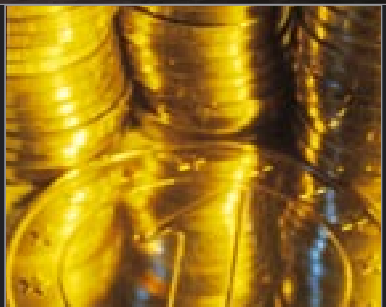



Soil Treatment using Lime

Simple

Effective



Economical

Ecological



An Age-Old Technique

Ever since ancient times, people have used lime as a binder for building structures. The oldest lime-based concrete known to us was found in Lepenski-Vir in Serbia, and dates from 5600 BC.

The Romans inherited this knowledge from earlier civilizations and developed it further. Their most striking application of the technique still visible today is the Pantheon, whose concrete dome was made from pozzolan material and air lime!

What would mediaeval architects have done without lime? The Gothic cathedrals, with their delicate spires and leaping buttresses, could not have been made without the flexibility and workability that lime - air-hardening lime in particular - provided.

The earliest known example of soil improvement with lime is the Via Appia, which was built on lime-stabilized soil. This road dates from Roman times and is still in use.

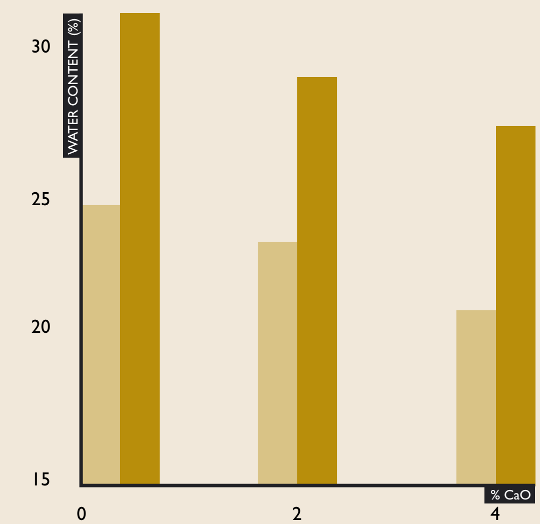
Closer to home, lime was widely used in the 1970s and 1980s for soil stabilization in the construction of many of Belgium's motorways.

Nowadays, the use of lime to improve the characteristics of silt and clay soils is still in full development. Improvements to machines, research in geotechnical laboratories, and innovations by lime suppliers have dramatically increased the use of lime-based procedures. Regardless of whether it is for large projects (motorways, high speed railways or airports) or more modest ones (car parks, industrial sites or local roads) the technical, economic and ecological advantages of stabilizing soils with lime are greatly appreciated by investors.

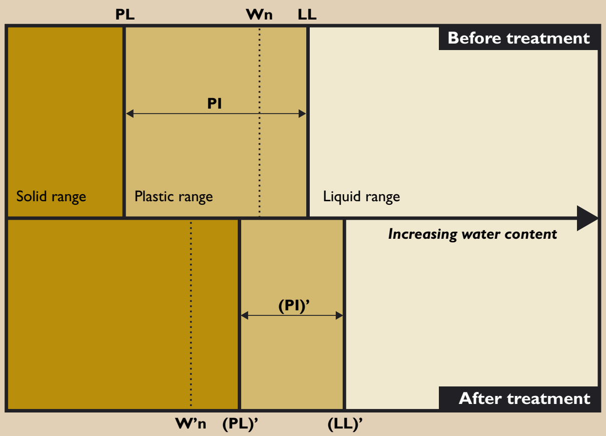
The steady rise of the costs associated with the disposal of surplus soil and an increasing awareness of environmental issues make this technique deserving of closer attention.

The solution for fine soils

When the transport or re-use of fine-grained soils has to be considered during the course of a project, stabilization with lime offers a good solution. Soils of this kind, i.e., soils containing significant levels of silt or clay, have changing geotechnical characteristics: they swell and become plastic in the presence of water, shrink when dry, and expand when exposed to frost. Site traffic is always a delicate and difficult issue when projects are carried out on such soils. In other words, the re-use of these materials is often difficult, if not impossible.
Once they have been treated with lime, such soils can be used to create embankments or subgrades for structures, thus avoiding expensive excavation works and transport.



Effect of quicklime on the water content of plastic clay treated in the laboratory, for two initial water contents.



