DEVELOPMENT
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Working Paper No. 38

Soil Testing for Soil-Cement Block Preparation

1993

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DTU Working Paper No.38 January 1993

Soil Testing For Soil-Cement Block Production

by Dr D.E.Gooding

ABSTRACT:

This working paper describes how to test soils to determine their suitability for use in soil-cement building blocks. Several reports covering this topic have been published over the last twenty years by a variety of organisations. This paper provides a brief description of the effects of soil properties on the handlability of blocks during moulding and the performance of the blocks after curing. It then undertakes a practical critique of the published tests for selecting soil, and for determining how much cement should be added to them, identifying a number of ambiguities, difficulties of performance and actual error in them. It concludes with recommended testing plans and three appendices. Appendix A describes selected procedures for field-testing soils to be used for block making, Appendix B describes laboratory test procedures: in both appendices the shortcomings identified earlier have been corrected. Appendix C is a bibliography.

CONTENTS:

INTRODUCTION

The purpose of this review is :

- to accurately describe the main soil selection tests and assess their usefulness
- to recommend test procedures for block makers under different circumstances.

The following report examines the process of soil selection for the purpose of soil-cement block production. Initially a brief explanation is given concerning the susceptibility of unstabilised earth constructions to water damage. This is followed by an introduction to soil-cement as a building material giving reasons for its use. Soil suitable for soil-cement construction is then considered from a particle grading and plasticity viewpoint, with due consideration to the underlying mechanisms responsible for strength and durability. Factors characteristic of a generally suitable soil are then put forward followed by a review of more specific criteria, previously published by other authors. The testing of soils for use in soil-cement is discussed with sections highlighting some misleading and inaccurate statements present in some of the soil testing literature. A coherent plan is then given to show the order in which the tests should be used. The main soil selection tests are fully described in Appendix A as field tests and Appendix B (simple) laboratory tests.

1. SOIL BUILDING

Some form of soil covers virtually the whole land surface of the Earth. This soil is usually readily processed with simple hand tools into an easily mouldable material which possesses good compressive strength when dry. Given soil's widespread availability, it is not surprising that it was traditionally widely used as a building material.

The major drawback to building with soil is its susceptibility to water. A soil wall may be considered as a load bearing skeleton of silt and sand glued together by clay. This glue-like behaviour when dry is caused by micro-droplets of water which exist at clay particle interfaces. Clay particles are usually electrostatically charged as a result of surface ion substitution. The charge tightly bonds a thin adsorbed layer of water to the particle's surface. The bonding is sufficiently strong for some adsorbed water to remain even at oven drying temperatures (105 -110°C). At the point of contact between two adjacent particles, a micro-droplet of water can exist where the two adsorbed water layers come into contact. These micro-droplets generate both surface and capillary tension forces which hold the clay particles together. However when any significant quantity of water is absorbed into empty soil pores, the droplets increase in size and the capillary and surface tension forces reduce, causing the soil to quickly soften and subsequently swell. On repeated wetting and drying the outer surfaces of a soil wall expand and contract more quickly than the main body. In a comparatively short time this leads to cracking and spalling of the outer surfaces and low durability for the wall. Moreover if the wall becomes saturated with water the compressive strength may fall sufficiently to allow complete collapse.

There are many methods to reduce a soil's susceptibility to weakening by water. These fall into the following broad categories: protecting the wall from exposure to water, reducing the permeability of the wall by increasing the soil density, making the soil water-repellant by the addition of a water-proofing agent and providing a secondary cementitious-type strength mechanism which is largely unaffected by water. I propose to centre the following report on the final category namely cementitious additives and concentrate on soil-cement.

2. WHAT IS SOIL-CEMENT AND WHY USE IT ?

Soil on its own can be used for construction, but unless it is protected from water the resulting building will not be very durable in any but the driest climates, as has been described above. Cementitious stabilisation in combination with densification gives soil both wet strength and erosion resistance. Densification or compaction reduces the soil's permeability and enhances the secondary cementitious bonding mechanism. Ordinary portland cement is the most commonly used stabiliser and at present usually the cheapest. Lime and lime-pozzolan stabilisation are growing in popularity because, unlike cement, lime may be produced economically by small-scale batching kilns. However, at present the quality of lime produced by such small-scale kilns is highly variable and liable to change from one batch to another. Moreover, a system of price subsidy exists in many countries so that despite cement relying on lime as a raw material and being more expensive to manufacture, it still remains cheaper than lime in the market place. The higher cost and variability of lime have led to the current dominance of cement.

Soil-cement is produced by dry-mixing a suitable soil[1] with a small quantity of cement and re-mixing the product with a specific quantity of water. The resulting damp soil is normally compressed in a mould, ejected and subsequently wet cured for 3-4 days then damp cured for at least two weeks before incorporation in a building. In many ways soil-cement may be seen as a simpler version of sand-cement, not requiring the sand to be first separated from other soil constituents. Sand-cement is widely used, though variable in quality as a result of poor curing.

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[1]. The criteria for a suitable soil will be examined in detail later but it should be noted that two or more unsuitable soils may be combined by simple mixing to produce one more successful soil.

Soil-cement blocks produced with compression are in general more dense and hence less porous than sand-cement. The resultant reduction of moisture loss during curing leads to a greater consistency in quality for soil-cement.

The minimum amount of cement required to stabilise a block depends on the type of soil, the degree of compression and the final application for the blocks. Generally the interest is to minimise the cement content to below 10%. Given suitable conditions, contents as low as 3% are possible.

The exact mechanism by which a small content of cement may stabilise a large mass of soil is not fully understood. Ordinary Portland Cement is made up of 45% tricalcium silicate (C_3S)[2] and 27% dicalcium silicate (C_2S). In the presence of damp soil these components hydrate to form mono and di-calcium silicate hydrate gels (CSH and C_2SH, see equation below). These gels then slowly crystallise into an insoluble interlocking matrix throughout the soil voids binding the soil particles together. As the matrix is insoluble it gives a strength mechanism which works to restrain the softening and swelling of the unaffected soil, thereby dramatically reducing the weakening effect of water. The interlocking calcium silicate fibres may be seen when a cured soil cement sample is examined under an electron microscope. The hydration of the calcium silicate also results in the release of free lime (CH) according to the reaction:

$$C_3S + 2H = C_2SH + CH$$
$$C_2S + 2H = CSH + CH$$

The free lime then reacts further with the clay fraction (pozzolanic reaction) by the removal of silica from the clay minerals and subsequently forms more calcium silicate gel which also gradually crystallises.

In summary soil cement is a building material which has superior strength and erosion resistance compared to unstabilized soil, without incurring the cost of the large quantities of cement found in concrete.

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[2]. C and S represent Calcium and Silicon respectively, not carbon and sulphur. This is in keeping with most of the published concrete literature and is acceptable, allowing these simple equations to be given as illustrations instead of the more complicated fully balanced chemical equations.

3. SOIL FOR SOIL-CEMENT

3.1 GENERAL PROPERTIES

Using a suitable soil for soil-cement block production will result in:

- strong blocks, namely those that after curing possess high wet strength and erosion resistance.
- handleable blocks, that immediately upon demoulding can be transferred to a curing area without a high breakage rate.
- blocks which will not seriously distort or crack during curing.
- blocks which will not expand and contract excessively in the building if subjected to wetting and drying cycles.

Specifically disqualified soils are:

- those containing organic matter.
- those which are highly expansive.
- those containing excessive soluble salts e.g gypsum and chalk.

For building purposes soil can be generally characterised in two ways, by a particle size distribution analysis and by a plasticity index. The particle size analysis will give information on the soils ability to pack into a dense structure and the quantity of fines present (combined silt and clay fraction), while the plasticity index gives an idea of the cohesion of the fines.

3.2 PARTICLE GRADING

The British Standard and MIT classification of soil particle sizes is given below:

coarse gravel.................. 60 to 20 mm.
medium gravel.................. 20 to 6 mm.
fine gravel.................... 6 to 2 mm.

coarse sand.................... 2 to 0.6 mm.
medium sand.................... 0.6 to 0.2 mm.
fine sand...................... 0.2 to 0.06 mm.

coarse silt.................... 0.06 to 0.02 mm.
medium silt.................... 0.02 to 0.006 mm.
fine silt...................... 0.006 to 0.002 mm.

clay........................... < 0.002 mm.

Gravel is not usually used in soil-cement production, as the large particle size may lead to a poor (rough) surface finish. A suitable soil will contain a mixture of sand, silt and clay-sized particles. The proportions of each of these three fractions influences the properties of the block and will be discussed below.

A particle size analysis will determine the fraction of a soil's particles that fall within each of the above size bands. If a dense block is to be produced, it is important that the soil used is "well graded". The theoretical distribution of particle sizes to provide a perfectly packed structure is called the Fuller curve. The Fuller curve is based upon the assumption that all of the particles are spherical and that the largest particles just touch each other, while there are enough intermediate particles to fill the voids between the largest, but without holding them apart. The intermediate sized particles are also similarly arranged with progressively finer particles filling the voids between larger ones. The Fuller distribution is an ideal model and never occurs naturally. However, a natural soil which has an even distribution of particle sizes, termed well-graded, is a good approximation.

The value of a well-graded soil for soil cement is that such a distribution of sizes gives a dense structure with a low specific surface area. A dense structure is important for several reasons. A densely packed arrangement will have a higher number of contacting particles, giving a better load bearing skeleton. The number and size of the inter-particle voids will be reduced, as will the number of linked voids. This will reduce the porosity of the soil and hence also its permeability, thereby reducing susceptibility to water penetration. As the interlocking calcium silicate matrix extends through the soil voids, a more compact void system requires less cement to provide a matrix of equal efficiency. Similarly if it is imagined that cement coats the soil particles' surface, a high specific surface area will lead to cement blinding, or a lower specific surface area soil will require less cement to provide the same particle surface coverage and consequently the same strength and durability.

The upper and lower limits to the soil's grading also need to be considered. A soil may be considered well-graded with a uniform distribution of particles from fine silt to coarse sand (coarse soil) or with a distribution from clay to fine sand (fine soil). The coarse soil will have a lower specific surface area than the fine soil as the same mass of soil will contain fewer and larger particles.

From the above consideration of specific surface area, it might be concluded that the more coarse soil would produce strong blocks with a lower cement content than that needed for the fine soil. This is however only the case when the blocks are kept within the mould to cure. A coarse soil containing no fines (silt and clay) is non-plastic and will not have sufficient cohesion to retain its shape on ejection from the mould or to allow easy transportation to the curing area. If the blocks are left to cure in their moulds (and the moulds are made strong enough to withstand a significant compaction pressure) then the machinery costs escalate unacceptably. The coarse soil could be considered to be a form of sand-cement containing large voids (a result of the lack of fines). Large voids would increase the porosity of the block and lead back to the common sand-cement problem of rapid drying before the cement has had time to adequately cure. Such a soil would be considered well-graded but still be unsuitable for soil-cement block production. Conversely a well-graded fine soil, containing little sand but a high clay content, would have a high specific surface area and expansivity (see below). The high clay content would give the soil cohesion and stability on ejection from the mould, but the high specific surface area would require a large amount of cement to provide a reasonable particle coverage.

A suitable soil will be well-graded but certain other limits should also be imposed: The largest particle size present should not be sufficiently large to cause a poor surface finish. Sufficient fines (silt and clay) should be present to allow handleability on demoulding but not enough to blind the small quantity of cement to be used.

3.3 PLASTICITY (FINES CONTENT)

The silt and clay content of a soil are responsible for soil cohesion and it is these fines which provide the fresh blocks with handleability until the initial set of the cement has occurred. The degree of cohesion provided to the block is dependant both on the fines present and the degree of compaction used to form the block. In general terms, a low-pressure moulding process will require a higher fines content than a high-pressure moulding process. This is because increased compaction will force the soil particles into more intimate contact, thus strengthening the fresh compact.

However, the fines and in particular the clay fraction can also lead to blinding of the cement as a result of their high surface area (see above). Head (Ref 2, Head 1980) reports that the approximate surface area of fine sand and medium silt are 0.023 and 0.23 square meters per gram, while for three major clay groups, kaolinite, illite and montmorillonite this increases to 10, 100 and 1000 square meters per gram respectively.

