European standards on construction materials and highly environment-consistent road techniques: experimental research on soil stabilization with lime.

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Synopsis

It is well-known that the clayey materials non-stabilised cannot be used for constituting road subgrades, embankments or subbase courses. Because their important fine part content and their strong plasticity make them too much sensitive to water action and so they are exposed to high reduction of bearing capacity.
Increasingly stricter restrictions on digging out of suitable natural material for the realisation of road embankments, together with problems related to the disposal of excavation soils, make it necessary to reconsider, in the field of material realisation methods, those soil stabilization techniques which have been long known and applied. More specifically, stabilization with lime has a strong environmental significance, because it allows to re-use extremely plastic clays which, even in those yards where considerable quantities of soil are moved, would be conveyed to dumps and cause the heavy well-known consequences on the environment. Furthermore, the CE marking of construction limes, compulsory in Europe since 1 August 2003, fixes their characterisation and filing according to harmonised technical specifications, making it possible to have different kinds of lime with different characteristics and costs. We may then wonder if effects on the soil to be stabilized are different too, because that would imply carrying out a relevant costs-benefits analysis before choosing the more suitable type of lime. Such assumptions were the starting point for an experimental research on the effects produced by some kinds of lime on clayey soils within a stabilization process. The properties of the "lime" product, which are partly marking-certified, have been reverified in laboratory in compliance with test methods provided for by harmonised reference standards; the stabilization process effects have instead been estimated through typical tests on soils, such as the determination of the standard Proctor compactation curve and of the immediate and post-saturation CBR.
The experimentation has shown that, in the same conditions, different kind of lime produce results sensitively diverse and that the non-controlled lime has not the same effectiveness as the CE markable one.
As well, in the application of the stabilization technique it is needed to fix in the Tenders the marked products. And it is necessary to assess the effects achieved from different classes binders thanks to pilot studies.

European standards on construction materials and highly environment-consistent road techniques: experimental research on soil stabilization with lime.

The "New Approach", defined in a Council Resolution of May 1985, represents an innovative way of technical harmonisation. It introduces, among other things, a clear separation of responsibilities between the EC legislator and the European standard bodies CEN, CENELEC and ETSI in the legal framework allowing for the free movement of goods. While EC directives define the *essential requirements*, protection of health and safety, that goods must meet when they are placed on the market, the European standards bodies have the task of drawing up the corresponding technical specification meeting the essential requirement of directives, compliance with which will provide a presumption of conformity with the essential requirements. Such specification are referred to as *harmonised standard*.
After issuing the first 89/106 directive on construction products, the European Commission gave the M114 mandate to the CEN, following which the EN 459-1, 459-2, 459-3 standards for lime have been drawn up.
Inspired from such documents, we wanted to inquire about the possibility to optimize clayey soil stabilization effects by means of limes favouring the improvement of the soil's physical and mechanical characteristics.
As a matter of fact, literature on stabilization with lime provides exhaustive information about methods, experimental applications and executive techniques; on the other hand, classes and requirements for acceptance of lime to use are generally neglected topics.

BUILDING LIME: DEFINITIONS, SPECIFICATION AND CONFORMITY CRITERIA

The EN 459-1 applies to building limes used as binders for preparation of mortar and production of other construction products. It gives definitions for the different types of building limes and their classification. It also gives requirements for their chemical and physical properties which depend on the type of building lime and specifies the conformity criteria.
In Italy, the previous standard for classification and definition of air limes requirements dates back to 1939 (Royal Decree n° 2231 entitled "Standards for limes acceptance"); this gives even more relevance to the introduction of the new standard drawn up by the CEN together with EN 459-2 and EN 459-3 which respectively specify test methods and the pattern for compliance evaluation.
Even if the EN 459-1 standard deals with different kinds of lime, here we will only consider calcium limes (table 1), which are suitable for stabilization and employed in this experimentation.

Tab 1: Designation of air calcium limes

DESCRIPTION	CODE
calcium limes 90	CL 90
calcium limes 80	CL 80
calcium limes 70	CL 70

For example, Calcium lime 90 as quicklime is named as EN 459-1 CL90-Q. 90 indicates the addition of Calcium Oxide and Magnesium Oxide, and Q shows delivery conditions, namely that it is a quicklime; on the other hand hydrated lime is marked with letter S. The composition of the construction lime, when tested according to EN 459-1, must comply with values shown in table 2.

Tab 2: Chemical requirements of air calcium limes

KIND OF LIME	CaO + MgO [%]	MgO [%]	CO_2 [%]	SO_3 [%]
CL 90	≥ 90	≤ 5	≤ 4	≤ 2
CL 80	≥ 80	≤ 5	≤ 7	≤ 2
CL 70	≥ 70	≤ 5	≤ 12	≤ 2

The physical properties of the above mentioned limes must comply with the values shown in tables 3 and 4.

