

Settling Dogah

GHANA HIGHWAY AUTHORITY.

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STANDARD METHODS OF TEST

FOR SOILS

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**DRAFT:**

**STANDARD METHOD OF TEST FOR SOILS.**

**INDEX:**

- S1 THE DETERMINATION OF REFERENCE DENSITY FOR COMPACTION CONTROL OF COHESIVE SOILS AND GRAVELS.**
- S2 THE DETERMINATION OF THE CALIFORNIA BEARING RATIO OF COHESIVE SOILS AND GRAVELS.**
- S3 THE DETERMINATION OF REFERENCE DENSITY FOR COMPACTION CONTROL OF GRADED CRUSHED-STONE SUB-BASE AND BASE.**
- S4 THE DETERMINATION OF REFERENCE DENSITY FOR COMPACTION CONTROL OF COHESIONLESS SANDS AND FINE GRAVELS.**
- S5 THE DETERMINATION OF THE IN-PLACE DRY DENSITY OF SOIL OR GRAVEL BY THE SAND REPLACEMENT METHOD.**
- S6 DETERMINATION OF ATTERBERG LIMITS OF SOIL FINES.**
- S7 SIEVE ANALYSIS OF GRANULAR SOILS.**
- S8 SCHEDULE FOR CONCURRENT SOIL TESTING.**
- S9 THE DETERMINATION OF THE GRAIN SIZE DISTRIBUTION IN SOIL FINES BY MEANS OF A HYDROMETER.**

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- S10 CLASSIFICATION OF SOILS AND SOIL-AGGREGATE MIXTURES FOR HIGHWAY CONSTRUCTION PURPOSES**

**DRAFT GHA TEST METHOD -SOILS 1.**

**THE DETERMINATION OF REFERENCE DENSITY FOR COMPACTION  
CONTROL OF COHESIVE SOILS AND GRAVELS.**

## DRAFT GHA TEST METHOD -SOILS 1.

### THE DETERMINATION OF REFERENCE DENSITY FOR COMPACTION CONTROL OF COHESIVE SOILS AND GRAVELS.

#### 1 SCOPE

- 1.1 The reference density for the control of compaction of cohesive soils and gravels is the Maximum Dry Density (MDD) achieved in the laboratory at Modified compactive effort on the minus 19 mm fraction, corrected for the fraction larger than 19 mm using the Bulk Specific Gravity of the oversize fraction.
- 1.2 This test method covers:
  - the laboratory sample preparation and compaction procedures used to determine the relationship between compaction moisture content and dry density of the minus 19 mm fraction of the gravel (compaction curve) when compacted at Modified compactive effort in 152.4 mm diameter mould to give a sample height of 116.4 mm;
  - the laboratory sample preparation and determination of the Bulk Specific Gravity of the oversize fraction;
  - the correction procedure for combining the above to determine the reference dry density against which the field dry densities are compared to determine the relative field compaction.
- 1.3 This test method applies to cohesive soils and gravels, crushed gravels and crushed stone with added cohesive soil binder, that have less than 30% by weight of the particles retained on the 19 mm sieve and a maximum particle size of 75 mm.

Where less than 5% by weight of the whole sample is retained on the 19 mm sieve the correction for the Bulk Specific Gravity of the fraction retained on the 19 mm sieve may be ignored.

For gravels where more than 30% is retained on the 19 mm sieve, or boulders larger than 75 mm are present, the method of compaction control using the measurement of field density by sand replacement method or direct transmission nuclear methods for comparison with the reference density determined using this method is inappropriate.

- 1.4 This test method will generally produce a well defined MDD and OMC where the minus 19 mm fraction is non-free draining.

For free draining sands and gravels the MDD and OMC may not be well defined, and determination of MDD and OMC by vibrating hammer compaction in method S4 should be used.

For non-cohesive graded crushed stone the Apparent Density as determined in method S3 should be used as the reference density.

## 1.5 Definitions

**Modified compactive effort:** The term for the 2700 Kn-m/m<sup>3</sup> compactive effort applied by 56 blows of a 4.536 kg rammer dropped through a height of 457 mm on each of 5 layers of soil approximately 25 mm thick in a cylindrical mould 152.4 mm diameter to give a trimmed sample height of 116.4 mm.

**Modified Maximum Dry Density (ModMDD):** The modified maximum dry density of a material is the highest density obtainable when the compaction is carried out at the modified compactive effort on the material at varied moisture contents.

**Modified Optimum Moisture Content (ModOMC):** The modified optimum moisture content is the moisture content at which the modified maximum dry density is obtained.

**Absorption:** The increase in the weight of a dry aggregate due to water in the pores of the material caused by soaking in water for 24 hours, but not including water adhering to the outside surface of the particles, expressed as a percentage of the dry weight. The aggregate is considered "dry" when it has been maintained at a temperature of  $110 \pm 5^\circ\text{C}$  for sufficient time to remove all uncombined water.

**Specific Gravity (SG):** The ratio of the mass (or weight in air) of a unit volume of a material to the mass of the same volume of water at stated temperatures. Values are dimensionless.

**Apparent Specific Gravity (Ap.SG):** The ratio of the weight in air of a unit volume of the impermeable portion of aggregate at a stated temperature to the weight in air of an equal volume of gas-free distilled water at a stated temperature.

**Bulk Specific Gravity (Bulk SG):** The ratio of the weight in air of a unit volume of aggregate (including the permeable and impermeable voids in the particles, but not including the voids between particles) at a stated temperature to the weight in air of an equal volume of gas-free distilled water at a stated temperature.

**Bulk Specific Gravity; saturated-surface-dry (Bulk SG:ssd):** The ratio of the weight in air of a unit volume of aggregate, including the weight of water within the voids filled to the extent achieved by submerging in water for approximately 24 h (but not including the voids between particles) at a stated temperature, compared to the weight in air of an equal volume of gas-free distilled water at a stated temperature.

## 2 APPARATUS

For determination of moisture-density relationship of minus 19 mm fraction.

- 2.1 A rigid cylindrical steel mould,  $152.4 \pm 0.5$  mm in diameter,  $177.8 \pm 0.5$  mm high, with detachable collar and a compaction base plate with a  $61.4 \pm 0.1$  mm thick spacer plate firmly attached to the base plate. With the spacer plate inside the mould the effective depth of the mould shall be  $116.4 \pm 0.5$  mm. The compaction base plate and spacer should be firmly bolted onto a concrete block at least 300 mm thick and

weighing at least 100 kg.

- 2.2 A 4.536 kg  $\pm$  20 g tamper with a 50.8  $\pm$  1.0 mm diameter face and with a sheath to give a 457.2  $\pm$  2 mm drop.
  - 2.3 A steel straight-edge, about 300 mm in length and having one bevelled edge.
  - 2.4 A riffler.
  - 2.5 A platform scale to weigh up to 100 kg, accurate to 10 g.
  - 2.6 A balance to weigh up to 20 kg, accurate to 1 g.
  - 2.7 A balance to weigh up to 2 kg, accurate to 0.1 g.
  - 2.8 A 450 mm diameter perforated plate sieve with 19.0 mm square opening complying with BS 410 or ISO 3310/2.
  - 2.9 An iron mortar and pestle and a rubber-tipped pestle.
  - 2.10 8 buckets of about 10 litre capacity with lid, or 8 basins, approximately 350 mm in diameter.
  - 2.11 A mixing basin, approximately 500 mm in diameter, with a wet jute sack similar to use as a cover to prevent the sample drying out during compaction.
  - 2.12 A garden trowel.
  - 2.13 A spatula.
  - 2.14 Suitable oven pans to hold about 1000 g of material for the determination of moisture contents.
  - 2.15 A drying oven, thermostatically controlled and capable of maintaining a temperature of 105 to 110 °C. This should be of sufficient size to hold a minimum of 8 oven pans (2.14) and preferably 16 or 24 to allow 2 or 3 sets of tests to be done per day.
  - 2.16 Measuring cylinders, 1000 ml and 500 ml in capacity.
  - 2.17 A wash bottle, spray-can or sprinkler.
  - 2.18 Filter paper disks, 150 mm diameter.
  - 2.19 A sample extruder (optional), i.e. a jack, lever, frame or other device adapted for the purpose of extruding compacted specimens from the mould.
- For calibrating the mould:**
- 2.20 A 180 x 180 mm glass plate approximately 7 mm thick.

- 2.21 Lubricating grease.
- 2.22 A wash bottle with fine spout, or 5 ml pipette.
- 2.23 A thermometer measuring 0 to 50 °C.

**For determining Bulk SG:**

**Method A - Using Pycnometer.**

- 2.24 A large pycnometer of at least 1 litre capacity, eg a preservative jar with a smooth flat rim, a glass sheet to act as a lid (or conical lid).

**Method B - Using immersed weight.**

- 2.25 A balance to weigh up to 5 kg, accurate to 0.1 g. The balance shall be equipped with suitable apparatus for suspending the sample container in water from the centre of the weighing platform or pan of the weighing device.
- 2.26 Sample Container - A wire basket or bucket of 3.35 mm or finer mesh, bucket of approximately equal breadth/diameter and height, with a capacity of about 5 litres. It shall be constructed so as to prevent trapping air when submerged.
- 2.27 Water Tank - A watertight tank into which the sample container may be placed while suspended below the balance.
- 2.28 Suitable non-corrodible oven pan containers to hold between 2000 g and 3000 g of material for the determination of moisture contents.

### **3 METHOD**

#### **3.1 Preparation**

- 3.1.1 The mass of the bulk sample required should be such that after air-drying there is at least 60 kg of material that passes the 19 mm sieve. For coarse wet gravels this could be up to 90 kg.
- 3.1.2 The bulk sample should be air-dried to the extent that it is sufficiently friable and free-flowing to be riffled and sieved. It is not necessary to dry the material so that it becomes dusty and fines are lost during the sieving and riffling process.
- 3.1.3 Where the material contains soil aggregations, these should be disintegrated as finely as possible with a mortar and rubber tipped pestle without reducing the natural size of the individual particles (see note 5.1).
- 3.1.4 The sample is sieved through a 19.0 mm sieve of 450 mm diameter, and the mass of the fractions finer and coarser than 19 mm weighed and recorded. Where a grading is also required the grading of the fractions coarser than 19 mm should be done at this stage.

- 3.1.5 Representative samples for the determination of moisture content of about 1.5 kg of the finer fraction and 3 kg of the coarser fraction are to be obtained by successive quartering. During this process on the fraction passing 19 mm it is expedient to obtain the representative samples for conducting the wet sieve analysis and preparing the fines for the Atterberg limit tests.
- 3.1.6 Determine the moisture contents by drying to constant mass in an oven at a temperature of 105 to 110 °C, record on Form S1/1 to the nearest 0,1 per cent. The finer fraction may be discarded or used as a check sieve analysis, but the coarser fraction must be retained for determination of Bulk SG.
- 3.1.7 The remainder of the finer fraction of the material is to be mixed thoroughly and the mass reduced to about 57 kg by removing some of the sample. The 57 kg of sample is then divided by successive riffling so as to obtain eight specimens (sub-samples) that can be considered identical for practical purposes. Five of these specimens are used for the compaction to determine the moisture-density relationship, from which the MoDMDD and MoDOMC are determined and three for the compaction for the CBR determinations.
- 3.1.5 For convenience the mass of the material in each of the eight specimens should be made the same (7 kg is recommended) by removing or adding small amounts of material. The mass of these specimens should be recorded to nearest 1 g on Form S1/2. The eight specimens should then be stored in a buckets with close fitting lids.

## 3.2 Determination of moisture-density relationship of finer fraction.

### 3.2.1 Mixing.

Five of the specimens are to be prepared so that they have moisture contents that bracket the optimum moisture content with a minimum of two specimens either side of OMC. This is done using the following procedure:

(i) The moisture in one of the specimens is adjusted by adding water until it is judged as having a moisture content close to optimum, as follows:

- A specimen is transferred from its bucket to the mixing basin, and a depression formed in the soil to receive the water added.

- A measured volume of water is placed in a measuring cylinder, spray-can or sprinkler (1000 cc is generally suitable). This is added incrementally, in increments of about one percent moisture in the specimen (70 cc for 7000 g), to the material in the basin. While adding the water care should be taken not to put water directly on to the basin. After each increment of water has been added the material should be mixed thoroughly by hand or with a trowel to ensure a uniform distribution of the water through out the specimen. Water is added until, in the opinion of the operator, the optimum moisture content is reached. The manner in which this subjective assessment is made is described in 5.2. The water remaining in the measuring cylinder, spray-can or sprinkler is then measured in order to obtain the quantity of water actually added to the soil. This is recorded on form S1/2 and then expressed as

a percentage of the mass of the air-dried specimen.

(ii) For silty sands and gravels of A-2-6 quality and better that are generally required for use in the pavement layers, the moist specimen should be transferred back to its bucket and closed with the lid. This should be allowed to stand for a minimum of half an hour so that the moisture may become evenly distributed throughout the specimen.

(iii) While the moisture is being left to equilibrate in this specimen, the four other specimens may be treated by mixing in different amounts of water. For the A-2-6 soils and better the amount of water added should be 1 and 2 percent of the mass of the air-dry sample more and less than the amount added to the first specimen. The mass of water added to each specimen should be recorded on Form S1/2.

(iv) For the more clayey soils of A-2-7 classification and poorer the specimens, after being thoroughly mixed with the water, should be placed in sealed containers for a minimum of 16 hours for the moisture to become evenly distributed. For these soils the difference between the amounts of water added to the specimens may be increased from 1 percent, but should not exceed 4 per cent.

(v) The remaining three samples should be retained in sealed containers until after the compaction of the first five have been completed and the amount of water to be added to obtain the OMC determined. This amount of water should then be thoroughly mixed with each of the three specimens, and the specimens returned to the buckets, for the same time as the moisture-density specimens, for the moisture to become evenly distributed.

### 3.2.2 Preparation of the mould

(i) The mould factor for the moulds should be determined as set out in 5.3.

(ii) The same mould should be used for all the compactions used to determine a moisture-density relationship, and its mass and mould factor recorded on Form S1/2. Where the last three specimens are being used only as a check on the MoDMDD and MoDOMC the same mould should also be used. Where they are being used to determine the CBR, other moulds should be used.

(iii) The clean, dry mould is weighed accurately and the mass recorded to the nearest 1 g on Form S1/2. All weighing of the moulds and specimens, including the mould calibrations should be made with the same balance.

(iv) The mould is then assembled on the compaction base plate with the spacer attached which must be firmly fixed to a concrete foundation plinth. Two 150 mm diameter filter papers are placed on the spacer plate to prevent the material from sticking to the plate. The collar is then fitted to the mould.

### 3.2.3 Compaction

(i) The specimen with the moisture content estimated to be closest to optimum moisture content is now returned to the mixing bowl and mixed again. It is to be covered with a wet sack to prevent moisture evaporating from the specimen during the compaction procedure. About 1000 g of material is weighed off and transferred to the mould. Alternatively a mug or tin that holds about 1000 g of soil can be used as a volume measure.

(ii) The surface of the soil is levelled and pressed down by hand. The surface of the layer is then tamped 56 times with a 4,536 kg tamper which is dropped exactly 457,3 mm at a rate of approximately 30 blows per minute. There is a strong tendency for operators to exceed this blow rate considerably giving spurious results if not properly supervised.

The blows must be distributed uniformly over the whole layer in four cycles of 14 blows each. In each cycle ten blows are applied to the outside circumference and four blows round the centre. When the tamper is raised, the operator should ensure that the guide sheath is with 5° of vertical and resting on the soil and that the tamper is right at the top of the sheath before being dropped. The fall of the tamper should be perfectly free. The operator should also ensure that the tamping face of the tamper is kept clean and that no cake of material is formed on the face.

(iii) After the tamping of the first layer, the depth of the surface of the tamped material below the top of the mould (without the collar), is measured and should be between 88 and 93 mm.

(iv) If the depth is not within this range, the mass of moist material weighed out for the next layer should be increased or decreased accordingly. Four more layers of material should be tamped in exactly the same manner and each layer should be about 25 mm thick. The depth from the top of the mould to the surface of a compacted layer should be within the following limits:

First layer:	88 to 93 mm
Second layer:	64 to 70 mm
Third layer:	39 to 46 mm
Fourth layer:	13 to 21 mm

(v) After the compaction of the fifth layer, the surface of the material should be between 5 and 15 mm above the top of the mould without collar. Where the surface of the compacted specimen is below the top of the mould, or more than 15 mm above the top of the mould, the compacted specimen is rejected and the compaction repeated with another specimen. To avoid this inconvenience it is essential that the depth to the surface of each layer is checked and the amount of material transferred to the mould for the next layer adjusted as necessary.

### 3.2.4 Removal of excess material

- (i) The material which adheres to the inside of the collar of the mould is gently eased from the collar with a spatula. The collar is turned round and carefully removed without disturbing the projecting layer of material.
- (ii) The projecting material is cut off carefully with a steel straight-edge, a little at a time, until the material is level with the top of the mould. Loose pebbles should be pressed in with the flat of the straight-edge. Where pebbles project slightly above the top of the mould these should be pressed in below the level of the mould.
- (iii) The excess material which was cut off, and, if required, also the remaining material in the mixing basin, is sieved rapidly through a 4,75 mm sieve. The material passing the sieve is spread over the surface of the material in the mould and tapped lightly with the flat of the straight-edge and cut off. If necessary this process is repeated to obtain an even and compact surface level with the top of the mould. The variation in trimming technique of different operators can cause a significant difference in the densities obtained.

### 3.2.5. Moisture condition check

The surface of the moulded material is inspected. If it is hard and unyielding to pressure from the thumb it is probable that the optimum moisture content has not been exceeded. If, however, the material tends to be slightly spongy or yields when pressed down by the thumb, then the optimum moisture content is likely to have been exceeded.

### 3.2.6 Determination of wet and approximate dry density of specimen.

- (i) The mould with compacted specimen is removed from the compaction base plate and spacer and weighed. The mass is recorded on form S1/2 to the nearest 1 g.
- (ii) The wet density of the compacted specimen is calculated, as explained in 4.2, and recorded on Form S1/2.
- (iii) The moisture content of the air dry sample is estimated from experience. This is added to the percentage of water added to the specimen to give the estimated compaction moisture content (ECMC). The determination of the optimum amount of water added to obtain the maximum dry density is very insensitive to the estimate of the moisture content of the air dry samples. All 8 specimens are to be assigned the same value. (See 5.4).
- (iv) The approximate dry density is calculated using the wet density and the ECMC.
- (v) The compacted material can now be removed from the mould with an extruder or other suitable means.

### 3.2.7 Determination of moisture content

(i) A representative sample is taken from the material removed from the mould and placed in a suitable container for the determination of the moisture content. The sample should be at least 1000 g.

Where the specimen is extruded, this is to be obtained by slicing the compacted specimen axially through the centre and removing the material from the full height of the cut faces.

Where it is broken out of the mould the material should be quickly broken with the cutting straight-edge, mixed, and then quartered twice to give a representative moisture sample that is about one quarter of the material in the mould.

(ii) The moist sample is weighed immediately to the nearest 0,1 g and dried to constant mass in an oven of 105 to 110 °C. The moisture content is determined to the nearest 0,1 per cent. The results are recorded on Form S1/2.

### 3.2.8 Establishing additional points of the moisture-density relationship curve

(i) Paragraphs 3.2.4 to 3.2.7 above describe the determination of the density of the specimen judged closest to the OMC and is one point of the moisture-density relationship curve. Additional points have still to be obtained.

(ii) The whole procedure is, therefore, carried out on each of the other four specimens prepared at various moisture contents.

(iii) After each compaction the approximate dry density for the compacted specimen must be calculated, using an assumed compaction moisture content. This is the percentage of water added plus the estimated moisture content of the air-dried material, which is the same for all 8 specimens.

(iv) The approximate dry densities are plotted against the assumed moisture contents and the relative position of the points will indicate the amount of water to be added to obtain the Optimum Moisture Content giving the Maximum Dry Density.

(v) The specimens should be compacted in the following sequence, so that adjustments may be made to the amount of water to be added if the subjective estimation of MoDOMC was in error.

- (1) Specimen at subjective MoDOMC.
- (2) Specimen with subjective MoDOMC plus one increment of water.
- (3) (a) Where the approximate dry density of (2) is less than (1) compact specimen with subjective MoDOMC less one increment of water and then the specimen with subjective MoDOMC less two increments of water.

Where these results do not include two points to the dry side of approximate MoDOMC one of the three remaining sub-samples will be required that can be compacted at subjective MoDOMC less three increments of water.

Where these results give two points on either side of the approximate MoDOMC or the specimen with the subjective MoDOMC is very close to the approximate MoDOMC the fifth specimen with plus two increments of water can be compacted to complete the moisture - density relationship.

- (b) Where the approximate dry density of (2) is more than (1) compact specimen with subjective MoDOMC plus two increments of water (3b).

Where the approximate dry density of (3b) is less than (2) add five increments of water to the specimen with the subjective MoDOMC less two increments to give plus three increments of water, mix well and compact after allowing the moisture to equilibrate for an appropriate time. During this time the specimen with subjective MoDOMC less one increment can be compacted.

Where the approximate dry density of (3b) is higher than (2) add five increments of water to both specimens with less than the subjective MoDOMC to give plus three and four increments of water, mix well and compact after allowing the moisture to equilibrate for an appropriate time.

- (vi) The Approximate Dry Density is plotted against the Estimated Compaction Moisture Content (ECMC) on Figure S1/1. This is used to estimate the optimum ECMC that will give the maximum approximate dry density. The amount of water that needs to be added to the specimen to give the maximum dry density is calculated by deducting the assumed moisture content of the air-dry specimens from the optimum ECMC.

### 3.2.9 Remaining 3 specimens.

- (i) The remaining three specimens are used to determine the MoDMDD and MoDOMC with greater accuracy by enabling the three dry densities to be averaged. This greater accuracy is required where statistic procedures are used for the quality control of degree of field compaction. They can also be used for the determination of CBR as described in method S2.

- (ii) These three specimens are individually mixed with the amount of water required to give the optimum ECMC determined as described above. After thorough mixing each is returned to it's bucket, for the same time as the previous five specimens, to allow the moisture to become evenly distributed.

- (iii) They are compacted and trimmed in the same manner as the previous samples (3.2.3 and 3.2.4). A small difference in this procedure is necessary for the specimens

to be used for determination of CBR. For this purpose a sample for determination of compaction moisture content is taken from the mixing bowl after compaction of the second layer, as the specimen is not broken out of the mould until after the CBR determination.

(iv) After each compaction the wet and approximate dry densities are determined as in 3.2.6. The approximate dry density is plotted on Figure S1/1 and compared with the approximate maximum dry density indicated from the moisture-density relationship. For a carefully conducted test, each should be within +/- 10 kg/m<sup>3</sup> of the approximate maximum dry density.

### 3.2.10 Calculations

#### (i) Moisture content.

The compaction moisture content for each specimen is calculated from the samples that have been dried in the oven. It is calculated to the nearest 0,1 per cent as follows:

$$MC = (a - b) / (b - c) \times 100$$

where MC = moisture content expressed as a percentage of the dry soil.  
a = mass of container and wet material (g)  
b = mass of container and dry material (g)  
c = mass of container only (g).

A check is to be made on these moisture contents by back calculating the air-dry moisture content of the specimens. These are the moisture content (%) determined by oven drying, less the percentage of water added to the air-dry specimen. In tests conducted to an acceptable standard the range of these back-calculated air-dry moisture contents should be less than 0.4%.

An odd result is indicative of an error in weighing or calculation of the moisture content.

Where this range is exceeded more care is indicated in one or more of the following:

- the sample splitting and preparation to make 8 identical specimens;
- the moisture addition and mixing;
- covering the moist specimen during compaction;
- obtaining the representative sample for moisture determination.

#### (ii) Wet density

The wet density ( $D_w$ ) of the specimen is calculated for each compaction moisture content to nearest 1 kg/m<sup>3</sup> as follows:

$$D_w = W \times F$$

where:  $W$  = mass of wet material (g)  
 $F$  = the mould factor of the mould determined as in 5.3.  
This is the reciprocal of the mould volume adjusted for the units in which the masses are expressed to give the densities in  $\text{kg/m}^3$ . For the standard mould of true dimensions this is 0.4710.

### (iii) Dry density

The dry density ( $D_d$ ) (and approximate dry density) for each specimen is calculated to nearest  $1 \text{ kg/m}^3$  as follows:

$$D_d = 100 \times D_w / (100 + MC)$$

where  $D_d$  = dry density ( $\text{kg/m}^3$ )

$MC$  = moisture content expressed as a percentage of the mass of dry soil. (For approximate dry density the ECMC is used in place of MC).

### 3.2.11 Moisture-density relationship

After the calculations have been completed the actual moisture contents are plotted against the respective dry densities for the five moisture-density specimens on Figure S1/2. The average of the dry densities and moisture contents of the three specimens compacted at the optimum ECMC are calculated and also plotted on figure S1/2.

The moisture-density curve should be drawn through the outer two points on each side of OMC and the peak of the curve biased to the average of the dry densities and moisture contents of the three specimens compacted at the optimum ECMC. The peak of the curve indicates the optimum moisture content (MoDOMC) and the maximum density (MoDMDD) of the fraction of the material smaller than 19 mm when compacted under modified effort.

### 3.2.11 Reporting of results

The MoDMDD shall be reported in  $\text{kg/m}^3$  to the nearest  $5 \text{ kg/m}^3$ .

The MoDOMC shall be reported in percent to the nearest first decimal figure.

## 3.3 Determination of Bulk Specific Gravity of Oversize Stone

### 3.3.1 Preparation of the stone

(i) The representative sample of the oversize aggregate that was dried to determine the moisture content is sieved through the 37.5 mm sieve and the material retained there on broken to just pass 37.5 mm sieve. This stone is thoroughly washed to remove dust or other coatings from the surface and sieved through the 19 mm sieve,

washing the smaller material passing to waste.

(ii) The aggregate retained on the 19 mm sieve is placed in a bowl and covered with water at room temperature and soaked for a period of  $24 \pm 4$  h.

(iii) The aggregate is removed from the water and allowed to drain for a few minutes. It is placed on a large absorbent cloth and dabbed with another cloth until all visible films of water are removed. It may be necessary to wipe the particles individually. A moving stream of air may be used to assist in the drying operation, but care is needed to avoid evaporation of water from the aggregate pores.

### 3.3.2 Method A - Using Pycnometer. Use Form S1/3A

(i) Two pycnometers are used. Ensure that each of the pycnometers is clean and determine its mass together with that of a marked sheet of glass (or cone lid).

(ii) The saturated surface dry aggregate is divided to give a representative sample of between 1600 and 2000 g. This is riffled to give two sub-samples.

(iii) The saturated surface dry sub-samples are places into the pycnometers. These should each take up 50% to 70% of the pycnometers' volume. The mass of each pycnometer, glass sheet and sub-sample is determined.

(iv) Clean water, at room temperature, is added to the pycnometers until it covers the aggregate. Three drops of the liquid detergent solution are added to the water, the pycnometer closed and shaken gently for two minutes. The pycnometer is filled to near the brim with water and allowed to stand for 30 minutes without disturbance.

(v) The pycnometer is filled with water at room temperature and the glass sheet is slid carefully over the brim from one side taking care that no air bubbles are trapped beneath the glass sheet. Alternatively the pycnometer is filled through the hole in the conical lid until it over flows. The pycnometer and glass sheet is dried and the mass of the pycnometer filled with aggregate and water plus the glass sheet (lid) is determined.

(vi) The contents of the pycnometer are transferred into a suitable oven drying pan and any finer aggregate that may have abraded during the shaking and transferring allowed to settle before the bulk of the water is syphoned off. The oven pan and aggregate is placed in an oven at 105 - 110 °C to dry, and the mass of the dry aggregate determined.

(vii) The pycnometer is cleaned and filled in the same manner with water at room temperature. The outside is dried and the mass of the pycnometer filled with water together with the glass sheet (lid) is determined.

