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Soil stabilization in new railway construction

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Abstract

Since ancient times, all kind of soils have been improving in order to obtain a better use of them, getting more support and better resistance to the passage of time and the weather effects. These soils were modified with small additions of different materials, improving or stabilizing such soils.

Clay stabilized with lime has been used for the construction of the Shersi's pyramids in Tibet more than 5,000 years ago. Later on, already in the modern era, cement Portland was used to give resistance to the soils in cobble roads. In addition, it was used as well to stabilize a network of rapidly building airfields during World War II, giving way to what today we know as the modern roads.

Currently, soils stabilization is a technique of application widespread in many public and private works as factories, airports, ports, and all kinds of roads, from rural roads to modern motorways.

The purpose of this communication is to show the use of the technique in the construction of new railway works, achievements and targets set for the near future.

Keywords: punctuality, stabilizing, recycling, efficiency, quick repair

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1. Object of this communication

Since ancient times, all kind of soils have been improving in order to obtain a better use of them, getting more support and better resistance to the passage of time and the weather effects. These soils were modified with small additions of different materials, improving or stabilizing such soils.

Clay stabilized with lime has been used for the construction of the Shersi's pyramids in Tibet more than 5,000 years ago. Later on, already in the modern era, cement Portland was used to give resistance to the soils in cobble roads. In addition, it was used as well to stabilize a network of rapidly building airfields during World War II, giving way to what today we know as the modern roads.

Currently, soils stabilization is a technique of application widespread in many public and private works as factories, airports, ports, and all kinds of roads, from rural roads to modern motorways.

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2. The technique

The load-carrying capacity of the platform and the tensions that comes to it through dynamic loads of rail traffic is critical for determinate thickness of layers in any superstructure seat in earthwork projects. One of the goals of a correct dimensioning about railway's superstructure is to obtain vertical tension on the top side of the platform results clearly lower than its bearing capacity.

To improve the ability to increase the support capacity of the embankments in areas where clays or other lands with low resistance are, lime or cement can be used in order to improve the results obtained with these soils and to minimize the transportation of large masses of earth.

In addition to other objectives, minimize the construction costs, both economic and environmental, and the tasks of maintenance are the targets, reducing the technical and mechanical damages that maintenance work involves.

The rail traffic planned for the future and stresses that it will generate must be taken in account as in any type of project. If it is expected that this traffic to overcome to the admissible, it must be intervened to reduce tensions, by means of the modification of the railway seat structure, the increase of the platform capacity bearing or both actions at the same time.

There are still various uncertainties we can found regarding to:

- dynamic actions in the case of the high speed railway,
- the fatigue of materials behavior that are more requested
- the lateral resistance of the track and
- the maintenance of the mechanical properties obtained in the construction of the structure.

Consequently, this is one of the aspects that most should worry. International research and standard organizations are continuously studying alternatives to the traditional solution that they confer greater reliability and stability to the high performance railway movement.

It is in this context where an alternative to the classic structure is proposed, based on the use of layers treated with hydraulic binders. The use of both binders, lime or cement, applied and mixed with the soil leave a structure more resistant. They reduce the tensions on the platform and increase the transverse strength, both in the vertical loaded via (which allows better performance in the railway operation), as in the discharged via (improving stability of the track against the efforts of thermal origin). The desired stiffness of the soil can be obtained, and even, this rigidity can change in the path depending on the soil characteristics and the dosage of binder. (modulus variable in the material).

Other advantages that these solutions based on the use of layers treated with hydraulic binders can provide are:

- Use of materials of the working path what allows economies in the building phase. It avoids the quarries (inside and outside the working unit) and the need for the supply by other agents (that lets all internal tasks coordination and an important improvement in the speed of execution).

- It is a more environmentally friendly solution: avoiding opening or quarrying and vehicles of heavy transport by roads, with the damage that they do. In addition also this technique prevents the need for landfill sites where to send the soils that otherwise should be removed from the work.

- Use of manufacturing equipments that exist normally in the works. It is not necessary to incorporate special machinery.

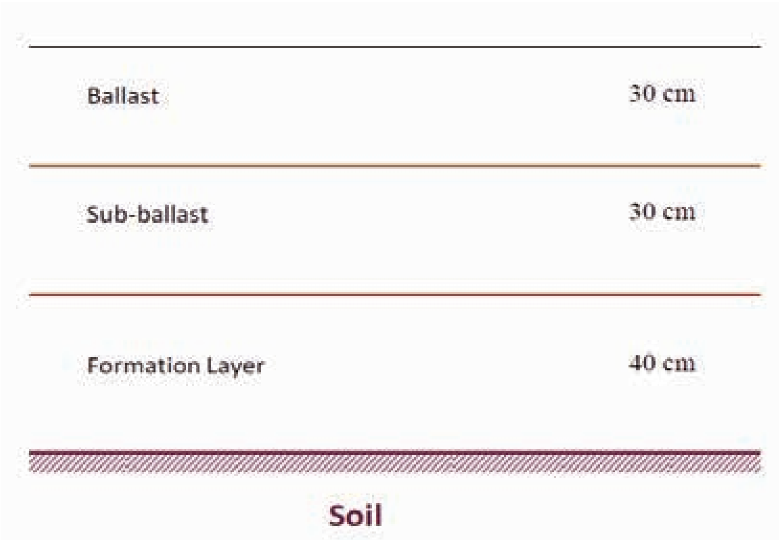
- Improves the impermeability of the base layer, obtaining greater stability in time (durability) and better performance against water. This increase of tightness is in addition to the 2% pumping that must be given to drain the water that has seeped through the ballast.

3. Traditional starting situation

Designers used to have abacuses to determine the thickness of the layers in the traditional railway (up to 200 km/h speed), according to the following parameters:

- Characteristics of the soils that constitute the platform on the stretch of railway considered.
- Characteristics of the platform as a whole.
- Climatic conditions of the location of the platform area.
- Characteristics of the traffic in the considered section.
- Characteristics of the superstructure.

Designers have been made various adaptations and extrapolations in the high speed train case in Spain. The structure that is used is reflected in the figure below:



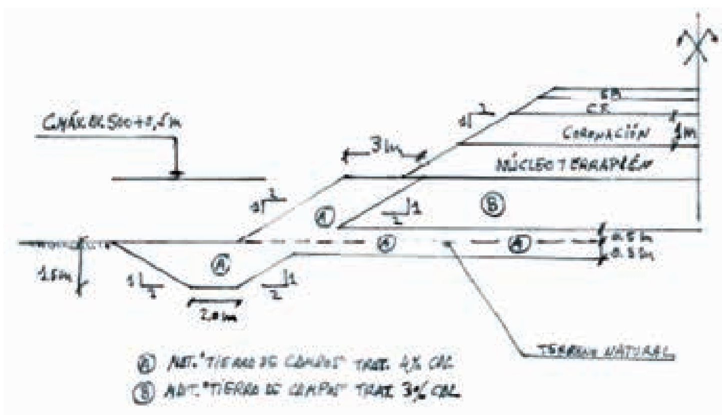
The demands of each layer are those listed below:

	Ballast	subballast	Track Bed	Soil	Platform
CBR	>22		>10	>5	10<CBR<20
E2 Modulus Plate-bearing	>1.700 kp/cm^2	>1.200 kp/cm^2	>800 kp/cm^2		
Permeability		< 10-6			
LA desgaste		< 24	<30		
Wet Micro-Deval		< 16	≤25		
Density (% MP)		> 98% PM	>95% PM	>1,75 kg/m3	
Max. size			≤10 mm		
Fines content			≤5%		
Atterberg limits				LL<50 If 0,35<LL<50, then Ip>0,73(LL-20)	
Type of soil					QS3, or QS2+40 cm QS3 or QS1+60 cm QS3

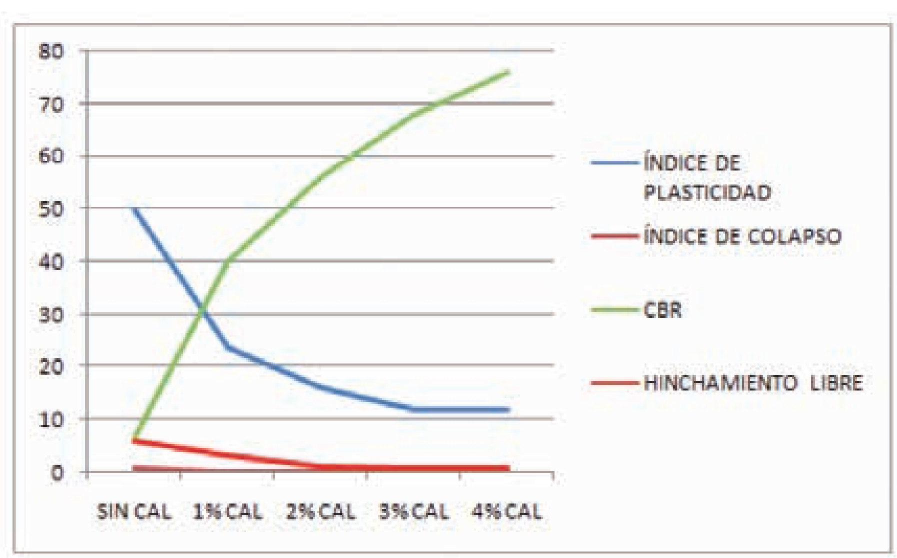
4. Alternative proposals

Stabilized materials make possible those soils of the own track can be used in different areas of the work that has to be built as the following:

- **Landfills:** treatment with a binder allows the reuse of the soils of the track, when their geotechnical properties are poor, and improving its support capacity.
- **Foundations for embankments or structures:** stabilization of soft soils that support embankments improves its ability to support and protect these areas of moisture, reducing the settlements of the embankments.
- **Zones of transition:** the stabilization of materials in the areas beside the engineering structures or hard points of the platform allows a gradual transition of behavior and rigidity of the materials.
- **Track bed layer:** any soil may be used provided that their geotechnical characteristics are improved. Thus, this layer will better support the solicitations during its service life, protecting the lower ones.
- **Special areas:** in certain cases, the compromised situation in some areas of the fillings, as flood areas, can be designed with some fillings stabilized with binder.



Modified of the soils characteristics in the case of using lime:



5. Potentially adverse factors

Three are the aspects which most negatively influence soil stabilization: its content in organic material, the soluble sulphates and the soils particles bigger than 80 mm.

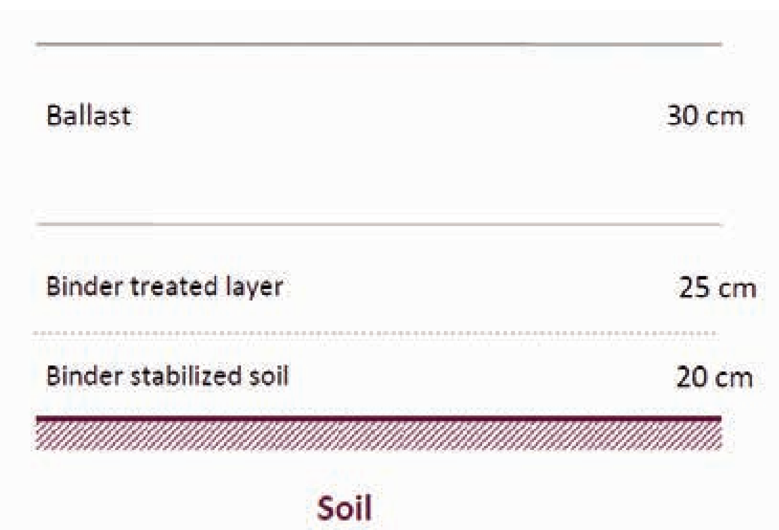
- The content in organic matter can inhibit the Pozzolanic reactions and retarder the effects of the binder on the ground. In case of soils with excessive rates of this, you should conduct studies seeing the evolution of the improvement to more long-term than usual, to dose correctly the necessary binder (lime can remove part of this organic matter).
- The content of soluble sulphates can form ettringite (trisulfoaluminato calcium) and other similar substances (thaumasite) produced by the soil and lime in a Pozzolanic reaction. They are very expansive and it can break the already mixed and compacted layers. The content of soluble sulphates can exist in the soil, or can be provided by existing groundwater that can affect stabilization through the reaction of sulphates solubilized in water with calcium aluminates hydrated.

  Lime needed for this reaction can come from lime added when this is used as a stabilizing agent, or from cement when it is released in the process of setting and curing.

  The use of sulfo-resistent cements does not exempt from the attention that must be paid in the works in which appear the sulfates. Normally cements that resist the attack of sulfur have a low content on alumina, therefore avoiding the formation of the product S - Al - Ca, whose stable form can contain up to 24 water molecules. However, in soil stabilization may be sufficient alumina content to form part of the damaging formula.
- The presence of big amount of big stones (bigger than 80-100 mm), especially if there is no continuous soil grading, makes impossible to achieve a good mixture and can cause problems in the machine.

6. Some example performed and comparative analysis

In order to improve the performance of the track structure and minimize implementation and maintenance costs, alternative solutions were used whose scheme responds to the following figure:



As you can see, 30 cm thick sub-ballast layer is replaced by a 25 cm thick treated material with a hydraulic binder layer. It allows the use of a soil of the working zone that does not require as stringent conditions as the one of sub-ballast features (for instance, many quarries don't meet the Los Angeles index in Northwest Spain). Also the thickness of the formation layer is considerably reduced (from 40 to 20 cm) when it is stabilized with cement and the required soil characteristics are much more permissive.

The soil may be the same used in the construction of any suitable layer (the formation layer for instance) or other which comply with some minimum requirements. The hydraulic binder could be medium resistant category cement or hydraulic lime. A 3-4% by weight of aggregates in case of cement and 1,5 – 2,5 % for lime jobs is usually used. The dosage depends on the nature of the soil to be treated, that is way previous tests with different provisions must be carried out.

The minimum requirements to the soil must be:

	UPPER LAYERS	FORMATION LAYER
Sieve size	< 80 mm Pass 2 mm 20 – 55 % Pass 0,063 mm 2-20 %	< 80 mm
Plasticity	LL < 30, IP < 10	LL ≤ 40, IP ≤15
Organic material	< 1 %	< 1%
SO3	< 0,5 %	
Salt water soluble		< 0,2 %
Minimum binder content by mass	3 % cement	3 % cement or 2 % Quick lime
Compression resistance 7 days specimens	2,5 MPa	1,5 MPa

As for the permeability of this layer, check that its value is less than 10 - 6 cm/s, which should be achieved easily.

Having one or some layers stabilized with hydraulic binder increases the degree and speed of consolidation of the structural package, which improves the lateral resistance of track.

In order to assess the behaviour of vertical stresses the structure of project and the different alternatives, a comparative analysis has been done. The program makes a multilayer analysis, commonly used for the assessment of different packages in different surfaces.

To use this program there are the following assumptions:

- Layers are horizontally infinite and finite vertically, except the bottom layer which is considered as a bottomless.
- Layers consist of homogeneous, isotropic and elastic materials and they are characterized by its modulus of elasticity E and its coefficient of Poisson.

Boundary conditions considered were as follows:

(a) On the surface:

- Tangential stresses are null, except in the case that horizontal loads are applied.

(b) At finite depth:

- In case of adhesion between two layers: stresses and deformations are equal on both layers at the level of the interface.

- In case of sliding between two layers: vertical normal stresses and vertical displacements are the same and a tangential stress is zero in both layers at the interface level.

(c) At infinite depth:

- Stresses and deformations are nil.

To determine the stresses and the resulting deflection in the layers with this program, the layers characteristics and the charge of a wheel type have been supposed. So, it has been obtained an estimate of the variation of the coefficient of ballast between the solution of project and the different alternatives and the value function of the dynamic load in each structure.

For estimation of stresses in the platform, the following elastic characteristics in each layer have been considered:

	E (MPa)	C.Poisson
Soil	50	0,35
Formation layer	100	0,35
Sub-ballast	150	0,35
Ballast	400	0,35
Soil stabilized	250	0,25
Soil cement	4.000 / 6.000	0,25

The determination of dynamic loads has been a rough, by the method of the SNCF estimate, based on a static 17.2 t axle load and have been considered two cases, both for speed of 350 km/h, obtaining the following values:

- With sub-ballast layer and a 50 kN/mm stiffness was obtained a dynamic loading of 12,68 t/wheel.
- With stabilized layers and a 62.5 kN/mm stiffness was obtained a dynamic loading of 14,14 t/wheel.

The output of the program provides graphically the maximum values of the stresses and deformations of each layer at the level of the different interfaces. It also indicates the place where these maximums are obtained and determines the value of deflection under the wheel and the radius of curvature of the deformed.

The following table is a summary of the results where deflection (Dk) and vertical stress on the top side of the platform (σ_z) are showed:

Summary of results:

	D_k 10^{-2} mm	σ_z platform
traditional section	84,11	$1{,}701 \cdot 10^{-2}$
20 S-EST + 25 SC (6000 MPa)	55,18	$1{,}364 \cdot 10^{-2}$
20 S-EST + 25 SC (4000 MPa)	57,96	$1{,}550 \cdot 10^{-2}$
25 S-EST + 20 SC (6000 MPa)	59,77	$1{,}662 \cdot 10^{-2}$
25 S-EST + 20 SC (4000 MPa)	62,21	$1{,}838 \cdot 10^{-2}$

The results of the following solutions can be highlighted:

- The solution with a layer treated with cement of 25 cm thickness and 6,000 MPa modulus of elasticity on a 20 cm of soil stabilized with cement, reduces a 34.4% deflections and a 19.8% the value of vertical stress on the upper face of the platform with respect to the natural soil solution.
- The solution with a layer treated with cement of 25 cm thick and 4,000 MPa modulus of elasticity on a 20 cm layer of soil stabilized with cement, reduces a 31.1% deflections and 8.88 % the value of vertical stress on the upper face of the platform with respect to the natural soil solution.
- In case of modifying the thickness, the solution with two layers treated with cement, one of 20 cm and 6000 MPa module over another stabilized 25 cm thick and 250 MPa module, decreases a 28.9% deflections and a 2.29% the vertical stress value on the top side of the platform with respect to the natural soil solution.

7. Conclusions

To carry out a practical assessment, it has been established the comparison of the different alternatives studied with regard to the usual section in railway superstructure with ballast (reference solution):

- 30 cm ballast (E = 600 MPa; v = 0.35)
- 30 cm sub-ballast (E = 200 MPa; v = 0.35)
- 40 cm formation layer (E = 100 MPa; v = 0.35)
- CBR soil > 5 (E = 50 MPa; v = 0.35)

In the absence of availability of quality aggregates in many areas of Spain, the possibility to modify this structure by replacing some of its layers made with natural soils by others treated with lime or cement has been studied. Different thickness and modulus of elasticity has been analyzed. In any case, the target is that aggregates and soils can ensure the stability of the superstructure over the passage of an important number of TBR and not be obliged to frequent maintenance tasks and high cost maintenance.

Acceptable results in comparative terms used a program prepared for road traffic have been obtained (vertical stress σ_z in the upper part of the Esplanade and the deflection of the Dk are the parameters achieved).

The following alternative among the studied ones is selected:

- 30 cm ballast (E = 600 MPa)
- 25 cm of soil treated with cement (E = 4,000 MPa)
- 20 cm of soil stabilized with cement (E = 250 MPa)

This solution has been implemented in a test section with good results. Several years later, different values were measured and compared with the ones obtained in a traditional section. The seats of the railroad ties varies between 0,40 and 0,50 mm. The results are in similar orders of magnitude in both sections. The stiffness increase measured is 17% higher in the case of stabilized soils. Probably a longer term project will be necessary in order to obtain more and best results.

Its advantages are:

- A reduction of 31.10 % in deflection.
- A reduction of 8.88 % in tension.
- An important height reduction.
- A 17% higher stiffness increase.
- A substantial reduction of the condition of the environment to avoid transport and manipulation of materials extracted in other areas and the poured eventually to landfill.
- Use of local soils of the working place (excavation and materials from the tunnels, with reduced technical limitations).
- Obtaining layers with more stable materials and greater life cycle.
- Reduction in the requirement for maintenance and repair work and its high cost that they hinder and restrict the exploitation of the railway traffic.
- It is possible to obtain the desired stiffness and even, this rigidity can change in the path depending on the soil characteristics and the dosage of binder (modulus variable in the material). It is more, the rigidity is more homogeneous than in the case of use only soil without binder.

8. Appendix 1: stabilizations in the spanish high speed railway

8.1 Stabilization with cement

- High speed Atlantic axis. Cerceda-Meirama, access Sogama branch section. Stabilization of formation layer and replacement of the Sub-ballast by a soilcement done on-site with the same equipment or larger percentage of cement stabilized soil. Company Ferrovial
- New railway access to the North and Northwest of Spain, Madrid - Valladolid.
- Tramo: Valdestillas-River Duero, stabilized with lime formation layer and stabilized with cement service roads, and stabilization of technical structures in Valdestillas blocks. Company: AZVI
- Tramo: Segovia-Valladolid. Work: Stabilized in slabs beside structures with cement and lime. Thickness 30 cm, April 2002. Company: Ute Valdestillla(Collosa-Comsa). Property: Entity manager of railway infrastructure
- Work: Ave Segovia source of this cross. Area 6,000 m2. Work: Stabilized with cement through the dry. Thickness 30 cm, July 2005. Company: Vias y Construcciones.
- Work: Segovia AVE station. Stabilization of the platform of the track shoulders.
- New railway access to the Northest of Spain, Madrid - Zaragoza - Barcelona:
- Ave L' Arboç (Tarragona). Work: Stabilized with cement. Thickness 30 cm, September 2002. Company: Ute Ave L' Arboç (Dragdos-Tecsa).
- Zaragoza - Lerida. Stabilization of a layer of the platform in deforestation between NII motorway towards Lleida to increase some capacity after spending the winter.
- AVE 350, Tr. Zaragoza. Area 165.000 m2. Work: Stabilized platform. Thickness 30 cm, March 2001. Company: Ute AVE350 (Tecsa, Guinovart, Coprosa).

- High speed Antequera-Granada line. Section: Pinos Puente-Granada. work: stabilized service roads and embankments of structures. UTE Vimac-Isolux Corsan
- Rail access to the Terminal del Prat (Barcelona port). Surface 3.100 m2. Work: Stabilized with cement, wet way. Thickness 40 cm, June 2012. Enterprise: Infesa (engineering and rail services)
- Ave El Casar (Cáceres). 200,000 m2 surface area... Extraction of material that fill the gaps between granite massifs, mixed and stabilized with cement with a bulldozer (could not be with mixing machine because of the large amount of big stones) and filling again. Thickness up to 40cm, October 2011. Company: Copisa
- Seville container terminal. 64,000 m2 surface area. Work: Stabilized with cement. Thickness 30 cm, June 2009. Enterprise: Rover Alcisa
- Salamanca. Work: Removal step level small roads in Pedroso de la Armuña (Salamanca). 20,000 m2 surface area. Work: Stabilized with cement. Thickness 25 cm, November 2006. Company: Extraco
- Ávila. Overpasses in the railway from Ávila. 20,000 m2 surface area. Work: Stabilized with cement. Thickness 20 cm, June 2005. Company: Intersa

8.2 Stabilization with lime

- New railway access to the North and Northwest of Spain, Madrid - Valladolid - León:
    - Section Madrid - Valladolid. Stabilization of formation layer, drying of the platform and stabilization with lime in Olmedo.
    - Section Madrid - Valladolid. Platform in Valdestillas drying with quick lime and stabilization.
    - Villada working platform: stabilized with lime formation layer. Company Azvi.
    - Ave Segovia Valladolid. 287,000 m2 surface area. Work: Stabilized with lime. Thickness 30 cm, September 2002. Company: Constructions Sanchez-Dominguez (Sando).
    - Property: G.I.F. (railway infrastructure manager).
    - AVE Palencia - León. Stabilization of the formation layer in Sahagun de Campos.
    - AVE Sahagún. Surface 300,000 m2. Work: Recycling with lime. Thickness 30 cm, may, August and September 2010. Company: Constructora San Jose.
    - LAV UTE Pozal in Medina del Campo (Valladolid)
    - LAV stretch Santas Martas-Bercianos del Real Camino (León) LAV stretch Bercianos de Real road - Rio Cea (León).
- High speed Bobadilla-Granada line. Section: Peña de Los Enamorados – Archidona. Work:
    - Stabilized with lime nuclei of embankment. UTE Dragados-Azvi.
    - LAV stretch stump-Valderrubio (Granada)
    - LAV stretch pine Puente-Granada (Granada) LAV stretch Vera - Los Gallardos (Almería)

- Perpignan. Stabilization of the platform with lime slurry.
- Railway connection of the LAV Madrid with the Mediterranean, C-14 stretch - runner Constantí (Tarragona)
- Salamanca. Work: Suppression of three level crossings in Peñaranda Bracamonte . 17,000 m2 surface area. Work: Stabilized with lime dry. Thickness 20 cm, January 2004. Company: Azvi. Property: Renfe.

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