How Lime Works

Effect of liming on the consistency of a soil

Drying: the Wn water content of the soil before treatment is reduced to W'n.
Flocculation: treatment with lime displaces the solid range of the soil to the right. This enables it to accept a higher water content whilst remaining solid.
The plasticity index PI = LL - PL (liquidity limit less plasticity limit) is reduced.

Mixing a limited dosage of unslaked lime into damp soil creates both "immediate" and "medium term" effects.

Immediate Effect: Soil Improvement

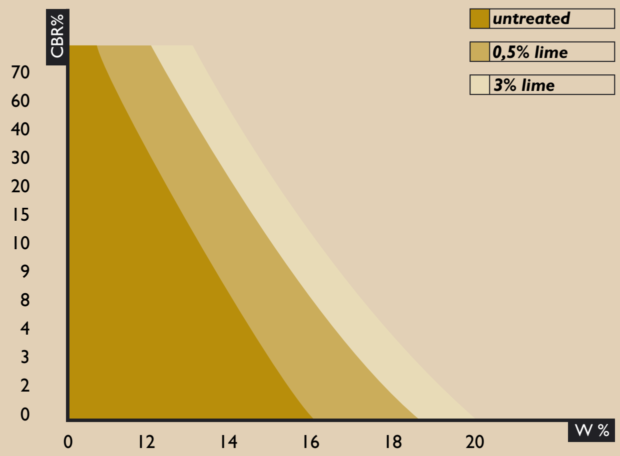
Drying: when the unslaked lime is mixed with damp soil there is an immediate reaction whereby a lot of heat is generated (exothermic hydration reaction). The result is a reduction of the natural water content of the soil by hydration and evaporation. This water loss is further increased by the aeration of the soil during the mixing process. Depending on the weather conditions, the water content can fall by 2 to 3% per percentage of added lime.
Floculation: the addition of lime affects the electrostatic field between the clay particles. As a result, they assume a granular structure.

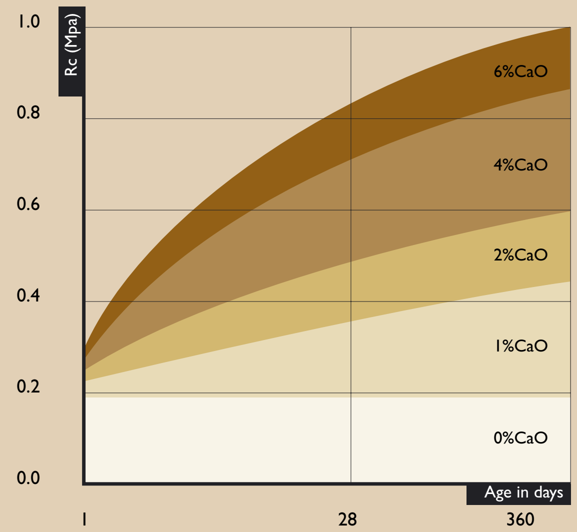
In geotechnical terms, these two phenomena are expressed as:

❶ A reduction in the plasticity index
The soil suddenly switches from being plastic (yielding and sticky) to being crumbly (stiff and grainy). In the latter condition it is easier to excavate, load, discharge, compact, and level.

❷ An improvement in the compaction properties of the soil
The maximum dry density drops, while the optimal water content rises, so that the soil moves into a humidity range that can be easily compacted. This effect is clearly advantageous when used on soils with a high water content, which is common in our areas.
A treatment with quicklime therefore makes it possible to transform a sticky plastic soil, which is difficult to compact, into a stiff, easily handled material. After compacting, the soil has excellent load-bearing properties.

❸ Improvement of bearing capacity
In most cases, two hours after treatment, the CBR (California Bearing Ratio) of a treated soil is between 4 and 10 times higher than that of an untreated soil. This reaction greatly relieves on-site transportation difficulties.





Increase in the carrying capacity of silt after liming

After two hours and with an initial water content of 14%, the CBR index, which was 9 before treatment increased to around 30 and 70 with lime levels of 0.5 and 3% respectively.

Long-term changes of geotechnical properties

Evolution of the compression resitance of plastic clay treated with lime as a function of time.

Medium Term Effects: Soil Stabilization

When lime comes into contact with a substance containing soluble silicates and aluminates (such as clay and silt), it forms hydrated calcium aluminates and calcium silicates. As with cement, this gives rise to a true bond upon crystallization. Called a pozzolanic reaction, this bonding process brings about improved resistance to frost and a distinct increase in the soil's compressive strength and CBR.

