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1994

# Testing aggregates —

## Part 104: Method for qualitative and quantitative petrographic examination of aggregates

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# Committees responsible for this British Standard

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British Aggregate Construction Materials Industries
British Civil Engineering Test Equipment Manufacturers' Association
British Steel Industry
County Surveyors' Society
Department of Trade and Industry (National Measurement Accreditation Service)
Department of Transport
PSA Projects Ltd.
Sand and Gravel Association Ltd.
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# Contents

# Foreword

This Part of BS 812 has been prepared under the direction of Technical Committee B/502, Aggregates, and gives a method for the petrographic examination of aggregates.

It is not intended that such an examination should form part of the routine assessment of the suitability of aggregates. However, there may be circumstances in which petrographic examination will be the only satisfactory means of assessment. In other cases it can enhance and clarify results obtained from other forms of assessment.

In some cases a less rigorous examination of aggregates may be sufficient and it is recommended that the qualitative examination given in clause **7** is used. Any such decision is, however, a matter for agreement between the client and the body undertaking the petrological examination and as such is outside the scope of this standard.

It has been assumed in the drafting of this Part of BS 812 that the execution of its provisions is entrusted to appropriately qualified people, experienced in aggregate petrography, and with access to an appropriately equipped laboratory. In certain special cases, other analytical techniques (including chemical analysis, X-ray diffraction and scanning electron microscopy) may provide useful additional information, but these are outside the scope of this standard.

Work on testing procedures for aggregates is being carried out in Europe under the auspices of CEN/TC 154, Aggregates. The method described in this Part of BS 812 is included in the programme of work of CEN/TC 154. It is envisaged that a European Standard, based on this method, will be published in due course.

Selected references on petrographic examination additional to those referenced in the text are included in annex C.

**Summary of pages**

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 18, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

## 1 Scope

This Part of BS 812 describes a general method for the examination of samples of coarse or fine aggregates to determine petrographic composition and to assist in the assessment of those aggregates for potential suitability for the intended use. The results relate only to the sample received at the laboratory and not necessarily to the deposit from which the samples are derived. The method is applicable to the determination of the proportion of any recognizable mineral or rock type, irrespective of the amount of such material, in the sample.

The major application of the method described is in the examination and assessment of processed aggregates.

## 2 References

### 2.1 Normative references

This Part of BS 812 incorporates, by dated or undated reference, provisions from other publications. These normative references are made at the appropriate places in the text and the cited publications are listed on the inside back cover. For dated references, only the edition cited applies; any subsequent amendments to or revisions of the cited publication apply to this Part of BS 812 only when incorporated in the reference by amendment or revision. For undated references, the latest edition of the cited publication applies, together with any amendments.

### 2.2 Informative references

This Part of BS 812 refers to other publications that provide information or guidance. Editions of these publications current at the time of issue of this standard are listed on the inside back cover, but reference should be made to the latest editions.

## 3 Definitions

For the purposes of this Part of BS 812, the definitions given in BS 812-101, BS 812-102, BS 6100-5.2 and BS 6100-6.3 apply, together with the following.

**3.1**
**alteration**

mineralogical changes imposed upon a rock or rock body by secondary geological activity

NOTE Altered rocks thus contain secondary minerals which may or may not be detrimental to the properties of those rocks. In petrographic examination geological alteration should be distinguished from "weathering" (see **3.8**).

**3.2**
**microcrystalline**

composed of crystals so fine that they can be resolved only under a microscope

NOTE The term is often confused with "cryptocrystalline" but may be distinguished by the fact that a cryptocrystalline texture is so fine-grained that it specifically requires a high power microscope to resolve individual crystals. Thus the term "microcrystalline" indicates a relatively coarser grain size than "cryptocrystalline" and does not necessarily require a high power microscope to resolve the individual crystals.

**3.3**
**monomictic**

aggregates essentially comprising particles of one rock or mineral type

**3.4**
**petrography**

the systematic description of rocks, usually in hand-specimen and thin section

NOTE The petrographic examination of aggregates comprises a description of that aggregate in terms of the constituent rock (or discrete mineral) types.

**3.5**
**polymictic**

aggregate comprising particles of many different rock or mineral types

**3.6**
**qualitative examination**

an examination in which some or all of the constituents of a sample are identified and described, but the proportions of those constituents are not established

**3.7**
**quantitative examination**

an examination in which the amounts and proportions of one or more constituents of a sample are determined

**3.8**
**weathering**

the process by which rocks are broken down and decomposed by the actions of external agencies such as wind, rain, temperature changes, plants and bacteria

NOTE In petrographic examination "weathering" should be distinguished from "alteration".

## 4 Principle

**4.1** The method involves the visual recognition and quantification of rock and mineral constituents of an aggregate sample to determine the petrographic composition.

NOTE It is assumed that the analyst is competent to recognize unambiguously the relevant mineral constituents in the sample.

**4.2** The laboratory sample is first subjected to a qualitative examination. Duplicate representative test portions are then prepared and subjected to a more detailed examination, employing both macroscopical and microscopical techniques. Methods are given to quantify the petrographic composition of the aggregate sample. These procedures allow for the thorough and statistically reliable petrographic examination of an aggregate sample.

## 5 Sampling

**5.1** The laboratory sample shall be taken in accordance with the procedures described in clause **5** of BS 812-102:1989.

**5.2** The minimum size of the laboratory sample aggregate shall be as given in Table 1.

NOTE 1 The minimum sample sizes given in Table 1 take precedence over the recommendations of clause **5** of BS 812-102:1989 for this procedure.

NOTE 2 The sample should be accompanied by a certificate of sampling as required in clause **9** of BS 812-102:1989.

**Table 1 — Minimum size of laboratory sample**

| Maximum particle size mm | Minimum mass kg |
|---|---|
| 50 | 200 |
| 40 | 100 |
| 20 | 13 |
| ≤ 10 | 2 |

**5.3** The aggregate samples shall be taken from processed material at a suitable stage of production.

NOTE 1 All aggregate sources exhibit some variability. It is therefore important to ensure that an adequate and well defined sampling scheme is used.

NOTE 2 Particular sampling difficulties may be encountered with crushed rock aggregate sources that exhibit varying degrees and intensities of veining, weathering and other exceptional non-uniformly distributed features. Special procedures may be necessary which are outside the scope of this standard.

NOTE 3 The sampling methods described are intended primarily for the examination of processed aggregates. The overall resource evaluation of a quarry, quarry site or rock mass is outside the scope of this standard.

NOTE 4 It is important that the laboratory sample should be neither oven-dried nor wetted until the qualitative examination has been initiated.

## 6 Apparatus

**6.1** *Sieves,* conforming to BS 410, of appropriate mesh size.

**6.2** *A sample divider,* appropriate to the maximum size of sample to be handled, as described in **4.5** of BS 812-102:1989.

**6.3** *A low-power microscope,* capable of magnifications up to × 40.

NOTE Stereoscopic and zoom facilities are desirable.

**6.4** *Apparatus and machinery suitable for the manufacture of* 30 μm *thick geological thin sections.* Sand samples and some coarse aggregates will also require materials and apparatus suitable for resin consolidation prior to manufacture of the thin section.

