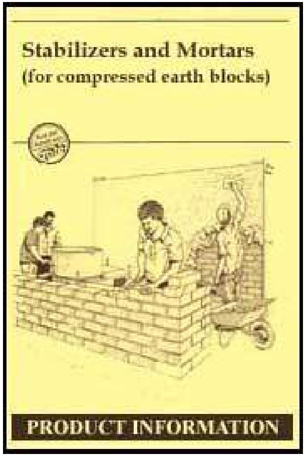

Stabilizers and Mortars (for compressed earth blocks) (GTZ, 1994, 20 p.)

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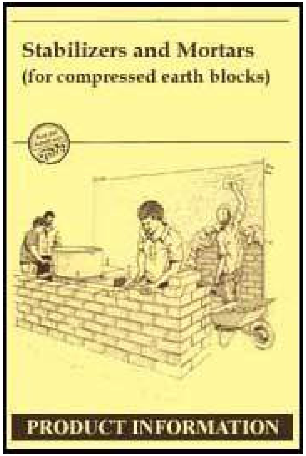

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A Publication of the Deutsches Zentrum fr Entwicklungstechnologien - GATE , a Division of the Deutsche Gesellschaft fr Technische Zusammenarbeit (GTZ) GmbH - 1994

NOTE 1: The technical details were provided by the producers. GATE is

not in a position to verify these data and therefore cannot accept responsability for any inaccuracies. In cases where prices have been quoted, these are subject to change and are thus meant to serve only as guidelines.

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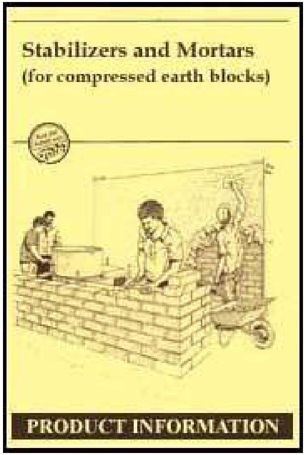


Bitumen

I. INTRODUCTION

Description

Bitumen is a product made up of a filler and at least 40% heavy hydrocarbons. It should not be confused with asphalt, which denotes products containing less than 20% hydrocarbons, the remainder consisting of filler, sand or gravel. (A word of warning should be given about the American use of the word "asphalt", which denotes the product known as "bitumen" in Europe, while in the USA "bitumen" is a black binding agent such as distilled bitumen or coal tar).

In its natural state, bitumen is too thick to be usable. To make it usable, it is either heated, or a "cutback" or emulsion is prepared. For stabilization purposes, these two methods are used.

"Cutback" is obtained by mixing the bitumen with a volatile solvent such as diesel fuel, kerosene, or naphtha. Depending on the mix used,

"cutbacks" take more or less time to dry. They cannot be used in the rain and are highly inflammable. Their viscosity is defined by an index (0 = very fluid; 3 = viscous).

Emulsions are obtained by dispersing bitumen in water with the help of an emulsifier, which is either of an anionic or a cationic kind. The emulsions obtained from the latter are more common and are compatible with many soil types. Emulsions are very fluid and are easily mixed with pre-moistened soils.

Conditions of use

The mixing of bitumen with the soil is crucial for the effectiveness of the stabilization. Too much mixing can increase water absorption after drying, as a result of a premature breakdown of the emulsion.

To ensure easy mixing, it is preferable to add the bitumen to a small quantity of soil and then to mix this small quantity into the remaining soil. If sand has to be added to the soil, the bitumen should be added to the sand and then the stabilized sand added to the remaining soil (especially for cutbacks). Emulsions should be diluted in the mixing water. These mixing methods are very important for low proportions (eg 2%) of bitumen.

How quickly the mix has to be used depends on the breakdown threshold of the product. Fast breakdown cutbacks and emulsions shorten drying times, hence such mixes must be used without delay. Bitumen-stabilized materials should preferably be dried out in dry air, rather than in a humid environment. A high temperature enhances the final effectiveness of the stabilization.

II. STABILIZER

Historical background

The use of bitumen as a stabilizer is very ancient. The Greek historian Herodutus describes how it was used in Babylon in the 5th century BC for making mortar to lay unfired moulded bricks. Even so, the use of bitumen throughout the course of history has been limited. Indeed bitumen as such was first produced on an industrial scale only a few decades ago, in the 1940s in the USA. Civil engineers have learnt to use bitumen in road construction. In Algeria, for example, nearly 28,000 kms of road have been built using this technique. Nowadays in the USA, stabilized earth blocks and bricks are sold under the name of "Bitudobe" or "Asphadobe". The material is also widely used in both Central and South America.

How stabilization occurs

Cutback and bituminous emulsions come in the form of microscopic droplets in suspension in a solvent or water. The stabilizer is mixed into the soil, and when the water or solvent evaporates the droplets of bitumen spread out to form strong, very thin films which adhere to and coat the soil particles. Bitumen improves the water-resistant properties of the soil (less absorption by clays) and can improve the cohesion of naturally non-cohesive soils, by acting as a binder.