The fines also affect the final cured block's expansion on wetting. Clay usually exists in small agglomerations which expand in three dimensions on wetting as water penetrates some of the numerous individual particle boundary fissures. The expansion of the clay fraction must be largely restrained by the calcium silicate matrix in order to minimise expansion and contraction of the cured block, on repeated wetting and drying. Hence for durability the clay fraction should be as small as possible to allow the lowest cement content. It might be expected from the large difference between the specific surface areas of the three clay types mentioned above that different clays have significantly differing expansion characteristics on wetting. This is the case, in general as the surface area of the clay fraction rises, so does the amount it will expand on wetting. As a result the type of clay as well as the quantity present will affect the block.

The fine fraction can be seen to be helpful to the block production process but to adversely affect the wet strength and durability of the final cured block. The quantity and type of clay should therefore be considered important soil parameters. The quantity of fines may be measured by using one of the sedimentation tests described later, however the clay type present is very difficult to determine without highly complex tests. In fact it is not necessary to know the clay type present but it is important to know the properties exhibited by the clay. The Atterburg tests defining liquid limit, plastic limit and plasticity index are used to quantify the plasticity of the finer fraction of a soil (only particles less than 0.425 mm are tested). These tests measure the percentage water contents at which the soil passes from a liquid state to a plastic state (liquid limit) and from a plastic state to a solid state (plastic limit). The numerical difference between the liquid and plastic limit (the plasticity index) thus gives the range of water content over which the soil may be considered plastic. As plasticity is dependent on the soil cohesion, it has been found that this index reflects the cohesive characteristics of the soil. Furthermore as cohesion is largely dependent on the specific surface area of the fines, these plasticity limits also reflect the expansivity of the soil. A soil with a low plasticity index will display low cohesion and usually low expansion on wetting, while a high index soil will display the reverse.

3.4 SUITABLE SOILS

A suitable soil should not contain organic material or excessive soluble salts which would interfere with the setting of the cement. It's sand fraction should be well graded to provide a densely packed load-bearing skeleton for the block and it's largest size particle should be small enough to give a smooth surface finish. The fine fraction should be just sufficient to provide enough cohesion to the fresh block to prevent damage on ejection and transportation from the mould. Too large a fines content will either require a large cement content for adequate stabilisation or will reduce the durability and wet strength of the final cured block. The cohesion of the fresh block will depend on the compaction pressure used and the type as well as the quantity of clay present in the fines.

From the above it should now be possible to see the role that each of the soil's component fractions plays in a soil-cement block and the importance of selecting a suitable soil. If the soil available on site appears unsuitable, it should be remembered that natural soil exists in distinct strata with differing compositions. If the different strata are adequately tested then it is a comparatively simple operation to mix suitable masses of two or more strata to produce an acceptable soil. Given the need to select at least a broadly suitable soil then the case for adequate soil testing should be clear.

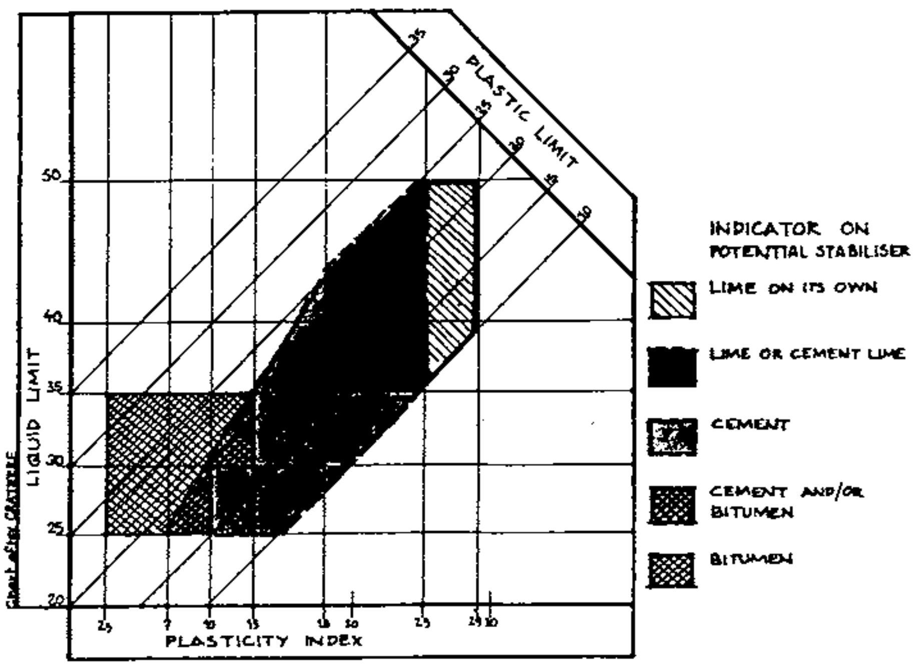
3.5 SURVEY OF CURRENTLY AVAILABLE CRITERIA FOR SOIL SUITABILITY.

The following is a brief review of published selection criteria from other authors. It is not an exhaustive review but rather included as an indication of the variation between authors and as a warning that such criteria should be used as a guide in initial soil selection rather than as a rigid set of rules. This variation is not surprising given the enormous variability of soil itself and the variation in production methods used by the different authors working in different climates. Some of the authors recommend criteria based only on particle size while others use criteria based solely on the Atterburg limits (Plasticity Index). In general it would be wise to consider both.

Ref No.3, Norton 1986. **Building With Earth, a Handbook.**

Atterburg limit criteria for stabilisation:

<u>Interpretation of Atterburg limits</u> (reproduced unmodified by Norton from a CRATerre original, Ref No. 7).



Particle size criteria for soil cement:

Optimum:	no specific optimum, "should have a high sand content".	
Limits :	sand/fine gravel (<5-6 mm)	45 - 75 %
	silt	15 - 30 %
	clay	10 - 25 %
cement :	variable	8 - 16 %

Not mentioned whether above is by weight or volume.

Ref No.6. United Nations 1964. **Soil-cement, its Use in Building.**

Particle size criteria for soil-cement:

Optimum: 75% sand. 25% silt and clay, of which more than 10% is clay.
Limits : minimum of 45% sand. 55% silt and clay.
maximum of 80% sand. 20% silt and clay.
cement : variable, between 4.75 % and 12.5 % by volume.

Ref No.4. International Labour Office 1987. **Small-scale Manufacture of Stabilised Soil Blocks**

No criteria is explicitly mentioned. Instead it is said that "Ideally, there should be an even distribution of each soil fraction in order to manufacture good-quality stabilised soil building blocks. If this were to be the case, about five per cent cement would be needed as a stabilising agent." The five fractions mentioned are: greater than 6 mm (coarse and medium gravel), greater than 2 mm (fine gravel), greater than 0.2 mm (coarse and medium sand), greater than 0.06 mm (fine sand) and less than 0.06 mm (combined silt and clay).

Ref No.11. Fitzmaurice, Robert 1958. Contained in Spence 1983. **Manual on Stabilised Soil Construction for Housing**

Atterburg criteria for soils most suitable for stabilisation:

liquid limit :	less than 40 percent
Plasticity index :	less than 22 percent and greater than 2.5 percent
Fitzmaurice's note :	primarily derived from temperate soils and only of limited application to tropical soils particularly laterites.

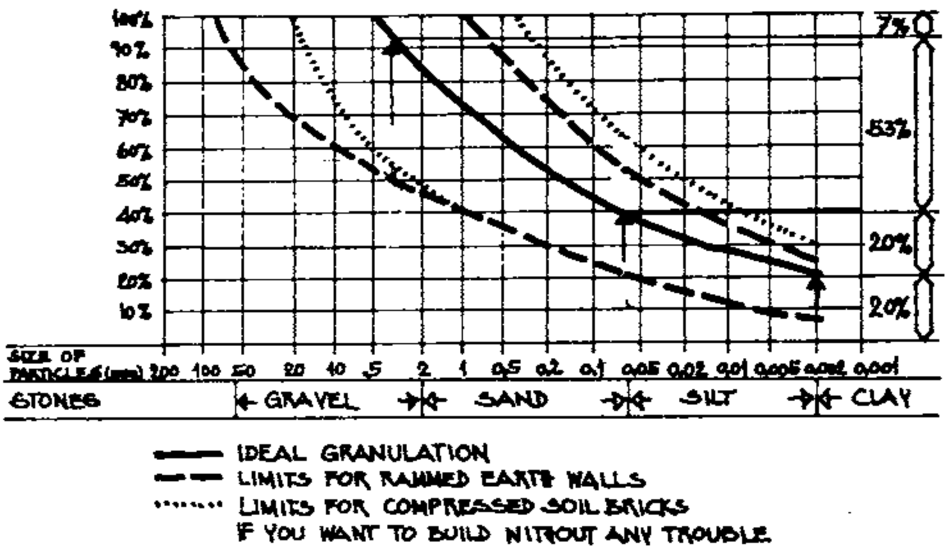
Ref No.2. Stulz, Roland 1983. **Appropriate Building Materials**.

Atterburg criteria for portland cement stabilisation.

> Plasticity index : 0 - 12
> Cement content : 6 -10 % (down to 3 % for sandy soils).
>
> Also "cement stabilisation of clayey soils (like red cotton soil) seems not to be useful."
>
> Includes atterburg three-axis graph by CRATerre. Identical to that used by Norton (as shown above) but without a similar key.

Particle size criteria for compressed soil bricks:

<u>Particle size criteria granulation curve</u> included in Stulz after CRATerre (Ref No.7)

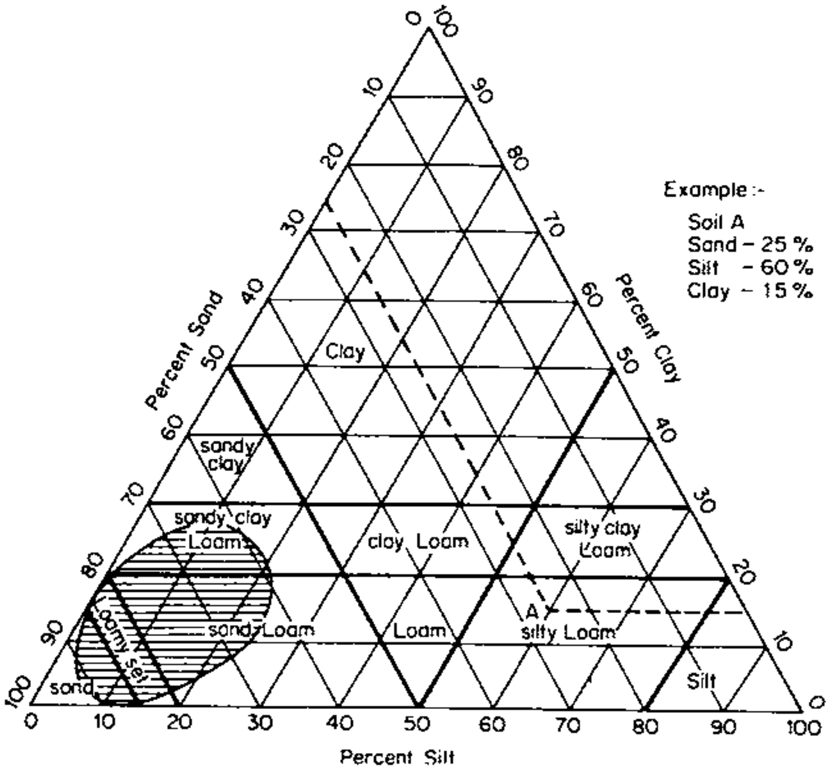


Ref No.11. Spence,R.J.S & Cook,D.J. 1983. **Building Materials in Developing Countries**.

Particle size criteria for soil-cement:

> Spence and Cook include a graphical plot on a triangular U.S. Bureau of Public Roads particle-size graph roughly between the limits:
> sand:90 - 60 % silt:25 - 0 % clay:25 - 0 %

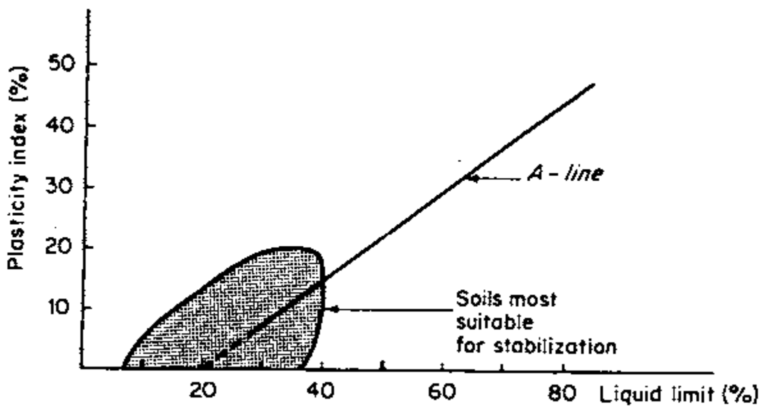
Triangular chart for particle size classification of soils: (shaded area indicates soils most suitable for stabilisation)



Atterburg limit criteria for stabilisation:

Applicable only to the fraction of soil finer than 0.4 mm, roughly between the limits; plasticity index 0 - 22 %, liquid limit 7 - 40 %.

