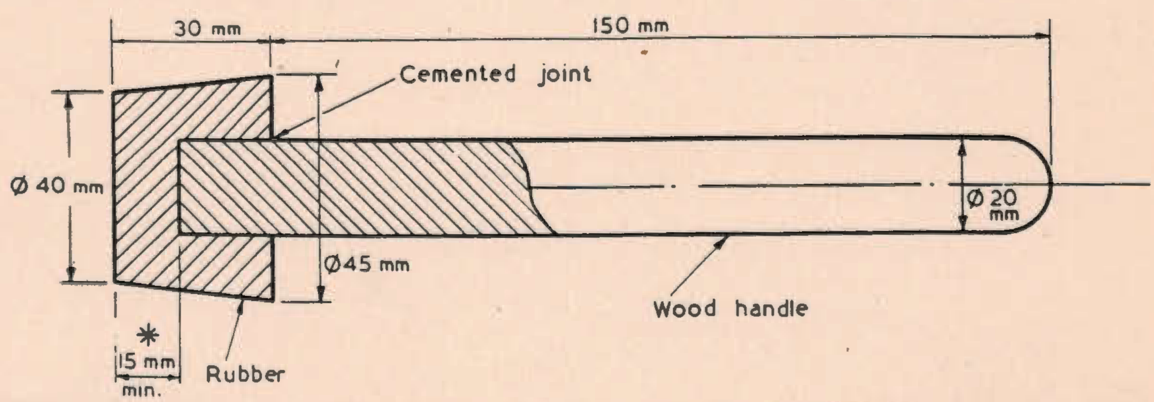
Soils with a greater proportion of material than about 10 % retained on a 37.5 mm BS test sieve cannot usefully be examined by any of the tests in this British Standard except the sieve analysis and the plasticity tests. They would, of necessity, fall into the range of materials classed as aggregates which are covered by BS 812.

1.5 Preparation of disturbed samples for testing

1.5.1. General. This clause covers the preparation of soil samples as received from the field and their allocation for subsequent tests (see Note 1).

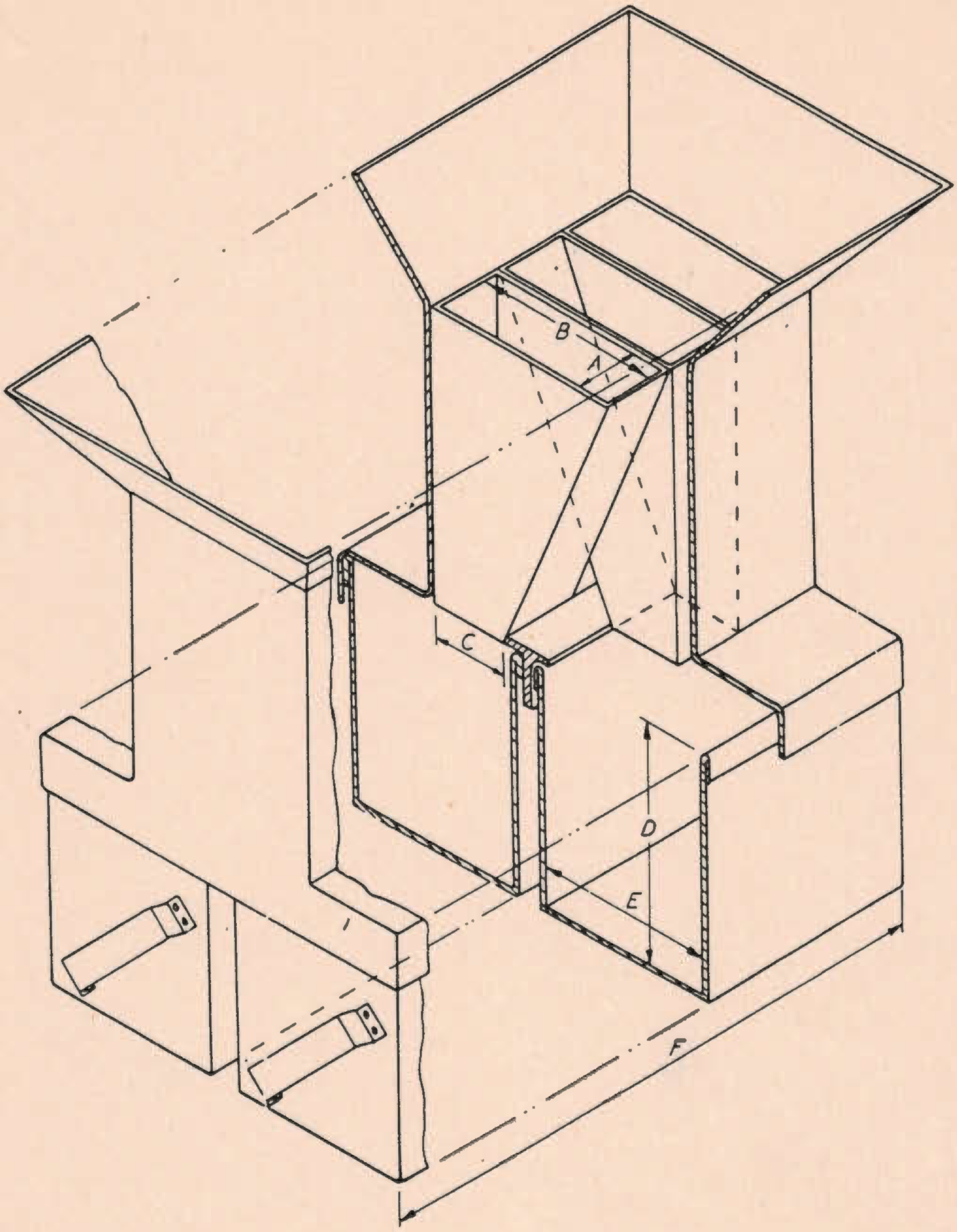
1.5.2 Apparatus. The following apparatus is required:

(1) a balance readable and accurate to 0.1 g.
(2) a balance readable and accurate to 1 g.
(3) a means of breaking up aggregations of soil without reducing the size of the individual particles, e.g. a mortar and a rubber pestle similar to the one illustrated in Fig. 2, or a suitable mechanical device.
(4) British Standard test sieves of the following sizes: 425 µm, 2 mm, 5 mm, 20 mm, 37.5 mm.
(5) a thermostatically controlled drying oven capable of maintaining a temperature of 45 °C to 50 °C and of 105 °C to 110 °C.
(6) Sample dividers, e.g. of the multiple-slot type (riffle box) similar to those shown in Fig. 3.



This design has been found satisfactory, but alternative designs may be employed provided that the essential requirements are fulfilled. (Essential dimension is indicated by an asterisk)

Fig. 2. Rubber pestle



NOTE. All dimensions except *A* are approximate only.

Maximum size of sample	Number of slots	Internal dimensions			Internal dimensions of the boxes (3 required)		
		A	*B*	*C*	*D*	*E*	*F*
mm		mm	mm	mm	mm	mm	mm
40	8	50	150	70	230	150	400
20	10	30	130	40	150	100	300
10	12	15	80	30	120	90	200
5	12	7	20	15	50	50	90

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

Fig. 3. A suitable type of sample divider (riffle)

1.5.3 General preparation of sample (see Note 1). The general method for the preparation of a sample is as follows:

(1) An assessment should be made of whether the soil is to be classified as a fine-grained, medium-grained or coarse-grained soil (see 1.4). In many cases this will be known or self-evident but, in doubtful cases or where confirmation is required, a portion of the sample should be sieved through the appropriate sieve or sieves, generally using the procedure given under Test 7(A) or 7(B). The size of sample used for this shall be in accordance with the following table.

Maximum size of material present in substantial proportion (more than 10 %)	Minimum mass of sample to be taken for sieving
mm	kg
> 20	15
< 20 but > 2	2
< 2	0.1

(2) The total mass of sample required depends on the soil group and the tests to be carried out but, to ensure a representative sample, the total mass should not, in general, be less than the following minimum masses:

fine-grained soils	500 g;
medium-grained soils	5 kg;
coarse-grained soils	30 kg

The actual mass of sample required can be assessed by multiplying the mass given in the table below (which includes some allowance for drying, wastage and rejection of stones where required) by the maximum number of tests envisaged. Where the total mass of sample so calculated is less than the minimum mass given above for the appropriate soil group then that minimum mass shall be taken.

Type of test		Soil group		
		Fine-grained	Medium-grained	Coarse-grained
Moisture content	Test 1(A)	50 g	350 g	4 kg
Moisture content	Test 1(B)	50 g	350 g	3 kg
Moisture content	Test 1(C)	50 g	350 g	–
Liquid limit	Test 2(A)	500 g	1 kg	2 kg
Liquid limit	Test 2(B)	500 g	1 kg	2 kg
Liquid limit	Test 2(C)	150 g	250 g	500 g
Plastic limit	Test 3	50 g	100 g	200 g
Linear shrinkage	Test 5	500 g	800 g	1.5 kg
Specific gravity	Test 6(A)	300 g	600 g	600 g
Specific gravity	Test 6(B)	100 g	100 g	100 g
Particle size distribution	Test 7(A)	150 g	2.5 kg	17 kg
Particle size distribution	Test 7(B)	150 g	2.5 kg	17 kg
Particle size distribution	Test 7(C)	100 g	100 g	100 g
Particle size distribution	Test 7(D)	250 g	250 g	250 g
Organic matter content	Test 8	150 g	600 g	3.5 kg
Sulphate content	Test 9	150 g	600 g	3.5 kg
Sulphate content	Test 10	150 g	600 g	3.5 kg
pH value	Test 11(A)	150 g	600 g	3.5 kg
pH value	Test 11(B)	150 g	600 g	3.5 kg
Compaction test*	Test 12	(10 kg) 25 kg	(10 kg) 25 kg	(10 kg) 25 kg
Compaction test*	Test 13	(10 kg) 25 kg	(10 kg) 25 kg	(10 kg) 25 kg
Compaction test*	Test 14	(50 kg) 80 kg	(50 kg) 80 kg	(50 kg) 80 kg
California Bearing Ratio	Test 16	6 kg	6 kg	12 kg

* The masses given in brackets apply only when the soil is not susceptible to crushing during compaction (see Note 2).

Tests not covered in this table are those in which undisturbed samples are used or where tests are made on the soil in situ.

(3) If the moisture content of the natural soil, as received, is required, representative samples of the following minimum masses shall be obtained by riffling or quartering.

	Test 1(A)	Test 1(B)	Test 1(C)
For fine-grained soils	30 g	30 g	30 g
For medium-grained soils	300 g	300 g	300 g
For coarse-grained soils	3 kg	2 kg	—

Where samples are being taken for moisture content determination the use of shallow trays for storing or carrying should be avoided as these expose the samples unnecessarily to evaporation or rainfall. Such samples should be kept covered, if not sealed, except when material is actually being extracted.

(4) If the California Bearing Ratio is to be determined (see Test 16) the appropriate quantity of material shall be removed from the main sample and sealed in a container so as to prevent loss of moisture until such time as the tests are carried out.

(5) The soil sample (or the remainder if procedures (3) or (4) are carried out) shall be brought to a state in which it may be crumbled, if necessary by drying it in air or in the oven. This shall be done at a temperature not exceeding 50 °C. Oven drying at 105 °C to 110 °C may be employed, provided this does not affect the results of the tests to be carried out subsequently (see Note 3).

1.5.4 Preparation for classification and chemical tests (Tests 1 to 11)

1.5.4.1 The aggregations of particles in the sample obtained in 1.5.3(5) shall be broken down in such a way as to avoid crushing the individual particles. Care shall be taken that no particles are crushed in this operation but that all aggregations of particles are broken down so that if the sample was sieved on a 2 mm BS test sieve only individual particles would be retained.

1.5.4.2 The sample obtained in **1.5.4.1** shall be mixed thoroughly and then subdivided either by quartering, by riffling, or by other suitable means until representative subsamples of the minimum masses given, after suitable further preparation where necessary, are obtained for the appropriate tests.

(1) *Tests 1(A), 1(B) and 1(C). (Determinations of the moisture content of the prepared samples).*

	Test 1(A)	Test 1(B)	Test 1(C)
For fine-grained soils	30 g	30 g	30 g
For medium-grained soils	300 g	300 g	300 g
For coarse-grained soils	3 kg	2 kg	—

(2) *Tests 2(A), 2(B), 2(C), 3, 4 and 5. (Determination of liquid limit, plastic limit, plasticity index and linear shrinkage).* Sufficient of the material obtained in **1.5.4.1** shall be taken so that when sieved through a 425 µm BS test sieve the following quantities of material passing the test sieve are obtained (see Note 4).

Test 2(A)	200 g
Test 2(B)	200 g
Test 2(C)	50 g
Test 3	20 g
Test 4	No additional sample required
Test 5	150 g

Care shall be taken that no particles are crushed but that all aggregations of particles are broken down so that only individual particles are left on the sieve (see Notes 5 and 6). The proportion of material passing the 425 µm BS test sieve shall be recorded (see Note 7).

