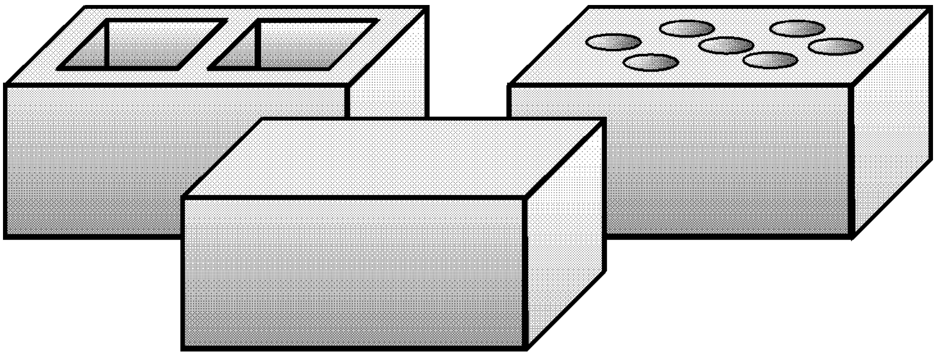
Development Technology Unit
School of Engineering
University of Warwick
Coventry CV4 7AL UK
Tel (Office) +44/0 1203 522339
Director 523122, Fax 418922
Email dtu@eng.warwick.ac.uk

Web site at http://www.eng.warwick.ac.uk/DTU/

Stabilised Soil Research Progress Report SSRPR03



Physical characteristics of soils that encourage SSB breakdown during moisture attack

Author: Mr D E Montgomery
November 1998

E-mail: d.e.montgomery@warwick.ac.uk

These reports cover 'work in progress' by research students in the Development Technology Unit (DTU) of the School of Engineering at Warwick University. Their primary purpose is internal - a format for recording ideas and data in a way that allows them to be better discussed before their incorporation into theses, DTU Working Papers or external publications. However they also have a secondary purpose, that of facilitating the sharing of our research with other innovators in the field of building with stabilised soil. Each report, after some initial internal discussion and refining will be posted as a title and synopsis on the DTU web pages (home page= http://www.eng.warwick.ac.uk/dtu). Full copies can be obtained from the respective named authors.

A dedication to someone special

Sometimes at the beginning of a publication one finds a dedication to a certain person or member of the family who has been an influence in the author's life either in general or specifically in generating the work in question. There is one person in my life that immediately springs to mind who is worthy of such a dedication. Furthermore, my experience with this person is not unique as millions of others have found him to be a great inspiration, comfort, guide and friend. "What's his name?" you may be asking yourself and, "Why haven't I heard of this incredibly influential person". The sad thing is that you probably have, but you have never accepted him as such or welcomed him into your heart and life. Well, now you have an opportunity to do just that. Please read on.

The man's name is Jesus and although he was born nearly 2000 years ago his testimony still remains and his power to save is just as great. "Save from what?" you may ask, sin and the consequences thereof, or more specifically, your sins and the consequences you face when you die. As humans we demand justice to be done, and justice will be done, but on a perfect scale and to a perfect standard. That leaves us all falling short and without hope when we come face to face with a holy God. But, God in his great love towards us send his only begotten Son into the world that the world through him might be saved. Jesus Christ died for you so that you would not have to be punished for what you have done wrong. You can be spared eternal punishment in hell and enjoy love and peace in the presence of God forever. Today the choice is yours. Reject God's free gift of love at your peril, accept it and who knows you too may have the joy of writing a dedication such as this someday. Please ponder the verses below and make your choice carefully, it will be the most important decision you ever make.

"*For by grace are ye saved through faith; and that not of yourselves: it is the gift of God: not of works, lest any man should boast.*" Ephesians 2:8,9.

"*For God so loved the world, that he gave his only begotten Son, that whosoever believeth in him should not perish, but have everlasting life.*" John 3:16.

"*For whosoever shall call upon the name of the Lord shall be saved.*" Romans 10:13

"*He that believeth on him is not condemned: be he that believeth not is condemned already, because he hath not believed in the name of the only begotten Son of God.*" John 3:18.

"*Jesus saith unto him, I am the way, the truth, and the life: no man commeth unto the Father, but by me.*" John 14:6.

Abstract

Soil is the major component of a stabilised soil block and consequently its properties are of great interest to the Stabilised Soil Block (SSB) manufacturer. Some soils are considered to be unsuitable for manufacturing SSB’s and need to be modified or discarded, whilst satisfactory soils have certain physical characteristics that can be generally suggested. The soil properties that have been found to yield satisfactory SSB’s are only a small selection of the wide range of different soil characteristics. The properties of the soil used will partly determine the way it performs under moisture attack. Other factors such as the forming technique and any stabilisation process applied will also affect the performance of the SSB during moisture attack.

The general characteristics of soil are listed in this report and special emphasis is placed on those that are known to cause detrimental effects to the SSB’s during moisture attack. If the poorer characteristics of the soil can be isolated and rectified by some means, then the result will be an enhanced product with better qualities. Those factors that cause expansion on wetting are the ones that prove to be the most negative of the characteristics. Those can be isolated into three parts, the presence of a clay fraction, the presence of porosity and the presence of moisture movement. Only with all three parts present will expansion occur and the removal or minimising of any of them will result in the removal or minimising of potential expansion of the SSB. How this can be done is the matter for another study.

