

POURED EARTH CONCRETE (PE) RESEARCH

ROAD EXPERIMENTATION REPORT

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INTRODUCTION

The technique of Poured Earth Concrete (PEC) can be used for several applications in buildings and constructions. For example, we can use it for public purpose such as roads.

Here we would like to experiment with the PEC behaviour in roads application. After some thought about what is expected, all the tools which have been used to design samples of different mixes or walls will be used to design the road:

- Density simulation according to aggregates proportions
 - o Knowing that the same Red Soil will be used, like in previous tests, this tool uses also the soil gradation which has been done before.
- Designing the mix to calculate each and every quantity of each and every component

But designing a road is totally different than designing a wall, so the first step was to define what we are looking for, and translate it into some characteristics and variables.

In a second part, this experimentation will be used for a landscaping project, called BOMBOO Project, on which works the Auroville town planning body "*L'Avenir d'Auroville*". Without giving too many details, PEC will be used for the construction of three roads in Bommayapalayam between the ECR and the beach.

The AVEI's participation began at the end of the project's design phase (at the end of August), and the project's first constructions should start soon after. So all these thought and designs have been done pretty quickly, regarding what can be done on a Road application for PEC Research.

1. ROAD MAIN DESIGN

1.1 SITE CHARACTERISTICS

There was not much available information about the site where we built the road portion. So in this first part, all the needed information will be listed while our case will be presented (to know about what data have to be collected, and what can be done with it, we mainly took sources in (1) and crossing them with other documents in the following folder [..\..\01 Documentation\2014 Théo\Roads](#)).

1.1.1 Soil characteristics

First, some soil characteristics have to be known. The most important one is the bearing capacity of the soil (in other words, what is the maximum load that the soil can support, before the rupture?). This figure is given as an admissible pressure, being in kN/m^2 .

According to this bearing capacity, you should know if it is necessary to stabilize the soil or not, and after evaluate the needed different dimensions of the road.

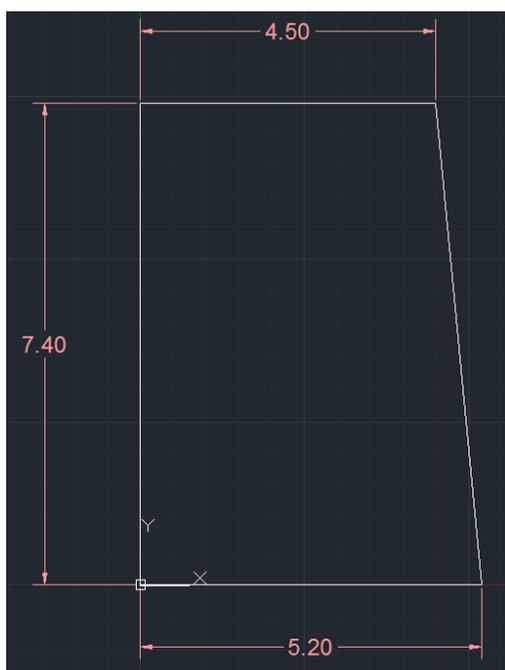
In our case, because the bearing capacity of the soil where we will build on is not known, we made different hypothesis:

- The place has already been used as a road, but without any road installations. But, that means that the soil is already compacted.
- Because of the previous hypothesis, we consider the bearing capacity of the soil as “good”.

On the other hand, the fact that our road will be in earth concrete, the layer of earth concrete will be really hard and not deformable (meanwhile a bituminous road is much more elastic). Which means that any loads on the surface will be well spread on the under layer, so the soil doesn't need to have a high bearing capacity according to this fact.

1.1.2 Dimensions

Here is a little drawing of the place where the road has been done:



So, we have a surface of about 35.89 m^2

1.1.3 Traffic

One of the other important data is about the traffic which will use the road. For us, we have to consider two cases: the experimental road in the entrance of the Auroville Earth Institute, and the possible construction in the project of Bommayarpallayam.