(3) *Test 6(A). (Determination of specific gravity).* A 200 g sample in the case of fine-grained soils and 400 g in the case of medium- or coarse-grained soils prepared as in **1.5.4.1** shall be taken, and stones larger than 37.5 mm diameter shall be broken down below this size. The sample shall be oven dried at 105 °C to 110 °C (see Note 8).

(4) *Test 6(B). (Determination of specific gravity).* A 50 g sample shall be taken from the material prepared as in **1.5.4.1** and, if necessary, ground to pass a 2 mm BS test sieve. A representative 5 g to 10 g subsample shall be obtained and oven dried at 105 °C to 110 °C (see Note 8).

(5) *Tests 7(A) and 7(B). (Determination of particle size distribution).* Sufficient material prepared as in **1.5.4.1** shall be taken and oven dried at 105 °C to 110 °C to give the minimum mass in accordance with the following table.

Maximum size of material present in substantial proportion (more than 10 %) retained on BS test sieve	Minimum mass of sample to be taken for sieving
mm	kg
63	50
50	35
37.5	15
28	5
20	2
14	1
10	0.5
6.3	0.2
Passing 2 mm, 600 µm, 300 µm or 63 µm	0.1

(6) *Tests 7(C) and 7(D). (Determination of particle size distribution).* (Applicable only to soils with more than 10 % passing the 63 µm BS test sieve. The following quantities of material prepared as in **1.5.4.1** are required:

Test 7(C) 60 g
Test 7(D) 200 g

(7) *Tests 8, 9, 10, 11(A) and 11(B). (Determination of organic content, sulphate content and pH value).* The preparation of the samples for these tests are fairly involved and are given, therefore, under the respective test procedures. The following quantities of material prepared as in **1.5.4.1** are required for each test:

for fine-grained soils 100 g;
for medium-grained soils 500 g;
for coarse-grained soils 3 kg

1.5.5 Preparation for compaction tests and strength tests (Tests 12 to 21). The methods of preparation of samples for appropriate tests are as follows.

(1) *Tests 12 and 13 (Compaction tests using a rammer).* A portion of the material, prepared as in **1.5.3(5)** and large enough to provide about 6 kg of material passing a 20 mm BS test sieve (for soils not susceptible to crushing during compaction), or about 15 kg of material passing a 20 mm BS test sieve (for soils susceptible to crushing during compaction), shall be taken (see Note 2). This portion shall be sieved on a 20 mm BS test sieve and the coarse fraction rejected after its proportion of the total sample has been recorded.

Aggregations of particles shall be broken down so that, if the sample was sieved on a 5 mm BS test sieve, only individual particles would be retained.

(2) *Test 14 (Compaction test using a vibrating hammer).* A portion of the material, prepared as in **1.5.3(5)** and large enough to provide about 30 kg of material passing a 37.5 mm BS test sieve (for soils not susceptible to crushing during compaction), or about 50 kg of material passing a 37.5 mm BS test sieve (for soils susceptible to crushing during compaction), shall be taken (see Note 2). This portion shall be sieved on a 37.5 mm BS test sieve and the coarse fraction rejected after its proportion of the total sample has been recorded.

Aggregations of particles shall be broken down so that, if the sample was sieved on a 5 mm BS test sieve, only individual particles would be retained.

(3) *Tests 15(A), 15(B), 15(C), 15(D), 15(E) and 15(F). (Dry density determinations).* These are site tests for which no sample preparation is required.

(4) *Test 16 (Determination of the California Bearing Ratio).* A portion of the material obtained as specified in **1.5.3(4)** and large enough to provide about 6 kg of material passing a 20 mm BS test sieve for each test, shall be taken. This portion shall be rubbed through a 20 mm BS test sieve and the coarse fraction rejected after its proportion of the total sample has been noted (see Note 9).

(5) *Test 17. (Determination of one-dimensional consolidation), Test 20 (Determination of the unconfined compressive strength using portable apparatus) and Test 21 (Determination of the compressive strength, etc.)* These tests are carried out on undisturbed samples of soil. The preparation of these samples is given under the relevant test procedures.

(6) *Test 18. (Shear strength determination by field vane) and Test 19 (Determination of the penetration resistance using the split-barrel sampler).* These are site tests for which no sample preparation is required.

NOTE 1. The procedure for sampling is not described in this standard. Reference should be made to CP 2001 for details of the methods.
NOTE 2. The soil should be considered susceptible to crushing during compaction if the sample contains granular material of a soft nature, e.g. soft limestone, sandstone, etc., which is reduced in size by the action of the rammer or vibrating hammer.
NOTE 3. Air drying has been specified in the preparation of soil samples for testing since with some soils irreversible changes take place in the soil when it is oven dried at 105 °C to 110 °C. With many soils, however, this effect is of negligible practical significance. Do not oven dry samples to be used for plasticity or pH tests at above 50 °C. Organic soils and certain tropical soils are even affected by air drying and should be used in their natural state.

In the United Kingdom samples may be air dried by leaving them spread out on trays in the laboratory with free access to air for three or four days. Some silts and clays without large particle sizes may be used in their natural state for certain tests instead of being air dried.
NOTE 4. When testing samples of natural soil, if no stones are present in the soil and it practically all passes the 425 µm BS test sieve, it is often convenient to carry out plasticity tests on samples without previously preparing them as described in 1.5.4.2(2). When soils are tested in the natural condition the results will usually differ from those obtained with air dried samples State in the test record that the soil in the natural condition was used.
NOTE 5. Care should be taken to see that test sieves are not overloaded (see Appendix A).
NOTE 6. With granular soils it is necessary to wet sieve through the 425 µm BS test sieve to obtain the fraction required. When this is carried out collect the material and water passing the test sieve and allow to stand. When the water has become substantially clear decant it and air dry the remaining sample as in 1.5.3(5).
NOTE 7. It should be remembered that the recorded proportion passing the 425 µm BS test sieve, will be only approximate as the determination is made with air dried soil.
NOTE 8. Oven drying of the soil has been specified for convenience. If there is any reason to believe that this will change the specific gravity due to loss of water of hydration the soil should be tested in its natural condition and the mass of soil used determined by oven drying at the end of the test.
NOTE 9. If the test is to be made on samples containing larger particles than 20 mm the fraction retained on the 20 mm BS test sieve should be removed. If this does not exceed 25 % of the whole it is unnecessary to make any correction. If the percentage retained on the 20 mm BS test sieve is greater than this, it should be replaced with a similar fraction of 20 mm to 5 mm material from the main sample.

2. Soil classification tests

2.1 Test 1. Determination of the moisture content

2.1.1 Test 1(A). Standard method (oven drying method)

2.1.1.1 *General.* This method covers the determination of the moisture content of soil as a percentage of its dry mass.

2.1.1.2 *Apparatus.* A thermostatically controlled drying oven capable of maintaining a temperature of 105 °C to 110 °C (see Note 1) is required, together with the following:

For fine-grained soils

(1) A glass weighing bottle fitted with a ground glass stopper or cap, or a suitable airtight non-corrodible metal container (a convenient size is 50 mm diameter and 25 mm high).

(2) A balance readable and accurate to 0.01 g.

(3) A desiccator (a convenient size is 200 mm to 250 mm diameter) containing anhydrous silica gel (see Note 2).

For medium-grained soils

(1) An airtight non-corrodible container of about 500 g capacity.

(2) A balance readable and accurate to 0.1 g.

(3) A scoop (a convenient size is one about 200 mm long and 100 mm wide).

For coarse-grained soils

(1) An airtight non-corrodible container of about 3 kg capacity.

(2) A balance readable and accurate to 1 g.

(3) A scoop (a convenient size is one about 200 mm long and 100 mm wide).

2.1.1.3 *Procedure.* The procedures for the various soils are as follows.

(1) *For fine-grained soils*

a. The weighing bottle or container shall be cleaned, dried, and weighed to the nearest 0.01 g (m_1). A sample of at least 30 g of soil shall be crumbled and placed loosely in the container or the weighing bottle, and the lid or stopper shall be replaced. The container or bottle and contents shall then be weighed to the nearest 0.01 g (m_2).

b. The lid or stopper shall then be removed, and the container or bottle with its lid and contents shall be placed in the oven and dried at 105 °C to 110 °C (see Note 3). The period required for drying will vary with the type of soil and the size of sample. The sample shall be deemed to be dry when the differences in successive weighings of the cooled sample (see *c.* and *d.*) at intervals of 4 h, do not exceed 0.1 % of the original mass of the sample (see Note 4). The lid or stopper shall not be replaced while the sample is in the oven.

c. After drying, the container or bottle and contents shall be removed from the oven and the whole placed in the desiccator to cool (see Note 5).

d. The lid shall be replaced and the container or bottle and contents shall then be weighed to the nearest 0.01 g (m_3).

(2) *For medium-grained soils*

a. The container shall be cleaned, dried and weighed to the nearest 0.1 g (m_1). A sample of at least 300 g of soil shall be crumbled and placed loosely in the container, and the lid shall be replaced. The container and contents shall then be weighed to the nearest 0.1 g (m_2).

b. The lid shall then be removed and the container and contents shall be placed in the oven and dried at 105 °C to 110 °C (see Note 3). The period required for drying will vary with the type of soil and the size of sample. The sample shall be deemed to be dry when the differences in successive weighings of the cooled sample (see *c.* and *d.*) at intervals of 4 h do not exceed about 0.1 % of the original mass of the soil (see Note 4). The lid shall not be replaced while the sample is in the oven.

c. After drying, the lid shall be replaced and the whole allowed to cool.

d. The container and contents shall then be weighed to the nearest 0.1 g (m_3).

(3) *For coarse-grained soils*

a. The container shall be cleaned, dried, and weighed to the nearest 1 g (m_1). A sample of at least 3 kg of soil shall be crumbled and placed loosely in the container and the lid replaced. The container and contents shall then be weighed to the nearest 1 g (m_2).

b. The lid shall be removed and the container and contents shall be placed in the oven and dried at 105 °C to 110 °C (see Note 3). The period required for drying will vary with the type of soil and the size of the sample. The sample shall be deemed to be dry when the differences in successive weighings of the cooled sample (see *c.* and *d.*) at intervals of 4 h do not exceed about 0.1 % of the original mass of the soil (see Note 4). The lid shall not be replaced while the sample is in the oven.

c. After drying, the lid shall be replaced and the whole allowed to cool.

d. The container and contents shall then be weighed to the nearest 1 g (m_3).

2.1.1.4 *Calculations**. The moisture content of the soil, w, shall be calculated, as a percentage of the dry soil mass, from the equation:

$$w = \frac{m_2 - m_3}{m_3 - m_1} \times 100\ \%$$

where

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

2.1.1.5 *Reporting of results.* The moisture content of the soil, w, for values up to 10 % shall be reported to two significant figures. For moisture contents above 10 % the result shall be reported to the nearest whole number (see Note 3). The method used to obtain the results shall be stated.

Notes on Test 1(A)

NOTE 1. A microwave oven may be employed provided preliminary tests show that the soil does not exceed a temperature of 110 °C before all the water is driven off. If a microwave oven is used metal containers are not suitable and the soil should be dried in glass, silica or polytetrafluoroethylene (PTFE) evaporating dishes.

NOTE 2. It is preferable to use self-indicating silica gel as the desiccant. Calcium chloride should not be used as it is known that many clays when oven dry are capable of absorbing water from it.

NOTE 3. *Soils containing gypsum.* Certain soils contain gypsum which on heating loses its water of crystallization. The moisture content determined by this method will be affected by approximately 0.2 % for each 1 % of gypsum. If it is suspected that gypsum is present in the soil the moisture content samples should be dried at not more than 80 °C and possibly for a longer time. If the standard conditions are not used, state in the test record the drying conditions used.

NOTE 4. *Drying time of soils.* 16 h to 24 h is usually a sufficient length of time for drying most soils, but certain soil types and large or very wet samples will require longer. The drying time will also depend on the amount of material in the oven.

NOTE 5. If the lids of the containers fit well and it is unlikely that the samples are to be left for a considerable time before weighing, the samples need not be placed in the desiccator to cool, unless glass weighing bottles with ground glass stoppers have been used.

2.1.2 Test 1(B) Subsidiary method (sand bath method)

2.1.2.1 *General.* This method covers the determination of the moisture content of a soil as a percentage of its dry mass. It is intended as a rapid alternative to Test 1(A), but is less accurate and is more suitable as a site test.

*See Form A, Appendix B.

The method shall not be used if it is suspected that the soil contains a large proportion of gypsum, calcareous matter or organic matter.

2.1.2.2 *Apparatus.* The following apparatus is required.