(viii) The temperature of the water is determined. Care should be taken to have the temperature of the water vary as little as possible during the test. The density of the water is determined from Table 5.3

(ix) the calculations are done as indicated on form S1/3A.

### 3.3.3 Method B - Using immersed weight.

(i) The test sample in the saturated surface-dry condition is weighed. Record this and all subsequent weights to the nearest 0.1 g.

(ii) After weighing, the whole of the saturated-surface-dry test sample is placed in the wire basket sample container and its weight in water at the ambient room temperature is determined. Measure and record the temperature of the water. All entrapped air is removed before weighing by shaking the container while immersed.

The container should be immersed to a depth sufficient to cover it and the test sample during weighing. The wire suspending the container should be of the smallest practical size to minimize any possible effect of a variable immersed length.

(iii) Carefully remove the whole test sample from the wire basket and place in an oven drying pan. Dry the test sample to constant weight at a temperature of  $110 \pm 5^\circ\text{C}$ , cool in air at room temperature 1 to 3 h, or until the aggregate has cooled to a temperature that is comfortable to handle (approximately  $50^\circ\text{C}$ ), and weigh.

(iv) The bulk specific gravity at the recorded test temperature is calculated as follows:

$$\text{Bulk SG} = A/(B-C)$$

where:

- A = weight of oven-dry test sample in air, g,  
B = weight of saturated-surface-dry test sample in air, g,  
C = weight of saturated test sample in water, g.

(v) The percentage of absorption is calculated as follows:

$$\text{Absorption, \%} = 100(B - A)/A$$

### 3.4 Correction MoDMDD and MoDOMC for Total Sample

3.4.1 The moisture content of the two fractions of the air-dry sample was determined as part of step 3.1.3. The mass of the dry finer fraction and the dry oversize fraction is calculated as follows:

$$M_D = 100 \times M_M / (100 + MC)$$

where:

- M<sub>D</sub> = mass of the dry material (finer or oversize fraction), g,  
M<sub>M</sub> = mass of the air-dry (moist) material (finer or oversize fraction), g, and  
MC = moisture content of the respective finer or oversize fractions expressed as a percentage of the mass of the dry material.

- 3.4.2 The percentage mass of the finer fraction and of the oversize fraction of the whole dry sample is calculated as follows:

$$P_f = 100 \times M_{df} / (M_{df} + M_{dc})$$

and

$$P_c = 100 \times M_{dc} / (M_{df} + M_{dc})$$

where:

$P_f$	=	percent of finer fraction by weight,
$P_c$	=	percent of oversize fraction by weight,
$M_{df}$	=	mass of dry finer fraction, and
$M_{dc}$	=	mass of dry oversize fraction.

- 3.4.3 The corrected Reference Dry Density of the total material (combined finer and oversize fractions) is calculated as follows:

$$CD_D = 100 \times D_f \times G_M \times W_D / (D_f \times P_c + G_M \times W_D \times P_f)$$

where:

$CD_D$	=	corrected Reference Dry Density of the total material (combined finer and oversize fractions),
$G_M$	=	bulk specific gravity of oversize stone,
$D_f$	=	Modified Maximum Dry Density the finer fraction, and
$W_D$	=	Density of water at temperature of bulk specific gravity determination (see Table 5.3 eg. 997.1 kg/m <sup>3</sup> @ 25°C).

- 3.4.4 The corrected Optimum Moisture Content of the total material (combined finer and oversize fractions) is calculated as follows:

$$C_w = (w_f \times P_f + w_c \times P_c)$$

where:

$C_w$	=	corrected Optimum Moisture Content (%) of combined fractions,
$w_f$	=	Optimum Moisture Content (%) of the minus 19 mm fraction,
$w_c$	=	water absorption (%) of oversize fraction,

## 5 NOTES

- 5.1 When the material contains soft and friable aggregate which will break up during compaction. e.g. certain types of ferricrete, calcrete, soft sandstone, etc., such aggregate should be disintegrated. The operator should use his discretion in borderline cases and also as regards the extent to which particles should be

disintegrated.

- 5.2 The soil material is at or near its optimum moisture content when it can be firmly squeezed in the palm of the hand to form a lump that sticks together when the hand is opened, and breaks cleanly into two sections when "bent" between the thumb and spread fingers.

At moisture contents dry of optimum the material will not stick together or will tend to crumble when the lump "bent".

At moisture contents wet of optimum the soil will tend to stick together in a sticky cohesive mass that has a spongy feel and is readily dented by the thumb pressure.

At the optimum moisture content, the moisture in the soil fines is typically slightly less than the plastic limit.

- 5.3 With use the moulds become distorted, and they should be calibrated regularly to determine the mould factor as described below. A quality assurance system should be established within the laboratory to ensure that each mould is re-calibrated after it has been used for compacting 500 specimens.

The mould factor (F) of the mould is the reciprocal of the mould volume adjusted for the units in which the masses are expressed (grams), such that when multiplied by the mass of the compacted specimen, the density is obtained in kg/m<sup>3</sup>. For the standard mould of true dimensions F is 0.4710.

To determine F of the mould, both ends of the mould and the circumference of the spacer plate are greased and mould, spacer and base plate assembled. Any excess grease that may be squeezed out between the mould and spacer plate is removed.

The assembled mould plus the 180 mm square glass plate is weighed.

Water is now poured into the mould and when it is full the glass plate is slid gently over the top of the mould. Before the glass plate quite covers the mould, the final drops of water are added by means of a wash bottle or pipette. When the container is covered fully by the glass plate, no air bubbles should be trapped under the plate. The outside of the mould and glass plate is dried.

The mould with water and glass plate is weighed and the mass of water in the mould is calculated.

This determination should be carried out at least in duplicate.

The temperature of the water is measured and the factor (F) of the mould is obtained as follows:

$$F(\text{Kg}/\text{m}^3 \cdot \text{g}) = \frac{\text{Density water at test temperature}(\text{Kg}/\text{m}^3)}{\text{Mass water}(\text{g})}$$

The density of the water ( $W_d$ ) at the test temperature is given in Table 5.3.

Table 5.3 Density of water at various temperatures.

Temp. °C	Density of water (Kg/m <sup>3</sup> )	Temp. °C	Density of water (Kg/m <sup>3</sup> )
15	999.13	23	997.56
16	998.97	24	997.32
17	998.80	25	997.07
18	998.62	26	996.81
19	998.43	27	996.54
20	998.23	28	996.26
21	998.02	29	995.97
22	997.80	30	995.67

- 5.4 When the sample is divided as required by riffling to give the eight exactly similar specimens for compaction at the different moisture contents, the air-dry moisture content of all the specimens are for practical purposes the same.

With this assumption the determination of the amount of water to be added to the specimens to obtain the maximum dry density is independent of the air-dry moisture content.

The shape of the moisture-density relation can be determined by calculating an approximate dry density for each specimen using an estimated compaction moisture content (ECMC) which is the air-dry moisture content plus the percentage of water added to the air-dry specimen.

The optimum ECMC is the ECMC giving the maximum approximate dry density. The amount of water to be added to compact a specimen at it's maximum dry density is

the optimum ECMC less the estimated air-dry moisture content.

The subjective estimation of the air-dry moisture content is not critical, but the same value must be assigned to the eight specimens. For simplicity the air-dry moisture can be assumed to be zero.

- 5.5 In following this method, the operator should ensure that the optimum moisture content obtained is the true optimum, as some materials, particularly sandy and silty materials, often have a false optimum at a lower moisture content than the true optimum.

The plastic limit can be used as a gauge for the optimum moisture content, as in many cases the optimum moisture content is approximately 2 per cent lower than the plastic limit. In estimating the optimum moisture content from the plastic limit, it should be remembered that the percentage of material passing the 0,425 mm sieve must be considered because the higher the percentage of this fraction, the more closely the plastic limit and the optimum moisture content agree.

- 5.6 In special circumstances the maximum dry density and optimum moisture content may also be determined using other compaction efforts. The test procedure remains the same except for the number of layers, mass of the tamper, and number of blows.
- 5.7 Once material has been compacted it should not be used for another compaction, i.e. fresh material should be used for every compaction.
- 5.9 Throughout the test the utmost care must be exercised to keep the following as constant as possible:
- (a) Grading of material
  - (b) Uniform mixing-in of water
  - (c) Time of standing before compaction
  - (d) Evaporation of water during test
  - (e) Height of fall of tamper
  - (f) Free fall of tamper
  - (g) Distribution of tamper blows
  - (h) Thickness of successive layers
  - (i) Final layer to project between 5 and 15 mm above the top of the mould
  - (j) Finishing off of the top surface.

## REFERENCES

- AASHTO Designation C127-88; D4718-87; T180-90; T99-90; T193-81.
- ASTM Designation D1557-91; D 698-91, T1883-92.
- BS 1377 (1975), Tests 1; 12; 13; 14; 16.
- SABS 197.
- TMH 1, tests A7; A8.

GHANA HIGHWAY AUTHORITY:  
CENTRAL MATERIALS  
LABORATORY:

**FORM S1/1:  
REFERENCE DENSITY OF  
COHESIVE GRAVEL.**

DATE \_\_\_\_\_

SAMPLE NUMBER		
LOCATION:		
DESCRIPTION		

AIR DRY BULK SAMPLE.		Fraction < 19 mm	Fraction > 19 mm
1	Mass of air-dry fraction:		
2	Mass DRY fraction. g. (1)*100/(100+(11))		
3	Total DRY mass of sample. g.		
4	Percent dry mass fraction. %. (2)/(3)*100.	Pf =	Pc =

MOISTURE CONTENT :		Fraction < 19 mm	Fraction > 19 mm
5	Container number		
6	Mass of container. g.		
7	Mass container + air-dry subsample. g		
8	Mass container + dry subsample. g		
9	Mass of water. g. (7) - (8)		
10	Mass dry subsample. g. (8) - (5)		
11	Moisture content. %. (9)/(10)*100.		

From S1/2

Modified Maximum Dry Density the finer fraction,  $D_f$ , \_\_\_\_\_  
Optimum Moisture Content (%) of the minus 19 mm fraction,  $w_f$ , \_\_\_\_\_

From S1/3A, or S1/3B.

Bulk Specific Gravity of oversize stone,  $G_M$ , \_\_\_\_\_  
Density of water at BSG temperature,  $W_D$ , \_\_\_\_\_  
Water absorption (%) of oversize stone,  $w_c$ , \_\_\_\_\_

The corrected Reference Dry Density of the total material:

$$CD_D = \frac{100 \times D_f \times G_M \times W_D}{(D_f \times P_f + G_M \times W_D \times P_f)}$$

The corrected Optimum Moisture Content of the total material:

$$C_w = w_f \times P_f + w_c \times P_c$$

**SAMPLE NUMBER:**

## MOISTURE CONTENT DETERMINATION

MOISTURE CONTENT DETERMINATION							
14	Oven-pan Number.						
15	Mass Oven-pan. (g).						
16	Mass Oven-pan + Wet Soil. (g)						
17	Mass Oven-pan + Dry Soil. (g)						
18	Mass of Water. (g). (16)-(17)						
19	Mass Dry Soil. (g). (17)-(15)						
20	MOISTURE CONTENT(%). (18)/(19)*100						
21	Back Calc. Air-dry MC. (%) (20)-(4)						
22	DRY DENSITY. 100*(12)/(100+(20))						

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FORM S1/3A  
BULK SPECIFIC GRAVITY  
AND DENSITY OF STONE.  
PYCNOMETER METHOD.

DATE. \_\_\_\_\_

SAMPLE NUMBER					
LOCATION:					
		Specimen A		Specimen B	
	Pycnometer/jar Number				
a	Mass empty jar				
b	Mass jar + water				
c	Mass water, (b - a)				
d	Mass jar + SSD stone				
e	Mass SSD stone, (d - a)				
f	Mass Jar + SSD stone + water				
g	Mass water added, (f - d).				
h	Mass water displaced, (c - g).				
i	Pan number.				
j	Mass of pan.				
k	Mass pan + dry stone.				
l	Mass dry stone. (k - j).				
m	BULK S.G. (l / h)				
n	Temp. of water.				
o	Density water @ test temp.				
p	Bulk Density Stone, (m * o)				
q	Absorption, % 100 * (e - l) / l.				

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CENTRAL MATERIALS LABORATORY.

FORM S1/3B  
BULK SPECIFIC GRAVITY  
AND DENSITY OF STONE.  
IMMERSION METHOD.

DATE: \_\_\_\_\_

OPERATOR: \_\_\_\_\_

SAMPLE NUMBER.

LOCATION

a	Soaking bowl number					
b	Mass saturated surface-dry aggregate. g					
c	Mass saturated surface-dry aggregate in water. g					
d	Temperature of water. C					
e	Density of water at test temperature. kg/cub.m.					
f	Oven-pan number					
g	Mass oven-pan. g					
h	Mass oven-pan + dry aggregate. g					
i	Mass dry aggregate. g. (h - g)					
j	BULK SPECIFIC GRAVITY. (i) / ((b) - (c)).					
k	BULK DENSITY STONE. kg/cub.m. (j) * (e)					
l	Absorption, %. 100 * ((b) - (i)) / (i)					

FIGURE S1/1: Estimated Moisture Content - Approximate Dry Density Relationship.

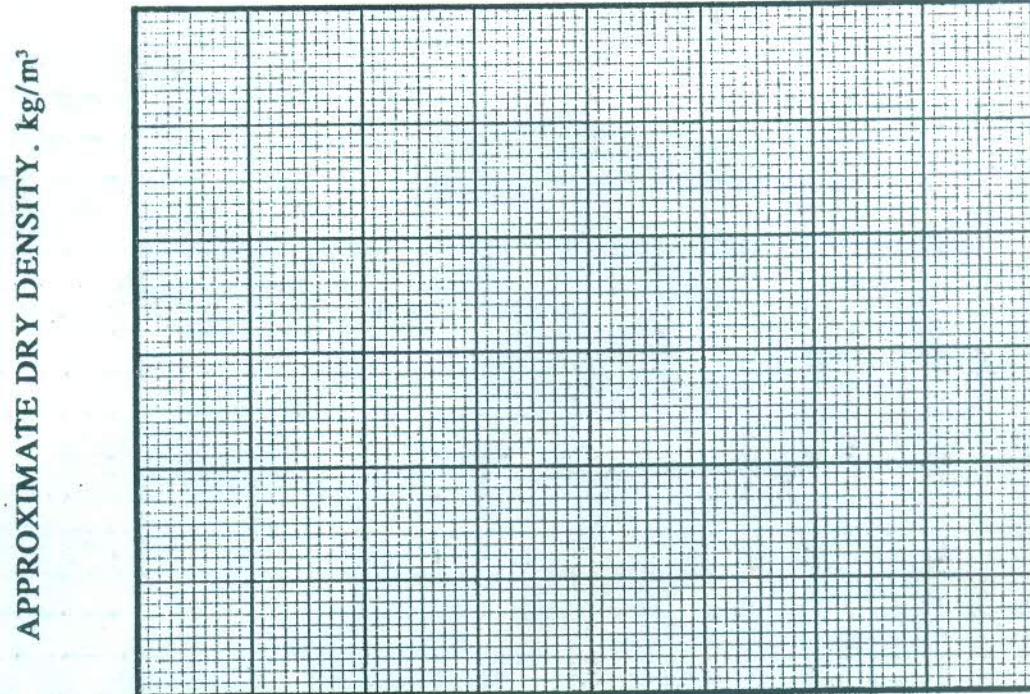
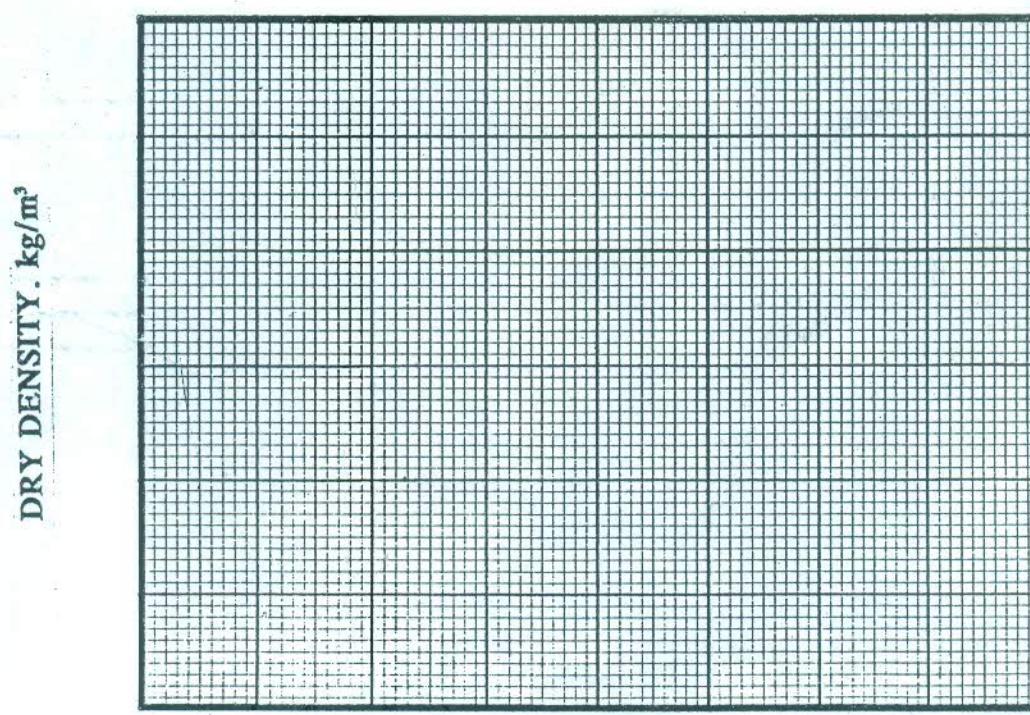


FIGURE S1/2: Compaction Moisture Content - Dry Density Relationship.



**DRAFT GHA TEST METHOD - SOILS 2.**

**THE DETERMINATION OF THE CALIFORNIA BEARING RATIO  
OF COHESIVE SOILS AND GRAVELS.**

## DRAFT GHA TEST METHOD - SOILS 2,

### THE DETERMINATION OF THE CALIFORNIA BEARING RATIO OF COHESIVE SOILS AND GRAVELS.

#### 1 SCOPE

- 1.1 This method of test is intended for determining the California Bearing Ratio of cohesive gravels when they are compacted in the laboratory at Modified Optimum Moisture Content using Modified effort compaction to produce samples that are at the Modified Maximum Dry Density.
- 1.2 The test is intended only for evaluating the quality of cohesive gravels for use as selected subgrade, subbase and base course layers of bituminous surface pavements.
- 1.3 The test is done as an extension of the determination of the maximum dry density and optimum moisture content of the portion of gravels passing the 19 mm sieve as described in method S1.
- 1.4 The test is conducted on the material from which aggregates retained on the 19.0 mm sieve have been removed. No compensation for the material retained on the 19 mm sieve by crushing it or replacing it with similar material passing 19 mm is to be done, as this compensation may give significantly different strength properties to the original material.
- 1.5 This test is not intended for use in characterising the bearing capacity of subgrade soils for the purpose of determining pavement thickness requirements as the moisture content for compaction and degree of compaction achieved are inappropriate.
- 1.6 The determination of the swell of the materials is also covered.
- 1.7 Definition

The California Bearing Ratio (CBR) of a material is the load in Newtons, expressed as a percentage of California standard values, required to allow a cylindrical piston with a cross sectional area of 1935 mm<sup>2</sup> to penetrate the surface of a compacted material at a rate of 1.27 mm (0.05 inch) per minute to depths of 2.54 mm (0.1 in.), and 5.08 mm (0.2 in.). The California standard values for these depths are 13.334 kN, and 20.016 kN respectively.

#### 2 APPARATUS

- 2.1 As required for test method S1 with the following additional apparatus.
- 2.2 Rigid cylindrical steel moulds,  $152.4 \pm 0.5$  mm in diameter,  $177.8 \pm 0.5$  mm high.
- 2.3 Perforated soaking base plate for each mould.

- 2.4 Annular  $4.536 \text{ kg} \pm 50 \text{ g}$  surcharge weights for use during soaking, or alternatively a combined unit for items 2.4 and 2.6, i.e. a surcharge weight of  $5.56 \text{ kg}$  with adjustable stem (Figure 2.4).
- 2.5 An annular  $5.56 \text{ kg} \pm 50 \text{ g}$  surcharge weight for use during penetration.
- 2.6  $1.024 \text{ kg} \pm 10 \text{ g}$  perforated plated with adjustable stem.
- 2.7 A tripod (Figure 2.4).

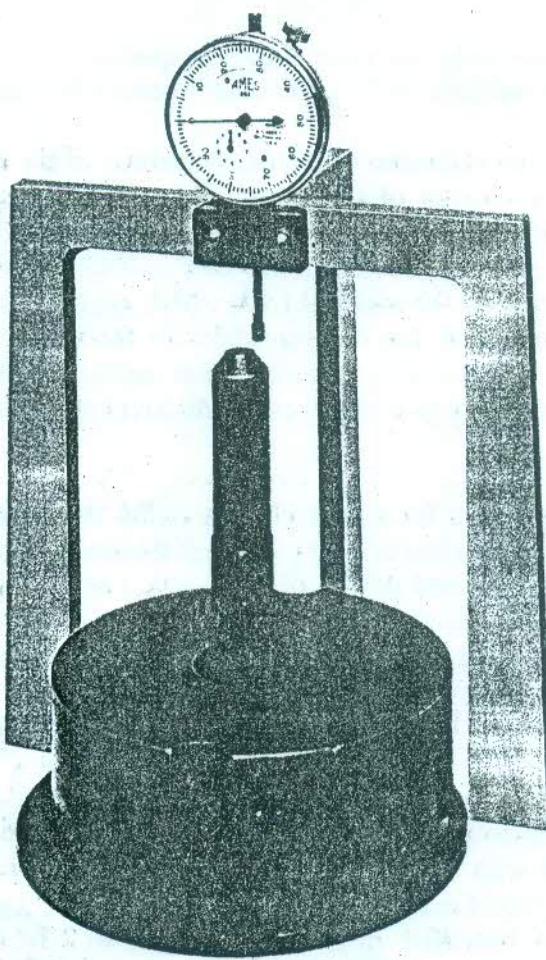


FIGURE 2.4  
Swell tripod and surcharge weight with adjustable stem.

- 2.8 A dial gauge reading in  $0.01 \text{ mm}$  with a range of  $25 \text{ mm}$ , to be fitted onto the tripod for measuring swell.
- 2.9 A dial gauge with  $0.127 \text{ mm}$  ( $0.0005 \text{ inch}$ ) divisions, range  $25.4 \text{ mm}$  and  $1.27 \text{ mm}$  per revolution, for measuring depth of penetration.

- 2.10 A compression testing machine with a capacity of at least 50 kN of total load, recordable to the nearest 50 N and capable of applying load at a rate of strain of 1.27 mm per minute.
- 2.11 A metal cylindrical piston with a diameter of  $49.6 \pm 0.5$  mm and weighing  $4.536 \text{ kg} \pm 50 \text{ g}$ . This is not attached to the compression machine. (See 6.1).
- 2.12 A stop-watch with a 60 second dial.
- 2.13 A soaking bath, about 300 mm deep.

### **3 METHOD**

#### **3.1 Preparation**

The material is prepared as set out in Method S1. Eight identical specimens of the material passing the 19 mm sieve were prepared and stored in sealed buckets. This was done in order to ensure that the material used for this test is exactly similar to that used for the determination of the moisture-density relationship. Five of these specimens were used to determine the compaction moisture content / density relationship. The remaining three are for the determination of CBR.

#### **3.2 Addition of water to give Optimum Moisture Content**

- 3.2.1 After each compaction of the determination of the moisture - density relationship the approximate dry density for the compacted specimen was calculated, using an assumed compaction moisture content. This was the percentage of water added to the air-dry specimen plus the estimated moisture content of the air-dried material. The latter is the same for all 8 specimens.
- 3.2.2 The Approximate Dry Density was plotted against the Estimated Compaction Moisture Content (ECMC) on Figure S1/1. The relative position of the points indicate the amount of water to be added to obtain the Optimum Moisture Content giving the Maximum Dry Density. The amount of water that needs to be added to each specimen to give the maximum dry density is calculated by deducting the assumed moisture content of the air-dry specimens from the optimum ECMC.
- 3.2.3 The three remaining specimens for the CBR determination are individually mixed with the amount of water required to give the optimum ECMC determined as described above. After thorough mixing each is returned to it's bucket, for the same time as the previous five specimens, to allow the moisture to become evenly distributed.

#### **3.3 Preparation of moulds**

- 3.3.1 The mould factors of three moulds should have been determined as set out in Method S1, Subsection 5.3 prior to commencing the test.
- 3.3.2 The clean dry moulds are lightly oiled on the inside and then weighed. One is assembled on the compaction base plate and spacer. Two 150 mm rounds of filter paper are placed on the spacer plate and the collar is fitted to the mould

### 3.4 Compaction

- 3.4.1 The moist material at the optimum moisture content is transferred from one of the buckets in which it has been stored to a mixing bowl. It is thoroughly but rapidly remixed and then covered with a damp sack, which should be kept over the material until compaction is completed so as to keep the moisture content at constant as possible.
- 3.4.2 The specimen is then compacted, trimmed and weighed in a similar manner to that described in method S1 paragraphs 3.2.3 and 3.2.4, but with a change to the taking of the sub-sample for determining the moisture content. As the specimen is not broken out of the mould until after the CBR determination, a sub-sample for determination of compaction moisture content is taken from the mixing bowl after compaction of the second layer. Further as the oven pans generally do not have covers or lids the mass of the pan and wet soil should be measured immediately after the sub-sample has been taken.
- 3.4.3 This process is repeated for the remaining two specimens.
- 3.4.4 After each compaction the wet and approximate dry densities are determined as in method S1 3.2.6 as a check on the accuracy of the testing procedure. The approximate dry density is plotted on Figure S1/1 and compared with the approximate maximum dry density indicated from the moisture-density relationship. For a carefully conducted test, each should be within +/- 10 kg/m<sup>3</sup> of the approximate maximum dry density.

### 3.5 Moisture content determination and checks.

- 3.5.1 The compaction moisture content for each specimen is calculated from the samples that have been dried in the oven. It is calculated to the nearest 0,1 per cent as follows:

$$MC = (a - b) / (b - c) \times 100$$

where MC = moisture content expressed as a percentage of the dry soil.  
a = mass of container and wet material (g)  
b = mass of container and dry material (g)  
c = mass of container only (g).

- 3.5.2 A check is to be made on these moisture contents by back calculating the air-dry moisture content of the specimens. These are the moisture content (%) determined by oven drying, less the percentage of water added to the air-dry specimen. In tests conducted to an acceptable standard the range of these back-calculated air-dry moisture contents should be within ± 0.2% of the average of the five back calculated air-dry moisture content from the moisture-density relationship.
- 3.5.3 Where this standard is achieved, the average of the moisture contents of the three CBR specimens should be within ± 0.2% of the Optimum Moisture Content determined from the moisture-density relationship.

3.5.4 Where these tolerances are exceeded the moisture -density and CBR test should be repeated giving more care to the following:

- the sample splitting and preparation to make 8 identical specimens;
- measuring the water to be added and sufficiency of mixing;
- keeping the moist specimen covered during compaction;
- obtaining the representative sample for moisture determination and weighing it promptly.

### 3.6 Soaking and swell measurement

3.6.1 Three perforated soaking base plates are placed ready with a 150 mm round of filter paper over the perforations. Each mould is then placed on the filter paper with the trimmed face of the specimen facing downwards and screwed down tightly onto the soaking plate. The surface of the moulded material which was against the spacer plate, and on which there is a round of filter paper, should be facing upwards. (See 6.2).

3.6.2 A perforated plate with adjustable stem is then placed on top of the filter paper on the surface of the material and a 4.536 kg surcharge weight is placed carefully on top of the plate. The whole assembly is then transferred to a soaking bath. To ensure that the water has free access to the bottom of the material in the mould, suitable strips are fitted to the bottom of the bath, or, alternatively, a layer of small stone chippings is placed in the bath. The tripod with the dial gauge is then placed on the mould with the rear leg on a mark on the rim of the mould so that the same position is used for subsequent readings of the swell. The stem of the perforated plate is adjusted so that the dial gauge reads 1 mm.