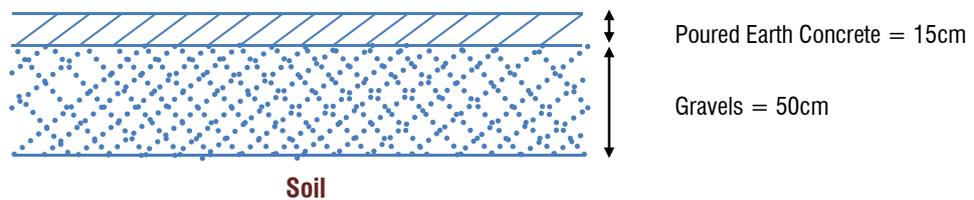
- For the first one in AVEI: the traffic will be very low = 30 to 40 passages of motorbikes, 4 passages of cars, 6 passages of trucks (according to an everyday observation since several months).
- For the second in Bommayarpallayam: We don't have such an accurate idea. But the road will be a second way from the ECR (East Coast Road), which is a high traffic road. We still can consider this way as a low traffic road because it may be less than 1500 vehicles/day (according to where it goes).

These facts give us some ideas about the needed strength of the road. Nevertheless, we don't have accurate data for this, so according to some ideas given by (1), we will just do a hypothesis saying that we don't need a big layer of earth concrete.

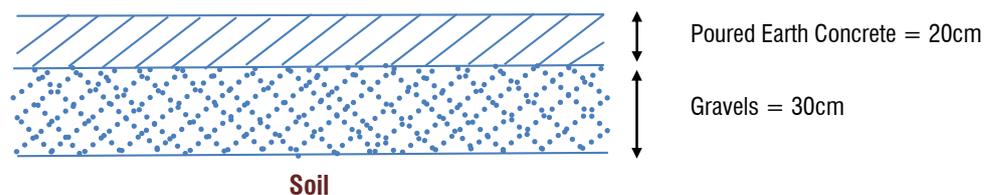
1.2 POSSIBLE STRUCTURES

According to the previous paragraph, we have some hypothesis about the site characteristics, but it does not allow us to be sure about which structure can be chosen. For this reason, two different structures have been presented in order to better choose what is possible to do:

- If we consider that the soil has a very low bearing capacity, then:



- If we consider that the soil has a low bearing capacity, then:



Each layer has a role and so different targets according to its size:

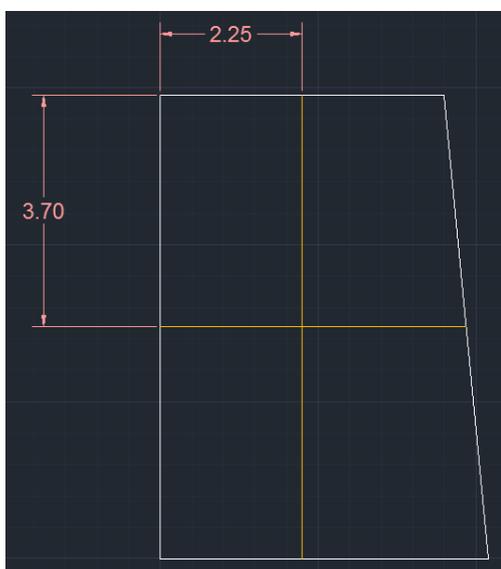
- The first layer in gravels has to be a good support for the second layer. It has to improve the bearing capacity of the soil by spreading the load and prevent any soil movements (unlike the soil, gravels are supposed to not move according to the weather).
- The second layer has to support the load without cracking or moving (which mainly depends on its thickness). It has to be adherent, evacuate the water, and spread the load to the ground.

1.3 JOINTS

The main reason to build a concrete road with joints is to avoid cracks, because of the shrinkage (or any volume movement because of the weather). In our case, we have even more reasons to do joints:

- Because of a new mix of earth concrete, we don't have any ideas of what can be the behaviour of our road.
- Joints can be used as drainage to evacuate the stagnant water on the surface.
- Joints are used for every concrete road which doesn't have any reinforcement (according to French standards). Knowing that here, around Pondicherry, the weather's characteristics (temperature and moisture) are particularly dangerous for any concrete constructions, it can be reasonable to do joints.

Here are the main dimensions of what we could have done:



For the realisation, two ideas have been presented for what we could have done:

- Let an oiled steel sheet of about 4mm thick while the Earth concrete is poured. Then remove it when it is hard enough.
- Cut directly into the concrete, about 5cm deep, after it is dried.