NOTE General guidance on the equipment required for making geological thin sections, and the various procedures to be employed, is given in Allman and Lawrence [1].

**6.5** *A petrographic (i.e. polarizing) microscope,* capable of high-resolution at magnifications up to × 500.

**6.6** *Point-counting apparatus for use with the petrographic microscope,* e.g. an electro-mechanical stage linked to a counting device, such that operation of any one of the counters automatically moves the thin section one further step along the traverse.

**6.7** *Balances,* for various mass ranges each capable of weighing the test portion to an accuracy of 0.1 %. (See Table 2.)

## 7 Qualitative examination of the laboratory sample

### 7.1 Aggregate type

Examine the laboratory sample to ascertain the general character of the aggregate, including its moisture condition, and record the approximate maximum particle size and whether it is natural or crushed. Make preliminary visual estimates of the proportions of constituents of interest.

NOTE The moisture condition of the sample should be a subjective assessment of whether the sample is dry, damp or wet.

Distinguish between natural sand or gravel aggregates, aggregates produced by crushing rock and artificial aggregates and record any observations. When aggregates have been produced in part by the crushing of coarse gravels or boulder deposits, or when aggregates, especially sand, have been produced by blending natural and crushed rock materials, state that the aggregate type is blended (see BS 6100-6.3 for definitions of different types of aggregates).

### 7.2 Particle description

Describe the general character of the aggregate particles in terms of nominal maximum size, grading, shape and surface texture. Note in particular the presence of any fine material and any particle coatings or encrustations before the sample is wetted.

NOTE 1 Guidance on the terminology used in describing particle shape and surface texture is given in Neville [2].

NOTE 2 To carry out the particle examination and description it may be necessary first to examine the sample as received and then wash it in order to make the required observations and comments.

### 7.3 Petrographic description

Identify and record the main rock (or mineral) types using the terms and definitions given in appendix A of BS 812-102:1989. When the rock type is uncertain (for example in fine-grained rocks), distinguish the types on the basis of visual appearance including colour, grain size and any other distinctive features. In a polymictic aggregate, when possible, indicate the rock type that is clearly dominant. Consider the petrographic composition in relation to the particle size distribution and state if there is a petrographic differentiation according to particle size.

## 8 Preparation of the test portions for quantitative evaluation

### 8.1 General

Quantitative evaluation of the petrographic composition of an aggregate involves selecting test portions from the laboratory sample, sieving the test portions into size fractions and assessing the composition of each size fraction by hand separation and weighing of subsamples, or point-counting in the case of material finer than 1.18 mm. The test portion mass required to achieve a specified relative error depends on the grading and composition of the aggregate under examination. The procedures are designed to give large enough test portions for the relative error of estimates of the proportions of constituents to be ± 10 % or better when duplicate test portions are examined. If a constituent is present as a small proportion it may be impractical to examine test portions large enough to give a relative error of ± 10 %, and in such circumstances a larger error then has to be accepted.

### 8.2 Minimum mass of test portion

The test portion mass shall be not less than the minimum mass shown in Table 2 for the size of aggregate being examined.

NOTE The procedures given in annex B include a calculation of the 95 % confidence limits for estimated proportions as a function of the actual proportions found and the actual test portion masses used.

The test portion masses given in Table 2 should lead to a relative error of ± 10 % for constituents present at a level of 20 %.

If a constituent is present at a level lower than 20 %, and a relative error of ± 10 % is required, then the test portion mass shall be determined from Figure 1 or from the following equation:

$$M = 0.0002\,(100 - P)\,\frac{(D_{\max})^3}{P} \qquad (1)$$

where

$M$ is the minimum mass of each test portion (in kg);

$P$ is the estimated proportion of constituent of interest [in % $(m/m)$];

$D_{\max}$ is the maximum particle size (in mm).

*Example.* If a constituent of interest is present at the 2 % level, Figure 1 shows that the test portion mass should be increased by approximately an order of magnitude over that given in Table 2 to achieve the required relative error of ± 10 %.

**Table 2 — Minimum mass of each test portion required to give a relative error of ± 10 % for an estimated proportion of a constituent of interest of 20 %, when using duplicate test portions**

| Maximum particle size<br>mm | Minimum mass of test portion<br>kg |
|---|---|
| 50 | 100 |
| 40 | 51 |
| 20 | 6.4 |
| 10 | 0.8 |

### 8.3 Oversize material

If the amount of oversized material, in a test portion of either a coarse or aggregate sand, falls outside the grading limits of BS 882, the test portion shall be examined as submitted, without adjusting its grading.

### 8.4 Fine material in coarse aggregate

Material finer than 5 mm in a coarse aggregate shall not be included in the calculation of the composition of the coarse aggregate. If the composition of such material is required, first separate the coarse and fine fractions of the laboratory sample using a 5.00 mm sieve, then prepare duplicate test portions of the material passing the 5.00 mm sieve and examine in accordance with **9.2**.

### 8.5 "All-in" aggregates

For "all-in" aggregates, first separate the coarse and fine fractions of the laboratory sample using a 5.00 mm sieve, then prepare duplicate test portions of each fraction in accordance with the appropriate procedures for either coarse aggregates or sand given in clause **9**.

### 8.6 Particle petrography in coarse aggregate

If, in exceptional circumstances, it is necessary to determine the proportion of a mineral contained within the particles of a coarse aggregate, then the test portions shall be crushed and a subsample taken from each. At each stage of the crushing and sample reduction procedures the test portion masses shall be not less than that permitted by equation (1). The subsamples shall be examined in accordance with **9.2**.

NOTE 1 As an aid in achieving this, use the estimated proportion of the constituent of interest $P$ and draw a line representing equation (1) on log/log paper, with $M$ as one axis and $D$ as the other. This graph may then be used to choose a convenient series of crushing and sample reduction stages, always keeping to the side of the line corresponding to a test portion mass in excess of that given by equation (1).

NOTE 2 All sample reduction or subsampling operations should use recognized methods such as rotary samplers or fractional shovelling.

### 8.7 Washing and drying of test portions

**8.7.1** Wash the test portions with tap water to remove adhering dust and loose particle coatings. Retain a portion of the removed dust for possible future examination and analysis.

NOTE When a test portion is to be analysed for water-soluble salts, retain a portion of the unwashed laboratory sample.

**8.7.2** Dry and weigh each test portion.

### 8.8 Determination of the required masses to be analysed

**8.8.1** For coarse aggregates, sieve into size fractions using 50.0 mm, 37.5 mm, 20.0 mm, 10.0 mm and 5.00 mm sieves. Determine the mass of each size fraction $m_i$ in kilograms to an accuracy of 0.1 % ($m/m$) of the test portion. Calculate the mass of each size fraction for analysis using the method given in annex A.

**8.8.2** For sand, sieve into size fractions using 10.0 mm, 5.00 mm, 2.36 mm, and 1.18 mm sieves, and determine the mass of each fraction in grams to 0.1 % of the test portion ($m/m$).

Calculate the mass of each size fraction for analysis, and the number of points to count in thin sections, using the method given in annex A.