For fine-grained soils

(1) A suitable airtight, non-corrodible metal container, approximately 50 mm in diameter and 25 mm deep.
(2) A balance readable and accurate to 0.1 g.
(3) A sand bath approximately 200 mm diameter and containing clean sand to a depth of at least 25 mm. A larger bath may be used to heat several samples at once.
(4) Equipment for heating the sand bath, e.g. a bottled gas or paraffin pressure stove.
(5) A palette knife (a convenient size is one having a blade 100 mm long and 20 mm wide).

For medium-grained soils

(1) A balance readable and accurate to 0.5 g.
(2) A heat-resistant tray about 200 mm square and about 50 mm deep.
(3) A sand bath containing clean sand to a depth of at least 25 mm and large enough to take the tray. A larger bath may be used to heat several samples at once.
(4) Equipment for heating the sand bath, e.g. a bottled gas or paraffin pressure stove.
(5) A palette knife (a convenient size is one having a blade 100 mm long and 20 mm wide).
(6) A scoop (a convenient size is one about 200 mm long and 100 mm wide).

For coarse-grained soils

(1) A balance readable and accurate to 1 g.
(2) A heat-resistant tray about 250 mm square and 50 mm to 70 mm deep.
(3) A sand bath, containing sand to a depth of at least 25 mm and large enough to take the tray.
(4) Equipment for heating the sand bath, e.g. a bottled gas or paraffin pressure stove.
(5) A palette knife (a convenient size is one having a blade 200 mm long and 30 mm wide).
(6) A scoop (a convenient size is one about 200 mm long and 100 mm wide).

2.1.2.3 *Procedure.* The procedures for the various soils are as follows.

For fine-grained soils

(1) The container shall be cleaned, dried and weighed to the nearest 0.1 g (m_1) (see Note 1). A sample of at least 30 g of soil shall be crumbled and placed loosely in the container, and the lid shall be replaced. The container and contents shall then be weighed to the nearest 0.1 g (m_2).
(2) After the lid has been removed, the container and contents shall be placed on the sand bath, which shall be heated by means of the stove, care being taken not to get the sand bath too hot (see Note 2). During heating, the sample shall be disturbed frequently and thoroughly with the palette knife to assist the evaporation of moisture.
(3) When the container and contents have been heated for a period sufficient to dry out the sample (usually 1 h is sufficient, see Note 3), they shall be removed from the sand bath, the lid replaced and the whole allowed to cool.
(4) The container and contents shall then be weighed to the nearest 0.1 g (m_3).

For medium- and coarse-grained soils

(1) The tray shall be cleaned, dried and weighed to the nearest 0.5 g (m_1). A sample, of at least 300 g for medium-grained, and 2 kg for coarse-grained soils, shall be crumbled and spread out evenly in the tray. The tray and contents shall be weighed to the nearest 0.5 g (m_2) for medium-grained soils, and to the nearest 5 g (m_2) for coarse-grained soils.
(2) The tray shall be placed on the sand bath which shall be heated by means of the stove, care being taken not to get the sand bath too hot (see Note 2). During heating the sample shall be disturbed frequently and thoroughly with the palette knife to assist the evaporation of moisture.
(3) When the tray has been heated for a period sufficient to dry out the sample (usually 1 h is sufficient, see Note 3) it shall be removed from the sand bath and allowed to cool.
(4) Immediately the tray is cool enough to handle, the tray and contents shall be weighed to the nearest 0.5 g for medium-grained soils, and to the nearest 5 g for coarse-grained soils (m_3).

2.1.2.4 *Calculations**. The moisture content of the soil, w, shall be calculated, as a percentage of the dry soil mass, from the equation:

$$w = \frac{m_2 - m_3}{m_3 - m_1} \times 100\ \%$$

where

m_1 is the mass of container (or tray) (g);

m_2 is the mass of container (or tray) and wet soil (g);

m_3 is the mass of container (or tray) and dry soil (g).

2.1.2.5 *Reporting of results.* The moisture content of the soil, w, shall be reported to the nearest whole number. The method used to obtain the results shall be stated.

Notes on Test 1(B)

NOTE 1. It is convenient when many containers are in use to bring them to a standard mass, e.g. 30.0 g, by the addition of solder to the inside of the lid.

NOTE 2. *Avoidance of overheating.* A convenient method of detecting overheating of the soil is by the use of small pieces of white paper mixed with the soil. Overheating is indicated if the paper turns brown.

NOTE 3. *Period of drying.* The drying period will vary with the type of soil, the size of sample and field conditions and it is suggested that when a large number of moisture determinations are to be made with one soil, several measurements should be made using different periods of drying to determine the minimum period required to effect adequate drying. The material shall be deemed to be dry if the additional loss of mass when it is heated for a further period of 15 min does not exceed 0.1 g for fine-grained soils, 0.5 g for medium-grained soils and 5 g for coarse-grained soils.

2.1.3 Test 1(C). Subsidiary method (alcohol method)

2.1.3.1 *General.* This method covers the determination of the moisture content of a soil as a percentage of its dry mass. It is intended as a rapid alternative to Test 1(A) but is less accurate and is more suitable as a site test. Because of the large quantity of methylated spirit required and the consequent risk of fire this method is not advised for use with coarse-grained soils. The method shall not be used if the soil contains a large proportion of clay, gypsum, calcareous matter or organic matter.

2.1.3.2 *Apparatus.* The following apparatus is required.

(1) An evaporating dish, preferably silica (a convenient size is one about 100 mm diameter for fine-grained soils, and about 150 mm diameter for medium-grained soils).

(2) A palette knife (a convenient size is one having a blade 100 mm long and 20 mm wide).

(3) A length of about 200 mm to 250 mm of rod, about 3 mm diameter (see Note).

NOTE. A piece of metal rod has been found to be the most useful means of stirring as the heat generated will soften a palette knife blade and crack a glass rod.

(4) A balance readable and accurate to 0.1 g for fine-grained soils, and 0.5 g for medium-grained soils.

(5) Methylated spirit.

2.1.3.3 *Procedure.* The procedure is as follows.

(1) The evaporating dish shall be cleaned, dried and weighed to the nearest 0.1 g for fine-grained soils, and 0.5 g for medium-grained soils (m_1).

(2) A sample of soil, about 30 g for fine-grained soils, and 300 g for medium-grained soils, shall be placed in the evaporating dish, and the evaporating dish and its contents weighed to the nearest 0.1 g or 0.5 g respectively. (m_2).

(3) A quantity of methylated spirit, about 30 ml for fine-grained soils, and 300 ml for medium-grained soils, shall be poured over the soil so that it is well covered. The methylated spirit shall be worked well into the soil with the palette knife and any large lumps of soil broken up.

(4) The evaporating dish shall be placed on a surface unlikely to be affected by heat and the methylated spirit ignited.

(5) The soil shall be stirred constantly with the piece of rod, care being taken to see that none of the soil is lost.

(6) The dish of soil shall be allowed to cool after the methylated spirit has burnt away completely, and when cool enough to be handled the dish and contents shall be weighed to the nearest 0.1 g for fine-grained, and 0.5 g for medium-grained soils (m_3).

*See Form A, Appendix B.

2.1.3.4 *Calculations**. The moisture content of the soil, w, shall be calculated as a percentage of the dry soil mass, from the equation:

$$w = \frac{m_2 - m_3}{m_3 - m_1} \times 100\,\%$$

where

m_1 is the mass of dish (g);
m_2 is the mass of dish and wet soil (g);
m_3 is the mass of dish and dry soil (g).

2.1.3.5 *Reporting of results.* The moisture content of the soil, w, shall be reported to the nearest whole number. The method used to obtain the results shall be stated.

2.2 Test 2. Determination of the liquid limit

2.2.1 Test 2(A). Preferred method using the cone penetrometer (see Note 1)

2.2.1.1 *General.* This method covers the determination of the liquid limit of the air dried soil. The method may also be used on a sample of soil in its natural state (see Note 2).

2.2.1.2 *Apparatus.* The following apparatus is required.

(1) A flat glass plate (a convenient size is one 10 mm thick and 500 mm square).
(2) Two palette knives (a convenient size is one having a blade 200 mm long and 30 mm wide).
(3) A penetrometer as used in bituminous material testing complying with the requirements of BS 4691, and generally as illustrated in Fig. 4.
(4) A cone of stainless steel or duralumin approximately 35 mm long, with a smooth, polished surface and an angle of 30 ± 1 °. To ensure that the point remains sufficiently sharp for the purposes of the test, the cone should be replaced if after continued use the point can no longer be felt when brushed lightly with the tip of the finger when the tip of the cone is pushed through a hole 1.5 mm in diameter, bored through a metal plate 1.75 ± 0.1 mm thick. The cone is fitted to the penetrometer in the manner shown in Fig. 4 in place of the needle or cone usually used with the apparatus. The mass of the cone together with its sliding shaft is 80.00 ± 0.05 g.
(5) A metal cup approximately 55 mm in diameter and 40 mm deep with the rim parallel to the flat base.
(6) An evaporating dish (a convenient size is one about 150 mm diameter), or a damp cloth.
(7) Apparatus for moisture content determination as described in Test 1(A).
(8) A wash bottle, preferably made of plastics, or a beaker, containing distilled water.
(9) A non-corrodible airtight container.
(10) A metal straightedge.

2.2.1.3 *Procedure.* The procedure is as follows.

(1) A sample weighing at least 200 g shall be taken from the material passing the 425 μm BS test sieve, which has been obtained in accordance with the procedure for the preparation of disturbed soil samples for testing (see 1.5 and Note 2). The proportion of material passing the 425 μm BS test sieve shall be recorded. The sample shall be placed on the flat glass and mixed thoroughly with distilled water using the palette knives until the mass becomes a thick homogeneous paste. This paste shall then be allowed to stand in the airtight container for about 24 h to allow the water to permeate throughout the soil mass (see Note 3).
(2) The sample shall then be removed from the container and remixed for at least 10 min (see Note 4). If necessary further water shall be added so that the first cone penetration reading is approximately 15 mm.
(3) The remixed soil shall be pushed into the cup with a palette knife, taking care not to trap air. The excess soil shall be struck off with the bevelled edge of the straight edge, to give a smooth surface. The cone shall be lowered so that it just touches the surface of the soil (see Fig. 7). When the cone is in the correct position, a slight movement of the cup will just mark the surface of the soil and the reading of the dial gauge shall be noted to the nearest 0.1 mm. The cone shall then be released for a period of 5 ± 1 s. If the apparatus is not fitted with an automatic release and locking device care shall be taken not to jerk the apparatus during these operations. After the cone has been locked in position the dial gauge shall be lowered to the new position of the cone shaft and the reading noted to the nearest 0.1 mm. The difference between the readings at the beginning and end of the test shall be recorded as the cone penetration.
(4) The cone shall be lifted out and cleaned carefully. 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

*See Form A, Appendix B.

2.1.3.4 *Calculations**. The moisture content of the soil, w, shall be calculated as a percentage of the dry soil mass, from the equation:

$$w = \frac{m_2 - m_3}{m_3 - m_1} \times 100\,\%$$

where

m_1 is the mass of dish (g);
m_2 is the mass of dish and wet soil (g);
m_3 is the mass of dish and dry soil (g).

2.1.3.5 *Reporting of results.* The moisture content of the soil, w, shall be reported to the nearest whole number. The method used to obtain the results shall be stated.

2.2 Test 2. Determination of the liquid limit

2.2.1 Test 2(A). Preferred method using the cone penetrometer (see Note 1)

2.2.1.1 *General.* This method covers the determination of the liquid limit of the air dried soil. The method may also be used on a sample of soil in its natural state (see Note 2).

2.2.1.2 *Apparatus.* The following apparatus is required.

(1) A flat glass plate (a convenient size is one 10 mm thick and 500 mm square).
(2) Two palette knives (a convenient size is one having a blade 200 mm long and 30 mm wide).
(3) A penetrometer as used in bituminous material testing complying with the requirements of BS 4691, and generally as illustrated in Fig. 4.
(4) A cone of stainless steel or duralumin approximately 35 mm long, with a smooth, polished surface and an angle of 30 ± 1 °. To ensure that the point remains sufficiently sharp for the purposes of the test, the cone should be replaced if after continued use the point can no longer be felt when brushed lightly with the tip of the finger when the tip of the cone is pushed through a hole 1.5 mm in diameter, bored through a metal plate 1.75 ± 0.1 mm thick. The cone is fitted to the penetrometer in the manner shown in Fig. 4 in place of the needle or cone usually used with the apparatus. The mass of the cone together with its sliding shaft is 80.00 ± 0.05 g.
(5) A metal cup approximately 55 mm in diameter and 40 mm deep with the rim parallel to the flat base.
(6) An evaporating dish (a convenient size is one about 150 mm diameter), or a damp cloth.
(7) Apparatus for moisture content determination as described in Test 1(A).
(8) A wash bottle, preferably made of plastics, or a beaker, containing distilled water.
(9) A non-corrodible airtight container.
(10) A metal straightedge.

