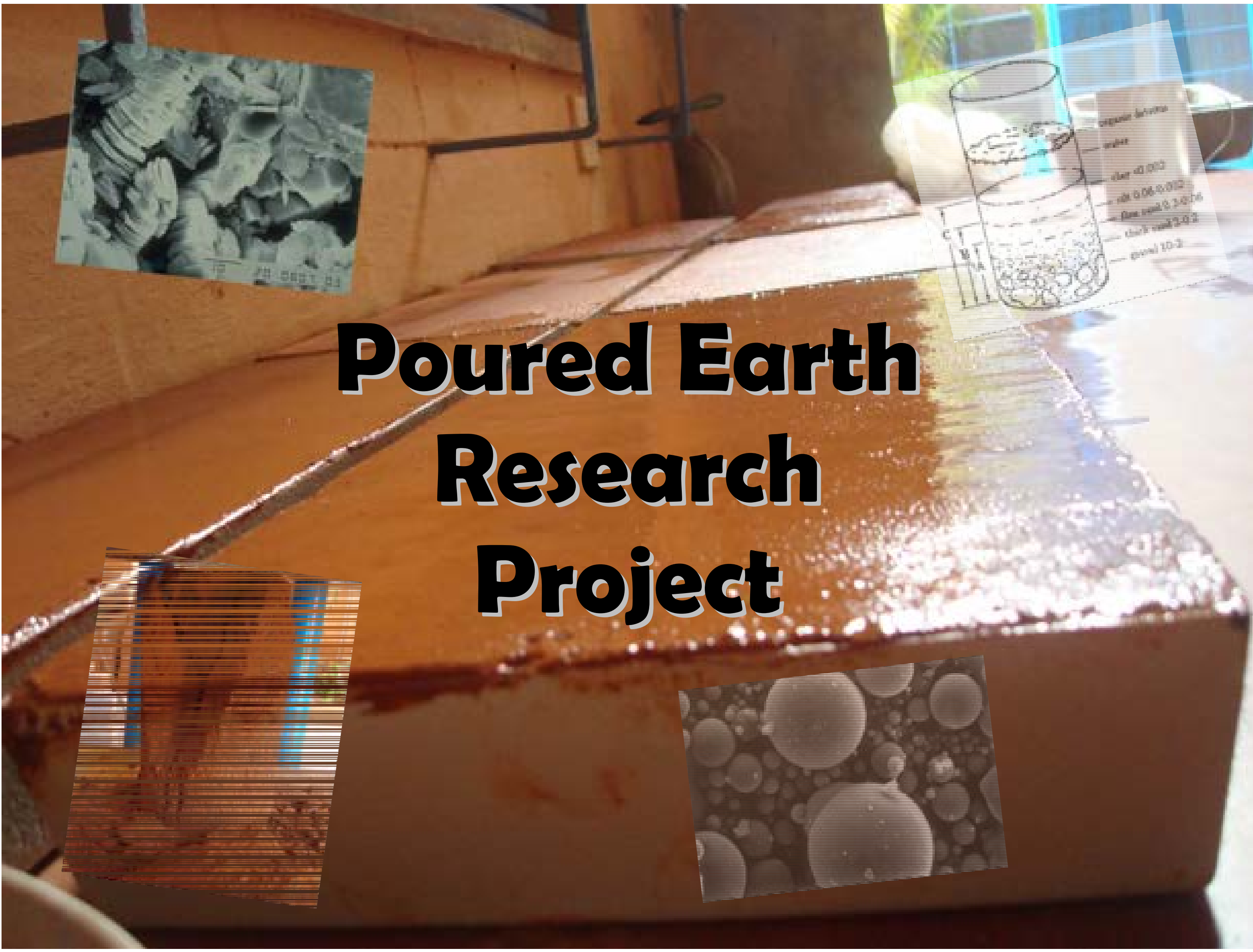
Auroville Earth Institute
UNESCO CHAIR EARTHEN ARCHITECTURE



Poured Earth Research Project

utc Université de Technologie Compiègne

PICARDIE LA RÉGION

Spring 2011
Albéric Lehuédé GM04
UTC Tutor: Kamel Khellil
Auroville Earth Institute
Auroville, India

Acknowledgement

I would like to thank Satprem and all the team for receiving me at the Auroville Earth Institute for this rich and exciting 6 months internship.

Thanks to the UTC, the mechanical department and Kamel Khellil for following my internship during those 6 months.

Thanks to Ayyappan for helping me wholeheartedly in all my researches, and to Amandine for following my work.

Thanks to CRATerre and Magali Aupicon for their help in my project.

A deep thank to the Conseil Général de Picardie in according me a precious grant which allowed me to attend this internship.

Many thanks to Dhanasekaran and his whole family for welcoming me in their house.

Warm thanks to all the volunteers of the Institute and their constant cheerful mood; to Marc, Eric, Tatiana and Cécile who welcomed me in India, and to Ngarrigü for his support.

Table of contents

ACKNOWLEDGEMENT **1**

TABLE OF CONTENTS **2**

TECHNICAL RUNDOWN **3**

INTRODUCTION TO EARTH ARCHITECTURE: **4**

AUROVILLE: **5**

THE AUROVILLE EARTH INSTITUTE: **6**

Educative outreach: *7*
Technologies: *7*

TRAINING COURSE: **7**

Soil identification: *7*
Stabilization: *8*
Block production: *9*
CSEB masonry: *10*
Rammed Earth: *11*

THE INTERNSHIP: **12**

Subject, position and timetable: *12*

POURED EARTH RESEARCH PROJECT: **13**

DOCUMENTATION: 14
THE TESTS: 14
The shrinkage test *15*
The slump test *17*
The compressive strength test *18*
THE MAIN EXPERIMENTS: 21
1 - Washing powder *21*
2 - Soapnut *27*
3 - Superplasticizer *29*
SYNTHESIS OF POURED EARTH PROJECT: 31

OTHER EXPERIMENTS AND R&D PROJECTS: **31**

1 - Maxeh additive *31*
2 - Local lime *32*
3 - Aeonian *33*

MANAGEMENT **35**

SEDAB PROJECT 35
EBL AND COMPUTER MAINTENANCE 36

CONCLUSION **37**

BIBLIOGRAPHY **38**

APPENDICES **39**

APPENDIX 1: FOLLOW-UP OF THE POURED EARTH PROJECT 39
APPENDIX 2: CALCULATIONS AND RESULTS TYPICAL EXCEL SHEET 41

Technical rundown

Poured Earth research project

The main subject of my internship was a research project on a new building technique with raw earth. This technique aims to liquefy earth enough so it can be poured as a classic concrete, but without adding much water to avoid shrinkage and cracks.

The tests

Three tests were performed to match the requirements of this technique and select admixture designs.
A shrinkage test to measure how much a sample would retract when drying.
A slump test to estimate and standardize the sufficient workability for an earth concrete to be poured.
A compressive strength test to measure the resistance of the final material to compression, which is the most important mechanical property for a building material.

The binders

As earth needs to be stabilized, cement and lime were used alternatively as binders for the earth concretes made in those experiments.

The plasticizers

Some products designed to reduce the need of water for an equivalent workability were experimented. The main ones were washing powder, natural Soapnut and classic concrete superplasticizers.

The additives

Some additives were also added in order to reinforce the material or reduce the shrinkage. The main ones were pozzolans: fly ash and rice husk ash.

Other R&D projects

Aeonian

A new clay stabilizer have been tested for CSEB at the Institute, I took part in the tests and the reports.

Maxeh

An additive for a poured earth specific technique from Mexico was proposed to the Institute, I took part in the tests and the reports.

Managerial tasks

SEDAB project

A social business project that needed to be clarified and properly launched, a trainee came especially for it and replaced me in the middle of my internship.

EBL and Computer maintenance

Since the managers of the Institute were not always present I had to handle some office management, notably following the work of the computer maintainer and the web designer on a new professional website project: Earth Builder Links.

Introduction to Earth architecture:

Since ages raw earth has been used all over the world as a building material to achieve amazingly long lasting buildings. There is hardly any continent or country which does not have numerous examples of earth constructions. Today 40% of the world population lives in an earth house. It is a local material, cheap, and allows building several floors. Many building techniques are known and used worldwide.

Ramasseum, Egypt, ~ 1300 BC
Built with adobes, oldest standing building in the world

Château de Reyrieux – Dombes, France, 18th C.

Earth architecture and the skill of earth builders disappeared from the end of the 19th century till the latter half of the 20th century. The Egyptian architect Hassan Fathy initiated the renaissance of earthen architecture; and the new development of earth construction really started in the 1950's with the technology of the compressed stabilized earth blocks (CSEB).
Since then, considerable scientific researches have been carried out by laboratories. The knowledge of soil laboratories concerning road building was adapted to earth construction. Today we benefit from a vast scientific knowledge: CRATerre – the International Centre for Earth construction which is based in France and is one of the world leaders since 1975.
Since 1960 – 1970, Africa has seen the widest world development for CSEB and takes, these days, a further step with semi industrialization and standards. India developed CSEB technology only in the nineteen eighty's, but sees today a wider dissemination and development of CSEB. Today, the Auroville Earth Institute is the Asian leader in earth architecture and construction, and is the representative for Asia of the UNESCO chair Earthen Architecture. This Chair aims to promote earth architecture for sustainable development and habitat.

Auroville:

Auroville is an experimental city founded in 1968 by “The Mother”, Sri Aurobindo’s companion.

Auroville aims to be a universal city where man and woman from everywhere could live in peace and harmony, above all belief, politic or nationality. The initial idea was that Auroville belong to nobody in particular but to humanity as a whole.
Spiritual and practical research was supposed to be developed there. There are 1600 Aurovillians at the moment and the same number of non permanent guests, but the objective is to reach 50 000 people.
At the origins the city has been founded in the desert, and since then Aurovillians have planted trees to form the actual dense forest of Auroville and its cooler climate.

Architecturally it aims to be built in a rotating galaxy shape with the Matrimandir in its middle, and different areas dedicated to specific sectors: cultural, residential, industrial and international.

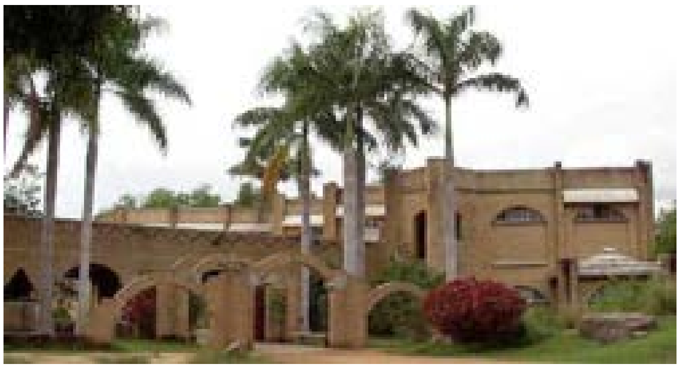
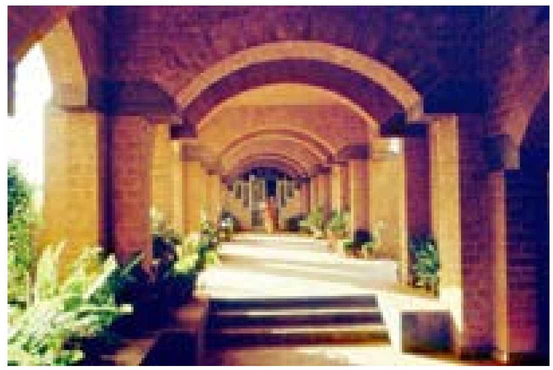
The Matrimandir

The Galaxy

But this huge and ambitious project did not realize itself without any problems.
Nowadays Auroville is very active in ecological issues and rethinking the way of living. It has a lot of agricultural activities, but also researches on sustainable architecture, energies and resources.
Everyone works according to its skills in small enterprises, bio agriculture, workshops and services.
Its population is impressively international with 50% of Indian people and the rest from every part of the world.
Auroville is only 40 years old today, and as the experience is still going on, it is an active center as much for research on alternative energy, building, social or economic solutions, as for a unique human experience. It is a place where one will inevitably come through reflections on society, economy and other various issues.

