CASE-STUDY ON LIME STABILIZATION OF SOILS FOR TRACKS: "CIRCUITO DE VELOCIDAD DE LOS ARCOS"

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ABSTRACT

Soil stabilization with lime has been assumed to be a good technique for constructing transportation infrastructures. In several conditions, it has been proved that the values of the deformation modulus obtained with these mixtures have greatly exceeded the minimum values specified in design criteria, resulting in supporting layers of roads and railway tracks with characteristics well above the ones necessary for such structures. In these situations, it would be more adequate to take into account this increase in stiffness in the design of upper-level layers, or, alternatively, to consider the decrease in the percentage of lime, in order to optimize the costs of the structural system. Usually, this is not possible since common technical specifications are prepared by default, without taking into consideration an adequate quality control of constructed layers. This optimization could turn this stabilization/treatment technique much more appealing and more economically competitive.
Therefore, it seems to be adequate, for quality control purposes, to rely on performance based specifications dully supported by in situ tests aimed to evaluate the mechanical properties of compacted layers, in particular of lime-treated materials, hence enabling an optimization of track design.
This paper presents the studies that have been done by taking into consideration in situ tests performed on soils stabilized with lime, during the recent construction of a specific race track in Spain: "Circuito de Velocidad de Los Arcos", in the Province of Navarra. The numerical analysis of the results of the tests performed by the Portable Falling Weight Deflectometer (PFWD), on compacted layers of available soils, with and without lime mixing allowed to evaluate the deformation modulus of constructed layers.

KEY WORDS

LIME / SOIL TREATMENT / LOAD TEST / DEFORMATION MODULUS.

1. INTRODUCTION

The present paper addresses the studies related to the in situ tests performed on soils stabilized with lime, during the construction of the race track "Circuito de Velocidad de Los

Arcos", in Navarra Province, Spain (Figure 1), by the company "Construcciones Samaniego".

Figure 1 – Location of the race track "Circuito de Velocidad de Los Arcos"

This project is a permanent race track that has to be approved by national and international car and motorcycle federations, for receiving competitions at the highest level.

In order to implement the track, apart from the layout requirements necessary to obtain an appealing lay-out from a sports viewpoint, the need to observe, as much as possible, the topography of the terrain was also taken into consideration, enabling to obtain a space dully integrated in the corresponding environment.

For this purpose, the natural corridor formed by the hills on the western part of the area was adopted for the main straight stretch of the circuit. Singular points for the public are to be installed on these higher sites, due to the remarkable panoramic view that can be achieved.

2. GEOLOGICAL/GEOTECHNICAL STUDY

The geological/geotechnical study was performed by the company I.T.C., S.A. (Instituto Tecnico de la Construccion S.A.) and was essentially based on the characterization of materials available at the construction site (60 Ha) of the race track.

The *in situ* tests comprised an extensive test program that included the drilling of boreholes at 10 to 20 meter depth and Standard Penetration Tests (SPT). From samples collected on boreholes, it was possible to define the corresponding lithological profiles, and from SPT tests, it was possible to derive the mechanical characteristics of each horizon.

According to TN GPO (2007), the final geotechnical profile, deduced from the *in situ* survey, is characterized by the presence of the materials as follows:

Quaternary Materials

- A vegetable soil occurs in a surface layer with a thickness ranging from 0.2 to 1.3m; it is a material with low organic material content, of a clay nature, and which exhibits parcels of silt, sand and gravel dispersed over a few zones.
- Some man-made deposits were occasionally detected, mainly consisting of clays and materials resulting from excavations on a tertiary stratum. These are very scarce embankments with no lateral continuity.

- Alluvial soils were only identified in the South and have been classified by ASTM D2488 as poorly graded soils with a high percentage of fines (GC) and as silt sands with gravel (SC – SM). The thickness of these soils ranges from 2.0 to 1.0 m, within the identified zone.
- The cohesive soils occur in a layer about 2.0 m thick and are classified as low plasticity silt sands with very low CBR values (2%).

Residual Soils and Tertiary Substrate
- Residual soils result from the decomposition, by meteorization, of a rock substratum in the vicinity.
- The tertiary substratum is attributed to "Los Arcos" formation, which consists of marl clays. At higher zones of the tertiary substratum, these clays are located on the surface, and in lower zones being located at depths ranging from 1.0 and 4.2m. These are very hard soils with low plasticity (CL) and having CBR values ranging from 0.8% and 4.6%.