Tab 3: Physical requirements of air calcium quicklimes

<table>
<tr><th>KIND OF LIME</th><th>STABILITY AFTER SLAKING
5.3.3 EN 459-2</th><th>POWER
5.9 EN 459-2</th></tr>
<tr><td>CL 90</td><td rowspan="3">Passed</td><td rowspan="3">≥26 dm^3/10 kg</td></tr>
<tr><td>CL 80</td></tr>
<tr><td>CL 70</td></tr>
</table>

Tab 4: Physical requirements of air calcium hydrated limes

<table>
<tr><th rowspan="4">KIND OF LIME</th><th colspan="2">FINENESS</th><th>MOISTURE</th><th colspan="2">STABILITY</th><th colspan="2">MORTAR TEST</th></tr>
<tr><td colspan="2">5.2 EN 459-2</td><td rowspan="2">5.11 EN 459 -2</td><td rowspan="2">5.3.2.1 EN 459-2</td><td rowspan="2">5.3.2.2 EN 459-2</td><td rowspan="2">5.5 EN 459-2</td><td rowspan="2">5.7 EN 459-2</td></tr>
<tr><td>0,09mm</td><td>0,2mm</td></tr>
<tr><td colspan="2">[%]</td><td>[%]</td><td>[mm]</td><td>[mm]</td><td>[mm]</td><td>[%]</td></tr>
<tr><td>CL 90</td><td rowspan="3">≤ 7</td><td rowspan="3">≤ 2</td><td rowspan="3">≤ 2</td><td rowspan="3">≤ 2</td><td rowspan="3">≤ 20</td><td rowspan="3">> 10 e < 50</td><td rowspan="3">≤ 12</td></tr>
<tr><td>CL 80</td></tr>
<tr><td>CL 70</td></tr>
</table>

The compliance certification system used for limes is n°2; this means that the producer plans and performs the compliance controls while an external Organism checks the effectiveness of the Production Control System.
The implementation of such system guarantees that each product is marketed only when meeting all the requirements quoted in the reference standard.

THE EXPERIMENTAL RESEARCH

In order to verify the importance of performing checks on stabilization materials, we performed an experimental research by mixing one kind of soil with two types of hydrated lime and two types of quicklime. What follows is a description of the materials employed, the tests carried out and the results achieved.

The soil

The soil used was taken during excavations for the realisation of a Sicilian road, and has the following characteristics:
Weight passing through an ASTM n°200 sieve=100%
Natural soil water content w_{nat} = 24%
Liquid Limit (LL) = 68
Plastic Limit (PL) = 28
Plasticity Index (PI = LL – PL) = 40
Group Index (GI) = 20
According to the UNI standard 10006, it therefore is an A7 (Figure 1).

Figure 1: Characteristics of soil used

The Proctor curve of the natural soil is represented in the following graph:

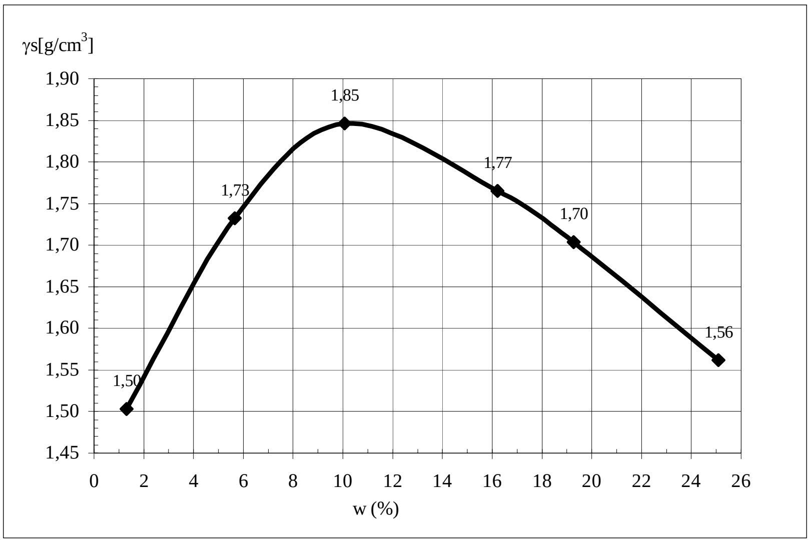

Figure 2: Proctor curve of natural soil

The diffractometric analysis performed on the sample (figure 3) revealed the following crystals species, in decreasing order: quartz (SiO2), calcite (CaCO3), kaolinite and montmorillonite. Silico-aluminate hydrate (kaolinite and montmorillonite) combined with lime, causes the typical stabilization reactions, forming calcium aluminate and calcium silicate.