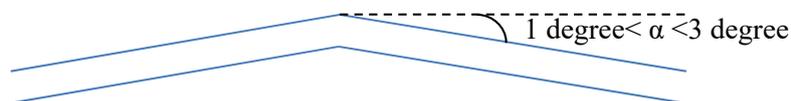
1.4 SURFACE TREATMENT

Like it was written before, the earth concrete layer has to be really adhesive so that vehicles don't slide. To reach this target, the road has to have particular surface treatment. Here are the different ideas which were presented:

- While the concrete is getting hard (and when it is hard enough), sweeping the surface with a hard broom. The aim of this method is to create stripes, not too deep (between 1 and 2mm), on the surface.
- Apply another layer, really thin, with binder-treated chips or 1/4" gravels. This layer must be applied directly after the earth concrete one, so that they get hard together.
- Apply a sand+chips layer directly after the earth concrete layer so that it gets stuck in it to produce an adhesive surface.

1.5 WATER EVACUATION

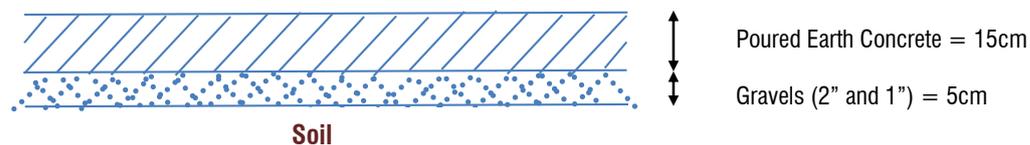
This point is particularly important for the poured earth concrete. If the mix absorb too much water (once it is cured and dried), there are more chances that it cracks because of expansion and shrinkage due to the variation of the weather. Indeed, a slope should be design in order to evacuate the water from the road to its sides:



1.6 FINAL DECISION, FINAL DESIGN

The main aim of this experimentation is to observe the behaviour of the PEC used for road construction. For this reason, and because of the previous noted hypothesis, the decision is the following one:

- Structure



- No joints have been done, in order to better observe the shrinkage of the all road portion.
- The surface treatment will be done by sweeping with a hard broom. This method is easier, cheaper and time saver.
- No side slopes have been done, as the site had already a natural slope in its length.

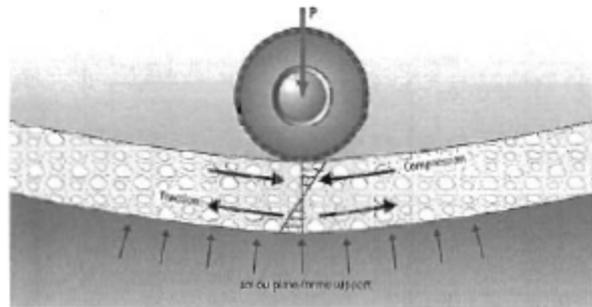
2. MIX DESIGN

After having chosen the General design (structure, dimension...), the proportion of each component of Earth Concrete mix had to be found. One of the first ideas was to take the same mix as had been tested before, so that we already have an idea of its behaviour. But the point is that it is not some application at all. Like walls, roads also need to have a good compressive strength and not too much shrinkage. But in addition they need to insure a good adhesion and resistance to abrasion. Indeed, we first have to define the targets, to then find the good mix.

2.1 TARGETS

Here are the main define targets that the mix should reach:

- Abrasion strength = the road has to be adhesive, but that also means that it has to resist to the abrasion created by vehicles. We don't have the method to test this strength, but the more visible little gravel pieces (1/4" gravels or chips) on the surface, the more the road will resist abrasion.
- Compressive strength = the road behaves like a continuous beam. This means that according to the vehicle, it will be load on several points. At these points, there will be compression on top part of the road and traction on the bottom part. We are here expecting.
- Water absorption = As for walls, less than 10% is wanted.
- Shrinkage = It is one of the most important, because if cracks appear and they are too wide or deep, then they can grow and more become dangerous for users as the road is damaged.
- Workability (Self-compacting concrete) = To make the work easier, it would be good to have a self-compacted concrete for this application so that workers don't have to vibrate the mix for a long time, and the all work is shorter in terms of time. Nevertheless, the shrinkage has to be avoided, and it can't be if add to much water is added to make the mixture more workable.