The Auroville Earth Institute:

Earth architecture was introduced in Auroville since the eighties. But it really developed itself since the creation of the Auroville Earth Institute in 1989 by UDCO, Government of India. This started a new era in earthen architecture.

The Visitors' Centre of 1200 m² / Le centre des visiteurs, 1200m²

For example the visitor's center, built with compressed stabilized earth blocks (CSEB) in 1992, demonstrated the potential of stabilized earth as a quality building material.

The Auroville Earth Institute is researching, developing, promoting and transferring earth-based technologies which are cost and energy effective. The emphasis is focused on the research and development of earth based technologies and their dissemination.
All the technologies are disseminated through training courses, seminars, workshops, manuals and documents. The Institute is also offering various services, and provides consultancy within and outside India. They work on every scale, as much locally as worldwide.

Internationally:

The Auroville Earth Institute is part of a world scale network with CRATerre (The International Centre for Earth Construction based in France), ABC Terra in Brazil and a number of Indian NGO's. A training convention has been passed with the School of Architecture of Grenoble, France, for giving long-term training courses to their students.
The Auroville Earth Institute is today the representative and resource centre for Asia of the UNESCO Chair "Earthen Architecture, Constructive Cultures and Sustainable Development". This Chair aims to accelerate the dissemination of scientific and technical know-how on earthen architecture among the higher education institutions, in the following three domains: environment and heritage, human settlements, and economy and production.
The Auroville Earth Institute is also member of BASIN South Asia (Building Advisory Service and Information Network) and it provides information and guidance to whoever asks for it.

Educative outreach:

One of the aims of the Auroville Earth Institute is to give people the possibility to create and build for themselves their own habitat, while using earth techniques.

The training course activities and the endeavor to promote raw earth as a building material for sustainable and cost effective development has brought since 1989 a series of twelve awards: eleven national awards and one international award. One of the major activities of the Auroville earth Institute is educative, with intensive training courses and long term courses to interns. People are coming from all over the world to learn something from the Auroville Earth Institute. Since the beginning of the trainings in 1990, more than 6 000 people from 63 countries have been trained: 5 695 trainees in India and 422 abroad in 13 other countries.

Masonry training course / Cours de maçonnerie

Technologies:

The most promoted technology today is Compressed Stabilized Earth Blocks (CSEB), it is a cost and energy effective technique and more eco-friendly than other construction techniques like concrete or fired bricks. CSEB are a mix of soil, sand and 5% of cement. They are manually compressed with the press Auram 3000. The production process is eco-friendly as it needs no other energy than human labor. The Earth institute also uses rammed earth for its foundations and sometimes walls.
A lot of research and development is held at the Earth Institute and my research project was part of it.

Training Course:

During my internship I had the opportunity to follow a two weeks training course from mid February to end February. It allowed me to learn a lot about earth in general, earth building history, techniques and architecture.
The main subjects of the training course were:

- Production and use of compressed stabilized earth blocks.
- Masonry with compressed stabilized earth blocks.

Unknown soils / Sols inconnus

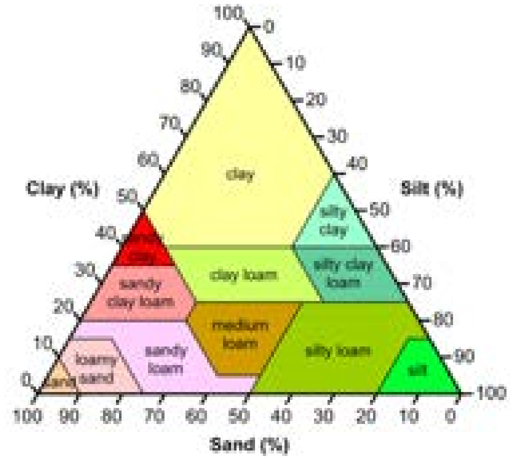
Soil identification:

The first step of the training course was the soil identification: how to identify roughly the components of a soil, and therefore know if it suitable for block making, by making some simple sensitive analysis. In fact not every soil is suitable for earth construction, but with some knowledge many soils can be used for CSEB production. In any case, topsoil and organic soils must not be used. Those can be identified by smelling the moist soil.

A soil is an earth concrete, since it has aggregates (silt, sand, gravels) and a binder (clay). But it is necessary to know in which proportions all this elements are.

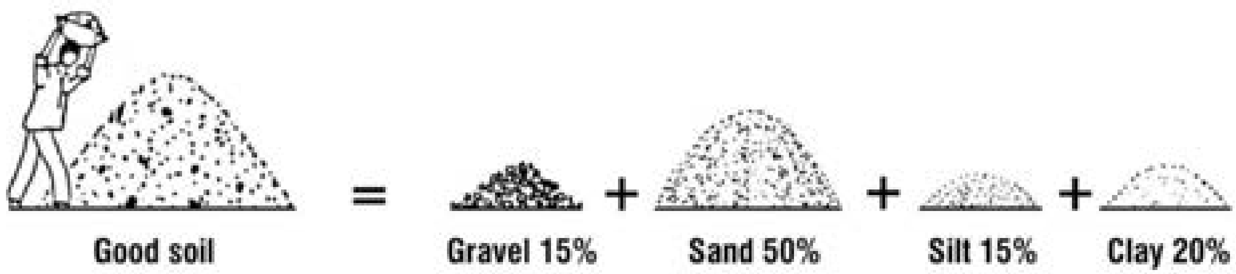
During the sensitive analysis, we focused on:

- Grain size distribution, to know quantity of each grain size
- Plasticity characteristics, to know the quality and properties of the binders (clays and silts)
- Compressibility, to know the optimum moisture content, which will require the minimum of compaction energy for the maximum density
- Cohesion, to know how the binders bind the inert grains
- Humus content, to know if they are organic materials which might disturb the mix



Soil classification / Classification des sols

A good soil for CSEB is more sandy than clayey. More generally, when stabilizing a soil with cement, the less clay in it, the stronger it will be. So a good soil for CSEB has these proportions:



According to the percentage of these 4 components, a soil will be called gravely, sandy, silty or clayey depending upon the primary one. The aim of this sensitive test is to identify in which one of these 4 categories the soil is in order to know how to properly use it.
The red soil from the Institute, used in all my experiments, is a silty-sand one.

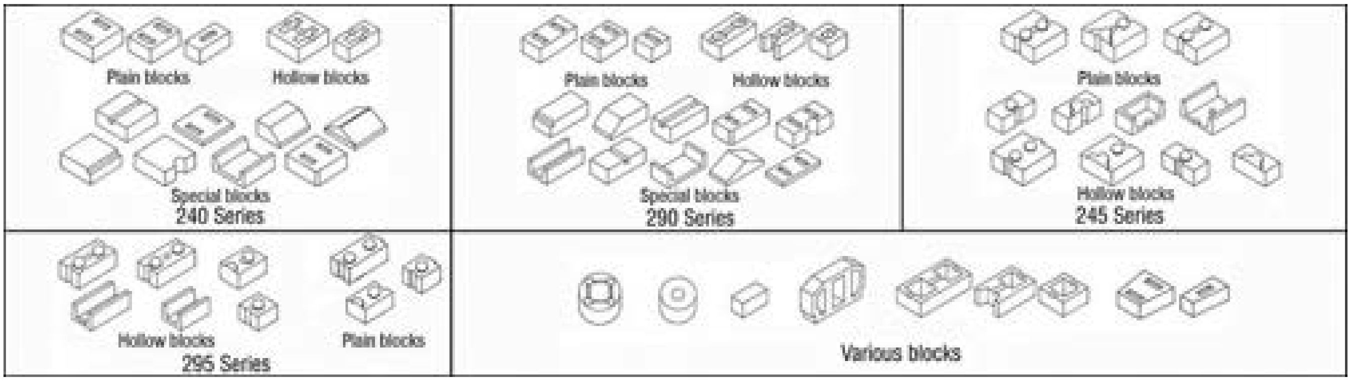
Stabilization:

For CSEB and rammed earth, the soil is mixed with sand and a stabilizer, then slightly moistened and the mix is poured into a steel press, either manual or motorized, and compressed. A lot of shapes can be given to the blocks, changing the compression moulds.

For example the Auram press 3000, designed by the Auroville Earth Institute, can produce 75 types of blocks with 17 different moulds. Today this press is being sold everywhere in the world, mostly in Asia and Africa.

The Auram press 3000/ La presse Auram 3000

The shape of the block matches special purposes and properties, like earthquake resistant hollow blocks for instance.



Variety of block produced by the Auram 3000 / Variété de blocs produit par l'Auram 3000

The choice of stabilizer depends on the soil quality and the requirements of the project.
Cement will be better for sandy soils and to achieve quickly higher strength.
Lim is more suitable for clayey soils but will take longer to harden.

At the Earth Institute, CSEB are stabilized with 5% cement and have an average compressive strength of 75kg/cm² (7,5MPa). With cement stabilization the blocks need to be cured during 28 days, after what they can be used freely. The soil stabilization allows people to build higher tinnier walls, having a better compressive strength. However, we have to keep in mind that cement production represent 7% of all green house gases emissions worldwide, and even if CSEB use less cement than in concrete (5% vs 15%), it still have a significant embodied energy.
In my own researches for the poured earth technique, the choice of stabilizer was a critical issue.