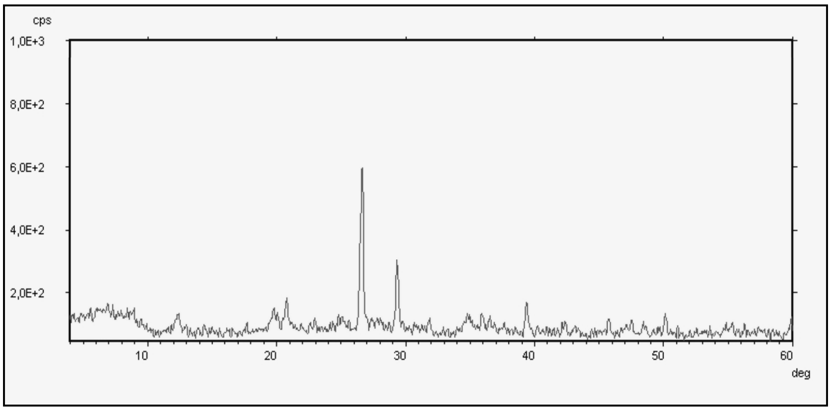

Figure 3: Diffractometric analysis

The limes

In the experiment we used two kinds of CE marked hydrated lime, a CL 70-S one and a CL 90-S one, a CE markable quicklime (CL 90-Q) and a non-markable quicklime, not complying with the 459-1 standard, which we will later name N.M.L. (Non-Markable Lime) quicklime. These products were offered by Sicomed Spa, which also kindly allowed us to use their laboratories for the experimental check of the lime's physical properties; chemical tests were instead performed by external laboratories. In tables 5, 6 we specified the characteristics of the limes we employed in the experimentation while figure 4 illustrate some of its phases.

Tab 5: Results of tests performed on hydrated limes

TEST	METOD	CL 90-S		CL 70-S	
		0,09 mm	0,2 mm	0,09 mm	0,2 mm
Fineness	5.2 EN 459 -2	≤ 7	≤ 1,3	≤ 7	≤ 1,8
Moisture [%]	5.11 EN 459 -2	≤ 0,07		≤ 0,02	
Stability [mm]	5.3.2.2 EN 459 -2	≤ 2		≤ 6,8	
CaO +MgO [%]	4 EN 459 -2	>92		>75	
MgO [%]	4 EN 459 -2	≤1,2		≤1,7	
CO_2 [%]	4 EN 459 -2	≤6		≤11,8	
SO_3 [%]	4 EN 459 -2	traces		traces	

Tab 6: Results of tests performed on quicklimes

TEST	METOD	CL 90-Q	N.M.L.
Power [dm^3 / 10 Kg]	p.to 5.9 EN 459 -2	27	18
CaO +MgO [%]	p.to 4 EN 459 -2	≥ 90	≥ 90
MgO [%]	p.to 4 EN 459 -2	≤ 2	≤ 2
CO_2 [%]	p.to 4 EN 459 -2	≤ 4	≤ 4
SO_3 [%]	p.to 4 EN 459 -2	traces	traces

Figure 4: Tools for power and stability determination

Two aspects should be especially highlighted: the CL 70-S differs from the CL 90-S in lower calcium oxide content and in a much higher calcium carbonate content. What follows will reveal that this composition considerably influences stabilization effects. The performance value of the N.M.L., which, as envisaged by production control procedures, was rejected by the company after testing, is below fixed limits; this too causes consequences on the behaviour of the mixtures used in the project.

Mixtures characterisation tests

The mixtures have been characterized by the special tests that the technical standards and the special tenders provided for. Generally, the percentages of lime we used were 4, 7, and 10% of the dry soil weight. We varied the water contents from 5 to 25% nearly.

For simplifying we represent the main results achieved in synoptic diagrams.

The variations of soil moisture resulting after the lime addition are strictly linked to the kind of binder used. While hydrated limes involve variations, as regard the w_{nat}, by few percentage points, the addition of the same quantity of quicklime involves very considerable and continuous in time variations (figure 5).

