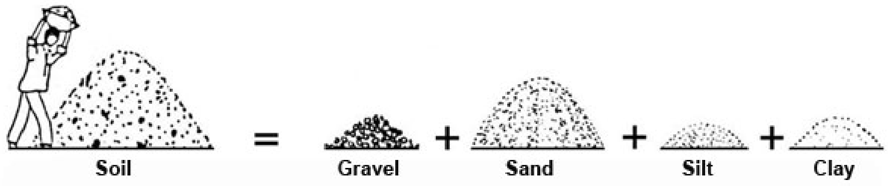
# EARTH AS A RAW MATERIAL

## INTRODUCTION

Soil is the result of the transformation of the underlying rock under the influence of a range of physical, chemical and biological processes related to biological and climatic conditions and to animal and plant life.

**A soil is an earth concrete**




*Composition of a soil*

Like a concrete that contains gravel, sand and cement as a binder, a soil contains gravel, sand, and, silt & clay which act as binders as well. But silt and clay are not stable under water. Hence the purpose of stabilisation is to stabilise silt and clay against water. Nevertheless, earthen buildings proved that they could last very long, especially when people mastered the material and when they maintained properly their buildings over the ages.

### FUNDAMENTAL PROPERTIES

Soils are composed of solid components, water and air. Soils are characterized by 4 fundamental properties:

**Granularity or texture**

It corresponds to the grain size distribution of a soil. It is a percentage by weight of the different grain sizes.
The grain size classification adopted by a large number of laboratories is based on the ASTM-AFNOR standards:

| Pebbles | Gravel | Sand | Silt | Clay |
|---|---|---|---|---|
| 200 to 20 mm | 20 to 2 mm | 2 to 0.06 mm | 0.06 to 0.002 mm | 0.002 to 0 mm |

For building with earth, pebbles should normally be removed.

**Compressibility**

It is the ability of a soil to be compressed to the maximum. It is related to the energy of compaction.
The Optimum Moisture Content (OMC) defines the compressibility.
The OMC is a percentage by weight of water to achieve the highest compression of a soil.

**Plasticity**

This property of a soil refers to its possibility to be submitted to deformation without elastic failure. It defines its ability to be moulded.

**Cohesion**

It defines the capacity of soil grains to remain together. This property is strongly linked with the plasticity.

### STRUCTURE OF A SOIL

It is how the grains are assembled:

- Granular structure = A lot of voids (i.e. gravel)
- Fragmented structure = Discontinuous (i.e. gravel and clay only)
- Continuous structure = The best = proportion of the best soil

## GOOD SOIL FOR COMPRESSED STABILISED EARTH BLOCKS

It depends of the type of stabiliser:

| Cement stabilisation: | Gravel | Sand | Silt | Clay |
|---|---|---|---|---|
| **It is more sandy than clayey.** | 15% | 50% | 15% | 20% |

| Lime stabilisation: | Gravel | Sand | Silt | Clay |
|---|---|---|---|---|
| **It is more clayey than sandy.** | 15% | 30% | 20% | 35% |

## TYPICAL SOILS

According to the percentage of the four solid components (gravel, sand, silt and clay), the soil will be classified as: gravely, sandy, silty or clayey soil.
The name of this classification is given by the component which influences the most the behaviour of the soil. In a sandy soil, for example, the sand proportion influences the most, the soil behaviour. Note that the soil has to be evaluated as whole and not as separate components. Therefore, it is necessary to examine how these various components combine with each other. For example, a soil might have more gravel than normal, but if the clay is very plastic and with the proper proportion, the soil might not be called gravely but probably good soil.

A soil will have sometimes 2 components influencing its behaviour: one very influent and another one to a lesser extent. Therefore, a more accurate classification will be defined as follows:

- Silty sand soil = Soil mainly sandy with an influent proportion of silt.
- Sandy silt soil = Soil mainly silty with an influent proportion of sand.

The quality of the binders, silt and clay, will also influence a lot the soil behaviour and one should understand that the variety of soils is as infinite as human beings. Therefore, it is impossible to give any fixed rule and / or procedure.