Block production:

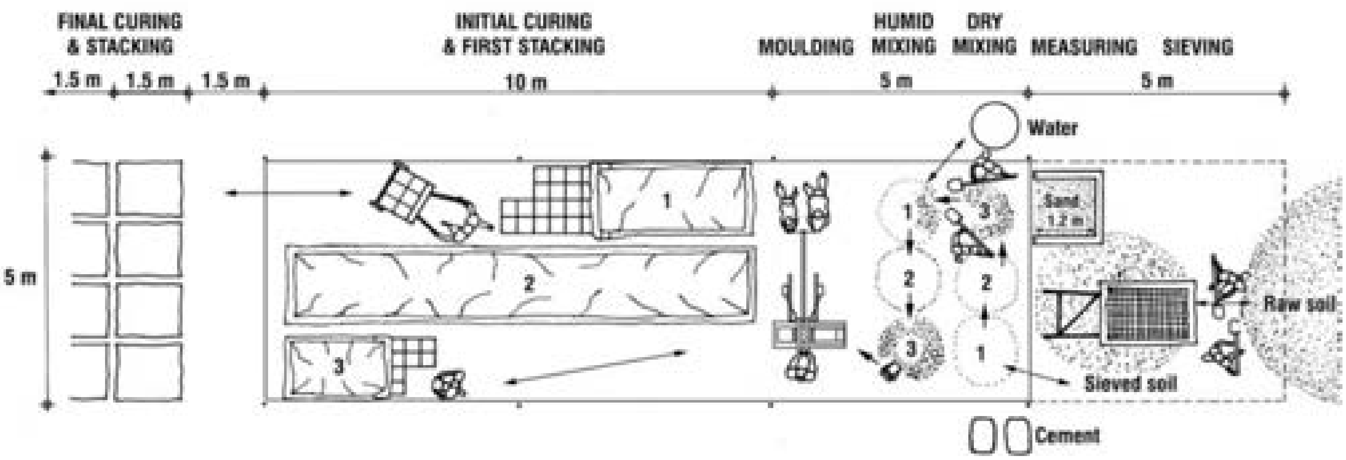
This course was rather theoretical, beginning with the presentation of earth architecture history and main buildings around the world.
After that the block production was presented on the technical and economical aspects. The last part was the practical production of CSEB.

The CSEB production is divided in 6 main stages, requiring a total of 11 to 14 persons:

- Sieving the raw materials
- Measuring and transporting the materials
- Mixing, dry and humid
- Pressing
- Initial curing and stacking
- Final curing and stacking

Curing is a necessary step for all cement based structures in order to achieve the reaction of cement, which needs water to be fulfilled.

Explaining the Auram press / Explication de la presse Auram



Typical blockyard organisation / Organisation typique de l'aire de production

The production cost of a 24x24cm block, the most used, is around 11,5 INR at the moment (0,19€). The main costs are labor, but also cement which is the most expensive raw element. Still, considering one m^3 of finished wall, this represents an overall cost reduction of 27% compared to a country fired brick wall, and 39% reduction compared to wire cut bricks.

Country fired brick / Brique en terre cuite

Wire cut bricks / Briques extrudées et coupées

CSEB have many other advantages, they are energy effective, resistant, eco friendly and a local product.

CSEB masonry:

This part of the training course was more practical since it was based on the building of block structures to learn masonry with earth blocks. We also learnt the kind of architecture adapted to earth blocks, especially vaults and domes.

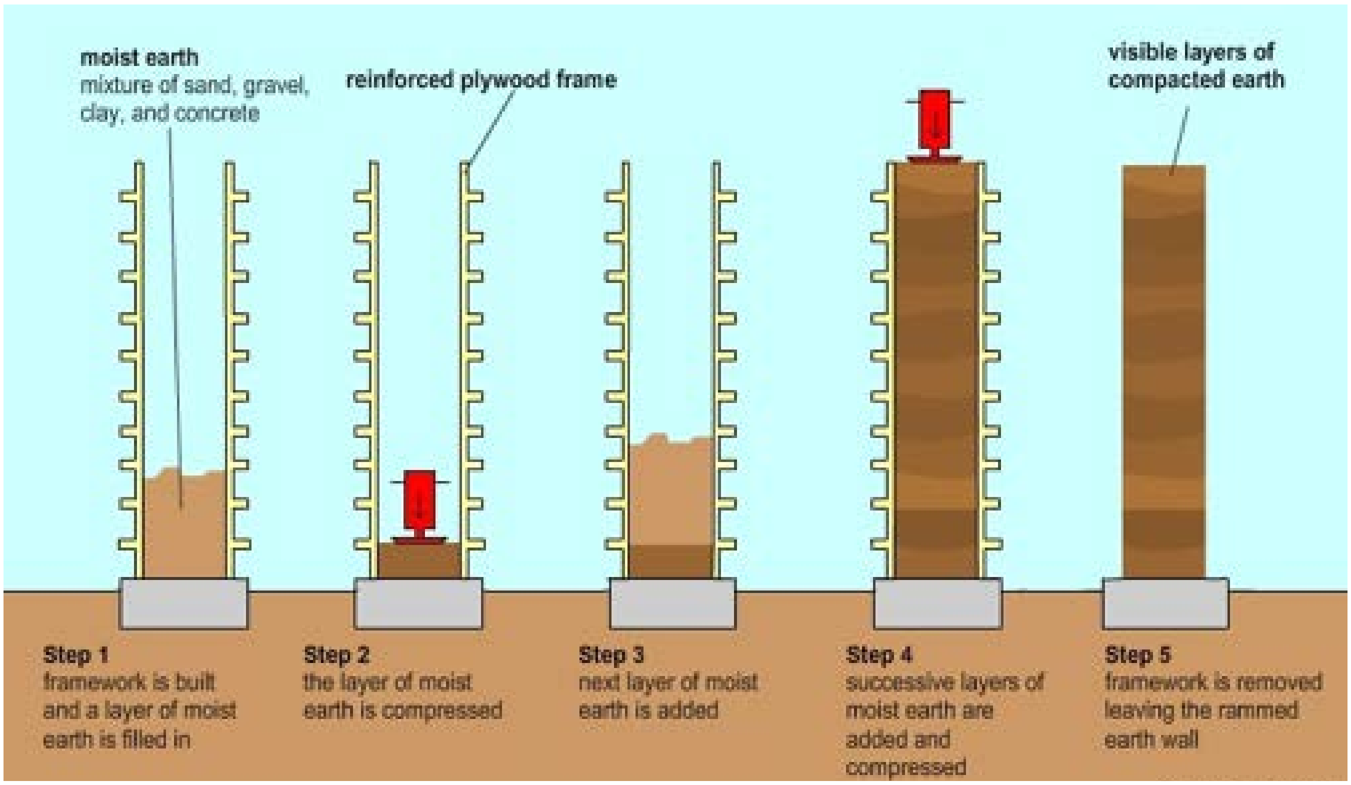
First we learnt the bond patterns and the theory of block laying in order to have the strongest structures. Then we built some structures on a reduced scale to grasp the fundamentals of earth architecture.

Dome masonry / réalisation de dômes

Rammed Earth:

Rammed earth is a form of raw earth construction used by the Institute initially to build foundations and walls. Other applications include floors or even roofs. Recently it has also been used for furniture, garden ornaments and other features.

Rammed earth is formed by compacting moist stabilized soil inside a removable formwork. Moist soil is placed in layers and compressed, giving the material a high compactness giving him its high strength.



Rammed earth process / Procédé du pisé

Once the soil has been adequately compacted the formwork is removed, often immediately after compaction, leaving the finished wall to dry out. This makes this earth building technique one of the fastest.

Rammed earth walls often exhibit a distinctive layered appearance as a result of the construction process, corresponding to the successive layers of soil compacted within the formwork. This attractive appearance explains why the walls are often left without any render or plaster, also that they don't need it since rammed earth shows exemplar energy and humidity regulation properties.

Training course rammed earth wall / Mur en pisé du cours

The Internship:

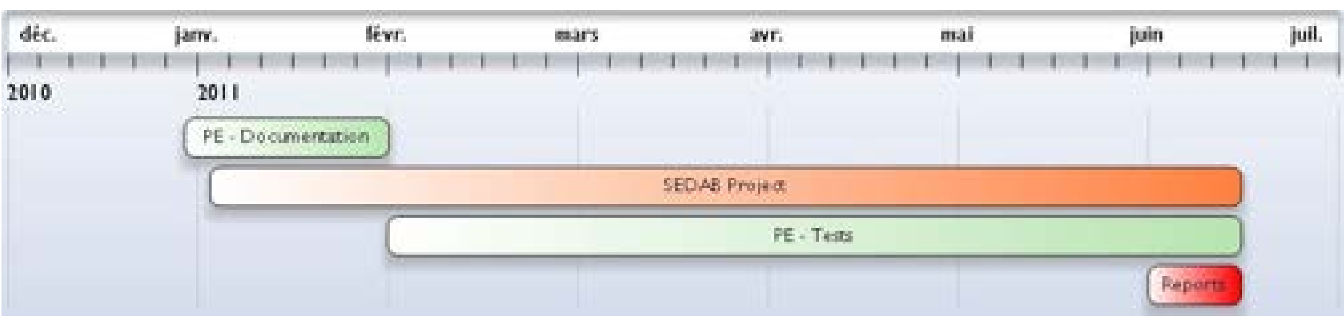
Subject, position and timetable:

Before I came it had been decided that I will work both on the poured earth research project and on unspecified project management simultaneously.

The poured earth research subject was defined as follow:

Everything has to be developed and searched regarding poured earth technique, either solid concrete or reinforced earth concrete, so it could be used here at the Institute for the next constructions.
The issue is to liquefy earth without adding water. This technique is already used in other countries so a documentary research would be a good start. After what, experiments will be needed with an analysis of the results.
The axes of research are:

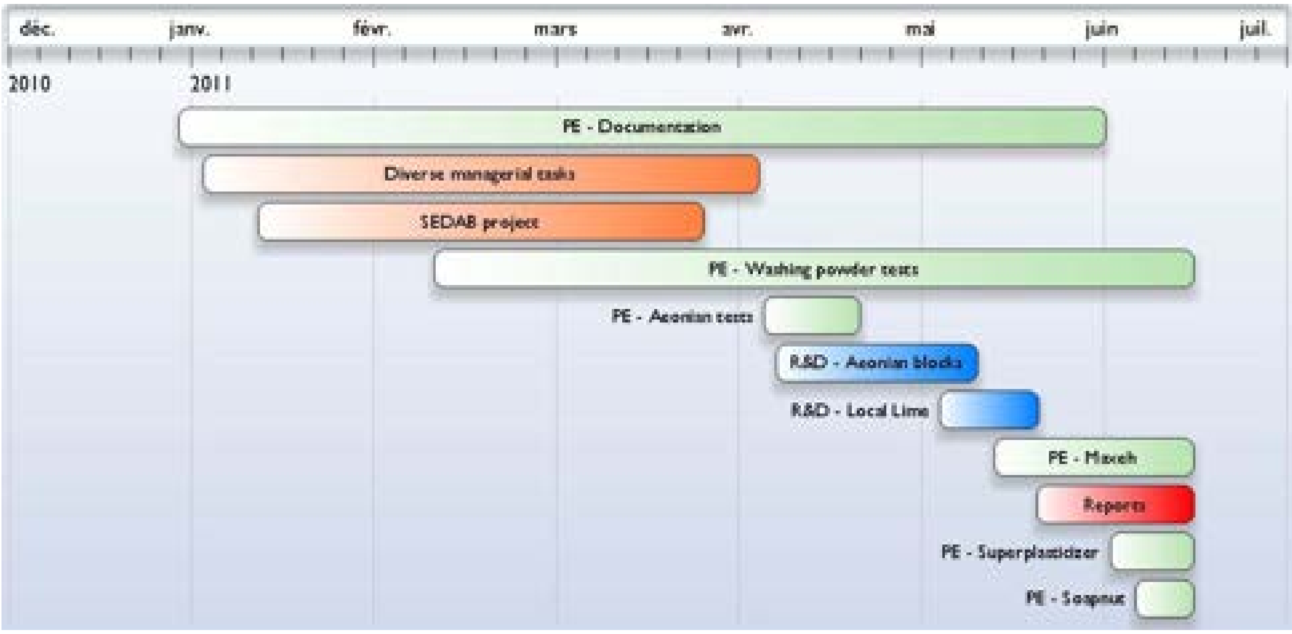
- *Compressive strength*
- *Most appropriated binder*
- *Additives (lime, plasticizers, fibers…)*
- *Earth quake resistance*
- *Shrinkage and crack control*
- *Quality control*



Planned timetable (PE= Poured Earth) / Planning prévisionnel

It turned out that I dedicated more time to the poured earth research project since a new intern dedicated to project management came specifically for the project I was working on during my internship. On the other hand, since Satprem, the manager of the Auroville Earth Institute went travelling during long periods I also had to take care of office management on some projects from time to time.