**8.8.3** Repeat **8.8.1** or **8.8.2** using the second test portion.

**8.8.4** The calculations of required test portion mass given in annex A assume a particle density of 2 600 kg/m$^3$. An appropriate adjustment to the required test portion mass shall be made for aggregates with densities that differ substantially from this value.

NOTE Density variations of less than ± 10 % from 2 600 kg/m$^3$ can usually be neglected.

## 9 Quantitative examination of a test portion

### 9.1 Coarse aggregate

**9.1.1** From each size fraction take an appropriate sample for analysis (see annex A), hand separate and weigh the constituent rock or mineral varieties, principally on the basis of visual differentiation. Avoid unnecessary subdivisions into groups of purely nomenclatural interest. The rock and mineral names given in appendix A of BS 812-102:1989 shall be used. The use of other terms shall be avoided as far as possible. Descriptive terms, such as the colour and grain size, shall be placed (when needed) in brackets after the rock or mineral name together with any appropriate comments on alteration or weathering. A category "others" may be included provided that a definition or description is given of the materials in it. Ill-defined categories such as "miscellaneous" or "unknown" shall not be used.

**9.1.2** Thin sections, when required, shall be made of selected particles of each constituent to verify rock types and investigate very fine-grained constituents and secondary minerals.

When thin sections are not prepared (see note 1) this shall be stated in the test report.

NOTE 1 Thin sections are usually prepared to investigate the composition of the samples. Agreement should be reached between parties when the preparation of thin sections for such a purpose is considered unnecessary.

NOTE 2 If required, the approximate composition of a coarse aggregate by volume may be calculated from the composition determined by mass using published values of relative density for the rock and mineral constituents concerned.

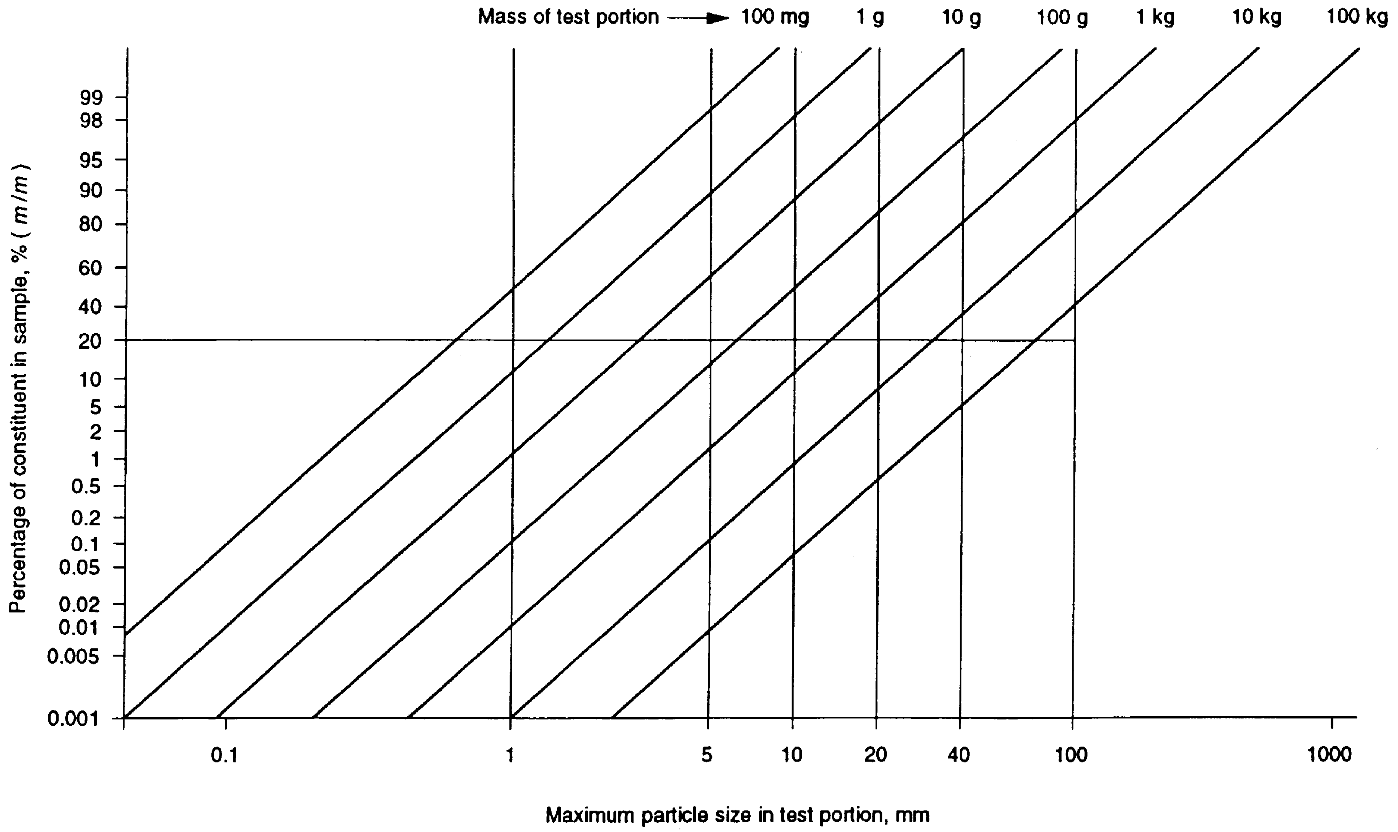


**Figure 1 — Mass of each test portion necessary to achieve a relative error of ± 10 % for a given constituent when using duplicate test portions**

### 9.2 Sand

**9.2.1** Hand-separate the 10.0 mm to 5.00 mm, 5.00 mm to 2.36 mm and 2.36 mm to 1.18 mm fractions (or subsamples of these fractions) into constituent rock or mineral varieties, as described for coarse aggregate in **9.1.1** and **9.1.2**. Use a low-magnification binocular microscope where necessary.

**9.2.2** The petrological microscope shall be used for making quantitative assessments by point-counting in thin section of the proportions of constituents in the size fraction finer than 1.18 mm. The point-count interval shall be at least 1.18 mm. At least one thin section shall be prepared from each test portion (see notes 2 to 6).

NOTE 1 Thin section examination using a petrological microscope should only be used exceptionally for quantitative assessments at coarser sizes when the constituents cannot be recognized in granular form.

Sections for examination shall include a sufficiently large number of grains (see note 5).

NOTE 2 For point-counting, a representative part of the sand should be consolidated with resin prior to the manufacture of sections. The sections to be examined should be unbiased and cut perpendicular to any possible stratification within the resin impregnated test portion.

NOTE 3 Point-counting of sections under a petrological microscope is a conventional method for quantifying the mineralogical composition of rocks or of mineral grains embedded in resin. It is based on the principle that, in a section cut at random through a sample, the ratio of the areas of the mineral surfaces estimates the ratio of the volumes of the minerals in the original sample. Estimates of the relevant areas are made by recording the separate mineral constituents that fall beneath the intersections (points) of a regular imaginary grid that extends over the surface of the section, provided that the linear interval between successive grid intersections is greater than the maximum diameter of the material under examination. This implies that large areas of sections have to be covered when large diameter particles are assessed by point-counting.

