# MAIN ROAD RN7 BETWEEN LA PACAUDIÈRE AND CHANGY (LOIRE, FRANCE) : A HIGH PERFORMANCE TREATED CAPPING LAYER AT THE LIMIT OF THE SPECIFICATIONS

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## ABSTRACT

A new section of main road Route Nationale 7 (RN7) has been under construction since 2007 between La Pacaudiere and Changy (Loire, France). This new way is 8 km long and goes across fine soils, essentially plastic clay and clay-sand. This clay-sand had to be treated with 1% lime and 5.5% cement in order to build a capping layer of 40 cm thick. The subgrade had to be treated with lime to get a EV2 modulus over 35 MPa.

At the beginning of the working, the clay-sand was put on a special area to be homogenized and treated with 1% lime. After then, the building company proposed another technical solution to build the capping layer : using a hydraulic road binder instead of cement and increase the mechanical performances of the subgrade formation (EV2 over 50 MPa), to reduce the thickness of the capping layer to 35 cm. A building trial was made in 2008 to compare both solutions. After treatment and compaction, the measurements by gamma densitometer with two probes showed that the average compaction rate at the bottom of the layer was 92% for the project solution and 98% for the building company solution. This last solution was accepted because compaction rate must be over 96% at the bottom of the layer.

Unfortunately, the laboratory study showed that the soil treated with the hydraulic road binder had bad mechanical performances in case of less compaction or less binder content. So, at the beginning of the working, an efficient monitoring plan was set up to guaranty optimal building conditions. Moreover, the building company, on the advice of LRPC from Lyon, has made the layer with high performance working machines such as an in-situ moistening machine, a pulvimixer and powerful compactors. Results of daily moisture content and gamma densitometer tests showed that the realisation objectives had been reached. Moreover, diametral compression tests and deflexion tests showed that mechanical performances had been reached too.

**KEY WORDS** : capping layer, hydraulic road binder, fine soil, gamma densitometer

## 1 INTRODUCTION

Under project ownership Direction Régionale de l'Environnement, de l'Aménagement et du Logement (DREAL) Rhône-Alpes and project management Direction Interdépartementale des Routes (DIR) Centre-Est, a new section of main road Route Nationale 7 (RN7) has been under construction since 2007 between La Pacaudiere and Changy (Loire, France).

This new section of RN7 is 8,9 km long and goes across fine soils, essentially plastic clay and clay-sand. There are neither rocks nor granular soils along this new way. This new road is a succesion of embankments (0,4 $M.m^3$) and cuttings (1 $M.m^3$). All of them are less than 10 m high.

Because of sustainable development reasons, one of the design objectives was to reuse as much as possible the cutting materials to build the embankments and the capping layer. This reuse has the consequence to treat the majority of the RN7 soils with lime and hydraulic road binders.

# 2 THE PROJECT'S GEOTECHNICAL DATA

## 2.1 Geotechnical studies

### 2.1.1 Families of soils

The geotechnical project's study defined seven different ground families (Table 1). In order to limit outside supply and to value site's cutting soils, the study focused on the research of materials to realise a treated capping layer over the entire project.
Because of its geotechnical characteristics, its homogeneity and its volume, the family F1 has been chosen.

Table 1 : Soil families

| Family | | F1 | F2 | F3 | F4 | F5 | F6 | F7 |
|---|---|---|---|---|---|---|---|---|
| % Fines ( <80 µm) | | 33.9 | 16.1 | 75.3 | 8.15 | 58.8 | 31.3 | 92.2 |
| Atterberg's limits | $w_L$ | 35.5 | - | 36 | - | 46.5 | 31 | 60 |
| | $I_P$ | 16.6 | - | 20 | - | 23.3 | 11.5 | 33.7 |
| VBS (methyl blue absorption) | | 1.7 | 1.16 | 1.75 | 0.82 | 3.9 | 2.7 | - |
| Moisture content w (%) | | 11.6 | 11.0 | 20.7 | 12.5 | 24.0 | 19.4 | 28.3 |
| GTR classification | | B5, B6, A1, A2 | B5, B6, B2 | A1, A2 | B4, C1B4 | A2, A3 | B6, A2 | A3, A4 |