3.6.3 After removal of the tripod and dial gauge, the bath is filled with water to a depth of about 10 mm above the top of the mould. The top of the stem of the soaking plate should be above the water.

3.6.4 The mould with material is allowed to soak for four days. Another swell reading with the tripod and dial gauge should be taken at this time, with the rear leg in the same position as for the initial reading.

### 3.7 Draining after soaking

3.7.1 After four days' soaking, and taking the swell measurement, the mould with perforated plate, etc., is removed from the water. The water is poured out by holding the mould in a slanting downward position and holding the perforated plate and soaking weight in position. It is held like this for about one minute and then returned to its normal position and allowed to drain for 15 minutes on a grid or a layer of chippings. The perforated plate with stem and the soaking weight are removed carefully.

NOTE: In all handling of the moulded material care should be exercised not to jar the material or loose any material from the mould.

### 3.8 Penetration

- 3.8.1 The mould containing the material, still screwed down on the soaking plate, is placed in the press and the 5.56 kg annular surcharge weight is placed carefully on top of the material in the recess of the mould as centrally as possible. The penetration piston is seated on the surface of the material through the centre of the annular weight (see 6.1).
- 3.8.2 The depth gauge is fitted in such a manner that the depth of penetration of the piston into the material can be measured. For presses with manual speed control, the speed of penetration is determined by means of the stopwatch. It is therefore desirable to have the stop-watch mounted next to the dial gauge, with the two zeros at the top of the dials in order that the rotation of the penetration gauge can be synchronised with the sweep of the second hand of the stop watch.
- 3.8.3 After setting the depth gauge to zero, the load is applied at a uniform rate of penetration of 1.27 mm (0.05 inch) per minute. Load readings are taken at every 0.508 mm (0.02 inch) of penetration as recorded on the depth gauge and recorded on form S2/2. The piston is allowed to penetrate beyond 5.08 mm (0.2 inch) to allow for an extension in the stress-strain curve if a correction is required which results in a considerable shift of the zero depth of penetration. With a depth gauge registering 1.27 mm per revolution, and a stop-watch with a 60-second dial, the hands of the gauge and the stop-watch should move round together.
- 3.8.4 After the penetration has been completed, the penetration piston, surcharge weight and soaking base plate are removed and the mass of the mould and soaked specimen determined. This is recorded on form S2/1 and the moisture content after soaking determined.

## 4 CALCULATIONS

4.1 The calculations of moisture content, wet and dry density are made as described in method S1.

4.2 Swell (per cent)

$$S = 100 \times (K-L)/116.4$$

where

S = swell expressed as a percentage of the moulded material before soaking, i.e. 116.4 mm

K = dial gauge reading after four days' soaking, mm.

L = dial gauge reading before soaking, mm.

The swell is reported to the nearest first decimal point on Form S2/1.

#### 4.3 California Bearing Ratio

- 4.3.1 For each specimen the stress-strain curve is drawn on a natural scale, i.e. the load readings are plotted against the depth of penetration as given on form S2/2.

In some cases the curve will have a concave downward shape, varying from an almost straight line relationship to a curve in which the rate of increase in the load readings decreases with the depth of penetration. No adjustment is made for the zero in this case.

However, many curves have a concave upward shape in the initial stages, and in order to obtain true stress-strain relationships, such curves should be corrected by extending the straight line portion of the curve downwards until it intersects the abscissa. The point of intersection is then taken as the zero depth of penetration.

Sometimes, particularly when dealing with material with a collapsing grain structure, it is found that the penetration curve has a long concave upward shape from the beginning to beyond 2.54 mm penetration where the first standard load reading is made. In such a case it is difficult and sometimes impossible to decide where the zero point adjustment should be made. Such materials will show the same collapsing properties in the field and since there is a danger that the evaluation may be too high, no zero point adjustment should be made.

Using this new zero, where applicable, the load is read off at 2.54 mm, and 5.08 mm penetration. The readings for the above depths of penetration are then expressed as a percentage of the California standard for that penetration.

This percentage is called the California Bearing Ratio (CBR) at the particular depth of penetration.

- 4.3.2 The CBR at 2.54 mm penetration is used for assessing the quality of materials.

- 4.3.3 Moisture content after soaking.

$$\text{Moisture Content after Soaking \%} =$$

$$\frac{100 \times (\text{Mass wet specimen after soaking} - \text{Mass dry specimen before soaking})}{\text{Mass dry specimen before soaking}}$$

### 5 REPORTING RESULTS.

- 5.1 The CBR of the material is reported as the average of the CBRs obtained on the three specimens compacted as described above.
- 5.2 The dry density associated with the CBR is the average of the three densities obtained. The maximum dry density obtained from the moisture density relation is quoted for comparison.

- 5.3 The compaction moisture content associated with the CBR is the average of the three compaction moisture contents obtained. The optimum moisture content obtained from the moisture density relation is quoted for comparison.
- 5.4 The saturated moisture content after soaking is the average of the three soaked moisture contents.

## 6 NOTES

- 6.1 If the penetration piston is attached to the penetration machine, a load of 45 N should be applied to the piston before the dial gauge is set at zero. This load is the same as the weight of a loose piston and ensures that the piston is truly seated.
- 6.2 Particular care should be taken with materials which do not adhere to the side of the mould and are liable to drop out of the mould if the mould is handled without the base plate. In this instance, after the surface of the moulded material has been finished off, a weighed soaking plate is inverted over the top of the moulded material on which a round of filter paper has already been placed. The soaking plate is screwed into position and the mould and soaking base plate is carefully removed from the compaction base plate and spacer, and inverted. The mould, material and soaking plate are weighed.
- 6.3 When granular materials are compacted, it will be found that the filter paper on the spacer plate side of the moulded material becomes fractured and should be covered with a fresh round of filter paper before the perforated plate with stem is placed in position.
- 6.4 Although it is not necessary to determine the mould factor and mass of the moulds for each test, these should nevertheless, be checked regularly.

## 7 REFERENCES.

AASHTO Designation: T 180-90; T 193-81; T 99-90.  
ASTM Designation: D 1883-92; D 1557-91; D 698-91;  
BS 1377 (1975), Tests 1; 12; 13; 14; 16.  
TMH 1, Tests A7; A8.

GHANA HIGHWAY AUTHORITY:  
CENTRAL MATERIALS LABORATORY.

FORM S2/1.  
CBR DATA FORM

DATE: \_\_\_\_\_

OPERATOR: \_\_\_\_\_

SAMPLE NUMBER:

MODIFIED COMPACTION.

MDD:

OMC:

NOTE: Data marked ( M/D (row No.) ) \* to be transferred from Moisture/Density Form.

Row	Parameter						
1	Mould Number.(M/D7)						
	No. Layers						
	No. Blows/Layer						
	Condition	Compacted	Soaked	Compacted	Soaked	Compacted	Soaked
2	Mass of mould.(M/D9)	*	*	*	*	*	*
4	Mass mould + wet soil.(M/D10)	*		*		*	
5	Mass wet soil.(M/D11)	*		*		*	
7	Compaction Moisture Content,%. (M/D20)	*	----	*	----	*	----
8	Mass dry soil. $100*(5)/(100+(7))$						
9	MC after soaking $100*((5)-(8))/(8)$	----		----		----	

SWELL

Initial Reading, mm.		----	----	----	----	----
Final reading after 4 day soak, mm.	----		----	----	----	
Swell: mm / %	----	/	----	/	----	/

CBR

Compacted Dry Density. (M/D22)		----	----	----	----	----
Relative Compaction, %MDD.		----		----		----
CBR @ 0.1 in. penetration.						
CBR @ 0.2 in. penetration.						

GHANA HIGHWAY  
AUTHORITY:  
CENTRAL MATERIALS  
LABORATORY.

FORM S2/2  
CBR LOAD - PENETRATION  
DATA RECORD.

DATE COMPACTED: \_\_\_\_\_

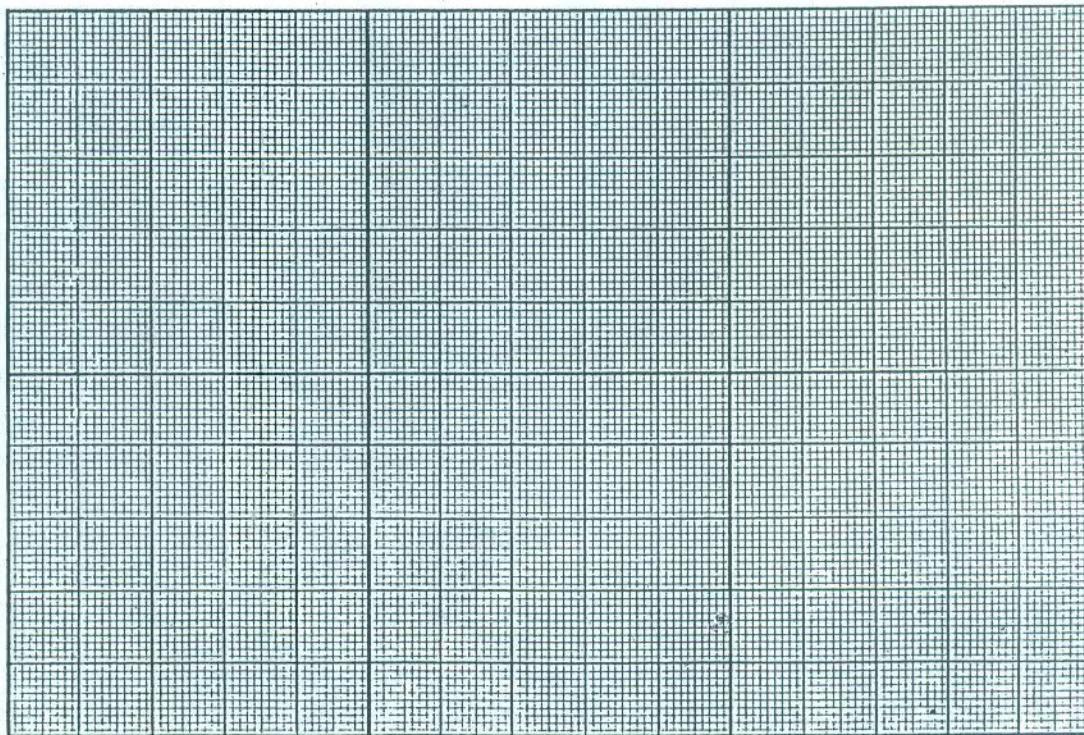
DATE PENETRATED: \_\_\_\_\_

SAMPLE NUMBER: \_\_\_\_\_

CBR LOAD RING NUMBER:	LOAD RING FACTOR: (kN/Div.):
STANDARD LOAD @ 0.1 in. Pen. 13.344 kN	STANDARD LOAD @ 0.2 in. Pen. 20.016 kN

PLUNGER PENETRATION (Inches)	SPECIMEN 6			SPECIMEN 7			SPECIMEN 8					
	MOULD No.:	Load ring dial Divs.	Corrected dial Divs	CBR.%	MOULD No.:	Load ring dial Divs.	Corrected dial Divs	CBR.%	MOULD No.:	Load ring dial Divs.	Corrected dial Divs	CBR.%
0.00												
0.02												
0.04												
0.06												
0.08												
0.100												
0.12												
0.14												
0.16												
0.18												
0.200												
0.22												
0.24												
0.26												

LOAD-RING DIAL (Divisions).



0.000

0.100

0.200

0.300

PLUNGER PENETRATION. (Inch)

**DRAFT GHA TEST METHOD -SOILS 3.**

**THE DETERMINATION OF REFERENCE DENSITY FOR COMPACTION  
CONTROL OF GRADED CRUSHED-STONE SUB-BASE AND BASE.**

## DRAFT GHA TEST METHOD -SOILS 3.

### THE DETERMINATION OF REFERENCE DENSITY FOR COMPACTION CONTROL OF GRADED CRUSHED-STONE SUB-BASE AND BASE.

#### 1 SCOPE

- 1.1 The reference density for the control of compaction of graded crushed-stone is the Apparent Density of the whole graded sample determined as described below.
- 1.2 This test method applies only to cohesionless graded crushed stone material derived from crushing hard durable and unweathered rock or boulders.
- 1.3 Where the required grading has been obtained by the addition of natural cohesive fines from weathered materials or by crushing of coarse weathered gravels the reference density should be determined as for Cohesive Gravels (GHA S1).
- 1.4 This method is used in association with the measurement of field density done using the sand replacement method.

#### 2 APPARATUS

- 2.1 A balance to weigh 5 kg accurately to within 0,5 g.
- 2.2 A large pycnometer of at least 1 litre capacity, eg a preservative jar with a smooth flat rim, a glass sheet to act as a lid (or conical lid).
- 2.3 A thermostatically controlled water bath capable of maintaining a temperature of  $25^{\circ}\text{C} \pm 1^{\circ}\text{C}$ .
- 2.4 A drying oven capable of maintaining the temperature between  $105^{\circ}\text{C}$  and  $110^{\circ}\text{C}$ .
- 2.5 A thermometer marked from 0 -  $110^{\circ}\text{C}$ .
- 2.6 Towels.
- 2.7 Liquid detergent, eg Teepol (10%) solution.

#### 3 METHOD

- 3.1 Take all the material as obtained from a 150 mm diameter sand replacement density hole in the crushed stone layer, place in an oven pan of known weight, weigh and record the mass.
- 3.2 Dry the material in the oven at  $105^{\circ}\text{C} - 110^{\circ}\text{C}$  to a constant mass and reweigh, thus also using the whole sample for determining the field moisture content.

3.3 When the dried material, which should be more than 3000 g, is too much for one pycnometer, the sample is riffled to give two or four sub-samples so that they each take up less than three quarters of the pycnometers' volume.

3.4 Ensure that each of the pycnometers is clean and determine its mass together with that of its marked sheet of glass (or cone lid).

3.5 Place the dried sub-samples into the pycnometers and determine the mass of each pycnometer, glass sheet and sample.

3.6 Add clean water at the ambient temperature to each pycnometer until they are approximately three quarters full. Add three drops of the liquid detergent solution to the water, close the pycnometers and shake each thoroughly for two minutes. Fill the pycnometers to near the brim with water. Leave them to stand for 30 minutes without disturbance. The temperature of the room and the water should be kept as constant as possible.

Table 3.1 Density of water at various temperatures.

Temp. °C	Density of water (Kg/m <sup>3</sup> )	Temp. °C	Density of water (Kg/m <sup>3</sup> )
15	999.13	23	997.56
16	998.97	24	997.32
17	998.80	25	997.07
18	998.62	26	996.81
19	998.43	27	996.54
20	998.23	28	996.26
21	998.02	29	995.97
22	997.80	30	995.67

3.7 Without shaking or jarring the pycnometers they are each placed on a spread-out towel and filled with water at the same ambient temperature. Carefully slide the glass sheet over the brim from one side. Make sure that no air bubbles are trapped beneath the glass sheet. Dry the entire pycnometer and glass sheet carefully and determine the mass of each filled pycnometer plus the glass sheet.

3.8 Remove the contents of the pycnometers, clean and fill them in the same manner with water at the same ambient temperature. Dry and determine the mass of each pycnometer filled with water together with the glass sheet.

3.9 The temperature of the water is measured and it's density determined from Table 3.1.

#### 4 CALCULATION

The apparent density of the material is calculated as follows:

$$\text{Mass of pycnometer + glass} = a$$

$$\text{Mass of pycnometer + glass sheet + material} = b$$

$$\text{Mass of material only} = (b-a)$$

$$\text{Mass of pycnometer + material + water + glass sheet} = d$$

$$\text{Mass of pycnometer + water + glass sheet} = e$$

$$\text{Apparent density of material (kg/m}^3) =$$

$$(b - a) / ((e - a) - (d - b)) \times (\text{density water at test temperature})$$

#### 5 NOTES

5.1 Do not apply suction to the water to remove air.

5.2 Where two or four pycnometers are used, the apparent density shall be calculated from the weighted average of the results.

5.3 For aggregates where the water absorption exceeds 1,0% the soaking period may be extended.

GHANA HIGHWAY AUTHORITY,  
CENTRAL MATERIALS LABORATORY.

FORM S3/1.  
APPARENT DENSITY  
GRADED CRUSHED STONE  
PYCNOMETER METHOD.

DATE: \_\_\_\_\_

OPERATOR: \_\_\_\_\_

SAMPLE NUMBER.

PROJECT:

	Sample location				
	Sub-sample.	a	b	c	d
	Pycnometer number.				
a	Mass pycnometer + lid. g.				
b	Mass pycnometer + lid + dry crushed stone. g.				
c	Mass dry crushed stone. g. (b - a)				
d	Mass pycnometer + lid + stone + water. g.				
e	Mass pycnometer + lid + water. g.				
f	Temperature of water. C.				
g	Density of water at test temperature. Kg/cub.m.				
h	APPARENT DENSITY. (g * c / ((e - a) - (d - b)))				

Weighted average APPARENT DENSITY. (sum c \* h) / (sum c).

**DRAFT GHA TEST METHOD -SOILS 4.**

**THE DETERMINATION OF REFERENCE DENSITY FOR COMPACTION  
CONTROL OF COHESIONLESS SANDS AND FINE GRAVELS.**

## DRAFT GHA TEST METHOD -SOILS 4.

### THE DETERMINATION OF REFERENCE DENSITY FOR COMPACTION CONTROL OF COHESIONLESS SANDS AND FINE GRAVELS.

#### 1 SCOPE

- 1.1 The reference density for the control of compaction of cohesionless sands and gravels is the Maximum Dry Density (MDD) achieved in the laboratory using vibrating hammer compaction similar to BS 1377 (1975) Test 14 as described below.
- 1.2 This test method covers the laboratory sample preparation and compaction procedures used to determine the relationship between moisture content and dry density of soils (compaction curve) when compacted in a 152.4 mm diameter mould using a vibrating hammer.
- 1.3 This test is suitable for cohesionless sands and gravels passing the 37.5 mm BS test sieve, and may be used for graded crushed stone. (see Note 1).

#### 2 APPARATUS.

- 2.1 A rigid cylindrical steel mould,  $152.4 \pm 0.5$  mm in diameter,  $177.8 \pm 0.5$  mm high, with detachable collar and compaction base plate with a  $61.4 \pm 0.1$  mm thick spacer plate firmly attached to the base plate. The mould should be easily attached to the base plate such that with the spacer plate inside the mould the effective depth of the mould shall be  $116.4 \pm 0.5$  mm. The compaction base plate and spacer should be firmly bolted onto a concrete block at least 300 mm thick and weighing at least 100 kg. A thin coating of oil shall be applied to the internal faces of the mould and collar before each test.
- 2.2 An electric vibrating hammer having a power consumption between 600 W and 750 W and operating at a frequency between 25 Hz and 45 Hz. (see Note 2).
- 2.3 A steel tamper attached to the vibrating hammer. The tamper shall have a circular foot of 145 mm diameter and shall not exceed 3 kg in mass.
- 2.4 A stop watch or stop clock.
- 2.5 A steel straight-edge, about 300 mm in length.
- 2.6 A riffler with 50 mm slot width.
- 2.7 A balance to weigh up to 20 kg, accurate to 1 g.
- 2.8 A balance to weigh up to 2 kg, accurate to 0.1 g.
- 2.9 Sieve: 37.5 complying with BS 410 or ISO 3310/1 and ISO 3310/2.

- 2.10 A device which will enable the sample depth to be measured to an accuracy of 0.5 mm, e.g. a vernier depth gauge.
- 2.11 An iron mortar and pestle and a rubber-tipped pestle.
- 2.12 8 buckets of about 10 litre capacity with lids, or 8 basins approximately 350 mm in diameter.
- 2.13 A mixing basin, approximately 500 mm in diameter.
- 2.14 A large metal tray ( a convenient size is one about 600 mm square with sides 80 mm deep).
- 2.15 A garden trowel.
- 2.16 A spatula.
- 2.17 Suitable containers to hold about 1500 g of material for the determination of moisture contents.
- 2.18 A drying oven, thermostatically controlled and capable of maintaining a temperature of 105 to 110 °C.
- 2.19 Measuring cylinders, 1000 ml and 500 ml in capacity.
- 2.20 A spray-can or sprinkler.
- 2.21 Filter paper disks, 150 mm diameter.
- 2.22 A sample extruder (optional), i.e. a jack, lever, frame or other device adapted for the purpose of extruding compacted specimens from the mould.

For calibrating the mould:

- 2.23 A 180 x 180 mm glass plate approximately 7 mm thick.
- 2.24 Lubricating grease.
- 2.25 A wash bottle with fine spout.
- 2.26 A thermometer measuring 0 to 50 °C.

### 3 METHOD

#### 3.1 Preparation

- 3.1.1 An adequate quantity of the material is air-dried to give a sample of more than 56 kg passing the 37.5 mm sieve. If the material contains soil aggregations, these should be disintegrated as finely as possible with a mortar and pestle without reducing the

natural size of the individual particles. The sample is sieved through a 37.5 mm sieve, and the mass of the fractions finer and coarser than 37.5 mm weighed and recorded.

- 3.1.2 The finer fraction of the material is mixed thoroughly and the mass reduced to about 57 kg by removing some of the sample. The 57 kg of sample is then divided by successive riffing so as to obtain eight specimens (sub-samples) that can be considered identical for practical purposes. Five of these specimens are used for the compaction to determine the moisture-density relationship, three for compaction at the optimum moisture content to define the maximum dry density more accurately and for CBR determinations where these are also required.
- 3.1.3 For convenience the mass of the material in each of the eight specimens should be made the same (7 kg is recommended) by removing or adding small amounts of material. The mass of these specimens should be recorded to nearest 1 g on Form S4/2. The eight specimens should then be stored in a buckets with close fitting lids.

### 3.2 Mixing

- 3.2.1 Five specimens having moisture contents such that they bracket the estimated optimum moisture content need to be prepared.
- 3.2.2 A specimen having a moisture content close to optimum should be prepared first. For these materials the amount of water to be mixed with air dried soil to give the maximum dry density will vary only a little with the type of material under test. In general, a moisture content of 5 % would be suitable for the first compaction.
- 3.2.2 Transfer one specimen to the mixing basin, and form a depression in the soil to receive the water added.
- 3.2.2 Add the 5 percent of water to the sample and mix thoroughly. It is important that the water is mixed thoroughly and adequately with the soil, since inadequate mixing gives rise to variable test results. With a thorough mixing there is no need to let the sample stand for the moisture to equilibrate and the sample can be compacted.

### 3.3 Preparation of the mould

- 3.3.1 The average cross-sectional area of the mould is determined as set out in 5.3. and recorded on Form S4/1.
- 3.3.2 The same mould should be used for all the compactions used to determine a moisture-density relationship.
- 3.3.3 The clean, dry mould with the collar firmly attached is weighed accurately and the mass recorded to the nearest 1 g on Form S4/1. It is then assembled on the compaction base plate with the spacer attached. Two 150 mm diameter filter papers are placed on the spacer plate to prevent the material from sticking to the plate.

### **3.4 Compaction**

- 3.4.1 The moist material is now mixed again, and a quantity sufficient to give a specimen 117 mm to 123 mm deep after compaction in the mould, shall be compacted in the mould in three layers of approximately equal mass, using the vibrating hammer fitted with the circular steel tamper.
- 3.4.2 Each layer shall be compacted for a period of 60 seconds and throughout this period a firm downward pressure shall be applied to the vibrating hammer so that the total downward force, including that resulting from the mass of the hammer and tamper, shall be 300 N to 400 N (see Note 5.6).
- 3.4.3 When the final layer has been compacted, any loose material around the sides of the mould shall be removed from the surface of the specimen. The straightedge shall be laid across the top of the collar of the mould and the depth of the specimen below the top of the collar measured to an accuracy of 0.5 mm. Readings shall be taken at four points spread evenly over the surface of the specimen, all at least 15 mm from the side of the mould, and the mean height,  $h$ , of the specimen calculated. If the specimen is more than 123 mm or less than 117 mm in height, it shall be rejected and a further test carried out on a new specimen.
- 3.4.4 The mould, together with the collar and soil should then be carefully removed from the compaction base plate, weighed and the mass recorded to the nearest 1 g.
- 3.4.5 The compacted material can now be removed from the mould with an extruder or other suitable means.

### **3.5 Determination of moisture content**

- 3.5.1 A representative sample is taken from the material removed from the mould and placed in a suitable container for the determination of the moisture content. The mass of the sample should be at least 1000 g.

Where the specimen is extruded, this is to be obtained by slicing the compacted specimen axially through the centre and removing the material from the full height of the cut faces.

Where it is broken out of the mould the material should be quickly broken with the cutting straight-edge, mixed, and then quartered twice to give a representative moisture sample that is about one quarter of the material in the mould.

- 3.5.2 The moist sample is weighed immediately to the nearest 0.1 g and dried to constant mass in an oven of 105 to 110 °C. The moisture content is determined to the nearest 0.1 per cent. The results are recorded on Form S4/1 or any similar form.

### **3.6 Calculation of approximate dry density**

- 3.6.1 Calculate the wet density of the compacted specimen, as explained in 4.2, and indicated on Form S4/1.

3.6.2 Calculate the approximate dry density using as moisture content an assumed moisture of the air dry sample plus the percentage of water added. (See Note 5.4)

### 3.7 Establishing additional points of the moisture-density relationship curve

3.7.1 Paragraphs 3.4 to 3.6 above describe the determination of the density of the sample judged close to the OMC and is one point of the moisture-density relationship curve. Additional points have still to be obtained.

3.7.2 The whole procedure is, therefore, carried out on each of the other four basins of prepared material at various moisture contents.

3.7.3 The second and third specimens should be compacted at 1% and 2% moisture above the first.

3.7.4 After each compaction the approximate dry density for the compacted specimen is calculated, using an approximate moisture content which is the percentage of water added plus the estimated moisture content of the air-dried material. The same moisture content for the air-dry specimens must be used throughout.

3.7.5 The Approximate Dry Densities are plotted against the Estimated Compaction Moisture Content (ECMC) on Figure S4/1. The relative position of the three points will indicate the amount of water to be added for the other two specimens. At least two points differing by about 1 per cent in moisture content should be obtained on either side of the peak of the moisture-density curve.

3.7.6 Figure S4/1 is used to estimate the optimum ECMC that will give the maximum approximate dry density. The amount of water that needs to be added to the specimen to give the maximum dry density is calculated by deducting the assumed moisture content of the air-dry specimens from the optimum ECMC.

#### 3.7.7 Remaining 3 specimens.

(i) The remaining three specimens are used to determine the VHMDD and VHOMC with greater accuracy by enabling the three dry densities to be averaged. This greater accuracy is required where statistic procedures are used for the quality control of degree of field compaction. They can also be used for the determination of CBR as described in method S2.

(ii) These three specimens are individually mixed with the amount of water required to give the optimum ECMC determined as described above.

(iii) They are compacted in the same manner as the previous specimens (3.4 to 3.6). A small difference in this procedure is necessary for the specimens to be used for determination of CBR. For this purpose a sample for determination of compaction moisture content is taken from the mixing bowl after compaction of the second layer, as the specimen is not broken out of the mould until after the CBR determination.

(iv) After each compaction the wet and approximate dry densities are determined as in 3.6. The approximate dry density is plotted on Figure S4/1 and compared with the approximate maximum dry density indicated from the moisture-density relationship. For a carefully conducted test, each should be within +/- 10 kg/m<sup>3</sup> of the approximate maximum dry density.

## 4 CALCULATIONS

### 4.1 Moisture content.

Calculate the moisture content of each specimen to the nearest 0.1 per cent as follows:

$$MC = (a - b) / (b - c) \times 100$$

where MC = moisture content expressed as a percentage of the dry soil.  
a = mass of container and wet material (g)  
b = mass of container and dry material (g)  
c = mass of container only (g).