Microscope stage attachments are available that allow a surface to be traversed in regular increments in two directions to simulate the imaginary grid and give a point by point coverage of the section. One of these, based on an electro-mechanical stage activated by a tabulator, is popularly used in point-counting.

NOTE 4 Point-counting using a square grid graticule placed within the eyepiece of the microscope may be used as an alternative to the method given in note 3. The grid intersections are counted as points within a series of microscopic fields that extend regularly over the section. Otherwise the principles are similar to those given in note 3; it is necessary that the interval between grid intersections is larger than the maximum particle diameter in the section, that no area is covered more than once and that a sufficient number of points is counted.

NOTE 5 The precision of point-counting depends on the number of points counted and the proportion of the constituents of interest in the sample. A chart for estimating the precision is provided in Figure 2 which can be used for determining the number of points to be examined. Counting at least 1 000 points exclusive of those landing on the resin will give a precision of better than ± 10 % relative when the constituent of interest is present at the 30 % level. When the constituent of interest is present at lower levels, or if a greater accuracy is required, the number of points should be increased, if necessary by using a large number of sections. The estimated precision of the point-counting operation (Figure 2) does not allow for errors caused by sampling or sample reduction (see **A.2**).

NOTE 6 Electronic image analysers are increasingly becoming available for use in petrographic analysis. These measure the areas of constituent components seen in a microscope field more easily provided there is sufficient difference between the optical properties of the minerals for the system to discriminate between them.

### 9.3 Calculation

Calculate the composition of each fraction, the overall composition of each test portion, and 95 % confidence limits for these estimates by the method given in annex B.

If the examination results for a test portion prepared in accordance with **8.2** indicate a constituent of interest to be present in a smaller proportion than that originally estimated, or to be present in a proportion of less than 20 % in the case of test portions prepared using the values given in Table 2, there may be a need for further examination. If so, recalculate the minimum mass of test portion in accordance with **8.2** and then repeat the preparation and examination procedures for any additional sample quantity required. Combine the findings of the two examinations and report the combination in accordance with clause **10**.

NOTE The examination of a further quantity of aggregate sample may be considered necessary to improve the accuracy of the determination of the proportion of a constituent of particular interest. Guidance on the calculation of 95 % confidence limits is given in annex B.

## 10 Report

The report shall affirm that the petrographical examination was carried out in accordance with this British Standard, and shall state whether or not a certificate of sampling is available. If available a copy of the certificate of sampling shall be provided. It shall be clearly stated in the report that the results and assessment relate specifically to the sample or samples submitted and examined (see notes to **5.3**).

NOTE Every effort should be made to ensure that the conclusions of the report can be easily understood by persons without experience of petrographic examination.

The petrographic report shall commence with a statement recording the laboratory sample markings, moisture condition, mass and the advised details regarding source and sampling procedure, and contain the following information.

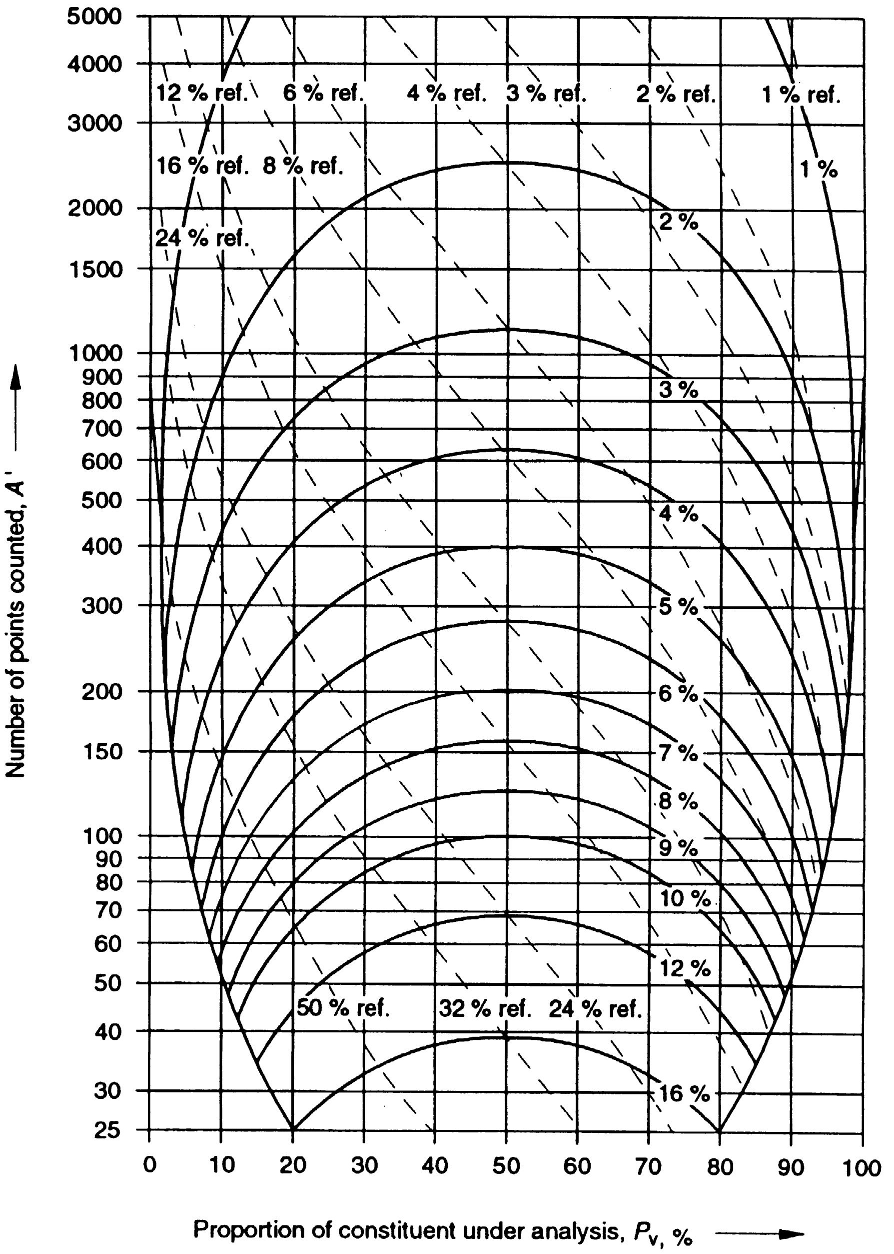
a) A brief explanation of the preparatory work carried out in order to produce the test portion(s) and details of the methods of examination employed.

b) The results of the qualitative examination in concise form and under the headings: aggregate type, particle description and petrographic composition. A preferred form for reporting the sample details and qualitative results is given in Table 3.

c) A summary of the results of the quantitative examination, giving the method of determination, the constituent proportions and 95 % confidence limits for the constituent proportions (calculated by the method described in annex B). A preferred form for tabulating these results is shown in Table 4. Round the final result in column 5 of Table 4 to the nearest 1 % (see BS 1957) and the 95 % confidence limits in column 6 to the nearest 0.1 %. The approximate overall contents of any mineral constituents determined in accordance with **8.6** shall be given as additional and separate items.