3. SOLUTIONS FOR THE FOUNDATION AND THE PAVEMENT STRUCTURE

3.1 General aspects

The lay-out design of the circuit presents both embankment areas and excavation areas. The design usually assumed an excavation slope of 1H:1V and an embankment slope of 3H:2V. Those values were meant to ensure the stability of slopes and their easy gardening.
Considering the indications of the geotechnical study, the design also predicts few soil improvements at specific locations, by recurring to different solutions: geotextiles, geogrids, gravel layers, among others. Those solutions are designed only for areas located under the main track and they are not required in the other zones.

3.2 Characteristics of layers

The design of the circuit platform considered all available soils as inappropriate or marginal. Therefore, to achieve an "E_3" platform, which is characterized by a deformation modulus in the second loading cycle of a Plate Load Test, E_{V2}, higher than 120 MPa, in accordance to the Standard 6.1 IC of the Dirección General de Carreteras (2003), one of the structures indicated in Figure 2 was to be constructed on both the embankment and the top of excavation zones. The first solution with 80 cm thickness, was adopted, was adopted, i.e.:
- bottom layer with 50 cm of stabilized soil of type 1: S-EST 1 (E_{v2}≥60 MPa), and
- upper layer with 30 cm of stabilized soil of type 3: S-EST 3 (E_{v2}≥300 MPa).

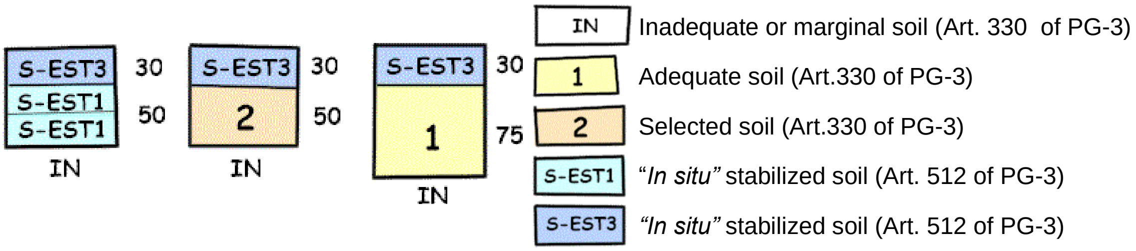


Figure 2 – Structure of E3 platform over a "marginal soil" (Dirección General de Carreteras, 2003)

The pavement structure, in accordance with Standard 6.1 IC (Dirección General de Carreteras, 2003), took into account the previously mentioned platform and the class of heavy traffic of type T_2 (200 < $AADT_h$ < 799, in which $AADT_h$ is the Annual Average Daily

Traffic of Heavy Vehicles). In those circumstances, the 1st. solution indicated in Figure 3 was chosen, i.e.:

- a bottom layer with 25 cm of a well graded crushed aggregate (ABGC); and
- an upper layer with 20 cm of bituminous mixtures, MB (9 cm of MB of type G-25 + 6 cm of MB of type S-20 + 5 cm of MB of type S-12).