2.2.1.3 *Procedure.* The procedure is as follows.

(1) A sample weighing at least 200 g shall be taken from the material passing the 425 μm BS test sieve, which has been obtained in accordance with the procedure for the preparation of disturbed soil samples for testing (see 1.5 and Note 2). The proportion of material passing the 425 μm BS test sieve shall be recorded. The sample shall be placed on the flat glass and mixed thoroughly with distilled water using the palette knives until the mass becomes a thick homogeneous paste. This paste shall then be allowed to stand in the airtight container for about 24 h to allow the water to permeate throughout the soil mass (see Note 3).
(2) The sample shall then be removed from the container and remixed for at least 10 min (see Note 4). If necessary further water shall be added so that the first cone penetration reading is approximately 15 mm.
(3) The remixed soil shall be pushed into the cup with a palette knife, taking care not to trap air. The excess soil shall be struck off with the bevelled edge of the straight edge, to give a smooth surface. The cone shall be lowered so that it just touches the surface of the soil (see Fig. 7). When the cone is in the correct position, a slight movement of the cup will just mark the surface of the soil and the reading of the dial gauge shall be noted to the nearest 0.1 mm. The cone shall then be released for a period of 5 ± 1 s. If the apparatus is not fitted with an automatic release and locking device care shall be taken not to jerk the apparatus during these operations. After the cone has been locked in position the dial gauge shall be lowered to the new position of the cone shaft and the reading noted to the nearest 0.1 mm. The difference between the readings at the beginning and end of the test shall be recorded as the cone penetration.
(4) The cone shall be lifted out and cleaned carefully. 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

*See Form A, Appendix B.

1 mm different from the first a third test shall be carried out. If the overall range is then not more than 1 mm a moisture content sample (about 10 g) shall be taken from the area penetrated by the cone and the moisture content determined as described in Test 1(A). The average of the three penetrations shall be recorded. 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.

(5) The operation described in **2.2.1.3**(3) and **2.2.1.3**(4) shall be repeated at least four times using the same sample to which further increments of distilled water have been added. The amount of water added shall be chosen so that a range of penetration values of approximately 15 mm to 25 mm is covered (see Note 5).

2.2.1.4 *Calculations**. The relationship between the moisture content and the cone penetration shall be plotted

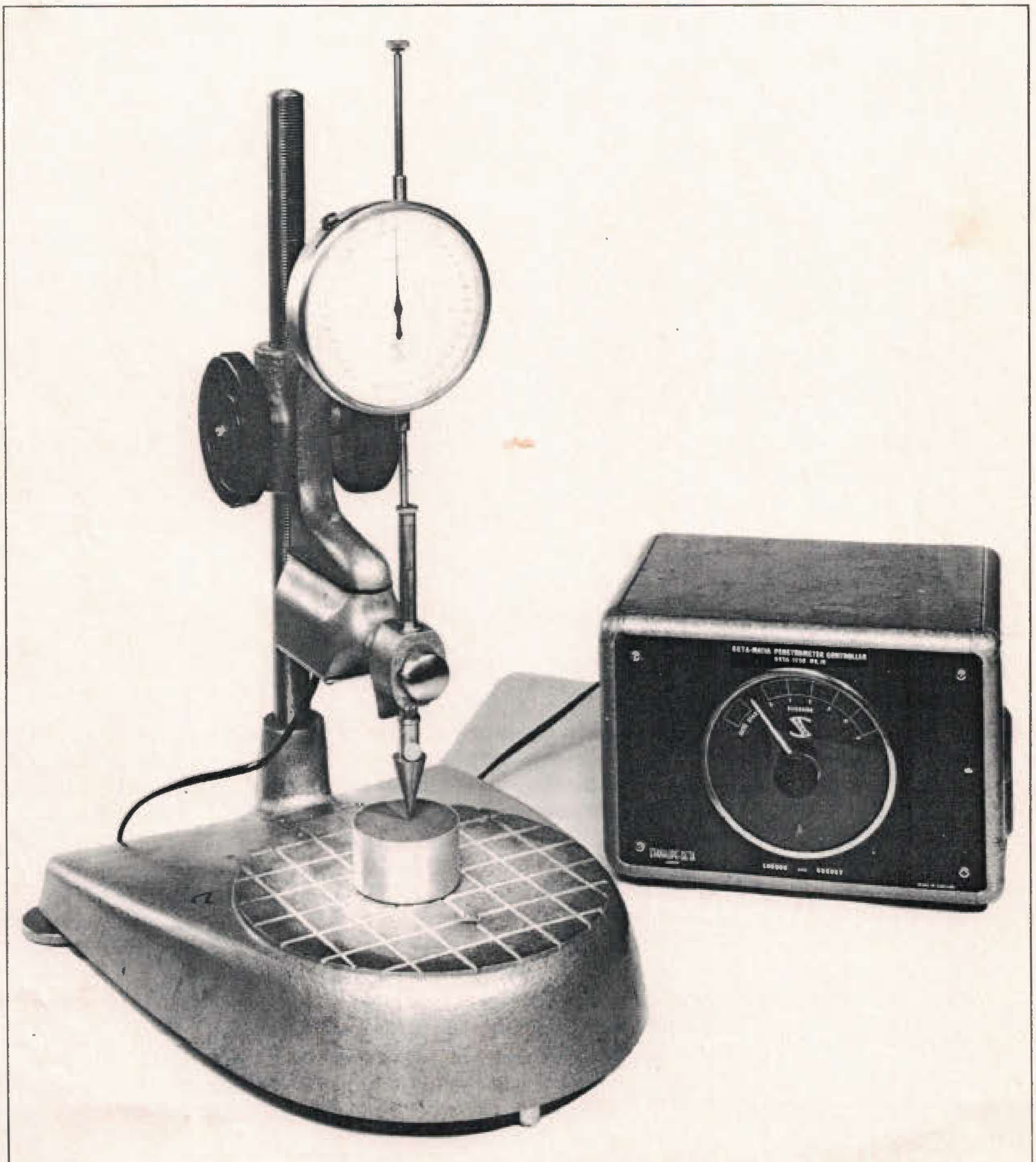


Fig. 4. Cone penetrometer used for the determination of the liquid limit of soils

with the percentage moisture contents as abscissae and the cone penetrations as ordinates, both on linear scales. The best straight line fitting the plotted points shall be drawn through them.

2.2.1.5 *Reporting of results.* The moisture content corresponding to a cone penetration of 20 mm shall be taken as the liquid limit of the soil and shall be expressed to the nearest whole number. The method of obtaining the liquid limit shall be stated, i.e. using the cone penetrometer. The percentage of material passing the 425 µm BS test sieve shall be noted. The history of the sample shall also be noted, i.e. natural state, air dried, or unknown.

Notes on Test 2(A)

NOTE 1. The method using the cone penetrometer is preferred to that employing the Casagrande apparatus (see Test 2(B)), as the test is both easier to carry out and is capable of giving more reproducible results. The cone penetrometer apparatus is easier to maintain in correct adjustment and the test procedure is less dependent on the judgment of the operator. The results obtained with the cone penetrometer may differ very slightly from those with the Casagrande apparatus, but in most cases these differences will not be significant and will be less than the normal variations likely to be obtained using the Casagrande apparatus.

NOTE 2. *The testing of samples of natural soil.* When nearly all the soil is likely to pass the 425 µm BS test sieve it is often convenient to remove the few coarse particles present by hand during mixing, and then test the sample without previously preparing it as described in 1.5. When soils are tested in the natural condition the results will usually differ from those obtained with air dried samples. Organic soils and certain tropical soils should be tested in their natural condition. State on the test report that the soil in the natural condition was used.

NOTE 3. A curing period of 24 h is recommended for most soils but for soils of low clay content it may not be necessary to cure for this length of time and the test can be made immediately after mixing.

NOTE 4. Certain soils may require as much as 40 min of continuous mixing immediately before testing to obtain reliable results.

NOTE 5. The test should always proceed from the drier to the wetter condition of the soil. Each time the soil is removed from the cup for the addition of water, the cup and the cone should be cleaned thoroughly and dried.

2.2.2 Test 2(B). Method using the Casagrande apparatus (see Note 1)

2.2.2.1 *General.* This method covers the determination of the liquid limit of the air dried soil. The method may also be used on a sample of soil in its natural state (see Note 2).

2.2.2.2 *Apparatus.* The following apparatus is required.

(1) A flat glass plate (a convenient size is one 10 mm thick and 500 mm square).
(2) Two palette knives (a convenient size is one having a blade 200 mm long and 30 mm wide).
(3) A mechanical device complying with the essential details illustrated in Fig. 5 (see Note 3).
(4) A grooving tool and gauge complying with the essential details illustrated in Fig. 6.
(5) An evaporating dish (a convenient size is one about 150 mm diameter), or a damp cloth.
(6) Apparatus for moisture content determination as described in Test 1(A).
(7) A wash bottle, preferably made of plastics, or a beaker, containing distilled water.
(8) A non-corrodible airtight container large enough to take about 200 g to 250 g of wet soil.

2.2.2.3 *Adjustment of apparatus.* The liquid limit device shall be inspected to determine that the device is clean, dry and in good working order so that the cup falls freely and does not have too much side play at its hinge. The grooving tool shall also be inspected to determine that it is clean, dry and that the critical dimensions are as shown in Fig. 6 (see Note 4).

The height to which the cup of the liquid limit device is lifted shall be adjusted so that when the cup is raised to its maximum height the 10 mm gauge will just pass between it and the base.

2.2.2.4 *Procedure.* The procedure is as follows.

(1) A sample weighing at least 200 g shall be taken from the material passing the 425 µm BS test sieve, which has been obtained in accordance with the procedure for the preparation of disturbed soil samples for testing (see 1.5). The proportion of material passing the 425 µm BS test sieve shall be recorded. This sample shall be placed on the flat glass plate and mixed thoroughly with distilled water using the palette knives until the mass becomes a thick homogeneous paste. This paste shall then be allowed to stand in the airtight container for about 24 h to allow the water to permeate throughout the soil mass (see Note 5).

(2) The sample shall then be removed from the container and remixed for at least 10 min (see Note 6).

A portion of the remixed soil shall be placed in the cup (the cup resting on the base) levelled off parallel to the base, and divided by drawing the grooving tool along the diameter through the centre of the hinge, at the same time holding it normal to the surface of the cup with the chamfered edge facing in the direction of movement (see Note 7). By turning the crank at the rate of two revolutions per second, the cup shall be lifted and dropped until the two parts of the soil come into contact at the bottom of the groove along a distance of 13 mm (see Note 8). This length shall be measured with the end of the grooving tool or a ruler. The number of blows at which this occurs shall be recorded.

(3) A little extra of the soil mixture shall be added to the cup and mixed with the soil in the cup.

(4) Operations (2) and (3) shall be repeated until two consecutive runs give the same number of blows for closure (see Notes 9 and 10).

(5) A quantity of soil (about 10 g) from the portions of the sample that have just flowed together shall be removed with a spatula and placed in a suitable container, and the moisture content determined by Test 1(A).

(6) Operations (2) to (5) shall be carried out at least four times using the same sample to which further increments of distilled water have been added. The moisture contents chosen or the amount of water added shall be such that when the moisture contents are plotted they are evenly distributed over a range between 50 and 10 blows. The test shall always proceed from the drier to the wetter condition of the soil. Each time the soil is removed from the cup for the addition of more water the cup and the grooving tool shall be washed and dried.

(7) If at any time during the above procedure the soil has to be left for a while on the glass plate it shall be covered with the evaporating dish or damp cloth to prevent it drying out.

2.2.2.5 *Calculations**. The relationship between the moisture content and the corresponding number of blows shall be plotted on a semi-logarithmic chart, with the percentage moisture contents as ordinates on the linear scale and the number of blows as abscissae on the logarithmic scale. The best straight line fitting the plotted points shall be drawn through them.

2.2.2.6 *Reporting of results.* The moisture content corresponding to the intersection of the flow curve with the 25 blows abscissa shall be taken as the liquid limit (LL) of the soil and shall be expressed to the nearest whole number. The method of obtaining the liquid limit shall be stated, i.e. using the Casagrande apparatus.

The percentage of material passing the 425 µm BS test sieve shall be noted. The history of the sample shall also be noted, i.e. natural state, air dried or unknown.

Notes on Test 2(B)

NOTE 1. The method using the Casagrande apparatus has been the accepted procedure for determining the liquid limit but experience has shown that it is difficult to maintain the apparatus in accordance with the standard and the results are subject to the judgement of the operator. For these reasons the method using the cone penetrometer is to be preferred, but provided that care is taken to ensure that the Casagrande apparatus is correctly maintained and the test procedure is strictly adhered to satisfactory results can be obtained. The results obtained using the Casagrande apparatus may differ slightly from those using the cone penetrometer method but in most cases these differences will not be significant and will be less than the normal variations likely to be obtained using the Casagrande apparatus.