NOTE 1 The detailed findings should also be appended, preferably in a tabulated form, with each segregated rock/mineral constituent being separately described. Such descriptions should be concise and concerned mainly with differentiating characteristics or features relevant to the suitability assessment. Geological details which merely define the rock or mineral type should be omitted.

NOTE 2 The methods of error assessment given in annex B are based on theoretical considerations and are intended to provide guidance that can be used to ensure that errors are not excessive. The confidence limits indicate the size of the errors that can occur in the test portion preparation and testing processes: they do not indicate the variation that occurs in the material from which the sample is derived, neither do they indicate the reproducibility of the test method.



NOTE 1. The figure is after Van de Plas and Tobi [3].

NOTE 2. Curved solid lines indicate absolute errors, broken lines indicate relative errors, e.g. in a total count of 900 points, 90 points fall on quartz, hence :

$A' = 900$, $P_V = \frac{90}{900} = 10\ \%$

The absolute error is ± 2 % (2) indicating a range of 8 % to 12 % within 95 % confidence limits. The relative error is $\frac{2}{10}$ or 20 % which can be inferred by extrapolation between the broken lines corresponding to 16 % and 24 %.

**Figure 2 — Chart for estimating errors involved in point-counting**

### Table 3 — Preferred form for reporting the sample details and results of the qualitative examination

**Sample details**

Laboratory reference ..........................................................................................
Client's reference ..........................................................................................
Date received ..........................................................................................
Sample mass ..........................................................................................
Moisture condition ..........................................................................................
Aggregate type ..........................................................................................
Aggregate source ..........................................................................................
Nominal maximum size ..........................................................................................
Grading ..........................................................................................
Dust/silt/clay ..........................................................................................
Sampling procedure ..........................................................................................
(BS 812 : Part 102 : 1989)
Other comments ..........................................................................................
..........................................................................................

**Petrographic details (of each significant constituent)**

Mineral or rock type ..........................................................................................
Colour ..........................................................................................
Particle shape ..........................................................................................
Surface texture ..........................................................................................
Surface coatings ..........................................................................................
Petrographic description ..........................................................................................
..........................................................................................

### Table 4 — Preferred form for tabulating the results of the quantitative examination

| Mineral or rock type | Method of determination | Percentage composition to 1 % | | | 95 % confidence limits to 0.1 % |
|---|---|---|---|---|---|
| | | Test portion 1 | Test portion 2 | Average | |
| | | | | | |

NOTE The true proportion of a constituent of the material represented by a sample will fall outside the 95 % confidence limit for that constituent in only one in 20 occasions, approximately.

# Annex A (normative) Calculation of the required test portion masses for analysis

## A.1 Coarse aggregate

A minimum mass of test portion, $M$, is selected for sieving according to the maximum size of the particles present and the proportion of the constituent to be analysed for according to the following equation:

$$M = \frac{0.0002\ (100 - p)\ (D_{\max})^3}{P} \qquad \text{(A.1)}$$

where

$D_{\max}$ is the maximum particle size (in mm);

$p$ is the proportion of constituent of interest [in % ($m/m$)].

NOTE Useful values calculated from equation (A.1) are given in Table A.1.

**Table A.1 — Minimum mass of test portion needed for sieving**

| Proportion of constituent of interest % ($m/m$) | Mass kg, $M$ | | | | |
|---|---|---|---|---|---|
| | Maximum particle size, $D_{\max}$ | | | | |
| | 50 mm | 37.5 mm | 20 mm | 10 mm | 5 mm |
| 20 | 100.0 | 42.2 | 6.40 | 0.80 | 0.100 |
| 10 | 225.0 | 94.9 | 14.4 | 1.80 | 0.225 |
| 5 | 475.0 | 200.4 | 30.4 | 3.80 | 0.475 |

Select a test portion, by an appropriate sampling method, of at least the mass given in Table A.1, sieve into size fractions and assemble the results (the form given in Table A.2 is recommended). Calculate the proportion in fraction, $G_i$ in % ($m/m$), using the following equation (see Table A.2).

$$G_i = \frac{M_i}{M} \qquad \text{(A.2)}$$

To avoid counting an unnecessarily large number of particles in the finer size fractions the minimum mass to be used in the analysis ($m_i$) from each size fraction is calculated using the formula:

$$m_i = \left(\frac{D_i}{D_{\max}}\right)^3 M_i \qquad \text{(A.3)}$$

where

$D_{\max}$ is the diameter of the coarsest size fraction present in the test portion (in mm).

*Example.* An example of the calculations is given in Table A.3.

It will be clear that, although the sample selected for sieving is relatively large (100 kg), the amount of material which is actually counted can be much less (34.9 kg) and this is concentrated in the coarser size fractions where the number of particles is small in a given mass.

## A.2 Sand

Calculate an estimate of the required test portion mass using the method given in **A.1**.

NOTE The values given in Table A.1 will prove useful.

Calculate an estimate of the number of points to be counted in thin section, made from the size fraction finer than 1.18 mm (see **A.4**).

Assemble the results of a sieve analysis of a test portion (the form given in Table A.4 is recommended).

NOTE It is more convenient to work in grams than kilograms with sand.

Calculate the proportion in fraction and mass in fraction using the following equations.

$$G_i = \frac{M_i}{M} \qquad \text{(A.2)}$$

$$m_i = \left(\frac{D_i}{D_{\max}}\right)^3 M_i \qquad \text{(A.3)}$$

Calculate the number of points to be counted in the < 1.18 fraction ($N$) using the following equation.

$$N = \frac{1000\ m_4}{{D_4}^3} \qquad \text{(A.4)}$$

*Example.* An example of the calculations is given in Table A.5. A sieve analysis has been carried out on an 800 g test portion. All the fraction passing 1.18 mm is to be used for the preparation of thin sections but the mass used in analysis, $m_4$, is calculated using equation (A.3) as the value is used to estimate the minimum number of points to be counted. An estimate of the number of grains of less than 1.18 mm diameter that comprise the 0.66 g of $m_4$ is given using equation (A.4):

$$N = 1000 \times \frac{m_4}{D^3{}_4} = 402 \qquad \text{(A.4)}$$

which is also the number of points to be counted in thin section with a count interval of more than 1.18 mm.