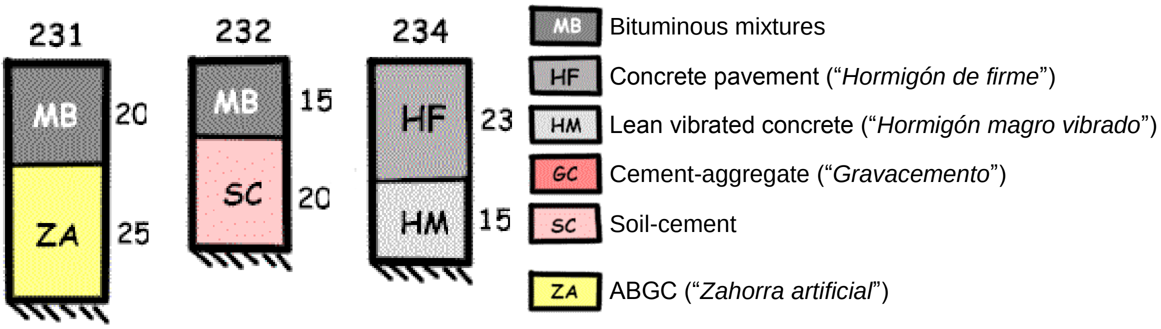


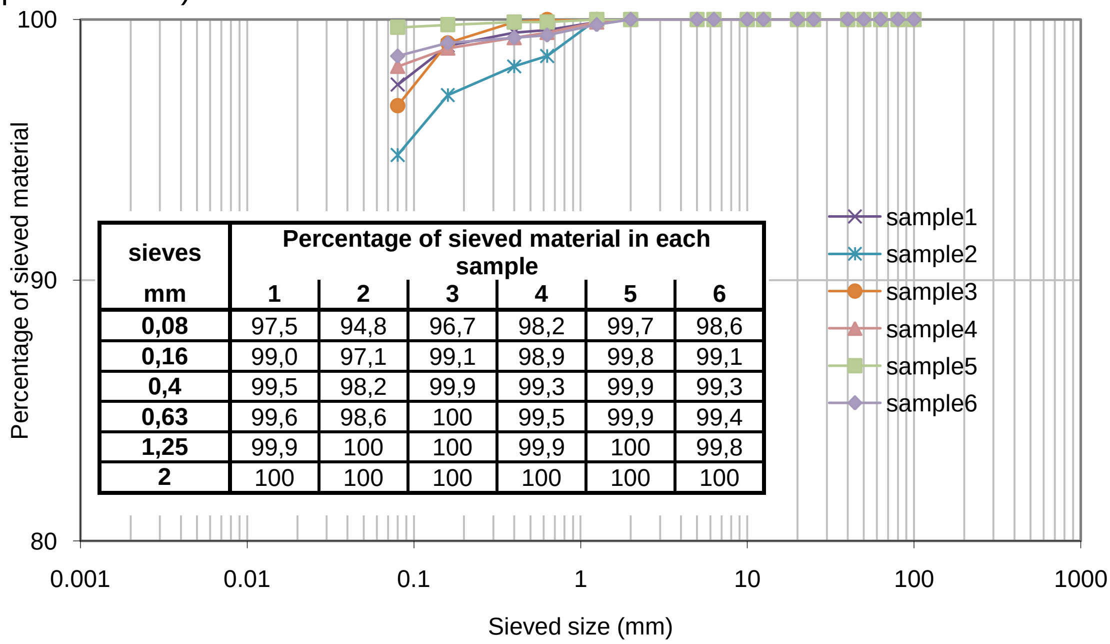
Figure 3 – Structure of the pavement over a E3 platform, by taking into account the heavy weight class T2 (Dirección General de Carreteras, 2003)

3.3 Study of the physical characteristics of lime treated soils

The identification and characterization of soils to be treated were based on the grading curve, the consistency limits, the compaction characteristics and the CBR, in accordance with the following indications (TN GPO, 2007).

- Grading Curve

The grading curves of the six samples of soils collected are presented in Figure 4. From the analysis of curves, it is concluded that this is a soil with a high percentage of fines, clayey in nature: all samples are classified as CL, in accordance with classification ASTM D 2487. In accordance with the standard AASHTO M 145, the samples are classified as A-7-6 and A-6 (clayey soils that under the pavement present a regular to very poor performance).



sieves	Percentage of sieved material in each sample					
mm	1	2	3	4	5	6
0,08	97,5	94,8	96,7	98,2	99,7	98,6
0,16	99,0	97,1	99,1	98,9	99,8	99,1
0,4	99,5	98,2	99,9	99,3	99,9	99,3
0,63	99,6	98,6	100	99,5	99,9	99,4
1,25	99,9	100	100	99,9	100	99,8
2	100	100	100	100	100	100

Figure 4 – Grading curves of natural soil samples.

- Atterberg limits

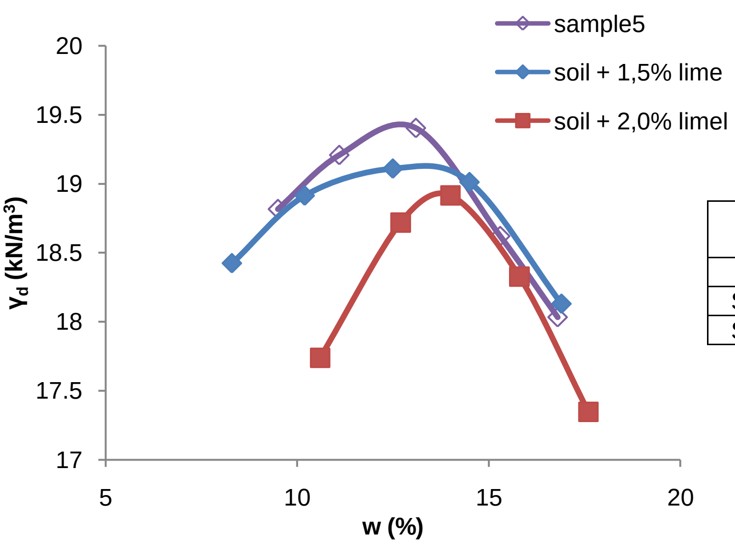
The values of the Attenberg limit of the tested samples are presented in Table 1.