### 2.1.2 Geotechnical characteristics of the treated capping layer's materials.

The chosen soil family (F1), is a quite homogeneous clay-sand formation (Figure 1), principaly located in cuttings at both extremities of the project. According to the French technical guide for the construction of embankments and capping layers (LCPC/SETRA, 2000a), also called GTR, these soils are classed B5, B6, A1 or A2. So they are fine soils with a weak plasticity, that have a very good ability for being mixed with lime or hydraulic binders. Also, the possible adjustment of their moisture content can be made easy : volume of water of contribution and time of imbibition limited, fast and homogeneous distribution of the water, moderate cohesion of materials facilitating the mixture and saving some energy.

The geotechnical data shows that the soils of family F1 have a moderate rate moisture, close to the Optimum Proctor Normal moisture $w_{OPN}$ (Table 2).

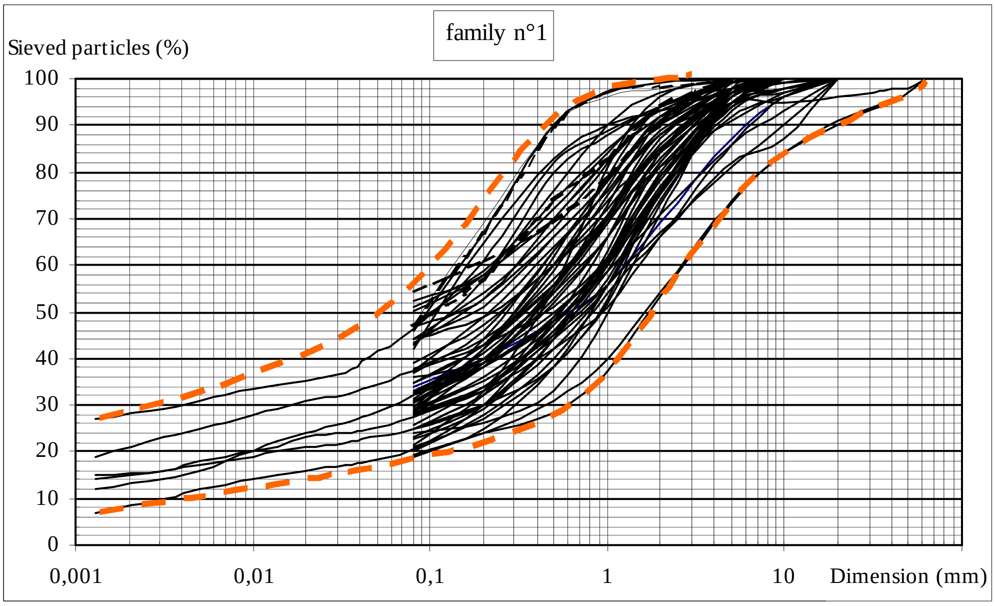



Figure 1 – Grading curve of family n°1.

Table 2 – Geotechnical data of family n°1

| Parameters | | Number of values | Range | Average | Standard deviation | Relative standard deviation | Observations |
|---|---|---|---|---|---|---|---|
| $w_L$ | | 36 | 21 à 53 | 35,5 | 8,2 | 23,20% | Clay characteristics variable |
| Ip | | 36 | 7 à 31 | 16,6 | 5,7 | 34,20% | |
| VBS | | 31 | 0,51 to 4,5 | 1,7 | 1,1 | 64,60% | |
| % fines ( < 80µm) | | 62 | 19,4 to 54,7 | 33,9 | 9,3 | 27,60% | % fines variable |
| OPN | $\rho d_{OPN}$ (t/m$^3$) | 9 | 1,88 to 2,01 | 1,94 | 0,05 | 2,50% | Homogeneous values |
| | $w_{OPN}$ (%) | 9 | 11 to 13,5 | 12,1 | 0,88 | 7,30% | |
| w (%) | | 30 | 7,4 to 17,1 | 11,6 | 2,2 | 18,60% | Hydrous states "s" and "th" have moisture contents very close |