### Table A.2 — Recommended form for setting out the calculation of the required test portion mass of a coarse aggregate

| Aggregate size fraction mm | Index of size $i$ | Maximum particle size $D_i$ mm | Mass in fraction $M_i$ kg | Proportion in fraction $G_i$ % ($m/m$) | Mass used in analysis $m_i$ kg |
|---|---|---|---|---|---|
| 50.0 to 37.5 | 1 | 50.0 | $M_1$ | $G_1$ | $m_1$ |
| 37.5 to 20.0 | 2 | 37.5 | $M_2$ | $G_2$ | $m_2$ |
| 20.0 to 10.0 | 3 | 20.0 | $M_3$ | $G_3$ | $m_3$ |
| 10.0 to 5.0 | 4 | 10.0 | $M_4$ | $G_4$ | $m_4$ |
| **Total:** | | | $M$ | 1.00 | $m$ |

### Table A.3 — Example of the calculation of the required test portion mass of a coarse aggregate

| Aggregate size fraction mm | Index of size $i$ | Maximum particle size $D_i$ mm | Mass in fraction $M_i$ kg | Proportion in fraction $G_i$ % ($m/m$) | Mass used in analysis $m_i$ kg |
|---|---|---|---|---|---|
| 50.0 to 37.5 | 1 | 50.0 | 8 | 0.08 | 8 |
| 37.5 to 20.0 | 2 | 37.5 | 60 | 0.60 | 25.3 |
| 20.0 to 10.0 | 3 | 20.0 | 24 | 0.24 | 1.536 |
| 10.0 to 5.0 | 4 | 10.0 | 8 | 0.08 | 0.064 |
| **Total:** | | | 100 | 1.00 | 34.9 |

### Table A.4 — Recommended form for setting out the calculation of the required test portion mass of a sand and of the number of points to count on thin sections

| Aggregate size fraction mm | Index of size $i$ | Maximum particle size $D_i$ mm | Mass in fraction $M_i$ kg | Proportion in fraction $G_i$ | Mass used in analysis $m_i$ kg |
|---|---|---|---|---|---|
| 10.0 to 5.00 | 1 | 10.0 | $M_1$ | $G_1$ | $m_1$ |
| 5.0 to 2.36 | 2 | 5.00 | $M_2$ | $G_2$ | $m_2$ |
| 2.36 to 1.18 | 3 | 2.36 | $M_3$ | $G_3$ | $m_3$ |
| < 1.18 | 4 | 1.18 | $M_4$ | $G_4$ | $m_4$ |
| **Total:** | | | $M$ | 1.00 | $m$ |

### Table A.5 — Example of the calculation of the required test portion mass of a sand

| Aggregate size fraction mm | Index of size $i$ | Maximum particle size $D_i$ mm | Mass in fraction $M_i$ g | Proportion in fraction $G_i$ | Mass to be used in analysis $m_i$ g |
|---|---|---|---|---|---|
| 10.0 to 5.00 | 1 | 10.0 | 40 | 0.05 | 40 |
| 5.0 to 2.36 | 2 | 5.00 | 120 | 0.15 | 15 |
| 2.36 to 1.18 | 3 | 2.36 | 240 | 0.30 | 3.15 |
| < 1.18 | 4 | 1.18 | 400 | 0.50 | 0.66 |
| **Total:** | | | 800 | 1.00 | 58.81 |

# Annex B (normative) Determination of constituent proportions and calculation of relative errors and 95 % confidence limits

NOTE Having prepared test portions of appropriate mass by the method given in annex A it is now necessary to determine the petrological composition of each fraction and subsequently calculate the overall constituent proportion and standard deviation for the coarse and fine aggregates.

## B.1 Coarse aggregates

NOTE 1 Table B.1 shows how the constituent proportions should be calculated from the masses of constituents determined in each fraction of coarse aggregate and Table B.2 provides a worked example.

NOTE 2 In these calculations only three constituent components have been assumed for simplicity. If more components are identified similar calculations should be performed throughout for further constituents D, E, F etc. as necessary.

As a first step, sort the fractions or subsamples of fractions (i.e. $m_1$, $m_2$, $m_3$, $m_4$) by hand-separation into their constituents and weigh. On the assumption that only three constituents (A, B and C) are present, record the results as the masses $mA_1$, $mB_1$, $mC_1$, in the coarsest fraction, $mA_2$, $mB_2$, $mC_2$ in the next coarsest fraction and so on in all the size ranges.

Subsequently, calculate and record the percentage composition of each size range as $PA_1$, $PB_1$, $PC_1$ in the coarsest fraction, $PA_2$, $PB_2$, $PC_2$ in the next coarsest fraction, etc., using the following equation.

$$P\alpha_i = 100\ m\alpha_i/m_i \qquad \text{(B.1)}$$

where

$\alpha$ is constituent $A$, $B$, $C$, etc.

Calculate the overall percentage composition of the coarse aggregate in terms of components A, B and C, expressed as $PA$, $PB$ and $PC$, using the following equation.

$$P\alpha = \Sigma G_i \cdot P\alpha_i \qquad \text{(B.2)}$$

Calculate the standard deviation ($SD$) of each constituent in each size range using the following equation.

$$SD\alpha_i = 0.0010\ \sqrt{\{(100 - P\alpha_i) \cdot P\alpha_i \cdot D_i^{3}/m_i\}} \qquad \text{(B.3)}$$

Finally, calculate the standard deviation of each constituent in the entire coarse aggregate using the following equation.

$$SD\alpha = \sqrt{\{\Sigma(G_i \cdot SD\alpha_i)^2\}} \qquad \text{(B.4)}$$

NOTE 3 Table B.3 shows how the results from the analysis of duplicate test portions should be combined to give the form of presentation required for the report and Table B.4 gives a worked example.

Calculate the combined standard deviation for each constituent from the standard deviations of the duplicate test portions using following equation.

$$COMSD\alpha = 0.5\ \sqrt{(SD'\ \alpha^2 + SD''\ \alpha^2)} \qquad \text{(B.5)}$$

Calculate the average percentage composition of the constituents from the duplicate test portions using the following equation.

$$AVEP\alpha = 0.5\ (P'\alpha + P''\alpha) \qquad \text{(B.6)}$$

Calculate the confidence limits and relative error for each constituent using the following equation:

$$CL\alpha = 2\ COMSD\alpha \qquad \text{(B.7)}$$

$$RE\alpha = 100\ CL\alpha/AVEP\alpha \qquad \text{(B.8)}$$

NOTE 4 In these calculations proportions should be rounded to 0.0001 and percentages to 0.1 %. If a computer program is used the accuracy should not be lower than this.

## B.2 Sand

NOTE 1 The method for sand is similar to that for coarse aggregates but involves additional calculations to combine the results of hand-separation together with those from point-counting on the finest material.

NOTE 2 Table B.5 shows how the constituent proportions should be calculated from the masses of constituents determined in each fraction of sand and Table B.6 provides a worked example.

NOTE 3 In these calculations only three constituent components have been assumed for simplicity. If more components are identified similar calculations should be performed throughout for further constituents, D, E, F, etc. as necessary.

Sort the fractions or subsamples of fractions, i.e. masses $m_1$, $m_2$, $m_3$ by hand-separation into their constituents and weigh. On the assumption that three constituents (A, B and C) are present, record the results as the masses $mA_1$, $mB_1$, $mC_1$, in the coarsest fraction, $mA_2$, $mB_2$, $mC_2$ in the next coarsest fraction, and so on in all the size ranges except for the finest fraction. Calculate and record the percentage composition in each size range as $PA_1$, $PB_1$, $PC_1$ in the coarsest fraction; $PA_2$, $PB_2$, $PC_2$ in the next coarsest fraction, etc., using equation (B.1).