	CUTBACKS			**EMULSIONS**		
CRACKING OR DRYING	**EUROPE**	**USA (ASTM)**	**BITUMEN CONTENT (%)**	**ANIONIC (NEGATIVE) (ASTM)**	**CATIONIC (POSITIVE) (ASTM)**	**VISCOSITY**
	SC 0	45 - 50				
SLOW	SC 1	SC 70	55-61	SS 1	CSS 1	FLUID
	SC 2	SC 250	63 -70	SS 1 h	CSS 1h	VISCOUS
	SC 3	70-75				
	MC 0	61 - 65				
MEDIUM	MC 1	MC 70	68 -72	MS 2	CMS 2	FLUID

	MC 2	MC 250	73 - 77	MS 2 h	CMS 2 h	VISCOUS
	MC3	79 -82				
	RC 0	62 - 65				
RAPID	RC 1	RC 70	70-73	RS 1	CRS 1	FLUID
	RC 2	RC 250	74-78	RS 2	CRS 2	VISCOUS
	RC 3	79 - 83				

Suitability of different bitumens

To ensure an even distribution of the bitumen in the soil, the latter should preferably be in a plastic state. Using a bitumen cutback or emulsion is, therefore, a delicate operation when stabilizing compressed earth blocks that are compacted at a water content close to the optimum (OMC). On the other hand, it is easy to use this kind of product when stabilizing earth mortar renders. Its effect in this case consists mainly in increasing the impermeabilization capacity of the render.

Table 1 (on the front page) summarizes some important characteristics of the various kinds of bitumen that can be used for stabilization.

Proportions of bitumen to be used

Normally 2 to 3% bitumen cutback, or 4 to 6% bitumen emulsion is

added, but can even be as high as 20%. Proportions vary in accordance with the grain size distribution of the soil, because bitumen stabilization involves the coating of the specific surface of the grains. The values given here are for the bitumen prior to its being diluted in a watery suspension or by a solvent. Bitumen has only a very slight effect on the colour of the material and has no particular smell once the stabilized products have dried out.

Soils that can be used

Although clayey soils have been successfully treated with cutback or emulsions, bitumen stabilization is more suitable for sandy or sandy-gravel soils, for soils lacking in cohesion, or when an impermeable finish is particularly desired. With extremely clean sandy soils, the low adhesion of the bitumen to the surface of the siliceous particles can lead to the separation of the bitumen under the action of water, with the result that the stabilizing effect of the bitumen on the soil is considerably reduced.

For emulsions, the following figures may be given:

High sand content soils: 4 to 6%
Low sand content soils: 7 to 12%

Clayey soils: 13 to 20%

These percentages are for the hydrocarbon itself and not for the liquid in which it is in suspension.

The correct type of bitumen emulsion can be selected with the aid of Table 2.

Effects of bitumen-stabilization

Some of the effects of bitumen-stabilizadon on soils are the following:

DRY DENSITY: Bitumen brings about a fall in density and increases the Optimum Moisture Content of water plus bitumen.

COMPRESSIVE STRENGTH: In a dry state, this increases with the proportion of bitumen up to a certain threshold value, after which it falls sharply, that is, once the ideal level of coating has been achieved. In a moist state, the strength rises steadily with the quantity of bitumen used, independently of dry strength.

ABSORPTION: This is a function of the moisture content during mixing and falls to very low levels after a certain threshold value has been reached. It is advisable to determine this value. After

several days' drying, water absorption is stable over time.

Effects of certain products on bitumen-stabilization

ORGANIC MATTER AND SULPHATES: The presence of these in the soil hinders the efficiency of bitumen stabilization as their adhesion to the "rains prevents the adhesion of the bitumen. Acid organic matter (eg forest soils) are very harmful. The neutral and basic organic matter found in arid and semi-arid regions are not particularly harmful.

SALTS: Mineral salts are very harmful. They can be neutralized by adding 1 to 2% by weight of cement. When bitumen-stabilizadon is carried out on an industrial scale, salt contents of more than 0.2 % are not accepted, but sometimes up to 6 %sodium chloride (NaCI) is permissible.

LIME: When the soil is too clayey, 1 to 2% lime can be added to flocculate the soil.

III. MORTAR

Bonding mortar

Bitumen mixes easily with soils to form a plastic or soft paste. It is therefore very easy to use as a bonding mortar and is especially suitable for bitumen-stabilized block masonry.

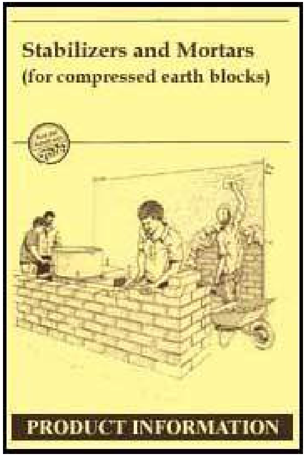
Plasters and renders

Bitumen-stabilized soils used for plasters and renders should be neither too clayey, nor too sandy and dusty. The quantity of bitumen used ranges from 2 to 6%. They are usually cutbacks; however, where bituminous emulsions are used, the mixture must be made slowly in order to avoid any breakdown of the emulsion. Bitumen-stabilization for renders is particularly effective on soils which have already been reinforced with straw or even with dung. The bitumen is added only at the end, 2 to 3 hours before the render is applied. Mixtures of asphalt, awn arabic and caustic soda solution are also highly effective. The support should be properly prepared, brushed and moistened.

HOW TO CHOOSE THE RIGHT EMULSION		
Fraction with grains of < 0.08 mm	**Moist soil with more than 5 % water**	**Dry soil with less than 5 % water**
0 to 5%	SS-1h	CMS-2h
	(CSS -1 h)	(SS -1 h*)

5 to 15%	SS-1h	CMS-2h
	(CSS -1 h)	(SS -1 h*)
15 to 20%	SS -1 h	CMS -2h
	(CSS -1 h)	
* the soil must be moistened in advance		

Explanation of the abbreviations in the two charts:		EMULSIONS	
		SS	Slow Setting
CUTBACKS		MS	Medium Setting
		RS	Rapid Setting
SC	Slow Curing	CSS	Cationic Slow Setting
MC	Medium Curing	CMS	Cationic Medium Setting
RC	Rapid Curing	CRS	Cationic Rapid Setting



Synthetic products

I. INTRODUCTION

Description

A number of industrial products have been and are stilt used for earth stabilization for building purposes. These consist either of synthetic products, or of by-products, and may even be industrial wastes. Others in this category may be natural products, which require sophisticated processing.