I was the only trainee and employee working on research and development, apart from Satprem and Ayyappan, the two directors of the Institute, when they had the time to. So it resulted in me working alone and being independent during most of my internship. Adding that Satprem was travelling a lot, I wasn't followed much; which encouraged me to take initiative and work independently. I designed most of the tests and Ayyappan helped me during the making process for some of them.
At some points I also helped out and worked on other R&D projects not related to poured earth as I was the only one with linked skills and available at those moments.



Real timetable / Planning réel

As we can see here, the Washing powder tests were the most important, were I carried out most of my experiments. On the other hand I did a lot of smaller tests, either because the product was not good enough to further experimentation, either because I had no more time.
In fact this internship was quite frustrating personally since I found a lot of leads at the end of it and could not carry out more experiments with those promising solutions.

Poured earth research project:

The complete follow-up can be found in Appendix 1.
The poured earth research project has been launched with my arrival at the Earth Institute; nothing had been done there before. Furthermore it is not a very common technique and it is not much developed elsewhere in the world. Except in CRATerre, the earth research center in France, with whom I communicated and exchanged information.
However, this building technique with raw earth is very promising since it would considerably shorten the working time and the human energy needed.

Earth is constituted of mineral particles from different sizes: gravels, sand, silt and clay, the finest.
Thus earth can be considered as a natural concrete. It has different sized aggregates: gravels, sand and silt, and a binder which is clay, sticking all those elements together.

Poured earth wall / Mur en terre coulée

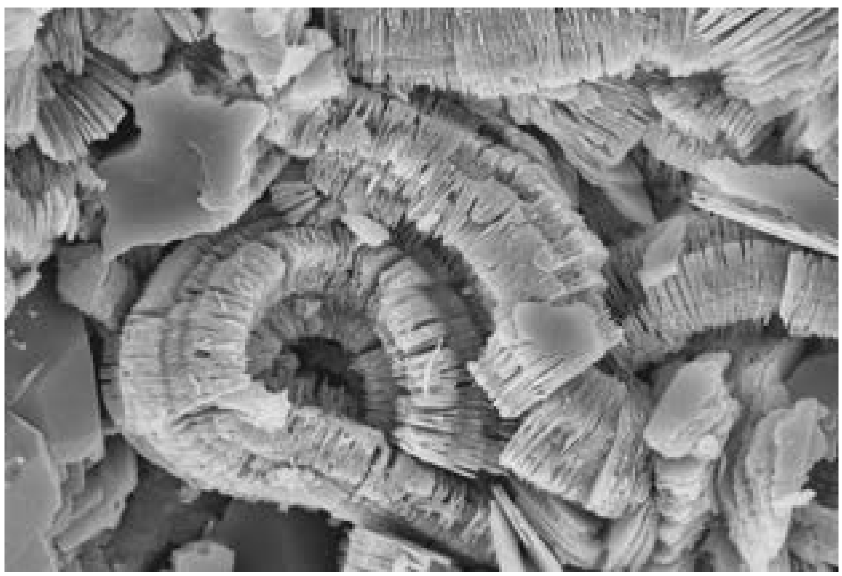
The objective of the poured earth technique is mainly the workability: we aim to pour earth just like a classic concrete In order to cast walls or slabs easily. But, as liquefying an earth concrete would require water, the adding of too much water results in high shrinkage and cracking when drying. So in order to avoid that, the clue is to find a way to liquefy an earth concrete without adding too much water. Also, contrary to earth blocks or rammed earth, the poured earth concrete is not compacted which would result in a lower compressive strength.

That is why the following experiments aim to find additives and suitable mix designs to minimize the shrinkage and reinforce the material.

Documentation:

So nothing had been done on poured earth at the Auroville Earth Institute previously. That is why the internship began with a documentation stage, and also because I was totally discovering earth as a material.

During this theoretical research and self-educating period I notably learnt about: particles science, minerals, earth composition and behavior, clay and colloids, earth building techniques, concrete, cement and lime, pozzolans such as fly ashes, plasticizers, Soapnut, mechanical properties and standards, and more generally about every material I had to deal with during the experiments.



Clay (kaolinite) platelet structure / Structure en plaquette de l'argile (kaolinite)

The tests:

During my experiments I performed three different sorts of tests: a shrinkage test, a slump test and a compressive strength test. It allowed me to quantify the most important properties, the qualifying basic criteria that the experimental mixes had to fulfill in order to be considered as a potential solution.

First of all, the density of the elements needed for the tests were measured by weighting one liter of this element, these measures were essential to convert the quantities from volume to mass and vice-versa.

Which is important since most of the materials were measured by mass but some liquid by volume, and in a real scale work, it would be measured by volume.

Here are the measured densities:

Material	Density (kg/L)	Material	Density (kg/L)
Red Soil	1,23	Fly Ash	0,88
Sand	1,50	Rice Husk Ash	0,28
Gravel chips	1,34	Washing powder	0,89
Half-inch gravels	1,33	Aeonian	1,12
Cement	1,34	Supaflo (Special)	1,22
Lime	0,51	Maxeh	0,7

The shrinkage test

The shrinkage test measures the shrinkage when drying, and thus the formation of potential cracks weakening the structure. It is the most important one since the poured earth technique faces a high shrinkage due to the massive adding of water necessary to reach a suitable workability.

Firstly, the aggregate elements of the designed mix were weighed, their ratio were defined by volume in order to match the volume of the mould, but taking into account the bulking ratio. Bulking ratio is the fact that mixing 1L of sand and 1L of soil won't make a 2L admixture but less, due to different particle size. Here we considered a 1,5 bulking ratio.
Then the stabilizer and additive, if any, were also weighed and added. Their quantity was defined in the specifications as a percentage in mass out of the dry aggregate mix. All the elements were then mixed dry.

Dry mix / Mélange sec

Next the plasticizer, if any, was weighted and diluted into water. This amount of water was slightly inferior to the estimated quantity of water required for the sample so that a maximum quantity of the plasticizer could be diluted, thus avoiding to reach saturation.
The water was added to the dry mix and everything was blended. If a plasticizer was used it was necessary to wait at least 2 minutes for the effects to be seen, but not longer since the cement would start to react and harden.
The resulting admixture had to reach a defined workability.
The goal was to reach the same texture and workability for all the samples, measuring the extra plain water needed to reach it for every different mix, then it could be possible to compare the water ratio and the effects of the plasticizers on water reduction.

The shrinkage moulds were rectangular (43x17x4cm), making a 2.9L volume, but taking into account the bulking ratio we had to prepare a larger volume of admixture.
After reaching a homogenized and complete admixture, a mould was greased with classic motor oil. The mix was then poured in it, the sample was slightly vibrated on a vibration table, and then leveled with a ruler to have a horizontal and smooth surface.

Rectangular mould / Moule rectangulaire

Vibration table / Table vibratoire

The samples were stored in the shade and left to dry for two weeks in their moulds. The shrinkage was firstly measured after one week, where most of the shrinkage occurs, and finally after two weeks. The presence of cracks was also very important to notice as it would reflect a too high shrinkage and a low cohesive material.

Works pace / Espace de travail

Shrinkage samples / Echantillons de retrait

After the test is completed, the samples are broken in pieces for some sensitive tests. Mostly to observe the internal structure, to appreciate the friability and the resistance to compression by crushing some parts by hand, which appeared to be impossible sometimes.

The slump test

All this protocol was done according to the European standard NFP 18-451.
The slump test allows measuring the workability of concrete. We wanted to use it to determine a standard workability for the poured earth technique, so that we could have a precise workability reference when adjusting the water content on a construction site.
In order to perform the slump test, we needed an Abrams' cone which has been made by Aureka, the metal workshop of Auroville. It is a cone of 30cm height, 10cm superior diameter and 20cm inferior diameter; which makes a volume of 5.5 Liters.

- The cone was firstly oiled on the interior surface to avoid friction. Then the admixture was poured in it in three equal layers.

Slump test equipement / Matériel test d'affaissement

Oiling the Abrams' cone / Huilage du cône d'Abrams

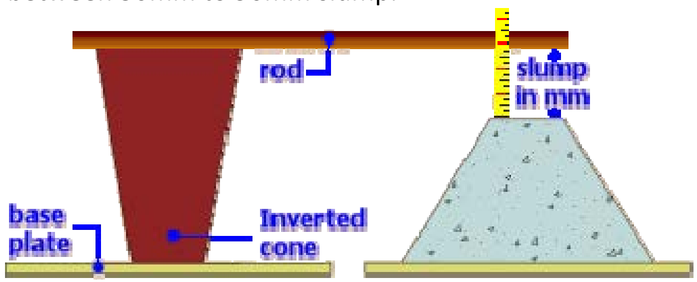
- A 1,6cm diameter rod was then used to tamp down the admixture 25 times per layer in order to allow air bubles to escape and to compact roughly the admixture. The top of the cone was finally leveled with the rod.

Then the cone was removed slowly and put at the side of the admixture to measure the slump easily.

Rodding / Piquage

Slump measurement / Mesure de l'affaissement

- Given the slump of the cone in mm, the concrete can be classified in a consistency class according to the table of the standards. Each class is corresponding to a particular use. We were aiming a sulmp class of S2, so between 50mm to 90mm slump.



Class	Slump range	Target slump
S1	10 ~ 40	20
S2	50 ~ 90	70
S3	100 ~ 150	130
S4	160 ~ 210	180
S5	210 ~ n/a	220

According to the standards: S1 concretes are most likely to be used for kerb and pipework bedding, S2 for simple strip footings and cast in-situ hard-standing slabs, S3 would be used for trench-filled foundations where a high flowability is required. S4 and S5 are likely to be used in specialist applications. When using concrete with high slump values (>150mm [S4 or S5]) there is a risk that the aggregates and cement will settle out or segregate.

- During the washing powder test, for each mix design, three cylinders were poured from the admixtures right after the slump test.

The compressive strength test

The samples

Since the slump test required a consequent volume of admixture, in order not to waste it the pouring of the cylindrical samples for the compressive strength test was done just after.

The casting of the cylindrical samples and the compressive strength test were all done according to the American standards ASTM C31.
The cylinders used here were cut out of pipes and had a 21cm height and a 10,4cm diameter. It is necessary to have at least a height twice longer than the diameter, and the diameter of the cylinder should be at least 3 times the nominal size of the coarse aggregate used in the earth concrete.

-The interior surface of the mould was oiled. Then the mould was placed on a ceramic tile in order to avoid adhesion when hardening and unmolding. The admixture was poured in two equal layers each tamped 25 times with a 1,6cm diameter rod.