2.2 MIX MODELLING

2.2.1 Dry mix

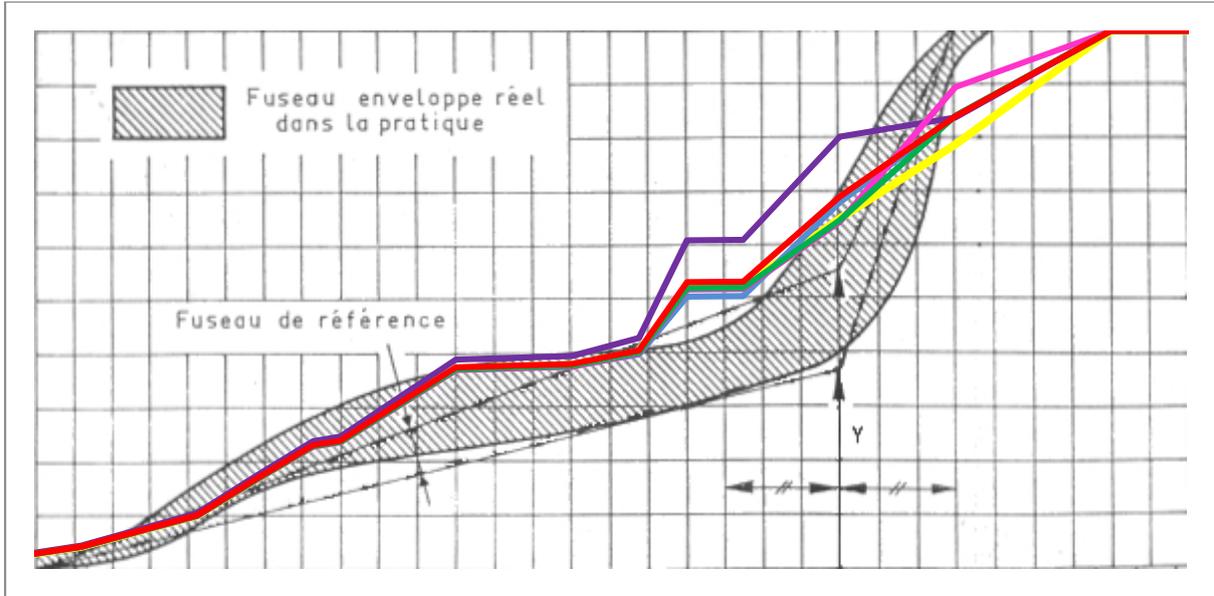
To model the dry mix, the same tool as we used for walls or other samples (2), was used. One more time, knowing that the compression strength is not the main target, this modelling is basically just an observation. However, it is still useful to know that we are not too far from the curve of the best density. With this, we can still expect that the mix will not absorb too much water, and it actually also affects the abrasive strength.

Using the modelling tool, we tried different mixes. The proportion of chips and half inch gravel was always kept high because they help for the adhesion and the abrasive strength. Then, the bigger aggregates will prevent the shrinkage.

In terms of soil proportion, it has been decided that there will not be more than 40% of soil in the dry mix. It was actually because of the results we had from the sample testing (3), which did not show a lot of good findings with 50% of soil.