Table 1 – Consistency limits of samples.

	Samples					
	1	2	3	4	5	6
w_L (%)	36.0	35.3	37.5	47.5	37.5	45.6
w_P (%)	19.8	18.6	16.3	20.2	17.7	22.0
IP (%)	16.2	16.7	21.2	27.3	19.8	23.6

- Compaction characteristics

By taking into account sample 5, a formulation study was developed in order to establish the characteristics to be expected for the soil-lime mixture.
Figure 5 presents the heavy compaction curves of sample 5 with no lime and with 1.5 and 2.0 % lime, respectively. The values of the maximum dry weight and of the optimum water content are presented in the same Figure.



	$\gamma_{d\ max}$ (kN/m^3)	w_{opt} (%)
Sample 5	19.40	12.7
Soil + 1.5% lime	19.11	13.0
Soil + 2.0% lime	18.91	13.9

Figure 5 – Compaction curves (modified Proctor) of sample 5 with no lime and with 1.5 and 2.0% lime

From the analysis of compaction curves, it is possible to observe, as expected, that the increase in the lime content leads to an increase in the optimum water content and to a decrease in the maximum dry weight of the mixture.

- CBR test

The CBR values of the different soil samples are indicated in Table 2. The CBR values referring to sample 5, containing 1.5 and 2.0% lime, are indicated in Table 3.

Table 2 – CBR values of soil samples

	Samples					
	1	2	3	4	5	6
CBR (%)	0.8	2.2	1.0	1.3	2.0	0.9

Table 3 – CBR values of sample 5 with different lime contents

	CBR (%)	
% of lime	1 day	7 days
1.5	13.2	16.0
2.0	16.0	19.0

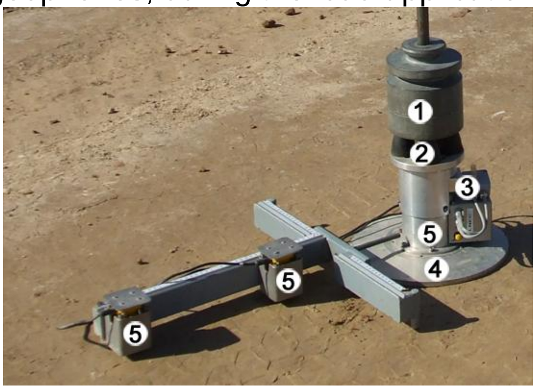
The CBR values clearly increase with lime addition. Furthermore, it is observed that these values tend to increase with time.

4. MECHANICAL CHARACTERIZATION OF THE SUBSTRUCTURE

4.1. Method

Within the scope of this work, *in situ* tests were performed in order to characterize the layers of the pavement substructure. For this purpose, a Portable Falling Weight Deflectometer (PFWD) Prima 100® (developed by Carl Bro Pavement Consultants) was used (Figure 6). The results provided by this method allow to calculate the equivalent modulus of deformation of compacted layers.
Essentiallly, PFWD consists of a circular load plate with a central hole load by impact. The diameter of the plate can be 100, 200 or 300 mm. A load cell measures the load applied on the tested surface. The deflections on the surface are calculated on 3 points, through the deformation velocity measured with geophones, during the load application.

a)



1 – drop mass
2 – shock absorbers
3 – load cell
4 – load plate
5 – geophones

b)

Figure 6 – Aspect of the PFWD: a) overview; b) detail of: the plate, the load cell, the shock absorbers, the drop mass and geophones

Figure 7 shows an example of the curves, of both the load and the deflections obtained in tests with PFWD.