- The surface was leveled with a trowel. The samples were unmolded 16 hours after and put under a plastic sheet.

Casting the sample / Coulée d'un échantillon

Poured samples / Echantillons coulés

The samples with cement were then cured for 27 days whereas the sample with lime were left under a plastic sheet for 14 days and then left outside for 14 more days.

- After 28 days of curing for cement based samples, and drying for lime based samples, they were ready for the compressive strength test.

The compression

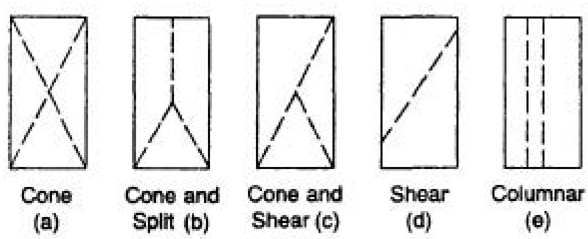
- Firstly the samples were weighed and measured to calculate their density in kg/m^3.

- One sample was put on the loading platform, between two panels of chipboard to avoid direct contact between the steel of the platform and the sample. The upper panel of the compressive machine was then screwed down until it reached the top of the sample. At this point the hydraulic valve was closed and the compression could start by operating the lever.

The compressive machine and a compression test / La machine de compression et un essai de compression

- When the sample cannot take any more load, the maximum load at failure in kN can be read on the indicator.

The type of failure is also important as it reveals if the sample was done correctly, a remaining cone at both ends is expected, like in figure (a).



Types of failure / Types de fracture

This figure shows five different types of fracture. The standard ASTM C 39-03 requires that reports include the type of fracture "if other than the usual cone."

An expected cone failure results when friction at the platens of the testing machine restrains lateral expansion of the concrete as the vertical compressive force is applied. This restraint confines the concrete near the platens and results in two relatively undamaged cones when the cylinder is tested to fracture. If the friction were eliminated, the cylinder would expand more laterally and exhibit a splitting failure similar to that shown in figure (e).

If requirements for perpendicularity of the cylinder ends or vertical alignment during loading aren't met, load applied to the cylinder may be concentrated on one side of the specimen. This can cause a short shear failure similar to that shown in figure (d), except that the failure plane intersects the end of the cylinder. This type of fracture generally indicates the cylinder failed prematurely, yielding results lower than the actual strength of the concrete.

Maximum load indicator Indicateur de charge maximum

Cone failure / Fracture conique

- The valve has to be opened for the plates to be moved and the crushed sample removed. The compressive strength in MPa is given by dividing the maximum load at failure in Newton by the surface of the sample in mm². If we want the compressive strength in kg/cm² then we have to apply:

$$F\ (kg/cm^2) = \frac{Load\ at\ failure\ (N) * 100}{Surface\ (mm^2) * 9{,}81(m/s^2)}$$

- For each test design, the average is made from the results of the three cylindrical samples.

The calculations excel sheets

During the internship, all the test designs, calculations and results were done with Microsoft Excel. Since I cannot put all of them in this report, I will present in Appendix 2 a typical sheet and the calculations that come with it.

The main experiments:

1 - Washing powder

Objective

The aim of these tests was to measure and quantify the effects of washing powder as a potential additive for the poured earth technique, and more precisely as a deflocculent of clay and thus a plasticizer.
This experiment was divided into the three different tests which were performed one after the other: the shrinkage test, then the slump test and finally the compressive strength test.

The dry aggregate mix was the same for every sample and was made with 40% Soil (Sandy silt), 40% Sand, 10% Gravel Chips and 10% half-inch Gravels, by volume.

What differentiated the samples from one another was the addition of fly ash, rice husk ash and the choice and ratio of stabilizer: lime or Portland cement here.

Why washing powder?

We were told washing powder could be used as a deflocculent for clay. In fact since it makes a basic solution with water it can neutralize positive charges on clay particles, separating the platelets and liberating the inner water that was contained between them and sticking them together with the Van der Walls forces.
Also a trade tip often employed in the building field is to use detergent when plasticizers are not available.
We could have used any basic solution for this but washing powder is available everywhere at reasonable price, and the sustainability of the process was one of our main concerns.

Shrinkage

Test design:
Firstly two mixes are realized, one without washing powder and another with 1.5% washing powder dissolved in the water added, no stabilizer are used for this test. The objective is to see if the two mixes need the same amount of water to reach the same texture as concrete.

It appears that both mixes need 600ml of water, hence there is no appearing influence of washing powder during this test. This could be explained by the delay of action of washing powder and the fact it interacts with the stabilizer.
The sample with washing powder is then poured into a rectangular tub, 43x17x4 cm, to observe the behavior when drying, and the shrinkage. It is named test 0.
12 other tests were then realized:

Finding the good workability / Recherchant l'ouvrabilité

The aggregate mix was the same for all samples: 40% Soil, 40% Sand, 10% Gravel Chips, 10% half-inch Gravels, by volume.

Name	Stabilizer	Plasticizer	Additive
Test 0		1,5% Washing	
Test 1	7,5% Cement	1% Washing	
Test 1 bis	7,5% Cement		
Test 2	4% Cement	1% Washing	4% Fly Ash
Test 2 bis	4% Cement		4% Fly Ash
Test 3	4% Cement	1% Washing	4% Rice Husk
Test 3 bis	4% Cement		4% Rice Husk
Test 4	7,5% Lime	1% Washing	
Test 4 bis	7,5% Lime		
Test 5	4% Lime	1% Washing	4% Fly Ash
Test 5 bis	4% Lime		4% Fly Ash
Test 6	4% Lime	1% Washing	4% Rice Husk
Test 6 bis	4% Lime		4% Rice Husk

Every dry mix was tested with and without washing powder so that the influence of this plasticizer could be truly estimated regarding different mix designs.
The Fly Ash and Rice Husk Ash are two pozzollans known to improve the long term strength, but the reaction is a long term one and begins at least after 7 days so we were not able to see it properly in this test. They can also be a substitute to cement up to 75 % and reduce the amount of water up to 20%. That is why we only put 4% of stabilizer along with the ashes, whereas the samples without ashes had 7,5% stabilizer.

Results and interpretations:

Name	Water ratio	Two weeks shrinkage (mm)	Shrinkage ratio	Observations
Test 0	13,5 %	5	1,166%	Long to harden (3 days)
Test 1	11,6%	4,5	1,044%	Long to harden (3 days)
Test 1 bis	12,4%	5,5	1,279%	
Test 2	11,35%	4,5	1,044%	Long to harden (3 days)
Test 2 bis	12,83%	5,5	1,282%	
Test 3	13,1%	4	0,932%	Long to harden (3 days)
Test 3 bis	16,36%	7	1,632%	
Test 4	14,9%	5	1,166%	
Test 4 bis	15,9%	5,5	1,282%	Bleeding
Test 5	13,6%	4	0,928%	
Test 5 bis	16,8%	6	1,395%	Bleeding
Test 6	16,2%	2	0,466%	
Test 6 bis	17,7%	3	0,696%	Bleeding

The samples with cement and washing powder (0,1,2,3) took longer to harden due to a negative effect of washing powder on cement; they stayed soft for 3 days at least. On the other hand the samples with lime were behaving properly.
The samples with lime and no washing powder (4bis, 5bis, 6bis) were bleeding, but the ones with washing powder (4,5,6) were not. This might be due to the excess of water in the “bis” samples which don’t have washing powder.
The amount of washing powder added was excessive. In fact the 1% washing powder is never totally diluted in the quantity of water used since saturation occurs first. Thus only 0,8% of washing powder would be enough for the same results.

Samples drying / Echantillons en cours de séchage

The washing powder was effectively reducing the amount of water needed, and thus the shrinkage. The reduction of water was different depending on the mix design but was found between 5% and 18%. But the shrinkage was still very high and it would have been too much for an entire wall or slab.

Now that the shrinkage had been emphasized it was necessary to see if the designed mixes were offering a sufficient strength, and more precisely enough compressive strength to be used for buildings.

Trials

Before making all the same design samples from the shrinkage test, we did some cylindrical samples to try the compressive machine and our moulds to be sure they were working properly.
The aggregate mix was the same for all samples: 40% Soil, 40% Sand, 10% Gravel Chips, 10% half-inch Gravels, by volume.

Sample	**Composition**	**Age of sample**	**Load at failure**	**Comp. strength**	**Comments**
1 – Rammed Earth	Classic rammed earth mix with 5% cement	24 days	100kN	11,5 MPa	
2 – Cement/WP	7,5% cement, 1% washing powder	22 days	0kN	0 MPa	No bleeding, Melting while curing
2 bis – Cement	7,5% cement	10 days	10kN	1,15 MPa	Average bleeding
3 – Lime/WP	7,5% lime, 1% washing powder	28 days	13kN	1,5 MPa	No bleeding
3 bis - Lime	7,5% lime	28 days	4kN	0,46 MPa	Average bleeding

We made one rammed earth sample, but also a sample with cement and washing powder which appeared to be totally melting while curing. We discovered at this point that washing powder was reacting negatively with cement, preventing him to react properly.

Sample melting / Echantillon se désagrégeant

To confirm this we made two 1:2:4 concrete cubes (10x10x10cm), one with 1% washing powder and one without. The cube with washing powder appeared to need 15% less water to reach the same workability, confirming the plasticizing property.

Concrete cube / Cube de béton

Compressive strength test / Essai de compression

Sample	Water needed	Maximum load at failure	Compressive Strength	Comments
1:2:4 concrete cube	550 mL	204 kN	20,4 MPa	Low permeability
1:2:4 concrete cube + 1% washing powder	470 mL (15% less)	103 kN	10,3 MPa	More workable but high permeability

In the end the washing powder cube was half less resistant than the other one, had a high permeability and a poor resistance to abrasion while curing.

It confirmed that washing powder cannot work with cement based earth concrete, along with soda, detergents or other strong bases.

Compressive strength

Test design:
The samples with cement and washing powder were removed from this test as I explained previously. However all the lime based designs were kept since washing powder seemed to react very well with it. The aggregate mix was the same for all samples: 40% Soil, 40% Sand, 10% Gravel Chips, 10% half-inch Gravels, by volume.

Name	Stabilizer	Plasticizer	Additive
Test 1	7,5% Cement		
Test 2	4% Cement		4% Fly Ash
Test 3	4% Cement		4% Rice Husk Ash
Test 4	7,5% Lime		
Test 4 bêta	7,5% Lime	1% Washing Powder	
Test 5	4% Lime		4% Fly Ash
Test 5 bêta	4% Lime	1% Washing Powder	4% Fly Ash
Test 6	4% Lime		4% Rice Husk Ash
Test 6 bêta	4% Lime	1% Washing Powder	4% Rice Husk Ash

- All samples were crushed 28 days after they were poured.
- One rammed earth sample had been done again to have a compressive strength reference, but it was not done properly and did not give proper results. We will then stick to the results of the previous one.

Results and interpretations:
The results presented here are an average of the results given by the three cylinders of each mix design.