# 3 SPECIFIC STUDIES FOR THE CAPPING LAYER

## 3.1 French method for the design of capping layers

### 3.1.1 Purpose of the capping layer

The capping layer is a layer between the subgrade and the pavement (Figure 2). Its main purposes are :

- Short term : to have grading and deformability characteristics adapted to the pavement set up ;
- Long term : to have deformability characteristics that insure a long life to the pavement and to protect the subgrade against frost.

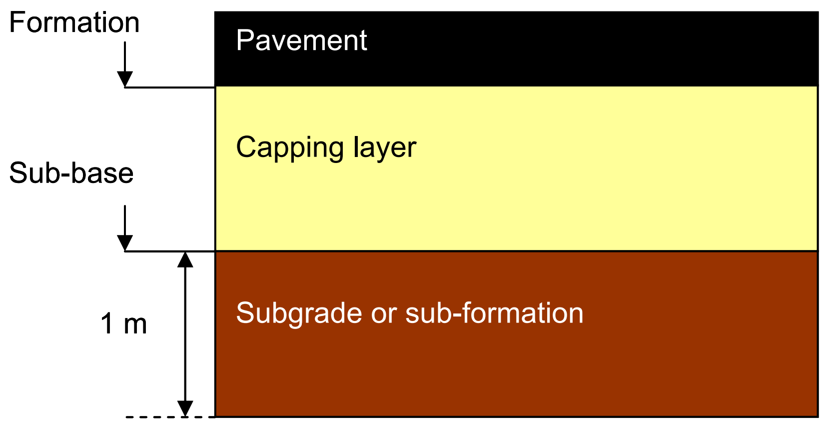



Figure 2 – position of a capping layer, between the subgrade and the pavement layer

To limit the risks of settlement over the long term, the GTR (LCPC/SETRA, 2000a) defines the intensity of compaction (Q/S) for each type of material and of plant used, with quality q4 for standard embankments and q3 for capping layers. The compaction qualities q4 and q3 are explained in Table 3, where $\rho_{dOPN}$ is the dry bulk weight in reference to the French standard Proctor test (NF P 94-093).

Table 3 – definition of compaction quality

| Position of the layer | Embankment | Capping layer |
|---|---|---|
| Compaction quality | q4 | q3 |
| Average dry bulk weight $\rho_{dm}$ | ≥ 95 % $\rho_{dOPN}$ | ≥ 98,5 % $\rho_{dOPN}$ |
| Dry bulk weight $\rho_{dfc}$ in the bottom(*) of the layer | ≥ 92 % $\rho_{dOPN}$ | ≥ 96 % $\rho_{dOPN}$ |

(*) : 8 deapest centimeters of the capping layer

### 3.1.2 Method for the design of treated capping layers

The design requires the mechanical classification of the capping layer. This classification is PF1 (most deformability) to PF4 (less deformability) and depends on three parameters:

- The deformability of the subgrade or sub-formation ;
- The thickness of the capping layer ;
- The mechanical characteristics of the capping layer material.

The mechanical behavior is different between a granular soil capping layer and a treated soil one (Figure 3).
For the first one, a vertical settlement will lead to a compression in the layer, that can be characterized by the static deformation module EV2 measured with the plate test (French standard NF P 94-117-1).
For the second one, a vertical settlement leads to a flexion of the treated layer. The consequence is that a compression strength takes place in the top of the layer and a tensile strength in the bottom of the layer.