Nomenclature

Aggregate: Pieces of crushed stone, gravel, etc. used in making concrete.
Brick: An object (usually of fired clay) used in construction, usually of retangular shape, whose largest dimension does not exceed 300mm.
Block: A larger type of brick not necessarily made of fired clay, but stabilised in some way, sometimes with central cores removed to reduce the weight.
Cement: Ordinary Portland Cement (OPC).
Clay: The finest of the particles found in soil, usually of less than 0.002mm in size and possesses significant cohesive properties.
Concrete: The finished form of a mixture of cement, sand, aggregate and water.
Dynamic Compaction: A process that densifies soil by applying a series of impact blows to it.
Fines: General category of silts and clays.
Gravel: A mixture of rock particles ranging from 2mm to 60 mm in diameter.
Green: Describing the state of material containing cement and water before it reaches the critical time, after which further plastic deformation hinders the final set strength.
Permeability: Describing a material that permits a liquid or gaseous substance to travel through the material.
Porosity: A measure of the void volume as a percentage of the total material volume.
Sand: A mixture of rock particles ranging from 0.06mm to 2 mm in diameter.
Silt: Moderately fine particles of rock from 0.002mm to 0.06mm in size.
Soil: Material found on the surface of the earth not bigger than 20mm in size, not including rocks and boulders and predominantly non-organic. If soil is to be used for building material it must not contain any organic material and it can be a natural selection of particles or a mixture of different soils to attain a more suitable particle distribution.
Stabilised soil: Soil which has been stabilised (treated to improve structural characteristics) by using one or more of the following stabilisation techniques: mechanical, chemical and physical.

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1. Introduction

Of the 29% of the earth's surface that is not covered with water, the vast majority has a soil layer on top of the underlying rock. It is this soil that supports life, man and his structures and will be the main focus of this report. Soil is a general term for particles formed by the gradual wearing away of parent rock material that is then deposited into layers onto the surface of the earth. The parent material of the rock from which the soil has been formed will largely define the composition of the soil present.

Between the top layer of soil and the rock structure there is usually a series of bands that each contain a soil with slightly different characteristics. The very top layer of soil usually contains organic material from the vegetation that has fallen to the ground and is slowly breaking down. Under this layer, one can find a mixture of organic material and small soil particles or "fines". The particle size grows as one digs deeper until the rock structure is reached. Size distribution in the soil is approximately dependent on depth. Larger particles dominate lower levels whilst finer particles the upper levels.

The basic composition of all of these layers may be the same as the underlying rock. Alternatively, material from elsewhere could have been deposited there by natural means, causing a different composition of the top layers to the bottom ones. Glaciation, floods and volcanic activity are some mechanisms through which soil from another area may be deposited locally. The composition of the small particles (sands) found in soil can generally be assessed as minerals that are silicas, silicates or limestones. As well as the solid rock particles and fragments, soil will have a proportion of water and air that fill the gaps between adjoining particles in the soil. This gives natural soil a non-homogenous and porous characteristic.

Soil that is used for building can undergo detrimental physical changes when it becomes wet. Soil will swell and contract when the water content changes and this usually leads to cracks forming in the structure. These physical changes are dependent on the characteristics of the soil both before and after processing to make the building material. The characteristics of the soil that cause these physical changes are the ones that are going to be investigated in this report. The majority of these physical changes are due to the presence off very small particles called clays. Clays perform a valuable function in the production of building blocks, but they can have a detrimental effect on the stability of the material if they get wet.

Clay is necessary to achieve sufficient green strength in a freshly formed block to enable de-moulding and handling without excessive breakage. The low moisture content and the clay particles act as a bonding agent throughout the mixture of other particles before any chemical stabilisation process has had a chance to occur. In the example of using cement as a stabiliser, a considerable period of time must pass before there is any significant gain in strength offered by the cement. A partnership of the clay and cement must be entertained, but their proportions need to be carefully monitored so that the clay gives sufficient initial strength and yet does not blind the cement particles or provoke excessive material expansion upon wetting.

2. Characteristics of soils

During this chapter the author will outline some properties of soil. These properties will include particle composition, shape, size and surface texture, some of which have standards for defining them. Ranges of values for these properties will be suggested but the basic techniques for discovering the properties of a soil sample will be described in a later chapter. This chapter will provide a summary of the characteristics that are possible to determine from a sample of soil.

2.1 Physical

Some of the physical characteristics that could be used to define soil particles are: colour, size, shape, surface texture, density and specific surface area. The variety of physical characteristics of soil particles that can be found is considered to be virtually infinite. The analysis of some of these characteristics can been done using a simple set of field tests and personal interpretation, or, more complex and accurate tests can be carried out in the laboratory. Systems for identifying some major characteristics have been developed to define different ranges of soil characteristics. The most common of these is the size distribution of the soil particles. Below is a list of physical characteristics than can define a sample of soil. See (Houben & Guillaud, 1989), (p. 30,31) for more details.