Name	Slump (mm)	Load at failure (kN)	Comp. strength (MPa)	Comp. strength (kg/cm^2)	Density (kg/m^3)	Comments
Test 1	2	20	2,35	24,0	2128	Small bleeding
Test 2	3,5	13,7	1,61	16,4	2103	Small bleeding
Test 3	4	9	1,06	10,8	2004	Small bleeding
Test 4	2	4,8	0,57	5,80	1907	Sample could be crushed by hand
Test 4 bêta	2	18	2,12	21,6	1898	
Test 5	2	5,3	0,63	6,40	1930	Sample could be crushed by hand
Test 5 bêta	4	7,7	0,98	10,0	1800	
Test 6	4,5	5,8	0,69	7,00	1779	
Test 6 bêta	11	0	0	0	1423	Load too low to be measured by the machine (<3kN)

All the failures were expected cone shaped failures; only the rammed earth sample and one sample from the first design had a shear failure, which implies that the two faces were not exactly parallel and a stress concentration on the upper part implied a shear failure all along the structure.

Shear failures / Fractures en cisaillement

- The samples with cement were bleeding whereas the lime samples had lower bleeding, and no bleeding at all when using washing powder.

- We can notice that the density have some influence on the compressive strength. What makes the strength of rammed earth is precisely its high density due to the compression it went through. Some densities here are higher than the one of compressed earth blocks, around 1700 – 1800 kg/m^3.
On the other hand the use of lime is lightening the material with almost the same strength as cement, which could be used to lighten an entire structure.

- From the results we have we saw that the two strongest mixes were those using 7,5% binder, which is not a surprise. Still, the samples with fly ash, either with cement or lime, were quite promising since they did not have their pozzolanic reaction completed yet.

- As we can see, the lime reacted very well with washing powder. Not only it reduced shrinkage and water content, but also it improved the strength of the material significantly. And knowing lime reaction is a long term one, it would eventually get stronger. Moreover, the pozzolanic reaction would also take place in the sample with fly ash, reacting with free lime over time and reinforcing again the material.

- Considering the shrinkage test results we could have thought rice husk ash was an efficient additive, but we saw here that it weakens a lot the material. This was probably due to its very low density.

- The slump test was not very functional with earth concrete: clay was sticking too much, holding the structure, so the results cannot be compared to the ones given by classic concrete. But they could be used as a local reference.

Conclusions

Washing powder is an efficient plasticizer considering it reduces the amounts of water needed and increases workability. But it is not working properly with cement, counteracting its reaction and weakening the material.
However, its effects with lime are positive and promising. The next steps were consisting in experimenting more natural equivalent products and finding better designs for this solution.

When considering the shrinkage test results we could have thought rice husk ash was an efficient additive, but we saw with the compressive strength test that it weakened a lot the material.

New Ideas that came from those tests:

- The shrinkage moulds were greased, helping the samples to shrink since there were no frictions to hold it. In a real context, the pouring of a wall for example, the friction on the ground would reduce the shrinkage. This should be taken into account and similar tests on a rough surface could have been done.
- The hardening time of lime samples was not fulfilled here; it could have been interesting to see the resistance after 56 days; same remark with the use of Fly Ash and the pozzolanic reactions which occurs during longer hardening times.

Unfortunately I came with those two conclusions too late to perform or modify further tests.

- Finding and using an equivalent natural product instead of washing powder, like soapnut which is easily available in India, would have been clever. And so we did.

- Since washing powder didn't seem to act well with cement, finding a plasticizer suitable for cement was required. Thus I figured that the classic plasticizers from concrete industry could be used.

2 - Soapnut

Objective

This test was following the ideas of the washing powder test. At the end of this previous test we concluded that washing powder could be a good plasticizer for an earth-lime concrete but that a natural substitute would be better.

Soapnut is a fruit easily available in India which produces natural soap when soaked into water.
Those tests were design to experiment this bio-product and see if it reacted well with lime and if it also acted as a plasticizer.
These tests included a shrinkage test, a slump test and a compressive strength test.

Soapnuts / Fruits de Sapindus

The Soapnut is a little fruit with a solid and rather big pit inside and is quite dry naturally.

After removing the pit, the fruit was cut in few pieces and soaked into water. We decided randomly to put 100g of fruits into 3 liters of water. The soap of the fruit is diluated into water quite easily in 48 hours.
The resulting solution could be used just like the soapy water produced with washing powder.


Soapnut

Test design and results:

Since this experiment occurred at the end of my internship, I just got the time to make the three tests with lime and a shrinkage sample with cement, knowing it will have poor cohesion and strength but to see if soapnut was reducing shrinkage and thus acting as a plasticizer.

The aggregate mix was the same for all samples: 40% Soil, 40% Sand, 10% Gravel Chips, 10% half-inch Gravels, by volume.

Sample	Stabilizer	Water ratio	One week shrinkage (mm)	Shrinkage ratio	Comments
Soap 1	5% Cement	18,1%	0,8	0,186%	No resistance to water, abrasion and compression
Soap 2	7,5% Lime	15,3%	3	0,698%	

- Cement effects were cancelled by soapnut as we foresaw it, but the shrinkage was the lowest we had ever had, every tests considered.
- The shrinkage with lime was quite important. But much lower than the similar test done with washing powder.

Slump test and compressive strength

The admixture “Soap 2” is also poured to make cylindrical samples and is submited to a slump test. But the sample is only crushed after 7 days, which is not very representative of the real compressive strength. Yet it gives a small idea of whether or not this product should be experimented further.

Sample	Slump (mm)	Density (kg/m^3)	Comp. strength (MPa)	Comp.strength (kg/cm^2)	Comments
Soap 2	7	1801	<0,35	<0	Too early

- Soapnut did have plasticizing effects and the workability was good.
- The sample did not have enough time to harden, its maximum load was under first graduation: 3kN.

Conclusions

Soapnut solution appears to be a very good plasticizer for cement, event if it does not work properly with it as a matter of strength and waterproofing.
But it is seemed to be a very efficient plasticizer for lime based earth concrete, even more effective thant washing powder which was more expensive and not natural at all.

3 - Superplasticizer

Objective

The objective of these tests was to experiment classic super plasticizers of the concrete industry as a solution for the poured earth technique.
The experiment here was constituted of a shrinkage test aiming to spot the best ratio of plasticizer.
The two plasticizers we used were *Supaflo* and *Supaflo Special* from the company *Don Construction Chemicals India Ltd,* they cost the same price.
Supaflo: High range water reducer, 200-1000ml / 50kg cement
Supaflo Special: High range water reducer, used for self compacting concrete, 200-1000ml / 50kg cement

What theoretical design?

The *Supaflo Special* specifications advised a dosage of 200ml to 1000ml per 50kg cement.
But those specifications were for classic concrete where the amount of cement is around 14%, consequently since the mix designs used only 5% cement, I was afraid I would require more plasticizer than the specifications.
I measured the density of the plasticizers (1,224 kg/L), then according to the specs, 200ml to 1000ml per 50kg cement made 0,2*1,224/50 to 1,224/50 = 0,5% to 2,5% out of cement mass.
So if considering a classic 1:2:4 concrete, cement is around 14% of the total mix in mass which gives us the ratio of plasticizer out of the total mix: 0,14*0,005 to 0,14*0,025 = 0,07% to 0,35 % out of the total concrete mix.
So I wondered if I should use the ratio out of the total mix or out of the cement quantity and decided to do it over the total mix to improve the effects since the quantity of cement is rather low in these designs.

Tests designs and results:

The test designs were meant to find the best ratio of plasticizer and find which of the two was more efficient. The same aggregate design was used for every sample: 40% Soil (Sandy silt), 40% Sand, 10% Gravel Chips, 10% half-inch Gravels, by volume and 5% cement in mass for every sample.

With *Supaflo:*

Sample	Composition	Water ratio	One week shrinkage	Shrinkage ratio
0	Nothing else	16,5%	2	0,47%
Sup 1	0,04% Supaflo	15,7%	1,5	0,35%
Sup 2	0,4% Supaflo	14,9%	2	0,47%
Sup 3	1% Supaflo	13,2%	3,5	0,81%

With *Supaflo Special:*

Sample	Composition	Water ratio	One week shrinkage	Shrinkage ratio
Sup Spe 1	0,5% Supaflo Spe.	15,5%	4	0,93%
Sup Spe 2	0,5% Supaflo Spe. 5% Fly Ash	14,8%	3,5	0,81%
Sup Spe 3	1 % Supaflo Spe.	12,3%	4	0,93%

As we can see the results were quite disturbing.
The water added did decrease when the amount of plasticizer increased, but the shrinkage was increasing as well. The more water, the less shrinkage; which seemed paradoxical.
I could explain this by two things:
- Either the amount of plasticizer was too high, which implied a "starvation" of water for the concrete and cement which cannot fulfill its reaction.
- Or the fact that I didn't cure the samples during the shrinkage test, implying another kind of starvation and the reaction with cement could not be fulfilled either.

With curing:
So new tests were done, but with curing this time.
As I had to choose between the two plasticizers I decided to keep the *Supaflo Special* since it was reducing water a bit more, but the two plasticizers remained quite similar in the end.
I also decided to use fly ash since it could have a water reducing effect too and will harden the structure with the pozzolanic reaction over time. Every sample had then 3% Fly ash in addition.

Shrinkage test with superplasticizer / Test de retrait au séchage avec superplastifiant

The common sample mix was: 40% Soil, 40% Sand, 10% Gravel Chips, 10% half-inch Gravels, by volume plus 5% cement and 3% Fly ash in mass.

Sample	Composition	Water ratio	One week shrinkage	Shrinkage ratio
Sup Spe beta 1	0,75% Supaflo Spe.	14,7%	2	0,47%
Sup Spe beta 2	0,75% Supaflo Spe.	14,3%	2	0,47%
Sup Spe beta 3	0,6% Supaflo Spe.	13,6%	3	0,70%
Sup Spe beta 4	0,2% Supaflo Spe.	15,9%	1	0,23%
Sup Spe beta 5	0,1% Supaflo Spe.	16,2%	2	0,47%
Sup Spe beta 0	Nothing else	17,3%	1	0,23%

The first three samples were very particular while mixing; they seemed "dry" but were very workable at the same time. They have no bleeding at all and it was impossible to render a smooth surface over the sample.

On the other hand the sample with 0,2% of plasticizer had a little bleeding enabling a smooth surface, it looked like it was the best ratio founded.

New Ideas that came from those tests:
The classic concrete plasticizers were working properly with cement for the poured earth technique and were very promising. Unfortunately those experiments occurred at the end of my internship and many things are still to be experimented with this product like finding a more profitable ratio of plasticizer or trying different aggregate mixes or different kinds of soils.

Conclusions

According to the results and observations, a plasticizer ratio of 0,2% in mass out of the aggregate mix was suitable.

Classic concrete plasticizers react with cement by surrounding the cement molecules and separating them, but since the mix designs used three times less cement than in concrete, the efficiency of concrete plasticizers might have been inevitably reduced.
Finding a product that acts on both cement as a plasticizer and clay as a deflocculent would probably be the clue and the most efficient solution.

Synthesis of poured earth project:

From the previous experiments we conclude that:

- Cement stabilized earth concrete cannot use any detergent like washing powder, Soapnut or soda. But they react well with super plasticizers which are the promising solution to master the poured earth technique.
- Lime stabilized earth concrete can use detergents as a plasticizer, washing powder does work, but Soapnut would be more suitable since it is natural, cheaper and sustainable.