A check is to be made on these moisture contents by back calculating the air-dry moisture content of the specimens. These are the moisture content (%) determined by oven drying, less the percentage of water added to the air-dry specimen. In tests conducted to an acceptable standard the range of these back-calculated air-dry moisture contents should be less than 0.4%.

An odd result is indicative of an error in weighing or calculation of the moisture content.

Where this range is exceeded more care is indicated in one or more of the following:

- the sample splitting and preparation to make 8 identical specimens;
- the moisture addition and mixing;
- covering the moist specimen during compaction;
- obtaining the representative sample for moisture determination.

### 4.2 Wet density

Calculate the wet density ( $D_w$ ) for each point to nearest 1 kg/m<sup>3</sup> as follows:

$$D_w = W \div (CSA \times h)$$

where: W = mass of wet material (g)  
h = mean height of the specimen (mm)  
CSA = the average cross-sectional area factor of the mould determined as in 5.3. For the standard mould of true dimensions this is 0.01815. This takes into account that the specimen weight is in grams and its height is in millimetres.

#### 4.3 Dry density

Calculate the dry density ( $D_d$ ) for each point to nearest 1 kg/m<sup>3</sup> as follows:

$$D_d = 100 \times D_w / (100 + MC)$$

where  $D_d$  = dry density (kg/m<sup>3</sup>)  
 $MC$  = moisture content expressed as a percentage of the mass of dry soil.

#### 4.4 Moisture-density relationship

After the calculations have been completed, the actual moisture contents are plotted on Figure S4/2 against the respective dry densities for the five moisture-density specimens. The average of the dry densities and the moisture contents of the three specimens compacted at the optimum ECMC are calculated and also plotted on figure S4/2.

The moisture-density curve should be drawn through the outer two points on each side of OMC and the peak of the curve biased to the average of the dry densities and moisture contents of the three specimens compacted at the optimum ECMC. The peak of the curve indicates the optimum moisture content (VHOMC) and the maximum density (VHMDD) of the fraction of the material smaller than 37.5 mm when compacted using the vibrating hammer.

#### 4.5 Reporting of results

The VHMDD shall be reported in kg/m<sup>3</sup> to the nearest 5 kg/m<sup>3</sup>.

The VHOMC shall be reported in percent to the nearest first decimal figure.

### 5 NOTES

- 5.1 The vibrating hammer method is preferred to Tests S1 in the case of highly permeable soils, such as clean gravels, uniformly graded and coarse clean sands, and graded crushed stone. Results given by vibrating hammer method provide a satisfactory guide to the optimum moisture content for site compaction of these materials using vibrating rollers. For natural sands and gravels the maximum density given by the test is only slightly greater than that obtainable on the site.
- 5.2 It is important that the hammer used shall have been maintained properly in accordance with the manufacturer's instructions and that its working parts are not badly worn.
- 5.3 To determine the cross-sectional area factor (CSA) of the mould, both ends of the mould and the circumference of the spacer plate are greased and mould, spacer and base plate assembled. Any excess grease that may be squeezed out between the mould

and spacer plate is removed.

The effective height from the spacer plate to the top of the mould is measured with a vernier depth gauge at six positions and the average height (h) mm calculated and reported to nearest first decimal figure.

The assembled mould plus the 180 mm square glass plate is weighed.

Water is now poured into the mould and when it is full the glass plate is slid gently over the top of the mould. Before the glass plate quite covers the mould, the final drops of water are added by means of a pipette or wash bottle. When the mould is covered fully by the glass plate, no air bubbles should be trapped under the plate. The outside of the mould and glass plate is dried.

The mould with water and glass plate is weighed and the mass of water in the mould is calculated.

Table 5.3 Density of water at various temperatures.

Temp. °C	Density of water (Kg/m <sup>3</sup> )	Temp. °C	Density of water (Kg/m <sup>3</sup> )
15	999.13	23	997.56
16	998.97	24	997.32
17	998.80	25	997.07
18	998.62	26	996.81
19	998.43	27	996.54
20	998.23	28	996.26
21	998.02	29	995.97
22	997.80	30	995.67

This determination should be carried out at least in duplicate.

The temperature of the water is measured and the density of the water ( $\text{kg/m}^3$ ) at this temperature determined from the table 5.3.

The CSA factor is numerically equal to:

$$\frac{(\text{Mass of water (g)})}{(\text{Density of water at test temperature}) \times (\text{mean specimen height (mm)})}$$

This will give the densities of the compacted soil in  $\text{kg/m}^3$  when the mass of the soil is in grams and the height of the specimen is in millimetres.

- 5.4 When the sample is divided as required by riffling to give the eight exactly similar specimens for compaction at the different moisture contents, the air-dry moisture content of all the specimens are for practical purposes the same.

With this assumption the determination of the amount of water to be added to the specimens to obtain the maximum dry density is independent of the air-dry moisture content.

The shape of the moisture-density relation can be determined by calculating an approximate dry density for each specimen using an estimated compaction moisture content (ECMC) which is the air-dry moisture content plus the percentage of water added to the air-dry specimen.

The optimum ECMC is the ECMC giving the maximum approximate dry density. The amount of water to be added to compact a specimen at its maximum dry density is the optimum ECMC less the estimated air-dry moisture content.

The subjective estimation of the air-dry moisture content is not critical, but the same value must be assigned to the eight specimens. For simplicity the air-dry moisture can be assumed to be zero.

- 5.5 The application of pressure combined with vibration is essential to ensure the required degree of compaction. The downward force required of 300 N to 400 N, including that resulting from the mass of the hammer and tamper, is greater than that required to prevent the hammer bouncing on the soil. It has been found in practice that operators can usually judge, with sufficient accuracy, the required pressure, but it is recommended that, when an operator lacks experience in this test, the vibrating hammer should be applied initially, without vibration, to a platform scale where a mass of 30 kg to 40 kg should be registered when the required force is applied.
- 5.6 The water added for each stage of the test should be such that a range of moisture contents is obtained which includes the optimum moisture content. In general, increments of 1% are suitable for cohesionless free draining sands and gravels.

**GHANA HIGHWAY AUTHORITY,  
CENTRAL MATERIALS LABORATORY.**

FORM S4/1

**DATE:** \_\_\_\_\_

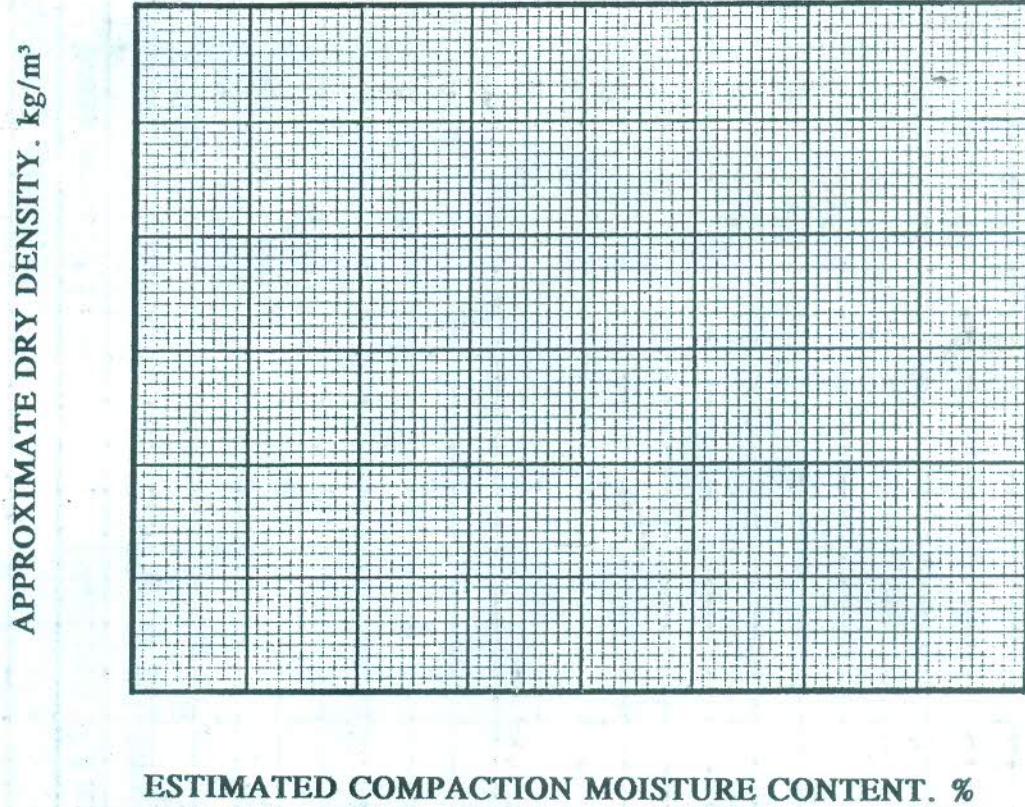
## MOISTURE - DENSITY RELATIONSHIP VIBRATING HAMMER COMPACTION.

**OPERATOR:**

## MOISTURE CONTENT DETERMINATION

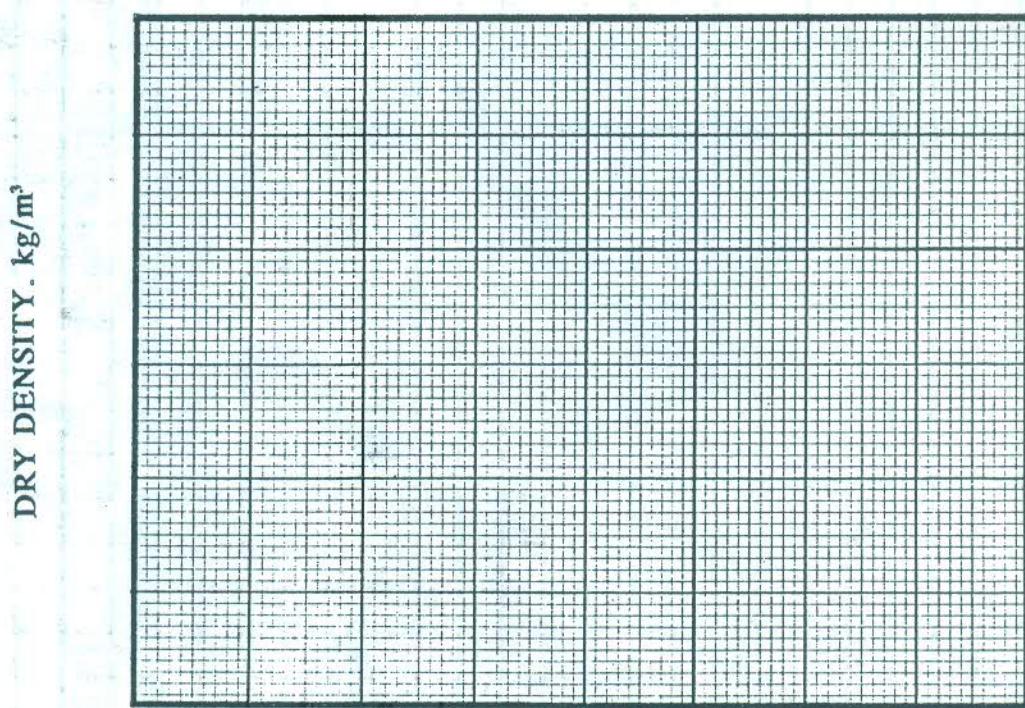
MOISTURE CONTENT DETERMINATION	
15	Oven-pan Number.
16	Mass Oven-pan. (g).
17	Mass Oven-pan + Wet Soil. (g)
18	Mass Oven-pan + Dry Soil. (g)
19	Mass of Water. (g). (17)-(18)
20	Mass Dry Soil. (g). (18)-(16)
21	<b>MOISTURE CONTENT(%). (19)/(20)*100</b>
22	Back Calc. Air-dry MC. (%) (21)-(4)
23	<b>DRY DENSITY. 100*(13)/(100+(21))</b>

**FIGURE S4/1: Estimated Moisture Content - Approximate Dry Density Relationship.**



**ESTIMATED COMPACTION MOISTURE CONTENT. %**

**FIGURE S4/2: Compaction Moisture Content - Dry Density Relationship.**



**COMPACTION MOISTURE CONTENT. %**

DETERMINATION OF CROSS-SECTIONAL AREA OF MOULD.

MOULD NUMBER:		CAL. 1	CAL. 2	CAL. 3	AVE
a	Mass Base-plate, Mould & Glass. g.				—
b	Mass Base-plate, Mould, Glass & Water. g.				—
c	Mass of Water. (b - a). g.				—
d	Temperature of Water. C.				—
e	Density of Water at Test Temp. Kg/cub.m.				—
f	Effective height of mould. mm.				—
g	CROSS-SECTION AREA. (c/e/f). (cf. 0.01815)				
MOULD NUMBER:		CAL. 1	CAL. 2	CAL. 3	AVE
a	Mass Base-plate, Mould & Glass. g.				—
b	Mass Base-plate, Mould, Glass & Water. g.				—
c	Mass of Water. (b - a). g.				—
d	Temperature of Water. C.				—
e	Density of Water at Test Temp. Kg/cub.m.				—
f	Effective height of mould. mm.				—
g	CROSS-SECTION AREA. (c/e/f). (cf. 0.01815)				
MOULD NUMBER:		CAL. 1	CAL. 2	CAL. 3	AVE
a	Mass Base-plate, Mould & Glass. g.				—
b	Mass Base-plate, Mould, Glass & Water. g.				—
c	Mass of Water. (b - a). g.				—
d	Temperature of Water. C.				—
e	Density of Water at Test Temp. Kg/cub.m.				—
f	Effective height of mould. mm.				—
g	CROSS-SECTION AREA. (c/e/f). (cf. 0.01815)				

**DRAFT GHA TEST METHOD - SOILS 5.**

**THE DETERMINATION OF THE IN-PLACE DRY DENSITY OF SOIL OR  
GRAVEL BY THE SAND REPLACEMENT METHOD**

## DRAFT GHA TEST METHOD - SOILS 5.

### **THE DETERMINATION OF THE IN-PLACE DRY DENSITY OF SOIL OR GRAVEL BY THE SAND REPLACEMENT METHOD**

#### **1. SCOPE**

**1.1** The in-place dry density of compacted soil or gravel, as defined below, is determined by making a hole in a compacted layer and dividing the dry mass of the material removed from the hole by the volume of the hole, which is determined by filling the hole with a fine sand of known density.

#### **1.2 Definition**

The in-place dry density of a material is the dry mass per unit volume of the material and is expressed in kilograms per cubic metre.

#### **2. APPARATUS**

- 2.1** A density device complete with accessories, viz. pouring can, dolly, garden trowel, chisel and three pegs (Figure S5-1) (see 5.1 and 5.2).
- 2.2** A balance with scoop to weight up to 6kg, accurate to 1 g.
- 2.3** About 10 kg of specially prepared and calibrated sand per test hole (see 5.3 and 5.4).
- 2.4** A drying oven, thermostatically controlled and capable of maintaining a temperature of 105 to 110 °C.
- 2.5** A small spade (border spade).
- 2.6** Paint brushes: a 100 mm and 20 mm width.
- 2.7** A road tamper for compacting the backfilled hole.
- 2.8** A 2 kg hammer.
- 2.9** Oven drying pans about 300 mm x 300 mm
- 2.10** A tablespoon.
- 2.11** A 300 mm stainless steel rule.
- 2.12** A set of 2 containers with close fitting lids of about 4 litre capacity and 1 container with close fitting lid of about 1.5 litre capacity. (eg. plastic buckets or tin billy cans). One set is required for each test hole being done in a batch of tests.
- 2.13** Sieves, 0.425 mm and 0.250 mm.

- 2.14 A basin, about 400 mm in diameter.
- 2.15 A cylindrical container with an internal diameter and height of  $152.0 \pm 5$  mm.
- 2.16 A 180 X 180 mm glass plate about 7 mm thick.
- 2.17 Lubricating grease.
- 2.18 A 5 ml pipette or wash bottle.
- 2.19 A thermometer, 0 to  $50^{\circ}\text{C}$ .

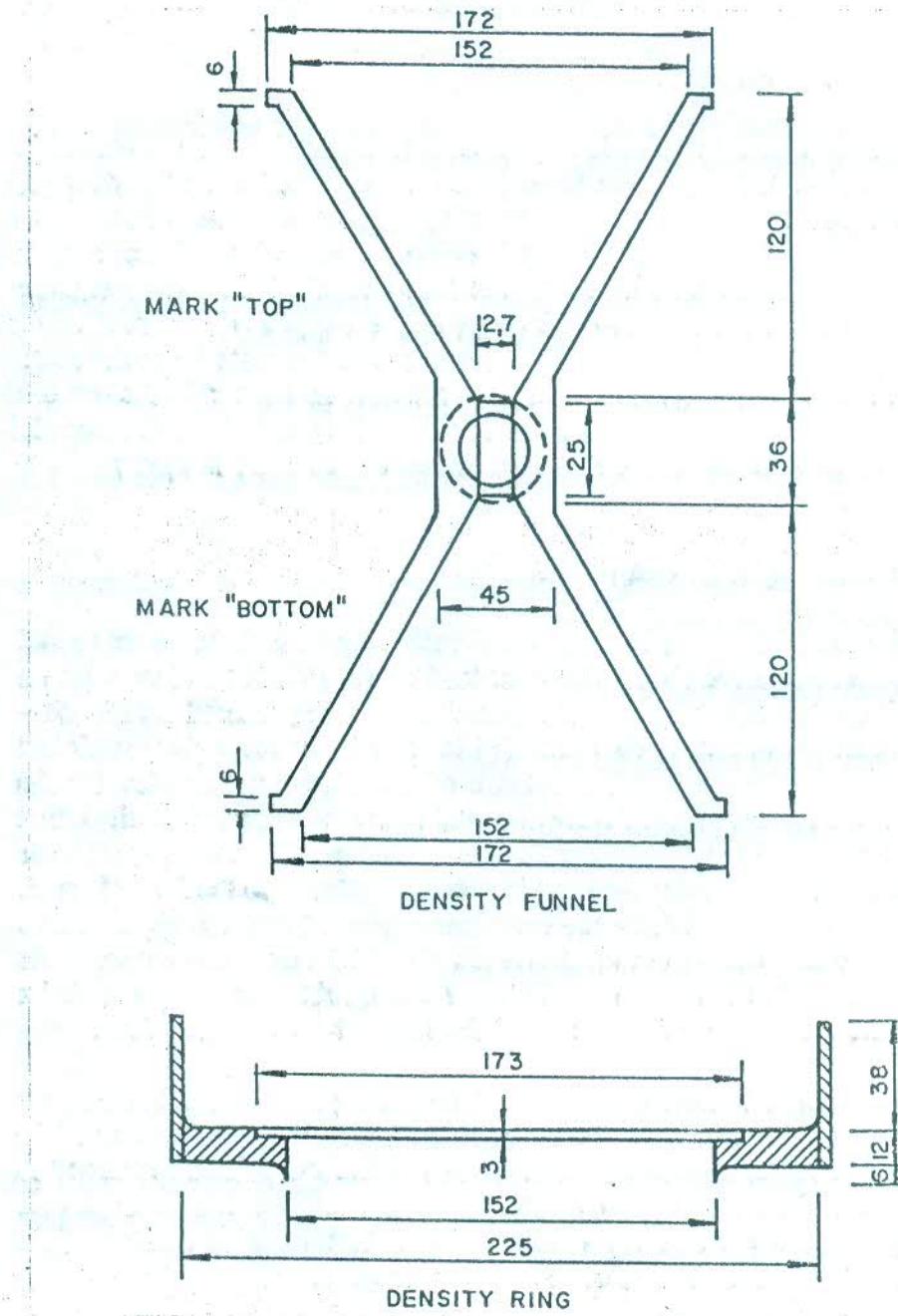


FIGURE S5-1: Sand density funnel and ring.

### **3. METHOD**

#### **3.1 Preparation**

- 3.1.1 Place about 2000 g of the prepared density sand in the 1 litre container and record the mass of the sand on form S5 (line b).
- 3.1.2 Place about 6000 g of the prepared density sand in one of the 4 litre containers and record the mass of the sand on form S5 (line e).
- 3.1.3 The point at which the density is to be determined is selected and a fairly even surface of about 300 mm by 300 mm is chosen. All loose material is brushed away to leave a clean and firm surface. If the surface is very uneven, it can be levelled by carefully skimming off the irregularities with the small border spade or steel straight edge.
- 3.1.4 The ring of the density device is now placed on the surface of the material and the dolly is placed on the ring. The three pegs are hammered in so that they just touch the rim of the ring (see 5.2). By means of light blows with the road tamper or 2 kg hammer on the dolly, the density ring is driven down until the lower surface of the ring makes firm contact with the surface of the material. If coarse aggregate near the surface prevents the penetration of the edge of the ring, the ring should be moved to another position. Care should be taken to ensure that the material in the centre of the ring is not loosened unduly. The three pegs are now hammered in the rest of the way to hold the density ring firmly in place. The dolly is removed and the material which may have been loosened in the ring is removed by brushing it lightly into the trowel or spoon.

#### **3.2 Volume of density ring and funnel**

- 3.2.1 The density funnel is now placed on the density ring so that the lower funnel rests in the recess in the ring. The machined recess should be clean with no soil or grit on the ring. The funnel tap is closed. The prepared and density-calibrated sand in the small container (which should be more than sufficient to fill the lower funnel and the volume of the ring not occupied by the material) is then poured from the small container into the upper funnel. When the sand level comes to within about 25 mm of the top of the upper funnel, the tap is opened completely and the sand is allowed to flow into the lower funnel. In the meantime the sand from the container is poured into the upper funnel keeping the sand level in the upper funnel about 25 mm from the top. As soon as the sand in the upper funnel stops flowing, the funnel tap should be closed carefully. On no account should the funnel be jarred (see 5.1).
- 3.2.2 The density funnel is now removed and inverted over the small container pouring the sand remaining in the upper funnel back into the container. The tap is opened and the sand confined in the orifice in the tap is also returned to the container. The lid is placed firmly on the container for return to the laboratory where it is weighed and the mass of sand remaining recorded (line c). This sand can then be returned to the bulk supply.
- 3.2.3 As much of the sand remaining in the density ring as can readily be transferred

by means of a trowel or tablespoon should be removed and placed in a bag for reprocessing before being returned to the bulk supply. Care should be taken to see that the surface of the material is not touched. When most of the sand has been removed, the remainder is brushed into the centre of the ring and carefully removed for reprocessing.

### 3.3 Removal of material from the density hole

- 3.3.1 The cold chisel or large screwdriver is now used to loosen the upper 50 mm of material in the density ring. The loose material is removed by means of a trowel and a spoon and placed in the empty second 4 litre container. Where an accurate assessment of the field moisture content at this time is required the lid should be placed on the container after the damp soil has been placed in it. When possible, only the chisel and the trowel are used to loosen the material, except when the layer of material is extremely hard, in which case a chisel and hammer may have to be used. The edge of the density ring should not be used as a fulcrum when using the chisel. The procedure should be push or tap the chisel into the soil and then rotate the chisel by means of the cross handles and move the chisel to and fro.

This process is repeated until the hole reaches the bottom of the layer.

The sides of the density hole must be cut vertically and should extend to the full depth of the layer to be tested, as otherwise a true average density is not obtained (see 5.6). If a stone is removed from the wall of the hole, the cavity should be cut away at the top so that there is a gradual slope down the wall to ensure the sand when poured, will fill the hole completely. As far as possible the sides and bottom of the hole should not be loosened, but maintained in their compacted state.

- 3.3.2 All loose material in the hole should be removed and collected in the container. Any material which may have fallen on the density ring should be collected by means of a brush and spoon.

- 3.3.3 The average depth of the hole is then measured.

### 3.4 Volume of the density hole

- 3.4.1 The density funnel is replaced on the density ring which should be perfectly clean. The funnel tap is closed. The prepared and density-calibrated sand in the large (4 litre) container (which should be more than sufficient to fill the hole, lower funnel and the volume of the ring not occupied by the material) is then poured from the container into the upper funnel. When the sand level comes to within about 25 mm of the top of the upper funnel, the tap is opened completely and the sand is allowed to flow into the hole and lower funnel. In the meantime the sand from the container is poured into the upper funnel keeping the sand level in the upper funnel about 25 mm from the top. As soon as the sand in the upper funnel stops flowing, the funnel tap should be closed carefully. On no account should the funnel be jarred (see 5.1).

- 3.4.2 The density funnel with sand remaining in the upper funnel is now removed and inverted over the large container that may still have sand left in it, pouring the sand remaining in the upper funnel back into the container. The tap is opened and the sand confined in the orifice in the tap is also returned to the container. The lid is placed firmly on the container for return to the laboratory where it is weighed and the mass of sand remaining recorded (line f). This sand can then be returned to the bulk supply.
- 3.4.3 The sand remaining in the density ring and hole should be removed and placed in the bag containing used sand, which must be prepared before being used again (see 5.5).

### 3.5 Drying and weighing of material

- 3.5.1 The material removed from the hole is taken to the laboratory in the container with the lid firmly closed. The mass of the material removed from the hole is determined and recorded (line h). For a nominal 150 mm thick layer this will normally be in excess of 4000 g.
- 3.5.2 This material is quickly riffled into two. One sample is used to determine the moisture content by oven drying at 105°C to 110°C to constant mass. This is used to calculate the dry mass of the material in the hole.
- 3.5.3 The other sample may be used for determining the Atterberg limits or for grading analysis as part of the site process control procedures.

## 4. CALCULATIONS

### 4.1 Wet density in kg/m<sup>3</sup>

$$D_w = (h) \times (A) / (g)$$

where

$D_w$	=	Wet density (kg/m <sup>3</sup> ) (i).
(h)	=	mass of wet material from density hole (g)
(g)	=	mass of sand to fill density hole (g)
(A)	=	poured density of sand (kg/m <sup>3</sup> ) (see 5.4)

The mass of sand to fill the density hole is obtained from the test data as follows:  
( letters in ( ) also refer to line number on form S5).

- |     |   |   |
|-----|---|---|
| (b) | = | mass of sand put in small container ;   |
| (c) | = | mass of sand left in small container after filling lower funnel and unoccupied part of ring;            |
| (d) | = | mass of sand taken for filling the lower funnel and unoccupied part of ring, ((b) - (c)).               |
| (e) | = | mass of sand taken initially in large container before filling the lower funnel, ring and density hole; |

- (f) = mass of sand left over in large container after filling the lower funnel, ring and density hole;  
(g) = mass of sand in density hole, ((e) - (f) - (d)).

The calculation should be carried out to the nearest 1 kg/m<sup>3</sup>.

#### 4.2 Moisture content.

The data for determining the moisture content of the sub-sample are recorded on lines (j) through (o) and calculated in the normal manner (p).

#### 4.3 Dry Density.

The dry density is calculated from the wet density and moisture content of the sub-sample.

$$\text{Dry density} = \frac{100 \times \text{Wet density}}{(100 + (\text{p}))}$$

The calculation should be carried out to the nearest 1 kg/m<sup>3</sup> and the dry density reported to the nearest 5 kg/m<sup>3</sup>.

### 5. NOTES

- 5.1 In windy conditions a density funnel with a metal cylinder welded to the top cone may be used to protect the sand from the wind. The metal cylinder should be 300 mm long and have the same inside diameter as the inside diameter of the tap of the funnel. All the sand is poured into the funnel before the tap is opened.
- 5.2 For granular material where the material may be disturbed when hammering in the pegs, three metal bars, approximately 10 mm long, 20 mm wide and 5 mm thick with a 12 mm hole drilled through one end may be welded, at an equal spacing, to the side of the density ring. The pegs for holding the ring are then hammered through the holes in the bars.

#### 5.3 Preparation of sand

- 5.3.1 A large quantity of sand (preferably quartzitic sand) should be washed thoroughly with water and the water decanted from time to time until clear. The sand is then dried and sieved through 0.425 mm and 0.250 mm sieves. The fraction passing the 0.425 mm sieve and retained on the 0.250 mm sieve is used in the density determination. Other closely graded fine sand (0.600 - 0.300 mm) may also be used. It is desirable that not more than one type of sand should be used on a job.