Colour: Can range from white through to black with shades of tan, brown, red, grey and even blue and green. This is however an arbitrary and trivial description that is not standardised and based entirely on personal interpretation. Good for quick visual identification and can even suggest chemical composition of the soil, but accurate measurement is not defined.

Shape: Broadly defined as three different categories; angular, sub-angular or rounded. This can be assessed using visual interpretation and/or the feel of the soil. Only used as a general descriptive term, as accurate measurement is not a viable option. The ratio of particle surface area to the surface area of a sphere of the same mass can be an indication of shape and is defined as:

$$\lambda = \frac{Surface\_area\_of\_particle}{Surface\_area\_of\_sphere}$$

Where: Rounded – $1 < \lambda < 1.2$

Semi-Angular – $1.2 < \lambda < 1.5$

Angular – $1.5 < \lambda$

Note: a four faced pyramid has λ value of 1.49.

Apparent bulk density: This is a measurement of the overall density of the soil sample including air and/or moisture present within the sample. The measurement of apparent bulk density is a trivial exercise, as one only needs the volume of a sample and its mass. Apparent density of a block is simply $\rho_{apparent} = \frac{M_{sample}}{V_{sample}}$ (measured in kg/m^3).

Specific bulk density: Can be accurately measured following British Standard BS7755: 1998. This method splits up the soil into two sections and measures the density of the two sections in different ways. For particles smaller than 2 mm in size a small sample is placed in a pyknometer and the displaced water at a known temperature will give the volume occupied by the soil. The sample is also accurately weighed to give the mass of the sample. The specific bulk density is calculated from the mass of the sample and the displaced volume of water in like manner to the apparent bulk density. For particles over 2 mm in size the sample is weighed and is then suspended in water that is resting on a set of scales. The mass of the displaced water gives the volume for a known ambient temperature and the specific bulk density can be calculated from these two values, (also measured in kg/m^3).

Size or texture: One of the most common methods of identifying the size of particles that can be found in a sample of soil is to use the British Standard BS7755: 1998 classification for particle sizes. This separates the soil into different fractions depending on physical dimensions by means of a number of different meshes and sieves. The sample of soil is passed through the largest mesh first and each subsequent mesh until all the soil has been separated off at a level appropriate to its size. For laboratory testing the soil needs to be dry and any particles deflocculated to ensure accurate results. The size ranges as defined by the British Standard along with their common names are listed below.

Trivial name	Size range in mm
Boulders	> 200
Cobbles	60 – 200
Gravel (Coarse)	20 – 60
Gravel (Medium)	6 – 20
Gravel (Fine)	2 – 6
Sand (Coarse)	0.6 – 2
Sand (Medium)	0.2 – 0.6
Sand (Fine)	0.06 – 0.2
Silt (Coarse)	0.02 – 0.06
Silt (Medium)	0.006 – 0.02
Silt (Fine)	0.002 – 0.006
Clay	< 0.002

Moisture content: Soil is very seldom totally dry, and how much moisture is present is important for determining the properties of the soil in general. Measuring this moisture content is done through a process of weighing and drying in an oven. Following British Standard BS1377: 1990 the sample must be weighed at regular intervals until the difference between consecutive weights are less than 0.1% of the whole sample mass. This usually means drying the sample for about 24 hours to ensure that it is virtually dry. The difference in mass from the initial weighing to the last weighing will be the mass of water. The moisture content is calculated as a percentage of the total mass of the sample before drying.

Porosity or voids ratio: A substance is considered porous if it has a matrix of voids throughout it. A very simple and common example of a porous object is a sponge. Soil is another such substance, but the porosity of soil can vary enormously depending on the particle size and distribution within the soil sample. To calculate the porosity of a sample of soil one needs to know both the apparent bulk density and the specific bulk density of the sample. The porosity or voids ratio is unity minus the ratio of the volume of soil alone to the volume of the sample, both of which will have been found when the apparent bulk density and the specific bulk density of the sample were measured. Porosity: $P = 1 - \frac{V_{soil}}{V_{sample}}$ (generally expressed as a percentage).

Permeability: A porous material becomes permeable when these air pockets are arranged in such a way so that a gas or fluid can pass through the substance. The permeability will largely depend on the porosity present in the sample. A sandy soil will be considered highly porous and will have a low resistance to the passage of water through it. A clayey soil is the opposite and will resist the penetration and passage of water. Permeability is a measure of how fast a fluid moves through a substance. The British Standard BS 8004:1986, (Craig, 1997), (p. 40) gives a list of coefficients of permeability and also tests for permeability that can be carried out in the laboratory. A falling head test and a constant head test are two ways that permeability can be measured. The flow of water through a sample is measured and described as a flow rate per unit of time. (Permeability of stabilised soil is too low to be measured by these means).