Other experiments and R&D projects:

During my internship I did experiment other products for the poured earth research project which were not very effective, or other experiments not directly linked to the poured earth project.

1 - Maxeh additive

The Maxeh product is an additive produced in Mexico which allows its creators to master the poured earth technique within certain conditions. The designers of this product came to visit us at the Auroville Earth Institute and we performed some tests with them. The aim of these tests was to see if we could use the Maxeh additive with our proper soils and conditions.

Original specifications:
Maxeh is initially used with silty sand soils containing no or a very few clay (5%<). According to the tests of the producers, the less clay in the soil, the better it works.
The specs are: 11% cement out of the aggregate mix which is 100% soil. Maxeh product dosage is

400g/50kg cement. So it makes 0,8% of Maxeh out of cement, and 0,088% out of the aggregate mix, in mass.

Test performed at the Earth Institute:
One first test was performed at the earth institute, including a shrinkage test and a compressive strength test.
All the elements were mixed dry, then the water was added until we reached a good workability.
Three moulds were then oiled: a rectangular mould (43x17x4cm), a cube (10x10cm) and a cylinder (Ø 10,4cm, h=21cm).
All the samples were poured at the same time from the same admixture.
The rectangular sample if left under shade to dry for one week to measure the shrinkage test. The two others are cured during 28 days and then crushed during the compressive strength test.
The mix design was: 100% red soil for aggregates, 11.6% cement and 0.09% Maxeh out of aggregate in mass. 28% water out of total dry mix.

Sample	One week shrinkage (mm)	Shrinkage ratio	Density (kg/m^3)	Compressive strength (MPa)
Rectangular	3,5	0,81%		
Cube			1840	1,8
Cylinder			1850	1,2

When curing the cube and the cylinder, it appeared they were expending a bit which resulted in some cracks weakening the material. This was due to the important amount of cement.
The shrinkage was quite high but it was without curing, maybe curing the sample would have reduced it.

Remarks
In this test the cement ratio was very high to meet the specifications, but more tests can be done with less cement.
A lot of tests can be done with this product as it is very efficient and promising. The following designs were not realized so they could be done in the future.

Conclusion
The Maxeh additive was quite impressive as it allowed using poured earth technique with great strength results. However, it was very restrictive and designed for a soil without clay, which is very rare, and uses a lot of cement, which is not eco-friendly nor sustainable.

Since this product is quite promising it worth the try to experiment it at the Earth Institute. It could have been a good solution for the poured earth technique but needs to be reviewed to match the soil variety and the economical issue.

2 - Local lime

Objective
The aim of these tests was to measure the efficiency of a lime produced locally in the region of Pondicherry. This lime was not pure but mixed with ashes in proportions we did not know. The type of

ashes was also unknown. I proceed to two shrinkage tests to see if we could have some use of this "local lime".

Tests designs and results
The common sample mix was: 40% Soil, 40% Sand, 10% Gravel Chips, 10% half-inch Gravels, by volume.

Sample	Local Lime ratio	Water ratio	Two weeks shrinkage	Shrinkage ratio
LL1	7,5%	17,0%	7	1,63%
LL1 x2	15%	19,1%	9	2,1%

As we can see this local lime was not very effective.
If we compare to our results is the washing powder test, the same amount of industrial Lime (7,5%) made 5,5mm shrinkage which is 21% less. Furthermore with à 15% of lime the shrinkage is even increasing.
So this local lime was not very effective and could not be used like that for the poured earth project, or any other use in fact.

3 - Aeonian

Objective
This test aimed to experiment a new stabilizer for earth: *Aeonian*, produced in the USA. This product is a stabilizer for clay, designed for roads at the origin. This stabilizer was tested for compressed stabilized earth blocks first, as it is the initial will of its producer. I followed the tests of the CSEB using Aeonian, which was an independent R&D project regarding CSEB, but since this product could have also be used for poured earth, I did some experiments with it. Shrinkage and compressive strength tests were carried out with this product.

Since we were testing here a stabilizer, it implied a potential reduction of cement if it worked, and thus could have been more ecological. Thus this product was experimented with different concentrations and different amounts of additional cement.

Test design and results
The same aggregate design is used for every sample: 70% red soil, 10% Sand, 10% Gravel chips, 10% half-inch Gravels, by volume. Since the product *Aeonian* was supposed to react mainly with clay I did not add much sand and gravels.

Then cement was then weighed and added, its quantity was defined in the specifications as a percentage in mass out of the dry aggregate mix.

The dosage of *Aeonian* product was suggested by its producer: trying both 1/300 dilution and 1/150 dilution.
For the 1/300 ratio: I mixed 4 liters of water with 4/300 = 13,3 mL of Aeonian
For the 1/150 ratio: I mixed 4 liters of water with 4/150 = 26,7 mL of Aeonian
The corresponding solution was added to the dry mix according to the design.

Sample	Cement ratio	Aeonian dilution	Water ratio	Two weeks shrinkage (mm)	Shrinkage ratio
A1	0%	1/300	10,9%	13	3,50%
A1 beta	0%	1/150	12,5%	15	3,49%
A2	3%	1/300	15,2%	4	0,93%
A2 beta	3%	1/150	15,2%	3,5	0,81%
A2 gamma	3%	1/150	17,4%	4	0,93%
A3	6%	1/300	14,8%	2,5	0,58%
A3 beta	6%	1/300	14,7%	3	0,70%

All the samples were very hard to mix and pour; the mixes were all very sticky and the workability was poor. But the samples with 6% cement were a bit easier to handle than the first ones.
The samples without cement (A1, A1β) took almost a week to dry and harden completely; they also had important cracks.

Crack on a cement free sample / Fissure sur un échantillon sans ciment

The design 2 gamma was done in larger quantities (10L) in order to do a slump test and a cylindrical sample to submit it to a compressive strength test. However the slump test did not work since the mix was too sticky and could not indicate anything.
While curing both the compressed earth blocks made with *Aeonian* and the cylindrical sample, we realized with Ayyappan that they were totally melting and had strictly no resistance to water.

The cylindrical sample was not done perfectly because of the low workability of the admixture.
The compressive strength test was made after 12 days of "curing" where the sample was melting.
It took no load and could have been crushed by hand easily.

With CSEB

The Aeonian product was tested for CESB, using the same two dilutions (1/150, 1/300) and cement ratios (0%, 3%, 6%) but also varying the type of soil, using soils more clayey, sandy or silty to see the difference. For all designs the workability was also poor. In the end most of the blocks were cracking, and the one which did not had resistance neither to water nor compressive strength.

Conclusions

The results were not good either for shrinkage, workability or compressive strength. The reactions implied with this product were not useful for poured earth on any aspect, and were making things even worse. The same results were found with CSEB, they were all cracking or very weak.

Management

Since the beginning of my internship it had been set up that I will work on some project management, which I partially did with the SEDAB project before being replaced by a full time trainee.
Furthermore, since the managers of the Earth Institute have travelled during an important part of my internship I helped out with some office management, mainly following the work of two employees in computer science, and using some managerial tools like a work time analysis software.

SEDAB project

The project was under Govt of India's Ministry of Rural Development SGSY and has a new project name: SEDAB, Sustainable Enterprise Development in the Bioregion of Auroville.
It is a project initiated by the government that aims to develop the Tamil villages in the region of Auroville and its surroundings on every aspect: economy, social aspects, education, infrastructures.
Thus, the government of India decided to make donations to the elected projects that would fulfill these objectives.
The Auroville Earth Institute presented a social business: a CSEB production project called E'blocks.

E'blocks

The project aims to develop the production of earth blocks in the Auroville Bioregion.

The production of E'Blocks shall have the following benefits at the village level:
- Enable Villages to locally produce an Eco-Friendly building material at a low cost.
- Develop Entrepreneurial skills among production groups.
- Increase Livelihood of villagers.
- Aid local infrastructure development using high quality building materials at a lower cost.
- Transfer Earth-construction techniques and skills though training and participation.
- Develop awareness on the use of green and energy efficient materials.

The production process is efficient under the right supervision and uses large amounts of unskilled labor and hence has the potential to generate employment in villages to produce bricks for cities/suburbs.

Project aim

The E-Block India and the Auroville Earth Institute will set up 6 production units in the Auroville Bioregion. Each unit shall use 2 machines producing blocks operated by a self help group of 27 persons.

My position in the project

After learning all the details of the project I focused on the financial part and searched information on the Clean Development Mechanism (CDM) instituted by the Kyoto protocol and which could have been a source of revenue for the project.
In fact the CDM says that polluting firms have to buy as much carbon credits on a dedicated financial market as they are polluting. But they buy those carbon credits to firms or organizations that win them by having pollution reduction activities. For instance producing E'blocks, instead of fired bricks or concrete, reduces the green house gases emissions, and thus allows the project to win carbon credits they can sell to polluting industries.

At the moment a carbon credit costs around 13€/ ton of CO², and according to our estimations the E'block project could save 3300 tons of CO²/year. But this is not enough to be recognized as a carbon credit producer by the UNFCCC, furthermore the process to be recognized is very expensive (first step costs 25 K€). So this income cannot be reached unless teaming up with other CSEB producers and share the expenses.

I also attended 4 workshops related to project management and organized by Aurovillians members of others SEDAB projects in Auroville. The themes covered during these workshops were: social business, business plan, and marketing.

Then a trainee from Sciences Politiques more skilled about finance and CDM replaced me on this project that required a full time employee on it.

EBL and computer maintenance

EBL

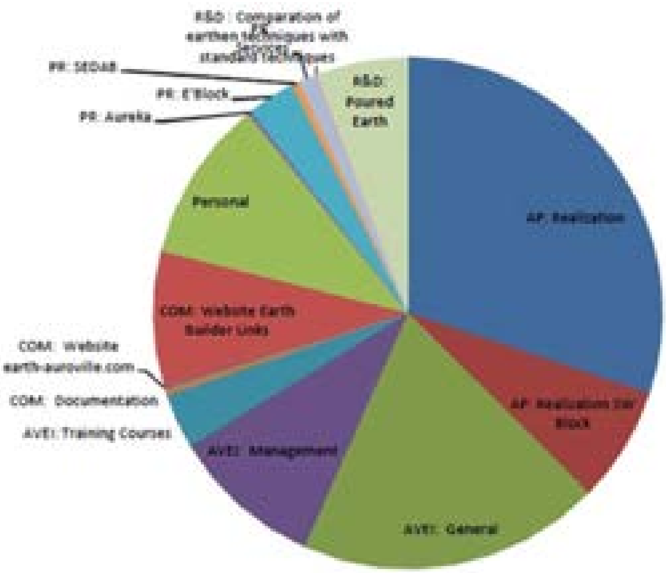
Earth Builder Links is a website aiming to gather all the professionals using earth as a building material, could be architects, engineers, builders or else, in a platform adapted to communication and sharing. The web designer charged to finish this website had a lot of difficulties so I was called upon to follow his work and help him when I could.

Computer maintenance

When I arrived at the Institute the computer maintenance wasn't done by anybody in particular and it was quite a mess with the server and the at least 15 computers. I helped out at the beginning until a new employee came to take care of it and I followed his work on computer maintenance.