1	Aggregate	REDSOIL	MASOIL	DUST	SAND	CHIPS	HALF	ONE	TWO	FOUR	TOT
	QUANTITY (%vol)	40	0	0	0	20	10	10	20	0	100
	QUANTITY (%mass)	37.13	0.00	0.00	0.00	20.23	10.04	11.47	21.13	0.00	100.00
2	Aggregate	REDSOIL	MASOIL	DUST	SAND	CHIPS	HALF	ONE	TWO	FOUR	TOT
	QUANTITY (%vol)	40	0	0	0	15	20	10	15	0	100
	QUANTITY (%mass)	37.24	0.00	0.00	0.00	15.22	20.14	11.51	15.90	0.00	100
3	Aggregate	REDSOIL	MASOIL	DUST	SAND	CHIPS	HALF	ONE	TWO	FOUR	TOT
	QUANTITY (%vol)	40	0	0	0	30	15	0	15	0	100
	QUANTITY (%mass)	37.74	0.00	0.00	0.00	30.84	15.30	0.00	16.11	0.00	100
4	Aggregate	REDSOIL	MASOIL	DUST	SAND	CHIPS	HALF	ONE	TWO	FOUR	TOT
	QUANTITY (%vol)	40	0	0	0	20	10	20	10	0	100
	QUANTITY (%mass)	36.80	0.00	0.00	0.00	20.04	9.95	22.74	10.47	0.00	100
5	Aggregate	REDSOIL	MASOIL	DUST	SAND	CHIPS	HALF	ONE	TWO	FOUR	TOT
	QUANTITY (%vol)	40	0	0	0	20	10	15	15	0	100
	QUANTITY (%mass)	36.96	0.00	0.00	0.00	20.14	9.99	17.13	15.78	0.00	100
6	Aggregate	REDSOIL	MASOIL	DUST	SAND	CHIPS	HALF	ONE	TWO	FOUR	TOT
	QUANTITY (%vol)	40	0	0	0	20	15	10	15	0	100
	QUANTITY (%mass)	37.23	0.00	0.00	0.00	20.28	15.10	11.50	15.89	0.00	100

Table 1: Dry mix modelling table



Graph 1: Dry mix modelling graph

2.2.2 Chosen proportions

In accordance with the aforementioned ideas (not more than 40% of soil, two inches gravels to avoid shrinkage, chips and half inch gravels for the adhesion and abrasion strength), the following proportions have been chosen:

	REDSOIL	CHIPS	HALF	ONE	TWO
QUANTITY (%vol)	40	20	10	10	20

Table 2: chosen proportion

Using the mix calculation proportion tool (4), we found these following volumes:

Cement	Lime	Red soil	Chips	Half	One	Two
(bag)	(L)	(L)	(L)	(L)	(L)	(L)
1	25	150	75	50	30	75

Table 3: Corresponding volumes

With the same proportion, knowing the dimension of the road, total volumes were also calculated. The total needed volume of the road was calculated with the following formula:

$$V_{needed} = V_{PEC\ layer} \times C_e \times C_l$$

With:

- V_{needed} = the volume that we need to produce
- $V_{PEC\ layer}$ = the volume of the Poured Earth Concrete layer
- $C_e = 1.4$ is the expansion coefficient
- $C_l = 1.1$ is the loss coefficient. We here consider the loss of earth concrete into the gravels layer.

2.2.3 Additives

In order to be able to compare the compressive strength with the other samples (for wall applications (3)), and to be able to expect a certain strength, cement was added as 9% of the total mass of the dry mix. Then, lime was also used as 3% of the total mass of the dry mix, because we know that, despite the time it takes to harden, lime will greatly improve the compressive and abrasion strength of the mix.

3. PHOTO REPORT

The realisation of the road was done by following several steps. In this section, each and every step will be presented by pictures and text explanation. The digging part started the 26th of August and was finished the day after, while the road casting took one full day, which was the 28th of August.

3.1 DIGGING



Picture 1: digging process

The digging was done using crowbars and shovels. The ground there was actually hard, because of the everyday passage it is already compacted.

Particular attention was given to each border, so that we can better observe any beginning of shrinkage.



Picture 2: digging process

This area may present a problem in the future. The plastic pipe does not move as the earth around it does, which can affect the concrete above (because of the thin gravel layer applied in between).

Because of this fact, this zone should be particularly observed all along the duration of the experimentation.



Picture 3: digging process

We can here better observe the structure of the ground, saying that because of the lumps that it makes, the base ground should have a bearing capacity high enough for the project.

3.2 GRAVEL SPREADING AND OTHER PREPARATIONS



Picture 4: Gravels spreading

A first layer of 2" gravels (5 cm thick) was spread. Even if this layer is thin, it will have several goals: to copy the behaviour of the grip between the PEC layer and the gravels layer, to prevent any ground movement, to prevent shrinkage, to spread the load on the ground...

But just a 2" gravels layer is not really effective because of a lot of holes.



Picture 5: Reference points

Some bricks have been fixed with mortar in order to have points of reference. It will help afterward to make the surface level.