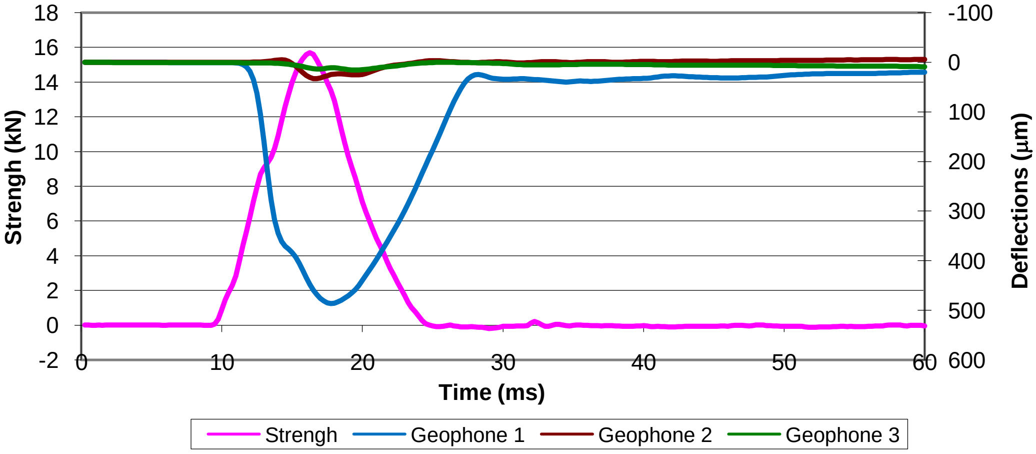


Figure 7 – Evolution of the load and deflections obtained with PFWD on a layer of lime treated soil at the platform of the race track “Circuito de Velocidad de Los Arcos”

4.2. Tested sites

The selection of the test sites took into account the state of works on the day of the test campaign and the characteristics of the cross sections. The characteristics of test sites are indicated in Table 4 and in Figure 8.

Table 4 – In situ test zones

Zone	Pks	Observations
1	0+075 0+100 0+125	Tests performed on natural soil (on the surface after a 1.5m excavation)
2	0+475 0+500 0+525	Tests performed on natural soil (on the surface after a 1.5m excavation)
3	3+475 3+500 3+525	Tests performed on an embankment with 2% of lime, in March 2008.

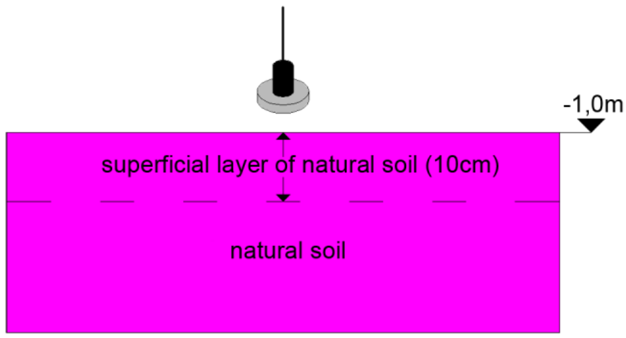


Figure 8 – Structure of the pavement foundation - areas 1 and 2

4.3. Numerical analysis of PFWD results

Table 5 presents the values of the equivalent modulus of deformation obtained with PFWD, for a 300mm diameter load plate tested with a pressure of about 226 kPa.

Table 5 – PFWD results

Zone	Pks	E [MPa]
1	0+075	46
	0+100	151
	0+125	91
2	0+475	97
	0+500	49
	0+525	69
3	3+475	104
	3+500	155
	3+525	128

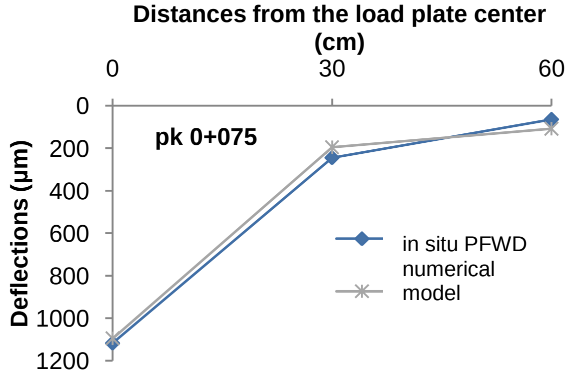
The values of the modulus measured in each area present a rather high dispersion. Moreover, it was observed that values obtained on the embankment built with lime treated soils (zone 3) are generally higher.