Plasticity chart showing soils most suitable for stabilisation



It can be seen from the above that there have been a number of criteria put forward for soil selection based on particle size or Atterburg limits or both. In broad terms these criteria are in agreement. A soil suitable for cement stabilisation should have a significant sand content (at least greater than 50%, preferably closer to 75%) and a low plasticity index & clay content (typically less than 25% clay). These criteria are however intended for use as a broad initial guide for soil selection. It must be emphasised that the testing procedure is not complete until the soil or soils selected have been used to produce, cure and test a trial set of blocks. Only after a trial set of blocks have been tested and proven to be acceptable should the main production run begin.

4. TESTS FOR SOILS.

4.1 TYPES OF TEST

Prior to soil-cement block production there are three main types of test which may be conducted:

First, field tests can divide the soils into broadly suitable and unsuitable categories and if suitable into potential high and low cement classes.

Second, laboratory tests can be used to characterise the soils by particle size distribution, plasticity or other numerical measures for relation to the selection criteria (see section 3.5) and enable simple soil modification by blending. Most small-scale manufacturers of blocks, especially those producing blocks at a rural building site, have little or no access to laboratory facilities and in particular accurate mass measurement to 0.01 g. For these block makers, judicious use of the field tests, the shrinkage test, production trials and past experience has to suffice. The laboratory tests are appropriate where medium or large-scale production is planned, where minimising cement content is especially important or when soil-cement block making is moving into a new area.

Third, trial production tests can be carried out on manufactured blocks to check that the final block properties required (dry strength, wet strength and durability) can be achieved. This paper is concerned with tests which are carried out on the unformed soil. It will therefore not cover the trial block testing procedures; for information on compression and durability testing of formed blocks, "Small-scale Manufacture of Stabilised Soil Blocks" should be consulted (Ref 4, ILO 1987).

The field and laboratory test procedures reported in the literature have been conducted by the author and evaluated using a carefully characterised soil (of a type suitable for soil-cement block making). For each published test he observed the accuracy of its description, its ease of performance and the accuracy of its results (in terms of internal consistency and agreement with British Standard Tests). A number of the tests examined were found to be misleading and incorrect in parts. The following sections are concerned with highlighting these problematic areas in an attempt to improve testing procedures as a whole.

4.2 FIELD TESTS

Field tests are for preliminary site surveying, to identify the soils most likely to be suitable and so restrict the number of soils to be more rigorously assessed by laboratory tests or trial production. The tests (described in appendix A) will provide a rough idea of a soil's grading and plasticity and also indicate whether a soil contains significant organic matter (reject outright), a predominance of gravel, a predominance of sand or a predominance of fines. They may also be able to distinguish whether silt or clay is the more significant fraction of the fines. They are generally fairly easy to perform and often require little or no experimental equipment, making them very cheap to implement.

However field tests are frequently reported without acknowledging the reliance they place on the operator's senses: although the methods employed are generally simple, the interpretation of the results is a skilled operation. Consider for example the dry strength test. The prepared soil sample is crushed between the fingers and the ease of crushing is taken as a measure of the soil's clay content. For a novice operator the ease of crushing is difficult to assess and as a result so too is the clay content. A skilled operator may compare the ease of crushing with that of soils he/she has previously tested and hence arrive at a more precise conclusion. Tests which rely on personal judgement are open to differing interpretation between operators and depend on the operator's skill for their accuracy. With training and experience these tests may provide a fast, quite accurate determination of the soil's characteristics, however for a novice they can only be expected to provide a more basic picture.

Table 4.2 (below) shows which tests are reported by which publication. The glass-jar sedimentation test will be discussed under laboratory tests (section 4.3) as it contains problems in common with the syphon sedimentation test. The remaining field test methods are generally in agreement and as such no further detailed comments will be made. The test descriptions and notes included in appendix A have been compiled by the author and are a combination of earlier reported methods and the author's own modifications. Each test begins with a brief resumé by the author giving comments on the use to which the test may be put, the accuracy which may be expected from the results, the time taken for completion and the limitations of the test.

All of the test results observed (both the good and the bad), plus the location and depth of the soil samples in question should be recorded in case it is later necessary to use a soil for blending which on preliminary examination had been rejected.

TEST NAME	REF.1	REF.2	REF.3	REF.4	REF.5	REF.6
SMELL	√	√	√	√	√	X
VISUAL-TOUCH	√	√	X	X	X	√
THREAD	√	√	X	√	ND	X
RIBBON	√	√	√	X	ND	√
SHINE	√	√	√	√	√	√
SEDIMENTATION GLASS-JAR *	X	√	√ a	√ b	√ c	√
DRY STRENGTH	√	√	√	X	X	√
SURFACE WATER	√	√	X	X	√	√

<u>Table 4.2. Reported Field Tests</u>

ND : Mentioned but not adequately described.
* : These tests are described in the laboratory test section covering sedimentation test.
a : Ill advised recommendation to add salt, ignores flocculation.
b : Over-concentrated solution causes inaccurate estimation of sand and fines content, salt added ignoring flocculation
c : Over-concentrated solution, test not intended to discriminate fines into silt and clay

4.3 LABORATORY TESTS

4.3.1 GENERAL CLASSIFICATION

The laboratory tests establish numerical values for certain soil parameters, primarily the percentage distribution of the different sizes of soil particle present and the plasticity limits. These values are subsequently used to determine the best available soil or combination of soils. All of these tests rely on accurate weighing and or some form of laboratory equipment. Scales with a resolution higher than one thousandth of the chosen sample weight are desirable.

There are four main types of test:

The sieving tests separate the different size fractions of the soil into discrete parts thereby indicating the soil's particle grading. The silt and clay fractions are too small to be easily separated by sieving and as such are normally reported as a combined fraction. The larger particles may be separated into a number of size fractions, depending on the number of sieve seizes available, according to the MIT and British Standard particle classification boundaries, given in section 3.2. A full laboratory analysis would give the percentage by weight of each of these size bands.

The sedimentation tests if correctly conducted have the ability to separate the larger sand and gravel size fractions from the combined fines fraction and under favourable circumstances to further distinguish the combined fraction into separate silt and clay fractions. However the simplest test, the glass-jar sedimentation test, is usually included under field tests because visual discrimination of the silt/clay boundary may not be possible. In this case the test can only be used to give an idea of the general relative proportions of sand and fines. In its coarsest form the glass-jar sedimentation test provides no more information than a sieving test and although less accurate, it does not require any mass measurement. Further, although the sedimentation time is long the operator time required to conduct the test is less than that for a sieving test.

The Atterburg or plasticity tests define the soil's liquid limit, plastic limit and plasticity. The test methods included are simplified versions of the more rigorous British Standard methods after Norton (Ref 2, Norton 1986). The Atterburg limits allow the soils plasticity characteristics to be related to the criteria given above in section 3.5.

The shrinkage test is a test of the soil's contraction on drying and gives a combined measure of the soil's particle grading, plasticity and clay type. It gives an overall idea of the soils behaviour and suitability for stabilisation. The degree of contraction may be thought of as a measure of the expansive force which the soil stabiliser will have to withstand when a manufactured block is exposed to water. The degree of contraction is then taken as a measure of the quantity of stabiliser required. The shrinkage test may be used as a straight-forward method of determining a soil's suitability for use where more complex testing is not possible or not justified for small-scale production. However it must be remembered that this test gives no direct information on the soil's constituent parts and as such will not allow easy soil modification. It was empirically designed for use with the Cinva Ram, a low-pressure (2MPa) manual-compaction moulding machine developed by VITA. It was intended to gauge the amount of stabiliser required for a given soil compacted with this machine[3]. It is very suitable

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[3]. It should be remembered from the above discussion of soil suitability that the compaction pressure used to compact the block does affect the soil requirements. The shrinkage test was empirically calibrated for the Cinva Ram (2MPa) and is not directly applicable to a machine operating at a different compacting pressure. In general if the

for small-scale production if soil modification is not considered cost-effective but it must be used in conjunction with tests on trial blocks.

If the results from these tests are to be useful, a great deal of time and care must be taken. This point is seldom mentioned. These tests appear simple to carry out and they produce numerical values which are relatively easy to interpret, but they are not fool-proof and will produce misleading results if not carefully performed. The sedimentation tests in particular are very delicate, requiring time and practice to perfect. In general soil tests are subject to two accuracy limitations, experimental care and measurement resolution. The following four sections deal with each of the four main test types, giving a simple theoretical background and examining certain misleading and inaccurate aspects contained in earlier reported test methods.

4.3.2 SIEVING TESTS

The sieving tests may be conducted wet or dry, on a complete natural soil sample or on the residue from a syphon sedimentation test. In order to appreciate which of these is the more suitable for any given circumstance a brief consideration of the underlying theory should be given. A sieve test separates the soil fractions by allowing particles with a diameter slightly smaller than the diameter of the sieve holes to pass and retains those which are slightly larger. For an accurate determination of the size fractions present the soil particles must be separate i.e. the soil should be in distinct particles not agglomerations of particles. The ease with which any given soil may be broken up into separate particles determines which method of sieving is appropriate. It should be noted here that dry sieving is only recommended by the British Standards Institute (BS 1377) for clean sands and gravels (i.e. without any significant quantity of cohesive material).

A sieve test conducted on oven-dry soil particles (Dried to constant weight at 105-110°C) should be preceded by a breaking-down operation where the particle agglomerations are broken into separate particles. For low cohesion soils, those with only a small clay content, this is quite readily done with a pestle and mortar; however for soils with a high clay content this may be very difficult. If the soil is not adequately broken down then an overestimate of the larger sizes and an underestimate of the combined silt and clay fraction is likely. This is particularly so for lateritic soils which become very hard on drying. In this case a significant quantity of clay-sized particles may remain trapped with the larger sand sized particles. If on examination it appears that the soil has not been completely broken down then

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machine compacts to a higher pressure then the cement content may be reduced for a given soil shrinkage, or alternatively the range of acceptable soil shrinkage values may be increased.

the soil is unsuitable for dry sieving and should be wet sieved or sedimented and subsequently dry sieved (see below).

For wet sieving a measured weight of oven dry soil is soaked in a large quantity of water or preferably water and a suitable dispersing agent. By soaking the soil any particle agglomerations soften and subsequently break up if the resulting suspension is adequately stirred. In order to successfully sieve this soil suspension a large quantity of excess water is required both to wash the particles through the sieves and to separate those particles which loosely adhere to each other as a result of the water's surface tension. Moreover a number of particles slightly smaller than a given sieve's diameter may be retained by water tension across the sieve holes. As a result an improvement in accuracy will be found if the retained samples are dried and resieved.

If the soil is first subject to a syphon sedimentation test, which removes the clay fraction, then a dry sieve test may be conducted on the settled soil residue. This soil residue will be cohesionless, if sedimentation separation has been successful, and therefore very easily broken down into separate particles.

ILO (Ref 4, ILO 1987) reports the dry sieve test as a "further soil testing procedure" without any mention of the necessity to break down the lumps of soil which are usually formed on drying and the consequent inaccuracy. The ILO also includes a section on laboratory testing methods which are "briefly discussed". A wet sieve test is mentioned[4] but without discussing when or why it should be used in preference to the dry sieve test, indeed the only sieving test method contained in the publication is the under-explained dry sieve method.

Norton (Ref 3, Norton 1986) does not report a dry sieve test on soil in a natural condition but rather only a dry sieve test on the residue from a syphon-sedimentation test. This is acceptable providing that the sedimentation test is correctly carried out. However the syphon-sedimentation test as reported by Norton may lead to flocculation (see Sedimentation Tests below) and consequently lead to subsequent further inaccuracy in the dry sieving.