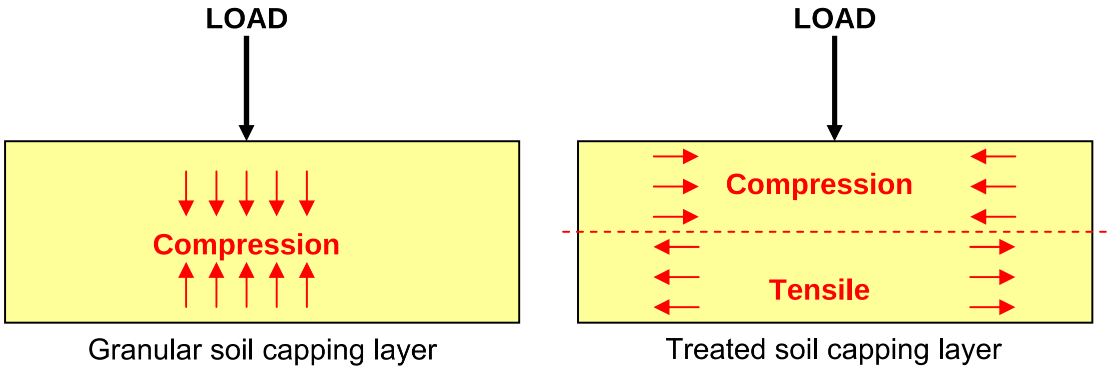



Figure 3 – mechanical behavior of a capping layer (treated or not treated)

Because of less compaction in the bottom, capping layers are characterized by their thickness and the traction resistance Rt and the deformation module of the bottom. The technical guide for soil treatment with lime and/or hydraulic binders (LCPC/SETRA, 2000b), also called GTS in France, defines several mechanical zones in reference to the mechanical characteristics of the soil (Rt, E) with 96 % compaction rate and 90 days after treatment (Figure 4).
Then the GTS (LCPC/SETRA, 2000b) defines the mechanical class of the treated material on the basis of its characteristics and method of preparation (Table 4).
At the end, the design of the capping layer is determined with its thickness, the mechanical class of the treated soil and the sub-formation class (Table 5).

Table 4 – mechanical class of capping layers, depending on their mechanical zone and set up conditions (LCPC/SETRA, 2000b)

| Treatment in stabilisation plant | In-place treatment | Mechanical class of material |
|---|---|---|
| Zone 1 | - | 1 |
| Zone 2 | Zone 1 | 2 |
| Zone 3 | Zone 2 | 3 |
| Zone 4 | Zone 3 | 4 |
| Zone 5 | Zone 4 | 5 |

Table 5 – design of treated capping layers (LCPC/SETRA, 2000b)

| Mechanical class of capping layer material | Capping layer thickness | | | | |
|---|---|---|---|---|---|
| | Sub-formation class AR1 | | | Sub-formation class AR2 | |
| Class 3 | - | 30cm | 40cm | 25cm | 30cm |
| Class 4 | 30cm | 35cm | 45cm | 30cm | 35cm |
| Class 5 | 35cm | 50cm | 55cm | 35cm | 45cm |
| Formation class obtained | PF2 | PF3 | PF4 | PF3 | PF4 |

## 3.2 The soil treatment specific studies

### 3.2.1 The project study

The specific project treatment study allows to select a 1% lime + 5 % cement mixture to reach a mechanical class 5 for a in place treatment. The conclusion of this study is to build a 40 cm thick capping layer over a sub-formation class AR12 to obtain a PF3 formation class.

The sub-formation AR12 is an average class between AR1 and AR2. In this project, this average class is obtained by lime treatment (between 2 % and 3 %) of the sub-formation.