Conditions of use

Conditions of use vary depending on each type of product. Manufacturers' recommendations must therefore be consulted. Certain products must be handled with care, eg acids. Others, such as amine quaternary derivates, which are intended to be used in very low concentrations, are difficult to mix m evenly. Finally, others, such as silicates and certain resins, for example, need to be prepared before use. These products are generally not very satisfactory from an economic point of view and their effectiveness is often doubtful. Some of these products have been known for a long time, while others have been abandoned. In general they are not widely used.

II. FIELD OF APPLICATION

List of products

The main "families" of products can be fisted as follows:

01 acids
02 sodas
03 salts
04 quaternary amine derivates
05 silicates
06 stearates
07 paraffins
08 waxes
09 latexes
10 adhesives
11 soaps
12 industrial wastes
13 to 17 various resins

Use

These are products which Vary widely in nature, and a some of them are efficient only if used together with other stabilizing products. Soda, for example, is used as an additive to cement or lime. The use of these products often depends on their local avaitabitity.

The products are used for mass stabilization of materials but mainly of render mortars, given the fact that they often have a high unit cost which limits their extensive use. The most commonly used products are salts for mortars

and renders, which provoke colloidal reactions, modifying the characteristics of water and resulting in flocculation. But salts are incompatible with cement which restricts their use with cement-stabilized compressed earth blocks. Amine quartenary derivates can sometimes serve as a base for commercial products as a body mass or mortar stabilizer. They act as a binder or water-repellent, either directly or in conjunction with cement or bitumen. Silicates are fairly cheap and often available; they perform welt with sandy son's and have a waterproofing action.

Nature of products

01 ACIDS

Using acids always entails some degree of risk. Each type of acid gives a specific reaction. They modify the pH of the soils in which they are incorporated, resulting in flocculation, the effects of which are often reversible. Some acids act as catalysts to form insoluble phosphates.

Hydrochloric acid (MCI) and nitric acid (HNO_3) result in moderate stabilization. Hydrofluoric acid (HF) is very effective in all soils except those with high aluminium contents, inducing a reaction which brings about the formation of insoluble and strong silica fluorides. The effectiveness of sulphuric acid (H_2SO_4) is doubtful. If phosphoric acid (H_3PO_4) is incorporated, a hydration reaction is set off with the formation of phosphoric anhydride (P_2O_5) which reacts with clayey minerals, and the creation of an insoluble gel of aluminium and iron phosphates, which cement the grains together.

02 SODAS

Sodas induce cementation by reacting with minerals which produce insoluble silicates and aluminates. Caustic soda (NaOH) acts as a dispersant by degrading the minerals by alkaline attack. The product reacts vigorously both with lateritic soils and with soils having a high aluminium content. The best strengths are obtained when an adequate curing period for the material is allowed. Caustic soda is not suitable for soils with a high montmorillonite content.

The following are also known to be used:

barium hydroxide: $Ba(OH)_2 . 8H_2O$

calcium hydroxide: $Ca(OH)_2$

potassium hydroxide: $KOH.1/2H_2O$

Iithium hydroxide: $LiOH. H_2O$

03 SALTS

Salts acting on soils induce colloidal reactions, alter the characteristics of the water and lead to flocculation. By increasing the attraction between fine soil grains, salts help to create larger particles. This flocculation reaction leads to a reduction in density and an increase in OMC, in permeability and in strength, but also to a reduction in plasticity. Salts act on pore water and reduce the loss of water from the soil, slowing evaporation, and reducing water absorption. However, the effectiveness of treating soil with salt depends on the extent of moisture movements in the stabilized material. The treatment is not always lasting, as the salts can be leached out and dissolved when the material is moistened again. The quantity of salt required is approximately 0.5 to 396. Four main salts are used:

sodium chloride: flocculent and aid to compaction; effective in non-saline soils;

calcium chloride: impermeabilizing agent;
ferric chloride: powerful coagulant and flocculant;
aluminium chloride: electrolytic coagulant, electrochemical consolidation of soil.

Salts should never be used in conjunction with cement.

04 QUATERNARY AMINE DERIVATES

Some cationic quaternary amine compounds are used alone or occasionally as secondary additives to cement or bitumens in concentrations of 5 to 10% of the cationic exchange capacity of the clay fraction. They act as binders and water repellents. They require a sophisticated production process and they are difficult to mix with soil when only low concentrations are involved. These products are expensive and are not readily available. The most effective quaternary amine derivates are aromatic or aliphatic amines, and amine salts. These products are often effective in quantities as low as 0.5%. They form a water repellent film around the grains, which because of their tensile-active properties reduce capillary water absorption. These treatments are particularly suitable where capillary rise presents problems and may be suitable for foundations which are constantly exposed to moisture. The products may lose their effectiveness if they

are immersed in water or if they are totally dried out over an extended period.

05 SILICATES

Sodium silicate is fairly cheap and available in many parts of the world. The quantity usually used is 5% and it has proved to be attractive for stabilizing sandy soils, clayey and silty sandy soils, soils rich in limonite (some laterites) in arid regions, and in general soils which lack cohesion. Sodium silicate also acts as an impermeabilizing agent, particularly where a surface treatment of the materials is required. A curing period of at least seven days is required if the effectiveness of the treatment is to be assured. The product is highly soluble but can be rendered insoluble by allowing it to react with slaked lime. Sodium silicate can be dissolved in water and is then known as "waterglass". Other silicates may be used such as potassium silicate and calcium silicate.