Effective surface area: Particles that are so small that they will pass through even the finest sieve usually have a different means of identification. This is called the effective surface area of the particles in question and is usually measured in m^2/g of material. This helps to distinguish between small and large clay particles for which any other classifications are useless. Three appropriate examples of this analysis are the three main types of clays Kaolinites, Illites and Montmorillonites that have approximate effective surface areas of $30m^2/g$, $80m^2/g$ and up to $800m^2/g$ respectively, (Houben & Guillaud, 1989), (p. 27).

Adhesion: Described as the ability of soil to stick to other objects at a given humidity. It will increase as the humidity increases up to a point after which it will then decrease as the humidity continues to rise. Of interest usually with soil sticking to metallic tools.

Specific heat capacity: Defined as the amount of energy required raising one kilogram of the soil by one degree Kelvin. Units are J/kgK, (joules/kilogram Kelvin).

Dry strength: Highly dependent on the quantity and type of clays present in the soil sample. Measured in MPa to crush (effectively describing the shear strength of the soil sample). The dry strength of clays varies from around 0.07 MPa to 7 MPa, (Craig, 1997), (p. 31).

Linear contraction: Sometimes described as the shrinkage of a particular sample. Linear contraction is highly dependent on the clay type and content and the water content. Standard shrinkage tests start with a soil at it's liquid limit. It is usually tested in a long narrow trough that is filled with moist soil and allowed to dry out. The contraction is limited to one direction and the linear quantity can be measured as either a percentage or as a ratio of overall length. The general rule is, the greater the shrinkage the greater the clay content.

2.2 Chemical

The chemical composition of the soil particles will be of interest when chemical stabilisation is taking place, or if the soil will be in an environment where the elements will be susceptible to chemical attack, (e.g. limestone is attacked by acid rain). Soil is generally a stable compound because it has been formed over a long period of time and any chemical changes will have already occurred to it in the environment. For the majority of cases the scientist can assume that soil will be chemically unaffected by the environment.

Composition: The soil particles will have roughly the same chemical composition as the parent rock from which the soil was formed. This chemical composition can range from salts or chalk composition through to iron and aluminium oxide composition. (Houben & Guillaud, 1989), (p. 36,37) gives more details on the many different types of soil that are present and their respective chemical composition.

Mineral content: Minerals present in the soil are unstable components that are being processed by the environment usually as a result of decaying organic matter. Any organic matter should be avoided and unstable components resulting from them should also be regarded as potentially detrimental to structure longevity.

Metallic oxides: Soil can contain a significant quantity of metallic oxides such that they are used to produce the metal through smelting the soil. Bauxite for aluminium and ferrous oxide for iron are two common oxides present in soils.

pH levels: Soils can be either acidic or basic in pH level, but they do not usually stray very far away from the neutral point. Their pH will depend on the H^+ and OH^- ions that are present and these ions will depend on the chemical composition of the particles themselves and their interaction with one another.

Sulphates: These are soluble compounds of elements and will be affected by changes in moisture. Leeching of soil can occur if water passes through it removing any soluble salts or substances with it. Sulphates can cause problems with cement and soils with sulphates present should be avoided if cement is being used as a stabilising medium.

3. Measuring soil characteristics

In the previous chapter many different physical and chemical characteristics of soil were defined. However, most of the processes for measuring each of those different characteristics were omitted, that will be the focus of this chapter. It is not necessary for all of the above characteristics to be determined for every soil sample taken. The relevant ones will be discussed and listed. Following this some techniques for measuring these properties will be described. Some techniques are restricted to the laboratory, whilst other are considered to be sufficiently accurate for field tests using limited equipment.

3.1 Some relevant properties for making SSB's

With so many different characteristics that one could discover about a sample of soil, it would be foolhardy to try and discover them all in every situation that soil is to be used for making SSB's. Only a small number of different characteristics are of real relevance to the scientist testing the soil. The chemical composition of the soil is of little importance once the absence of unstable compounds and organic matter has been established. The physical properties are of greater interest for making SSB's as these will help to determine its ease of mixing, forming, de-moulding, porosity, permeability, shrinkage, dry strength and apparent bulk density.

The particle size distribution or texture of the soil is a necessary characteristic to determine, as it will help the scientist to measure the sand, fines and clay content. These are necessary to ensure that the material being used falls within the parameters suggested for making SSB's. The moisture content of the soil is another critical characteristic as it affects a number of factors in SSB production. What moisture content the soil has in relation to its optimum moisture content is of great interest to the SSB manufacturer as this will help determine potential shrinkage. For soil mechanics the Optimum Moisture Content (OMC) is defined as the maximum amount of water that can be added to the sample that completely fills all the air voids present throughout the material and no more. The moisture content also has a marked effect on material workability, cement curing, drying times, de-mould slump and porosity.

Consequently the OMC for a soil may not necessarily be the optimum moisture content for stabilised soil material.

3.2 Field tests

Field-testing methods are many and varied, and will depend vastly on the judgement and previous experience of the person carrying them out. There also seems to be conflicting information about what certain tests reveal about the characteristics of the soil. Gooding noted these differences in his thesis and the summary below is largely taken from his suggestions for interpreting the results received from each test. Assuming that the exact characteristics of the soil are not necessary, these field tests will give the user a reasonable idea of the type of soil that is present.