In general, in non-winter conditions, the soil develops sufficient strength after three to six months. A slow curing process during road construction is a marked advantage, as it allows greater flexibility when working with the treated soil.

The long-term hardening facilitates the design of foundations for industrial platforms. The stabilizing effect gives load-bearing qualities to the treated soil.

Numerous advantages in a broad range of applications

➔ In the space of a few hours an impassable soil is transformed by lime into a soil which construction equipment can negotiate without any trouble. An added bonus is that the soil becomes less sensitive to moisture. This immediate and spectacular effect makes it possible to build job site roads that can be used regardless of weather conditions. The cost of the treatment is more than compensated by eliminating the expenses associated with work delays.

➔ Treating soils on site makes it possible to reduce the major haulage operations, which are an inevitable part of earth-moving works, and the supply of granular materials. This is of significant benefit to the immediate surroundings of the construction site. Less transport means less noise nuisance, less disruption, and less wear and tear on the surrounding roads.

➔ The technique makes it possible to retain high quality raw materials for quality applications. The building of embankments using moist plastic soils treated with lime can result in considerable savings on materials brought in from elsewhere, often at great cost, and the inevitably high costs of waste soil disposal. Furthermore, haulage operations are greatly reduced. This represents not only a financial gain but also an ecological bonus.

➔ Lime treatment makes it possible to construct good quality capping layers and beds for roads, railway tracks, and runways. The stiffe-

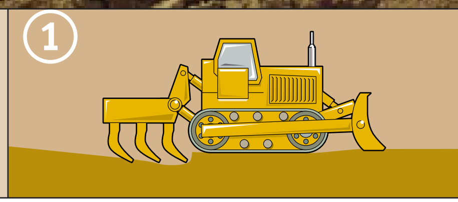
ning/curing of the structure means that the slopes of the structure have greater stability.

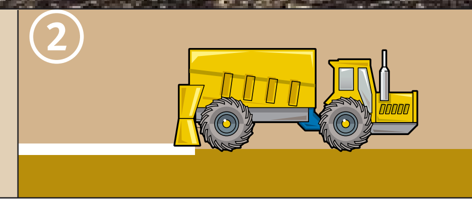
➔ Because it is such a simple process, lime-stabilization of soil is easy to apply to “small” works, such as foundations for car parks, industrial platforms, and agricultural and forestry roads.
The greatest benefits of this procedure, namely the savings on aggregate and disposal charges, are indeed the same as for all major earthmoving works. Moreover, on smaller sites, this work can be done by lighter equipment.

It is generally estimated that lime stabilization becomes an attractive solution when the area to be treated is greater than 500 to 1000 m^2. Nonetheless, it still remains advisable to entrust the work to specialized firms.

➔ To achieve a rapid curing of the treated layers, mixed lime-cement treatment is often used. In such cases, it is essential to work the lime into the soil before adding the hydraulic binder. The lime ensures that the clay/silt soil becomes friable, thus making the material more granular. The working area that has been treated with lime is then perfectly serviceable for vehicles, which makes it possible to spread out the cement in uniform fashion. This improves working conditions and allows homogeneous mixing to take place, thus yielding better results.

Execution



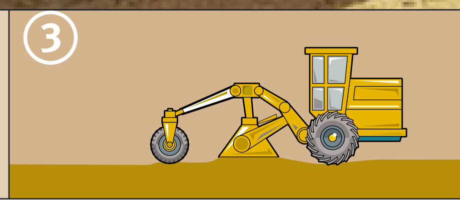


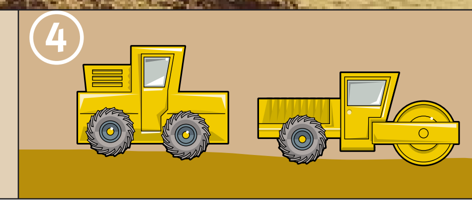
In general, soil treatment involves several phases. These various phases may be performed in different sequences, depending on whether the soil is to be treated on the spot or whether transport of the soil before or after the treatment is planned.

❶ **Preparation of the soil**: part of the aim of ploughing is to remove large elements which might hinder the mixing-in of lime, whilst it also helps to modify the humidity of the soil by ventilating or moistening it. This operation is not always necessary. It may be carried out with a ripper, a harrow or a plough.