A wet sieve test has also been reported by Norton. He states that "it should be used for analysing lateritic soils in order to ensure that clay particles trapped in fissures on larger particles are washed out." However he does not advocate soaking of the soil to facilitate this but rather to "mix the soil sample with water, and wash it through the sieves. " If the soil sample is not soaked before mixing then significant quantities of clay will remain adhered to the larger particles. The wet sieve test

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[4]. A reference is given to a Road Research Laboratory paper, West,G & Dumbleton, M. J. "Wet sieving for the particle size distribution of soils" (Crowthorne, United Kingdom, Road Research Laboratory, 1972).

relies on water to disperse the soil grains, if sufficient soaking time is not allowed for this dispersion to take place then the test will be subject to the same inaccuracies mentioned above for the dry sieve test.

Norton does not mention that the initial soil sample to be tested should be carefully weighed out nor does he state whether the sample should be oven dried, air dried or damp. Rather he suggests that all of the material remaining on the sieves should be dried out and weighed and that the material carried by the wash water should be collected, dried out and separated with the syphon sedimentation test. In order to sieve such a wet sample a considerable quantity of water is required to wash the particles through, frequently tens of litres (several gallons). To collect and dry such a large quantity of water is both time consuming and impractical without very large collection vessels. If this method is employed for soils containing significant quantities of combined silt and clay then concentration problems will be encountered with the syphon sedimentation test. For example if 1kg of a fine soil containing 40% combined silt and clay fraction is wet sieved either 400g of material will have to be sedimented (four times the recommended concentration) or the dried material will have to be re-wetted, thoroughly mixed (to evenly re-distribute the silt and clay fractions) and subdivided before re-drying to ascertain the new dry weight of the smaller samples.

The wet sieving test, as reported by Norton, will not give reliable results unless the soil is left to soak adequately and will be very time consuming if the wash water is collected and dried. A more sensible method would be to accurately weigh an oven-dried soil sample, soak this in water or preferably water and a dispersing agent and allow the wash water to go uncollected. The weight of the separate dry retained materials may then be related to the original dry sample weight to give the percentage of each size fraction and the combined silt and clay fraction may be assumed to be the difference between the original total dry sample weight and the sum of the dry fraction weights. The clay content may be determined by a separate syphon sedimentation test and the silt fraction assumed to be the difference between the original sample weight and the combined sand, gravel and clay fractions.

4.3.3 SEDIMENTATION TESTS

The sedimentation tests are based upon Stoke's law of sedimentation which predicts the velocity in free fall of any diameter spherical particle of known specific gravity in a fluid of known viscosity at low concentration. For sedimentation testing it is assumed that the specific gravity is the same for each soil particle, each particle is approximately spherical and each soil grain exists as a separate particle. Hence the rate of fall is dependant only on the diameter of the particle. Larger diameter particles will fall more quickly than smaller diameter ones and hence the settled material will be graded with large particles at the bottom and fine particles at the top. One problem which may be thought of with this method of separation concerns the distances that particles have to fall. A small particle initially close to the bottom of the vessel falling slowly may settle in the same time as a large particle initially at the top of the vessel, leading to contamination. This does occur, but as the velocity of fall is proportional to the square of the particle diameter larger particles fall significantly faster than small ones and the contamination is only minor.

At high concentrations the particles interfere with each other, leading to "wipe-down" whereby small particles are carried down by larger ones. Similarly if the soil sample is not sufficiently dispersed agglomerations of particles will fall more quickly than would be the case for separate particles. Particle agglomeration may occur as a result of two separate factors; firstly, as the result of insufficient soaking whereby particles, primarily clay and silt, remain bound together or bound to larger sand particles and secondly when the silt and clay particles, initially dispersed, reassociate as a result of electrostatic interaction to form flocs (flocculation). In either case settlement will be affected and the measured fractions incorrect.

The glass-jar sedimentation test uses the differential settlement phenomena to give an idea of the relative proportions of different sized particles. A suspension of soil is allowed to settle undisturbed in a parallel sided vessel. As a result of the differential settling and a usually slightly discontinuous range of particle sizes, the material forms settled layers of gravel, sand, silt and clay. The height of each different soil layer formed is measured relative to the total settled height and taken to be the relative proportions of each discernable size fraction. The formation of layers is readily visible in light coloured soils which do not contain a perfectly continuous range of particle sizes but for other soils the layers may be less visible. For most soils it is possible to determine the boundary between the sand and silt layers as sand grains may be individually discriminated while silt grains appear as a homogenous mass. However it is frequently difficult to see the boundary between silt and clay as both material's grains are too small to be discerned. More complex timed methods have been put forward to attempt to overcome this discrimination problem but there are problems with these too (see below).

The syphon sedimentation test also uses the differential settlement phenomena. Rather than attempting to use the settled layers as indicators of the sample's different size fractions it attempts to separate the clay fraction by allowing heavier soil fractions to settle out of a suspension so that the remaining fluid, containing the clay particles, can be dried separately. If the initial dry soil mass is known then the percentage of clay may be found. This test depends on the clay remaining in suspension longer than any other heavier soil component and as such relies on the initial suspension being dilute and effectively dispersed. If "wipe-down" or agglomeration occur then the material syphoned off in suspension will be less than the true clay fraction. Moreover if flocculation occurs it is frequently not possible to discern the level of the settled material and hence the correct level for the separation disk. The flocs, containing both silt and clay particles, interfere with each other and slowly settle en masse in a loosely packed arrangement rather than as discrete particles. In this condition silt does not settle significantly faster than clay and hence cannot be distinguished. The formation of a flocculated suspension is usually readily apparent as a pronounced clear layer of water will form quite rapidly above the remaining suspended material during settlement. If the syphon sedimentation test is to be used the soil suspension must be both fully dispersed and deflocculated, a point frequently neglected by the literature.

The "sedimentation bottle test" (glass-jar sedimentation test) of ILO (Ref 4, ILO 1987), reports that "the bottle is first filled to one third with clean, uncontaminated water. Approximately the same volume of dry soil (which has passed through the 6 mm sieve) and a teaspoon full of common salt are added. Salt facilitates the dispersion of soil particles." Using equal volumes of dry soil and water will give a highly concentrated suspension of soil and lead to significant wipe-down of the fine fraction (see above). The diagram included with this description actually worsens this situation with mistaken captions. Diagram 1 shows "1. Bottle one third filled with water." diagram 2 then shows a full bottle with a one third volume of water resting on a two thirds volume of soil stating "2. Add one teaspoon full of salt and fill bottle with soil." Filling a bottle containing one third of water with dry soil will produce an intensely concentrated suspension.

Having shaken the soil bottle it is stated that "Two or three minutes later the water will start clearing....Two or three distinct layers will be observed, with the lowest layer containing fine gravel, the central layer containing the sand fraction and the top layer containing the combined silt and clay fraction....The individual percentages can be determined by direct measurement of the depth of each layer." This is most misleading. The above implies direct measurement of the layer height after only two to three minutes. Only the sand sized fraction would have settled in this short time, silt and clay particles fall much more slowly (clay falling at approximately twelve millimetres per hour) and would still be in suspension. Moreover unless the soil were to be predominantly clean gravel and sand, a high concentration of fines would be present which would not enable "distinct layers" to be seen rather the entire depth would appear muddy. This sedimentation bottle test has failed to produce any distinct layers when performed by the author on a known well-graded soil containing seventy six percent sand, fifteen percent clay and nine percent silt. The solution was too concentrated, the whole appearing as thick flocculated liquid. The relative volume of soil to water should be reduced to at least one quarter to three quarters.

Furthermore, Grimshaw (Ref 9, Grimshaw 1971) has reported that salt is a clay flocculant causing these particles to agglomerate into larger flocs, not to disperse as mentioned above. The addition of salt has been put forward, by Webb (Ref 5, Webb 1988) reporting that "salt will speed up the final settlement of particles". This is correct as the flocs formed are larger and heavier than individual clay particles and hence fall more quickly. However Webb puts forward this glass-jar type sedimentation test with salt to quickly and roughly determine the relative sand and fines content. It must be remembered that the fines are not separated into silt and clay fractions and may not be distinguished when flocculation occurs (see above). More suitable dispersants which do not cause flocculation are listed in appendix A page 39.

Norton (Ref 3, Norton 1986) suggests a "Simple particle separation by sedimentation" test which uses a timed observation system rather than visually discriminating settled layers. This test advises that a jar should be one third filled with slightly compacted dry soil and this height (h), measured from the base of the jar, be recorded. Water and a pinch of salt is then added to fill the jar to three quarters full. The jar is shaken, soaked for one hour and re-shaken. After the final shaking the jar is left to stand and a stopwatch is started. "When one minute is up, mark on the side of the jar....This amount (T1) is fine gravel and sand....After 30 minutes mark again....(T2) is fine gravel, sand and silt together. After 24 hours mark again....(T3) includes fine gravel, sand, silt and clay. The depth of clay = T3-T2. The depth of silt = T2-T1. Divide each depth by the total (h)...." and so gain the percentage proportion of each particle size. As has been mentioned earlier, a dry soil will expand on wetting. If the settled heights are related to the initial compacted height of the soil as described, then in general the sum of the soil fractions will exceed one hundred per cent. A more satisfactory solution is to relate the measured heights to the total settled soil height of the soil after twenty four hours. Again it is recommended that "a pinch of salt" should be added. This is not correct, in this test Norton is proposing to separate the silt and clay fraction and has apparently ignored the flocculating effect of salt. If flocculation occurs the level of the fully settled material will be obscured by the semi-settled flocculated layer. If the top of the flocculated layer is taken to be the settled height nonsensical results will follow as the settled height apparently reduces as the floc settles. Again flocculation will be apparent as a marked clear layer quickly appearing above the remaining suspended material. If flocculation occurs the suspension must be deflocculated.

Soil flocculation may occur without the addition of salt (chlorinated water among other things may have this effect), if it does then the suspension must be treated with one of the compounds listed in appendix A, page 39, to deflocculate and redisperse it.

4.3.4 ATTERBURG TESTS

The Atterburg or plasticity tests define the moisture content at which the soil passes from a liquid state to plastic state and from a plastic state to a solid state; these boundary points are the liquid and plastic limits respectively. The transition from liquid to plastic to solid is a gradual process, viscosity and shear resistance increase as the water content decreases. The precise boundaries between the states are defined by the tests themselves and not as a result of theoretical analysis or an intrinsic soil property, e.g. the plastic limit of a soil is the moisture content at which a thread of soil with particles greater than 0.425mm removed will break when rolled down to 3mm. Because of this reliance on the testing method different test procedures and even different test operators will give varying results. It is therefore most important that care is taken to follow the method given and to have the tests conducted by the same operator. The most important piece of equipment for the plasticity tests given in appendix B is the hand of the operator.

The plastic limit test described in appendix B is that used by the British Standards Institute (BS1377). The liquid limit test reported is a simplified version of the Casagrande liquid limit test. The full Casagrande test requires the use of a piece of specialised equipment which mechanically taps the curved dish by vertically dropping it a set distance at a set rate. In the simplified version of the test the curved dish is tapped horizontally by the operators hand. The simplified test given was first reported in "Handbook for Building Homes of Earth" (Ref No.1) and subsequently repeated unaltered by Norton (Ref 3,Norton 1986) and Stulz (Ref 2, Stulz 1983). It should be remembered when using this variant of the test that it is likely to give more variable results than the original. The force which is used to manually tap the curved dish depends on the operator, so it is desirable that the same operator conducts each test if comparisons are to be valid.

Other authors either describe very similar tests to those given in the appendix or refer the reader to the British Standard tests (BS1377). Concerning those tests which they describe two points need to be mentioned. Firstly sample preparation may be incompletely specified, it is not always clear that the soil sample to be tested must have all particles larger than 0.425 mm removed prior to testing for both the liquid and plastic limit tests. Secondly, the soil mixing operations should be very thorough. The soil should be mixed for at least ten minutes (up to 30 or 40 minutes for heavy clays). Mixing should continue for several minutes even after the disappearance of any wet or dry spots. For the liquid limit test it is not sufficient to add and mix soil or water to the sample while it is still in the curved dish. The sample should first be removed from the dish to allow mixing in a larger, more suitable container.

Stulz (Ref 2, Stulz 1983) suggests that "If you already know that you are going to add a stabiliser to your soil, then add the same proportion of stabiliser to your sample as you intend to use in your house". This is misleading as the term stabiliser is normally used to include cementitious compounds; cement, lime and pozzolanas etc. I believe that by "stabiliser" Stulz is referring to soil modifiers i.e. sand and clay rather than stabilisers. The modified soil should be tested but without the addition of cementitious stabilisers which will dramatically change the plasticity of the soil. In the case of cement the hydration reaction begins immediately the cement contacts water and initially progresses quickly. As a result the plasticity of the soil will change quickly with time and not allow any meaningful results to be obtained.