## 3.3 The project adaptation

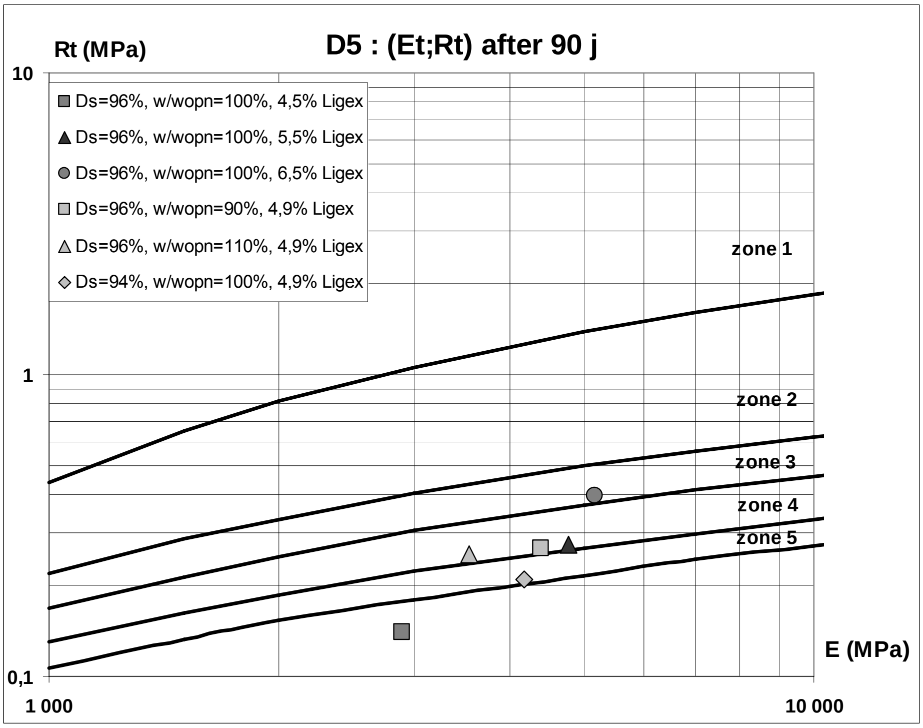
### 3.3.1 The working company's proposal

At the beginning of the earthworks, the working company proposed a technical adaptation of the design of the capping layer.

To begin with, it proposed to replace cement with the Hydraulic Road Binder (HRB) LIGEX 103. The ownership DREAL Rhône-Alpes accepted this idea.
Then, the working company proposed to change the design of the capping layer. The comparison between initial and adapted solutions are summarised in Table 6.

Table 6 – comparison of the two capping layer design solutions

| | Initial design solution | Adapted design solution |
|---|---|---|
| Sub-formation treatment | 35 cm at 2-3 % lime | 35 cm at 1% lime + 3 % LIGEX 103 |
| Sub-formation class | AR12 | AR2 |
| Capping layer thickness | 40 cm in 1 layer | 35 cm in 1 layer |
| Formation class obtained | PF3 | PF3 |




The main reason of this adaptation is the difficulty to obtain a good compaction in the bottom of a 40 cm thick layer.

### 3.3.2 Results of the laboratory tests

The laboratory tests showed that the mechanical zone 4 should be obtained with a 1% lime + 5,5 % HRB LIGEX 103 (Figure 4). But Figure 4 also shows that the results are near zone 5, that is generally insufficient to obtain a mechanical class 5 by in-place treatment. Figure 4 also shows that the treated material has insufficient mechanical characteristics in case of less compaction or less binder content.

In case of treated soils in zone 5, the GTS (LCPC/SETRA, 2000b) recommends to make the treatment in a stabilisation plant. Indeed, with this method, it's easier to control the water content, the rate of binder and the mixture than by in-place treatment.

It's also possible to reach the mechanical class 5 with a zone 5 by in-place treatment, but only by adapted working machines able to control the mixture and by an effective monitoring plan.

Figure 4 – treated soil classification

### 3.3.3 Specific trial and results

In advise of LRPC from Lyon, a trial was made to compare both solutions. The purpose of this trial was also to define the best method to set up the capping layer with a q3 compaction objective.