## SOIL IDENTIFICATION

Identifying the quality of a soil is essential. Not every soil is suitable for earth construction. But with some knowledge and experience most soils can be used. Topsoil and organic soils must not be used. They should be removed and kept for agriculture.

All over the world many laboratories can analyse soil samples, mostly for road building. Fewer laboratories can do it for buildings. Nevertheless these laboratory tests are often not accessible by the common man.

Since millennia people have known what to do with their local soil. They developed simple field tests to check the properties and behaviour of their soil. Therefore, the Auroville Earth Institute practices only field tests, called sensitive analyses, to identify a soil's quality. These simple sensitive analyses can be performed after a short training. They follow the four fundamental properties of the earth and they can be practiced by anybody, as we use our senses.

### Sensitive analyses

The aim of these sensitive analyses is to identify in which category the soil sample belongs: Gravely, Sandy, Silty, Clayey or combined soil, i.e. sandy clay or clayey sand, etc. Then, according to this classification, one will know what to do with the soil and which earth technique to select. Basic tests to be performed:

| | | |
|---|---|---|
| **Granularity** | Looking and touching | Look at a dry or humid soil and touch it to define the percentage and the size of the grain sizes. |
| **Compressibility** | Pressing | Add a little water, if the soil is dry, to get a moist soil and compress it by hand to make a ball. Evaluate how much pressure you need. |
| **Plasticity** | Shaping the ball | Add more water and make a cohesive ball. Evaluate how easy it is to shape it and how cohesive it is. |
| | Stretching the ball | Pull the ball like rubber elastic and try to break it. Evaluate the strength of the ball. |
| | Sticking a knife | Stick a knife into the cohesive ball and pull it out. Evaluate how the soil sticks on it. |
| | Cutting the ball | The ball is cut in 2 pieces. Examine the aspect of the cut. |
| | Water absorption | Print with the thumb a small depression on the ball. Fill it with water and evaluate the time of absorption. |
| **Cohesion** | Diluting the ball | Add much more water to the ball and try to loosen the cohesion of the soil. Evaluate how much the soil sticks to the hand. |
| | Washing the soil | Add much more water to the soil and wash away silt and clay. Evaluate the amount of fine sand, which remains in the palm. |
| **Humus content** | Smelling the soil | Take some moist soil and smell it. |

The aim of these sensitive analyses is to find out in which categories goes the soil sample: Gravely, Sandy, Silty, Clayey or combined soil i.e. sandy clay. Then, according to this classification, one must look into the recommendations for stabilization and soil improvement.
Note that the soil identification should be practiced twice: first on the raw soil, before doing any modification, and also after correcting the soil (i.e. after sieving).

### Laboratory Tests

They follow also the four fundamental properties of the earth, but they need special equipment. Laboratory analysis cost relatively a lot according to the laboratory. Analysing a soil sample will take a few days as the sedimentation test is done over several days:

| | |
|---|---|
| **Granularity** | Grain size distribution by sieving and sedimentation |
| **Compressibility** | Proctor for getting the optimum moisture content (OMC) |
| **Plasticity** | Atterberg's limits to get these limits:<br>- LL = Liquid Limit (%)<br>- PL = Plastic Limit (%)<br>- PI = Plasticity Index (%)<br>Note: PI = LL - PL |
| **Cohesion** | 8 test (sample prepared with a mortar < 2 mm) |

| **Example of Atterberg's limits** | | |
|---|---|---|
| Sand | 0 % ≤ LL ≤ 10 % | 0 % ≤ PI ≤ 5 % |
| Sandy soil | 20 % ≤ LL ≤ 30 % | 10 % ≤ PI ≤ 20 % |
| Silty soil | 20 % ≤ LL ≤ 40 % | 10 % ≤ PI ≤ 25 % |
| Clay | LL ≥ 50 % | PI ≥ 25 % |
| Clayey soil | 25 % ≤ LL ≤ 50 % | 15 % ≤ PI ≤ 35 % |

## IMPROVING AND STABILISING SOILS

According to the original soil quality, adding materials like gravel or sand can do some easy improvement. Mixing soils can also be a way to get better specifications. According to the technique, the improvement of soils will vary. We can mention here what to do for the improvement of soils for producing CSEB.