06 STEARATES

Stearates are salts or esters of the stearic acid contained in animal fats. They act as impermeabilizing agents. Aluminium and magnesium stearates as well as zinc stearate may be suitable.

07 PARAFFINS

Paraffins are a mixture of solid saturated hydrocarbons characterized by their inertness in the presence of chemical agents. They can be used as a compaction agent but must first be dissolved in a fatty medium.

08 WAXES

Industrial waxes can be used as an aid to compaction. They are often added to other stabilizers.

09 LATEXES

Industrial or synthetic latex dissolved in water and added at the rate of 3 to 15% can give good results. These products are binders and impermeabilizing agents.

10 SYNTHETIC ADHESIVES

Synthetic glues with one or two components can be used. The one known to give very good and surprising results is the common polyvinyl acetate based white wood glue.

11 SOAPS

The use of between 0.1 and 0.2% of ionic detergent has no effect on strength but reduces water sensitivity by about 25%

12 INDUSTRIAL WASTES

Certain industrial wastes can be used for stabilizing soil.

SUMP OIL: This has no lasting effect, because it is washed off by rain. It is an impermeabilizing agent.

BLAST FURNACE SLAG: These are silica slags which can approach Portland cement in composition. They are usually finely ground and blended with Portland cement to produce Portland blast furnace cement, whereby the slag content can reach 80%.

LIGNIN AND LIGNOSULPHATES: These are by-products of the wood industry. Soluble in water they can be rendered insoluble by mixing with chrome salts (potassium or sodium bichromate) resulting in a thick gel, known as chromolignin. They are good waterproofing agents, but expensive.

MOLASSES: A product of the sugar industry, this improves compressive strength and reduces capillarity, A quatity of 5% is suitable for sandy and silty soils. Add lime for clayey soils.

POZZOLANAS: These are materials that contain silica and/or alumina, eg fly ash (from power generating stations), burnt clay (rejects from brick production) and rice husk ash. They are not cementitious themselves, but when finely ground end mixed with lime, the mixture will set and harden at ordinary temperatures in the presence of water, like cement.

OTHER PRODUCTS: Plastified sulphur sulphonates and siliconates (water repellents).

13 FURFURAL-BASED RESINS

Furfural is a toxic aldebyde found in grain alcohols and in the following materials: rice hulls, peanut shells, cotton seed, cane-trash, maize cobs and stalks and olive pits. It is present in percentages ranging from 10 to 20%.

FURFURAL ANILINE: A resin formed from furfural and aniline, which is a cyclic amine derived from benzene, and is nowadays obtained from coal. Mix 70% of aniline with 30% of furfural. The product is highly toxic and between 2 to 6% is adequate for soil stabilization. It makes grains water repellent by ionic exchange and cements them together by polymerization.

FURFURYL ALCOHOL: This is an organic compound derived from furfural. It polymerizes in the presence of certain catalysts giving rise to polymers with excellent mechanical properties. It improves both dry and wet mechanical strengths, and slows water absorption.

RESORCINOL-FURFURAL: This product is used in an aqueous solution catalyzed by soda in a basic medium. It is toxic and often very expensive.

FURFURAL-UREA AND PHENOL-FURFURAL: Stabilizers which have been tested alone or mixed with furfural aniline: disappointing results.

14 FORMALDEHYDE-BASED RESINS

Formaldehyde is a volatile liquid obtained by the oxidization of methyl alcohol. It is a toxic substance and its use should be limited to locations that are not often frequented by people or animals.

RESORCINOL-FORMALDEHYDE: This is a mixture of resorcinol, antiseptic phenol derived from benzene and formaldehyde. This yields a resin which acts by cementation and as a water repellent. Reduces water absorption.

PHENOL-FORMALDEHYDE: Results known to be satisfactory.

FORMALDEHYDE-UREA: The action of this compound is similar to that of furfural aniline.

CALCIUM-SULPHAMATE-FORMALDEHY DE: The results obtained have not been satisfactory.

MELAMINE-E;ORMALDEHYDE: Good results for dry strength, but a 50% loss of strength in a moist state.

15 RESINS BASED ON ACRYLIC COMPOUNDS

CALCIUM ACRYLATE: This water-soluble resin forms an insoluble gel with soil which is rubbery or stiff depending on the moisture content

ACRYLIC NITRATE: This resin is used for grouting. Cements and waterproofs. Acrylic amine nitrate, which is another derived compound has a similar action.

POLYACRYLAMINES: Cationic polymer.

16 UREA-BASED RESINS

DIMETHYLOL UREA: Gives the best known results for urea-based resins although wet strengths remain low.

17 POLYVINYL-BASED RESINS

POLYVINYLIC ALCOHOL: Non-ionic stabilizer which forms strong flexible films by the evaporation of the aqueous solution although it is soluble in water. Must be combined with natural oils or water repellents in order to be effective.

POLYVINYL ACETATE: This is the best product for sandy soils because it improves their cohesiveness. The product is completely destroyed if immersed in water.

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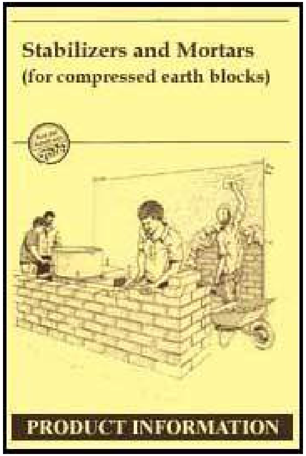

Specialized Commercial Products

I. INTRODUCTION

Description

A number of products are now commercially available. Many of these are presented by the manufacturers or their agents as "miracle" products. The importance of verifying the real performance of a product systematically, and of determining how well-founded the sales arguments are, which are put forward in publicity, oral presentations

and laboratory reports, cannot be overstated.