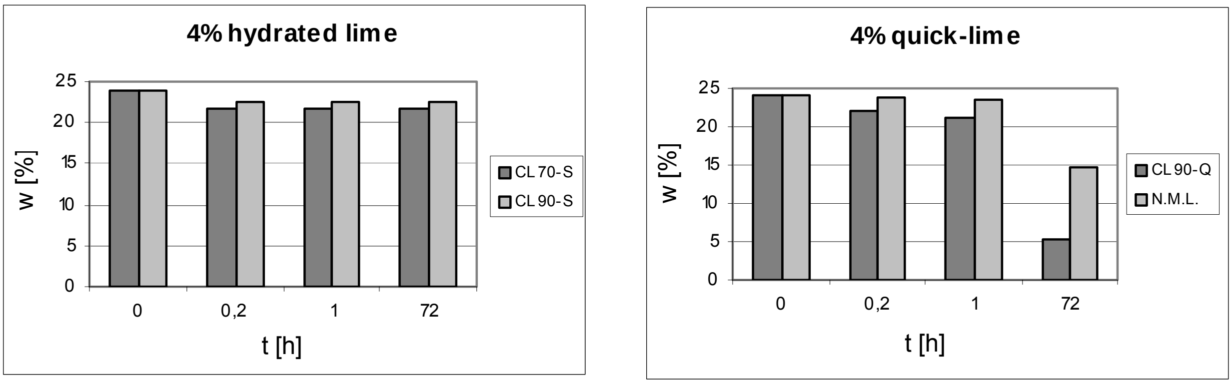

Figure 5: Variation of water content

As well, graphs show that the effects of the two hydrated limes are comparable, while calcium oxides differ not only for the variations they produce but for the speed of their reactions too. This tallies with the characterisation test results achieved, especially with the power which shows that the slaking reaction of non-markable lime is slower and less effective that the CL 90-Q one.

Increasing the quantity of lime, we notice little moisture reductions as regard the examined case. This is mainly due to the addition of higher percentage of dry material, more than the lime properties (figure 6).

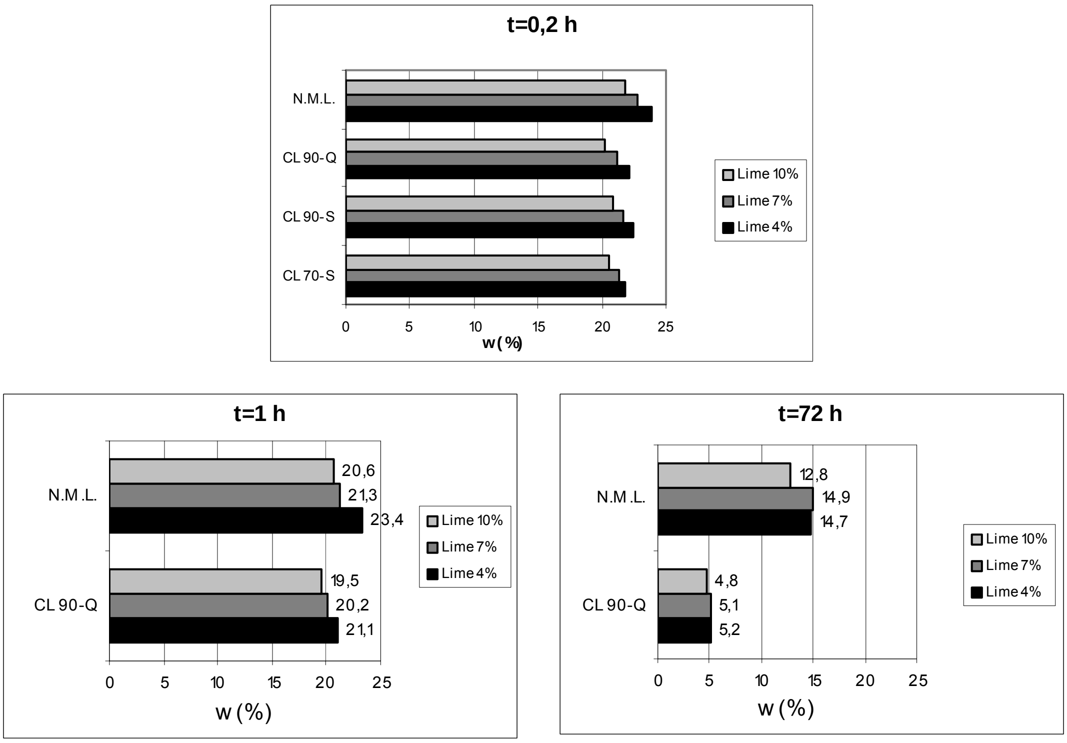

Figure 6: Variation of moisture according to the lime content

Instead the kind of lime does not especially influence the water susceptibility of soil: the plasticity index, even if very high yet, decreases by some percentage points employing the oxides or the hydrates. Figure 7 reports two typical performances.