NOTE 2. *The testing of samples of natural soil.* When nearly all the soil is likely to pass the 425 µm BS test sieve it is often convenient to remove the few coarse particles present by hand during mixing and then test the sample without previously preparing it as described in 1.5. When soils are tested in the natural condition the results will usually differ from those obtained with air dried samples. Organic soils and certain tropical soils should be tested in their natural condition. State on the test record that the soil in the natural condition was used.

NOTE 3. *Specification of the base.* Make the base of the liquid limit apparatus of four equal vulcanized rubber laminations giving a total thickness of 50 mm. The hardness of each rubber lamination measured on the full thickness, but otherwise as in BS 903: Part A26 (1969) shall be 84 IRHD to 94 IRHD at 20 ± 2 °C and the resilience measured with a Lupke pendulum as in BS 903: Part A8 (1963) shall be 20 % to 35 % at 20 ± 2 °C. The laminations shall be adequately bonded together and shall be made basically as in BS 1154, compound number Z16, with the necessary variations to give the required physical characteristics. A single block of rubber having the same dimensions may be used providing the specified hardness and resilience of the rubber is uniform throughout the block.

NOTE 4. *Wear on the grooving tool.* Withdraw the grooving tool from use when the tip has worn to a width of 3 mm and reshape to the proper dimension, 2 mm. It may be found useful to have a standard check gauge of the correct dimension against which the tool can be checked.

NOTE 5. A curing period of 24 h is recommended for most soils, but for soils of low clay content it may not be necessary to cure for this length of time and the test can be made immediately after mixing.

NOTE 6. Certain soils may require as much as 40 min of continuous mixing immediately before testing, to obtain reliable results.

NOTE 7. With soils having low plasticity indices it is sometimes difficult to cut a smooth groove in the soil with the grooving tool specified. Hitherto an alternative tool (the A.S.T.M. type tool) has been recommended for use with such soils but it is considered that its action in cutting the groove is not correct. The usual action of the tool is that of the insertion of a wedge into the pat of soil causing the two halves of the pat to slide at the cup-soil face. During the test the tendency is then for the soil to slide back again on this same face instead of flowing as it should do.

It does not necessarily follow that because a smooth groove cannot be obtained, the soil is non-plastic and it should be recorded that the liquid limit could not be obtained.

NOTE 8. Sometimes the soil flows so as to leave a gap between two areas of contact. The test should continue until there is a length of continuous contact for 13 mm.

NOTE 9. Some soils tend to slide on the surface of the cup instead of the soil flowing. If this occurs the result should be discarded and the test repeated until flowing does occur. If, after additional increments of water, sliding still occurs, the test is not applicable and a note should be made that the liquid limit could not be obtained.

NOTE 10. Care should be taken to see that the sample does not dry out between repeat tests as the number of blows for closure will increase gradually as the samples dries out.

2.2.3 Test 2(C). One point method using the Casagrande apparatus (see Note 1)

2.2.3.1 *General.* This method covers the determination of the liquid limit of the soil. The advantage of the method is speed, since it involves taking one measurement of the moisture content only.

2.2.3.2 *Apparatus.* The apparatus required for this test is the same as that for Test 2(B).

2.2.3.3 *Adjustment of apparatus.* The liquid limit device shall be inspected to determine that it is in good working order, that the cup falls freely and that it does not have too much side play at its hinge. The grooving tool shall be

*See Form C, Appendix B.

inspected to determine that the critical dimensions are as shown in Fig. 6 (see Note 2).

The height to which the cup of the liquid limit device is lifted shall be adjusted so that when the cup is raised to its maximum height the 10 mm gauge will just pass between it and the base.

2.2.3.4 *Procedure.* The procedure is as follows.

(1) A sample which has been obtained in accordance with the procedure for the preparation of disturbed samples for testing (see 1.5), weighing at least 50 g, shall be taken from the material passing the 425 µm BS test sieve (see Notes 3 and 4). The proportion passing the 425 µm BS test sieve shall be recorded. This sample shall be placed on the flat glass plate and mixed thoroughly with distilled water using the palette knives until the mass becomes a thick homogeneous paste at a moisture content as near as possible to that corresponding to the 25 blows value (see Notes 5 and 6). This may be checked with the liquid limit machine until experience with the soils under test renders this step unnecessary. The mixing shall be carried out for at least 10 min.

(2) The sample shall then be placed in the airtight container and stored for at least 24 h at normal room temperature (see Note 7).

(3) Immediately before testing, the soil shall be removed from the airtight container and remixed for at least 1 min.

(4) A portion of the soil-water mixture shall be placed in the cup (the cup resting on the base) levelled off parallel to the base, and divided by drawing the grooving tool along the diameter through the centre of the hinge, at the same time holding it normal to the surface of the cup with the chamfered edge facing in the direction of movement (see Note 8). By turning the crank at the rate of two revolutions per second, the cup shall be lifted and dropped until the two parts of the soil come into contact at the bottom of the groove along a distance of 13 mm (see Notes 9 and 10). This length shall be measured with the end of the grooving tool or a ruler. The number of blows at which this occurs shall be recorded. The number shall be between 15 and 35 blows.

(5) A little extra of the soil mixture shall be added to the cup and mixed with the soil in the cup.

(6) Operations (4) and (5) shall be repeated until two consecutive runs give the same number of blows for closure (see Note 11).

(7) The soil shall then be removed from the cup, placed in a suitable container and the moisture content determined as in Test 1(A).

2.2.3.5 *Calculations.* The liquid limit shall be calculated by multiplying the moisture content obtained by the factor corresponding to the number of blows obtained in the test. The factors are given in the following table.

Number of blows	Factor	Number of blows	Factor	Number of blows	Factor	Number of blows	Factor
15	0.95	21	0.98	26	1.00	31	1.02
16	0.96	22	0.99	27	1.01	32	1.02
17	0.96	23	0.99	28	1.01	33	1.02
18	0.97	24	0.99	29	1.01	34	1.03
19	0.97	25	1.00	30	1.02	35	1.03
20	0.98						

2.2.3.6 *Reporting of results.* The liquid limit calculated as above shall be expressed to the nearest whole number. The percentage of material passing the 425 µm BS test sieve shall be noted.

The history of the sample shall also be noted, i.e. natural state, air dried or unknown. The method used to obtain the result shall also be stated, i.e. one point method using the Casagrande apparatus.

Notes on Test 2(C)

NOTE 1. The one point method using the Casagrande apparatus has the advantage of speed but the results are likely to be less reliable than those obtained using the procedure given in Tests 2(A) or 2(B). The method is therefore suitable where speed of test is important and a possibly less accurate result is acceptable.

NOTE 2. *Wear on grooving tool.* Withdraw the grooving tool from use when the tip has worn to a width of 3 mm and reshape to the proper dimension, 2 mm. It may be found useful to have a standard check gauge of the correct dimension against which the tool can be checked.

NOTE 3. If it is suspected that the liquid limit is above about 120 % the procedure given in Tests 2(A) and 2(B) should be carried out using a 200 g sample.

NOTE 4. When nearly all the soil is likely to pass the 425 µm BS test sieve it is often convenient to remove the few coarse particles present during mixing and then to test the sample without previously preparing it as described in 1.5. When soils are tested in the natural condition the results will usually differ from those obtained with air dried samples. Organic soils and certain tropical soils should be tested in their natural condition. State on the test record that soil in the natural condition was used.

NOTE 5. As can be seen from the table of correction factors, the nearer the moisture content is to that at 25 blows the less the error due to the variation of the slope of the flow line from the slope of the calculated line which is obtained from the equation:

$$LL = w\left(\frac{n}{25}\right)^{\tan B}$$

where

LL is the liquid limit (%)

w is the moisture content (%) corresponding to n blows;

$\tan B$ = 0.092 (the slope of the calculated flow line for British soils).

NOTE 6. The amount of distilled water added should be such that the number of blows is less rather than more than 25 as during storage some moisture tends to evaporate on to the sides of the container causing the soil to be drier when actually tested.

NOTE 7. A curing period of 24 h is recommended for most soils, but for soils of low clay content it may not be necessary to cure for this length of time and the test can be made immediately after mixing.

NOTE 8. With soils having low plasticity indices it is sometimes difficult to cut a smooth groove in the soil with the grooving tool specified. Hitherto an alternative tool (A.S.T.M. type tool) has been recommended for use with such soils but it is considered that its action in cutting the groove is not correct. The usual action of the tool is that of the insertion of a wedge into the pat of soil causing the two halves of the pat to slide at the cup-soil face. During the test the tendency is then for the soil to slide back again on this same face instead of flowing as it should do.

It does not necessarily follow that because a smooth groove cannot be obtained, the soil is non-plastic and it should be recorded that the liquid limit could not be obtained.

NOTE 9. Some soils tend to slide on the surface of the cup instead of the soil flowing. If this occurs the result should be discarded and the test repeated until the flowing does occur. If, after additional increments of water, sliding still occurs, the test is not applicable and a note should be made that the liquid limit could not be obtained.

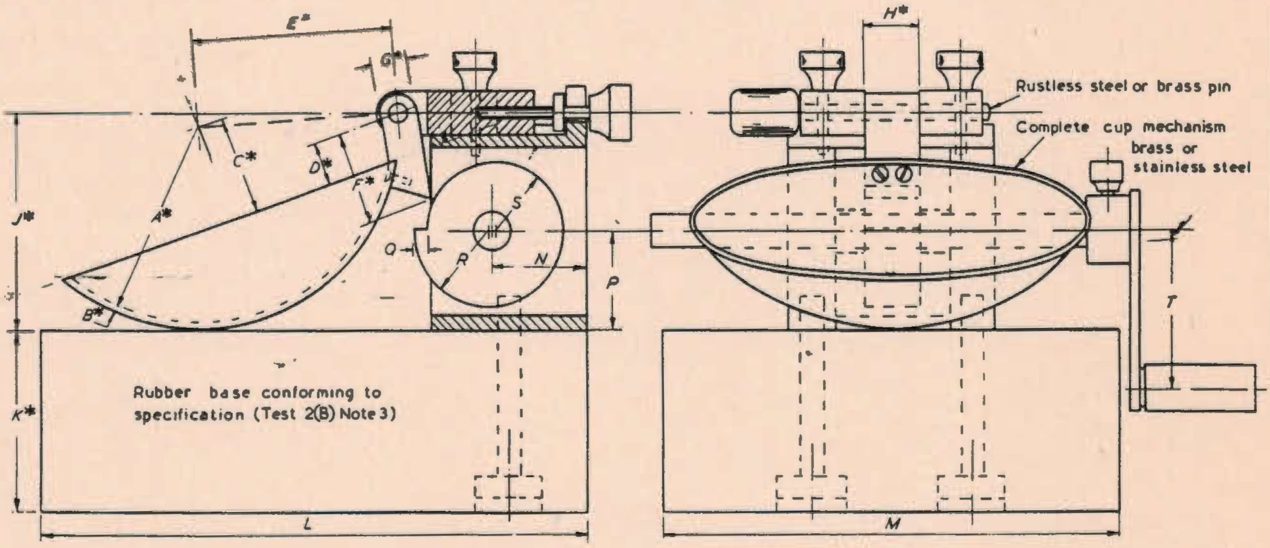
NOTE 10. Sometimes the soil flows so as to leave a gap between two areas of contact. The test should continue until there is a length of continuous contact for 13 mm.

NOTE 11. Care should be taken to see that the sample does not dry out between the repeat tests as the number of blows for closure will increase gradually as the sample dries out.

Dimensions

Letter	*A*	*B*	*C*	*D*	*E*	*F*	*G*
mm	54 ± 0.5	2 ± 0.5	27 ± 0.5	12.5 ± 0.5	56 ± 0.5	25 ± 0.5	10 ± 0.5

Letter	*H*	*J*	*K*	*L*	*M*	*N*	*P*	*Q*	*R*	*S*	*T*
mm	16 ± 0.5	60 ± 0.5	50 ± 0.5	150	130	27	28	6	22	19	45

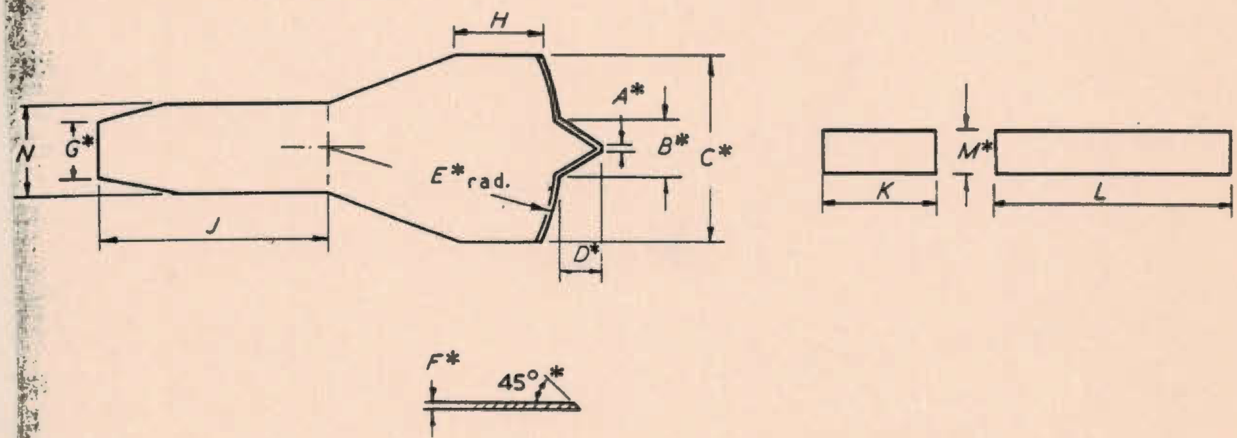


This design has been found satisfactory, but alternative designs may be employed provided that the essential requirements are fulfilled. (Essential dimensions are indicated by an asterisk.)