Picture 6: Gravels spreading

So, in the same layer, 1" gravels are spread to fill holes and have indeed created a good gravel layer.



Picture 7: Gravels gradation

We can better see here how was the gradation of this layer.

How much of each gravels?



Picture 8: Site preparations

The ground at the right side (here on the picture) has been planed to be able to correctly level the surface.



Picture 9: Site preparations

Like it was said before, we paid attention to the borders. Particularly here on the front side (opposite to the gate). First, it will be the way to go on the gravels to spread the Earth concrete. It has to be strong so that we don't damage the border with wheelbarrows.

On a second hand, we will observe here the shrinkage of the road portion (if the border is considered as something which can't move).

3.3 CASTING

3.3.1 Site settings



Picture 10: site settings

Here is a first picture of the setting. The road depression is in the background, the mixer was set in the middle in order to separate the material stock zone from the casting zone. It is actually the way the mixer is designed to work: one side is used to fill the hopper and the other side is to pour the mix.



Picture 11: site settings

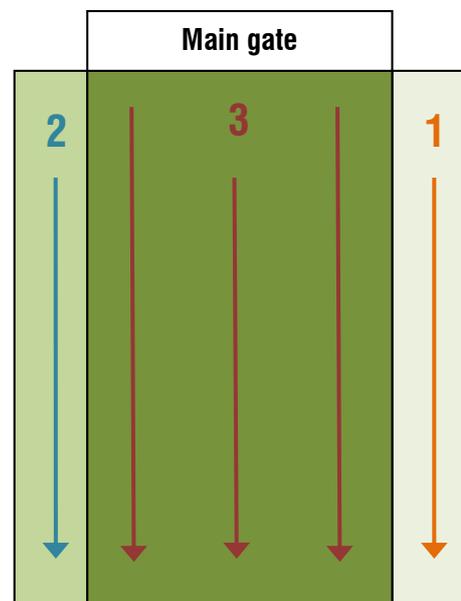
In the material stock zone, every component of the mix is set close to the mixer: water barrels, piles and wheelbarrows of gravels and soil, cement and lime bags.

3.3.2 Process

3.3.2.1 Pouring plan

The available equipment does not allow us to directly pour in one time the all road, we had to plan the way to pour the Earth concrete.

The first step (1 and 2) is to pour the sides (about 60cm width). These two lines will harder while the third one is pouring, so that it can help for the levelling.



3.3.2.2 First mix



Picture 12: Water spreading

Before each and every mix, water should have been spread before pouring the Earth concrete, in order to avoid water loss by the contact with hot gravels or by soil absorption.



Picture 13: first machine filling

The mixing machine has a certain volume capacity. Here, for 1 cement bag, the machine can contain 5 to 6 times this volume. In our case, we wanted to put more than 8 times the cement bag volume. So as to verify if it is possible or not, we tried.



Picture 14: first machine filling

All the dry mix was firstly put into the hopper, following this sequence:

1. ~40 L. water in the drum
2. 40 L. Gravel chips
3. ½ Bag cement
4. 15 L. lime
5. 75 L. soil
6. Mixing 2 min. to get a liquid paste
7. 40 L. Gravel 2"
8. 15 L. Gravel 1"
9. 20 L. Gravel ½"
10. Mixing to get a smooth paste



Picture 15: first machine filling

Then, while the hopper was going up, a part of the mix fell down from it, because it was too much.

This part was after taken from the ground to put again in the mixer. The only problem here is that we cannot really know if it affects the mix proportions.



Picture 16: Hand mix

Finally, the machine was not able to mix that all with the water. Some parts were totally dry while others were too liquid, and it was not mixing well.

Then, the mix with water was finished by hand, on the ground (quantity in the next section "Notes and data").



Picture 17: First mix pouring

Afterwards, the mix was poured, vibrated and then levelled.



Picture 18: First mix pouring

Because of the heat, the difficulty and the time to pour this first mix, it was hardening too quickly, so that it was necessary to speed up the levelling by using hand compactors.



Picture 19: First mix pouring

Then, the top was smoothed.

3.3.2.3 Second and other mixes



Picture 20: Half mixes

After this first mistake, it was decided to only do half mix per half mix. This means that the quantities have been changed (see next section "Notes and data"). Then, we could not use directly full wheelbarrows to put components in the hopper.