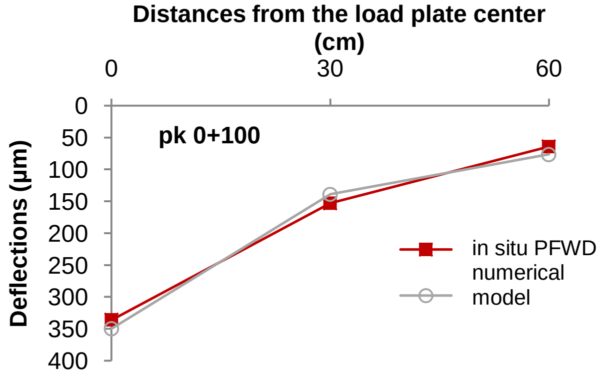
The interpretation of the deflections of the load tests and the determination of the modulus of layers was done with a numerical model using finite element (FEM) code, in an axisymmetric equilibrium modelling.
The load test was modelled on a layered elastic medium, by changing the modulus of the different layers materials. In an iterative way, it was possible to calculate the deflection curves that best fit the field results obtained during *in situ* load tests performed with the PFWD.
The points selected for test interpretation were the nodes located in the upper boundary of the model, at the same distance to the center of the load plate as the corresponding PFWD geophones (0, 30 and 60 cm distance to the load plate centre).
In the first place, the aim was to approximate the deflections obtained in the numerical analysis to the deflections obtained from the *in situ* test with PFWD on layers of untreated soil, referring to zones 1 and 2. A remark is due to the fact that a 10 cm thick upper layer was considered (Figure 8), presenting different characteristics from the rest of the medium, because the soil was rather loose due to the passage of working equipment. Furthermore, during the construction, this layer was expected to be compacted, before the placement of overlying layers.
Table 6 indicates the values obtained for the modulus of the two layers of natural soil and the corresponding deflections obtained from the numerical simulation.

Table 6 –Modulus of the natural soil (two layers) – zones 1 and 2

Pk	$E_{sup\ nat\ soil}$ [MPa]	$E_{nat\ soil}$	Deflections Df1 [µm]	Df2	Df3
0+100	140	140	350	139	76
0+075	20	100	1095	195	107
0+500	20	120	1034	162	89
0+125	50	140	550	140	76
0+475	40	200	548	97	53
0+525	20	100	1095	195	107

The graphs of Figures 9 and 10 show the deflections obtained on the numerical model for the hypotheses considered, as well as the deflections obtained in the *in situ* PFWD tests in zones 1 and 2, respectively.
Concerning tests performed in zone 1, it is observed that the modulus of the soil beneath the loose superficial layer ranges from 100MPa to 140MPa, in accordance to the tested zone. In the case of Pk 0+100, the superficial layer presents a modulus similar to the one of the remaining soil, probably due to the fact that this is a more compacted zone.





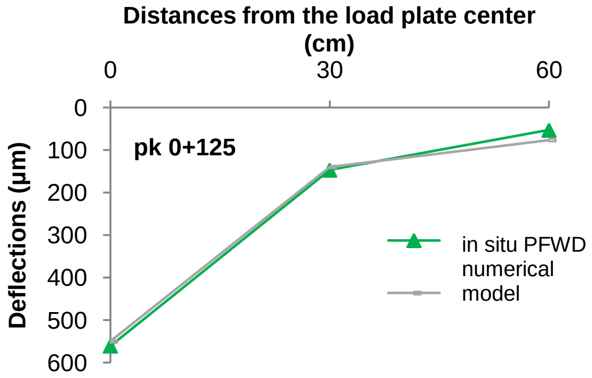


Figure 9 – Deflections obtained in PFWD tests in zone 1 and the best fit by the numerical model

Regarding the tests performed in zone 2, it can be observed that the modulus of the soil beneath the superficial layer ranges from 100 MPa to 200 MPa, depending on tested zone.