### Improvement of soils for CSEB

Often sand has to be added to soil if CSEB's have to be stabilised with cement. Note that it is not advisable to mix clay if the soil is too sandy, as clay is hard to crush when dry and sticky when wet. Improvement can also be done by sieving the soil or by mixing different qualities of soil. Stabilising a soil will also improve it.

**The following recommendations have to be considered as general guidelines and not as rules. The infinite variation of soil qualities makes impossible to define strict rules for soil suitability.**

| **Gravely Soil** | **Sandy Soil** |
|---|---|
| • Sieving (# 8 to 10 mm) is indispensable to remove the coarse gravel.<br>• A maximum of 15% to 20% by weight of gravel passing the screen should be allowed.<br>• The maximum size for the gravel passing through the sieve should be ∅10 mm.<br>• If the soil is too gravely, a more clayey soil should be added, but not pure clay.<br>• Stabilisation can be 3 to 4% by weight of cement could be sufficient, if the clay content is high enough.<br>• Stabilisation can be 6% if the soil is too gravely. | • Sieving (# 10 to 12 mm) is only required to loosen and aerate the soil.<br>• Do not sieve in a very windy area, especially if the soil is dry (not to loose the fine clay).<br>• Stabilisation can be 5% by weight of cement, if the soil is not too sandy.<br>• If the soil is too sandy, 6 % by weight of cement might be preferable, especially for handling fresh blocks.<br>• If the soil is not too sandy and has a good clay quality, 4 % by weight of cement could give good results too. |

| **Silty Soil** | **Clayey Soil** |
|---|---|
| • A slight crushing might be required.<br>• Sieving (# 6 to 10 mm) is required if the lumps are too big and cohesive.<br>• Adding 10% to 20% of coarse sand might be needed to give more skeletons to the soil. Remember that adding sand depends of the silt size: if the grain size of the silt is near very fine sand, no sand should be added.<br>• Stabilisation should be 6% minimum by weight of cement. | • Crushing might often be required.<br>• Sieving with mesh (# 6 to 8 mm) is required, if the soil is dry.<br>• Adding 20 to 40% of coarse sand is needed to reduce the plasticity and give some skeleton.<br>• Stabilization can be:<br>- 5 to 6% min. by weight of cement, if clay is not too plastic. Sand will be added as mentioned above.<br>- 6 to 7% by weight of lime if clay is very plastic. Sand quantity will be reduced or could not be needed.<br>- A combination of cement-lime stabilisation could also give good results: 2% cement + 5% lime. Some sand will be needed (10 to 15 %).<br>• **Note for the stabilisation:**<br>- Cement stabilisation will need 4 weeks curing (even for the combined one with lime).<br>- Lime stabilisation will not need curing (blocks should only be kept 6 days under plastic sheets). |

# SOIL STABILISATION

A modern practice is to stabilise the earth. It aims originally to stabilize silt and clay against water, so as to give lasting properties when the soil gets wet.

## Procedures

There are 3 procedures to stabilise the earth.

| | PRINCIPLE | ACTIONS |
|---|---|---|
| **Mechanical** | The soil is compacted. | - Density and mechanical strength are increased.<br>- The water resistance is increased.<br>- The permeability and porosity are decreased. |
| **Physical** | The texture of the soil is corrected by adding or removing aggregates, which are inert materials. | - The soil is sieved to remove the coarse particles.<br>- Different soils are mixed to get a better texture.<br>- Gravel or sand is added to reinforce the skeleton.<br>- Clay is added to bind better the grains. |
| **Chemical** | Processed products, which are active materials like chemicals, are added to the soil. | - They help binding the grains of the earth. |

## Methods

Six methods are used to stabilise the earth

| | DEFINITION | EXAMPLES |
|---|---|---|
| **Densification** | Create a dense medium, blocking pores & capillary | - Compaction<br>- Adding components<br>- Mixing different soils |
| **Reinforcement** | Create an anisotropic network limiting movement | - Straw<br>- Fur<br>- Synthetic fibres |
| **Cementation** | Create an inert matrix opposing movement | - Cement<br>- Fly ash |
| **Linkage** | Create stable chemical bonds between clay and sand | - Lime |
| **Imperviousness** | Surround every earth grain with a waterproof film | - Bitumen<br>- Resins<br>- Various chemicals |
| **Waterproofing** | Avoid the water absorption and adsorption by the surface | - Paints, plaster * |

## Stabilisers

Many stabilizers can be used. The nature of the stabilised will depend of the soil quality, the need and the type of technique used: Fibres (natural or synthetic), natural products (straw, fur, juice of plants, latex, etc.) can be used for techniques which need a lot of water (adobe, wattle and daub, cob, etc.).