4.3.5 SHRINKAGE TEST

There is a large number of shrinkage-type tests which have been reported. The test which will be discussed here is a linear shrinkage test conducted on natural soil which has had particles larger than 6mm removed. This test has been included as a laboratory test because it requires a large mould and up to seven days of drying. The shrinkage test gives an idea of the gross behaviour of the soil on drying. The change in length of the soil sample may be considered to represent the expansion force which the soil stabiliser will have to resist when the final block becomes wet. In general the smaller the soil's contraction on drying the smaller the quantity of stabiliser required.

This test has been reported with two different but broadly similar experimental techniques. The method included here requires the soil mix to be at or near its liquid limit, while the other method frequently reported requires the soil to be at its optimum moisture content for maximum density moulding. The near-liquid-limit method has been chosen as this mixture of soil will contain more water and hence give slightly higher shrinkage values. The greater variation in liquid limit moisture content (between soils) compared to the more similar optimum moisture content will give a broader range of shrinkage values for different soils and hence will allow better discrimination. Again the recommended cement addition given by this test are only a guide and must be verified with trial block production.

The test has been calibrated by VITA for use with the Cinva Ram compacting machine (details are given with the test in appendix B) but not for other machines. Webb (Ref 5, Webb 1988) has suggested a very similar set of values for the Brepack machine which operates at five times the compaction pressure of the Cinva Ram, however it appears that the two sets of data are not comparable as the set given for the Brepack will produce blocks to a higher strength standard than that for the Cinva Ram. The cement saving appears small unless blocks of the same strength are compared. For instance, Webb cites blocks produced in Kenya from "Murram soil containing about 16 per cent clay stabilised with 4 per cent cement by weight under a compaction pressure of 10 MPa" and states that these "compared favourably with blocks made on a block press machine which used 18 per cent cement as a stabiliser. In this case the compacting pressure was 2 MPa". In this case the 18 per cent cement content used with low-pressure compaction was apparently equivalent to a 4 per cent content at high-pressure compaction. This is an extreme example but does illustrate the trend which is not apparent from the table included with the shrinkage test in Appendix B.

One final point to mention with respect to the cement content table from Webb is that for shrinkages of less than 15mm (in 600 mm) the soil should not be automatically rejected. It is not clear why Webb has chosen to reject this class of shrinkage. If the soil does have some plasticity, sufficient to allow adequate green strength for demoulding, then a low shrinkage soil should produce admirable blocks when compacted to high pressure. Lower shrinkage on drying will reflect the soil's potential to produce blocks which will be less prone to expansion on wetting and hence more durable. It is the requirement for green strength on demoulding which governs the minimum cohesion and hence shrinkage value. It would be expected that a high pressure machine should be able to handle soils with lower shrinkage than would a low pressure machine; from the VITA table the reverse would appear to be the case. A better guide would be that at either pressure soils with shrinkage down to a nominal value of 5mm should be investigated but zero shrinkage materials (0 - 5 mm) should be rejected.

This test is most useful where the scale of production does not justify the use of more elaborate tests or where it has been initially decided that soil modification will not be used. It does not give useful information for predictive soil modification but may be used to check the effectiveness of soil modification by trial.

5. COHERENT SOIL TESTING PLANS

In general the literature concerned with soil testing provides a number of suitable tests but does not provide a logical testing plan for their implementation. The following section discusses the soil-testing needs for differing project sizes and purposes. From this discussion it is hoped that the reader may be able to appreciate the need for different scales of soil testing. The large variation in scale of production, climatic conditions and use to which the final structure is put does not lend itself to specific recommendation, however certain generalisations are possible and would appear helpful as these are usually lacking elsewhere. The section is completed with an example of a coherent testing plan, comprising a testing tree for the field tests and a set of coherent laboratory tests, suitable for a medium scale producer.

In general there are two paths which may be followed by a soil-cement block producer, to use the available soil in its natural state or to use a modified soil (one produced by the combination of two less suitable soils). The decision whether to modify the natural soil is a complicated one. If the available soils are quite unsuitable for block production then either the soil must be modified or an alternative site must be found. Often however, although the available soil is acceptable for production in its natural condition, if it is modified blocks may be produced which are either of better quality or cheaper. The former is achieved by maintaining the cement content while improving the soil hence increasing block strength, the latter by maintaining the strength while reducing the cement content. The difference in cost or block properties resulting from modification depends on the degree of improvement which would be possible. The further away from the "ideal" soil the natural soil lies then the greater the improvement possible and hence the greater the justification for modification.

In small-scale block production, for example for a single building (self-built unit), the savings made through soil modification of an acceptable soil[5] are likely to be small. In this case the additional cost in terms of time and equipment required to perform all of the laboratory soil tests may not be justified. If the soil appears suitable from the field tests and the simple shrinkage box test, it would generally be more appropriate to use the natural soil, increasing the cement content if greater wet strength is required. If none of the available soils are suitable then modification will be necessary. In this case modification may be done by trial and error, checking the results with the simple shrinkage box test. This will then not require the grading or plasticity to be known but will take a significant time to perform adequately (the shrinkage test may take up to 12 days to complete). If the equipment is available it will always be beneficial to conduct the laboratory tests but adequate blocks may be produced without. The most fundamental piece of equipment required for laboratory testing is an accurate weighing balance, ideally capable of weighing to one thousandth of the sample weight.

In medium-scale block production, for example local village/community building programmes, the economies resulting from modification may be more significant and hence justify the increased testing costs resulting from a more complete laboratory testing program. Such a programme would include the determination of the soil's grading and plasticity characteristics. A more complete testing program enables faster more reliable modification processes to be used. The soil may be predictively modified to meet the criteria mentioned earlier in section 3.5, rather than imprecise modification by trial and error. The choice between modifying or not modifying should be based on the relative cost of the cement to that of the labour or machinery required to perform the additional soil blending

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[5]. "acceptable soil" here means one which may be stabilised without modification even if quality improvement is possible through modification as opposed to an unacceptable soil which will not allow adequate stabilisation unless it is modified.

operation. If the relative cost of cement is high and significant cement saving is possible through modification, then in general it will be economically beneficial to modify such a soil to minimise its cement content. However if labour costs are high then it may be preferable to accept a high cement content and not modify the soil. Each case should be judged on its own merits.

For large-scale block production, involving considerable capital expenditure, then a full laboratory analysis including soil grading, plasticity and chemical composition may be justified. This type of test programme is not feasible without a well equipped, dedicated soil testing laboratory. (These are usually available through the government department dealing with road building). In this case several soil samples considered suitable from the field test selection process would be sent away to a soil laboratory to be tested, either so that the best can be identified or so that an optimum soil-blending formula can be devised. Even after full laboratory soil testing, trial block production testing must be carried out with the modified soil and local on-site laboratory testing is desirable to monitor the soil used throughout the project.

The above argument assumes that the final properties required of the soil-cement blocks are known. This is frequently not the case and deserves a brief consideration. Numerous standards have been developed for fired clay products and concrete blocks, especially in the developed world. However in general building material standards are much less advanced in under-developed countries and in the case of soil-cement blocks frequently non-existent. One draft specification for stabilised soil building blocks backed by the United Nations Commission for Human Settlements (UNCHS) in Nairobi, Kenya 1990, was based on a report presented by the Building Research Establishment (Ref 14, Webb 1991). This specification requires that water absorbtion after 24 hours of soaking should not exceed 15% of the original mass and that the minimum unconfined wet compressive strength after 24 hours immersion should not be less than 1.5 MPa (N/mm^2). It further suggests that the wet compressive strength should not be greater than 50% of the dry compressive strength. This specification may be used as an initial base standard for simple single storey buildings constructed with soil-cement blocks in arid or semi-arid regions. However it might be as well to remember that, provided enough strength is present to allow the wall to be self-supporting, durability is the factor which governs the building's life. A wet strength of 1.5 Mpa may be sufficient to prevent building collapse but might be inadequate for reasonable durability in less arid regions. The field of building standards relating to stabilised-soil building blocks is one which requires a large amount of further work. The wide variation in climatic conditions throughout the world necessitates regional or national building standards rather than global ones. At present these standards do not exist and a degree of judgement must be used when deciding the final block properties required. It would seem that the above specification can be taken as the minimum acceptable standard but that for areas with high rainfall the wet strength requirement should be increased to 2.8 Mpa or an external render applied to the wall. In such conditions any economic analysis carried out to asses the viability of soil modification should include due consideration of the cost of this external render or lack of it.

It may now be seen that the soil testing programme should be tailored to the scale of the project and the available testing equipment or testing funds. Soil testing is a supplement to reduce the number of trial blocks which need to be produced. A thorough testing plan should identify soils which are likely to be suitable and disqualify the unsuitable ones. All the above scales of production should utilise the basic field tests to reduce the number of soils to be subsequently considered. The simple laboratory tests will then further simplify the selection and modification of the soil. Full-scale laboratory testing will provide more accurate values for the grading and plasticity of the tested soils, although this accuracy improvement should be very minor if the simple laboratory tests are carried out correctly. Full-scale testing will also provide information on the chemical composition of the soil. The chemical composition may reveal the presence of soluble salts, primarily sulphates, which can attack the hardened cement's calcium silicate hydrate matrix and possibly lead to a reduction in strength with time. This reduction in strength with time may take several years to become apparent and therefore cannot be tested practically by trial block production.

The following sections show how the soil tests given in Appendices A and B may be used to provide a coherent soil test plan without undue duplication. Not every test mentioned in the Appendices need be conducted in every case; a number of the tests are alternatives which may be used according to the equipment available or can be used as cross checks if required.

5.1 PRELIMINARY ON-SITE SOIL TESTING PLAN

The initial field tests should be conducted on-site to assess the gross suitability of the available soils, arranging them into one of the categories listed below. Fines in this categorisation refers to the combined silt and clay content it should be noted that a soil containing clay-free fines regardless of the quantity of fines should be reported as very low clay and considered unsuitable.

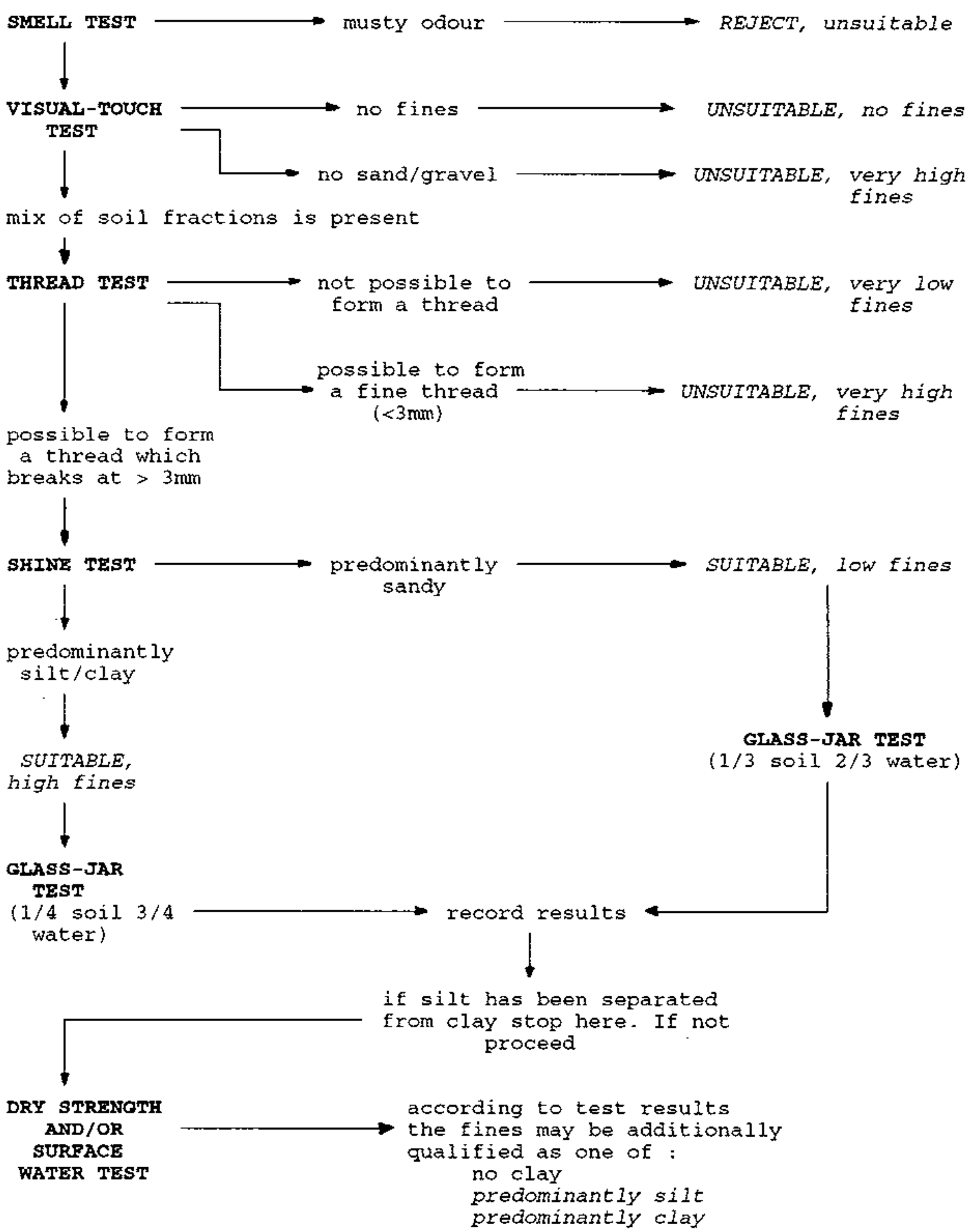
- *Organic...............Unsuitable.* REJECT.
- *Very low clay.........Unsuitable* unless clay added.
- *Very low/zero fines...Unsuitable* unless clay/silt added
- *Low fines.............Suitable,* low cement content likely
- *High fines............Suitable,* high cement content likely
- *Very high fines.......Unsuitable* unless sand added

Smell test. If musty smell is present record as organic and reject soil as unsuitable. If no smell proceed.