Fig. 5. Casagrande liquid limit apparatus

Dimensions

Letter	A	B	C	D	E	F	
mm	2 ± 0.25	11 ± 0.25	40 ± 0.5	8 ± 0.25	50 ± 0.5	1.5 ± 0.1	
Letter	G	H	J	K	L	M	N
mm	13 ± 0.5	20	50	25	50	10 ± 0.25	20



This design has been found satisfactory, but alternative designs may be employed provided that the essential requirements are fulfilled. (Essential dimensions are indicated by an asterisk.)

Fig. 6. Grooving tool and height gauge (brass or stainless steel)

2.3 Test 3. Determination of the plastic limit

2.3.1 General. This method covers the determination of the lowest moisture content at which the soil is plastic. The method may also be used on a sample of soil in its natural state (see Note 1).

2.3.2 Apparatus. The following apparatus is required.

(1) A flat glass plate (a convenient size is one 10 mm thick and 500 mm square).

(2) Two palette knives (a convenient size is one having a blade 200 mm long and 30 mm wide).

(3) Apparatus for the moisture content determination of fine-grained soils as described in **2.1.1.2**.

(4) A length of metal rod 3 mm in diameter and about 100 mm long (optional).

2.3.3 Procedure. The procedure is as follows.

(1) A sample weighing about 20 g shall be taken from the material passing the 425 µm BS test sieve, which has been obtained in accordance with the procedure for the preparation of disturbed soil samples for testing (see **1.5**). The proportion of material passing the 425 µm BS test sieve shall be recorded. The air dried soil shall be mixed thoroughly with distilled water on the glass plate until it becomes homogeneous and plastic enough to be shaped into a ball (see Note 2).

(2) The ball of soil shall be moulded between the fingers and rolled 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. From this sample, two subsamples of about 10 g each shall be weighed and a separate determination carried out on each. Each subsample shall be divided into four approximately equal parts and each part treated as specified in (3).

(3) The soil shall be formed into a thread, about 6 mm in diameter, between the first finger and thumb of each hand. The thread shall be rolled between the tips of the fingers of one hand and the surface of the glass plate (see Fig. 7). The pressure shall be sufficient to reduce the diameter of the thread to about 3 mm in five to ten complete (forward and back) movements of the hand. (Some heavy clays will require 10 to 15 movements when the soil is near the plastic limit, as the soil hardens at this stage.) It is important to maintain uniform rolling pressure throughout the test; it is not correct to reduce the pressure as the thread diameter approaches 3 mm. The soil shall be picked up and moulded between the fingers to dry the soil further. The soil shall be formed into a thread and rolled out again. This procedure shall be repeated until the thread shears both longitudinally

and transversely when it has been rolled to about 3 mm in diameter. The metal rod may be used to gauge this diameter. (It is sometimes possible to gather the pieces of soil together after they have crumbled, and to reform a thread and continue rolling under slight pressure. This shall not be done. The first crumbling point is the plastic limit.)

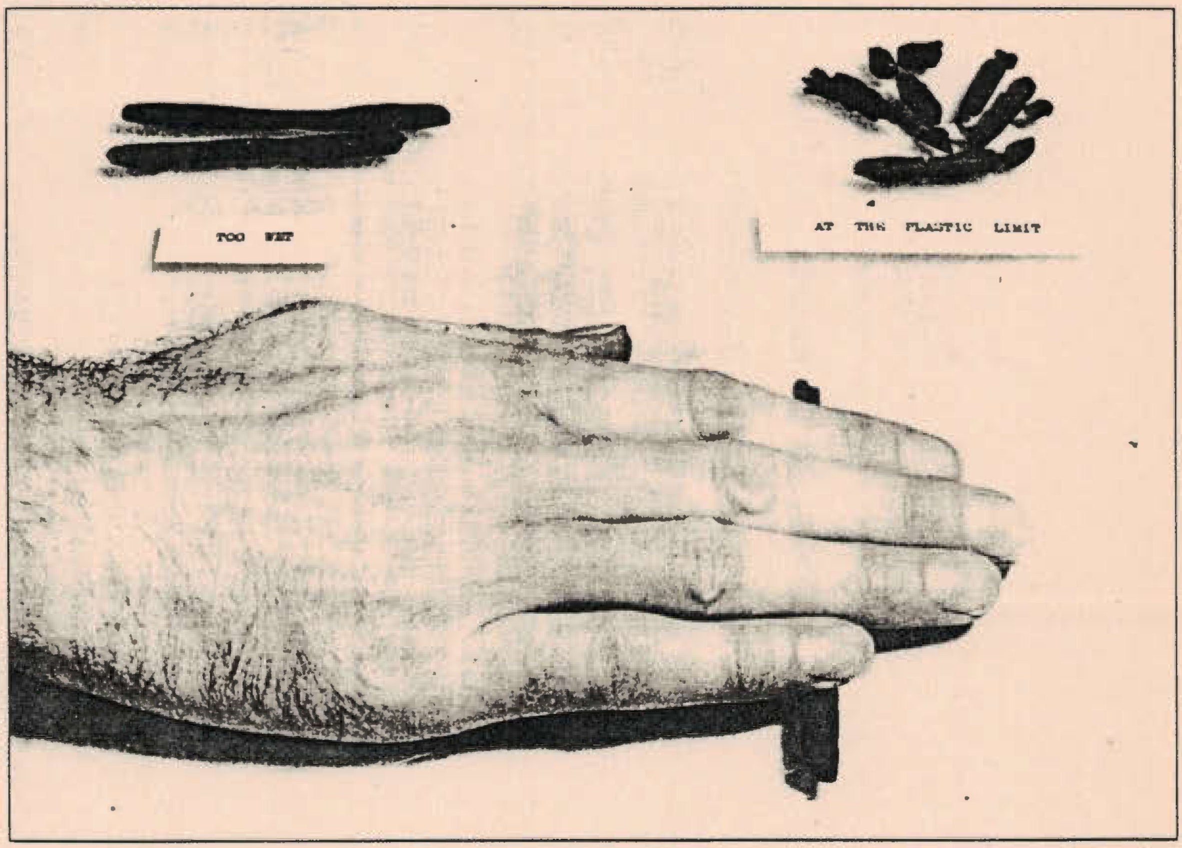


Fig. 7. Determination of the plastic limit

(4) The portions of the crumbled soil thread shall be gathered together and transferred immediately to the container. The other three pieces of soil shall be treated similarly and placed in the same container. The container shall only remain open while the crumbled soil is being placed in it. The moisture content of the soil shall be determined as in Test 1(A)*.

(5) The other duplicate sample shall be treated similarly, so that two completely separate determinations are made.

2.3.4 **Reporting of results.** The average of the moisture contents determined in 2.3.3 shall be taken as the plastic limit (PL) of the soil and shall be expressed to the nearest whole number. If the two results differ by more than 0.5 % moisture content, the test shall be repeated. The percentage of material passing the 425 μm BS test sieve shall be noted. The history of the sample shall also be noted, i.e. natural state, air dried or unknown.

Notes on Test 3

NOTE 1. When nearly all the soil is likely to pass the 425 μm BS test sieve it is often convenient to remove the few coarse particles present by hand during mixing and then to test the sample without previously preparing it as described in 1.5. When the soils are tested in the natural condition the results will usually differ from those obtained with air dried samples. Organic soils and certain tropical soils should be tested in their natural condition. State on the test record that soil in the natural condition was used.

NOTE 2. When the liquid limit test is carried out on a soil in the natural state it is convenient to put aside a little of the thoroughly mixed material for the determination of the plastic limit. This soil shall be used as in 2.3.3 except that, in cases where it is initially too wet, it shall be allowed to dry in air until the required consistency is obtained.

*Form B or C, Appendix B.

2.4 Test 4. Determination of the plasticity index

2.4.1 General. This method covers the determination of the plasticity index of a soil.

2.4.2 Procedure. The liquid limit (LL) and plastic limit (PL) shall be determined by the procedures given in 2.2 and 2.3 respectively.

2.4.3 Calculations. The plasticity index (PI) shall be calculated from the equation:

$$PI = LL - PL$$

2.4.4 Reporting of results. The numerical difference calculated shall be reported as the plasticity index (PI) except that when the plastic limit cannot be determined or when the plastic limit is equal to or greater than the liquid limit, the material shall be reported as non-plastic (NP).

2.5 Test 5. Determination of the linear shrinkage

2.5.1 General. This method covers the determination of the linear shrinkage of soils.

2.5.2 Apparatus. The following apparatus is required.

(1) Two palette knives (a convenient size is one having a blade about 100 mm long and 20 mm wide).

(2) A flat glass plate (a convenient size is one 10 mm thick and 500 mm square) or an evaporating dish approximately 150 mm diameter.

(3) A mould made of brass, or other suitable material of the type illustrated in Fig. 8 (see Note 1).

(4) Silicone grease.

(5) An oven capable of maintaining temperatures of 60 °C to 65 °C and 105 °C to 110 °C.

(6) A means of measuring a length of up to 150 mm to within 0.5 mm.

2.5.3 Procedure. The procedure is as follows.

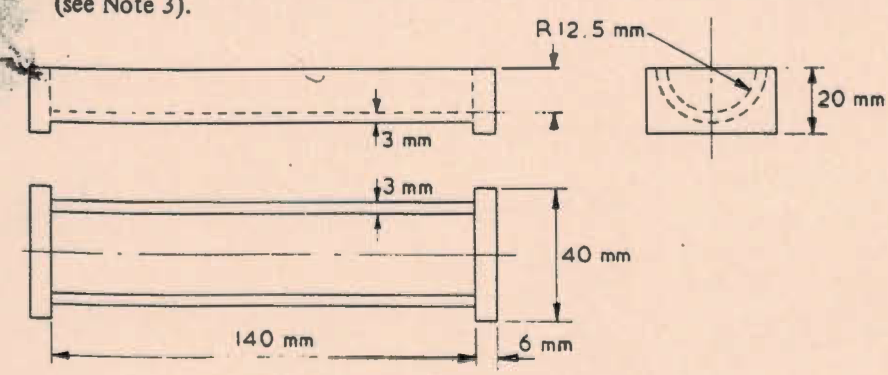
(1) The mould shall be cleaned thoroughly and a thin film of silicone grease shall then be applied to its inner walls in order to prevent the soil from adhering to the mould.

(2) A soil sample weighing about 150 g shall be taken from the material passing the 425 μm BS test sieves which has been obtained in accordance with the procedure for the preparation of disturbed soil samples for testing (see 1.5). The proportion of material passing the 425 μm BS test sieve, expressed as a percentage of the total mass of dry soil, shall be recorded. The sample shall be placed on the flat glass plate and mixed thoroughly with distilled water using the palette knives until the mass becomes a smooth homogeneous paste, with a moisture content approximating to the liquid limit of the soil (see Note 2).

(3) Soil-water mixture shall be placed in the mould such that it is slightly proud of the sides of the mould. The mould shall then be gently jarred to remove any air pockets in the mixture. The soil shall then be levelled off along the top of the mould with the palette knife. All soil adhering to the rim of the mould shall be removed by wiping with a damp cloth.

(4) The mould shall be placed so that the soil-water mixture can air dry slowly in a position free from draughts until the soil has shrunk away from the walls of the mould, drying can then be completed first at a temperature of 60 °C to 65 °C until shrinkage has largely ceased, and then at 105 °C to 110 °C to complete the drying.

(5) The mould and soil shall then be cooled and the mean length of the soil bar measured. If the specimen has become curved during drying it shall be removed carefully from the mould and the lengths of the top and bottom surfaces measured. The mean of these two lengths shall be taken as the length of the oven dry specimen (see Note 3).



Material: non-ferrous

This design has been found satisfactory, but alternative designs may be employed provided that the essential requirements are fulfilled (see Note 1).