❷ **Spreading**: spreading bagged lime over an area divided into compartments may be considered for very small sites or on sites where the geometry is complex. In most cases, the lime is dispersed using a spreader fitted with a weighing device (ideally this should be matched to the speed of the vehicle). This operation should be carried out with a maximum of precision and regularity. The lime is supplied pneumatically to the spreader, either directly from the silo vehicle or by using buffer silos.

❸ **Mixing**: the purpose of this operation is to spread out the soil while at the same mixing the lime evenly into it. Depending on the





nature of the soil, the size of the construction site, and the type of structure concerned, this work will be done with pulvimixers, rotary paddle mixers, disk ploughs or plough shares.
It is recommended that mixers with closed chambers be used on sites where dust nuisance may be an issue.

❹ **Compaction**: when grading, the layer thickness than can be compacted by rolling should be taken into account. After grading, the treated soil has to be compacted using a compacting machine (pneumatic-tyre roller or tamping roller).

In warm weather and when the soil is wet, it is advisable to carry out the compaction 2 to 4 hours after mixing, to give the unslaked lime ample time to bind with the water and evaporate. Should there be a risk of rain, compaction of the soil should be done before any water can again penetrate the treated layers.
Should large quantities of lime be added in order to achieve higher bearing capacities or strength within a short period of time, then the humidity of the soil must be kept under control. When higher dosage levels of lime are used, additional moistening of the soil may be necessary.
It is also important to ensure that the entire mass of the treated soil is handled. For this reason, embankments are usually built up in horizontal layers of 0.3 to 0.5 metres thick.

Economic Balance

The main direct economic benefits of working with lime are as follows:

❶ Limitation of the need for enbankment materials brought in from outside and the elimination of their transporting costs.

❷ Reduction of transport movements in the immediate vicinity of the construction site.

❸ Machines can move about with far greater ease. Delays due to weather conditions are reduced, leading to improved productivity. As a result, the overall construction duration and costs can be dramatically reduced.

❹ Structures have a longer service life (embankments, capping layers) and are cheaper to maintain.

Every construction site is unique. Lime treatment must always be weighed against more traditional solutions (based on the use of materials brought in from outside).

The various elements that must be taken into account in a comparative cost analysis are the following:

➔ **For “On-site treatment”**: binder delivery costs (lime, possibly cement) and the handling (storage, preparation, spreading, grading, and compaction) of on-site treated soils.

➔ **For “New materials”**: cost of the purchase and transport of granular materials (natural or recycled aggregate), processing costs (grading and compacting) and the cost of disposing of the removed soil.

For comparison purposes, we may examine two types of project on a relatively small site (the costs quoted here may be considerably less for a larger site because of the greater scale).

Distances:

➔ between the structure and the quarry or recycling centre: ±20 km
➔ between the works and the disposal site: ±20 km
➔ between excavation and fill: ±300 m

Cost Evaluation

1. Building an Embankment

EXCAVATION AND ENBANKMENT WITH NEW AGGREGATES MATERIAL		EXCAVATED SOIL TREATED WITH 2.5 % LIME	
Excavation soil	2,00 €/m³	Excavation soil	2,00 €/m³
Transport to the disposal site	6,00 €/m³	Moving from excavation site to embankment site	1,50 €/m³
Disposal (1,7 t/m³ x 6 €/t)	10,20 €/m³	Disposal of the soil in the embanked area	0,50 €/m³
Purchase of recycled aggregates (2 t/m³ x 5,5 €/t)	11,00 €/m³	Purchase of lime delivered to the site (2 % x 1,7 t/m³ x 105 €/t)	3,60 €/m³
Carriage of the new materials from the recycling centre to the site	6,00 €/m³	Mixing and spreading	2,20 €/m³
Grading and compaction of the paving materials	2,00 €/m³	Grading and compaction	2,00 €/m³
TOTAL*	37,20 €/m³	TOTAL*	11,80 €/m³

* based on prices for 2005-2006

For very large earthmoving projects (e.g., in excess of 20,000 m²), the total cost of lime treatment can be very significantly reduced. For on site soil stabilization, increased work scale (lime, spreading, and mixing) and improved productivity can represent savings of between € 0.75 to € 1.00 per cubic metre, which represents overall savings of 7% on lime treatment costs.