Actitime

Actitime is a time manager and analysis software which synthesizes every month the nature of the working hours spent by each employee and trainee, and then offers tools to analyze this information. For instance the time distribution on the different tasks of a project, or the problems where too much time is spent on, and then allows equilibrating and managing more precisely one's working time.



Actitime Analysis tool / Outil d'analyse Actitime
(Realisation was the main ongoing building project)

Conclusion

The poured earth research project is not finished since no final technique was kept nor decisive elements were retained, but a lot of solutions have been discovered and many leads have been found. Some products like superplasticizers and Soapnut are very promising and will have to be experimented further. On the other hand some potential solutions were rejected, like the Aeonian product for instance.
I would also say it was a bit frustrating for me since the project evolved a lot and solutions were founded at the time I had to leave, and I couldn't finish everything I had started.

On the management aspect, the SEDAB project allowed me to learn more about CSEB and to vary my internship, doing marketing, workshops, project management, etc. but it was time taking and I could not have reached this point in the poured earth project at the same time.

As a mechanical engineer, I did learn a lot about the earth material, but more generally about building materials such as concrete, lime, cement, fly ash, etc. and their properties, behaviors, limits. The internship was very formatting since it was combining perfectly theoretical knowledge on materials science and practice through experiments.

The training courses and the internship also gave me a good vision of the building domain as a whole, working with architects was a rewarding experience and brought me a lot. I liked more precisely the earth building techniques and architecture which impressed me a lot, and still impress me.

Finally this internship in Auroville, India, was an incredible human experience. Discovering the Indian culture and way of life was extremely rewarding, and working in English was also a formative adventure.

Happy Holi

Bibliography

Books & Publications

Bâtir en terre – AVEI Library

An introduction to poured earth - Michael Frerking

Earth Manual, U.S. DEPARTMENT OF THE INTERIOR

Bilan CRATerre 2005-2009, CRATerre

Graine de Batisseur rapport 2004-2010, CRATerre

Dossier Béton d'argile, Caracol

Compte Rendu GAIA, CRATerre

Cohésion et comportement mécanique de la terre comme matériau de construction, Laetitia Fontaine

Concrete Technology, ML Ghambir

Norme NF EN 12390-1 & 3

ASTM C39C39M

Main websites

Wikipedia.org

www.earth-builder-links.com

www.earth-auroville.com

http://www.eco-caracol.com

http://www.maxehterracreto.com/

http://www.estigc.fr/labo/beton/abrams.htm

http://webarchive.nationalarchives.gov.uk/+/http://www.berr.gov.uk/files/file15138.pdf

http://www.la.refer.org/materiaux/chapitre_six.html

http://www.vbcoa.org/resources/testcylinders.pdf

Appendices

Appendix 1: Follow-up of the poured earth project

29/12/2010: Starting Project
Launch of Poured Earth Project. Beginning the documentation with the books of the Institute library.

03/01/2011: Web Documentation
Started to search on the web for information. Learnt more about earth and earth architecture

13/01/2011: Web Documentation & Correspondence
Followed web researches. Started to correspond with CRATerre & Korea about Poured Earth.

23/01/2011: Web Documentation & Correspondence
Followed web researches, found good CRATerre documents. Followed the correspondence with CRATerre & Korea about Poured Earth, no answers from CRATerre and not usefull documentation from Korea.

04/02/2011: Web Documentation & Correspondence
Followed web researches, found Caracol documents.
Asked information to Caracol. Found the dispersant used by Caracol: Hexametaphosphate and Lignosulfonates. Made researches on them.

11/02/2011: Web Documentation, Correspondence and First Washing Powder Tests
Satprem suggested using washing powder as a plasticizer. Tests with washing powder and cement, and also additives as fly ash and rice husk ash, are planned, designed and cast.
CRATerre in answering through Magali Aupicon, she is doing a summarize project on every documentation and results on poured earth during the past five years. Her work should be released in September. She sent documentation on their last workshop on poured earth.
She is willing to help and we will share every new information and results we find.
Laetitia Fontaine from CRATerre has started a 3 years research program including the research of natural stabilizers.

14/02/2011 – 26/02/2011: Training course

05/03/2011: Web Documentation, Correspondence, Washing Powder Tests
Lionel Ronsoux from CRATerre has made tests with earth and wood ashes, but don't have results yet.
A new stabilizer for earth is offered to the Institute by Sunil Rastogi, it is called Aeonian and Satprem will first do tests with it for blocks.
The tests with washing powder and cement are completed. The washing powder is effective, reducing the amount of water needed and therefore the shrinkage. Moreover, the mix with Rice husks ash and washing powder seems to be the best regarding the shrinkage.

12/03/2011: Web Documentation, Correspondence, Washing Powder Tests
Planned and designed the shrinkage tests with washing powder and lime. Studied the idea of using soda with lime and cement, it appeared to be impossible. Searched the properties of rice husk ashes and fly ashes as a substitute to cement, and also as a plasticizer additive.Drew and ordered an Abrams cone at Aureka.

19/03/2011: Web Doc, Coressp, Washing Powder Tests, Compressive Strength Documentation
Casted the shrinkage tests with washing powder and lime. Searched for standards and protocols on compressive strength tests for concrete. Searched for standards and protocols on slump tests for concrete.

26/03/2011: Web Doc, Coressp, Washing Powder Tests, Compressive Strength Documentation
Received new documents from Korea about cementless earth concrete.
Received new documents and links from CRATerre about compressive strength test and samples making.
Searched for standards and protocols on compressive strength tests for concrete.

02/04/2011: Web Doc, Coressp, Cylindrical samples, Compressive Strength Documentation
Ended the test with washing powder and lime.
Made one cylindrical sample of rammed earth, and one of poured earth with washing powder.
After noticing the melting of the poured earth sample while curing, made two concrete 10x10x10 cubes, one with washing powder and one without. It appeared washing powder cannot work with cement.

09/04/2011: Web Doc, Coressp, Cylindrical samples, Aeonian Test
Designed and started the shrinkage tests using Aeonian binder. Received the slump cone from Aureka.
Made one cylindrical sample of poured earth without washing powder and one of Aeonian poured earth.

16/04/2011: Web Doc, Coressp, Aeonian Test, Compressive Strength Documentation
Received documentation on European standards for compressive strength tests from Magali Aupicon.
Exchanged information with Kang Nam-Yi, Korean student studying Hwangto concrete.

23/04/2011: Web Doc, Coressp, Aeonian Test, Compressive Strength Documentation
Finished the Aeonian Tests.
Cast two cylindrical samples using Lime and Washing powder and one using Lime only, to see if washing powder has a negative influence on lime like with cement. Designed the compressive strength test and samples.

30/04/2011: Web Doc, Cylindrical samples
Made cylindrical samples for compressive strength test: rammed earth and cement based samples.

07/05/2011: Web Doc, Cylindrical samples, Local Lime
Made cylindrical samples for compressive strength test: lime with and without washing powder based samples.
Made two shrinkage tests with a local lime to test this product.

14/05/2011: Web Doc, Cylindrical samples, Maxeh
Finished to make the cylindrical samples.
Got the visit of Enrique Martinez and his team for the presentation of Maxeh additive, made some test with it.

21/05/2011: Web Doc, Supaflo, Wall
Went to Pondicherry to buy super plasticizer SUPAFLO and SUPAFLO SPECIAL, made some shrinkage test with them.
Started to design a poured earth wall. Cured the cylindrical samples.

28/05/2011: Web Doc, Supaflo, Compressive strength test, Wall
Started crushing cylindrical samples to measure compressive strength. Followed the shrinkage test with super plasticizers.

04/06/2011: Web Doc, Supaflo, Compressive strength test, Wall
Finished the compressive strength test. Made new shrinkage tests and designs with the super plasticizers.

11/06/2011: Web Doc, Supaflo, Wall, Soapnut, Reports
Followed the tests with plasticizers. Designed the proportions and mixes for the walls.
Made new tests with soapnuts as a natural substitute to washing powder. Started the reports.

18/06/2011: Soapnut, Reports
Followed the tests with Soapnut. Typed the test reports and the internship report.

Appendix 2: Calculations and results typical excel sheet

Test design:

(PIV) = Percentage in Volume		1 - Cement (11/02/2011)			1bis - Cement - No washing powder (11/02/2011)			Name and date of the sample
	Density (kg/L)	*Quantity (L)*	*Mass (Kg)*	*Percentage*	*Quantity (L)*	*Mass (Kg)*	*Percentage in mass*	
Soil	1,23	1,25	1,538	40 % (PIV)	1,25	1,538	40 % (PIV)	Aggregates, percentage in volume to match the real scale constructions
Sand	1,5	1,25	1,875	40 % (PIV)	1,25	1,875	40 % (PIV)	
Gravel	1,33	0,313	0,416	10 % (PIV)	0,313	0,416	10 % (PIV)	
Gravel chips	1,345	0,313	0,420	10 % (PIV)	0,313	0,420	10 % (PIV)	
Total of the mix		3,13	4,248		3,13	4,248		
Cement (% in mass out of dry mix)	1,34	0,238	0,319	7,5%	0,238	0,319	7,50%	Binders, percentage out of total aggregate mix
Lime (% in mass out of dry mix)	0,51	0	0	0	0	0	0	
Rice Hull Ash (% in mass out of dry mix)	0,28	0	0	0	0	0	0	Additives, percentage out of total aggregate mix
Fly Ash (% in mass out of dry mix)	0,88	0	0	0	0	0	0	
Washing Powder (% in mass out of dry mix)	0,89	0,0477	0,0425	1,00%	0	0	0	
Water (% over the total dry mix)	1	0,530	0,530	11,50%	0,560	0,560	12,26%	Water ratio, percentage out of total mix (aggregate+ binders+ additives)
Total		3,941	5,140		3,923	5,127		Total mass and volume

Shrinkage results:

Observations	t0	Good texture, workable	Good Texture, workable
	One Week	Apparently dry	Apparently dry
	Two Weeks Shrinkage (mm)	4,5	5,5
	Mould size (mm)	431	430
	Shrinkage ratio	1,044%	1,279%

Compressive strength and slump results:

Observations	t0, casting time	2 mm slump, taken out of mould 16 hours after pouring, covered with plastic sheet for 48 hours, average bleeding			3,5 mm slump, taken out of mould 16 hours after pouring, covered with plastic sheet for 48 hours, average bleeding		
Compressive strength test	Age of the samples	28 days			28 days		
	Weight of the samples (g)	3874	3828	3702	3736	3784	3770
	Length (mm)	208	213	210	210	212	210
	Area of the samples (mm²)	8495	8495	8495	8495	8495	8495
	Length/Diameter ratio	2,00	2,05	2,02	2,02	2,04	2,02
	Density (kg/m^3)	2193	2116	2075	2094	2101	2113
	Average Density	2128			2103		
	Type of failure	Diagonal	Cone	Cone	Cone	Cone	Cone
	Load at failure (kN)	21	20	19	13	13	15
	Compressive strength (MPa)	2,47	2,35	2,24	1,53	1,53	1,77
	Average Compressive Strenght (MPa)	2,35			1,61		
	Average Compressive Strenght (kg/cm²)	24,00			16,40		