The majority of these commercial products are based on known industrial products and behave in the same way. The turnover of these products on the market is very high: they appear under one name, disappear a short time later, only to reappear either under another name or manufactured by another company. Manufacturers do not always describe their product in precise detail, and keep their formula secret. It will be noted that the majority of these products are not patented. This is because they are already public property. To give an example, a product which IS 90% sulphuric acid will be described as "a liquid catalyst, soluble in water and inducing ion exchange". Consequently it appears to be essential to insist that salesmen identify their product exactly and, if necessary, obtain the advice of specialists (eg from chemical engineers). This precaution does not necessarily lead to these products being systematically rejected; some of them are effective, albeit for clearly specified applications.

Conditions of use

The quantities of these products used for stabilization purposes are usually extremely low, often in the order of 1% or 0.1%, or even 0.01%. The difficulty of achieving uniform mixing can thus be appreciated. For

example, when processing one tonne of soil, the addition of one kilo of the product requires very thorough mixing and professional attention to the work.

Price surveys carried out by manufacturers usually indicate a price which IS well below that of cement or lime stabilization, which is usually used as a point of reference. However, as soon as the suggested quantity proves ineffective and the quantity required has to be increased, there is a distinct risk of exceeding the budget. Furthermore, the real retail price of these integrated products often includes an excessive profit margin, especially if one remembers that they are only moderately effective and that they are often very common industrial chemicals. Prices are set in relation to what the market will bear by comparison with conventional stabilizers. It is not uncommon to find that products with identical formulae can be purchased directly from suppliers of industrial chemicals at prices up, to 20 to 50% lower.

The use of such products may prove to be satisfactory, but it is essential to carry out preliminary tests and studies. In any event, it is advisable to find out if other users have obtained positive results.

II. FIELD OF APPLICATION

Origin of products

Many of the products on the market have been formulated for use inroad stabilization. A large number were developed in a military context, with a view to achieving the quickest possible stabilization of impassable roads or constructing landing strips and heliports on marshy ground in the space of just a few hours. The original purpose of these products should not therefore be forgotten. The demands imposed by the temporary stabilization of roads and their conditions of use are very different from those imposed by the construction of permanent buildings. Some of these products, which are highly effective on roads, rapidly lose their effusiveness when used to stabilize walls. Laboratory reports must be interpreted in the light of these applications m the field of road construction. Moreover a large number of tests and trials are carried out on samples prepared by the product manufacturers themselves. This practice, of course, makes it impossible for the laboratory to guarantee the product itself, even though the results obtained on the material can be guaranteed.

Stabilization

Most of these products are intended to be used as stabilizers for compressed earth blocks. A good number of them can also be used as

stabilizers for plasters and renders.

COMMERCIAL PRODUCTS			
PRODUCT	**MANUFACTURER OR DISTRIBUTOR**	**COUNTRY**	**REMARKS**
STABILIZERS			
CONSERVEX	CONSOLID AG	Switzerland-France	Impermeabilizing agent to be used with CONSOLID 444
CONSOLID 444	CONSOLID AG	Switzerland-France	Compacting aid to be used with CONSERVEX
MUREXIN SB-86	FORSTER & HAENDEL	Austria	Probably of the same nature as the CONSOLID products
MUREXIN SB-99	FORSTER & HAENDEL	Austria	Probably of the same nature as the CONSOLID products
UNIVEST	HLST	Germany	Liquid polymer
RENDER ADDITIVES			
ACROPOL	REX CANDY	Australia	
DARAWELD- C	_	United States	High polymer resin emulsion
SUPERIOR ADDITIVE EL	United States	Acrylic modifier for	

REY 200		renders	
UNI 719	F.I.T.	Australia	Alkali metal alkyl silicone compounds
WATERPROOFERS			
700 S	SICOF	France	Epoxy resin
ADOBE PROTECTOR EL REY	United States	Water repellent	
DARAWELD- C	_	United States	High polymer resin emulsion
DYNASYLAN FH	DYNAMIT NOBEL	France	Silicon resin, silane
PROTIDRAL	SARL CYBEO	France	Silicone resin, siloxane
REPELLIN S-101	PIDILITE IND. LTD	India	To be sprayed or brushed
ROCAGIL AL 6	RHONE POULENC	France	Acrylic resin, organic polymer
SD 104	RHONE POULENC	France	Acrylic resin, organic polymer
SOIL SEAL	_	United States	Latex acrylic balanced

			polymers spray mixed with water

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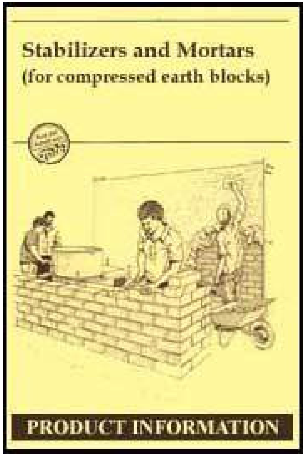

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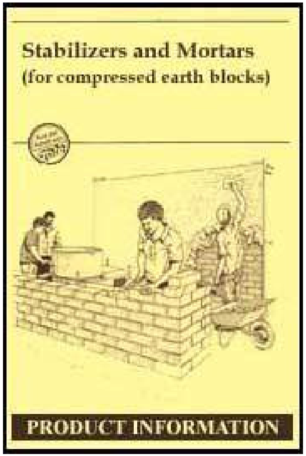

Acknowledgements

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GATE (German Appropriate Technology Exchange), a programme of the Deutsche Gesellschaft fr Technische Zusammenarbeit (GTZ) GmbH, acts as a centre for the dissemination and promotion of appropriate technologies for developing countries.