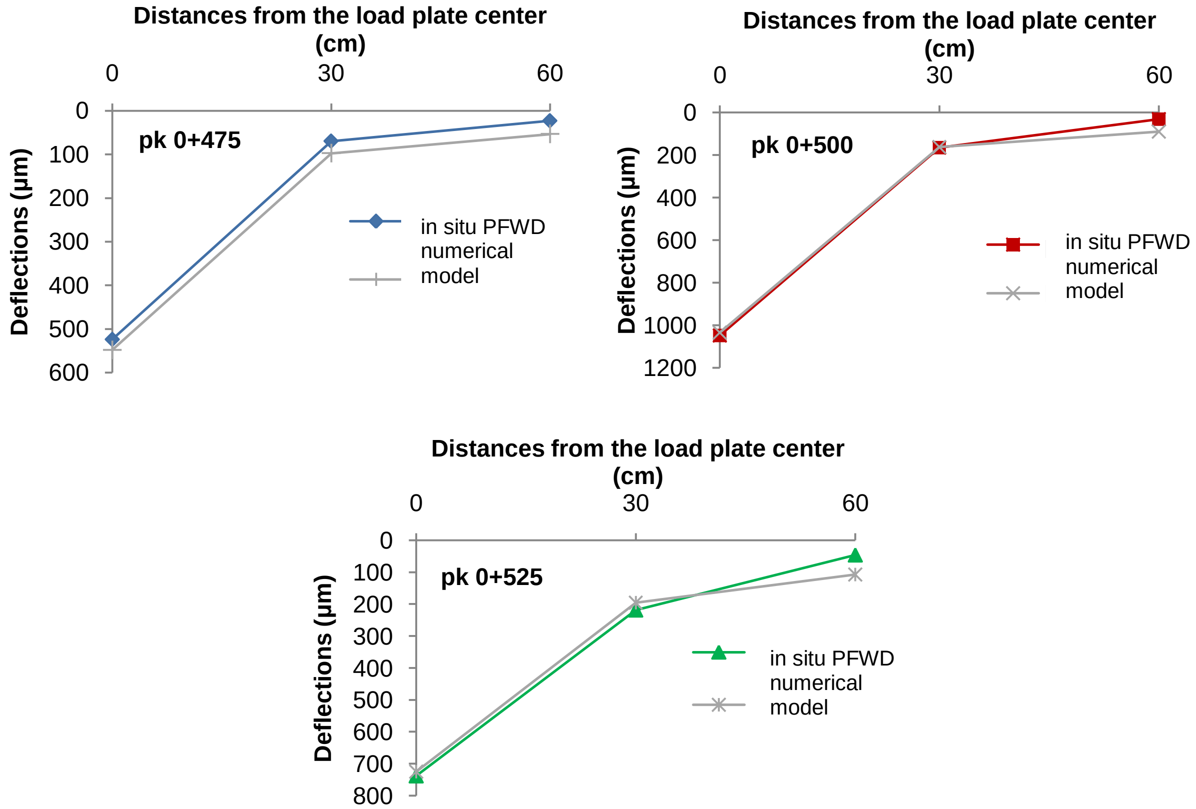


Figure 10 – Deflections obtained in PFWD tests in zone 2 and the best fit by the numerical model.

Generally, the tested areas exhibit fairly high values of the modulus, which confirms the information available. In fact, during the excavation of these two areas, it was verified that these soils had a surprisingly high bearing capacity.

In the analysis of the mechanical characteristics of the soil stabilized with lime, available in zone 3, a structure like that of the figure 8 was considered. Similarly to the interpretation of results obtained in zones 1 and 2 (soil without treatment), it was also necessary to consider a 10cm upper layer, with different mechanical characteristics. In this case, the upper layer presented worse characteristics probably because the soil treated about 6 months before has not been properly protected and because it has been subject to high working traffic.

Table 7 indicates the values obtained for the modulus of the two layers of treated soil and the corresponding deflections obtained from the numerical simulation.

Table 7 – Modulus of the treated soil of the embankment (two layers) – zone 3.

Pk	$E_{soil-lime\ overl.}$	$E_{soil-lime}$	Deflections Df1	Df2	Df3
	[MPa]		[μm]		
3+475	25	400	474	23	17
3+500	40	400	329	28	17
3+525	30	400	410	25	17

The graphs of Figure 11 show the deflections obtained on the numerical model, for the hypotheses considered, and the deflections obtained by PFWD in zone 3.
Taking into account that the upper layer is expected to be corrected before placing the pavement structure, it was considered that the modulus of deformability of the soil layer treated with lime was about 400 MPa. This is a very high value, when compared with the requirements of the design specifications.