Here, buckets have been used to measure volumes of each component. The level is done by hand and don't accurately know their volumes. It is possible that it leads to some mistakes in the proportions.



Picture 21: Half mixes

One mix was done in two steps:

- First these components are added in the hopper: Chips, Cement, lime, Soil. This mix is stirred during 2 minutes.
- Then 2", 1" and 1/2" gravels are added and mix for 2 minutes
- And finally the water is added, and the mix is stirred until the consistency is visibly good.



Picture 22: Half mixes

Once the mix has the good consistency, it is slowly poured in a 200L wheelbarrow, in order to get everything from the inside. The rotating container is hit to make the lasts parts fall.



Picture 23: slump test

For each and every mix, a slump test was done before the rest was poured.

It permits to verify the workability, get an idea of the link between workability and water content (see part 3.4.1 Water content).



Picture 24: Half mixes pouring

Then, the wheelbarrow's content is poured onto the gravel.



Picture 25: Levelling

The levelling is done in several steps:

- The mix is vibrated
- The steel ruler is used a first time to begin the levelling
- Then the holes are filled using trowels
- The steel ruler is passed a second time
- And these two previous actions are repeated until it is levelled.



Picture 26: Last hand mix

At the end, just a little mix was needed to finish the casting, so it was done by hand.



Picture 27: Last hand mix pouring

Unfortunately, this last hand mix was not enough. Because of a lack of time, the last part has been filled up with 1" gravels and then cover again by Earth concrete.



Picture 28: Result

Here is the result!

4. ACTUAL PROPORTIONS AND DATA

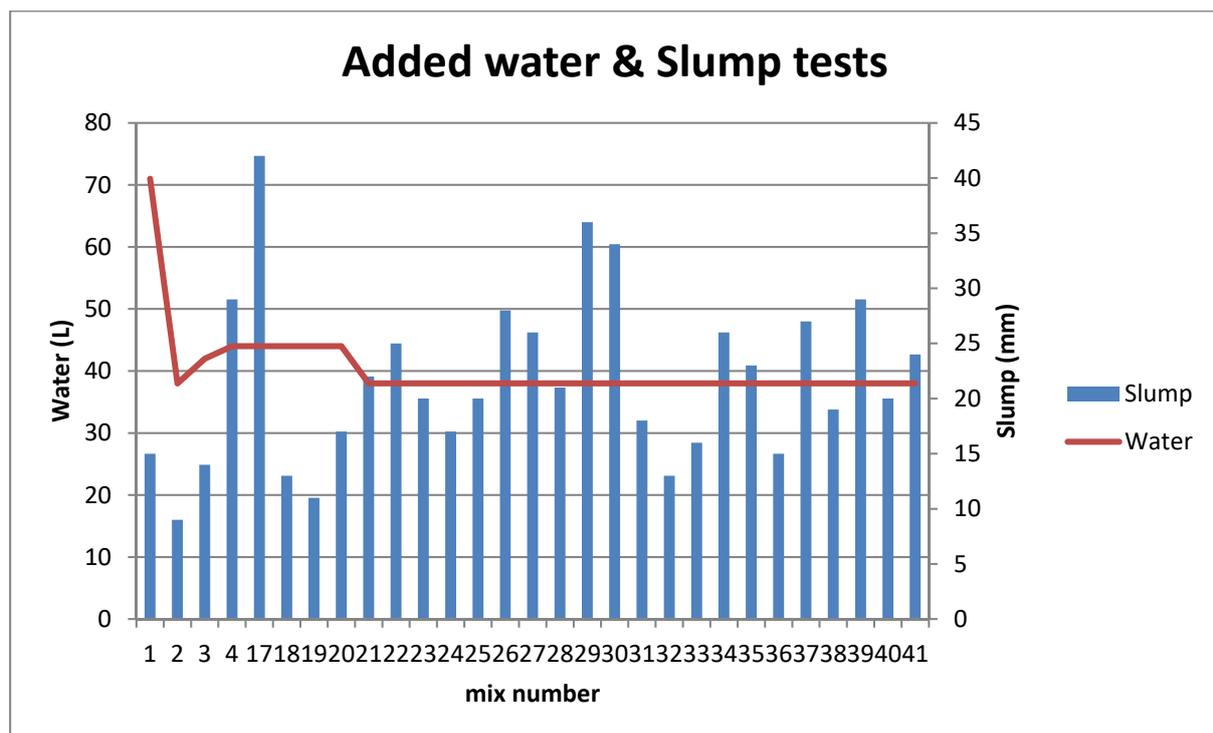
Here is presented all the notes and data, collected from the road casting, which has to be used and kept for future research and projects.