In the case of the finest fraction, cast either the entire fraction or a subsample of it into a resin block from which a thin section or sections are prepared containing sufficient grains for point-counting (see annex A). Record the number of points counted of constituent A, B or C as $nA_4$, $nB_4$, $nC_4$ which together totals $n_4$. Calculate the proportion by mass of each constituent determined by point counting ($PA_4$, $PB_4$, $PC_4$) using the following equations:

$$T = \Sigma' \rho\alpha \cdot n\alpha_4 \qquad \text{(B.9)}$$

$$P\alpha_4 = 100\rho\alpha \cdot n\alpha_4/T \qquad \text{(B.10)}$$

NOTE These equations convert volume proportion to a mass proportion by making allowance for the density of each constituent.

Calculate the overall percentage composition of the sand in terms of components A, B, C, expressed as *PA*, *PB*, *PC*, using equation (B.2).

Calculate the standard deviation (*SD*) of each constituent in each size range using the following equations.

$$SD\alpha_i = 0.0316 \sqrt{\{(100 - P\alpha_i) \cdot P\alpha_i \cdot D_i^3/m_i\}} \qquad \text{(B.11)}$$

$$SD\alpha_4' = \sqrt{\{(100 - P\alpha_4) \cdot P\alpha_4/n_4\}} \qquad \text{(B.12)}$$

Calculate the overall standard deviation for each constituent in the sand (*SDA*, *SDB*, *SDC*) from results obtained by both hand-separation and point-counting using the following equation.

$$SD = \sqrt{\{\Sigma(G_i \cdot SD\alpha_i)^2 + (G_4 \cdot SD\alpha_4')^2\}} \qquad \text{(B.13)}$$

Combine the results from the duplicate analysis of sand as given in **B.1** for the coarse aggregates (Table B.3 and Table B.4).

### Table B.1 — Recommended form for the calculation of the constituent proportions and standard deviations for coarse aggregates

| **Size fraction** (mm) | **50.0 to 37.5** | **37.5 to 20.0** | **20.0 to 10.0** | **10.0 to 5.00** | **Total** |
|---|---|---|---|---|---|
| Index, *i* | 1 | 2 | 3 | 4 | — |
| Particle size | $D_1 = 50.0$ | $D_2 = 37.5$ | $D_3 = 20.0$ | $D_4 = 10.0$ | — |
| Mass in fraction, *M* (kg) | $M_1$ | $M_2$ | $M_3$ | $M_4$ | *M* |
| Proportion in fraction to 0.0001 | $G_1$ | $G_2$ | $G_3$ | $G_4$ | 1.0000 |
| **Constituent** | **Mass of constituent in subsample,** *m* (kg) | | | | |
| A | $mA_1$ | $mA_2$ | $mA_3$ | $mA_4$ | — |
| B | $mB_1$ | $mB_2$ | $mB_3$ | $mB_4$ | — |
| C | $mC_1$ | $mC_2$ | $mC_3$ | $mC_4$ | — |
| Total | $m_1$ | $m_2$ | $m_3$ | $m_4$ | — |
| | **Constituent in subsample,** *P* % (*m*/*m*) | | | | |
| A | $PA_1$ | $PA_2$ | $PA_3$ | $PA_4$ | *PA* |
| B | $PB_1$ | $PB_2$ | $PB_3$ | $PB_4$ | *PB* |
| C | $PC_1$ | $PC_2$ | $PC_3$ | $PC_4$ | *PC* |
| Total | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |
| | **Standard deviations,** *SD* % | | | | |
| A | $SDA_1$ | $SDA_2$ | $SDA_3$ | $SDA_4$ | *SDA* |
| B | $SDB_1$ | $SDB_2$ | $SDB_3$ | $SDB_4$ | *SDB* |
| C | $SDC_1$ | $SDC_2$ | $SDC_3$ | $SDC_4$ | *SDC* |

NOTE Entries in Table B.1 are calculated from the following equations.

$G_i = M_i/M$ (A.2)

$P\alpha_i = 100\ m\alpha_i/m_i$ (B.1)

$P\alpha = \Sigma G_i \cdot P\alpha_i$ (B.2)

$SD\alpha_i = 0.0010 \sqrt{\{(100 - P\alpha_i) \cdot P\alpha_i \cdot P\alpha_i \cdot D_i^3/m_i\}}$ (B.3)

$SD\alpha = \sqrt{\{\Sigma(G_i \cdot SD\alpha_i)^2\}}$ (B.4)

where

$i = 1, 2, 3$ or 4;

$\Sigma$ is summation over $i = 1$ to 4;

$\alpha$ is constituent A, B, C, etc. to 0.01 %.

The values calculated from equations (B.1) to (B.4) should be calculated to 0.01 %.

### Table B.2 — Example of the calculation of constituent proportions and standard deviations for coarse aggregates

| **Size fraction** (mm) | **50.0 to 37.5** | **37.5 to 20.0** | **20.0 to 10.0** | **10.0 to 5.00** | **Total** |
|---|---|---|---|---|---|
| Index, *i* | 1 | 2 | 3 | 4 | — |
| Particle size | $D_1 = 50.0$ | $D_2 = 37.5$ | $D_3 = 20.0$ | $D_4 = 10.0$ | — |
| Mass in fraction, *M* (kg) | 8.0 | 60.0 | 24.0 | 8.0 | 100.0 |
| Proportion in fraction to 0.0001 | 0.0800 | 0.6000 | 0.2400 | 0.0800 | 1.0000 |
| **Constituent** | **Mass of constituent in subsample,** *m* kg | | | | |
| A | 6.400 | 19.491 | 1.213 | 0.049 | — |
| B | 1.440 | 5.316 | 0.292 | 0.014 | — |
| C | 0.160 | 0.506 | 0.031 | 0.001 | — |
| Total | 8.000 | 25.313 | 1.536 | 0.064 | — |
| | **Constituent in subsample** % (*m*/*m*) | | | | |
| A | 80.00 | 77.00 | 78.97 | 76.56 | 77.68 |
| B | 18.00 | 21.00 | 19.00 | 21.88 | 20.35 |
| C | 2.00 | 2.00 | 2.02 | 1.56 | 1.97 |
| Total | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |
| | **Standard deviations,** *SD* % | | | | |
| A | 5.00 | 1.92 | 2.94 | 5.30 | 1.47 |
| B | 4.80 | 1.86 | 2.83 | 5.17 | 1.42 |
| C | 1.75 | 0.64 | 1.02 | 1.55 | 0.49 |

### Table B.3 — Recommended form for combining the results from the analysis of duplicate test portions

| **Constituent** | **Standard deviation** | | | **Percentage composition** | | | **95 % confidence limits** | **Relative error** |
|---|---|---|---|---|---|---|---|---|
| | **test portion 1** % | **test portion 2** % | **combined** % | **test portion 1** % | **test portion 2** % | **average** % | % | % |
| A | *SD′A* | *SD″A* | *COMSDA* | *P′A* | *P″A* | *AVEPA* | *AVEPA* ± *CLA* | ± *REA* |
| B | *SD′B* | *SD″B* | *COMSDB* | *P′B* | *P″B* | *AVEPB* | *AVEPB* ± *CLB* | ± *REB* |
| C | *SD′C* | *SD″C* | *COMSDC* | *P′C* | *P″C* | *AVEPC* | *AVEPC* ± *CLC* | ± *REC* |

Entries in Table B.3 are calculated from the following equations.