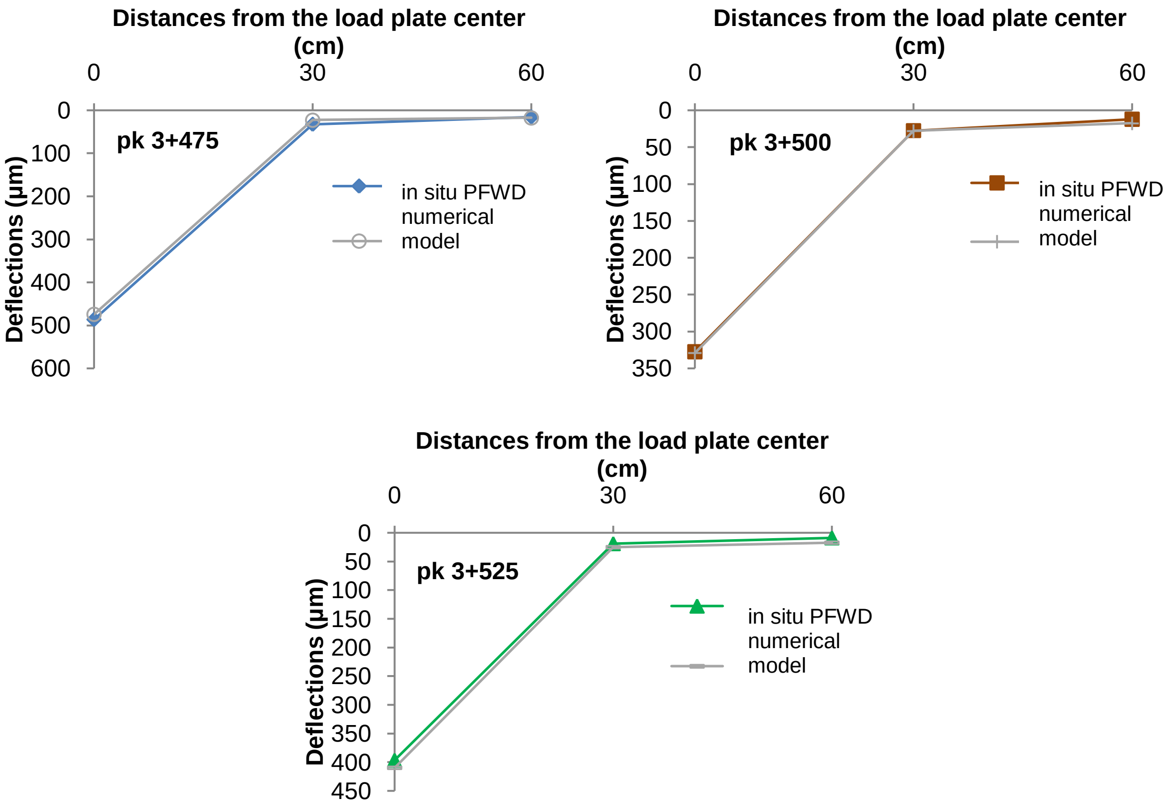


Figure 11 – Deflections obtained on PLAXIS® for hypotheses considered vs Deflections obtained in PFWD tests with the 300mm plate, in zone 3.

5. CONCLUSIONS

The *in situ* tests performed on the race track “Circuito de Velocidad de Los Arcos” allowed for the assessment of the deformability of the soil layers with and without lime treatment. The numerical analysis of the results of tests performed with PFWD, enabled to determine, with higher accuracy, the deformation modulus of the substructure layers. In the lime treated soil, it was observed that the values of the modulus significantly exceeded the minimum values established in the project specifications. Nonetheless, due to normative requirements, the lime content was not reduced.
Hence, the lime content must be determined as a function of the pre-established objective. Higher percentage of lime will lead to layers with better performance, being nonetheless

excessive for the objective to be achieved. This difference may prove to be crucial for choosing the treatment rather than the soil replacement solution.
Since values higher than the required ones are consistently observed, it seems to be appropriate, within the framework of the quality assurance, to use performance based specifications for determining the mechanical characteristics of layers, so as to optimize the design of the substructure layers of transportation infra-structures.
This approach, besides giving construction quality indicators, it also enables the designer to validate the design assumptions and, if necessary, to reformulate them, in particular as regards to the used materials, the thicknesses and the methods employed for constructing layers.
However, the decrease in the lime content will only be possible if both specific equipment and an accurate execution control are employed.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

TN GPO (2007). Proyecto Constructivo de Pista. Circuito de Velocidad de Los Arcos. Arquitectura e ingeniería A.I.E. Spain.
Dirección General de Carreteras (2003). Secciones de firme: Instrucción de carreteras. Norma 6.1 IC. Ministerio de Fomento. Spain.