2. Construction of foundations for an industrial building or the sub- base of a road

COSTS FOR MAKING A CONTINUOUS AGGREGATE PAVEMENT		COSTS OF A MIXED LIME + CEMENT TREATMENT	
Grading and compaction. Earth works and loading excess soil (m³ on-site)	2,00 €/m³	Ploughing	0,40 €/m³
Transport to the disposal site	6,00 €/m³	Purchase of lime delivered to the site (1,5 % x 1,7 t/m³ x 105 €/t)	2,70 €/m³
Disposal (1,7 t/m³ x 6 €/t)	10,20 €/m³	Spreading and mixing of lime	2,20 €/m³
Purchase of continuous natural paving aggregate (2 t/m³ x 7 €/t)	14,00 €/m³	Pre-grading and compaction	1,00 €/m³
Transport of the paving aggregate from the quarry to the site	6,00 €/m³	Preparation 2nd stage	0,40 €/m³
Grading and compaction of the aggregate paving	2,00 €/m³	Purchase of the cement delivered to the site (6 % x 1,7 t/m³ x 75 €/t)	7,65 €/m³
		Spreading and mixing of cement	2,50 €/m³
		Grading and Compaction	2,00 €/m³
TOTAL*	40,20 €/m³	TOTAL*	18,85 €/m³

* based on prices for 2005-2006

Let us compare the costs of building foundations for an industrial building either by providing a paving of natural aggregate, or by means of a mixed treatment (urgent need for high bearing capacity) lime + cement. In the latter case, 1.5% lime and 6% of class 32.5 cement is applied. This level of added lime and cement makes it possible to achieve a bearing capacity equal to a continual natural aggregate paving. The procedure is suitable for numerous clay and silt soils on Belgian sites and takes into account a safety margin to compensate the lack of specific laboratory research.

Conclusion: when applied to a foundation of an average area (> 2,000 m²), the cost factor for an on-site mixed lime/cement treatment is 2 times cheaper than for a conventional treatment requiring the removal of material and the delivery of a natural aggregate paving material.

Soil Recycling

Although the technique of on-site soil treatment has long been firmly established, methods for recycling the soil via a central mixing plant (permanent or mobile) are still being developed. This relatively new application can make a major contribution to the reduction of soil surpluses. The technique is worth considering when the volumes of soil involved are relatively small or the space available is limited.

Soil improvement using lime treatment in a mobile mixing plant or a plant linked to a permanent recycling centre is generally attractive when:

- ➔ There is only limited space for maneuvring with a spreading machine and earth-moving equipment.
- ➔ The soil must quickly be improved so that it can be re-used on another job site.
- ➔ Good friability must be obtained quickly so that further mixing with cement can be carried out.
- ➔ Savings can be achieved by treating small volumes, thus avoiding disposal costs.
- ➔ There are good reasons for avoiding dust formation on site. A closed installation limits dust formation during treatment.
- ➔ It is possible to work on a storage site where the soils which have been treated with lime can be stored for weeks or even months without any loss of quality.

In general, the mixing plant comprises the following components:

- ➔ A storage silo for the lime, using either a vertical or horizontal storage system. A measuring device allows exact quantities of lime to be delivered from the silo (accuracy of 0.1 to 0.5% for an application of 1.5 to 3% of dry soil mass);
- ➔ An incoming storage area for the soil that is to be recycled;
- ➔ A mixing unit that either works continuously or in batches of various capacities (3-5m^3), to allow the uniform mixing of the lime-soil mix.

Limited space requirements: an installation of this kind needs only 100 m^2 for its operations.

Output: the production of such an installation can easily reach 1000 T a day.

Principal applications: structural backfilling, sub-bases and trench backfilling.

Recommendation for using recycled soil:

- ➜ In general, the stabilized soil is built up in layers of 30 to 40 cm thick. The exact thickness of the layer depends on the compaction equipment used.
- ➜ The depth of compaction is tested with a percussion sounder (light percussion sounding apparatus from the Belgian Road Research Centre (BRRC)) and by a plate-loading test on the finished layer. These tests are carried out immediately after completing the back-filling to ensure that we measure the compaction and not the effect of the hydraulic/pozzolan reaction.