Several working machines were used during the trial:

- Additive spreader with monitor registering weight of additive spread per unit area;
- In situ moistening machine;
- Pulvimixer;
- Two sorts of compaction rollers : smooth vibrating drum rollers V5 and vibrating tamping rollers VP5. Classification of rollers is explained in GTR (LCPC/SETRA, 2000a);
- Several numbers of load applications were applied with both sorts of rollers and the trials were stopped when the top of the capping layer cracked. After that, the compaction rate was measured with a gamma densitometer double probe test (French standard NF P 94-062). 4 measurements were made by trial area.

The best results of compaction were obtained by applying 7 loads of smooth vibrating drum rollers V5.

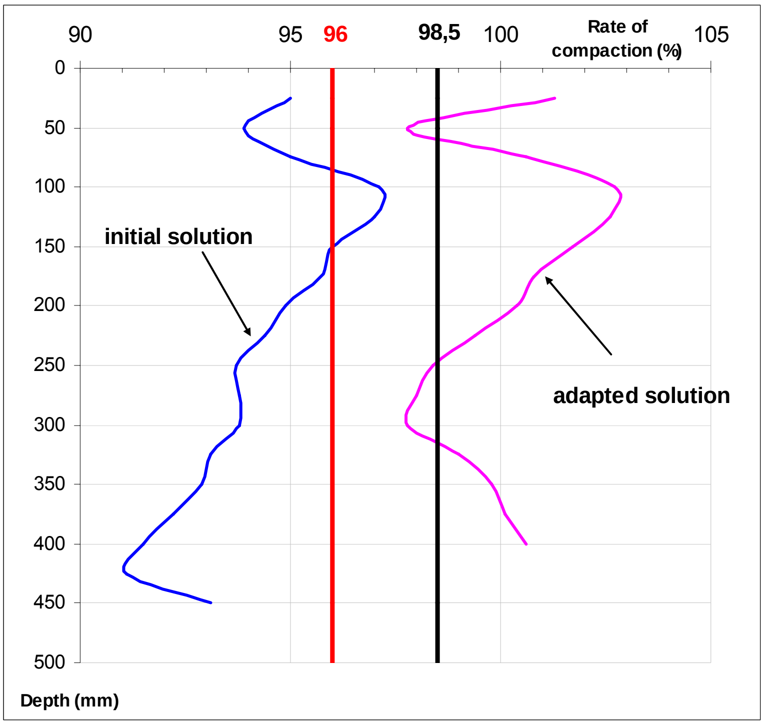



Figure 5 – double probe measurements

Figure 5 shows that the initial solution doesn't reach the compaction quality q3. The average compaction rate is 94%, instead of 98,5% and the bottom compaction rate is 92% instead of 96%. For the adapted solution, the average compaction rate is 100% and the bottom compaction rate is 98%.

The important difference between the results of the two trials can be explained by the fact that the adapted solution's capping layer is only 35 cm thick and the subgrade is much less deformable than the initial solution's one.

After these results, it was decided to confirm the working company's adapted solution for the full scale project.

# 4 APPLICATIONS TO THE FULL-SCALE PROJECT

## 4.1 Set up of the capping layer and monitoring

### 4.1.1 Set up of the capping layer.

At the beginning of the work in 2007, the capping layer's material was selected in the cuttings and put on a special area to be homogenized and treated with 1% lime. The objective of this first treatment was to stabilize this soil during winter 2007-2008.

A few days before building the capping layer, the sub formation level was treated with 1% lime + 3% HRB. The mixing was done by heavy gnaged ploughshares at the rear of a powerful tractor, the compaction by smooth vibrating drum rollers V5 and the grading by laser guided grader.