#### 5.4 Calibration of the sand (determination of poured density)

- 5.4.1 To eliminate any possible errors it is advisable to calibrate the density sand with the same funnel that is used for the in-place density test.

#### **5.4.2 Mass of sand required to fill funnel**

The density funnel is placed with the lower funnel resting on the glass plate. The funnel tap is closed. About 1700 g of the density sand is accurately weighed and transferred to the pouring can. The sand is then poured into the upper funnel. When the level of the sand comes within about 25 mm of the top of the upper funnel, the funnel tap is opened, and the sand allowed to flow into the lower funnel. The remainder of the sand in the can is poured into the upper funnel, maintaining the level at about 25 mm from the top of the funnel. When the sand stops flowing into the lower funnel, the tap is closed carefully without jarring the funnel.

The density funnel is removed and the sand remaining in the upper funnel, including the sand contained in the orifice in the tap, is transferred to the scale scoop and weighed.

This determination should be carried out in triplicate and the average mass of sand required to fill the lower funnel recorded.

#### **5.4.3 Mass of sand required to fill container (see 2.15) and funnel**

The density funnel is placed centrally over the container so that the lower funnel is on top of the container. The funnel tap is closed. About 6000 g of the density sand is accurately weighed and transferred to the pouring can. The sand is then poured into the upper funnel. When the level of the sand comes within 25 mm of the top of the upper funnel, the funnel tap is opened, and the sand allowed to flow into the lower funnel and the container. The remainder of the sand from the can is poured into the upper funnel, maintaining the level at about 25 mm from the top of the funnel. When the flow through the tap ceases, the tap is closed carefully without jarring the funnel.

The funnel is then removed and the sand in the upper funnel and tap orifice, as well as any sand that may have remained in the pouring can, is transferred to the scale scoop and weighed.

The determination should be carried out in triplicate and the average mass of sand required to fill the funnel and container is recorded.

#### **5.4.4 Volume of the container**

A fairly thin film of lubricating grease is applied to the top edge of the container. The container and the glass plate are weighed. Water is now poured into the container and, when full, the glass plate is slid gently over the top of the container. Before the glass plate quite covers the container, the final drops of water are added from a pipette. When the container is covered fully by the glass plate, no air bubbles should be entrapped under the plate. The container with water and glass plate are now weighed.

The temperature of the water is measured.

This determination should also be carried out in triplicate to obtain an average value for the mass of water in the container.

#### 5.4.5. Calibrations

$$5.4.5.1 \quad A = 1000 \times W / V$$

where

A = poured density of the sand ( $\text{kg/m}^3$ )

W = mass of sand to fill container(g)

V = volume of container (ml).

#### 5.4.5.2 W is obtained from the test data as follows:

s = mass of sand initially taken for filling lower funnel

t = mass of sand over after filling funnel

s - t = mass of sand in lower funnel

u = mass of sand initially taken for filling lower funnel and container

v = mass of sand over after filling funnel and container

u - v = mass of sand in funnel and container

and  $W = (u - v) - (s - t)$  (i.e. mass of sand in container only).

#### 5.4.5.3 V is obtained from the test data as follows:

m = mass of container and glass plate and water

n = mass of container and glass plate

m - n = mass of water

The relative density of water at the temperature at which the test is carried out (see Method S1) is d.

Volume of container) V (ml) =  $((m) - (n)) / (d)$

#### 5.4.5.4

Substitute the above values for W and V in the formula in 5.4.4.1:

$$A = [(u - v) - (s - t)] / (m - n) \times d \times 1000$$

- 5.5 Once sand has been used for a density determination, it should be resieved. (This, of course, does not apply to clean sand returned to the bulk supply.) After the sand has been used for some time, it tends to become dirty, in which case it should be rewash as well as resieved and its poured density (or factor) redetermined. Whenever a new batch of sand is prepared, it should be calibrated.
- 5.6 Layers in the road foundation are normally constructed to a compacted thickness of between 100 and 150 mm and density determinations are normally limited to approximately these minimum and maximum depths. In any case, a determination to a depth of less than 100 mm is more subject to error and may not be very reliable, whereas a determination to a depth of more than 150 mm creates practical difficulties in the digging of the hole. It should also be remembered that the poured density of the sand is determined in a 152,4 mm deep container. Another consideration is the effect of density gradients, and although the construction of layers considerably thicker than 150 mm may be permissible (or unavoidable in the case of very coarse material), it is considered that the density determinations should be limited to a depth of 150 mm.
- 5.7 If a large stone is encountered in the density hole, the determination should not be attempted. Apart from the practical difficulty of removing the stone, the test result will be meaningless. Another spot should then be selected for the determination. If the material contains a large proportion of very coarse aggregate, i.e. aggregate of, say, more than 75 mm in diameter, the density test is hardly considered worthwhile as the results will not be sufficiently reliable.

## 6 REFERENCES

AASHTO Designation T 191  
AASTM Designation D 1556

CONE NUMBER:

A POURED DENSITY OF SAND, kg/cub.m.

FIELD DENSITY SAND REPLACEMENT.

	PARAMETER	TEST 1	TEST 2	TEST 3	TEST 4
b	Initial mass sand in small container, g				
c	Mass sand in small container after filling lower funnel & ring, g.				
d	Mass sand in lower funnel and ring, g. ((b) - (c))				
e	Initial mass sand in large container, g.				
f	Mass sand in large container after filling lower cone, ring & density hole, g.				
g	Mass sand in density hole, g. ((e) - (f) - (d)).				
h	Mass wet soil removed from density hole,g.				
i	In-place Wet Density, kg/cub.m. ((h) / (g) * (A))				

MOISTURE CONTENT DETERMINATION.

j	Oven pan number.				
k	Mass of oven pan, g.				
l	Mass of oven pan + wet soil, g.				
m	Mass oven pan + dry soil, g.				
n	Mass of water, g. ((l) - (m)).				
o	Mass of dry soil, g. ((m) - (k)).				
p	MOISTURE CONTENT, %. (100 * (n) / (o)).				
q	IN-PLACE DRY DENSITY, kg/cub.m. (100 * (i) / (100 + (p)))				

**DRAFT GHA TEST METHOD - SOIL 6**

**DETERMINATION OF ATTERBERG LIMITS OF SOIL FINES.**

## DRAFT GHA TEST METHOD - SOIL 6

### DETERMINATION OF ATTERBERG LIMITS OF SOIL FINES.

#### 1 SCOPE.

1.1 This test method covers two procedures for the wet preparation of soil fines finer than 0.425 mm. These are:

(a) Procedure A is used to prepare soil fines when the coarse-grained particles of a sample are soft and pulverize readily, or when the fine particles are very cohesive and tend to resist removal from the coarse particles. Procedure A should also be used for soils with a classification A-1, A-3 and A-2 that are being investigated for use in the pavement layers. These soils have less than 35% passing the 0.075 mm sieve.

(b) Procedure B is used if the true natural gradation and plasticity characteristics of soils, that may change their characteristics greatly when dried, are desired. These soils should be shipped to the laboratory in sealed containers. This should be used for soils with classifications A-4 to A-7.

1.2 The liquid and plastic limits of many soils that have been allowed to dry before testing may be considerably different from values obtained on undried samples. If the liquid and plastic limits of soils are used to correlate or estimate the engineering behaviour of soils in their natural moist state, samples should not be permitted to dry before testing unless data on dried samples are specifically desired.

Liquid limit and plasticity index values derived from samples containing their natural moisture are usually, but not always, equal to or higher than values derived from similar samples of the dried soil. In the case of fine-grained organic soil, there is a radical drop in plasticity due to oven drying.

1.3 It also covers the test procedures for the determination of:

- (a) Liquid Limit using the Casagrande apparatus;
- (b) Liquid Limit using the British Standard cone penetrometer;
- (c) Linear Shrinkage;
- (d) Plastic Limit;
- (e) Plasticity Index;
- (f) Liquidity Index.

1.4. Definitions

(i) Atterberg limits - originally, seven "limits of consistency" of fine-grained soils were defined by Albert Atterberg. In current engineering usage, the term usually

refers only the liquid limit, plastic limit, and the shrinkage limit.

(ii) Consistency - the relative ease with which a soil can be deformed.

(iii) Liquid Limit (LL) Casagrande cup - the water content, in percent, of a soil at the arbitrarily defined boundary between the liquid and plastic states. This water content is defined as the water content at which a pat of soil placed in a standard cup and cut by a groove of standard dimensions will flow together at the base of the groove for a distance of 13 mm when subjected to 25 shocks from the cup being dropped 10 mm in a standard liquid limit apparatus operated at a rate of 2 shocks per second.

NOTE 2 - The undrained shear strength of soils at the liquid limit is considered to be  $2 \pm 0.2$  Kpa (0.28 psi).

(iv) BS CONE Liquid Limit, - the water content, in percent, of a soil at the arbitrarily defined boundary between the liquid and plastic states. This water content is defined as the water content at which the standard cone penetrates the soil placed in a standard cup to a depth of 20 mm.

(v) Linear Shrinkage, - the linear shrinkage of a soil at the liquid limit moisture content, is the decrease in one dimension, expressed as a percentage of the original dimension of the soil mass, when the moisture content is reduced from the liquid limit to an oven-dry state.

(vi) Plastic Limit (PL) - the water content, in percent, of a soil at the boundary between the plastic and brittle states. The water content at this boundary is the water content at which a soil can no longer be deformed by rolling into 3.2 mm diameter threads without crumbling.

(vii) Plastic soil - a soil which has a range of water content over which it exhibits plasticity and which will retain its shape on drying.

(viii) Plasticity Index (PI) - the range of water content over which a soil behaves plastically. Numerically, it is the difference between the liquid limit and the plastic limit.

(ix) liquidity index - the ratio, expressed as a percentage, of (1) the natural water content of a soil minus its plastic limit, to (2) its plasticity index.

## 2 APPARATUS.

### Sample preparation and general items.

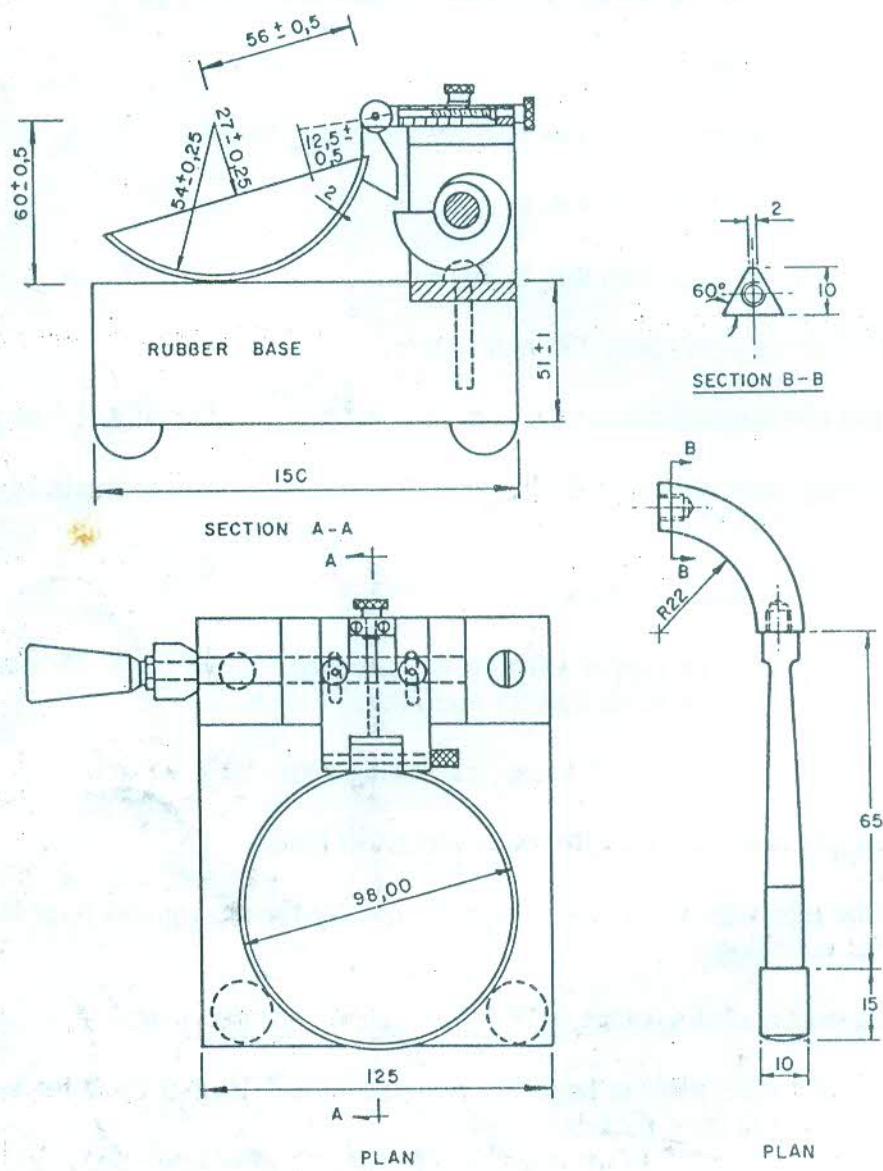
2.1 A riffler with 25.0 mm to 40 mm openings.

2.2 Tests sieves, complying with ISO 3310/1 and ISO 3310/27, with sieves larger than 4.75 mm of perforated plate and sieves 4.75 mm and smaller of woven wire mesh:

- (a) A 19.0 mm sieve of 450 mm diameter.
  - (b) 19.0 mm, 9.5 mm, 4.75 mm, 2.0 mm, 1.00 mm and 0.425 mm sieves, recommended diameter 200 mm, with pan and cover.
- 2.3 A mechanical sieve shaker (optional).
- 2.4
- (a) Platform scale to weigh to 100 kg accurate to 100 g.
  - (b) A balance to weight up to 25 Kg accurate to 1 g.
  - (c) A balance to weigh up to 3 kg, accurate to 0.1 g.
  - (d) A balance to weigh up to 100 g, accurate to 0.01 g.
- 2.5 Basins and pans:
- (a) Large pan or concrete slab for air-drying sample.
  - (b) Basins about 500 mm in diameter.
  - (c) Basins about 350 mm in diameter.
  - (d) Oven pans about 250 mm square.
- 2.6 A 150 mm nominal diameter iron mortar and pestle and a rubber-tipper pestle.
- 2.7 A drying oven, thermostatically controlled and capable of maintaining a temperature of 105 to 110 °C.
- 2.8 Brushes for cleaning sieves:
- (a) A brass or copper wire brush, measuring about 50 X 25 mm, with bristles not more than 25 mm long.
  - (b) A hard-bristle nail-brush, measuring about 80 X 25 mm.
- 2.9 A supply tank with distilled water and wash bottles.
- 2.10 Plastic tubs with lids of about 500 cc capacity for storing soil fines in both dry and moist condition.
- 2.11 Two steel-bladed spatulas, with a blade about 100 mm long.
- 2.12 A ground-glass plate at least 300 mm square and 10 mm thick for mixing soil and rolling plastic limit threads.
- 2.13 An evaporating dish ( a convenient size is about 150 mm diameter), or a damp cloth to cover the sample to prevent it drying during testing.

For Casagrande Liquid Limit.

- 2.14 A Casagrande liquid limit device. (Figure 2/1) The base of the apparatus must be made of hard rubber with a Shore D value of 85 to 95 at  $23 \pm 2^\circ\text{C}$ .
- 2.15 An ASSHTO curved grooving tool. (Figure 2/2)
- 2.16 A calibrating plate with a thickness of  $10,0 \text{ mm} \pm 0,1 \text{ mm}$ .
- 2.17 A burette with a capacity of 50 ml or 100 ml, or wash bottle.
- 2.18 Corrosion resistant moisture content pans with a capacity of 30 to 45 ml with lids, which will prevent the loss of moisture prior to and during weighing.

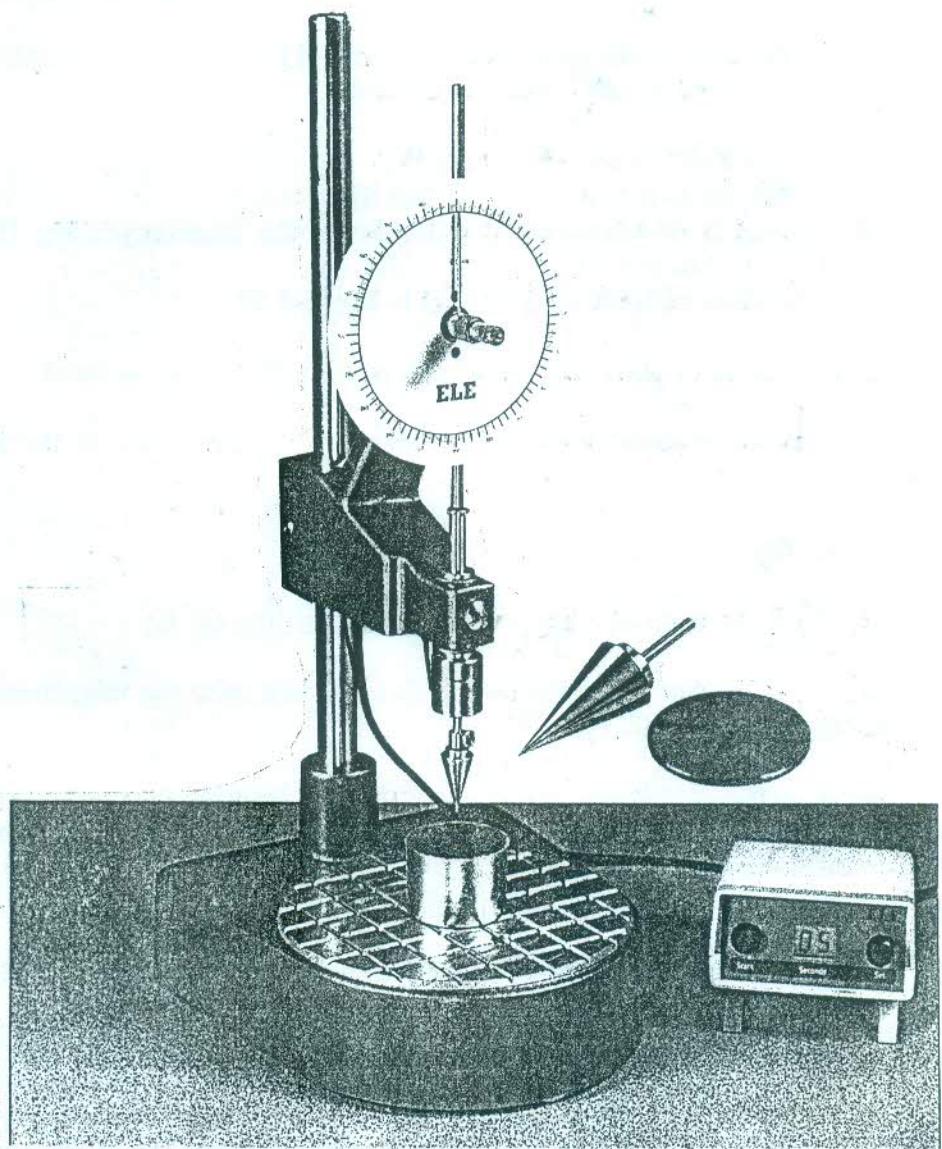


**FIGURE 2/1:  
LIQUID LIMIT DEVICE**

**FIGURE 2/2:  
GROOVING TOOL**

### British Standard Cone Liquid Limit

- 2.19 A penetrometer as used in bituminous material testing complying with the requirements of BS 4691.
- 2.20 A cone of stainless steel or duralumin approximately 35 mm long, with a smooth polished surface and an angle of  $30 \pm 1^\circ$ . 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  $1.75 \pm 0.1$  mm thick. The cone is fitted to the penetrometer in place of the needle used for the determination of penetration of bitumen. The mass of the cone together with its sliding shaft is  $80.00 \pm 0.05$  g.
- 2.21 Metal cups approximately 55 mm in diameter and 40 mm deep with the rim parallel to the flat base.



**FIGURE 2/3: CONE PENETROMETER FOR LIQUID LIMIT.**

### For Linear Shrinkage.

- 2.22 Shrinkage troughs with inside dimensions of 150 mm long x 10 mm wide x 10 mm deep and made of 1.6 mm thick brass or stainless steel.
- 2.23 Small thick bristle paint brush about 5 mm wide.
- 2.24 Paraffin wax and suitable dish in which to melt it.
- 2.25 Vernier gauge.

### **3. SAMPLE PREPARATION.**

#### **3.1 PROCEDURE A**

##### **3.1.1. Sampling**

(i) Ideally the sample obtained in the field should be a large bulk sample of about 70 Kg that can be used for all the following tests:

Atterberg Limits as described here-in;  
Sieve analysis as described in Method S7.  
Determination of Maximum dry density of the fraction passing 19 mm as described in Method S1;  
Determination of CBR as described in Method S2.

A minimum sample of about 2000 g of soil passing 19 mm is required.

(ii) Dry the soil sample as received from the field, using one of the following methods:

- (1) air-dry at ambient temperature;
- (2) dry in an oven at a temperature not exceeding 60°C;
- (3) dry using any warming device that will not raise the temperature of the sample above 60°C.

(iii) Break up thoroughly any aggregations of particles using the mortar and rubber-covered pestle or other suitable device. When the sample contains particles of soft shale or sandstone or similar weak material, proper care must be exercised to avoid excessive reduction in the size of the particles.

(iv) Separate the sample on the 19 mm sieve and record the mass of both fractions.

(v) Select a representative portion of the fraction passing the 19 mm sieve by the method of successive quartering or by use of the sampler rifler. From the large bulk sample it is convenient to prepare four such portions. These are to be used for the preparation of fines, grading analysis, moisture content determination, and a spare incase a duplicate test is required.

This portion must be sufficient to provide an adequate amount of material passing the 0.425 mm sieve for the tests to determine soil constants. For most granular materials about 2000 g will be sufficient. The amounts of material required to perform the individual tests are as follows:

Liquid limit, Casagrande cup, g	150
Liquid limit, BS Cone penetrometer, g	150
Plastic limit, g	20
Linear Shrinkage, g	130

### 3.1.2 Preparation of Tests Samples

(i) Weigh the portion of the test sample selected and record as the weight of test sample uncorrected for hygroscopic moisture. Separate this material into two portions using the 0.425 mm sieve, which should be protected by a 2.00 mm sieve. With a sieve shaker it is convenient to use all the sieves listed to avoid overloading individual sieves. Set aside the portion passing the 0.425 mm sieve for later recombination with additional material washed from the portion retained on the 0.425 mm and larger sieves.

(ii) Place the material retained on these sieves in a bowl of about 350 mm diameter, cover with water, and allow to soak for at least 16 hours until the particle aggregations become soft. During this period the soil and water is agitated to assist with separating the fines from the coarser material.

(iii) After soaking agitate the soil and water thoroughly and wash the material first on a 2.00 mm sieve, and then on the 0.425 mm sieve in the following manner:

Place an empty 2.00 mm sieve on the bottom of a clean bowl and pour the water from the soaked sample into the sieve. Add sufficient water to bring the level approximately 10 mm above the mesh of the sieve. Transfer the soaked material to the sieve in increments not exceeding 0.5 kg, stirring each increment with the fingers while agitating the sieve up and down. Crumble or mash any lumps that have not slaked, using the thumb and fingers. Raise the sieve above the water in the pan and complete the washing operation using a small amount of clean water. Transfer the washed material retained on the sieve to a clean pan before placing another increment of soaked material on the sieve.

Repeat the above procedure using the 0.425 mm sieve.

(iv) Set aside the bowl containing the washings for a period of several hours or until the water above the particles is clear. Decant, pipet, or siphon off as much of the clear water as possible. In some instances, the wash water will not become clear in a reasonable length of time in which case the entire volume must be evaporated.

(v) Dry the soil remaining in the pan at a temperature not exceeding 60°C until it is of a thick paste consistency which has a moisture content between the plastic and liquid limits. This can generally be done by placing the bowl in a sunny location.

(vi) Add the air dry material passing the 0.425 mm sieve prepared in 3.1.2 (i) to the paste and mix thoroughly. Adjust the moisture content of the prepared fines until it is a little above the plastic limit and below the liquid limit. Place this in a plastic tub sealed with the lid and store for at least 16 hours to allow the moisture to equilibrate.

**NOTES:**

In some areas it is possible that the cations of salts present in the tap water may exchange with the natural cations in the soil and alter significantly the values of the soil constants should tap water be used in the soaking and washing operations. Unless it is known that such cations are not present in the tap water, distilled or demineralized water should be used.

The soaking and washing operation will remove soluble salts contained in the soil. When soluble salts are present in the soil, all the wash water should be evaporated so the salts remain in the soil sample.

## **3.2 PROCEDURE B**

### **3.2.1. Samples**

(i) Samples prepared in accordance with this procedure must be brought from the field to the laboratory in sealed containers and must contain all their natural moisture.

(ii) the sample should be sufficient to produce about 500 g of material finer than 0.425 mm.

### **3.2.2 Preparation of test Samples**

(i) Samples obviously containing only particles passing the 0.425 mm sieve may be used in the tests to determine soil constants without first washing on the 0.425 mm sieve.

(ii) Select a representative portion of the moist sample estimated to contain sufficient particles passing the 0.425 mm sieve to make the required tests for determination of soil constants. Soak this selected portion of the moist sample and wash on the 0.425 mm sieve as described in 3.1. Reduce the moisture content of the material passing the 0.425 mm sieve until the mass reaches a putty-like consistency (such as 30 to 35 drops of the cup in the liquid limit test) but never below the natural moisture content.

(iii) This reduction of moisture content may be accomplished as follows:

- by settlement of the soil fines and decanting the clear water,
- by exposure to air at ordinary room temperature,
- by heating in an oven at a temperature not exceeding 110°C,
- by boiling,
- by filtering on a Buchner funnel,
- by use of filter candles.

(iv) During evaporation and cooling, stir the sample often enough to prevent overdrying of the fringes and soil pinnacles on the surface. Cool the heated samples to normal room temperature before testing.

(v) For soil samples containing soluble salts, use a method of water reduction that will not eliminate the soluble salts from the test sample.

(vi) Adjust the moisture content of the prepared fines until it is a little above the plastic limit and below the liquid limit. Place this in a plastic tub sealed with the lid and store for at least 16 hours to allow the moisture to equilibrate.

(vii) A curing period of 16 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.

3.3 The method of preparation used shall be noted on from S6.

#### 4 LIQUID LIMIT USING CASAGRANDE CUP.

##### 4.1 Procedure

- 4.1.1 Transfer about 150 g of the prepared soil fines from the plastic tub to the glass sheet and again mix thoroughly. Adjust the water content of the mixture, if necessary, by adding small increments of distilled or demineralized water or by allowing the mixture to dry at room temperature while mixing on the glass plate. The soil should be at a water content that will result in closure of the groove in 25 to 35 blows.
- 4.1.2 Place a portion of the prepared soil in the cup of the liquid limit device at the point where the cup rests on the base, squeeze it down, and spread it into the cup to a depth of about 10 mm at its deepest point, tapering to form an approximately horizontal surface. Take care to eliminate air bubbles from the soil pat but from the pat with as few strokes as possible. Heap the unused soil on the glass plated and cover with the inverted storage dish or a wet towel.
- 4.1.3 For more plastic soils the material is then divided into two equal portions with one cut of the grooving tool. The groove should fall along the centre-line drawn through the cam-follower attached to the bowl.
- 4.1.4 For slightly plastic or non-plastic soils more care should be taken in the cutting of the groove. After the wet material has been transferred to the bowl, it is again mixed slightly and then bedded down in the bowl by pressing it down with the spatula and tapping the bowl a few times before grooving. The groove should be so cut in the material as to avoid tearing of the sides of the groove or slipping of the soil cake in the bowl. Instead of making one clear cut, a succession of light cut which gradually result in the required cut may be found to work better. When tapping, the operator should ensure that the soil portions actually flow together and do not slide together. If the soil portions slide together, the material should be remixed slightly and the test repeated. If the soil portions continue to slide, it must be accepted that the liquid limit cannot be determined by this method.