Fig. 8. Mould for linear shrinkage test

2.5.4 Calculations*. The linear shrinkage of the soil shall be calculated as a percentage of the original length of the specimen from the equation:

$$\text{Percentage of linear shrinkage} = \left(1 - \frac{\text{Length of oven dry specimen}}{\text{Initial length of specimen}}\right) \times 100$$

2.5.5 Reporting of results. The linear shrinkage of the soil shall be reported to the nearest whole number together with the proportion of soil that passes the 425 μm BS test sieve. The history of the sample shall also be noted, i.e. natural state, air dried or unknown.

Notes on Test 5

NOTE 1. The mould may conveniently be made from 3 mm thick brass tube of 25 mm internal diameter, cut in half to form a semi-cylindrical trough. The ends of 6 mm flat brass are brazed on.
NOTE 2. This moisture content is not critical to within a few per cent.
NOTE 3. Should a specimen crack badly, or break, such that measurement is difficult, the test should be repeated at a slower drying rate.

2.6 Test 6. Determination of the specific gravity of soil particles

2.6.1 Test 6(A). Method for fine-, medium- and coarse-grained soils

2.6.1.1 *General.* This method covers the determination of the specific gravity of soil particles. It is not suitable for soils containing more than 10 % of stones retained on a 37.5 mm BS test sieve and such stones should be broken down to less than this size.

2.6.1.2 *Apparatus.* The following apparatus is required.

(1) A gas jar, 1 litre in capacity, fitted with a rubber bung (see Fig. 9).
(2) A ground glass plate for closing the gas jar (see Fig. 9).
(3) A mechanical shaking apparatus capable of rotating the gas gar, end over end, at about 50 rev/min. (see Note 2).
(4) A balance readable and accurate to 0.2 g.
(5) A thermometer to cover the temperature range 0 °C to 50 °C, readable and accurate to 1 °C.

2.6.1.3 *Procedure.* The procedure is as follows.

(1) A sample weighing 200 g in the case of fine-grained soil and 400 g in the case of medium- and coarse-grained soils shall be obtained in accordance with the procedure for the preparation of disturbed soil samples for testing (see 1.5). This sample shall have been oven dried (see Note 3) and then stored in an airtight container until required.
(2) The gas jar and ground glass plate shall be dried and weighed to the nearest 0.2 g (m_1).
(3) Approximately 200 g of fine-grained soil or 400 g of medium- or coarse-grained soil shall be introduced into the gas jar directly from the container in which it has been cooled. The gas jar, ground glass plate and contents shall be weighed to the nearest 0.2 g (m_2).
(4) Approximately 500 ml of water at a temperature within ± 2 °C of the average room temperature during the test (see Note 4) shall be added to the soil. The rubber stopper shall then be inserted into the gas jar and in the case of medium- and coarse-grained soils the gas jar and contents shall be set aside for at least 4 h. At the end of this period, or immediately after the addition of water in the case of fine-grained soils, the gas jar shall be shaken by hand until the particles are in suspension and then placed in the shaking apparatus and shaken for a period of 20 min to 30 min.

The stopper shall then be removed carefully and any soil adhering to the stopper or the top of the gas jar shall be washed carefully into the jar; any froth that has formed shall be dispersed with a fine spray of water. Water shall then be added to the gas jar to within 2 mm of the top. The soil shall be allowed to settle for a few minutes and the gas jar then filled to the brim with more water. The ground glass plate shall then be placed on the top of the jar taking care not to trap any air under the plate. The gas jar and plate shall then be carefully dried on the outside and the whole weighed to the nearest 0.2 g (m_3).
(5) The gas jar shall be emptied, washed out thoroughly, and filled completely to the brim with water. The glass plate shall be placed in position taking care not to trap any air under the plate. The gas jar and plate shall then be dried carefully on the outside and the whole weighed to the nearest 0.2 g (m_4).
(6) The procedure outlined in (1) to (4) shall be repeated on a second sample of the same soil so that two values for specific gravity are obtained.

*See Form D, Appendix B.

2.6.1.4 *Calculations**. The specific gravity, G_s, of the soil particles shall be calculated from the quation:

$$G_s = \frac{m_2 - m_1}{(m_4 - m_1) - (m_3 - m_2)}$$

where

m_1 is the mass of gas jar and ground glass plate (g);
m_2 is the mass of gas jar, plate and soil (g);
m_3 is the mass of gas jar, plate, soil and water (g);
m_4 is the mass of gas jar, plate and water (g).

2.6.1.5 *Reporting of results.* The specific gravity of the soil particles shall be reported to the nearest 0.01. If the two results differ by more than 0.03 the tests shall be repeated.

Notes on Test 6(A)

NOTE 1. A gas jar has been found to make a very effective pycnometer but any container of similar capacity can be used provided that it can be shaken in a mechanical shaking apparatus, and provided that the mouth can be sealed in such a way that its volume is constant.
NOTE 2. An end-over-end shaker has been specified but shaking machines giving a vibrating motion would also be suitable. The choice of shaking machine depends on the type of pycnometer used.
NOTE 3. Oven drying of the soil has been specified for convenience. If there is any reason to believe that this will change the specific gravity due to loss of water of hydration, the soil should be dried at not more than 80 °C. This fact should be reported.
NOTE 4. If there is a large difference between the air temperature and water temperature sufficient water should be drawn for the required number of tests and allowed to stand in the room in which the tests are being done until the temperature is within the given range.

2.6.2 Test 6(B). Method for fine-grained soils

2.6.2.1 *General.* This method covers the determination of the specific gravity of soil particles of fine-grained soils. The method may also be used for medium- and coarse-grained soils if the coarse particles are ground to pass, say a 2 mm BS test sieve before using.

2.6.2.2 *Apparatus.* The following apparatus is required.

(1) Two density bottles (pycnometers) of approximately 50 ml capacity with stoppers.
(2) A water bath maintained at a constant temperature to within ± 0.2 °C. (If standard density bottles are used this constant temperature is 20 °C).
(3) A vacuum desiccator (a convenient size is one about 200 mm to 250 mm in diameter).
(4) A desiccator (a convenient size is one about 200 mm to 250 mm in diameter) containing anhydrous silica gel.
(5) A thermostatically controlled drying oven, capable of maintaining a temperature of 105 °C to 110 °C.
(6) A balance readable and accurate to 0.001 g.
(7) A source of vacuum, e.g. a good filter pump or a vacuum pump.
(8) A Chattaway spatula (a convenient size is one having a blade 150 mm long and 3 mm wide; the blade has to be small enough to go through the neck of the density bottle), or a piece of glass rod about 150 mm long and 3 mm diameter.
(9) A wash bottle, preferably made of plastics, containing air-free distilled water (see Note 1).
(10) A sample divider of the multiple slot type (riffle box) with 7 mm width of opening.
(11) A length of rubber tubing to fit the vacuum pump and the desiccator.

2.6.2.3 *Procedure.* The procedure is as follows.

(1) The complete density bottle with stopper, shall be dried at 105 °C to 110 °C, cooled in the desiccator and weighed to the nearest 0.001 g (m_1) (see Note 2).
(2) The 50 g sample obtained as described in the procedure for the preparation of disturbed samples for testing (see 1.5) shall if necessary be ground to pass a 2 mm BS test sieve. A 5 g to 10 g subsample shall be obtained by riffling, and oven dried at 105 °C to 110 °C (see Note 3). This sample shall be transferred to the density bottle direct from the desiccator in which it has been cooled. The bottle and contents together with the stopper shall be weighed to the nearest 0.001 g (m_2).
(3) Sufficient air-free distilled water (see Note 4) shall be added so that the soil in the bottle is just covered. The bottle containing the soil and liquid, but without the stopper, shall be placed in the vacuum desiccator, which shall then be evacuated gradually. The pressure shall be reduced to about 20 mm of mercury. When using a water pump, because of variation in mains pressure, care shall be taken to ensure that the required vacuum is maintained.

Care shall be taken during this operation to see that the air trapped in the soil does not bubble too violently, so as to prevent small drops of the suspension being lost through the mouth of the bottle. The bottle shall be

*See Form E, Appendix B.

allowed to remain in the desiccator for at least 1 h until no further loss of air is apparent.
(4) The vacuum shall be released and the lid of the desiccator removed. The soil in the bottle shall be stirred carefully with the Chattaway spatula, or the bottle vibrated. Before removing the spatula from the bottle the particles of soil adhering to the blade shall be washed off with a few drops of air-free liquid. The lid of the desiccator shall then be replaced and the desiccator evacuated again.
(5) The procedure outlined in (3) and (4) shall be repeated until no more air is evolved from the soil (see Note 5).
(6) The bottle and contents shall then be removed from the desiccator and further air-free liquid added until the bottle is full. The stopper shall then be inserted. The stoppered bottle shall be immersed up to the neck in the constant-temperature bath for approximately 1 h, or until it has attained the constant temperature of the bath (see Note 6).

If there is an apparent decrease in volume of the liquid the stopper shall be removed and further liquid added to fill the bottle and the stopper replaced. The bottle shall then be returned to the bath and sufficient time shall be allowed to elapse after this operation to ensure that the bottle and its contents again attain the constant temperature of the bath. If the bottle is still not completely full this process shall be repeated.
(7) The stoppered bottle shall then be taken out of the bath, wiped dry and the whole weighed to the nearest 0.001 g (m_3).
(8) The bottle shall then be cleaned out and filled completely with air-free liquid, the stopper inserted and then the whole immersed in the constant temperature bath for 1 h or until it has attained the constant temperature of the bath. If there is an apparent decrease in the volume of the liquid, the stopper shall be removed and further liquid added to fill the bottle and the stopper replaced. The stoppered bottle shall then be returned to the bath and sufficient time shall be allowed to elapse after this operation to ensure that the bottle and its contents again attain the constant temperature. If the bottle is still not completely full this process shall be repeated. The bottle shall then be taken out of the bath, wiped dry and the whole weighed to the nearest 0.001 g (m_4) (see Note 7).
(9) Two determinations of the specific gravity of the same soil sample shall be made (see Notes 8 and 9).

2.6.2.4 *Calculations**. The specific gravity of the soil particles, G_s, shall be calculated. If water has been used as the air-free liquid, then the following equation shall be used:

$$G_s = \frac{m_2 - m_1}{(m_4 - m_1) - (m_3 - m_2)}$$

where

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

If some other air-free liquid has been used reference should be made to Note 4.

2.6.2.5 *Reporting of results.* The average of the values obtained shall be taken as the specific gravity of the soil particles and shall be reported to the nearest 0.01. If the two results differ by more than 0.03 the tests shall be repeated.

Notes on Test 6(B)

NOTE 1. Obtain the air-free distilled water by boiling a quantity of distilled water for at least 30 min in a container that can be sealed from the atmosphere during cooling. Take care to see that the container is strong enough to resist the reduction in pressure inside it during cooling.
NOTE 2. *Standard density bottles.* If a density bottle conforming to BS 733 is used then in order to avoid distortion it should not be dried by placing it in an oven. It may be dried by rinsing with acetone or an alcohol-ether mixture and then blowing warm air through it.
NOTE 3. Oven drying of the soil has been specified for convenience. If there is any reason to believe that this will change the specific gravity due to loss of water of hydration the soil should be dried at not more than 80 °C. This fact should be reported.
NOTE 4. *Alternative liquids for specific gravity determination.* With certain soils, e.g. those containing soluble salts, Kerosene (paraffin oil) or white spirit may be preferred. If one of these is used, record the fact and carry out a separate experiment to determine the specific gravity of the liquid at the temperature of the test. The equation for the specific gravity of the soil particles, G_s, given in 2.6.2.4 then becomes:

$$G_s = \frac{G_L (m_2 - m_1)}{(m_4 - m_1) - (m_3 - m_2)}$$

where

G_L is the specific gravity of the liquid used, at the constant temperature;
m_1 is the mass of density bottle (g);
m_2 is the mass of bottle and dry soil (g);
m_3 is the mass of bottle, soil and liquid (g);
m_4 is the mass of bottle when full of liquid only (g).

*See Form F, Appendix B.

NOTE 5. Experience has shown that the largest source of error in the test is due to the difficulty in ensuring the complete removal of air from the sample. To obtain reliable results the soil should be left under vacuum for several hours, preferably overnight.
NOTE 6. If a constant temperature room or cabinet is available then this procedure need not be carried out in a water bath.
NOTE 7. If 2.6.2.3(8) is used to find the volume of the density bottle then the test may be carried out at any temperature provided it is constant throughout the test.
NOTE 8. Many soils have a substantial proportion of heavier or lighter particles. Such soils will give erratic values for the specific gravity even with the greatest care in testing and a number of repeat tests may be needed to obtain a good average value.
NOTE 9. Clean quartz and flint sands generally have a specific gravity close to 2.65; low values would suggest the presence of organic matter.