The Information and Advisory Service on Appropriate Technology (ISAT), was established as a section of GATE, in 1991 and has at its

disposal the full range of services the GTZ offers. ISAT specializes in a large variety of appropriate technologies for developing countries, whereby the technologies that ISAT focusses on principally include those which:

- **help satisfy basic needs,**
- **make efficient and environmentally sound use of locally available resources,**
- **mobilize existing skills and promote self-help,**
- **extend user's scope for action and promote independent action.**

ISAT offers its services (question-and-answer service, various types of publications and films) to German development co-operation organizations as well as organizations and individuals in developing countries. Requests for literature and documentation on specific areas of appropriate technology can be addressed to ISAT.

BASIN is a coordinated network of experienced international professionals, set up to provide qualified advice and information in the field of building materials and construction technologies.

The activities of BASIN are divided between four leading European, non-profit appropriate technology organizations, each of which covers a

separate specialized subject area, in order to provide more qualified expertise with greater efficiency.

The services offered by BASIN encompass:

- **responses to technical enquiries;**
- **maintenance of a documentation and computer database with evaluated information on documents, technologies, equipment, institutions, consultants, projects, etc;**
- **monitoring of practical field experiences;**
- **preparation of publications to close information gaps;**
- **organization of training courses, workshops, seminars and exhibitions;**
- **implementation and management of research and development projects.**

This Product Information Portfolio was conceived to inform users as objectively as possible about stabilizers and mortars for compressed earth block construction, and more specifically about the various

products commonly used and how they are best applied. The aim was not to deal with the technologies in depth, since such literature is available elsewhere, but to give sufficient information on possible uses for the user to understand the advantages and limitations of the various materials available in different regions.

For further information, please contact the respective BASIN Partners at the addresses given above.

Note: The technical details were obtained from technical literature, laboratory analyses, and to some extent from manufacturers of certain products. GATE is not in a position to verify these data and therefore cannot accept the responsibility for any inaccurracies.

Text, illustrations, layout:
CRATerre, K.Mukerji (1994)

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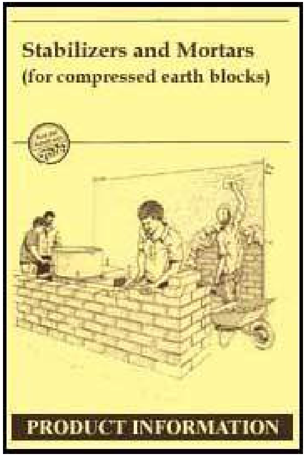
Stabilizers and Mortars (for compressed earth blocks) (GTZ, 1994, 20 p.)



(introduction...)

Introduction

General

Compressed earth block construction is one of the most widely used technologies in building with earth. The key feature of the technology is the compression of the soil in a mould with the help of a manual or motorized press, to form a regular block of appropriate shape and size.

The characteristics of the product itself and the scope of production scales possible, which range from small workshops to industrial units, make it a high quality product and a technologically advanced material.

In the final analysis, a block made only of unfired earth still displays certain weaknesses due to

its excessive water absorption,

its poor resistance to abrasion and impact,

its low tensile strength, which can lead to building problems, some of which can be very serious.

Such problems can be solved in two ways:

1. the most important and cheapest is by architectural means, ie by respecting certain rules for the suitable design of earth buildings; and/or

2. by using specific products:

- within the element itself: stabilizers which improve certain characteristics of the soil;

- in the structure: by using a good bonding mortar;

- on the building surface: through the use of plasters and renders.

It is these products, that this Product Information portfolio is about.

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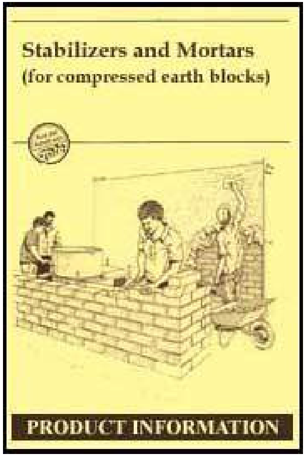


Stabilizers

Definition

The cohesion of a soil is essentially assured by its clay content. The extent to which clay will bond depends on its particular mineralogical characteristics. But its capacity to bond decreases significantly when the clay is in direct contact with water. In addition, clay swells in the presence of water, causing movements in the soil structure. Clay is, therefore, a natural binder, which is cheap, but unstable.

Stabilization is a technical process, the object of which is to neutralize or at least restrict the detrimental behaviour of the clay present and thus reduce the natural sensitivity of soil to water, which leads to a loss of strength and cohesion. The degree of sensitivity of a soil to water varies according to the proportion of clay compared with other inert constituents (sand, silt), and according to its mineralogical nature. There are, in fact, several distinct types of clay, the principal ones

being:

> **kaolinite, which is relatively stable,**
>
> **illite, which is of average stability, and**
>
> **montmorillonite, which is highly sensitive to water (causing swelling, etc).**

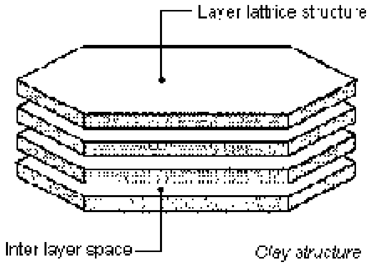
The behaviour of each type of clay is linked to its mineralogical structure and more particularly to the layers, which are the basic elements of clay micelles (large clay molecules).The degree of bonding and the extent of swelling of various clays are determined by the structure of these layers.