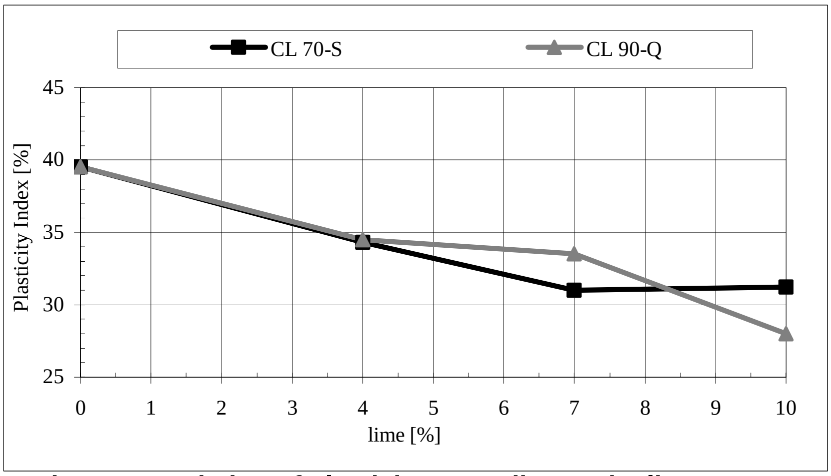

Figure 7: Variation of plasticity according to the lime content

As far as the Proctor curve is concerned, the characteristic performance of stabilization with lime is generally confirmed with all the types of binder. By increasing the lime contents, curves moves down and at right, namely the w_{opt} increases and the $\gamma_{s,max}$. decreases. In figure 8 we transfer the CL 70-S performance. In the other cases we achieved similar performances.

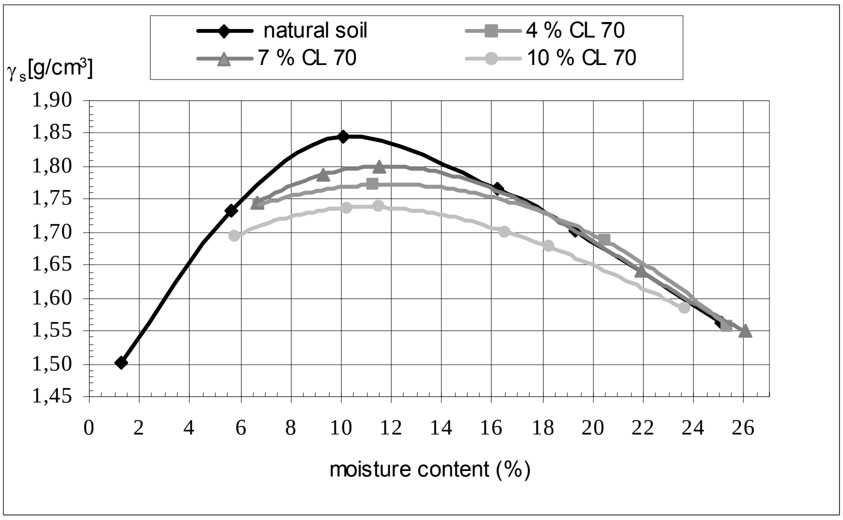

Figure 8: Proctor curve according to the variation of the percentage of added CL70-S

CBR tests has highlighted that, compared to the one of the soil as sample, adding lime always increases the bearing capacity. By analysing figures 9, 10, and 11 we deduce that the highest CBR values are always produced in 10% water contents nearly (optimum moisture of the soil as sample). We also deduce that we obtain the highest rise of immediate bearing capacity with 7% of CL 90-S.

For water contents below 10-12%, apart from the percentage and the kind of lime, we reach a CBR always higher than 80%. However this data is not much significant because, for too low moisture values, the test pieces are not much cohesive (figure12) and the resistance found is essentially ascribable to the lateral bordering due to the punch.
For high water contents (over 20%), the CBR values reduce significantly - even if they are still higher than the ones of the soil as sample – and we achieve the best results by employing hydrated limes: by 20% of water content, the CL 70-S produces an immediate CBR which varies between 40 and 50% and with the CL 90-S the values vary between 20 and 40%. Taking into account of a water contents equal to the natural one of the soil, with CL 70-S and CL 90-S we achieve small CBR.
Generally quicklime produced less important effects, moreover, an lime contents rise does not involve considerable rise of bearing capacity, this confirms that it is suitable to use low percentage of quicklime in this applications. For the diverse water contents considered and the different quantities of binder employed, the CL 90-Q always provides CBR values higher than the ones we obtained by filling the soil with the non-markable lime.