For CSEB and rammed earth, the most common stabilisers are cement and lime. Other stabilisers like chemicals, resins can be used as well. Cement will be preferable for sandy soils and to achieve quickly a higher strength. Lime will be preferred for very clayey soil, but will take a longer time to harden and to give strong blocks. Cement or lime stabilisation of soils will increase a lot the strength, and stabilised earth could be exposed to water or even immersed. The densification of soils by compression (rammed earth, CSEB) or by adding water (shaped, cob, adobe, and wattle & daub) will also give cohesion and more resistance. In this case the earth should not remain in contact with water for long.

## Suitability of stabilisers and their percentage for CSEB

It depends on the soil quality and the particular requirements. The average stabilizer proportion is rather low: 5% for cement and 6% for lime. These low percentages are part of the cost effectiveness of CSEB and stabilised rammed earth.

| | SUITABILITY | MINIMUM % | AVERAGE % | MAXIMUM % |
|---|---|---|---|---|
| **Cement** | Mostly for sandy soil | 3% | 5% | No technical maximum<br>Economic maximum: 7 - 8 % |
| **Lime** | Mostly for clayey soil | 2% | 6% | 10% |

## When to stabilise

The stabilisation of soils is dependent upon the soil quality and the technique to be used. It is not always needed, especially when the material is not exposed to water. The stabilisation is not necessarily required when the architecture is well designed and when maintenance will be done.

## THERMAL CHARACTERISTICS OF STABILISED EARTHEN WALLS

| PROPERTIES | SYMBOL | UNIT | CLASS A | CLASS B |
|---|---|---|---|---|
| Specific heat | C | KJ/Kg | ~ 0.85 | 0.65 - 0.85 |
| Coefficient of conductivity | $\lambda$ | W/m°C | 0.46 – 0.81 | 0.81 – 0.93 |
| Damping coefficient | m | % | 5 - 10 | 10 - 30 |
| Lag time (for 40 cm thick wall) | d | h | 10 - 12 | 5 - 10 |

Note that earthen walls have a different thermal behaviour than any other materials. We speak of hydro-thermal behaviour. Therefore, as clay is just stabilised and not burnt, it can still absorb and release some moisture through evaporation and condensation.

Thus this phenomenon will happen with the difference of moisture/temperature between the outside and inside:

- The outside temperature is higher: the wall will evaporate moisture. This will cool down the wall and thus the building inside.
- The temperature is lower outside: the wall will condense moisture. This will create heat in the wall and thus the building inside.

This phenomenon, which is called "latent heat", happens on a daily basis and also from season to season. Thus this saying from France: *"Earthen buildings (rammed earth) are cool in summer and hot in winter."*

Note that this hydro-thermal behaviour is more effective in temperate climates than in tropical climates. Unfortunately there is no enough data on such behaviour.

**Notes**

- These values are the result conducted in laboratories by recognized authorities. They give an idea of what can be reasonably expected of a product made in accordance with the rules of the art.
- The soil quality, the nature of stabiliser, the percentage of stabiliser and the compression pressure influence a lot these values. Especially, the more the earth is compressed, the less thermal advantage the material has.
- These values can be obtained with 5 to 10 % cement stabilisation and a compression pressure of 2 – 4 MPa.
- Source: "Earth Construction, a comprehensive guide" – CRATerre, Hugo Houben and Hubert Guillaud

## SOIL SUITABILITY ACCORDING TO THE TECHNIQUE

According to the soil quality, the technique will vary. Some techniques may require more gravely soils than others, i.e. rammed earth. On the other side, a clayey soil will be more suited for wattle and daub, etc.