Smell test: Detects the presence of organic material if a musty odour is sensed. Soil with organic material is unsuitable for manufacturing SSB's and should be rejected. The organic layer usually exists on the top of the soil and can easily be removed to reveal more suitable soils underneath.

Visual-touch test: This test will determine the range of particle sizes present. A soil containing mostly large particles (over 2 mm in size) is a sandy and gravely soil, it will easily break up and run through the fingers. Such a soil has a low fines content and is unsuitable for making SSB's. Conversely a soil containing no sand particles and only smaller particles that is hard to the touch, difficult to break up and reveals a fine powder that is difficult to wash off is classified as a soil with an excess of fines and clays. This too is unsuitable for making good SSB's.

Thread test: If a mixture of sands and fines is present then the soil can be formed into a thread upon the addition of some water to increase its plasticity. If the thread can be rolled to a diameter of less than 3 mm then the fines content is too high and more sand will need to be added. If a thread of as little as 5 mm diameter cannot be formed then insufficient fines is present and more will need to be added. A thread that breaks up at a diameter of around 4 mm has a sufficient fines content for making SSB's.

Shine test: After the above tests have been carried out the shine test indicates the level of fines present in the sample. A mixture with a high fines content will achieve a shiny surface if scratched with the fingernail. This shiny surface is caused by a moderately high presence of silt and clay and is be acceptable for making SSB's. A dull surface finish will indicate a sandy composition with a low fine content and this is also suitable for SSB production.

Glass-jar test: This test will give the investigator a rough idea of what percentage of each fraction is present in the soil sample. The test requires a glass straight-sided jar to be a quarter or a third filled with soil and the remainder filled with water. The jar is then sealed and rotated end over end for several minutes to ensure that all the particles have been broken up and held in suspension within the water. The jar is then placed on a flat surface and left undisturbed for some time. A cloudy mist of very fine particles may stay in the solution indefinitely, held there by Brownian motion, but these are only particles less than 0.0002 mm, (Craig, 1997, p. 7) and can be ignored. All the other fractions should have settled to the bottom within a few days and should be easily distinguishable from one another. A sandy layer should be present at the bottom with smaller particles at higher levels. The particles in suspension fall out of solution according to Stokes' law, which states the larger the particle size the faster the decent velocity and vice versa, (Craig, 1997, p. 6). The clay and silt fractions may not be distinguishable from one another and these can often be combined to yield a simple coarse to fines ratio for the soil sample. The quantity of the different fractions can be found by measuring the depth of particles within each fraction and calculating each fraction as a percentage of the whole settled depth.

A basic analysis of the results found from the glass-jar test can be summarised as follows:

- More than 80% sand and gravel (if present) indicates very low fines content and is considered unsuitable for making SSB's.
- Between 70 – 80% sand shows a low fines content and can be used for SSB's.

- Between 50 – 70% sand shows a high fines content and can also be used for SSB’s.
- Less than 50% sand indicates very high fines content and should not be used for manufacturing SSB’s.

Shrinkage test: A mould of dimensions 40 × 40 × 600 mm is filled with soil near its liquid limit, (the point at which the soil passes from a solid state to a liquid state). This soil is then left to dry out slowly. The mould walls are treated with grease or a lubricant so that as the bar of soil shrinks in size it slides along the mould walls. The difference between the initial length and the final length is the linear shrinkage. This is usually represented as a percentage of the original length.

All the above field-tests it can be done on a relatively short period of time with simple equipment. The interpretation of the results is where the inconsistencies can arise, especially between different field scientists. Nevertheless these tests are sufficient as a preliminary check for initial analysis and use for even medium-sized projects. Small projects would be classified as the building of one or two dwellings undertaken by an individual or family. Larger projects would have significant funding and could justify further tests to establish soil characteristics more accurately.

3.3 Laboratory tests

The larger projects that require more careful analysis of the soil properties will find that field tests will be insufficient and laboratory testing will need to compliment these to ensure an accurate analysis of the soil present. Testing is usually only justified if a very large amount of soil will be used and an area of land is being surveyed for excavation. The survey will reveal the different properties of the soil in different locations and will help to direct the SSB manufacturer to the best source of soil for making the SSB’s. Below is a list of characteristics and the methods for accurately measuring those properties.

Particle distribution: Accurate measurement of the particle distribution has already been hinted at in chapter two, where the particle size distribution or texture of the soil was defined as a physical characteristic of soil. British Standard BS7755: 1998 classification for particle sizes describes a process that separates the soil into different fractions depending on physical dimensions by means of a number of different meshes and sieves. The exact method of this should be referenced from the British Standard as such standards are updated regularly, or its local or national equivalent.

Apparent and specific density: If these two values for the soil are known then the porosity can be measured. Measuring the apparent density is straightforward as only the overall volume and dry mass is required of the soil sample. The water must be removed from the sample before weighing as it will add to the overall mass of the soil and give an inaccurate density of the soil and air mixture. Suggested measurements and calculations are as follows:

Volume of undisturbed soil sample (including air voids that may be partially filled with water) = V

Mass of dried soil sample = M

Apparent Density $\rho_{app} = \frac{M}{V}$

The specific density has to be measured in accordance with British Standard BS775:1998 and again this should be referenced to include current changes and modifications.