- 4.1.5 Verify that no crumbs of soil are present on the base or the underside of the cup. Lift and drop the cup by turning the crank at a rate of 1.9 to 2.1 drops per second until the two halves of the soil pat come in contact at the bottom of the groove along a distance of 13 mm.

NOTE: - Use the end of the grooving tool, or a scale to verify that the groove has closed 13 mm.

- 4.1.6 Verify that an air bubble has not caused premature closing of the groove by observing that both sides of the groove have flowed together with approximately the same shape. If a bubble has caused premature closing of the groove, reform the soil in the cup, adding a small amount of soil to make up for that lost in the grooving operation and repeat 4.1.1 through 4.1.4.

- 4.1.7 If the soil slides on the surface of the cup, repeat 4.1.1 through 4.1.4 at a higher water content. If, after several trials at successively higher water contents, the soil pat continues to slide in the cup or if the number of blows required to close the groove is always less than 25, record that the liquid limit could not be determined, and report the soil as nonplastic without performing the plastic limit test.

- 4.1.8 Record the number of drops, N, required to close the groove on form S6. For the first trial this should be between 27 and 35 blows. Where this was achieved, remove a slice of soil approximately the width of the spatula, extending from edge to edge of the soil cake at right angles to the groove and including that portion of the groove in which the soil flowed together, place in a weighed container, cover and weigh immediately recording the data on form S6.

Where more than 35 blows were required, transfer the soil back to the glass plate, add a little more water and remix. Repeat 4.1.2 through 4.1.8 until the groove closes in 27 to 35 blows.

- 4.1.9 Return the soil remaining in the cup to the glass plate. Wash and dry the cup and grooving tool and reattach the cup to the carriage in preparation for the next trial.

- 4.1.10 Remix the entire soil specimen on the glass plate adding distilled water to increase the water content of the soil and decrease the number of blows required to close the groove. Repeat 4.1.2 through 4.1.8 for two additional trials producing successively lower numbers of blows to close the groove. One of the trials shall be for a closure requiring between 23 and 27 blows, and the other trial for a closure requiring 15 to 23 blows.

- 4.1.11 Determine the water content,  $W^N$ , of the soil specimen from each trial. Make all weighings on the same balance. Initial weighings should be performed immediately after completion of each trial.

#### 4.2. Calculations

- 4.2.1 Plot the relationship between the water content,  $W^N$ , and the corresponding number of drops, N, of the cup on a semilogarithmic graph with the water content as ordinates on the arithmetical scale, and the number of blows as abscissas on the logarithmic scale. Draw the best straight line through the three or more plotted points.

- 4.2.2 Take the water content corresponding to the intersection of the line with the 25-blow abscissa as the liquid limit of the soil. Computational methods may be substituted for the graphical method for fitting a straight line to the data and determining the liquid limit.

## 5 BRITISH STANDARD CONE LIQUID LIMIT.

### 5.1 Procedure.

- 5.1.1 A sample weighing at least 300 g is taken from the material passing the 0.425 mm BS test sieve, which has been stored in the plastic tub at a moisture content slightly above its plastic limit. The sample shall be placed on the flat glass and mixed thoroughly for at least 10 minutes using the palette knives until the mass becomes a thick homogeneous paste. Certain soils may require as much as 40 min of continuous mixing immediately before testing to obtain reliable results.
- 5.1.2 If necessary further water shall be added so that the first cone penetration reading is in the range 15 mm to 18 mm.
- 5.1.3 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 straight edge of the palette knife, to give a smooth surface. The cone shall be lowered so that it just touches the surface of the soil. 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  $5 \pm 1$  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 on form S6.
- 5.1.4 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 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. 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.
- 5.1.5 The operation described in 5.1.3 and 5.1.4 shall be repeated at least twice using the same sample to which further increments of distilled water have been added. The amount of water added shall be chosen so that the penetration values obtained are in the range 18 mm to 22 mm and 22 mm to 25 mm. 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.

## 5.2 Calculations.

5.2.1 The relationship between the moisture content and the cone penetration shall be plotted with the percentage moisture contents as abscissae and the cone penetrations as ordinates, both on linear scales. This is included on form S6. The best straight line fitting the plotted points shall be drawn through them.

## 5.3 Reporting of results.

5.3.1 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.

# 6 LINEAR SHRINKAGE.

## 6.1 Procedure

### 6.1.1 Waxing the trough.

Before waxing the troughs should be examined for dents and distorted sides, and any faults corrected before use.

A clean, dry shrinkage trough is first warmed to prevent premature setting of the wax. The inside of the trough is then covered completely with a thin layer of molten wax applied by means of a small paint brush. Any excess of molten wax is shaken out by tapping the trough lightly in an inverted position. The layer of wax is now chilled by rubbing the outside of the trough with a damp cloth. This prevents the tendency to crack on cooling, leaving the surface of the trough partly exposed. The film of wax in the trough should weigh from 0,1 to 0,2 g to obtain satisfactory results. Before using, the trough should be inspected carefully, so as to ensure that there are no patches without wax.

### 6.1.2 Filling the trough

The test should be done immediately after:

- (a) the liquid limit trial using the Casagrande cup that gives a closure of the groove in the range 23 to 27 blows has been completed so that the moist material left over can be used for filling the trough without further mixing. The number of taps required for groove closure should be recorded, since this value is required in the calculation of the linear shrinkage.
- and (b) the liquid limit trial using the BS cone that gives a penetration in the range 18 mm to 22 mm has been completed so that the moist material left over can be used for filling the trough without further mixing.

Fill one half of the waxed trough with the moist soil by taking small pieces of soil on the spatula and pressing the soil down against the one end of the trough and working along the trough until the whole side is filled and the soil forms a diagonal surface from the top of one side to the bottom of the opposite side (see Fig. (a)).

The trough is now turned round and other portion is filled in the same manner (see Fig. (b)). The hollow along the top of the soil in the trough is now filled so that the soil is raised slightly above the sides of the trough (see Fig. (c)). The excess material is removed by drawing the blade of the spatula once only from the one end of the trough to the other. The index finger is pressed down on the blade so that the blade moves along the sides of the trough (see Fig. (d)). During this process the wet soil may pull away from the end of the trough, in which case it should be pushed back gently with the spatula.

**N.B.** The soil surface should no account be smoothed or finished off with a wet spatula.

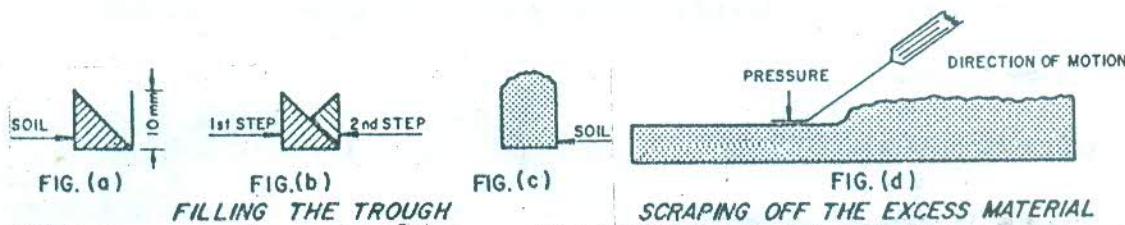


FIGURE 6.1.2

### 6.1.3 Drying the wet material

The trough with wet material is now placed in a position so that the soil-water mixture can air-dry slowly until it has shrunk away from the walls of the mould. It is then placed in a drying oven and dried at a temperature of between 105 and 110 °C until all shrinkage has stopped. As a rule the material is dried out overnight - though three hours should be sufficient time in the oven. The trough with material is taken out and allowed to cool in the air.

### 6.1.4 Measuring the shrinkage.

It will be found that the ends of the dry soil bar have slight lip or projecting piece at the top. These lips must be removed by abrading with a sharp, narrow spatula, so that the end of the soil bar is parallel to the end of the trough (see Fig. (e)). If the soil bar is curved, it should be pressed back into the trough with the finger-tips so as to make the top surface as level as possible.

The loose dust and sand, removed from the ends, as well as loose material between cracks should be emptied out of the trough by carefully inverting the trough whilst the material is being held in position with the fingers. The soil bar is then pressed tightly against one end of the trough. It will be noticed that the soil bar fits better at the one end than at the other end. The bar should be pressed tightly against the end at which there is a better fit. The distance between the other end of the soil bar and the respective end of the trough, is measured by means of a good pair of inside vernier callipers, to the nearest 0.5 mm and recorded on Form S6.

## 6.2 Calculations.

- 6.2.1 The linear shrinkage from both the Casagrande cup and the BS cone liquid limit trials indicated above are calculated from the following formula:

$$LS = 100 \times (\text{shrinkage mm}) / (\text{original length}).$$

The linear shrinkage is reported to the nearest 0.5% on Form S6.

Note: After testing, the soil bar should be examined to ensure that the corners of the trough were filled properly and that no air pockets were contained in the soil bar.

## 7 PLASTIC LIMIT

### 7.1 Preparation of Test Specimen

- 7.1.1 Select a 20-g portion of soil from the prepared soil fines that have been stored in the plastic tub at a moisture content a little above the plastic limit. Reduce the water content of the soil to a consistency at which it can be rolled without sticking to the hands by spreading and mixing continuously on the glass plate. The drying process may be accelerated by exposing the soil to the air current from an electric fan, or by blotting with paper that does not add any fibre to the soil, such as hard surface paper towelling or high wet-strength filter paper.

### 7.2 Procedure

- 7.2.1 From the 20 g mass, select a portion of 1.5 to 2.0 g. Form the test specimen into an ellipsoidal mass. Roll this mass between the palm or fingers and the ground-glass plate with just sufficient pressure to roll the mass into a thread of uniform diameter throughout its length. A normal rate of rolling for most soils should be 80 to 90 strokes per minute, counting a stroke as one complete motion of the hand forward and back to the starting position. This rate of rolling may have to be decreased for very fragile soils. The thread shall be further deformed on each stroke so that its diameter is continuously reduced and its length extended until the diameter reaches  $3.2 \pm 0.5$  mm. A 3.2-mm diameter rod or tube is useful for frequent comparison with the soil thread to ascertain when the thread has reached the proper diameter, especially for inexperienced operators. This process should take no more than 2 minutes. The amount of hand or finger pressure required will vary greatly, according to the soil. Fragile soils of low plasticity are best rolled under the outer edge of the palm or at the base of the thumb.

- 7.2.2 When the diameter of the thread becomes 3.2 mm, break the thread into several pieces. Squeeze the pieces together, knead between the thumb and first finger of each hand, reform into an ellipsoidal mass, and re-roll. Continue this alternate rolling to a thread 3.2 mm in diameter, gathering together, kneading and rerolling, until the thread crumbles under the pressure required for rolling and the soil can no longer be rolled into a 3.2-mm diameter thread. It has no significance if the thread breaks into

threads of shorter length. Roll each of these shorter threads to 3.2 mm in diameter. The only requirement for continuing the test is that they are able to be reformed into an ellipsoidal mass and rolled out again. The operator shall at no time attempt to produce failure at exactly 3.2 mm diameter by allowing the thread to reach 3.2 mm, then reducing the rate of rolling or the hand pressure, or both, while continuing the rolling without further deformation until the read falls apart. It is permissible, however, to reduce the total amount of deformation for feebly plastic soils by making the initial diameter of the ellipsoidal mass nearer to the required 3.2-mm final diameter. If crumbling occurs when the thread has a diameter greater than 3.2 mm, this shall be considered a satisfactory end point, provided the soil has been previously rolled into a thread 3.2 mm in diameter. Crumbling of the thread will manifest itself differently with the various types of soil. Some soils fall apart in numerous small aggregations of particles, others may form an outside tubular layer that starts splitting at both ends. The splitting progresses toward the middle, and finally, the thread falls apart in many small platy particles. Fat clay soils require much pressure to deform the thread, particularly as they approach the plastic limit. With these soils, the thread breaks into a series of barrel-shaped segments about 3.2 to 9.5 mm in length.

- 7.2.3 Gather the portions of the crumbled thread together and place in a weighed container. Immediately cover the container.
- 7.2.4 Select another 1.5 to 2.0 g portion of soil from the original 20-g specimen and repeat the operations described in 7.2.1 to 7.2.3 until the container has at least 6 g of soil.
- 7.2.5 Determine the water content, in percent, of the soil contained in the container using oven drying to constant mass at 105 °C to 110 °C. Make all weighings on the same balance. The lid of the container should be included in both the wet and dry weighings, although it should be removed from the container while it is drying in the oven.
- 7.2.6 Repeat 7.2.1 through 7.2.5 to make another container holding at least 6 g of soil. The intent of performing two plastic limit trials is to verify the consistency of the test results. It is acceptable practice to perform only one plastic limit trial when the consistency in the test results can be confirmed by other means.

### 7.3. Calculations

- 7.3.1 Compute the average of the two water contents. If the difference between the two water contents is greater than two percentage points, repeat the test. The plastic limit is the average of the two water contents

## 8 PLASTICITY INDEX

### 8.1 Calculations

- 8.1.1 Calculate the plasticity index as follows:

$$PI = LL - PL$$

where:

LL = the liquid limit.

PL = the plastic limit.

Both LL and PL are whole numbers. If either the liquid limit or plastic limit could not be determined, or if the plastic limit is equal to or greater than the liquid limit, report the soil as nonplastic, NP.

## 9 REFERENCES.

ASTM Designation: D 2217; D 4318; D 2216; D 2240; D 2487; D 2488; D 3282.

BS 1377: Tests 1(A); 2(A); 2(B); 3; 4; 5.

TMH 1: Tests A1; A2; A3; A4.

GHANA HIGHWAY AUTHORITY:  
CENTRAL MATERIALS  
LABORATORY.

DRAFT FORM S6.  
ATTERBERG LIMITS  
OF  
SOIL FINES.

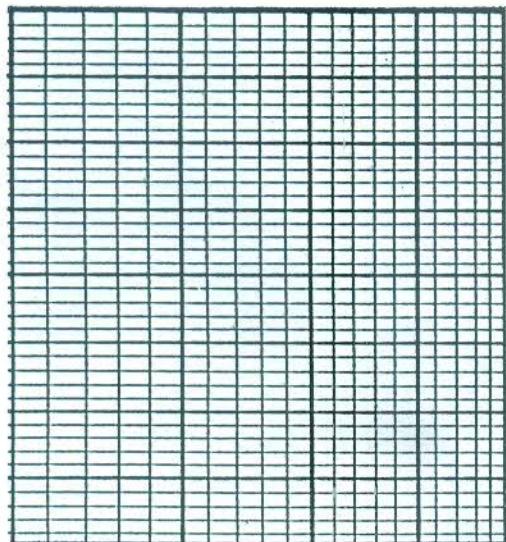
DATE \_\_\_\_\_

SAMPLE NUMBER:	OPERATOR:
SAMPLE LOCATION:	
SAMPLE DESCRIPTION:	
Mass Air-Dry Sample:	Preparation A / Preparation B / Air-dry
Soaking Bowl Number:	PI Tub Number:
Settlement Bowl Number:	Evaporation Pan No.

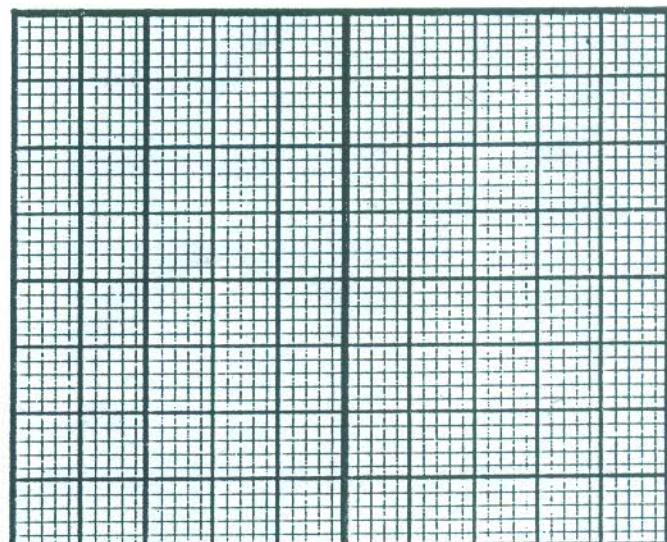
### MOISTURE CONTENT DETERMINATIONS

Type of test	Casagrande cup	Liquid Limit.	B. S. Cone	Liquid Limit	Plastic Limit.			
Test Number.	1(27-35)	2(23-27)	3(15-23)	1(15-18)	2(18-22)	3(22-25)	1	2
No. Blows - Cone penetration								
Container Number.								
Mass of wet soil + Container.								
Mass of dry soil + Container.								
Mass of Container.								
Mass of water.								
Mass of dry soil.								
Moisture Content.								

MOISTURE CONTENT



Number of taps.



Penetration (mm)

Casagrande Cup Liquid Limit.:			BS Cone Liquid Limit.:						
Shrinkage Mould No.	Shrinkage: mm. %		Shrink Mld No.	Shrinkage: mm. %					
Average Plastic Limit:									
PLASTICITY INDEX; Casagrande:			PLASTICITY INDEX; BS Cone:						

**DRAFT GHA TEST METHOD - SOILS 7.**

**SIEVE ANALYSIS OF GRANULAR SOILS**

## DRAFT GHA TEST METHOD - SOILS 7.

### SIEVE ANALYSIS OF GRANULAR SOILS

#### 1. SCOPE

- 1.1 This method describes the sample preparation and washed sieve analysis of soils and gravels.
- 1.2 A distinction is made in the procedure between those soils which do and do not contain particles with a size greater than 19 mm.
- 1.2.1 Procedure A is for soils and gravels that contain particles of greater size than 19 mm. The sample is air-dried to allow any soil aggregations to be disintegrated, and separation to be done on the 19 mm sieve. This is generally applicable to granular soils with 35% or less passing the 0.075 sieve, (ie. soils of AASHTO classification A-1, A-3, and A-2) that are considered for use in the pavement layers.
- 1.2.2 Procedure B is for finer soils of A-4, A-5, A-6 and A-7 that are generally characterised for subgrade assessment and use as common fill. Some of these soils never dry out in nature and may change their characteristics greatly when dried. In procedure B the sample is kept at and above its natural moisture content until after the proportion finer than 0.075 mm, which is most effected by any drying, has been removed from the sample. Soils to be processed in accordance with procedure B should be shipped to the laboratory in sealed containers.

#### 2. APPARATUS

- 2.1 A riffler with 25.0 mm to 40 mm openings.
- 2.2 The following tests sieves, complying with BS 410 or ISO 3310/1 and ISO 3310/2, with sieves larger than 4.75 mm being of perforated plate and sieves 4.75 mm and smaller of wire mesh:
  - (a) 75.0 mm, 53.0 mm 37.5 mm 26.5 mm and 19.0 mm sieves of 450 mm diameter.
  - (b) 19.0 mm, 13.2 mm, 9.50 mm, 6.7 mm, 4.75 mm, 2.00 mm, 1.00 mm, 0.425 mm, 0.300 mm, 0.150 mm, 0.075 mm sieves of 200 mm diameter, with pan and cover.
- 2.3 A mechanical sieve shaker.
- 2.4 (a) A platform scale to weigh to 100 Kg to accuracy of 100 g;  
(b) A balance with a pan to weigh up to 25 kg accurate to 1 g;  
(c) A balance with a pan to weigh up to 2000 g accurate to 0.1 g.  
(d) A balance to weigh up to 200 g, accurate to 0.01 g.

- 2.5 Basins and pans:
- (a) Large pans for air-drying sample.
  - (b) Basins about 500 mm in diameter.
  - (c) Basins about 350 mm in diameter.
  - (d) Oven pans about 250 mm square.
- 2.6 A 150 mm nominal diameter iron mortar and pestle and a rubber-tipper pestle.
- 2.8 A drying oven, thermostatically controlled and capable of maintaining a temperature of 105 to +/- 10°C.
- 2.9 Brushes for cleaning sieves:
- (a) A brass or copper wire brush, measuring about 50 X 25 mm, with bristles not more than 25 mm long.
  - (b) A hard-bristle nail-brush, measuring about 80 X 25 mm.
- 2.10 A supply tank for distilled or de-aired water.

### 3 SAMPLE PREPARATION

#### 3.1 Procedure A

3.1.1 Ideally the sample obtained in the field should be a large bulk sample that can be used for all the following tests:

Atterberg Limits as described method S6;  
Sieve analysis as described here-in;  
Determination of Maximum dry density of the fraction passing 19 mm and  
bulk specific gravity of the coarse fraction as described in Method S1;  
Determination of CBR as described in Method S2.

The minimum mass required for this is about 70 kg and for a wet coarse gravel would be about 100 kg.

3.1.2 Dry the soil sample as received from the field, using one of the following methods:

- (1) air-dry in large pan at ambient temperature (preferred);
- (2) dry in an oven at a temperature not exceeding 60°C;
- (3) dry using any warming device that will not raise the temperature of the sample above 60°C.

- 3.1.3 Break up thoroughly any aggregations of particles using the mortar and rubber-covered pestle or other suitable device. When the sample contains particles of soft shale or sandstone or similar weak material, proper care must be exercised to avoid excessive reduction in the size of the particles.
- 3.1.4 Separate the sample at 19 mm by sieving through a 450 mm diameter sieve with 19 mm apertures. Place the fraction passing 19 mm back in the drying tray, and the fraction retained in a 500 mm diameter bowl.
- 3.1.5 At this stage the grading of the particles larger than 19 mm is done (see 4.1). During this sieving more material passing the 19 mm sieve may be produced. This should be added to the rest of the material passing the 19 mm sieve. The air-dry mass of this fraction is then determined. Use form S7-A for recording the data when procedure A is used.
- 3.1.6 Four representative portions of the fraction passing the 19 mm sieve are obtained by successive use of the sampler riffler. Each portion should have a mass of about 2000 g. These are to be used for the grading analysis, moisture content determination, the preparation of fines for Atterberg limits, and a spare incase a duplicate test or additional fines for the Atterberg limits is required.
- 3.1.7 Where only the grading of a material with a maximum size of 19 mm is required, (eg. after compaction and CBR test) a sample of about 4000 g should be used. This is divided into two by riffling or quartering.

## 3.2 Procedure B

- 3.2.1 Samples prepared in accordance with this procedure must be transported from the field to the laboratory in sealed containers and must contain all their natural moisture.
- 3.2.2 The minimum recommended mass of the sample required from the field is dependent on the nominal maximum size as indicated below:

Nominal Maximum Size, mm	Minimum Mass, g.
Up to 2.00	1000
4.75	2000
9.50	4000
19.0	8000

This sample should be representative of the material to be characterised.

- 3.2.3 The sample received from the field is to be divided into four sub-samples that are as similar as possible. Where practical the sample should be quickly mixed and divided by successive quartering. In the case of firm clays and silts it may only be practical to cut the sample into four with a pallet knife. Care should be taken to ensure that the soil dries as little as possible during this operation.

- 3.3 Amount of material finer than 0.075 mm.
- 3.3.1 The procedure for determining the amount of material finer than 0.075 mm is the same for both methods of preparation and is done only on material smaller than 19 mm. Use form S7-A for procedure A and form S7-B for procedure B.
- 3.3.2 Two of the four sub-samples are selected. One is used as an auxiliary sample to determine the moisture content. The other is used for the washed grading.
- 3.3.3 Place the auxiliary moisture content sub-sample in an oven pan of known mass, weigh, and from the difference determine the wet mass of the sample. The sub-sample is then dried to constant mass in an oven at 105°C to 110°C, and the moisture content determined in the usual manner.
- 3.3.4 After oven drying and weighing this sample can be used for a check grading by continuing with the washing procedure described in 3.3.5 onwards. Form S7-C may be used for this purpose. This check grading will indicate the effect of drying the sample on the determination of fines.
- 3.3.5 Place the sub-sample for the washed grading in a suitable soaking bowl of known mass, weigh, and from the difference determine the wet mass of the sub-sample.
- 3.3.6 The grading sub-sample is covered with clean water and allowed to soak for 24 hours +/- 4 hours. Several times during this period the sample should be agitated to facilitate the separation of the particles finer than 0.075 mm from the coarser particles.
- 3.3.7 At the end of this period the sample is agitated vigorously to bring the material finer than 0.075 mm into suspension in the water. This dirty water with the soil fines in suspension is then poured carefully through the 0.075 mm sieve to waste. With a little practice, by allowing the agitated water to stand for a short while for the particles larger than 0.075 to settle, this can be done without having a larger sieve for protection and with very little material retained on the 0.075 sieve. This process is repeated several times with more water until most of the material finer than 0.075 mm is washed away. The small amount retained on the 0.075 mm sieve should be left in the sieve.
- 3.3.8 The washing is then completed in the following manner:

Add more water to the sample, and agitate thoroughly. Place an empty 2.00 mm sieve on the bottom of another bowl and pour the water from the partially washed sample into the sieve. Add sufficient water to bring the level approximately 10 mm above the mesh of the sieve. Transfer the remainder of the material to the sieve in increments not exceeding 0.5 kg, stirring each increment with the fingers while agitating the sieve up and down. Crumble or mash any lumps that have not slaked, using the thumb and fingers. Raise the sieve above the water in the pan and complete the washing operation through the 2.00 mm sieve using a small amount of clean water. Transfer the washed material retained on the sieve to a clean pan to be used for oven drying before placing another increment of soaked material on the sieve.

Repeat the above procedure for the material and water passing the 2.00 mm sieve using a 0.425 mm sieve. The washed material retained on the 0.425 sieve is added to the oven pan containing that retained on the 2.00 mm sieve. It may be necessary to back wash into the oven pan to remove all the material retained on the 0.425 mm sieve. This water can be decanted when it is clear, before the pan is put in the oven.

Repeat this procedure a third time for the material and water passing the 0.425 mm sieve using the 0.075 mm sieve with the material previously retained on it still in place. The washed material retained on the 0.075 mm sieve is added to the oven pan containing that retained on the 2.00 mm and 0.425 mm sieves. It will be necessary to back wash this material into the oven pan to remove all the material retained on the 0.075 mm sieve. This water can be decanted when it is clear, before the pan is put in the oven.

- 3.3.9 The washed material retained on the 2.00 mm, 0.425 mm, and 0.075 mm sieves is then dried to constant mass in an oven at 105°C to 110°C, its dry mass recorded and the sample retained for dry sieving.

#### 4 SIEVE ANALYSIS

##### 4.1 Fraction larger than 19 mm.

- 4.1.1 Take the whole of the fraction retained on the 19 mm sieve and sieve it successively through the 75 mm, 53 mm, 37.5 mm, 26.5 mm and 19 mm sieves of 450 mm diameter into the receiving pan.
- 4.1.2 Determine the air-dry ("moist") mass of the material retained on each of the sieves. This can be recorded on form S7-A.
- 4.1.3 Select from the material retained on each of the sieves 19 mm and larger a similar proportion of the material retained on each to give a representative sample of between 2000 g and 3000 g. Determine the moisture content by drying to constant mass in an oven at 105°C to 110°C.

If required this oven dry sample may then be used to determine the bulk specific gravity as described in method S1.

##### 4.2 Sieve analysis of fraction passing 19 mm after washing through 0.075 mm.

- 4.2.1 After oven drying to constant mass and weighing, the material passing 19 mm and not washed through the 0.075 mm sieve is sieved through a nest of 200 mm diameter sieves with the following apertures: 19.0 mm, 13.2 mm, 9.50 mm, 6.7 mm, 4.75 mm, 2.00 mm, 1.00 mm, 0.425 mm, 0.300 mm, 0.150 mm, and 0.075 mm with pan and cover .
- 4.2.2 The sieving should be thorough. It may be done by hand but preferably by means of a mechanical sieve shaker. On no account should any sieve be overloaded as some of the fine material may be kept back if the layer on the

sieve is too deep. If necessary, the material should be divided into fractions which are then sieved separately. After sieving, the material retained on each sieve is weighed and the masses recorded in the appropriate column of Form S7-A (or S7-B/C). Weighing should be accurate to the nearest 0.1 g.