The capping layer was built in 2008, following the next elementary operations :

- Delivery of the soil on the area and adjustment of the moisture content by an in situ moistening machine ;
- Spreading of the HRB and mixing with a powerful horizontal shaft soil pulveriser ;
- Preliminary compaction by applications of smooth vibrating drum rollers V5 ;
- Checking of compaction rate and moisture content ;
- Fine grading by a laser guided grader and final compaction ;
- Implementation of a surface protection.

| | | |
|---|---|---|
|  |  |  |
| Sub-base lime treatment | Spray with in-situ moistening machine | Mix (in 2 times) |
|  |  |  |
| Fine grading and bulk weight monitoring | Final compaction (1 or 2 load applications) | Implementation of surface protection |

Figure 6 – selected pictures of the capping layer's building

### 4.1.2 Daily monitoring

The day-to-day monitoring focused on verifying:

- the spreading weight per unit area ;
- the number of load applications : 8 applications of load defined in the trial areas ;

- the moisture content : the specific soil treatment study shows that the moisture content must be between 11.2% and 13.6% after treatment ;
- the compaction rate, that must be over 98,5%.

The two following paragraphs deal with verifying the compaction rate and the moisture content.

#### 4.1.2.1 Daily compaction rate monitoring.

The working company proposed to controle the compaction rate by a gammadensitometer Troxler (French standard NF P 94-061-1). This test is faster than the gammadensitometer with two probes but has two disadvantages: the measurement is an average one and the maximum depth is only 30 cm.
The results of the adapted solution trial area showed that the average compaction rates between 0 and 35 cm and between 0 and 30 cm is the same. This can be explained by the fact that the subgrade level of the adapted solution is very rigid, so the compaction rate increases between 30 cm and 35 cm depth in this particular case (Figure 5).

On the advice of LRPC from Lyon, the method was accepted by the project manager and the objective of the monitoring was to reach more than a 98,5 % compaction rate between 0 and 30 cm depth in the capping layer.

Figure 7 shows the results of the 402 measurements during the capping layer's building. The average value is 100,1 % and the standard deviation is 1,5 %. This result is in accordance with the measurements on the trial area: the gammadensitometer with two probes shows that the average value in the trial area layer is 100% (Figure 5).

Only 25 values (7% of all) didn't reach the compaction rate objective of 98,5%. In the area of these 25 bad values, 1 or 2 more loads of V5 were applied to reach the objective.

#### 4.1.2.2 Daily moisture content monitoring.

During all the capping layer's building, the working company made every day one moisture content test before treatment and another one after treatment. The objective of these tests was to have a treated soil's moisture content:

- over 11,2%, value under which the compaction becomes too difficult (dry soil) and value necessary to warranty the normal chemical reaction between the soil and the binder ;
- under 13,6%, because it's the value over which the soil is wet and could be destructurated by application of heavy rollers.

These two values were determined in the working company's soil treatment study.

The results of the in situ Troxler tests made several times every day after compaction are in accordance with the results of laboratory tests, realised every day on treated samples.
Figure 7 shows that 87 % of the in situ measurements reach the objective. Only 6 % of the values are under 11,2% and 7% over 13,6%.
These extreme values can be explained by the fact that the soils are generally heterogeneous materials. The two moisture content limits (11,2% and 13,6%) were determined in reference to the Proctor test references ($w_{OPN}$ and $\rho_{dOPN}$), that were measured on an average sample of the clay sand. So these Proctor references may well be variable.

But in fact, Figure 7 shows that quite all extreme moisture content's measurements (under 11,2% or over 13,6%) correspond to a rate compaction over than 98,5%.