Porosity/permeability: In simple terms the volume of dispersed air voids within a sample is proportional to the porosity. Porosity can be easily calculated from the specific and apparent bulk densities of the soil sample if they are known. The porosity can be calculated both before and after processing of the soil.

Permeability can be measured as a function of the flow rate of a fluid through a porous substance. Darcy’s empirical law defines the permeability of soil, but this is only limited to one dimensional flow of water through a fully saturated soil, (Craig, 1997), (p. 39).

Darcy's law states: q = Aki

where q = the volume of water flowing per unit of time, A = cross-sectional area of the soil corresponding to the flow q, k is the co-efficient of permeability and i is the hydraulic gradient.

Darcy's law can also be written as:

$$v = \frac{q}{A} = ki$$

where v is the discharge velocity of the water through the soil.

4. Effect of moisture on soils

The fundamental problem with building with soil is that it will lose compressive strength when it becomes wet. This is not a desirable characteristic for walls supporting a roof structure with inhabitants underneath it. Consequently it is the responsibility of the designer to ensure that either the weakening effect that moisture has on the soil is greatly reduced, or the possibility of the soil getting wet is removed. For building with soil where there is little or no rain, then the problem is negligible, but for wetter climates it is a serious concern. Techniques used in the past to overcome the problems of building with soil in wet climates have included mechanical and chemical soil stabilisation, wall painting or rendering and use of wide roof eaves.

4.1 Detrimental characteristics

It is important to isolate the characteristics that are most useful for the SSB manufacturer to know about the soil that is being worked with, so that they can be closely monitored. These are usually the characteristics that greatly affect the resistance of the soil to moisture attack. Below is a list of these poor characteristics and how they might be improved for general use.

High porosity/permeability: These are two characteristics of soil that can cause the potential swelling and cracking that is so detrimental to SSB's durability. No matter how much clay is present, if water cannot penetrate then the clay will not swell and integrity can be preserved. Render or paint will provide such protection, but only at significant cost and regular maintenance is always required. A high porosity will permit moisture to penetrate the surface of the block and then subsequently flow into the internal structure of the soil particles distributing moisture to other soil particles. This process causes water to coat the soil particles and by the process of surface tension drive neighbouring particles further apart. This mechanism is particularly severe with the clay fraction of the soil. Reducing the porosity can be achieved by compacting the soil and therefore increasing its apparent bulk density. Porosity of the soil itself can never be reduced to zero, but a significant improvement to the resistance of moisture penetration can result through compaction.

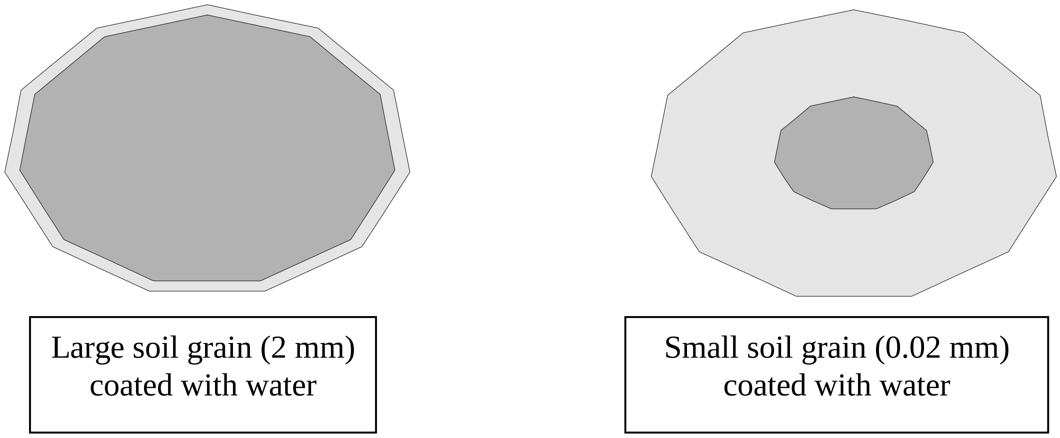
A very high level of porosity in the finished block will mean that the structure will no longer be able to keep out the elements, such as wind, rain and temperature variation. Clearly this is undesirable, as these are some of the most basic functions of a dwelling. As porosity cannot be removed completely from a basic building material such as soil, the level of porosity that is acceptable or even desirable needs to be identified. Taking the other extreme, in a hermetically sealed dwelling, there is no potential for the passage of air or moisture from the inside of the dwelling to the outside world. This is also unacceptable as humidity and oxygen levels from respiration will make the living space uncomfortable. A balance between the two extremes needs to be rationalised.