Physical Stabilization

Modifying the proportion of clay or the mineralogical nature of the clay content can already have a stabilizing effect on the behaviour of a soil. Correcting the characteristics of a clayey soil by adding sand or another soil, which is not very plastic, is common practice and constitutes an elementary form of stabilization.

A second form of stabilization is to reduce the proportion of voids in a

soil. The penetration of water into the material, leading to the swelling of the clay layers, depends on the presence of large voids. This proportion can be reduced, either by increasing the density (ie by compacting the soil mechanically), or by adding a material with a complementary granulometric composition, the finer or coarser grains of which will allow a more regular distribution and a better volume occupancy. Adding a "thinning" sand to a clayey soil helps both to improve its compactness and to achieve a quantitative reduction in the proportion of its clay content.



FIGURE

Physico-Chemical Stabilization

Finally, the characteristics of the clay layers themselves can be affected directly during the manufacturing process, by adding a stabilizer, which has a direct or indirect physico-chemical stabilizing effect on the layers.

Stabilizers are very commonly used in the production of compressed earth blocks.

Various groups of products can be classified according to the way they act on clay plates. This classification is important, since for each group there is a particular way of proceeding and each has varying degrees of efficiency, depending on the type of soil. A simplified classification of additives is shown in the chart below.

The Need for Physico-Chemical Stabilization

No single method of stabilization precludes the use of another; on the contrary, the most durable earth blocks result from a rational use of several stabilization methods.

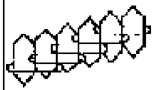
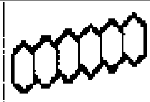
In general, the following points must be remembered

> **Good technical results can be obtained at the outset by careful soil selection, correcting the granular composition as necessary, and reducing the proportion of voids by adequate compaction.**
>
> **Stabilization by adding a physico-chemical product is not essential.**

Physico-chemical stabilization is necessarily costly, partly because of the cost of the stabilizer, and partly because of the higher quality standards, which need to be respected in preparing and mixing the soil, and in the additional operations it requires.

First and fore most, attention must be paid to the architectural aspects of building with earth in order to limit damage caused by weathering; poor design cannot be compensated for by the indiscriminate stabilization of materials. Stabilization must only be considered in addition to proper building design, and the decision to stabilize should be taken only after comparing the building costs with and without stabilization (ie considering the costs of surface protection, architectural design features, maintenance, etc). It must, however, be recognized that stabilization does provide additional guarantees of durability for buildings and materials. It also facilitates certain operations, such as storing blocks in the open before use.

STABILIZATION METHODS

Stabilizer		Nature	Process	Means	Principle	Symbol
without stabilizer			mechanical	compaction	creation of a dense material, blocking pores and capillarity	
with stabilizer	inert stabilizer	minerals	physical			
		fibres		reinforcing	creation of an isotropic matrix, opposing any movement	
	physico-chemical stabilizer	bonding	chemical	cementation	formation of an inert matrix, opposing any movement	
				bonding	formation of stable chemical bonds between clay crystals	
		water repellants		water-proofing	coating of soil particles with an impermeable film and filling pores and ducts	
				water-repelling	maximum elimination of water absorption and adsorption	

FIGURE

Principal Requirements of Stabilization

The efficacy of stabilizers is linked to a certain number of conditions:

the stabilizer must be selected to suit the soil type;

the soil must be prepared (ie sifted, crushed, sieved) with particular care, in order to ensure that the stabilizer can be uniformly distributed throughout the material;

the soil-stabilizer mix must be perfectly homogeneous;

in the case of stabilizers which begin to cure quickly, such as Portland cement, the time between mixing and use must be kept to a minimum;

curing conditions - humidity, temperature, etc - must be suited to the type of stabilizer.

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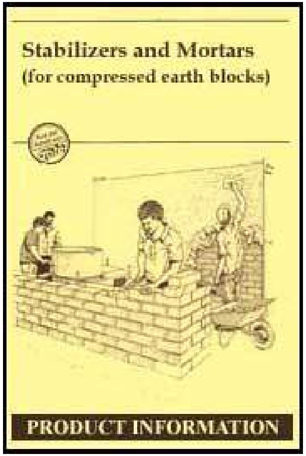


Mortars

Definition

The term "mortar" is collectively used to refer to bonding mortar in masonry, interior plasters and external renderings of buildings.

A mortar is a mixture of a fine aggregate filler (eg sand) and a water activated binding medium (eg lime or cement, or a combination of these), possibly with an additive (such as a colouring agent, fibres, a lightweight aggregate, or a chemical composite). Water is added to the

dry mortar mix, just enough to activate the binder(s) and make a workable paste, which hardens when the binder sets and dries, but is applied while it is plastic.

bonding mortar / plaster / render

=

aggregate + binder (+ additive) + water

Note: Earth is, in fact, a natural mortar. The clay portion acts as the binder and the inert components (silt, sand and gravel) as the aggregates.

Types of Mortar

The proportion of the different materials making up a mortar will vary depending on the use to which the mortar is to be put.

Bonding Mortars

In horizontal masonry joints, the function of the mortar is to

spread the vertical loads exerted in the wall, and

compensate for poor workmanship and any dimensional variations in the blocks, so that they can be laid in more or less horizonal and vertical alignment.