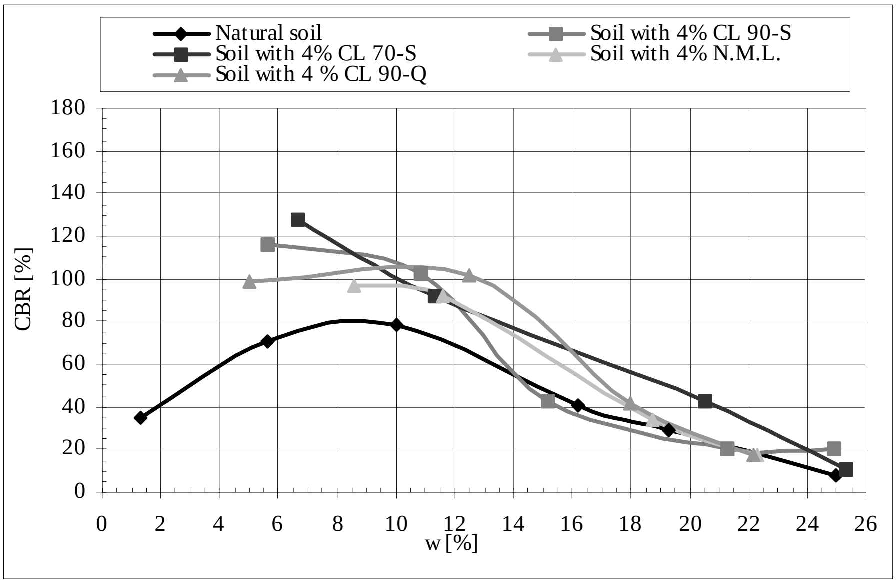

Figure 9: Immediate CBR for 4% of lime characterised mixtures

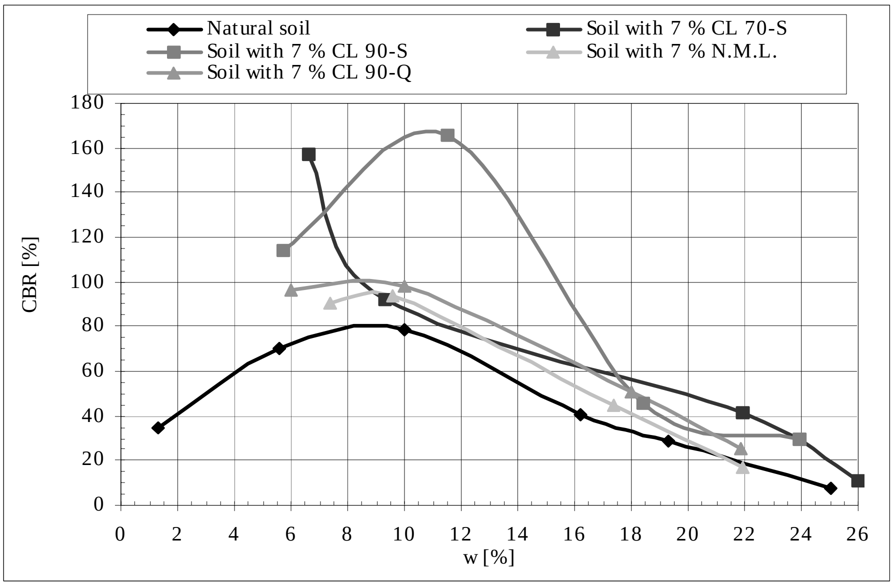

Figure 10: Immediate CBR for 7% of lime characterised mixtures

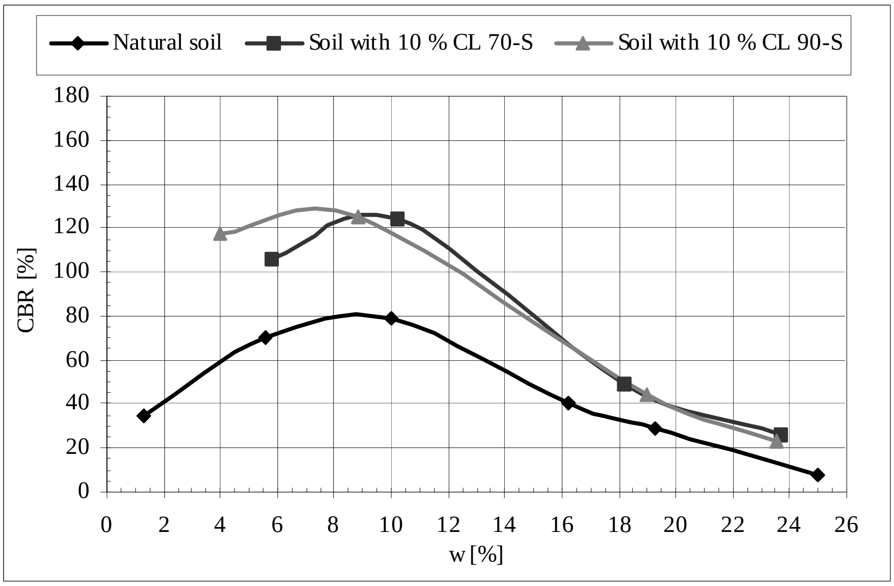

Figure 11: Immediate CBR for 10% of lime characterised mixtures

Figure 12: Test pieces made up with different percentages of water

In this experiment, we have determined no kind of lime which has effects clearly better than the other ones have. This evidences the need of careful preliminary studies in the application of technique, in order to determine the percentage together the more suitable class of product.