$COMSD\alpha = 0.5\sqrt{(SD'\alpha^2 + SD''\alpha^2)}$ (B.5)

$AVEP\alpha = 0.5\,(P'\alpha + P''\alpha)$ (B.6)

$CL\alpha = 2\,COMSD\alpha$ (B.7)

$RE\alpha = 100\,CL\alpha/AVEP\alpha$ (B.8)

The values calculated from equations (B.5) to (B.8) should be calculated to 0.01 %.

### Table B.4 — Example of combining the results from the analysis of duplicate test portions

| **Constituent** | **Standard deviation** | | | **Percentage composition** | | | **95 % confidence limits** | **Relative error** |
|---|---|---|---|---|---|---|---|---|
| | **test portion 1** % | **test portion 2** % | **combined** % | **test portion 1** % | **test portion 2** % | **average** % | % | % |
| A | 1.47 | 1.41 | 1.02 | 77.68 | 81.32 | 79.50 | 79.50 ± 2.04 | ± 2.6 |
| B | 1.42 | 1.32 | 0.97 | 20.35 | 17.80 | 19.08 | 19.08 ± 1.94 | ± 10.2 |
| C | 0.49 | 0.54 | 0.36 | 1.97 | 2.20 | 2.09 | 2.09 ± 0.72 | ± 34.4 |

### Table B.5 — Recommended form for the calculation of the constituent proportions and standard deviations for sand

| **Size fraction** (mm) | **10.0 to 5.00** | **5.00 to 2.36** | **2.36 to 1.18** | **< 1.18** | **Total** |
|---|---|---|---|---|---|
| Index, $i$ | 1 | 2 | 3 | 4 | — |
| Particle size | $D_1 = 10.0$ | $D_2 = 5.00$ | $D_3 = 2.36$ | $D_4 = 1.18$ | — |
| Mass in fraction, $M$ (kg) | $M_1$ | $M_2$ | $M_3$ | $M_4$ | $M$ |
| Proportion in fraction to 0.0001 | $G_1$ | $G_2$ | $G_3$ | $G_4$ | 1.0000 |
| **Constituent** | **Mass of constituent in subsample,** $m$ g | | | **Number of points counted,** $n$ | **Density,** $\rho$ g/cm$^3$ |
| A | $mA_1$ | $mA_2$ | $mA_3$ | $nA_4$ | $\rho$A |
| B | $mB_1$ | $mB_2$ | $mB_3$ | $nB_4$ | $\rho$B |
| C | $mC_1$ | $mC_2$ | $mC_3$ | $nC_4$ | $\rho$C |
| Total count | — | — | — | $n_4$ | — |
| Total subsample mass | $m_1$ | $m_2$ | $m_3$ | $m_4$ | — |
| Total, $T$ | — | — | — | — | T |
| | **Constituent in subsample,** $P$ % | | | | Total |
| A | $PA_1$ | $PA_2$ | $PA_3$ | $PA_4$ | $PA$ |
| B | $PB_1$ | $PB_2$ | $PB_3$ | $PB_4$ | $PB$ |
| C | $PC_1$ | $PC_2$ | $PC_3$ | $PC_4$ | $PC$ |
| Total | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |
| | **Standard deviations,** $SD$ % | | | | Total |
| A | $SDA_1$ | $SDA_2$ | $SDA_3$ | $SDA_4$<br>$SDA_4'$ | $SDA$ |
| B | $SDB_1$ | $SDB_2$ | $SDB_3$ | $SDB_4$<br>$SDB_4'$ | $SDB$ |
| C | $SDC_1$ | $SDC_2$ | $SDC_3$ | $SDC_4$<br>$SDC_4'$ | $SDC$ |

NOTE Entries in Table B.5 are calculated from the following equations.

$G_i = M_i/M$ (A.2)

$T = \Sigma'\rho\alpha \cdot n\alpha_4$ (B.9)

$P\alpha_i = 100m\,\alpha_i/m_i$ for hand-separation (B.1) to 0.01 %

$P\alpha_4 = 100\rho\alpha \cdot n\alpha_4/T$ for point-counting (B.10) to 0.01 %

$P\alpha = \Sigma G_i \cdot P\alpha_i$ (B.2) to 0.01 %

$SD\alpha_i = 0.0316\,\sqrt{\{(100 - P\alpha_i)\cdot P\alpha_i \cdot D_i^3/m_i\}}$ (B.11) to 0.01 %

$SD\alpha_4' = \sqrt{\{(100 - P\alpha_4)\cdot P\alpha_4/n_4\}}$ (B.12) to 0.01 %

$SD = \sqrt{\{\Sigma(G_i \cdot SD\alpha_i)^2 + (G_4 \cdot SD\alpha_4')^2\}}$ (B.13) to 0.01 %

where

$\Sigma$ is summation over all fractions $i$ = 1, 2, 3, 4 (i.e. across a row)

$\Sigma'$ is summation over constituents $\alpha$ = A, B, C. (i.e. down a column)

The values calculated from equations (B.1), (B.2) and (B.9) to (B.13) should be calculated to 0,01 %.

### Table B.6 — Example of the calculation of constituent proportions and standard deviations for sand

| **Size fraction** (mm) | **10.0 to 5.00** | **5.00 to 2.36** | **2.36 to 1.18** | **< 1.18** | **Total** |
|---|---|---|---|---|---|
| Index, *i* | 1 | 2 | 3 | 4 | — |
| Particle size | $D_1 = 10.0$ | $D_2 = 5.00$ | $D_3 = 2.36$ | $D_4 = 1.18$ | — |
| Mass in fraction, *M* (g) | 40 | 120 | 240 | 400 | 800 |
| Proportion in fraction to 0.0001 | 0.0500 | 0.1500 | 0.3000 | 0.5000 | 1.0000 |
| **Constituent** | **Mass of constituent in subsample**, *m* g | | | **Number of points counted,** | **Density,** $\rho$ g/cm$^3$ |
| A | 30.88 | 12.00 | 2.43 | 306 | 2.65 |
| B | 8.48 | 2.70 | 0.66 | 88 | 2.80 |
| C | 0.64 | 0.30 | 0.06 | 8 | 2.60 |
| Total count | — | — | — | 402 | — |
| Total subsample mass | 40.00 | 15.00 | 3.15 | 400 | — |
| Total, *T* | — | — | — | — | 1078.10 |
| | **Constituent in subsample**, *P* % | | | | Total |
| A | 77.20 | 80.00 | 77.14 | 75.22 | 76.61 |
| B | 21.20 | 18.00 | 20.95 | 22.86 | 21.48 |
| C | 1.60 | 2.00 | 1.90 | 1.93 | 1.92 |
| Total | 100.00 | 100.00 | 99.99 | 100.01 | 100.01 |
| | **Standard deviations**, *SD* % % | | | | Total |
| A | 6.63 | 3.65 | 2.71 | 0.09<br>2.15 | 1.49 |
| B | 6.46 | 3.50 | 2.63 | 0.09<br>2.09 | 1.45 |
| C | 1.98 | 1.28 | 0.88 | 0.03<br>0.69 | 0.49 |

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