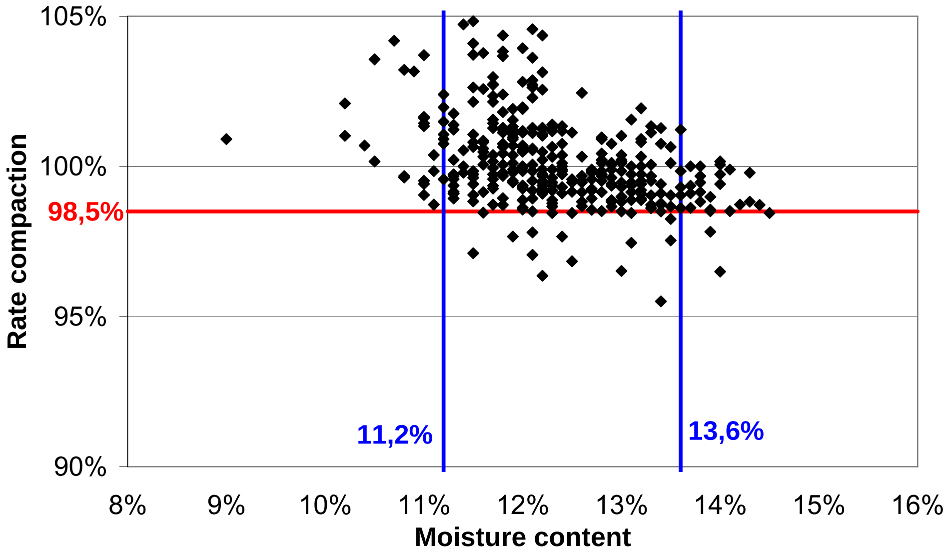



Figure 7 – results of gammadensitometer measurements

The results of the troxler monitoring show that the capping layer was made in good conditions of compaction and wetting, which is essential to succeed in building treated capping layers.

## 4.2 Mechanical class and acceptance

After building the treated capping layer, it was necessary to verify its mechanical class.
11 corings were made in the capping layer with the objective to test the samples from the bottom of the layer in laboratory.

Unfortunately, it was not possible to test the bottom of the layer because the samples in this area had a bad geometrical form, that is essential to measure a representative modulus in the laboratory test.
The bad form of the samples in this area can be explained by the following facts :

- the method of coring (diameter 100 mm and injection of water) may have not been adapted to these treated soils. A larger diameter would probably have given better results ;
- the capping layer and the subgrade layer are not sticked. So it's possible that the sample has rotated and damaged during the coring.

While destructing the trial area, it was possible to see that the bottom of the capping layer was very hard. So there was no doubt that the bottom of the capping layer is well treated.

Two samples from the middle of the layer were tested in laboratory. Even if these samples are not representative of the bottom of the capping layer, the results (Table 7) are much better than the one of the working company preliminary study (Figure 4).

Table 7 – laboratory tests on core samples

| | Sample 1 | Sample 2 |
|---|---|---|
| Compaction rate | 104,6 % | 103,3 % |
| Tensile strength Rt (MPa) | 0,47 | 0,37 |
| Tensile modulus E (MPa) | 4 929 | 3 031 |

At the end of the working, the acceptance of the formation was made by deflectograph (French standard NF P 98-200). The results (Table 8) show that the deflection measurements are much better than the specifications of the GTS (LCPC/SETRA, 2000) for a formation PF3.

Table 8 – results of deflection tests

| | Specification for a formation PF3 | Average deflexion (mm) | Standard deviation |
|---|---|---|---|
| Deflexion (mm) | < 0,6 mm | 0,17 mm | 0,07 mm |

## 5 CONCLUSIONS

Earthworks of main road RN7 between La Pacaudiere and Changy began in 2007. The particularity of this new road is that near from all the embankments are constituted by treated soils and the capping layer is made of treated soils too.
During the works, the working company proposed an adapted capping layer : a new hydraulic road binder and a new design. But this adapted design couldn't be guaranteed with the results of the laboratory tests.

The adapted solution was accepted by the project manager and the owner, but following the advice of LRPC from Lyon, the working company had to use powerful machines and an efficient monitoring plan that would control the compaction, the moisture content and the binder content of the treated soil.

All the results of the monitoring show that the capping layer has been made in good conditions and has reached sufficient mechanical characteristics that will insure the durability of the infrastructure. This experience was possible because of the good complementarity between the owner's and project manager's objectives, the working company's abilities and the experimented adviser in soil treatment.

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