- 4.2.3 The maximum mass retained on each sieve after the completion of the sieving should be less than the masses given in table 4.2.3.

TABLE 4.2.3. Maximum allowable mass retained on sieves.

sieve size (mm)	Maximum allowable mass on sieve (g)
19	1000
13.2	800
9.5	650
6.7	500
4.75	400
2.00	300
1.00	200
0.425	200
0.300	150
0.150	150
0.075	100

## 5. CALCULATIONS

- 5.1 Fraction greater than 19 mm.

- 5.1.1 The air-dry ("moist") mass of the material retained on each of the sieves 19 mm and larger was determined (see 4.1.2.)

- 5.1.2 The moisture content of these coarse aggregates was determined (see 4.1.3)

- 5.1.3 Calculate the dry mass of each fraction retained on the sieves coarser than 19 mm using the moist mass recorded and the moisture content (MC) determined in 4.1.3.

$$\text{Dry mass} = \frac{100 \times \text{Moist mass}}{(100 + MC)}$$

- 5.1.4 The air-dry ("moist") mass of the material passing the 19 mm sieve was determined (see 3.1.5.)

- 5.1.5 The moisture content of the aggregates finer than 19 mm was determined on an auxiliary sample (see 3.3.3)

- 5.1.6 Calculate the dry mass of the fraction finer than 19 mm using the moist mass recorded (3.1.5) and the moisture content (MC) determined in 3.3.3.

$$\text{Dry mass} = \frac{100 \times \text{Moist mass}}{(100 + MC)}$$

- 5.1.7 Sum the dry masses of the material retained on each of the sieves and passing 19 mm (Pan) to determine the total dry mass. Calculate the percentage of the total dry mass retained on each sieve and passing the 19 mm sieve and record in the appropriate column.
- 5.1.8 Calculate the percentage passing each sieve size starting with that passing 19 mm and sequentially adding the percentage retained on the larger sieves. Check that subject to rounding errors the percentage passing the largest sieve is 100%.
- 5.2 Fraction smaller than 19 mm.
- 5.2.1 The moisture content of the air-dry (moist) auxiliary sample was determined (see 3.3.3). The mass of air dry (moist) sample for grading determined (see 3.3.5) and from it the dry mass of this sample is calculated using the moisture content of the auxiliary sample.
- 5.2.2 The dry mass of the sample after washing through the 0.075 mm sieve was determined (see 3.3.9) The mass of the material finer than 0.075 that was washed away is the difference between the dry masses before and after washing. This is recorded in the two appropriate places on form S7-A.
- 5.2.3 The mass of the material retained on each of the sieves (see 4.2.2), in the pan (passing 0.075 mm) and washed through the 0.075 mm are added to give the total mass of the sample. This should be compared with the dry mass of the sample before washing, and for a properly conducted test should be within 1 g of each other.
- 5.2.4 The percentage of the total mass retained on each sieve and passing 0.075 mm (mass in pan plus that washed away) is calculated and recorded in the "% retained" column.
- 5.2.5 The percentage of the minus 19 mm fraction passing each sieve size is calculated starting with that passing 0.075 and sequentially adding the percentage retained on the larger sieves. The percentage passing 19 mm should be 100% allowing for rounding errors.
- 5.2.6 The grading of the fraction smaller than 19 mm can then be plotted on figure S7.
- 5.2.7 The percentage of the total sample passing each sieve size is calculated by multiplying the percentage of the minus 19 mm sample passing the sieve size by the percentage passing 19 mm and dividing by 100.
- 5.2.8 The grading of the total sample is also plotted on figure S7.

## 6. NOTES

- 6.1 Clean rain water may be used instead of distilled or deionized water.
- 6.2 It is essential that the particle size should not be altered during preparation. Only friable decomposed material and soil clods should be disintegrated. The extent to which decomposed material is to be disintegrated cannot be specified and must be left to the discretion of the operator. Material from compacted

layers in the road should be prepared without disintegrating the decomposed material.

## 7. REFERENCES

- ASTM Designation: C 117; C 136; D 421; D 422; D 1140; D 2216; D 2217; D 4318; D 2487; D 2488; D 3282.
- AASHTO Designation T 87; T 88; T 89; T 90; T 146.
- BS 1377: Tests 1(A); 7A; 7B.
- TMH 1: Tests A1; A5; A6; B4.
- SABS 197

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DRAFT FORM S7-A  
WASHED SIEVE ANALYSIS  
AIR-DRY GRANULAR  
SOIL.

DATE : \_\_\_\_\_  
OPERATOR: \_\_\_\_\_

SAMPLE NUMBER:
SAMPLE LOCATION:
SAMPLE DESCRIPTION:
Mass Sample Received:

GRADING OF AIR-DRY COURSE AGGREGATE					AIR-DRY MOISTURE CONTENTS.		
Sieve Aperture	Mass Retained	Dry Mass. g.	Percent Retained	Percent Passing		Passing 19.00 mm	Retained 19.00 mm
-----	-----	-----	-----	-----	Container Number.		
75.0					Mass Moist Agg + Cont.		
53.0					Mass Dry Agg + Cont.		
37.5					Mass of Container.		
26.5					Mass of water.		
19.0				-----	Mass of dry Aggregate.		
Pan				-----	Moisture Content.		
Total Dry Mass							

GRADING OF MINUS 19 mm FRACTION

Mass Bowl No.	
Mass Bowl + air-dry (moist) sub-sample	
Mass air-dry (moist) sub-sample	
Mass dry sub-sample	
Mass Bowl + dry sample after washing	
Mass dry sample after washing	
Mass minus 0.075 washed away	

SIEVE APERTURE mm	MASS RETAINED g	% RETAINED %	% PASSING MINUS 19 mm	% PASSING Total Sample
19.0				
9.5				
4.75				
2.00				
1.00				
0.425				
0.300				
0.150				
0.075				
PAN +				
Mass Washed Away				
Total -19mm				

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DRAFT FORM S7-B  
WASHED SIEVE ANALYSIS  
OF MOIST SAMPLE.

DATE: \_\_\_\_\_  
OPERATOR: \_\_\_\_\_

**SAMPLE NUMBER:**

**MOISTURE CONTENT SUB-SAMPLE**

	Container Number.	
a	Mass moist sample + container.	
b	Mass dry sample + container.	
c	Mass of container.	
d	Mass of water, g. ((a) - (b))	
e	Mass of dry sample, g. ((b) - (c))	
f	<b>Moisture Content, %. (100 * (d) / (e))</b>	

**WASHED GRADING SUB-SAMPLE**

g	Mass Bowl No.	
h	Mass Bowl + moist sub-sample	
i	Mass moist sub-sample, g. ((h) - (g))	
j	Calc. mass dry sub-sample, g. (100* (i) / (100 + (f)))	*
k	Mass Bowl + dry sample after washing	
l	Mass dry sample after washing, g. ((k) - (g))	
m	Mass minus 0.075 washed away	

SIEVE APERTURE mm	MASS RETAINED g	% RETAINED %	% PASSING 19 mm
19.0	-----	-----	
13.2			
9.5			
6.7			
4.75			
2.00			
1.00			
0.600			
0.425			
0.300			
0.150			
0.075			
PAN +			
0.075 Washed Away. (m)			
<b>TOTAL *</b>	*		

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DRAFT FORM S7-C  
WASHED SIEVE ANALYSIS of  
OVEN -DRIED SAMPLE.

DATE: \_\_\_\_\_

OPERATOR: \_\_\_\_\_

SAMPLE NUMBER:

SAMPLE LOCATION:

SAMPLE DESCRIPTION:

Mass Sample Received:

GRADING OF OVEN DRIED MINUS 19 mm FRACTION

Oven pan Number.

Mass of oven dry sample.

Soaking bowl Number.

Mass <sup>of</sup> oven pan + dry sample after washing

Mass dry sample after washing

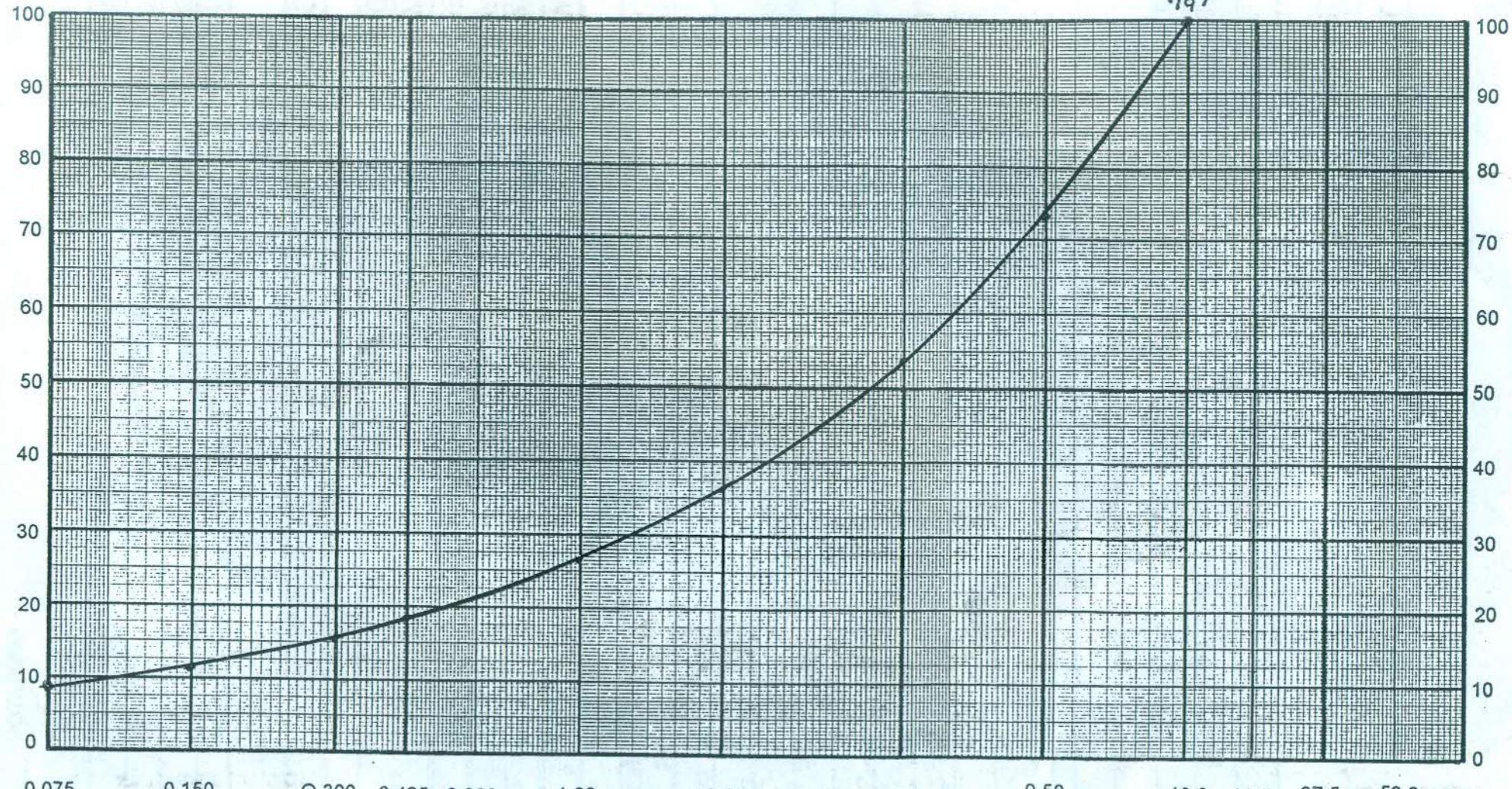
Mass minus 0.075 washed away\*

SIEVE APERTURE mm	MASS RETAINED g	% RETAINED %	% PASSING 19 mm
19.0			
16.0			
13.2			
9.5			
6.7			
4.75			
	3.35		
2.00			
1.00			
0.600			
0.425			
0.300			
0.150			
0.075			
PAN +			
Washed Away*			
TOTAL - 19mm			

## SIEVE ANALYSIS

$$\left(\frac{d}{d_0}\right)^{0.45}$$

CUMULATIVE PERCENTAGE PASSING



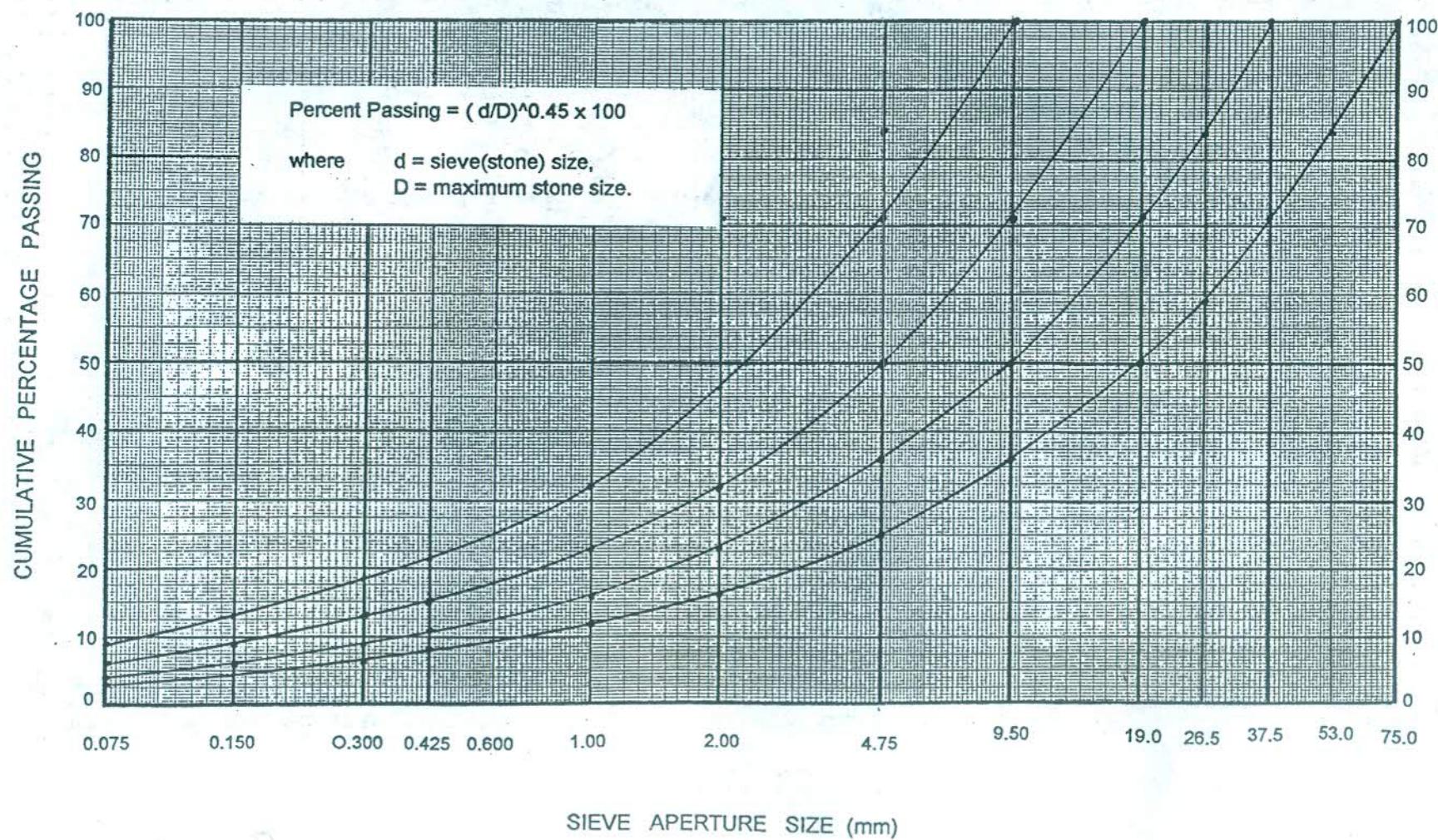
SIEVE APERTURE SIZE (mm)

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FIGURE S7 / 2.

SAMPLE NUMBER. \_\_\_\_\_

GRADING SHEET FOR SIEVE ANALYSIS.  
WITH MAXIMUM DENSITY GRADINGS.



**DRAFT GHA TEST PROCEDURE - SOILS 8.**

**SCHEDULE FOR CONCURRENT SOIL TESTING.**

## **DRAFT GHA TEST PROCEDURE - SOILS 8.**

### **SCHEDULE FOR CONCURRENT SOIL TESTING.**

#### **1. INTRODUCTION.**

The following set of tests are commonly required on a soil or gravel to characterise them for use in pavement construction:

**(i) THE DETERMINATION OF REFERENCE DENSITY FOR COMPACTION CONTROL. (S1).**

This includes the determination of the moisture / density relationship at Modified compactive effort (including MDD and OMC), of the fraction of soil smaller than 19 mm, and the Specific Gravity of the coarse aggregate ( $> 19$  mm).

**(ii) THE DETERMINATION OF THE CALIFORNIA BEARING RATIO. (S2).**

This is done of on three specimens of the fraction smaller than 19 mm, that are identical to those used for the determination of the moisture / density relationship, but compacted at Modified OMC to Modified MDD.

**(iii) SIEVE ANALYSIS. (S7).**

This includes a dry grading of the fraction of the bulk sample larger than 19 mm, and a washed grading of a sub-sample of the fraction smaller than 19 mm.

**(iv) DETERMINATION OF ATTERBERG LIMITS OF SOIL FINES. (S6).**

This includes the wet preparation of the soil fines from a sub-sample of the fraction smaller than 19 mm, and the determination of Liquid Limit by BS cone, (used as standard) and Casagrande cup, Plastic Limit and Linear Shrinkage.

Each of these tests is done over a period of 3 to 6 days, as time has to be allowed for soaking and drying as well as technicians actually working on the samples. Some aspects of the sample preparation, testing and results are common to more than one of the tests. It is therefore expedient for them to be done concurrently in a planned manner. This is detailed in the schedules for each day given below.

Where a laboratory has a regular supply of samples to be tested the use of this schedule allows the laboratory work to be planned so that the testing of 1 or 2 samples are started each day. This evens out the work load in the laboratory, and makes more efficient use of the limited equipment available.

It is considered expedient to assign laboratory staff to a section to do each test and work as a group for this concurrent testing. A group that could start and continue 1 or 2 sets of tests each day should consist of 3 sections staffed as follows:

- Section 1: Technician plus 2 assistants for moisture / density, SG coarse aggregate, and CBR;
- Section 2: Technician plus 1 assistant for grading;
- Section 3: Technician plus 1 assistant for Atterberg Limits;

More groups would be needed if more than 2 samples were regularly required to be started each day.

## 2. SAMPLE RECEPTION.

When the sample is received it should be weighed, and the mass entered in the "Sample Record Ledger" along with details of source and tests to be conducted. These should be checked to ensure that sufficient sample has been received to do the tests in the standard manner.

That day or as soon as practical there after, the sample should be spread on the drying slab or pan and air-dried to about 4% moisture below the estimated OMC. At this state the material should be sufficiently friable for soil aggregations to be disintegrated, and sufficiently free-flowing to be riffled and sieved through sieves with openings of 19 mm and larger. It is preferable not to air-dry the material completely, as this causes problems with loss of dust during the sample preparation, that may affect the results, and makes working conditions less pleasant.

The sample should then be rebagged and stored ready for testing.

## 3. DAILY TESTING SCHEDULE.

### 3.1 DAY 1

Combined sample preparation of air-dry sample, (Sect 1 & 2):

- Break lumps of soil aggregations with rubber tipped pestle or similar, and remove majority of fines from coarse material;
- Separate into two fractions at 19 mm by sieving whole bulk sample through a 19 mm sieve, (450 mm diameter).

For grading and SG of coarse aggregate, (Sect 2):

- Remove fines from coarse aggregate retained on 19 mm by brushing with stiff brush;
- Sieve coarse aggregate through 75 mm, 53 mm, 37.5 mm, 26.5 mm and 19 mm sieves, (preferably 450 mm diameter) and determine mass of each fraction. Record on grading work-sheet.

- Select a representative portion from each fraction and combine to obtain 2000 g - 3000 g aggregate for moisture content determination and later use for SG determination.
- Add any further material passing 19 mm to that of the bulk sample passing 19 mm, weigh and record total mass of material passing 19 mm on grading work sheet.

For grading and Atterbergs, (Sect 2 and 3):

- Divide (riffle) material passing 19 mm to obtain 4 sub-samples of about 2000 g. These are for use as follows:
  - (i) Determine moisture content of air-dry minus 19 mm fraction for grading analysis and calculation of reference density. This is weighed and placed in the oven to dry, (Sect. 2).
  - (ii) Washed grading analysis. Weigh air-dry sample, record mass on grading work sheet, place in bowl, cover with water and allow to soak to Day 2, (Sect. 2).
  - (iii) Atterberg Limits. Weigh and sieve through 0.425 mm sieve protected by 2.00 mm and 4.75 mm sieves. Store soil fines, and place material retained on 0.425 mm and protection sieves in a bowl, cover with water and soak to Day 2, (Sect. 3).
  - (iv) This is a spare and should be retained for a repeat of grading or Atterbergs. For materials with a small amount of soil fines it can be added to the Atterbergs sample to give sufficient soil fines.

For moisture / density, and CBR, (Sect 1):

- Remix remaining material passing 19 mm and adjust to weigh about 58 Kg by removing some (representative) material.
- Divide the 58 Kg into 8 identical sub-samples by successive riffling. Adjust each sub-sample to 7000 g by removing or adding material. Place each sub-sample in a bucket and seal with a lid until required on Day 2.

### **3.2 DAY 2.**

For grading and moisture / density, (Sect 2):

- weigh dry coarse and fine samples and calculate moisture contents.
- Calculate dry mass of each coarse fraction and total larger than 19 mm and of fraction smaller than 19 mm. Transfer result to moisture / density for use for correction of MDD for oversize. Transfer coarse aggregate sample to Section 1 for determination of Specific Gravity.

- Remove fines smaller than 0.075 mm by washing soaked minus 19 mm sub-sample through 0.075 mm and protection sieves. Transfer all material retained on 0.075 mm and protection sieves to an oven pan and place in oven to dry.

For SG coarse aggregate, (Sect 1);

- Collect oven dry coarse aggregate sample form grading Section, place in bowl, cover with water and allow to soak to Day 3.

For determination of moisture / density and CBR, (Sect 1):

- Prepare 5 sub-samples with different moisture contents, with 2 on either side of Optimum Moisture Content, and allow to equilibrate.
- Compact in order OMC, OMC + 1%, OMC + 2%, OMC - 1%, and OMC - 2%.
- After compaction and trimming of each sub-sample, weigh and calculate wet density.
- Determine the approximate dry density using the estimated comaction moisture content. Plot the position of each approximate dry density against the estimated compaction moisture content before removing the sub-sample from the mould and starting to compact the next sub-sample. This is to allow the facility of adjusting the moisture content of the sub-sample should the subjective estimate of the OMC of the first sub-sample be too far from the OMC.
- Remove sub-sample from mould, break down aggregations, and divide by quartering to obtain a moisture content sample of about a quarter of the compacted sub-sample. Weigh and record mass and place in oven to dry until Day 3.
- From the "approximate dry density" to "estimated compaction moisture content" relationship determine the "estimated compaction moisture content" giving the maximum "approximate dry density". Calculate optimum amount of water to be added.
- Mix the optimum amount of water to be added with each of the 3 CBR sub-samples and allow to equilibrate for the same time as the moisture / density sub-samples.
- Compact CBR sub-samples in the same manner as moisture / density sub-samples except take a representative sample for moisture content determination from the mixing bowl after compacting the second layer.
- Trim, weigh and calculate approximate dry density. Check to establish that it is close enough to previously determined maximum approximate dry density.

- Fit soaking base plate and filter papers to trimmed face of sample, invert and place soaking swell plate and surcharge on sample.
- Put CBR sub-samples with soaking swell plate and surcharge weight into soaking bath, set swell gauge and record initial reading.

For determination of Atterberg Limits, (Sect. 3):

- Wash soaked sample through 0.425 mm and protective sieves being sure to collect all residue washed through 0.425 mm.
- Allow wash residue to settle, decant clear water and allow water in residue to evaporate to a paste. This process may extend through into Day 3.

### 3.3 DAY 3.

For grading, (Sect 2):

- Weigh oven dry sample retained on 0.075 mm and calculate mass of material smaller than 0.075 mm washed away.
- Sieve dry material through nested sieves (19 mm down to 0.075 mm) into receiving pan.
- Weigh material retained on each sieve and pan, and record mass.
- For the material smaller than 19 mm, calculate percentage of material passing each sieve, (include material < 0.075 mm washed away). Plot grading curve.
- Adjust grading of material passing 19 mm for material larger than 19 mm and plot grading curve of whole sample.

For SG coarse aggregate, (Sect 1);

- Thoroughly wash soaked SG sample to remove loose surface particles.
- Surface dry sample and follow pycnometer procedure for determining SG.
- Quantitatively transfer all aggregate from pycnometer into an oven pan and place in oven until Day 4 to dry.

For determination of moisture / density and CBR, (Sect 1):

- Remove moisture samples (8) from oven, weigh and calculate moisture contents.
- Check MC with "estimated compaction moisture content" for constant difference. Rectify any abnormalities if possible, or arrange repeat test.

- Calculate dry density and plot moisture / density relationship including CBR samples. Check CBR samples are close enough to MDD and OMC.

For determination of Atterberg Limits, (Sect. 3):

- Continue to allow water to evaporate from residue to form a paste. It may be necessary to boil residue to speed up this process.
- Mix previously sieved air-dry soil fines with paste and store in sealed plastic tub until Day 4.

#### **3.4 DAY 4.**

For SG coarse aggregate, (Sect 1);

- Remove dry aggregate from oven, cool and weigh.
- Calculate SG of oversize ( $> 19$  mm) aggregate.
- Calculate reference density from MDD of minus 19 mm material and amount and SG of oversize.

For determination of Atterberg Limits, (Sect. 3):

- Remove wet material from plastic tub to glass sheet and mix for minimum 10 minutes.
- Divide sample for Plastic Limit test and Liquid Limit (BS and Casagrande) with Linear Shrinkage.
- Conduct PL and LL tests to produce required moisture content samples, weigh and place in oven until Day 5 to dry.
- From LL sample fill Linear Shrinkage mould and allow to air-dry. At end of day place in oven to dry until Day 5.

#### **3.5 DAY 5.**

For determination of Atterberg Limits, (Sect. 3):

- Remove MC samples from oven, cool and weigh.
- Calculate MC for LL, and PL. Calculate PI.
- Remove Linear Shrinkage sample from oven, cool and measure shrinkage.
- Compare BS and Casagrande LLs, and PI and LS for anomalies.

### 3.6 DAY 6.

For determination of moisture / density and CBR, (Sect 1):

- Measure swell of CBR samples after 4 days soaking.
- Drain sample and do CBR penetration.
- Remove soaking plate, weigh and calculate wet weight of sample and MC after soaking.
- Calculate CBR and complete summary sheet, (Form S2/1).

## DRAFT GHA TEST METHOD - SOILS 9.

### THE DETERMINATION OF THE GRAIN SIZE DISTRIBUTION OF SOIL FINES BY MEANS OF A HYDROMETER

#### 1 SCOPE

- 1.1 This method covers the quantitative determination of the distribution of particle sizes in soils. The distribution of particle sizes larger than 0.075 mm is determined by sieving as described in method S7, while the distribution of particle sizes smaller than 0.075 mm is determined by a sedimentation process, based on Stokes's law as defined below, using a specially calibrated hydrometer.
- 1.2 This method does not give absolute results, but gives data which are comparable and consistent if the method is followed in detail (see 5.1).
- 1.3 Stokes's law:

Stokes's law states that: Maximum grain diameter (d)

$$d = \sqrt{(300 n L / 980 (G-G_1) T)}$$

where

n = Viscosity of the suspending medium in Pascal-seconds. The viscosity of distilled water at 20°C is 0,001005 Pa.s.