A major factor that would concern a dwelling designer is the time taken for the building material to respond to changes in climate both inside and outside the dwelling. For example, if outside has a very high humidity and the inside is kept comfortably dry, how long will it take (assuming the conditions are sustained until equilibrium is reached) for the inside of the wall to have the same characteristics as the outside. Perhaps a better analogy is using one of heat. If the outside temperature is 10°C and the inside temperature is 20°C then there is a thermal gradient of 10° between the internal and external faces of the wall. The thermal gradient exists because the wall possesses a thermal resistance and the internal temperature is being sustained by a heat source. If that heat source was removed the temperature of the wall would equalise and the gradient would be reduced to zero. The same principle can be applied to the moisture content of the wall. If the outside is wet due to rain, and the wall is porous then the moisture will migrate to the inside face of the wall saturating the wall. Ensuring that the internal face of a wall can remain dry and the wall itself can survive a 50-year storm would not be an unreasonable request for the average homeowner.

Depth of moisture penetration is another consideration that would concern the SSB builder as a small degree of penetration can be tolerated, but deeper penetration may be unacceptable in the long term. Moisture ingress affects the strength of SSB's but the effect on strength is usually not so significant to cause collapse. A more common mode of failure is spalling of the surface of the blocks as moisture has penetrated, caused expansion and subsequent contraction and cracks have occurred. These cracks permit further moisture penetration and cause more expansion and cracking to occur. These cracks if permitted to continue begin to jeopardise the integrity of the block surface initially and then the structural strength of the block itself. Over time the surface of the block falls away permitting deeper moisture penetration and progressive destruction of the block.

High fines/clay content: The smallest of the particles in the soil are the ones that exhibit the greatest expansion when they become wet. If there is a high percentage of this fraction of soil then the potential expansion will be significant as more particles become coated with water and drive neighbouring particles apart. There are two remedies for the effect of this type of soil, firstly to reduce the fines/clay content by mixing in coarser grains, or to add a stabiliser such as cement in such high quantities that the particles are restrained from moving when water is added. Both will work in practice, but the latter is an expensive exercise and the former should be attempted if possible.

The larger sized fractions of soil are generally unaffected by moisture. They will gain a thin film of water on their surface, but this will be small compared to the grain size. The smaller grain fractions achieve a similar thin film of water on their surface that is of the same order or magnitude or bigger than the grain size. The diagram below illustrates this phenomenon.



The Large soil grains will be coated with a thin layer of water, but this will not increase the size of the particle significantly. If thicker layers of water tried to coat the particle gravity would begin to have an effect and excess water would drip off the bottom of the grain. The surface tension that holds the water onto the grain surface will not be strong enough to create pore pressure that pushes other particles further away from each other. The small grains, on the other hand, will be significantly larger when coated with water and will cause a volumetric expansion of the particles. At this scale the surface tension will be strong enough to move particles further apart and to cause significant overall expansion.

High linear contraction: Again, this linear contraction is due to the presence of clays and fine particles that shrink back together when the moisture around them is removed. The contraction will also depend on the moisture content when the soil is formed and then left to dry/harden/cure. Higher initial moisture contents will result in higher overall shrinkage of the soil. Clearly reducing the initial moisture content will help to reduce initial shrinkage, but ultimately it is the clay content that will determine the amount of expansion and shrinkage. Again the shrinkage can be limited by the addition of cement to the soil. The amount of shrinkage will determine the quantity of cement that will be required to effectively stabilise the soil. As described in (International Labour Office, 1987), (p. 38-39), the cement to soil ratio is as follows for a given shrinkage as determined by the shrinkage test described in chapter 3.2.

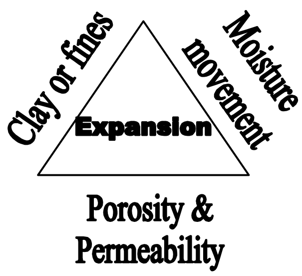
Measured Shrinkage (mm)	Cement to soil ratio
Under 15	1:18 parts (5.56%)
15 – 30	1:16 parts (6.25%)
30 – 45	1:14 parts (7.14%)
45 – 60	1:12 parts (8.33%)

Adhesion: If the soil is moist and has a high adhesion to metallic surfaces, it will cause significant problems when de-moulding. The simplest way of reducing the adhesion exhibited by the soil is to reduce the moisture content when the soil is formed in the mould.

4.2 Significance to making SSB's

The above section detailed the characteristics that the SSB manufacturer would want to avoid. In practise these characteristics are impossible to remove altogether and a compromise needs to be made somewhere along the line. This section aims to explain the effects that the above characteristics have on SSB's produced in the field.

Expansion of a SSB can only occur if three characteristics are present: Clays or fines and Porosity & Permeability and Moisture movement. If any one of those is absent then expansion and contraction will not occur, (ignoring chemical and thermal expansion and contraction). The diagram to the right illustrates the idea.



It is the job of the SSB manufacturer to minimise these characteristics in the blocks that are being produced so that potential expansion is reduced to acceptable levels. External environmental changes will cause the moisture levels to rise and fall over time. This will not have an effect on the SSB unless the moisture levels within the SSB also change. Moisture will only be able to penetrate the SSB if porosity and permeability are present. Swelling and shrinkage will only take place if the moisture reaches a fraction of clay present within the SSB and sufficient cement is not present to resist the potential expansion offered by the clay or fines. Therefore there are three factors that want to be controlled: the clay fraction, the porosity of the material and the rate of moisture movement.