Designation/certification of the treated products: the treated products are marketed under a variety of names. The products may be certified according to a voluntary quality-assurance system for recycled products.
Such certification systems are additional to the environmental certificates required by law. Soil with both certificates comply with environmental requirements and meets the warranted geotechnical specifications.
This solution guarantees the quality of the treated soil and allows the clients, both public and private, to specify the material in specifications as an economic alternative to more traditional materials.
Soil recycling is a fundamental technique that makes it possible to recycle excavated soils (e.g., from trench backfilling) and limit or entirely eliminate the need for transport to a disposal site.
This ecologically attractive technique offers the contractor an economically effective solution.

Limits of the technique: some reservations must nonetheless be made regarding the use of the techniques on excessively wet soils. Soil in which moisture reaches extreme levels cannot be brought to an acceptable quality even with substantial lime overdosing. In such cases, the more time-demanding technique of soil dewatering must be applied. Subsequently, a limited lime application can bring about the flocculation of the soil to obtain acceptable levels of workability and stiffness.

Quality Criteria for Lime

The quicklime (CaO) used for soil treatment is available as a ground powder (0/2 mm) with a bulk density of $\cong 1$ t/m^3. In order to guarantee effectiveness in the moist conditions encountered in Belgium and elsewhere in Western Europe, careful attention must be given to the quality of the lime.
The lime should conform to the specifications imposed by the Belgian standard (NBN) EN 459-1 CL90-Q and the supplementary specifications set out in technical regulations PTV 459 and TRA 459. These documents, which form the basis of a voluntary certification system, can be downloaded at **www.cric.be**.

The supplementary specifications, which are essential parameters for soil stabilization, concern grain size distribution, CaO content (active calcium oxide) and reactivity (hydration speed, the T60 test).

Dust Formation

The lime must be fine if it is to react optimally to the soil. Soil treatment may therefore entail a greater or lesser degree of dust formation. The extent of the dust formation depends on the material used and the weather conditions.
When works are carried out in open country, dust formation will not cause problems. After all, lime is widely used as a fertilizer on agricultural land.
However, when lime is used close to residential areas or busy roads, the dust may be a serious nuisance.
A few simple measures can substantially limit the release of dust:
- ➜ judicious choice of storage system/area;
- ➜ connection of the silos' air vents to filters maintained in good condition;
- ➜ avoid spreading works in strong winds;
- ➜ fit spreading machines with dust valances.

In certain cases where no dust formation at all is permissible or where the conditions are difficult (strong wind), the use of low dust lime is the best solution. This product is available on the Belgian market and fulfills the standard specifications EN 459 and PTV 459.

Four practical guides to soil treatment with lime. How do I get started?

Belgium's Road Research Centre (CRR–OCW) is recognized by professionals as the leading standard-setting organization for earthmoving and roadworks. They have published an overview of the technique and recommendations under the title "Handleiding voor grondbehandeling met kalk en/of cement / Traitement des sols à la chaux et/ou au ciment (R74/04)". (Dutch and French).

This manual underlines the specific requirements for soil treatment: preliminary soil tests, site organization, choice of suitable equipment, quality controls, etc.

The manual guides decision-makers and technicians through the various stages of soil treatment. It summarizes the current state of knowledge both in practical and theoretical terms.

The following aspects are discussed:

❶ **Soil knowledge**: characterization of various soil types and lab tests to determine the suitability of soils for treatment and the appropriate dosage.

❷ **Soil treatment**: description of the various treatment methods and their effect on the soil: distinction between immediate effect (soil improvement) and medium-term strength development (soil stabilization).

❸ **Procedures**: equipment required, delivery and storage of binders, main phases of treatment, tests, practical recommendations, safety requirements and description of soil treatment in fixed and mobile installations.

In addition, the BRRC has published a number of practical guides that discuss the various applications of this soil treatment. These provide a clear and quick answer to such questions as, "Can the soil be treated?", "What binder should be used?", and "What dosage should be adopted?".

The same approach is used to discuss the various stages of the treatment: preparation, execution, and testing:

➔ Taking representative samples and determining uniformity or non-uniformity;
➔ Analysis of samples and formulation design;
➔ Performance of the treatment;
➔ Tests during and after treatment;
➔ Standards referred to.