During the casting it was planned that for each and every mix we would always write down the water content and the slump test. But firstly because it was an experimentation, and secondly because of any working conditions, some mistakes and problems happened (as it has been presented in the previous section). This is a main reason why both the following results and interpretations have to be taken with care.

4.1.1 Water content

While observing this graph, one has to remember the previous section saying that:

- The first mix was done on the ground.
- From the second mix to the fourth, the team was searching for the exact needed water content.
- Then the afternoon (from the mix 21), this volume of added water was changed.
- From the 4th to the 17th, the slump measurement was not done properly, so that we can't use them.



Graph 2: Water content and slump test

This graph has two different topics of interpretations:

- On the one hand, if the slump can vary that much even with constant water content, it is because some other variables can influence the slump: the duration of the stirring, the temperature (outside, temperature, the used water or even the gravels), the moisture...
- On the other hand, it must be noted that the slump test was never done each time in the same way and by the same person. This means that we finally can't use any of the slump test data.

4.1.2 Real used proportions

4.1.2.1 Per mix

Here is presented the proportions used all along the road casting. Like it was said before, the first mix is a mistake because of material excess. What is interesting in this table is the comparison of percentages between the theory and the application.

		Cement	Lime	Red soil	Chips	Half	One	Two
		(bag)	(L)	(L)	(L)	(L)	(L)	(L)
Mass percentages wanted		9	3	40	20	10	10	20
First mix	Volumes	1	25	150	75	50	30	75
	Mass percentages	8.49	2.66	36.71	20.00	13.33	9.07	20.89
Other mix	Volumes	0.50	15	75	40	20	15	40
	Mass percentages	8.49	3.18	36.69	21.32	10.66	9.07	22.27

Table 4: Used proportion (volumes and mass percentages)

The table lead to the fact that, for both first and other mixes, we are not that far from the wanted percentages.

The main mistake is done with the proportion of soil in the mix, which is about 4% less than the wanted one.

4.1.2.2 Final quantities

The following table is a summary of all the quantities of each material we needed to make the poured earth concrete road. Note that the sub course was 5 cm thick and 35.89 m². However about 3 m³ of 2" gravel were used to do it.

	Cement	Lime	Red soil	Chips	Half	One	Two	Water
	(bag)	(bag)	(L)	(L)	(L)	(L)	(L)	(L)
Subtotal PE Road	21	9	3,150	1,680	840	630	1,680	1,730
Subtotal sub course						1,000	2,000	
Grand total	21	9	3,150	1,680	840	1,630	3,680	1,730

Table 5: Final proportions

4.1.2.3 Sequences for filling the concrete mixer

The filling of the mixer was initially done as per the usual way:

1. Aggregates - 2. Sand and cement - 3. dry mixing - 4. Adding water - 5 wet mixing.

However the mixer was doing a lot of lumps and kind of paste because of the addition of earth. Therefore the sequence of filling the hopper mixer was done as such:

1. Filling ~40 L. water in the drum (44 L. in the morning and 38 L. in the afternoon)
2. Loading the hopper with: 40 L. Gravel chips, ½ Bag cement, 15 L. lime, 75 L. soil
3. Filling the drum with water and letting it mix it for ~2 minutes (to get a liquid paste)
4. Loading the hopper with: 40 L. Gravel 2", 15 L. Gravel 1", 20 L. Gravel ½"
5. Mixing for a few minutes

4.1.3 Number of workers

The units for the following number of workers are “man/day”.

	WORK	WORKER	MASON	SUPERVISOR
Sub Course	Site preparation	4	0.25	0.25
	Digging	13.5	1	0.25
	Gravel laying	6	2	0.25
Wearing Course	Casting	11	2	1
	Curing	2	-	-

5. REFERENCES

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