Visual-touch test.	To determine relative coarse/fine fraction present. If no fines are present record as unsuitable, no fines. If no sand/gravel present record as *unsuitable, very high fines* (proceed to shine and bite test to determine if fines are predominantly silt or clay for future reference). If a mixture of coarse and fine present proceed.
Thread test	To identify high plastic clay content and non-plastic soils. If a high plastic clay content present record as *unsuitable, very high fines.* If it is not possible to form a thread then non-plastic, record as *unsuitable, very low fines.* If neither proceed. (The ribbon test may be used as an alternative or for verification)
Shine test	To tentatively determine whether a combination soil is high or low fines. Predominantly sandy record as *suitable, low fines.* Predominantly silty or clayey record as *suitable, high fines.* Proceed with sedimentation test (use one third of a jar of soil if predominantly sandy and one quarter to one sixth if predominantly fines).
Sedimentation test	To give a rough analysis of relative sand/silt/clay composition. (Here the fines content may be further described by the recording the separate percentages of silt and clay not previously included in the above categorisation plan.) Less than fifty percent sand/gravel record as *unsuitable, very high fines.* Fifty to seventy percent sand record as *suitable, high fines.* Seventy to eighty percent sand record as *suitable, low fines.* Greater than eighty percent sand record as *unsuitable very low fines* (these are arbitrary boundaries and intended as a guide only). If no clay is present record as *unsuitable, very low clay.*
Dry strength and wet-shaking	These are additional mechanical tests on the fine soil fraction (< 0.425 mm.) and provide information on the clay content of the fines. These tests should be carried out if the glass-jar sedimentation test fails to discriminate silt from clay. If these tests show that no clay is present in the fines then the soil should be reported as *unsuitable, very low clay.*

Soils which are considered suitable from the on-site testing plan may then be more closely examined with the simple shrinkage box test and/or the following simple laboratory tests (dependant on the equipment and funds available). Such further testing will determine which soil is likely to produce the most acceptable blocks, remembering the points mentioned above in the consideration of suitable soils, section 3.4.

5.2 FIELD TESTING TREE TO ILLUSTRATE A COHERENT TEST PLAN



This field testing tree diagram illustrates one sequence in which the field tests may be carried out. This diagram does not include every possible field test but should illustrate that basic soil selection is possible if the tests are used coherently in a logical order.

5.3 LABORATORY TESTING PLANS

Laboratory tests will provide more precise detailed information on the soil's grading and plasticity. This information should be used to select the soil most likely to produce acceptable blocks based on the selection criteria given in sections 3.4 and 3.5. Laboratory test analysis for soils considered suitable on the basis of the above preliminary tests may be conducted using one of the following plans. Which plan is used depends on the resources available, Plan 1 requires accurate weighing equipment as the soil samples used for sedimentation and dry sieving are small. Plan 2 requires a moderately large supply of water for effective wet sieving. Plan 3 relies on representative soil samples being used. Other plans are of course possible.

If no single soil seems suitable or only barely suitable then a combination of two (or if justified more) soils may frequently produce a more successful material. For example a soil without fines may be improved (modified) by adding a suitable quantity of a clayey soil containing a high fines content. The grading information gained from the laboratory tests will enable the relative amounts of each soil type required to be provisionally calculated. Although the modified soil should be re-tested using the laboratory tests the modification process will be greatly simplified.

PLAN 1.

Sedimentation test (syphon)	Used to measure the clay fraction of the soil. The settled material may be subsequently dried and used in the dry sieve test.
Dry sieve test.	The settled material from above may be sieved dry to determine the gravel, sand and silt fractions.
Atterburg tests	Should be conducted using the original soil, suitably sieved, to determine the liquid/plastic limits and plasticity index.

PLAN 2.

Wet sieve test (fines retained)	Used to determine the gravel and sand fraction of the soil and to separate the silt/clay fraction for sedimentation.
Sedimentation test (syphon).	The material passing the 0.063 mm wet sieve may be separated into silt and clay fractions.
Atterburg tests	As above.

PLAN 3.

Wet sieve test (fines discarded)	Used to determine the gravel and sand fractions of the soil.
Sedimentation test (syphon)	A separate portion of the above sample is sedimented to determine the clay fraction. The silt fraction is found by adding the total measured soil percentages and taking this figure away from 100 %
Atterburg tests.	As above.

APPENDIX A : FIELD TESTS

Smell test

USE :	For determining the presence of organic material.
ACCURACY :	Medium to high.
TIME :	Fast.
LIMITATIONS :	This test does not determine the quantity of organic matter present.

EQUIPMENT: Minimal; small cooking stove or fire and a suitable pan.

METHOD: Take a representative sample of moist soil and smell it. If the soil smells musty then a significant quantity of organic matter is present (soil containing organic matter is unsuitable for building and should not be used). If a musty odour is not present, heat the soil in a pan and smell again. If there is now a musty odour then the soil again contains too much organic matter and should be discarded. If the soil does not smell musty at all then the soil is probably inorganic.

NOTE: Usually the top layer of soil will be organic but subsequent lower layers may be inorganic.

Visual-Touch test

USE:	For initial on-site examination of soil to determine the presence of gravel,sand, silt and clay.
ACCURACY:	Dependant on skill of tester.
TIME:	Fast.
LIMITATIONS:	Very difficult to tell silt from clay by a visual examination.

EQUIPMENT: None.

METHOD: Visual..Take a representative dry sample of soil. Breakdown any lumps or clods by rubbing between the fingers and examine to gain an idea of the proportion of different size particles. Particles larger than 2 mm are defined as gravel (BS1377) while those smaller than this but still visible to the naked eye form a continuum of coarse through medium to fine sand. The smallest grains visible to the naked eye are fine sand, approximately 0.06 mm. The conventional size boundaries are listed below. The dust which cannot be distinguished as single grains is a combination of silt and clay, normally called the fines.

Touch..The feel of the soil can also be an indicator of its basic components if rubbed both wet and dry. Sands are coarse particles which have a rough feel when rubbed between the fingers. They lack cohesion when wet, they do not stick together well. Dry silt has a similar but less pronounced feel to dry sand and shows limited signs of cohesion when wet. Dry clay usually forms hard but smooth clods. If these are broken down when dry the resulting powder has a smooth slippery feel. When wet, clay has a greasy or sticky feel and is very cohesive.

NOTE: This test is useful if it is used to gain a first broad idea of the soil constituents however unless the soil is a pure sand, silt or clay or the operator has considerable experience it is very difficult to assess the percentage composition. A no fines soil should be reported as *unsuitable, no fines*. Similarly a soil with little or no sand/gravel should be reported as *unsuitable, very high fines*. Further testing should be carried out if a mixture of sizes is observed.

British Standard and MIT definition of soil particle sizes:

Coarse gravel................ 60 - 20 mm
Medium gravel................ 20 - 6 mm
Fine gravel.................. 6 - 2 mm

Coarse sand.................. 2 - 0.6 mm
Medium sand.................. 0.6 - 0.2 mm
Fine sand.................... 0.2 - 0.06 mm

Silt......................... 0.06 - 0.002 mm
Clay......................... > 0.002 mm

Thread test

USE: To test for the presence of a large quantity of plastic clay or pronounced lack of fines.
ACCURACY: Low.
TIME: Fast.
LIMITATIONS: Only gives a vague estimate as different clay types have different plasticity. Requires prior operator experience for successful interpretation.

EQUIPMENT: A smooth surface, a sheet of glass or similar.

METHOD: A small representative sample of moist, easily mouldable, soil should be formed into a cylinder about the same size as a thumb. This cylinder should then be lightly rolled with uniform pressure on a smooth flat surface by the outstretched fingers of one hand, forming a thread of soil (if it is not possible to form a thread report as *unsuitable, very low fines*). The thread will reduce in size until it breaks, either by snapping into shorter pieces or shearing along the length of the sample. The size at which the thread breaks gives an indication of the clay content. If the sample will easily form a 3 mm or lower diameter thread then there is probably a high plastic clay content. If the thread breaks at a larger diameter than 3 mm then there is either a moderate sand and silt fraction present or the clay is only slightly plastic. If the sample appears to have a high plastic clay content then it should be reported as unsuitable, very high fines.

NOTE: This is a simplified version of the Atterburg plastic limit. For the full test see the laboratory tests section.

Ribbon test

USE:	To test for the presence of a large quantity of plastic clay or pronounced lack of fines.
ACCURACY:	Low.
TIME:	Fast.
LIMITATIONS:	Only gives a vague estimate as different clay types have different plasticity. Requires prior operator experience for successful interpretation.

EQUIPMENT: none

METHOD: Take a representative sample of soil sufficient to form a roll about the diameter of the thumb but three times longer (A comfortable size to fit in the palm of the hand with the fingers rolled in to make a hollow fist). Wet this soil so that the sample is damp but not overly sticky. Hold the sample in the palm of the hand with the fingers rolled over and push the sample out from between the thumb and first finger, flattening it to form a ribbon 4 - 6 mm in thickness. Let the ribbon hang down from the hand, without supporting it, and see how long it gets before it breaks. Compare the length at which it breaks with the lengths given below.

.. 0 cm, no ribbon at all. This indicates that the soil contains very little or no clay and should be reported as *unsuitable, no clay*.

.. 4 - 10 cm, short ribbon. This indicates a soil containing a low to moderate quantity of clay and should be reported as provisionally suitable. The longer the ribbon then the larger the quantity of stabiliser which will be required for adequate stabilisation.

.. 25 cm and longer, long ribbon. This indicates a soil containing a high quantity of clay and should be reported as *unsuitable very high fines*. Such a soil would require an uneconomically high quantity of stabiliser for adequate durability.

NOTE: The lengths given above are not a set of rigid rules but should be treated as a set of guidelines. With experience of testing the local soils these lengths should be revised to improve the selection accuracy.

Shine test

USE:	For determining the major soil components and identifying a silt or clay dominated soil.
ACCURACY:	Low.
TIME:	Very fast.
LIMITATIONS:	This test determines which is the major soil component (sand, silt or clay). It does not determine the quantities present.

EQUIPMENT: Sharp knife (optional).

METHOD: Take a representative sample of soil. Moisten it and form into a ball. Cut the ball with sharp knife or polish a section of it with a fingernail. If the resulting surface is shiny the soil is predominantly clay. If the surface is dull and feels abrasive or harsh then the soil is predominantly sand or silt. Sand and silt may be distinguished by closely examining the surface. If the surface appears grainy then the soil is a sand. If grains cannot be seen the soil is silty.

Bite test

USE:	For differentiating between silt and clay on-site.
ACCURACY:	Dependant on skill of tester.
TIME:	Very fast.
LIMITATIONS:	Only useful for distinguishing on a presence/absence basis.