L = the distance in centimetres through which the grains settle in a period of time, T

T = time in minutes, period of sedimentation.

G = relative density of soil particles

G<sub>1</sub> = relative density of suspending medium (which is 0,99823 for water at 20°C)

#### 2 APPARATUS

- 2.1 A balance to weigh up to 200 g, accurate to 0,1.
- 2.2 A canning jar, wide mouth, about 1000 ml capacity.
- 2.3 A Bouyoucos cylinder graduated at 1130 and 1205 ml.
- 2.5 A dispersing apparatus with paddle. The paddle is attached to a 120 to 150

mm long shaft which is rotated (by an electric motor) at a rate of 1450 revolutions per minute. If such a disperser is not available an egg whisk with 4 vanes may be used.

- 2.6 A tablespoon.
- 2.7 A stop-watch.
- 2.8 A water bath suitably lined or fitted with a thermostat unit to maintain a constant temperature of  $20 \pm 1^{\circ}\text{C}$ .
- 2.9 A wash bottle.
- 2.10 A dish or small basin  $\pm 150$  mm in diameter
- 2.11 A thermometer, measuring 0 to  $50^{\circ}\text{C}$ , graduated in  $0,2^{\circ}\text{C}$ .
- 2.12 A pipette, 10 ml in capacity.
- 2.13 Sodium silicate solution to be prepared as follows:

Dissolve sodium silicate (preferably the waterglass solution) in distilled water until the solution gives a reading of 36 at  $20^{\circ}\text{C}$  on the standard soil hydrometer. Filter the solution.

- 2.14 Sodium oxalate solution - this consists of a filtered saturated solution of sodium oxalate.

### 3 METHOD

#### 3.1 Preparation of sample

- 3.1.1 Place about 150 g of the wet soil fines prepared for the determination of the Atterberg limits (Method S6) in an oven pan and dry to constant mass. Disaggregate the fines into a powder using a mortar and rubber tipped pestle.
- 3.1.2 Weigh out, accurately to 0.1 g, 100 g of the dry soil fines. If the material consists mainly of the fine material with a relatively high percentage of silt and/or clay, weigh out 50 g accurately to 0.1 g.
- 3.1.3 The weighed sample is transferred to the canning jar, and about 400 ml each of the sodium oxalate and sodium silicate solutions (see 5.3) are added. The soil-water mixture is stirred well with a glass rod and left to stand for at least two hours but preferably overnight.
- 3.1.4 After the mixture has been allowed to stand, it is dispersed for 15 minutes with the standard dispersing paddle or five minutes with the egg whisk. The paddle is washed clean and distilled water, and the wash water is allowed to run into the container with the suspension.

### **3.2 Filling the cylinder and correcting the temperature**

- 3.2.1** The suspension is poured into the Bouyoucos cylinder and the canning jar is rinsed with distilled water from the wash bottle. All the suspension is transferred quantitatively to the cylinder.
- 3.2.2** The cylinder is then filled with distilled water to the 1205 ml mark (1 130 ml for a 50 g sample) with the hydrometer inside.
- 3.2.3** The hydrometer is removed, and the cylinder inverted a few times with the palm of one hand held as a stopper over the mouth of the cylinder to ensure that the temperature is uniform throughout.
- 3.2.4** It is then placed in the thermostat bath which is kept as near to 20°C as possible. When the contents of the cylinder are approximately at 20°C (see 5.4), the cylinder is again shaken end over end until a homogeneous suspension is obtained. The cylinder is returned to the water bath and the time recorded. The water in the bath should come to almost the top of the contents of the cylinder but should not be too high as it will then not be possible to read the hydrometer.

### **3.3 Hydrometer readings**

- 3.3.1** Sixty minutes after the cylinder has been placed in the bath, the hydrometer is inserted and a reading is taken to the nearest 0,5. The temperature of the contents is also determined.
- 3.3.2** The hydrometer is removed and the cylinder is shaken again as described above. It is placed on a table and the stop-watch started. After about 10 seconds the hydrometer is inserted and a reading is taken at 18 seconds and 40 seconds.
- 3.3.3** The temperature measured for the one-hour reading is also taken as the temperature for the 18 and 40 seconds readings.
- 3.3.4** The hydrometer readings, taken to the nearest 0,5 and the temperature should be recorded on any suitable data sheet.

## **4 CALCULATIONS**

- 4.1** Table 4.1 gives the maximum diameter of the particles as indicated by hydrometer after different time intervals (see 5.6).
- 4.2** Corrections to the hydrometer readings.
  - 4.2.1** If the temperature of the suspension at the time of the hydrometer reading is not 20°C, a correction should be made to the reading in accordance with the table 4.2.

TABLE 4.1

Hydrometer reading at	Maximum diameter of particles in mm	Common term
18 seconds	0,075	Material passing 0,075 mm sieve
40 seconds	0,05	Silt + clay
1 hour	0,005	Clay

TABLE 4.2.

Degrees Celsius	Correction
18,2 - 18,4	-0,6
18,5 - 18,7	-0,5
18,8 - 19,0	-0,4
19,1 - 19,3	-0,3
19,4 - 19,5	-0,2
19,6 - 19,8	-0,1
19,9 - 20,1	0,0
20,2 - 20,4	+0,1
20,5 - 20,6	+0,2
20,7 - 20,9	+0,3
21,0 - 21,2	+0,4
21,3 - 21,5	+0,5
21,6 - 21,8	+0,6

4.2.2 If a 50 g sample is used, the readings must be doubled after the correction for temperature has been made. The rest of the calculations are then the same as set out below.

4.3 The material smaller than 0.075 mm (18-second reading) is always expressed as a percentage of the total sample. The material smaller than 0.05 mm is expressed as a percentage of the total sample and also as a percentage of the soil fines (i.e. the fraction passing the 0.425 mm sieve). The material smaller than 0.005 mm is only expressed as a percentage of the soil fines.

4.4 The soil fines is divided into three fractions viz:

Fine sand: passing the 0.425 mm and retained on the 0.05 mm;

Silt: smaller than 0.05 mm and larger than 0.005 mm;

Clay: smaller than 0.005 mm.

These fractions are expressed as percentages of the soil fines and are calculated as follows:

#### 4.4.1 Fine sand

The percentage of fine sand in the soil fines ( $P_1$ ) is obtained by subtracting from 100 the reading obtained with the hydrometer at 40 seconds (the mass of soil fines used for hydrometer analysis).

$$P_1 = (100 - F)$$

where

F = 40-second hydrometer reading.

#### 4.4.2 Silt

The percentage of silt in the soil fines ( $P_2$ ) is obtained by subtracting the one-hour hydrometer reading from the 40-seconds reading.

$$P_2 = (F - C)$$

where

C = one-hour hydrometer reading.

#### 4.4.3 Clay

The percentage of clay ( $P_3$ ) in the soil fines is the one-hour hydrometer reading.

### 5 NOTES

- 5.1 If absolute results are required the method given in ASTM Designation D 422 should be used.
- 5.2 Demineralized water or clean rain-water and sometimes even tap water may be used instead of distilled water. If any water other than distilled or demineralized water is used it is necessary to carry out comparative tests with distilled water.
- 5.3 If the dispersing agents are being used up regularly and rapidly equal volumes of each may be premixed and 10 ml of the mixture added instead of 5 ml of each agent.

- 5.4 A skilled operator will be able to make up the suspension in the cylinder so that the temperature is very near to the required 20°C by using warm and/or cold water when filling up the cylinder. It will then not be necessary to leave the cylinder with suspension in the water bath to acquire the right temperature. This procedure is in fact commonly followed.

In this respect, it must be emphasized, however, that if the temperature in the cylinder is slightly high, it is unsound practice to make the water bath slightly colder (or vice versa) in order to obtain more or less the correct temperature in the cylinder when the one-hour reading is taken. This means that the temperature in the cylinder is never constant during the settlement period. furthermore, if the correct temperature cannot be obtained, it is better theoretically to have a slightly high temperature than a slightly low temperature.

- 5.5 The percentage passing the 0.075 mm sieve which is obtained from the 18-second reading, can also be determined by wet sieving. The procedure is fully described in Method S7, which is considered to be a more accurate method. In case of dispute, Method S7 shall be regarded as the referee method.
- 5.6 The maximum particle sizes after 40 seconds and one hour are those given by Bouyoucos in his paper. The maximum particle size after 18 seconds has been obtained from Stokes's equations, assuming average test conditions as far as L and G are concerned.
- 5.7 The hydrometer method of determining particle size distribution as detailed above does not give absolute results, but does give data which are comparable and, provided the method is followed in detail, these data are consistent. The method is rapid and the calculations have been reduced to a minimum.
- 5.8 The hydrometer should be kept in a soap solution (of about 10%) when not in use, as this removes all traces of grease which may be present as a result of handling and which will result in wrong readings.
- 5.9 Calcareous materials and some materials containing soluble salts cannot always be tested, as the suspension becomes flocculated. If excessive flocculation occurs, the one-hour readings are not taken. Only the 40-second readings are taken.

## REFERENCES

AASHTO Designation T88-51  
ASTM Designation D422 - 63  
ASTM 152H

Bouyoucos, G.J. Directions for making mechanical analysis of soils by the hydrometer method. Soil Science Vol. 42, 3 September 1936.

## DRAFT GHA TEST METHOD - SOILS 10.

### CLASSIFICATION OF SOILS AND SOIL-AGGREGATE MIXTURES FOR HIGHWAY CONSTRUCTION PURPOSES

#### 1. Scope

- 1.1 This standard describes a procedure for classifying mineral and organomineral soils into seven groups based on laboratory determination of particle-size distribution, liquid limit, and plasticity index. It should be used when a precise engineering classification is required for highway construction purposes. Evaluation of soils within each group is made by means of a group index, which is a value calculated from an empirical formula.

NOTE 1 - The group classification, including the group index, should be useful in determining the relative quality of the soil material for use in earthwork structures, particularly embankments, subgrades, subbases, and bases. However, for the detailed design of important structures additional data concerning strength or performance characteristics of the soils under field conditions will usually be required.

#### 2. Terminology

##### 2.1 Descriptions of Terms Specific to This Standard:

- 2.1.1 The following terms are used in this standard to maintain consistency with common highway usage.
- 2.1.2 Boulders - rock fragments, usually rounded by weathering or abrasion, that will be retained on a 75 mm sieve.
- 2.1.3 Coarse sand - particles of rock or soil that will pass a 2.00 mm sieve and be retained on a 0.425 mm sieve.
- 2.1.4 Fine sand - particles of rock or soil that will pass a 0.425 mm sieve and be retained on a 0.075 mm sieve.
- 2.1.5 Gravel - particles of rock that will pass a 75 mm sieve and be retained on a 2.00 mm sieve.
- 2.1.6 Silt-clay (combined silt and clay) - fine soil and rock particles that will pass a 0.075 mm sieve.
- 2.1.6.1 Silty - a fine-grained material that has a plasticity index of 10 or less.
- 2.1.6.2 Clayey - a fine-grained material that has a plasticity index of 11 or more.
- 2.1.7 Soil fines - fine soil and rock particles that will pass a 0.425 mm sieve.

### **3. Significance and Use**

- 3.1 This standard classifies soils from any geographic location into groups (including group indexes) based on the results of prescribed laboratory tests to determine the particle-size characteristics, liquid limit, and plasticity index.
- 3.2 The assigning of a group symbol and group index can be used to aid in the evaluation of the significant properties of the soil for highway and airfield purposes.
- 3.3 The various groupings of this classification system correlate in a general way with the engineering behaviour of soils. Also, in a general way, the engineering behaviour of a soil varies inversely with its group index. Therefore, this standard provides a useful first step in any field or laboratory investigation for geotechnical engineering purposes.

### **4. Apparatus**

- 4.1 Apparatus for Particle-Size analysis - See Test Method S 7.
- 4.2 Apparatus for Liquid Limit and Plastic Limit Tests - See Test Method S 6.

### **5. Test Sample**

- 5.1 Test samples shall present that portion of the field sample finer than the 75 mm sieve and shall be obtained as follows:
  - 5.1.1 Air-dry the field sample,
  - 5.1.2 Weigh the field sample,
  - 5.1.3 Separate the field sample into two fractions on a 75 mm sieve,
  - 5.1.4 Weigh the fraction retained on the 75 mm sieve. Compute the percentage of plus 75 mm material in the field sample, and note this percentage as auxiliary information, and
  - 5.1.5 Thoroughly mix the fraction passing the 75 mm sieve and prepare test samples as described for methods S6 and S7.

NOTE 2 - If visual examination indicates that no boulder size material is present, omit 5.1.3 and 5.1.4.

NOTE 3- For fine soils that may contain organic matter or irreversible mineral colloids the wet method of preparation should be used. These materials should be transported to the laboratory in sealed containers in order that they do not dry out from their natural moisture content. The field sample should be divided to provide 3 similar sub-samples, one each for Atterberg Limits and Sieve Analysis with an auxiliary moisture content sub-sample.

## 6. Testing Procedure

- 6.1 Determine the percentage of the test sample finer than 0.075 mm, 0.425 mm, 2.00 mm sieves in accordance with Test Method S7.
- 6.2 Determine the liquid limit and the plasticity index of a portion of the test sample passing a 0.425 mm sieve in accordance with Test Method S6.

NOTE 4. The Liquid Limit and Plasticity Index to be used for this standard are those determined using the Casagrande cup liquid limit device with the AASHTO grooving tool.

## 7. Classification Procedure

- 7.1 Using the test data determined in Section 6, classify the soil into the appropriate group and subgroup in accordance with Table 1. Use Figure 1 to classify silt-clay materials on the basis of liquid limit and plasticity index values.

NOTE 5 - All limiting values are shown as whole number. If fractional numbers appear on test reports, convert to the nearest whole number for the purpose of classification.

- 7.1.1. With the required test data available, proceed from left to right in Table 1 and the correct classification will be found by the process of elimination. The first group from the left into which the test data will fit is the correct classification.

NOTE 6 - Classification of materials in the various groups applies only to the fraction passing the 75 mm sieve. Therefore, any specification regarding the use of A-1, A-2 or A-3 materials in construction should state whether boulders are permitted.

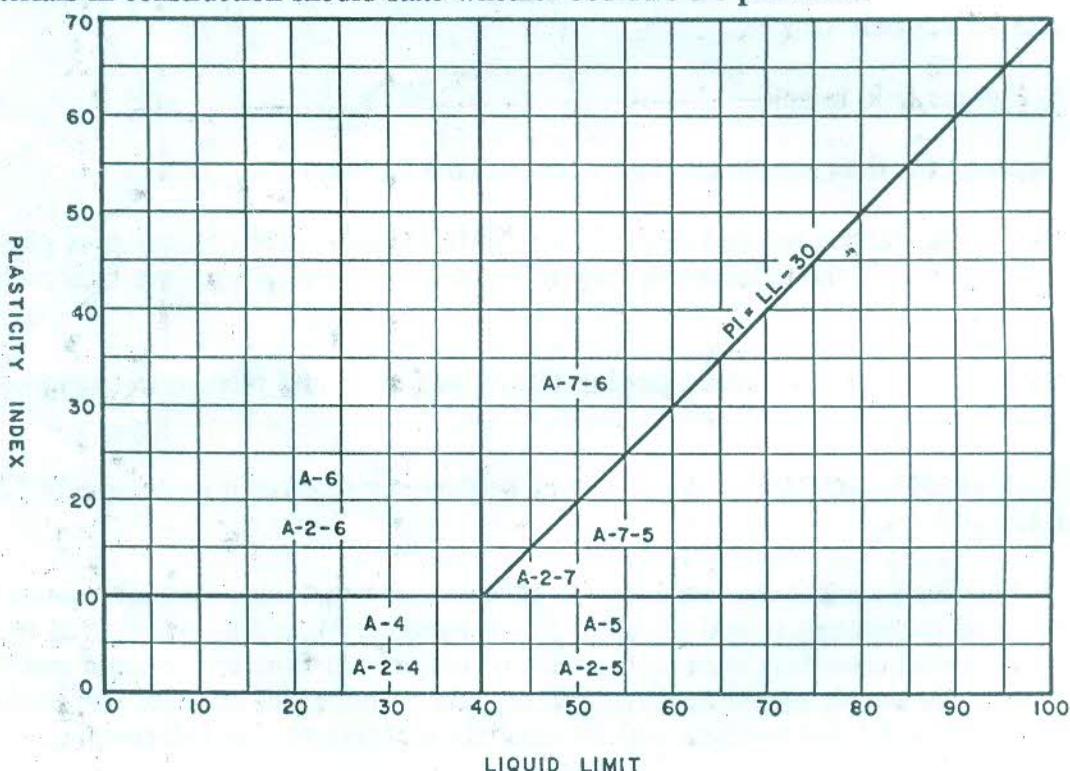


FIGURE 1: Liquid Limit and Plasticity Index for Silt-Clay Materials.

TABLE 1: Classification of Soils and Soil-Aggregate Mixtures.

General classification	Granular materials (35% or less passing 0.075 mm sieve)							Silt- clay materials (more than 35% passing 0.075 mm sieve)			
	Group classification		A-1	A-3	A-2			A-4	A-5	A-6	A-7
	A-1-a	A-1-b		A-2-4	A-2-5	A-2-6	A-2-7				A-7-5 A-7-6
Sieve analysis, percentage passing: 2.00 mm sieve 0.425 mm sieve 0.075 mm sieve	50 max. 30 max. 15 max.	50 max. 25 max.	51 min. 10 max.	35 max.	35 max.	35 max.	35 max.	36 min.	36 min.	36 min.	36 min.
Characteristics of fraction passing 0.425 mm Liquid limit (%) Plasticity index (%)	6 max.	N.P.	40 max. 10 max.	41 min. 10 max.	40 max. 11 min.	41 min. 11 min.	40 max. 10 max.	41 min. 10 max.	40 max. 11 min.	41 min. 11 min.*	
Group index <sup>b</sup>	0	0	0	0	4 max.		8 max.	12 max.	16 max.	20 max.	
Usual types of significant constituent materials	Stone fragments, gravel and sand	Fine sand	Silty or clayey gravel and sand				Silty soils		Clayey soils		
General rating as a sub-grade	Excellent to good				Fair to poor						

CLASSIFICATION PROCEDURE: With required test data available, proceed from left to right on above chart and correct group will be found by process of elimination. The first group from the left into which the test data will fit is the correct classification.

\*Plasticity index of A-7-5 sub-group is equal to or less than liquid limit minus 30. Plasticity index of A-7-6 sub-group is greater than liquid limit minus 30.

$$\text{ex} > P_I = 27, LL = 58 \quad \therefore A-7-6 = 28$$

$$\begin{aligned}
 P_I &\leq LL - 30 \\
 P_I &> LL - 30
 \end{aligned}
 \quad 
 \begin{aligned}
 P_I &= 58 - 30 \\
 &= 28
 \end{aligned}
 \quad 
 A-7$$

## 8. Description of Classification Groups

### 8.1 Granular Materials, containing 35% or less passing the 0.075 mm sieve:

8.1.1 Group A-1. The typical material of this group is a well-graded mixture of stone fragments or gravel, coarse sand, fine sand, and a nonplastic or feebly-plastic soil binder. However, this group also includes stone fragments, gravel, coarse sand, volcanic cinders, etc., without a soil binder.

8.1.1.1 Subgroup A-1-a includes those materials, consisting predominantly of coarse sand, either with or without a well-graded soil binder.

8.1.1.2 Subgroup A-1-b includes those materials consisting predominantly of coarse sand, either with or without a well-graded soil binder.

8.1.2 Group A-3. The typical material of this group is fine beach sand or fine desert-blow sand without silty or clay fines, or with a very small amount of nonplastic silt. This group also includes stream-deposited mixtures of poorly-graded fine sand and limited amounts of coarse sand and gravel.

8.1.3 Group A-2. This group includes a wide variety of "granular" materials which are borderline between the materials falling in Groups A-1 and A-3, and the silt-clay materials of Groups A-4, A-5, A-6, and A-7. It includes all materials containing 35% or less passing a 0.075 mm sieve which cannot be classified in Groups A-1 or A-3, due to the fines content or the Atterberg Limits, or both, in excess of the limitations for those groups.

8.1.3.1 Subgroups A-2-4 and A-2-5 include various granular materials containing 35% or less passing a 0.075 mm sieve and with a minus 0.425 mm portion having the characteristics of Groups A-4 and A-5, respectively. These groups include such materials as gravel and coarse sand with silt contents or plasticity indices in excess of the limitations of Group A-1 and fine sand with nonplastic-silt content in excess of the limitations of Group A-3.

8.1.3.2 Subgroups A-2-6 and A-2-7 include materials similar to those described under Subgroups A-2-4 and A-2-5, except that the fine portion contains plastic clay having the characteristics of the A-6 or A-7 group, respectively.

### 8.2 Silt-Clay Materials, containing more than 35% passing 0.075 mm sieve:

8.2.1 Group A-4. The typical material of this group is a nonplastic or moderately plastic silty soil usually having 75% or more passing 0.075 mm sieve. This group also includes mixtures of fine silty soil and up to 64% of sand and gravel retained on a 0.075 mm sieve.

8.2.2 Group A-5. The typical material of this group is similar to that described under Group A-4, except that it is usually of diatomaceous or micaceous character and may be highly elastic as indicated by the high liquid limit.

8.2.3 Group A-6. The typical material of this group is a plastic clay soil usually having 75% or more passing a 0.075 mm sieve. This group also includes mixtures of fine

clayey soil and up to 64% of sand and gravel retained on a 0.075 mm sieve. Materials of this group usually have a high volume change between wet and dry states.

- 8.2.4 Group A-7. The typical material of this group is similar to that described under Group A-6, except that it may be elastic as well as having the high liquid limits characteristic of Group A-5 and as subject to high-volume change.

8.2.4.1 Subgroup A-7-5 includes those materials with plasticity indices equal to or less than the liquid limit minus 30, and which may be highly elastic as well as subject to considerable volume change.

8.2.4.2 Subgroup A-7-6 includes those materials with plasticity indices greater than the liquid limit minus 30, and which are subject to extremely high volume change.

NOTE 7 - Highly organic soils (peat or muck) may be classified in an additional group, Group A-8. Classification of these materials is based on visual inspection and is not dependent on the percentage passing the 0.075 mm sieve, liquid limit, or plasticity index. The material is composed primarily of partially-decayed organic matter, generally has a fibrous texture, a dark brown or black colour, and an odour of decay. These organic materials are unsuitable for use in embankments and subgrades. They are highly compressible and have low strength.

## 9. Group Index Computation

- 9.1 The classifications obtained from table 1 may be modified by the addition of a group-index value. Group-index values should always be shown in parentheses after the group symbol, eg A-2-6(3), A-4(5), A-6(12), A-7-5(17), etc.

- 9.1.1 The group index is calculated from the following empirical formula:

$$\text{Group index} = \frac{(F - 35)[0.2 + 0.005(LL - 40)]}{+ 0.01(F - 15)(PI - 10)} \quad (\text{PGI-LL}) \quad (\text{PGI-PI})$$

where:

F = percentage passing 0.075 mm sieve, expressed as a whole number (this percentage is based only on the material passing the 75 mm sieve),

LL = liquid limit, and

PI = plasticity index.

The first term can be referred to as the Partial Group Index - Liquid Limit, (PGI-LL), and the second term as the Partial Group Index - Plasticity Index, (PGI-PI).

- 9.1.2 The group index of soils in the A-2-6 and A-2-7 subgroups shall be calculated using only the Partial Group Index - Plasticity Index. (ie. the Partial Group Index - Liquid Limit, which is negative is reported as zero).

- 9.1.3 If the calculated group index is negative, report the group index as zero (0).
- 9.1.4 If the soil is nonplastic and when the liquid limit cannot be determined, report the report the group index as zero (0).
- 9.1.5 Report the group index to the nearest whole number.

9.2 The following examples illustrate the calculations for the group index:

- 9.2.1 Assume that an A-6 material has 55% passing a 0.075 mm sieve, a liquid limit of 40, and a plasticity index of 25, then:

$$\begin{aligned}\text{Group index} &= (55 - 35)[0.2 + 0.005(40 - 40)] \\ &\quad + [0.01(55 - 15)(25 - 10)] \\ &= 4.0 + 6.0 = 10\end{aligned}$$

- 9.2.2 Assume that an A-7 material has 80% passing a 0.075 mm sieve, a liquid limit of 90, and a plasticity index of 50, then:

$$\begin{aligned}\text{Group index} &= (80 - 35)[0.2 + 0.005(90 - 40)] \\ &\quad + [0.01(80 - 15)(50 - 10)] \\ &= 20.3 + 26.0 = 46.3 \text{ (report as 46)}\end{aligned}$$

- 9.2.3 Assume that an A-4 material has 60% passing a 0.075 mm sieve, a liquid limit of 25, and a plasticity index of 1 then:

$$\begin{aligned}\text{Group index} &= (60 - 35)[0.2 + 0.005(25 - 40)] \\ &\quad + [0.01(60 - 15)(1 - 10)] \\ &= 25 \times (0.2 - 0.075) + 0.01(45)(-9) \\ &= 3.1 - 4.1 = -1.0 \text{ (report as 0)}\end{aligned}$$

- 9.2.4 Assume that an A-2-7 material has 30% passing a 0.075 mm sieve, a liquid limit of 50, and a plasticity index of 30, then:

$$\begin{aligned}\text{Group index} &= 0.01(30 - 15)(30 - 10) \\ &= 3.0 \text{ (note that only the PI portion of the formula was used)} \\ &\quad \begin{matrix} (15)(20) \\ 0.01(300) \end{matrix}\end{aligned}$$

## 10. Discussion of Group Index

- 10.1 The empirical group index formula devised for approximate within-group evaluation of the "clayey-granular materials" and the "silt-clay materials" is based on the following assumptions:

10.1.1 Materials falling within Groups A-1-a, A-1-b, A-2-4, A-2-5, and A-3 are satisfactory as subgrade when properly drained and compacted under moderate thickness of pavement (base or surface course, or both) of a type suitable for traffic to be carried or can be made satisfactory by additions of small amounts of natural or artificial binders.

10.1.2 Materials falling within the "clayey granular" Groups A-2-6 and A-2-7 and the "silt-clay" Groups A-4, A-5, A-6, and A-7 will range in quality as subgrade from the approximate equivalent of the good A-2-4 and A-2-5 subgrades to fair and poor subgrades requiring a layer of subbase material or an increased thickness of base course over that required in 10.1.1, in order to furnish adequate support for traffic loads.

10.1.3 A minimum of 35% passing a 0.075 mm sieve is assumed to be critical if plasticity is neglected, but the critical minimum is only 15% when affected by plasticity indices greater than 10.

10.1.4 Liquid limits of 40 and above are assumed to be critical.

10.1.5 Plasticity indices of 10 and above are assumed to be critical.

- 10.2 There is no upper limit of group index value obtained by use of the formula: The adopted critical values of percentage passing the 0.075 mm sieve, liquid limit, and plasticity index, are based on an evaluation of subgrade, subbase, and base-course materials by several highway organizations that use the tests involved in this classification system.
- 10.3 Under normal conditions of good drainage and thorough compaction, the supporting value of a material as subgrade may be assumed as an inverse ratio to its group index; that is, a group index of 0 indicates a "good" subgrade material and a group index of 20 or greater indicates a "very poor" subgrade material.

NOTE 8 - Group index values should only be used to compare soils within the same group and not between groups.

## 11. Referenced Documents

### 11.1 ASTM Standards:

- D420 Guide for Investigating and Sampling Soil and Rock
- D421 Practice for Dry Preparation of Soil Samples for Particle-Size Analysis and Determination of Soil Constants
- D422 Test Method for Particle-Size Analysis of Soils
- D653 Terminology Relating to Soil, Rock, and Contained Fluids
- D1140 Test Method for Amount of Material in Soils finer Than the No. 200 (75-um) Sieve
- D2217 Practice for Wet Preparation of Soils Samples for Particle-Size Analysis and Determination of Soil Constants
- D4318 Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils
- D3282 Standard Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes.