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The behaviour of expansive clayey embankments reinforced with lime addition

Le comportement des terrassements avec argiles gonflantes renforcées avec de la chaux

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ABSTRACT
Severe problems arise in road and railway works when expansive clayey materials must be used. One solution is to reinforce them with the addition of water and lime, to reinforce the clay and make it more resistant and less expansive. This paper presents several laboratory and field studies, and real experiences recorded on diverse sites in Spain in recent years. A classification of these materials is also introduced to choose the most convenient solution.

RESUME
L´utilization des materiels argilleuses gonflantes presente plusieurs problems dans les chantiers des routes. Une solution pour eviter le gonflement et renforcer l´argile c´est l´addition de l´eau et de la chaux. Dans cette communication on presente des éstudies –dans le laboratoire et dans le chantier- developpées dans l´Espagne, aussi comme des ouvrages réeles realizeés pendant les dermiéres années. On presente, aussi, une classification de cettes materiaux pour selectioner la solution le plus convenable.

1. INTRODUCTION

Usually, when an embankment is designed:
- Laboratory tests are performed on altered samples, along the stretch, or possible borrowing zones.
- Using that laboratory data (grading, Atterberg limits, etc.) one proceeds to classify each soil type in the area, within the groups defined by the official standards (AASHTO, etc). Naming of these groups ranges from the most appropriate: graded soil, tolerable soil, etc., to even include code names: A-5, ML-OL, etc.
- If the established criteria are fulfilled, the material foreseen may be used, proceeding to include project specifications for that material to be used in a specific zone.

That ease of design may lead to severe problems when the materials present in the area are not the usual ones. In Spain, the greatest increase in volumes of earth movements in road works was from 1980 onward, proving that, it would be necessary to reuse everything excavated from the actual site, to avoid major environmental impacts and major transport costs.

2. CLASSIFICATION OF MATERIALS

The former Condition Sheet PG-3, by the Ministry of Public Works (M.P.W.) of Spain distinguished four types of materials for embankments: a) Selectioned, b) Adequate, c) Tolerable, d) Inadequate (from greater to lesser quality). It depreciated the “inadequate” or clayey or plastic muds materials, which meant a large volume of the available materials had to be eliminated: Miocene and Pliocene clays from the Central Meseta, Miocene clay from Southern Spain, gypsum rock, etc.

At present (2000-2003), Spain has now included a new type of material: the “marginal”, that is supposedly half way between “tolerable” and “inadequate”, that generally includes expansive materials (liquid limit between 40 and 120 under Casagrande line A and between 65 and 90 above it). These “marginal” materials fulfil the following conditions: a) Organic matter content lower than 5 %. b) Swelling on expansion testing under 5 %. As far as expansive soils are concerned, the PG-3 defines these as those that give rise to free swelling of more than 3% in samples remoulded and compacted in the manner to be used on site (free swelling trial in edometer). These may not be used in crowns or backing, in order to not to suffer damp variations, but they may be used in core, under the conditions of “Special Study”, compacting the damp side. With soluble salts other than gypsum, the material may be used in cores as long as it has less than 1%. For a content of more than 1%, the soil is clearly marginal and requires a “Special Study”.

3. EXAMPLES WITH MARGINAL MATERIALS

The following is a list of a series of works in which expansive “marginal” materials have been used – from the early 90s to present – in road works (trunk roads and dual carriageways) or for filling in major town planning projects:
- Motorway in the Venta de Baños (Palencia, Northern Spain): Tertiary, greyish expansive clay was used, with some carbonate. A section of the encapsulated type was used, surrounding the clay with natural crushed rock with some fine graded material (25-35 %), (Oteo, 1994).
- Technological Park of Malaga: Brown Miocene clay was used, with medium to high expansiveness, in a “sandwich” solution, alternating it with layers of fragmented, compacted slate. (Oteo, 1994).
- Stretch II of the M-45 Dual Carriageway in Madrid: Sepiolithic clay from the route was used (with dry densities of 750 to 1,100 Kg/m^3), treated with lime (1.8-2.4 %), in core as well as in the surrounding zones (Oteo et al, 2001).
- Stretch I of the M-45 Dual Carriageway in Madrid: The grey “clays” (known locally as “peñuelas” (small boulders) were used, which have a medium to high plasticity in sandwich solution, alternated with adequate borrowed material.
- Valdemingomez Zone: Expansive grey clays were used (“peñuelas”) and brown ones, for the embankments, in an encapsulated sandwich solution.
- P.A.U. of Vallecas: Use made of grey and brown clay for

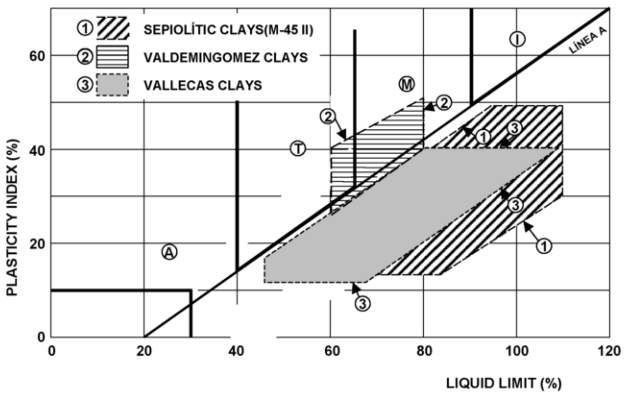

Figure 1. Plasticity of some clayey soils stabilized with lime.

road embankments, in encapsulated solution.

– Cuenca Trunk Road: Tertiary grey marl clays, with low plasticity. These were treated with lime (2 %) in core and backings.
– New stretches of a Motorway in Tierra de Campos (Palencia): The possibility has been studied of using the clayey formation (of medium plasticity) treated with lime (1,5-3 %).
– Motorway A-321, Jerez-Los Barrios: A detailed study has been carried out of stabilisation of the clayey soil on stretch V, (Ortuño and Rodriguez, 2000).

On Stretches I and II of Motorway M-45 in Madrid, we have followed the methodology described in the preceding chapter (design of embankment, study of properties, etc.). On Stretch I, medium expansive clays have been used, with little or no gypsum, with dry densities of about 1.20 to 1.40 t/m3, that (often) entered the upper zone of the Casagrande Line A (Fig. 1). In that case, the criteria of compacting the damp side has been used, not using additives and making a sandwich type design, "reinforcing" the embankment with strips of adequate material.

On Stretch II of that Motorway, the materials are sepiolithic clays, clay with gypsum, gypsum, etc. The plastic clays, with and without clearly sepiolithic levels, are usually located underCasagrande Line A (Figure 1), as we have already said, although they are not mudstone based. The "in situ" dry densities of these materials vary from 0.70 to 1.10 t/m^3, with swelling pressures of up to 300 KPa (if they suffer loss of humidity, this may reach 400-500 KPa) and Lambe

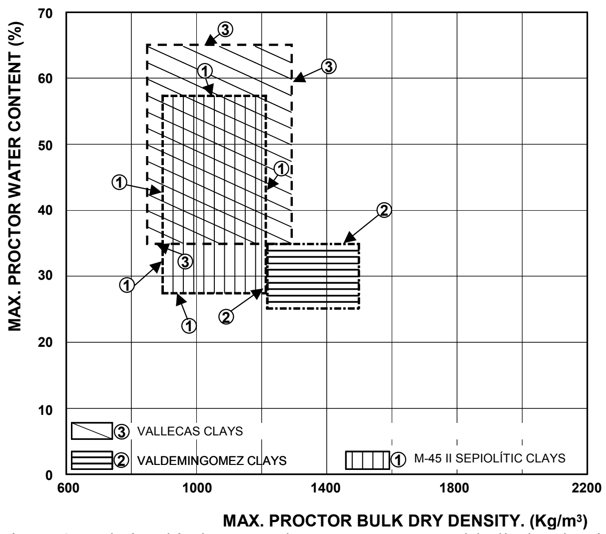

Figure 2. Relationship between the water content and bulk dry density (optimum proctor conditions) o some soils stabilized with lime.

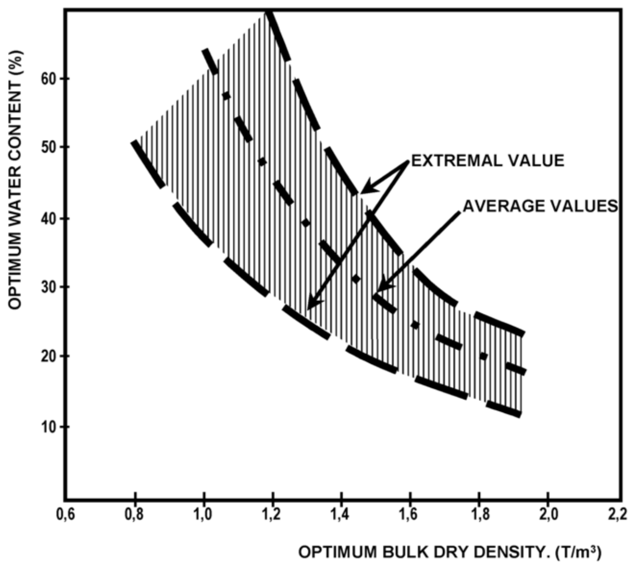

Figure 3. Relation ship betwen optimum water content and dry density (proctor conditions) in marginal materials.

classification of "critical expansiveness" on the sepiolithic levels. The sulphate content reaches 0.5%.

These light, expansive clays with "in situ" watter content between 21 and 49%, with liquid limits between 53 and 112, have been used in embankments of up to 10 m in height, so the foundations and backing has 2.4% lime added (in relation to the total weight), while in the core 1.8% lime has been used. The mix of clay and lime has been made during the process of compacting with a "split foot" roller, with gradual addition of water. The test trials have given values under 5 mm at 24 h and under 3 mm after 30 days.

4. PROPERTIES OF SOME MARGINAL MATERIALS

In Fig. 1, the zone has been represented in which the plasticity is grouped for some of the materials in the examples listed in the preceding section. It varies considerably in the examples shown: a) there are several that are for similar materials (Miocene clay or "peñuelas" from the South of Madrid and sepiolithic clays), such as those used on the M-45 I, those of Vallecas and those of stretch II of the M-45, in which the liquid limit varies from 45-50 to 105-110, (with plastic index between 12-15 and 40-50, always below Casagrande Line A); the smectytic minerals they contain fulfil their water holding capacity and make them "expansive"; b) the Valdemingomez clays, although geographically near to the preceding ones, contain somewhat more carbonates and sulphates, which changes their water holding capacity, almost always being located below Line A; c) slightly expansive brown clay, from the Technological Park of Malaga, are less plastic, with a liquid limit between 32 and 70, practically above Line A.

A most interesting parameter is that of dry density of the marginal soils. Its dry density may be very low, due to their structure and make up. In Fig. 2, the dry density is related with the liquid limit of the marginal materials and some structural filling performed. One may see in this figure how there is a very ample field of variation for those soils: dry densities from 850 Kg/m^3 (sepiolithic clays of the south of Madrid) up to about 1,800 Kg/m^3 (Technological Park of Malaga), through intermediate values of 1,200-1,400 Kg/m^3 in the clays of Valdemingomez (Valencia road 30-40 Km from Madrid. A band has been traced that would represent the variation W_o- γ_{do}

(optimum humidity, optimum dry density of the Proctor compacting test) of these examples, with their average value and the two extremes (Fig. 3). Thus, it is difficult to control these soils with the classical criteria that dry density (after compacting) is a proportion of the optimum Proctor and that the appropriate humidity is ± (1-2)% of the optimum Proctor compacting test. Marginal and expansive materials are more heterogeneous than non expansive ones, due to the presence of smectytic materials, fissures, etc. Due to this, other methods may be more adequate, such as that of the "print" (Swiss) or loading plate.

5. REINFORCEMENT TREATMENTS WITH LIME

The clayey materials with the lowest density among those listed (sepiolithic lumps or "peñuelas") have geotechnical characteristics of doubtful quality when compacted and, moreover, involve the risk of expansiveness, as infiltration of water from the road surface. In the backing, on the contrary, weather conditions may lead to retraction (due to strong drying out), alternated with swelling (due to cyclical dampening). This may be avoided, only partially, by compacting the damp side of the core (humidity of about the plastic limit + 2-3 %). But that does not avoid problems on the backing, in contact with the effects of the weather. In materials with very low density (900-1.200 Kg/m^3) the structure is so open that the ease to take in water is so great, giving rise to a constant problem of expansiveness. Moreover, in these optimum low densities, lasting structures are not achieved by compacting, which leads one to consider treating them with an additive that achieves:

a) Increased "cohesion", short or long term, thanks to a cementing effect with the clayey particles and existing (and/or added) water.
b) Obtaining a more or less plastic, less expansive structure, in which the cementing effect decreases the facility of water entry.
c) Increased resistance to action (changes in humidity, water or wind erosion of backings, etc).

This may be achieved by reinforcing the soil with an agglomerate or cementing factor such as lime. However, we do not aim to obtain one or two layers of improved or stabilised material, but rather mass reinforcement of the material, so it may be used throughout the embankment. The cementing effect of the lime may be seen in the laboratory. For example, Fig. 4 shows the results obtained, using the clays from the "Tierra de Campos" faces (Palencia, Spain) as base material. Specifically,

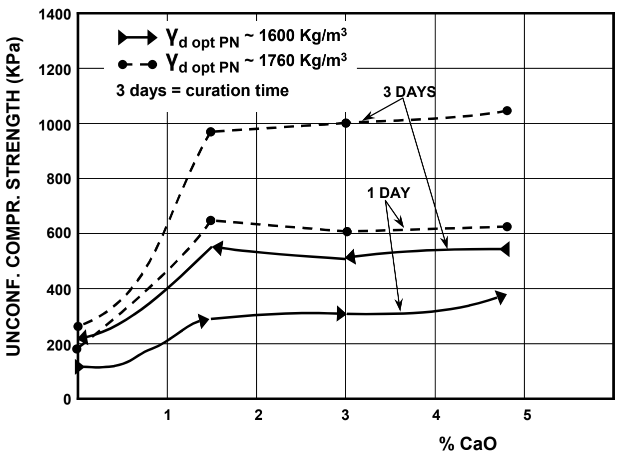

Figure 4. Unconfined compressive strength of the "Tierra de Campos" soils, with differents lime contents.

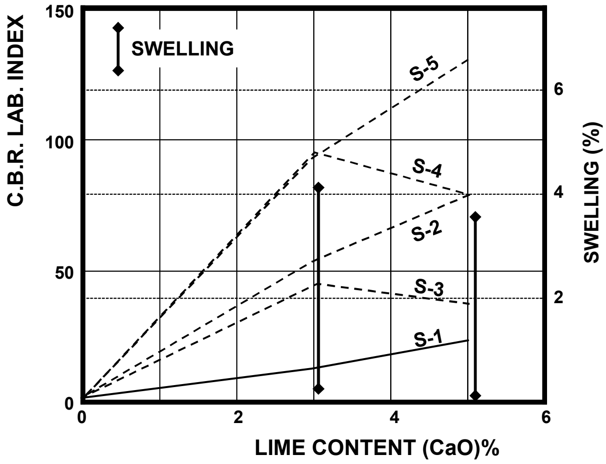

Figure 5. Obtained results by lime stabilization of miocene clays from Cordoba, Spain. (Pérez et al, 1998).

test pieces of clay-lime were produced, previously kneading and compacting them in a miniature Harvard mould Harvard (Ø 1.5 "). They were then immediately broken under simple compression, when they had no lime, or were cured (in a humid chamber, wrapped in plastic) for several days. That Fig. 4 shows how that resistance is about 120 to 230 KPa without reinforcement, (according to the optimum dry density of the Normal Proctor obtained, between 1,600 and 1,760 Kg/m^3). On adding different percentages of lime, the resistance is clearly increased, up to a magnitude that may be about double 1 day of curing, but which may be nearly four times greater after 3 days curing. Fig. 5 includes other results obtained with Andalucian Miocene clays (South of Spain) with lime. Here, one notes how the C.B.R. gradually increases with the lime content and how the optimum results are between 3 and 5 % of same. The swelling in that test also clearly decreases with the lime. Again, one may note that the greatest degree of crumbling in the laboratory is due to higher lime content that shows that these are not necessary in the field.

In the case of expansive clayey soil (with or without lime), one resorts it the field to the procedure of control of the compacting process (machinery used, number of stops, etc), given the variations already stated of the Proctor reference parameters. What must be set is a material treated with lime, as follows:

- The degree of crumbling of the material placed. The maximum sizes of blocks must not be greater than 5-6 cm.
- The water to add. On the M-45 II in Madrid, about 8 l/m^2 (± 20-30 %, according to temperature) was added.
- The necessary machinery, for the extraction face, as well as that of compacting ("split foot" roller of more than 30 T seems the most adequate).
- The number of runs to be performed in the compacting process, (5 to 7 double).
- Thickness of layers. (Must not exceed 30 cm).
- One must also set the procedure for extraction and use of the borrowing and humidity at origin, that must be at the plastic limit plus 2-3 %, and distribute the lime in various runs.

On these bases, we have obtained marvellous results in clayey materials of medium plasticity and high plasticity from Madrid, Cuenca, Palencia, etc, and in the sepiolithic clays of .low density in the south east of Madrid. The presence of sulphates is usually limited to 4-5 %,

In cutting zones of these plastic marginal materials, precaution must also be taken to reinforce the bottom of the

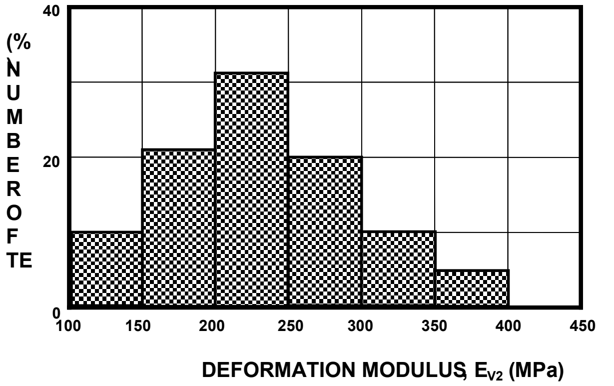

Figure 6. Distribution of the e_{V2} moduli distribution in sepiolitic clays reinforced with lime, m-45 ii (Oteo et al, 2001).

cutting (with 2 or 3 layers of soil with lime) to ensure the levelling is water proofed, a measure that must be increased with lateral ditches to lead the water away from the natural ground.

Fig. 6 shows the distribution of the deformation module E_{v2} obtained in loading plate test (2nd cycle) in sepiolithic clays with lime (1.6 % minimum; 2.4 % maximum), about 7 days after compacting. As is shown from that figure, 70 % of the tests had a result of more than 200 MPa, reaching values exceeding 300 MPa (15 % of the tests). That is, much higher modules are obtained to those obtained on embankments of normal soil (tolerable and adequate).

6. SECTIONS USED IN FIELD WORKS

Just as previously indicated, different solutions have been used, according to the nature of the material, the purpose of the filling, etc. According to this, we have established a lassification for these marginal materials, which is that shown in Fig. 7. In it, five types of marginal materials are distinguished and, for each one of these, a proposed solution is established, (Fig. 8), (The relevant sections of the most usual soils have been eliminated, with dry densities above 1,500 Kg/m^3). This classification and solutions must be taken as a guideline and not as absolute truths, although we believe their adoption is already backed by certain real practice.

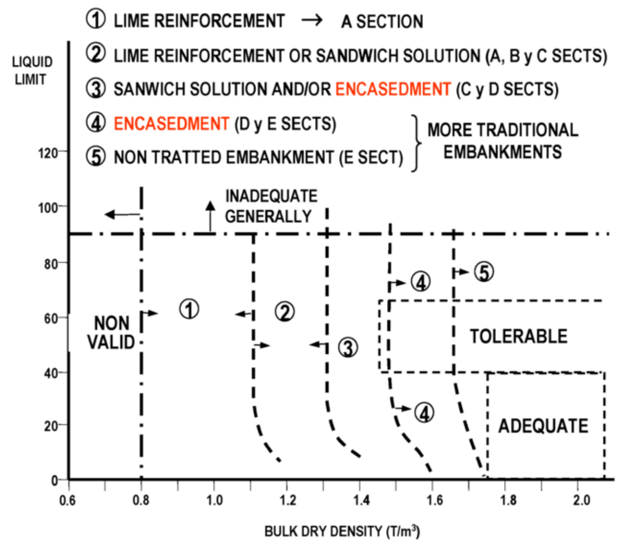

Figure 7. Clayey materials clasification criteria for embankments

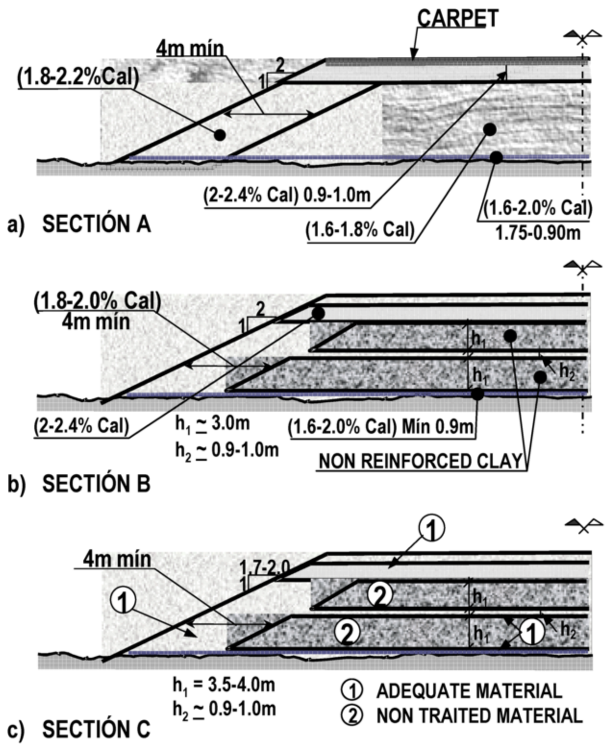

Figure 8. Embankments recommended sections, in marginal clayey materials.

7. CONCLUSIONS

- One must not think, when dealing with expansive materials only of their plasticity but also in that their grading must be analysed and one must establish the variation in their optimum Porctor dry density, a very important parameter to distinguish their possible use and behaviour.
- The geotechnical properties of the marginal materials have been analysed, when they are reinforced with slaked lime.
- A classification of these materials has been established, in order to establish practical and constructive sections

REFERENCES

Ortuño, L. y Rodriguez, J. L. (2000). “La estabilización del suelo con cal como mejora de suelos. Estudio realizado en el tramo V de la A-381: Jerez-Los Barrios” (Stabilisation of the ground with lime for soil improvement. Study performed on stretch V of the A-381: Jerez-Los Barrios. II Andalucian Road Conference, Cadiz, Vol II. Pages 1.309-24.

Oteo, C.(1994).”Reglas generales de proyecto” (General project rules). III National Symposium on Road Geotechnique, Vigo. General Rpport, pages 183-205.

Oteo, C.; Domingo, A.; Velasco, J. y Castanedo, J. (2001). “Special design and treatments of Swelling clays and other marginal materials in a Spanish motorway”. XIV Int. Conf. on S.M. and G.E. Istanbul, Vol III, pages 2.171-75.

Perez, F.; Caballero, A. y Ayuso, J. (1998). “Estabilización de suelos con cal: Posibilidades en Andalucía” (Ground stabilisation with lime: possibilities in Andalucia). I Andalucian Road Congress. Volume II, pages 1,701-86.