Table 7 shows all immediate CBR values measured.

Tab 7: Results of immediate bearing capacity tests

		Immediate CBR [%]			
		w ≈ 5 %	w = w_{opt}	w ≈ 20%	w = w_{nat}
Natural soil		70,28	78,27	29,14	7,85
Soil with CL 70-S	4 %	127,61	91,9	42,86	10,57
	7 %	157,28	92,14	41,43	11,3
	10 %	105,7	124,56	49,28	25,71
Soil with CL 90-S	4 %	115,71	102,14	20,36	20,71
	7 %	114,28	165,71	45,71	30
	10 %	117,14	124,70	43,8	22,86
Soil with CL 90-Q	4 %	99,06	101,43	42,11	17,43
	7 %	96,21	98,43	51,17	25,75
Soil with N.M.L.	4 %	87,42	82,93	30,78	11,26
	7 %	81,43	84,34	40,11	15,34

Finally, we performed the post-saturation CBR tests, generally taken as reference in the Special tenders, on the test pieces made at the W_{opt} of the mixture, with 7 days of maturing and 4 days of imbibition. Moreover, we consider the more significant percentages of lime as regard the results achieved with immediate bearing capacity tests. Figure 13 reports the data obtained:

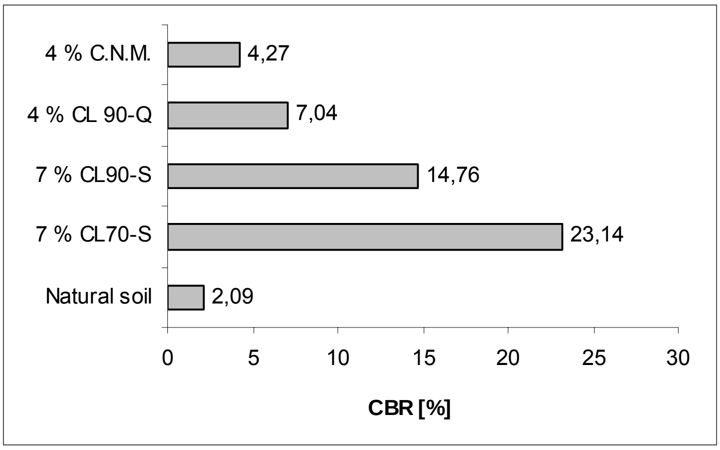

Figure 13: Results of post-saturation bearing capacity tests

Even after the maturing lime is more effective than oxide, furthermore we can make some important remarks:

- In the case of the hydrate, the rise of the bearing capacity, as regard the soil as sample, is bigger by adding CL70-S than by adding CL 90-S (the quality of this lime is higher than the one of the previous because of the higher content of calcium oxide and magnesium oxide). This apparent inconsistency is certainly due to calcium carbonate content of the CL 70-S: in the reactions which happen during the maturing, such carbonate forms a framework which stiffens the mixture and improves its mechanical characteristics.
- the oxide use does not improve very much the soil resistance to imbibition. Then we reveal that in such kind of soil, the markable quicklime is very much effective for the moisture diminution however not on the bearing capacity as well, while the N.M.L produces effects less evident on moisture and almost no effects on the bearing capacity.

TECHNICAL REQUIREMENTS

A survey of Special Tenders for road works in Europe has shown a certain awareness of the Administration towards employing silt-clayey materials stabilized with lime for subgrades and embankments.
We noticed that not all of the Tenders are in compliance with standards in force (figure.14) and that not all of them take into account the impossibility of determine absolutely optimum classes of lime for the stabilization (figures15,16).

Articolo 41*"Formazione dei rilevati"*:

"... possibilità di un riutilizzo del materiale proveniente da scavi di sbancamento appartenente ai gruppi A_4, A_5, A_6 e A_7 previa idonea correzione."