EQUIPMENT: None.

METHOD: Take a pinch of soil and lightly grind it between the front teeth. Any sand present will feel harsh or gritty and unpleasant. Silt will also feel gritty but much less unpleasant. Clay will feel smooth or flour-like.

Sedimentation test (glass jar)

USE:	A simple test to give a rough numerical value to the percentage fraction of soil components.
ACCURACY:	Medium to low.
TIME:	Slow (up to 24 hours).
LIMITATIONS:	The results from this test give an idea of the soil's component parts to a low accuracy. The low accuracy is due to the difficulty in discriminating the layer boundaries and the slow settling movement of these boundaries over time.

EQUIPMENT: 1 Wide transparent glass jar (> 65 mm diameter), straight sided and flat bottomed with a capacity greater than half a litre.
1 Bung for the glass jar (optional).
1 Stopwatch or clock.
1 Ruler long enough to measure the height of settled material.
A supply of clean drinking water.

METHOD: A representative sample of soil is loosely placed in the glass jar up to one quarter of its depth for sandy soils or one quarter to one sixth of its depth for silty or clayey soils. Clear drinking water is placed into the jar to fill it almost to the top. The bung is then placed in the mouth of the jar and the jar left undisturbed until the soil is completely soaked with water. The jar is then shaken vigorously for one or two minutes and placed on a flat level surface to stand undisturbed for one hour. The jar is then reshaken for a further minute, replaced on the flat surface and the stopwatch started. The jar must now be left UNDISTURBED. After forty five minutes it should be possible to see a layer of sand settled at the bottom of the jar and a further layer of silt settled above. The cloudy suspension above the silt layer is the soil's clay content (If a pronounced clear layer is seen the soil has flocculated and should be treated with one of the chemical agents listed below). The clay settles out much more slowly than the sand or silt, settling at approximately 12 mm per hour. After a further twelve to twenty four hours the clay should also have settled. The different components can now be measured by measuring the height of the three layers. If the silt/clay boundary cannot be seen and the suspension has not flocculated then the experiment may be repeated using the timing system put forward by Norton (1986), the height of settled material is recorded after 1 minute, 30 minutes and 12 to 24 hours (depending on fineness of clay). The total depth of the sediment (not including the water remaining above) is taken as 100% of the soil. The height of each layer is then recorded as a percentage of the total depth. The three values then taken to be the sand, silt and clay content of the soil.

NOTE: This test has been in wide use for a long time but with some significantly different methods of application. The test is based upon Stoke's law of sedimentation which predicts the rate of settling for a spherical particle in free fall. This is only strictly valid for low concentrations of spherical particles. The jar test then has two sources of primary error in that the particle concentration is not low and the particles are not spherical, particularly so when considering the clay fraction, most clay particles being a plate-like shape. Results from this test should always be treated with caution.

This test frequently contains instructions to add a pinch of salt as a deflocculent. This is incorrect: salt should not be added except under special circumstances (for details see above, section 4.3.3 Sedimentation tests). Suitable deflocculents / dispersants are listed overleaf.

Deflocculents after Head (Ref 8, Head 1980):

sodium bicarbonate	starch
sodium carbonate	sodium silicate
sodium hexametaphosphate	tannic acid
sodium tetraphosphate	sodium hydroxide
sodium oxalate	trisodium phosphate | for laterites.
sodium tripolyphosphate	tetrasodium phosphate | for laterites.
sodium polyphosphate	

also: gum arabic (Ref 6, United Nations 1964)

Dry strength test

USE:	Additional test to estimate whether silt or clay predominate in the fines of a combination soil.
ACCURACY:	Low, dependant on operator judgement.
TIME:	Slow if sedimentation is used to prepare the sample, faster if dry sieved.
LIMITATIONS:	Only low accuracy without prior operator experience.

EQUIPMENT:

EITHER	1	Wide transparent glass jar (> 65 mm diameter), straight sided and capacity greater than half a litre.
	1	Syphon tube of suitable length approx 5 mm diameter.
	1	Separation disk with stem. A flat disk just smaller than the diameter of the glass jar attached to a suitable stem so that the disk may be lowered into the jar.
	1	Stopwatch to time thirty seconds.
	1	Wide dish to collect the syphoned liquid. Approx 150 mm diameter.
		A source of clean water (as clear as possible).
OR	1	0.06 mm. sieve and collector

SYPHONING METHOD: Place loose soil into the jar up to one quarter of its depth. Add water to nearly fill the jar, cover the mouth and shake vigorously. Leave to stand for one hour to allow the soil to soak.

Shake the jar vigorously for approx two minutes and stand on a solid flat surface. Time for thirty seconds from placing the jar on the flat surface.

Lower the separation disk quite quickly into the jar so that it covers (without disturbing) the sand settled after thirty seconds. Syphon off the liquid containing the remaining suspended matter into the wide dish. The easiest way of doing this is to tie one end of the syphon tube to the base of the separation disk's stem. This anchors the tube, preventing it from floating.

The particles will slowly settle out of the water in the wide dish leaving clear water. This water should then be decanted off, either by carefully pouring, without disturbing the settled material, or preferably by syphoning. Not all of the water should be removed like this as inevitably some material would be lost. The remaining water should be evaporated off.

DRY SIEVING METHOD: If a 0.06 mm sieve is available the silt and clay portion of the soil may be removed from the soil mass by dry sieving. A representative sample of soil should be dried and completely sieved through the 0.06 mm sieve. The material passing through the sieve should be collected and used for the test below. See section 4.3.2 for a discussion of sieving techniques.

The resulting material should then be well mixed with a little water to evenly distribute the particles and a representative sample should be formed into a 2 cm diameter ball. This ball should be soft but not sticky, (a dough-like consistency).

The ball should then be dried out either by gently heating or by leaving in the sun.

When dry the ball should be crushed between the first finger and thumb. The resistance of the ball to crushing gives an estimate of the type of fine predominating. If the ball falls apart when picked up then the soil either has a very low fines content or no clay and should be reported as *unsuitable, very low fines*. If the ball crushes easily the fines are very fine sand, inorganic silt or a combination of very fine sand, silt and a small quantity of clay. This reaction should be reported as *suitable, low fines*. If it crushes with moderate difficulty the fines are an organic clay, a silty clay or a sandy clay and should be reported as probably *suitable, high fines*. If the ball cannot be crushed or only with considerable difficulty the fines are an inorganic highly plastic clay and should be reported as probably *unsuitable, very high fines*.

Surface water test

USE:	Additional test to estimate whether silt or clay predominate in the fines of a combination soil.
ACCURACY:	Low to medium.
TIME:	Slow if sedimentation is used to prepare the sample, faster if dry sieved.
LIMITATIONS:	Requires careful observation.

EQUIPMENT: As for the dry strength test above.

METHOD: Follow the instructions for the dry strength test (above) to produce a soft 2 cm ball. The ball is then held in the palm of one hand and repeatedly jarred horizontally by striking against the other hand.

As the ball is jarred either a film of water may appear on the surface, characterised by a shiny appearance, or no change will occur. After noting the preceding reaction, squeeze the ball with the fingers of the other hand. Either the water will disappear from the surface, the mass hardening and eventually crumbling or the appearance will not change, the ball being deformed into a soft plastic mass.

Repeat the above shaking and squeezing steps several times to be sure of the reaction.

If water appears and disappears quickly, the ball hardening when squeezed then the fines are a very fine sand or an inorganic silt. Reported as *unsuitable, very low clay*.

If water appears and disappears slowly then the fines are a slightly plastic silt or a silt containing a small amount of clay. Reported as *suitable, low clay*.

If no water appears on shaking and the ball is deformed into a soft plastic mass on squeezing then the fines are predominantly clay. Reported as provisionally *unsuitable, very high clay*.

NOTE. If the sample is a silt containing some clay, water will appear on shaking but may only partially disappear on squeezing, the ball feeling slightly plastic. Reported as *suitable, high clay*.

APPENDIX B : LABORATORY TESTS

Dry Sieve Test

USE:	To separate grades of sand on a size basis and give a value for the total fines content (silt and clay) for low-cohesion soils.
ACCURACY:	High (providing the soil is sufficiently broken down).
TIME:	Medium/slow.
LIMITATIONS:	The results from this test usually give an accurate breakdown of the sand fractions but silt and clay are too fine to be easily separated by sieving. If the soil is not easily broken down into individual particles the wet sieve test should be used.

EQUIPMENT: Nesting sieves

6 mm	Coarse and medium gravel
2 mm	Fine gravel
0.6 mm	Coarse sand
0.2 mm	Medium sand
0.063 mm	Fine sand

Suitable sized collector to catch the combined silt and clay fraction passing the 0.063 mm sieve.
Mass measurement balance.

METHOD: The dry sieve test is very simple to conduct if suitable sized sieves are available or can be made. A large (2 Kg) representative sample of soil is taken and thoroughly dried either in a pan over a stove or by spreading the sample out and leaving it in strong direct sun. From the dry sample two accurately weighed sub samples of about 1 Kg are taken, (500 g is adequate if the soil is fine). The following procedure is then carried out on each and the results averaged. The sieves are stacked in order of decreasing size, the 6 mm sieve at the top of the stack and the collector at the bottom. The weighed soil sample is then broken down into individual particles either by hand or by light grinding in a pestle and mortar. Re-weigh the sample if any material is lost in grinding. Place the weighed sample in to the top sieve. The set of sieves is then shaken until no more material passes from one sieve to the next, this may take some time to complete, (15 minutes or more), as particles slightly larger than the sieve aperture size tend to jam in the holes and blind the sieve. If this occurs gentle brushing of the sieve with a soft brush will unblock these holes, but care must be taken not to force material through the holes as this would give a false value.

Once material transfer has stopped the soil particles lying on top of each sieve are carefully removed and weighed, remembering to brush the material from any blinded holes. The mass of the material on each sieve is converted to a percentage of the total mass hence giving a simple particle size analysis, but without distinguishing silt and clay. Soil loss during the experiment can be checked by comparing the initial mass with the sum of the mass of the separated fractions.

NOTE: This test may be carried out with the sediment from the syphon test (described below), the material in the collector should then be silt as the clay will have been removed but the smaller sample size requires more accurate mass measurement. If accurate mass measurement is available this will give a more reliable result than dry sieving as the clay fraction, which tends to adhere to larger particles when dry, will have been washed off.

Sedimentation test (syphon)

USE:	A more accurate version of the glass jar test enabling direct measurement of the clay fraction weight.
ACCURACY:	Medium to high.
TIME:	Slow.
LIMITATIONS:	The accuracy of the results depend on successfully separating the clay fraction (see comments above on flocculation).

EQUIPMENT:
1 Flat bottomed glass jar, approximately 65 mm internal diameter and 1 litre capacity (a rubber bung to close the end of the cylinder is useful but not essential).
1 Flat circular disk on a stem such that it may be lowered into the cylinder. The disk should be slightly smaller than the internal diameter of the cylinder with the stem 10 cm longer than the height of the cylinder.
1 Flexible rubber syphon tube to remove suspended material from the cylinder.
1 Stopwatch or clock.
1 Weighing balance accurate to at least 0.1 g preferably 0.01g.
1 Heat proof container to receive the syphoned suspension.
A clean supply of water.

METHOD: Weigh out a representative 100 g sample of dry soil and place it in the cylinder. Add clean water to 200 mm, measuring the height from the internal cylinder base. Close the cylinder with the palm of one hand or a suitable sized rubber bung and shake it vigorously end over end to produce a uniform suspension of soil. This may take some time depending on the type of soil. If the soil does not appear to form a uniform suspension then leave it to soak for thirty minutes and reshake. Once a uniform suspension has been formed place the cylinder on a flat steady level surface and begin to time 20 minutes.

At the end of 20 minutes slowly lower the disk to cover the settled material, taking care not to disturb it. If the soil contains a high proportion of fines, it may not be possible to see the upper edge of the settled layer. If this is the case then repeat the experiment using a smaller soil sample. (The top layer of material is silt, if the disk is allowed to rest on the surface then some silt will be forced up around the edge of the disk. Any silt forced back into suspension will give a misleadingly high value for the clay fraction.) The remaining suspended material may now be syphoned off with the rubber syphon tube. The syphoning operation is more simple to perform if the tube is tied to the stem just above the upper face of the disk. This stops the tube from floating or curling.