2.7 Test 7. Determination of the particle size distribution

2.7.1 Test 7(A). Standard method by wet sieving

2.7.1.1 *General.* This method covers the quantitative determination of the particle size distribution in a soil down to the fine sand size. The combined clay and silt fraction can be obtained with this method by difference.

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 coarser material. Other procedures using wet sieving of the coarser material may be used provided that no material other than the silt and clay fraction is lost in washing (see Note 1).

2.7.1.2 *Apparatus.* The following apparatus is required.

(1) British Standard test sieves as follows: 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, 63 µm and appropriate receivers (see Notes 2 and 3).
(2) A balance readable and accurate to 0.5 g.
(3) A balance readable and accurate to 0.01 g.
(4) Sample dividers, e.g. the multiple slot type (riffle boxes) similar to those shown in Fig. 3.
(5) A thermostatically controlled drying oven capable of maintaining a temperature of 105 °C to 110 °C.
(6) At least six evaporating dishes (a convenient size is about 150 mm diameter).
(7) At least six metal trays (a convenient size is about 300 mm diameter and 40 mm deep).
(8) Two or more large metal or plastics watertight trays, or a bucket of about 12 litres capacity. (Convenient sizes for the trays are in the range 500 mm to 1000 mm square and 80 mm to 150 mm deep.)
(9) A scoop (a convenient size is one about 200 mm long and 100 mm wide) or a beaker (about 500 ml).
(10) Sieve brushes, and a wire brush or similar stiff brush.
(11) Sodium hexametaphosphate (commercial grade is suitable).
(12) A quantity of rubber tubing about 6 mm bore.
(13) A mechanical sieve shaker (optional).

2.7.1.3 *Procedure.* The procedure is as follows.

(1) The oven dried subsample obtained as described in the procedure for the preparation of disturbed samples for testing (see 1.5) shall be weighed to 0.1 % of its total mass (m_1) (see Note 4).
(2) The subsample shall then be placed on the 20 mm BS test sieve (see Appendix A) and any particles too coarse to pass through the test sieve shall be brushed with a wire brush or similar stiff brush until the individual particles are clean of any finer material. Care shall be taken when dealing with soft materials to ensure that the brushing is not removing parts of the large particles (see Note 5). The fraction retained on the 20 mm BS test sieve shall then be sieved on the appropriate larger sieves and the amount retained on each sieve weighed and recorded.
(3) The fraction of the oven-dry material passing the 20 mm BS test sieve shall be weighed to 0.1 % of its total mass and the mass recorded (m_2). It shall then be riffled so that a fraction of convenient mass (about 2 kg) is obtained. The fraction shall be weighed to 0.1 % of its total mass and the mass recorded (m_3).
(4) The riffled fraction shall then be spread out in the large tray or placed in the bucket and covered with water.
(5) Sodium hexametaphosphate shall then be added at the rate of 2 g/litre of water and the whole shall be stirred well to wet the soil. The soil shall then be allowed to stand for at least 1 h in this solution and shall be stirred frequently.
(6) The material shall then be washed, a little at a time, through a 2 mm BS test sieve nested in a 63 µm BS test sieve. The material passing the 63 µm sieve containing the silt and clay being allowed to run to waste. The washing shall be continued until the water passing the 63 µm BS test sieve is virtually clear. All the material retained on the sieves shall then be tipped into separate trays or evaporating dishes. Care shall be taken to see that neither test sieve is overloaded in the process either with material or with water (see Appendix A). The maximum amount of material initially on the 63 µm BS test sieve shall not exceed 150 g.
(7) When the whole of the sample has been washed all the retained material shall then be dried in an oven at 105 °C to 110 °C.

(8) When dry, the fractions shall be dry sieved through the appropriate sieves down to the 6.3 mm BS test sieve and the amount retained on each sieve weighed and recorded.

(9) If the fraction passing the 6.3 mm BS test sieve is small, i.e. not more than 150 g, the sample can be sieved on the appropriate sieves down to and including the 63 µm BS test sieve. The amounts retained on each sieve shall be weighed and the masses recorded. If a mechanical shaker is available these steps can be performed in one operation provided the test sieves are all of the same diameter. Care shall be taken to ensure that sieving is complete. The minimum period of shaking shall be 10 min.

(10) If the fraction passing the 6.3 mm BS test sieve is large, i.e. substantially greater than 150 g, the fraction shall first be weighed and the mass recorded (m_4). It shall then be riffled so that a fraction between 100 g to 150 g is obtained. This fraction shall be weighed and the mass recorded (m_5), and then sieved on the appropriate sieves down to and including the 63 µm BS test sieve. The amounts retained on each sieve shall be weighed and the masses recorded.

(11) The fraction passing the 63 µm BS test sieve shall be obtained by difference, i.e. by adding the masses of material retained on each of the sieves used, and having made due allownace for any subdivision of the sample, subtracting the total from the original mass (m_1).

2.7.1.4 *Calculations**. The calculations are as follows.

(1) For samples containing particles larger than 20 mm in size the mass of material retained on each of the coarse series of sieves shall be calculated as a percentage of m_1. For example:

$$\text{Percentage retained on 37.5 mm sieve} = \frac{m(37.5\text{ mm})}{m_1} \times 100$$

(2) The mass of material retained on the range of sieves between 20 mm and 6.3 mm shall be calculated as a fraction of m_2 and then as a percentage of m_1. For example:

$$\text{Percentage retained on 10 mm sieve} = \frac{m(10\text{ mm}) \times m_2}{m_1 \times m_3} \times 100$$

(3) The mass of material retained on each of the sieves finer than the 6.3 mm BS test sieve shall be calculated as a fraction of m_4 and then as a percentage of m_1. For example:

$$\text{Percentage retained on 300 µm sieve} = \frac{m(300\text{ µm}) \times m_2 \times m_4}{m_1 \times m_3 \times m_5} \times 100$$

(4) The cumulative percentages by mass of the sample passing each of the sieves shall be calculated.

2.7.1.5 *Reporting of results.* The results obtained shall be reported on a semi-logarithmic chart of the type shown in Fig. 10.

Alternatively, the results shall be reported in the form of a table showing to the nearest 1 %, the percentage by mass passing each of the sieves used.

Notes on Test 7(A)

NOTE 1. *Wet sieving of both coarse and fine material.* A procedure that allows the process of washing the sample free of silt and clay and the process of sieving the coarser fractions to be combined in a single wet sieving operation is described by West and Dumbleton†. Reduction of the sample mass by riffling at intermediate stages in the process, to avoid sieve overloading, is not possible in such a wet method. The method is therefore only suitable for soils containing little gravel-sized material (say less than 10 % retained on the 10 mm sieve).

NOTE 2. *Choice of sizes of test sieves.* The sizes of the test sieves used for the test should cover adequately the range for the particular soil used, but it will not generally be necessary to use every size for every test.

NOTE 3. Where large numbers of tests are to be carried out it may be advantageous to have two sets of sieves, one for the wet sieving and one for the dry sieving processes.

NOTE 4. If separation of the silt and clay fractions is required then a second riffled sample shall be retained and a fine analysis carried out as in Test 7(C) or 7(D).

NOTE 5. Certain soils, e.g. laterites, have large amounts of the clay fraction in the interstices of the larger particles. Treat these soils as described in this method but then wash the large particles retained on the 20 mm BS test sieve in sodium hexametaphosphate solution; estimate the amount of clay removed and allow for it in the final calculations.

NOTE 6. Do not dry the retained material on the sieve as it is detrimental to sieves to heat them.

2.7.2 Test 7(B). Subsidiary method by dry sieving

2.7.2.1 *General.* This method covers the quantitative determination of the particle size distribution in a soil down to the fine sand size. This method shall not be used unless it has been shown that for the type of material under test it gives the same results as the method of analysis by wet sieving. In cases of doubt the method shall not be used.

*See Form G, Appendix B.

†West, G. and Dumbleton, M.J. Wet sieving for the particle size distribution of soils. Department of the Environment, TRRL Report LR 437. Crowthorne: 1972 (Transport and Road Research Laboratory.)

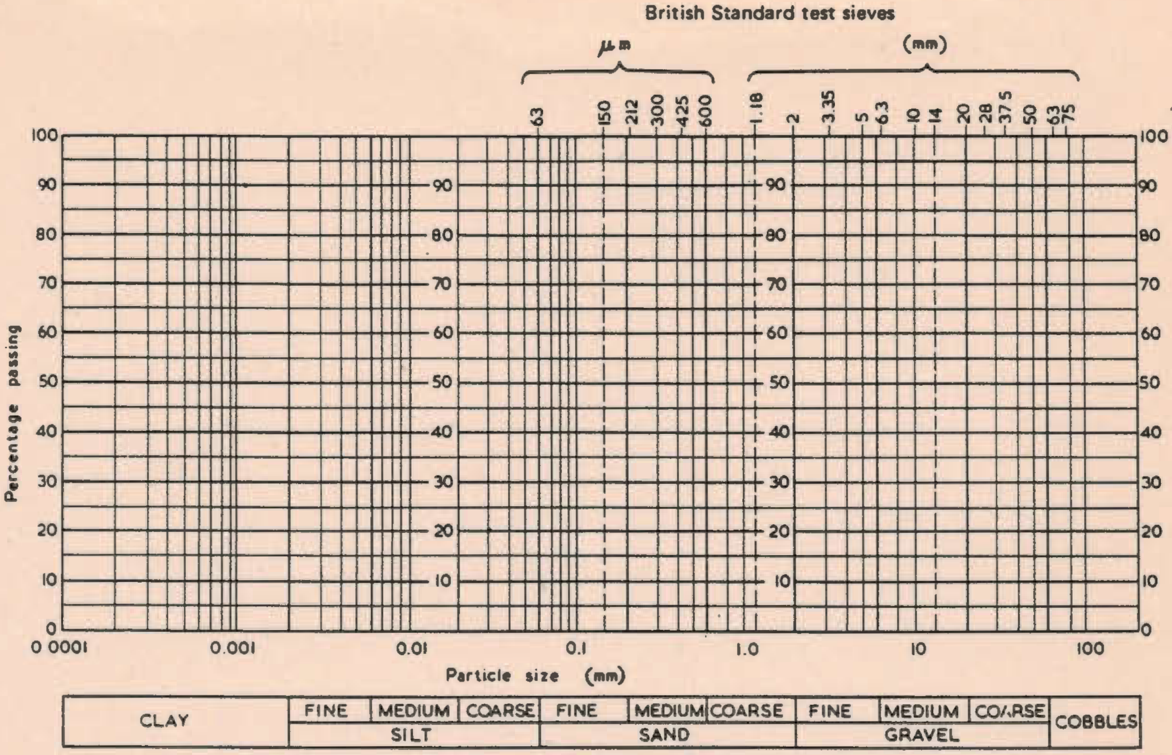


Fig. 10. Particle size distribution chart

2.7.2.2 *Apparatus.* The following apparatus is required.

(1) British Standard test sieves as follows: 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, 63 µm and appropriate receivers (see Note 1).
(2) A balance readable and accurate to 0.5 g.
(3) A balance readable and accurate to 0.01 g.
(4) Sample dividers, e.g. the multiple slot type (riffle boxes), similar to those shown in Fig. 3.
(5) A thermostatically controlled drying oven capable of maintaining a temperature of 105 °C to 110 °C.
(6) Sieve brushes.
(7) At least six metal trays (a convenient size is about 300 mm diameter and 40 mm deep).
(8) At least six evaporating dishes (a convenient size is about 150 mm in diameter).
(9) A light hammer and/or a mortar and a rubber pestle (see Fig. 2).
(10) A scoop (a convenient size is one about 200 mm long and 100 mm wide).
(11) A mechanical sieve shaker (optional).

2.7.2.3 *Procedure.* The procedure is as follows.

(1) The oven dried subsample obtained as described in the procedure for the preparation of disturbed samples for testing (see **1.5**) shall be weighed to 0.1 % of its total mass.
(2) The largest size test sieve appropriate to the maximum size of material present shall be fitted with the receiver and the subsample placed on the sieve (see Note 2 and BS 1796).
(3) The test sieve shall be agitated so that the sample rolls in irregular motion over the test sieve. Any particles may be hand placed to see if they will fall through but they shall not be pushed through. The material from the test sieve shall be rubbed with the rubber pestle in the mortar and resieved to make sure that only individual particles are retained. The amount retained on the test sieve shall be weighed.
(4) The material retained in the receiver shall be transferred to a steel tray and the receiver fitted to the next largest sized test sieve. The contents of the steel tray shall then be placed on the sieve and operation (3) repeated (see Note 3).
(5) Operations (3) and (4) shall be repeated through all the test sieve sizes used. Note that if a mechanical shaker is available these steps can be performed in one operation provided the test sieves are all of the same diameter. Care shall be taken to ensure that sieving is complete. A minimum of 10 min shaking shall be used.
(6) If any test sieve becomes overloaded the material on the test sieve shall be sieved in parts, the parts not to exceed the masses given in Appendix A.