| SOIL TYPE | TECHNIQUE | REMARKS |
|---|---|---|
| Gravely | - Filled in | None |
| | - Rammed earth<br>- CSEB | It can be used for raw rammed earth if the soil is cohesive enough and if it has enough clay.<br>A cement stabilisation (~ 5%) will increase the cohesion when fresh and the resistance when dry. |
| | - Poured | If the clay content is enough. |
| Sandy | - Filled in | None |
| | - Covered | None |
| | - Rammed earth<br>- CSEB | It can be used for raw rammed earth if the soil is cohesive enough and if it has enough clay.<br>A cement stabilisation (~ 5%) will increase the cohesion when fresh and the resistance when dry. |
| | - Poured | If the silt & clay are not too active.<br>A cement stabilisation (~ 5%) will be useful. |
| Silty | - Filled in | None |
| | - Covered | None |
| | - CSEB | It might be improved with coarse sand if the clay content is enough.<br>It requires a cement stabilisation (~ 6 to 8 %). |
| | - Cob | Mixing a soil slightly more clayey might be needed if the soil is not cohesive enough. |
| | - Adobe | Mixing a soil slightly more clayey might be needed if the soil is not cohesive enough. |

| | | |
|---|---|---|
| Clayey | - Filled in | None |
| | - Covered | None |
| | - Rammed earth<br>- CSEB | An improvement with sand and a cement stabilisation (~6%) will be needed. |
| | - Shaped | A stabilisation with sand, natural fibres or cow dung might be needed. Lime can be a suitable stabiliser. |
| | - Cob | A stabilisation with sand or straw might be needed. |
| | - Adobe | A stabilisation with sand or straw might be needed. |
| | - Extruded | An improvement with sand and a stabilisation with lime (~ 8%) might be needed. |
| | - Wattle & daub | A stabilisation with sand or natural fibres is needed. |
| | - Straw clay | None |
| Clayey gravel | - Cut blocks | Example of soil very suitable: laterite. |
| | - Rammed earth<br>- CSEB | Some sand might be needed. It can be used for raw rammed earth. A cement stabilisation (~ 5%) will give good results. |
| Sandy silt | - Filled in | None |
| | - Covered | None |
| | - CSEB | It requires a higher % of cement (~5 to 7%). |
| | - Cob | Mixing a soil slightly more clayey might be needed if the soil is not cohesive enough. |
| | - Adobe | Mixing a soil slightly more clayey might be needed if the soil is not cohesive enough. |
| Clayey silt | - Dug out | If the soil is cohesive enough. |
| | - Filled in | None |
| | - Covered | None |
| | - Cob | A stabilisation with sand or straw might be needed. |
| | - Adobe | A stabilisation with sand or straw might be needed. |
| | - Straw clay | If the soil is plastic and sticky enough. |
| Gravely clay | - Filled in | None |
| | - Covered | None |
| | - Rammed earth<br>- CSEB | Some fine sand might be needed. A lime stabilisation will be useful (~ 6 %). |
| | - Adobe | A stabilisation with natural fibres or sand might be needed if the clay content is too high. |
| Sandy clay | - Filled in | None |
| | - Covered | None |
| | - CSEB | Some coarse sand might be needed. A lime stabilisation will be useful (~ 6 %). |
| | - Cob | A stabilisation with sand, natural fibres or cow dung might be needed. Lime can be suitable. |
| | - Adobe | A stabilisation with natural fibres might be needed. |
| | - Extruded | A lime stabilisation will be useful (~ 8 %). |
| | - Wattle & daub | A stabilisation with natural fibres will be needed. |
| Silty clay | - Filled in | None |
| | - Covered | None |
| | - Cob | A stabilisation with sand or straw might be needed. |
| | - Adobe | A stabilisation with sand or straw might be needed. |
| | - Extruded | An improvement with sand and a stabilisation with lime (~ 8%) might be needed. |
| | - Wattle & daub | A stabilisation with sand or natural fibres is needed. |
| | - Straw clay | None |
| Sandy gravel<br>Silty gravel<br>Gravely sand<br>Silty sand<br>Gravely silt | - No technique | Not suitable for earth construction |