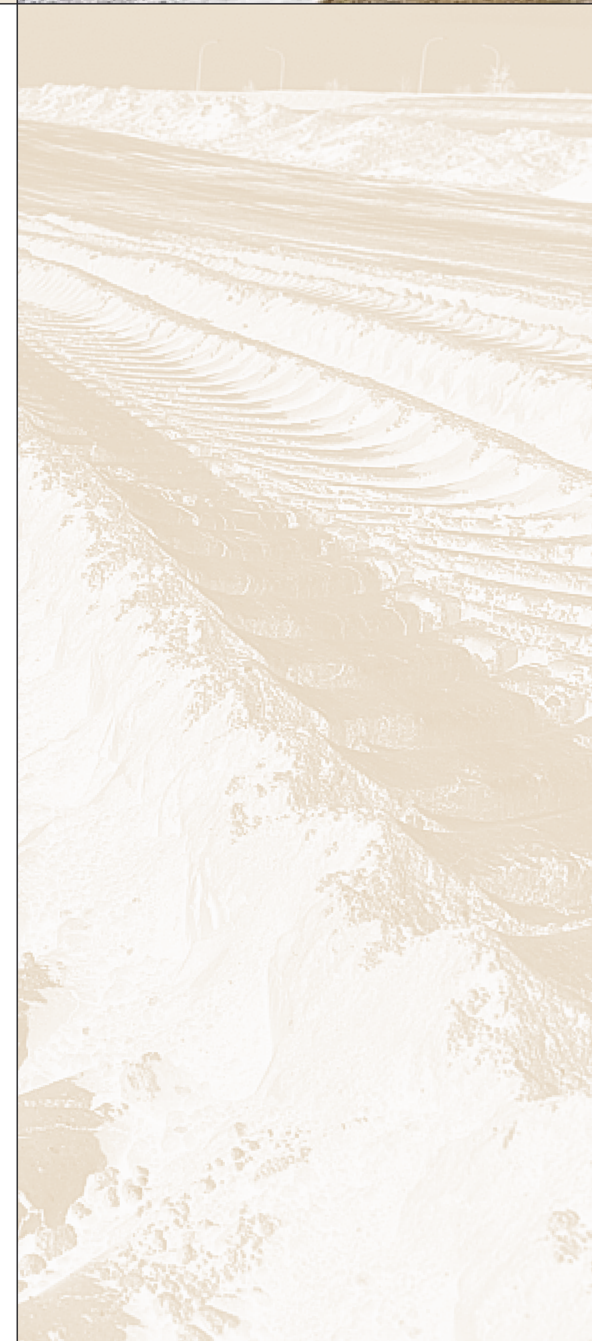
The practical guides available at **www.brrc.be** are the following:

❶ Manual for soil treatment with lime and/or cement.

❷ Soil improvement for the backfilling of drainage trenches and the enclosure of pipes.

❸ Soil stabilization for sub-bases.

❹ Improvement of soil for earthmoving works and railbeds.



Safely working with lime

When using quicklime (CaO, calcium oxide) on a job site, some simple safety precautions should be taken.

General safety measures on a job site

Wear a helmet.

Wear a fluorescent safety jacket.

Wear safety shoes.

To be properly protected

Eye protection: to prevent any lesion

Wear safety glasses at all times during lime handling.

Respiratory system protection:

If the atmospheric dust exceeds occupational exposure standards, wear suitable personal protective equipment.

Skin protection: to avoid redness, itching, and burns

Wear long-sleeve garment and trousers. Do not wear clothes that are tight around the neck or the wrists, because the irritation due to friction and sweating would be accentuated by lime. Rubber, leather or fabric/composite gloves provide suitable hand protection. Wear hightop boots that seal out dust.

First Aid measures

Eye contact

Speed is essential. Rinse immediately and thoroughly with water for at least 20 minutes. In any case, seek medical attention.

Inhalation

Move away from exposure and keep warm and at rest. Breathe fresh air. Irrigate nose and throat with water for at least 15 to 20 minutes. Medical attention is recommended.

Skin

Carefully and gently brush the contaminated body surfaces in order to remove all traces of product. Wash affected area immediately with plenty of water for at least 15 to 20 minutes. Remove contaminated clothing. Consult a physician if exposed area is large or if irritation persists.

Ingestion

Unlikely to cause any reactions. Do not induce vomiting. Wash mouth with water, drink copious quantities of water, see a doctor if an awkward feeling persists.

Lime is irritating (Xi) to respiratory system (R37) and to the skin (R38). It can cause serious damage to the eyes (R41). Quicklime reacts to water with a high production of heat, steam and dust. The safety datasheet, as per the CE directive, is available from your lime supplier.
Anti-poison center: tel 070/245 245.

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