The material syphoned off is then dried, weighed and recorded as the clay fraction. The purity of the dried clay fraction may be tested with the bite test above if silt contamination is suspected. The settled material should then be combined sand and silt, these should now be separated by sieving. The sieving may be done wet or dry. In this case, the soil having had the cohesive clay component removed, dry sieving is the more appropriate. The settled material should be dried and placed into the top of the set of sieves as described above for the dry sieve test. In this case the material passing the 0.063 mm sieve is the silt fraction.

NOTE: This test is also based on Stoke's law of sedimentation and hence open to the problems mentioned for the glass jar sedimentation test. In particular salt is not a suitable deflocculent, one of the reagents mentioned above (Glass-jar sedimentation test) should be used if required. Flocculation should always be avoided if possible as it results in significant "wipe down" of the clay fraction (see below) and frequently results in a semi-settled layer of combined silt and clay above the settled material, causing difficulty in determining the level for the disk.

The syphon test uses a less concentrated sample of soil than the glass jar test and hence is more accurate but it is still prone to "wipe down" whereby the larger soil particles carry the smaller particles down with them. These effects can be reduced by carrying out a second syphon test on the settled remains of the first test, subsequently combining the two clay fraction values to give a more accurate reading. However this does increase the time required for the test.

Wet sieve test

USE:	To separate sand from the fines, particularly for lateritic soils which are difficult to breakdown when dry and may contain clay trapped in particle fissures.
ACCURACY:	Medium to high.
TIME:	Slow, dependant on the drying time after wet washing.
LIMITATIONS:	Flushing the soil particles down through the set of sieves requires quite large quantities of water which must be subsequently dried off before weighing the sample. Care must be taken when handling this water to prevent loss.

EQUIPMENT:

Nesting sieves	6 mm	Coarse and medium gravel
	2 mm	Fine gravel
	0.6 mm	Coarse sand
	0.2 mm	Medium sand
	0.063 mm	Fine sand

Two or more large sized collectors to catch the wash water carrying the combined silt and clay fraction passing the 0.063 mm sieve.
Mass measurement balance.
A clean supply of drinking water.

METHOD: A representative dry sample of soil is weighed out accurately, about 1 kg for fine soils and 2 kg for coarse soils. This sample is mixed in a suitable clean bowl with an excess of water and left to soak for 1 hour. If available a dispersant should be added to aid the particle separation. Suitable dispersants are listed above under the glass jar sedimentation test. After one hour the soil is remixed and poured into the nesting sieves making sure to rinse any soil residue into the sieves with more water. The soil is then washed through the sieves with more water until no further particle transfer occurs between sieves. This may be checked by judicious inspection. This will require a large quantity of water and hence the collector should be regularly checked and replaced when nearly full.

When washing has been completed the soil fractions on each sieve should be dried, weighed and recorded as a percentage of the initial mass.

The wash water should be left to stand undisturbed until clear. This clear water can then be removed by syphoning or carefully pouring off without allowing any material to be lost. The residue is then either dried, weighed and recorded as a percentage as above or further separated into silt and clay fractions by the Sedimentation test (syphon).

SIMPLIFIED METHOD: If the wash water is allowed to run to waste then the total fines content may be found by subtracting the combined collected masses from the initial mass. The clay fraction may then be found from a separate sedimentation test and the silt fraction would be assumed to be the difference between the combined sand and clay percentage and 100%.

Atterburg Limit tests

USE:	To provide an indication of the properties of the soil fraction finer than 0.425 mm.
ACCURACY:	Medium to high.
TIME:	Medium/slow.
LIMITATIONS:	Considerable difficulty may be experienced finding the plastic limit when the soil contains a low plasticity clay. Tests on the same sample may give different results if performed by different operators.

EQUIPMENT:	1	Curved dish approx 93 mm diameter, 27 mm deep at centre.
	1	Grooving tool to form a 2 mm wide, minimum 8 mm deep groove with sides 60 degrees off horizontal, or a knife to cut the groove.
	2	Water proof, air-tight containers one large enough to hold approx 250 g of soil the other large enough to hold approx 100 g of soil.
	1	0.425 mm. sieve.
	1	Flexible blade to mix the soil.
	1	Smooth surface. eg. plate glass 200 x 200 mm.
	1	3 mm diameter rod (optional).
	1	Mass measurement balance.
		A supply of clean drinking water.

METHOD: Dry a representative sample of soil, grind it in a pestle and mortar to break up any agglomerations of particles and sieve it through the 0.425 mm sieve to give a sample of about 200 g. Place this sample into the larger air-tight container and seal it. The following two tests should be performed on this sieved sample.

Liquid Limit. Mix about 70 g of the soil sample with the drinking water to form a thick homogenous soil paste. The mixing operations should continue for about 10 minutes but if the soil contains a moderate to high quantity of clay then the mixing stages should be very thorough taking up to 30 or 40 minutes each. With the flexible blade, smooth this paste into the curved dish, taking care not to trap any air. The soil should be 8 mm deep at the centre of the dish and full height at the edge. Using the grooving tool (or a sharp knife), divide the paste in two across a diameter leaving a clean groove 2 mm wide with sides 60 degrees from the horizontal.

Solidly hold the dish level in one hand with the groove pointing away from the body. Gently tap the dish horizontally against the heel of the other hand by moving it 30-40 mm (keep the empty hand still). After 10 taps the groove should close so that the two portions of soil come into contact along the bottom of the groove over a continuous distance of 13 mm. If the groove closes before 10 taps then the soil is too wet. It should be removed from the dish and more dry soil mixed with it and the test repeated. If the groove does not close after 10 taps then the soil is too dry. It should be removed, mixed with more water and the test repeated.

When the groove just closes over 13 mm the soil is at its liquid limit, put the sample into a pre-weighed container, seal it and reweigh it. Then dry the sample and weigh it again The plastic limit is now found by calculating the mass of water in the sample as a percentage of the soils dry mass.

Plastic Limit. Take about 10 g of the sieved soil sample and mix it with water to form a thick paste which should be malleable but not sticky. Roll the soil into a ball with the hands until it begins to dry and crack slightly. Divide the ball into four roughly equal parts and follow the following procedure for each part.

Mould the soil into a cylinder about 6 mm diameter. Place it on the flat surface and roll it under the fingertips with an even light pressure to reduce its diameter to 3 mm (check with the 3 mm rod) after between five and ten back-and-forth movements, slightly more for heavy clays. It is important to maintain a uniform rolling pressure throughout (do not reduce the rolling pressure as the thread approaches 3mm). If the sample breaks into pieces by shearing longitudinally or laterally at 3 mm diameter it is at the plastic limit. If it breaks before 3 mm, slightly wet the sample and retest. If it does not break at 3 mm it is too dry. Roll the sample between the palms of the hands and retest. If the soil always breaks before 3 mm then it should be recorded as non plastic[6].

When the soil breaks at 3 mm, quickly gather the pieces together, place then into a pre-weighed air-tight container, seal the container and repeat the test with the next soil sample. When all samples have been tested weigh and record the sealed container's mass then dry the sample and reweigh. Calculate the percentage of water as a fraction of the dry weight. This percentage is the plastic limit.

Plasticity Index. The plasticity index is the numerical difference between the liquid and plastic limit recorded as the nearest whole number.

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[6]. A non plastic soil may still be suitable for soil cement production provided that some clay is present. The plastic limit test is a standard reference and failure to produce a result does not automatically mean that the soil should be rejected. For soil with a low clay content or containing a clay of low plasticity considerable difficulty may be experienced in attaining a plastic limit despite the soil exhibiting some plasticity.

Shrinkage test

USE:	To provide an indication of the cement content required for a given soil compacted with a low pressure moulding machine such as the Cinva Ram.
ACCURACY:	Medium.
TIME:	Slow (at least seven days drying time).
LIMITATIONS:	Requires a large soil sample and mould. It may take seven days for the shrinkage to be complete. This test has been calibrated for use with particular presses and as such is not directly relevant to machines operating at different compaction pressures.

EQUIPMENT:

- rectangular mould box of internal dimensions 40x40x600 mm.
- 6 mm sieve.
- mixing container and mixing implements.
- a supply of clean water (drinking water).
- a ruler or tape measure.
- a lubricant, either silicone grease, mould release oil, used engine oil or grease.

METHOD: The internal length of the mould cavity is accurately measured and recorded. All of the internal mould faces are smeared with the available lubricant to reduce the tendency of the soil to adhere to the mould.

A representative damp soil sample is taken and sieved through the 6mm sieve. This soil is then thoroughly mixed with water until it has a wet pudding or porridge-like consistency (this should occur near the liquid limit, see above). The mould is then filled with this soil mixture, in three roughly equal layers. After the addition of each layer the mould box is tapped to remove any air trapped in the soil. When the final layer has been tapped the excess soil is removed from the top of the mould leaving a smooth flat soil surface. It is important that the soil does not extend beyond the internal edge of the mould wall as this will increase the soil drag as the sample dries.

The mould containing the soil sample is then placed in a shaded area to dry. Once the soil appears to be shrinking away from the box sides it may be moved into direct sunlight to speed the drying process. The mould should be protected from rain throughout the drying time.

When the drying is complete the length of the dry soil sample should be accurately measured and recorded. If the sample has cracked across its width and separated into several pieces these pieces should be pushed together and the combined length recorded. If the soil has hogged up out of the mould forming a crescent-shaped length, the length of both upper and lower faces should be measured and their average recorded as the dry length. Cracking indicates a soil containing a high sand/silt fraction while hogging indicates a high clay content.

The linear shrinkage on drying may then be found by subtracting the dry soil length from the length of the mould box. This shrinkage length may then be referred to the table given below after VITA for the low-pressure (2MPa) Cinva Ram machine and after Webb for the high-pressure (10MPa) Brepack machine (Ref 5, Webb 1988).

Measured Shrinkage (mm. per 600 mm)	Recommended* Cement percentage (for Cinva Ram)	Recommended* Cement percentage (for Brepack)
under 5	too difficult to handle when block making	
5 - 15	5.56	perhaps insufficient clay (see sect'4.3.5)
15 - 30	6.25	5.0
30 - 45	7.14	6.7
45 - 60	8.33	8.3
over 60	not suitable for use unless more sand is added	

* The Cinva Ram blocks are to meet a wet strength criteria of around 1MPa, while the Brepack blocks meet a criteria of around 2.8 MPa. If the same strength criteria were to be used the high-pressure Brepack blocks would probably require about 40% less cement that the low-pressure Cinva blocks.

APPENDIX C: BIBLIOGRAPHY

Publications dealing directly with soil-cement and testing procedures

1. Handbook For Building Homes of Earth, Department of Housing and Urban Development, Office of International Affairs, Washington, D.C. 20410 (undated).

2. Stulz, R. (1983). Appropriate Building Materials, Intermediate Technology Publications Ltd. London, U.K / SKAT. St.Gallen, Switzerland.

3. Norton, J. (1986). Building With Earth: A Handbook, Intermediate Technology Publications Ltd. London, Great Britain.

4. International Labour Office. (1987) Small-scale Manufacture of Stabilised Soil Blocks, Technology Series, Technical Memorandum No.12, ILO Publications. Geneva, Switzerland.

5. Webb, D.J.T. (1988). Stabilised Soil Building Blocks, Ph.D. Thesis, University of Newcastle-upon-Tyne.

6. United Nations. (1964). Soil-Cement its Use in Building, United Nations Publication, Sales No.: 64.IV.6

7. Doat, P. et al. (1979). Construire en Terre, CRATerre, Paris.

Publications dealing with full laboratory soil testing methods:

8. Head, K.H. (1980). Manual of Soil Laboratory Testing, Pentech Press, London.

Publications dealing with the properties of clay:

9. Grimshaw, R.W. (1971). The Chemistry and Physics of Clays, Ernest Benn, London.

10. Worrall, W.E. (1968). Clays: Their Nature, Origin and General Properties, Maclaren, London.

General references:

11. Spence, R.J.S. & Cook,D.J. (1983). Building Materials in Developing Countries, Wiley, Chichester, England.

12. Ingles, O.G. & Metcalf, J.B. (1972). Soil Stabilization Principles and Practice, Butterworths, London.

13. Carter, M. & Bentley, S.P. (1991). Correlations of Soil Properties, Pentech Press, London.

14. Webb, D.J.T. (1991). The work of the Building Research Establishment, on lime stabilised soil blocks for Third World housing, Paper presented at the First International Seminar on Lime and Other Alternative Cements, 9-11 December 1991, Stoneleigh, UK, held by the Intermediate Technology Development Group, Rugby, UK.