Controlling the clay fraction: Too much clay results in unacceptably high expansion upon wetting or excessive amounts of cement to combat this. Too little clay causes low adhesion between particles and hence causes high breakage rates on de-moulding of the SSB's. Either situation is unacceptable and this can only be achieved by monitoring the clay and moisture content when the soil is to be formed. How closely this has to be done to achieve satisfactory results is not clear. An optimum fines content for making SSB's was suggested by the United Nations to be about 25% of which more than 10% is clay, (Gooding, 1993), (p. 263). From the literature it is unclear how much a change of say ±5% to the clay content will have on the overall performance of the SSB.

Porosity: An ideal for the level of porosity for any type of SSB would have to be zero. Since this is a physical impossibility a small amount of porosity needs to be tolerated. The greater the porosity the more susceptible the SSB will be to the elements and more specifically, the permitting of water penetration. In certain cases it is impossible to avoid water getting onto the face of the block, e.g. blowing rain, but what must be stopped is the water penetrating into the block itself. Water in the block will cause expansion and deterioration of compressive strength unless it is compensated for with a high cement content. If the level of porosity at the surface is much less than deeper into the block then this also is an acceptable situation. If water does not penetrate the surface then it will not matter if the porosity is lower where the water does not reach as this area will be unaffected. Using steel-sided moulds and dynamic compaction give good surface finishes and will result in a slightly lower surface porosity than deeper into the SSB core.

Possible moisture penetration models:

Capillary action without differential pressure - Unknown mechanism but very effective on small pored materials.

Gravitational force pushing water into pores of SSB - Surface water on SSB pushes water into SSB through pores.

Pressure difference flow - Low pressure internally in block with high pressure outside SSB drives moisture from one side to the other.

Moisture levels: More water means more shrinkage upon drying and potentially higher adhesion to metal surfaces, but some moisture is required to keep the soil in a workable state and also to hydrate any cement particles if they are used to help in the stabilisation process. Careful control of the moisture levels is also required to ensure that the soil has adequate adhesion to itself to reduce SSB breakage upon de-moulding. If the moisture level change during the life of the SSB, then moisture movement has occurred. Initially this happens when the block is dried out after it is formed. Subsequent moisture movement should be avoided. Moisture will only be able to enter or level the block if porosity and permeability are present and these can be reduced by adjusting the particle size distribution and the apparent density of the finished block.

5. Conclusions and recommendations

The characteristics that define soil are many and varied. Defining a soil with any degree of accuracy from all the different soils present in the world is a difficult task. With such a variable substance, one can appreciate the difficulties posed to the SSB manufacturer to ensure that the soil that is chosen will be acceptable for the intended task. An even greater problem is determining what effect slight changes to the soil's texture, porosity and moisture content will have on the finished product. This is not helped by the fact that these properties will affect one another as they are sometimes inter-dependant. For example, if the moisture content is high during manufacture then there will be a higher porosity when all the moisture has been removed. If the texture is carefully controlled then this will have an effect on the porosity and apparent density.

Further analysis of how different characteristics affect one another in general should be looked into more closely. A cause and effect chart displaying all the different characteristics and how each is effected by changes in different characteristics would be very helpful. It may be possible to determine that all the different characteristics are linked mathematically and any change in one property will result in changes in a number of others. This model may have to be limited to only a few simple characteristics as the overall variability and complexity of soil may be too difficult to model with any degree of accuracy.

The mechanism through which water penetrated a block is another area where further study should be undertaken. How and why water wishes to permeate a porous substance against the forces of pressure and gravity is a question that needs to be answered. The adhesion of water to surfaces and the internal cohesion that it has with itself are major factors in the situation. How these forces can be hindered so that water is less likely to penetrate a block would be very useful to know if it is possible. Water cannot penetrate certain porous objects because the pores are too small for the water to penetrate into them. At what level this occurs and whether it can be achieved by modifying soil characteristics physically is not known at the moment and should be investigated further.

6. Summary

Some physical characteristics of soil have a major influence in the potential for expansion when it becomes wet. These can be isolated into the clay/fines fraction, the porosity/permeability and the moisture movement. Only with all three factors present will expansion occur. Monitoring the clay fraction and apparent density can be easily done using simple tests, but finding the porosity and hence the potential for moisture movement is a bit more complex. Cement will hinder expansion to a certain degree, but if the root problem can be eliminated rather than trying to constrain the effect of the problem then that would be much more advantageous.

As the SSB's will be in an environment that exhibits changes in moisture and clay is an important component of the block's composition then the only factor that can be reduced is the porosity and permeability of the SSB. The porosity cannot be reduced to zero, but there may be a point at which the SSB becomes impermeable to water. This is the desired condition and this may be achieved by monitoring the particle size and distribution, the moisture content and the apparent density of the final SSB. How exactly this can be done in practice is still open to further discussion. At least now we know the offending characteristics that cause material expansion and consequently we are better equipped to minimise their effects and to deal with their consequences.

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