• **Articolo 44 *"Stabilizzazione delle terre con calce"*** ":

"La calce da utilizzare dovrà essere del tipo calce idrata che deve rispondere ai requisiti di accettazione indicati nei R.D. n. 2231 del 16 novembre 1939. Prima dell'inizio dei lavori, L'Impresa dovrà presentare alla Direzione lavori e sottoporlo alla sua approvazione, tutte quelle prove di pre-qualificazioni per individuare le quantità di acqua e di calce con cui si dovrà effettuare l'impasto. La determinazione preventiva della quantità di acqua e di calce vanno valutate , prendendo almeno tre miscele sperimentali con diversi tenori di calce."

Figure 14: Draft of Italian Tender

"Cahier des Charges-Type CCT RW 99, Chapitre C, Matériaux et produits de construction "
La chaux

Les chaux utilisées en construction sont conformes à la norme NBN ENV 459-1 (définitions, spécifications, critères de conformité).

Chaux pour le traitement des sols:

Les caractéristiques de la chaux vive grasse moulue sont les suivantes :
– granularité : refus à 2 mm < 5 % et passant à 0,080 mm > 30 %
– teneur conventionnelle en oxyde de calcium : ≥ 80 %
– vitesse d'hydratation : une température de 60° C doit être atteinte en moins de 10 minutes.

Figure 15: Draft of Belgian Tender of 1999

"Cahier des Charges-Type 2004, Chapitre C, Matériaux et produits de construction "
La chaux
On distingue :
– la chaux aérienne vive qui est composée principalement d'oxyde de calcium. Selon la norme NBN EN 459-1 elle est qualifiée par la dénomination CL pour l'aspect chaux calcique et Q pour l'aspect chaux vive ;
– la chaux aérienne éteinte, ou hydratée, qui est composée principalement d'hydroxyde de calcium. Selon la norme NBN EN 459-1, elle est qualifiée par la dénomination CL pour chaux calcique et S pour l'aspect chaux hydratée.
– la chaux hydraulique naturelle, contenant un certain pourcentage (jusqu'à 22 %) d'argile ce qui lui confère des propriétés de prise hydraulique. Selon la norme NBN EN 459-1, elle est qualifiée par la dénomination NHL.
Les chaux utilisées en construction sont conformes à la norme NBN EN 459-1 (définitions, spécifications, critères de conformité) et portent le marquage CE (système 2).

Chaux pour le traitement des sols:
Les caractéristiques de la chaux vive grasse moulue sont les suivantes :
– granularité : refus à 2 mm < 5 % et passant à 0,080 mm > 30 %
– composition chimique : chaux selon la désignation normalisée EN 459-1 CL90-Q
– vitesse d'hydratation : une température de 60° C doit être atteinte en moins de 10 minutes.

Figure 16: Draft of Belgian Tender of 2004

As an example, the Italian Tender has fixed, rather anachronistically, the compliance of lime with standards which dates back to 1939. The Belgians ones are properly updated as far as standards(from the figures we can also deduce the path which led gradually to the introduction of the new standards), however, they only cope with the quicklime CL90-Q classifiable.
After that experimentation, it seems opportune proposing the introduction in the tenders of directions which provide for the survey of the more suitable typology of binder for a certain soil apart from the research of its suitable content during the pilot study for the planning and the control of mixtures of stabilised soil. In addition, employing CE products is the essential premise for this purpose.

CONCLUSION

This report highlights the need to reconsider the environmental significance of soil stabilization techniques and encourages road engineers to go deeper into this subject so to consciously estimate the opportunity of employing them and promoting their use. Basically, such knowledge concerns implementation techniques and involved materials, which are mainly soil and, in this case, lime. This research focuses on the different types of lime available on the market, which differ in chemical and physical characteristics and were included more than one year ago among those construction products for which CE marking is compulsory. This means that such products are continuously controlled within each business by means of a Production Control System. It therefore cannot and must not happen that the declared characteristics of a material are different from its real ones; on the other hand, it was discovered that this could still happen with unmarked limes. To demonstrate the validity of these statements, we carried out an experiment using different kinds of lime, on which we performed the starting tests provided for by UNI standard EN 459-1, according to the methods quoted in UNI standard EN 459-2.
The experiment involved two types of CE marked calcium hydroxide (CL 70-S and CL 90-S), thus proving that different classifications correspond to different effects, together with two quicklimes, one of which was intentionally non-markable as it did not meet any standard minimum requirements.

Our theory was proved right: the experiment demonstrated that, other conditions being equal, different kinds of lime produce visibly different effects and that not-controlled lime (C.N.L.) is not effective as the markable one (CL 90-Q). Finally, through the critical analysis of Italian and foreign technical documents, we underlined the need to review standards and Special Tenders with a view to current provisions on lime. A standard tender draft was also proposed, so that both the content and the type of binder, classified in compliance with UNI standard EN 459-1, are mentioned among the variables taken into account in pilot studies.

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