In horizontal and vertical joints, it serves to

fill the voids between blocks, preventing air and rainwater from passing through

At the foot of the wall, it has an additional function, which is to

prevent water from rising up from the soil by capillary action. In this event, it has to be waterproof and is referred to as an anti capillary barrier, or waterproof joint.

In general terms, mortar used for bonding ensures that

blocks are bonded together, and by friction gives the wall a certain resistance to eccentric or lateral forces.

Plasters

Plasters are layers of mortar applied to interior walls and ceilings to cover up uneveness in the background, providing smooth hygienic,

crack free surfaces.

A plaster is typically appllied in several coats: one thin coat (forming a key) to ensure that the plaster adheres to the surface, a main coat (the body of the plaster) to ensure that the surface is impermeable and to make it smooth, and a thin surface coat (finishing coat) for appearance and to achieve complete impermeability. Each of these coats has a specific function and a particular mortar should be selected to suit each one.

Renders

Renders are principally the same as plasters, but applied on external building surfaces, not only to protect them against weathering, rain penetration and mechanical damage, but also to cover up unpleasant and uneven surfaces, or as decoration.

The Need for Mortar in Building with Earth

The use of mortars for laying blocks and/or protecting walls is a significant cost factor, which needs to be considered carefully, before deciding whether or not it can be done without.

Bonding Mortars

The development of semi-industrial presses, allowing the manufacture of blocks of very accurate dimensions has led certain manufacturers to introduce building systems, which do not require the use of a masonry mortar, for instance, by using interlocking blocks, which can be laid dry, or blocks that can be bonded by an adhesive. The short-term economic advantage is attractive. But laying the blocks remains a manual operation and can, therefore, never be completely perfect. Using a mortar enables imperfections in laying to be rectified and allows each course to be level. In addition, the bond between the blocks created by the mortar is important to the final strength of the building; comparative tests have shown that the compressive strength and shearing strength of the construction can fall by 50%, if no mortar is used. Finally, a mortar will also ensure that the joint is windproof and that water cannot infiltrate between blocks. Hence, the use of mortar for laying blocks or bricks is generally recommended.

Plasters and Renders

A great many earth buildings, even in exposed areas, are never rendered. It is, therefore, wrong to think that the durability of a building is systematically linked to the presence of a render.

The first function of a plaster finish or rendering is to improve the

appearance of a building. If rendering is to be avoided, the building must be attractive in itself This will only be achieved by the careful use of high quality materials and workmanship. Hence, in order to economize on plasters and renders, it is often necessary to invest in the training of manufacturing personnel and builders, end to encourage the development of their professional pride.

External rendering has an additional function, namely to protect the body of the wall against weathering. In order to avoid the need for rendering, either the facade must be sheltered from inclement weather, or the wall must be made resistant to weathering. The first of these measures implies that the problem has been addressed at the architectural design stage, through the use of overhanging roofs, organic or artificial barriers, and suitable orientation. The second presupposes that the building materials or the material making up the wall have been reinforced and made insensitive to the effect of water. Therefore, at the production stage, stabilization procedures are used, either throughout or solely for the surface of the wall. In practice, several solutions are often used in combination, making it possible either to eliminate the need for rendering or reduce the stresses it will have to withstand. This simplifies the formulation of the mortar mix and gives a greater guarantee of its viability over a significant period of time.

Main Characteristics of Mortars

The main characteristics of mortars are

appearance;

workability, in the ease with which it can be applied;

adhesion to the blocks;

compatibility with the blocks, in terms of natural moisture permeability and mechanical cohesion;

impermeability, either only to prevent rainwater penetration or to provide complete waterproofness;

compressive strength;

resistance to shocks and impact;

capacity to withstand cracking caused by

- movements in the masonry structure,

- differential dimensional variations in the masonry

structure due to rapid variations in temperature and humidity,

- internal stresses in the mortar as it dries and sets.

A mortar's capacity to withstand cracking is linked to its capacity to accept deformation, which is measured by its modulus of elasticity, (E). Elasticity is the capacity of a mortar to accept deformation without breaking. The more it can accept deformation, the lower is its modulus of elasticity.

Specific Characteristics of Earth Walls

Even a cursory understanding of the principles of preparing a masonry or plastering mortar, or protective coat (such as whitewash), clearly shows the importance of suiting the composition of the product to the nature and physical and mechanical characteristics of the material it is applied on. Most often, problems encountered with plasters on earth buildings are due to the composition of the mortar being unsuitable to the specific nature of the materials, which is either poorly understood or not taken into account.

The characteristics of earth as a building material, which need to be taken into account are essentially as follows:

Shrinkage during drying and settling

During drying out, the withdrawal of water often results in dimensional shrinkage (0.2 to 1 mm/m for compressed earth blocks); it is therefore preferable to wait for a month after completing the masonry work. By waiting still longer, other problems can also be avoided, especially those resulting from general movements in the building (mainly caused by settling), which are fairly frequent during the first year of the life of any built structure.

Dimensional variations

Earth is susceptible to significant thermal expansion (0.02 to 0.2% for stabilized compressed earth blocks, compared with 0.02 to 0.05% for concrete blocks and 0 to 0.02% for fired bricks). Swelling due to wetting will vary according to the mineralogical nature of the clay contained in the soil and the proportion of stabilizer, but can be quite significant. When subjected to a load, an earth wall changes shape perceptibly. Tests have shown that at the limit of its modulus of elasticity, an earth wall is 4 times more flexible (or less rigid) than a concrete block wall. The capacity of the mortar to accept deformation must, therefore, be at least as high as that of the blocks (ie it should have a low elasticity modulus).

Mechanical cohesion

Earth has only fairly low tensile strength. The shrinkage of a mortar capable of high mechanical performance, for example due to its rapid dilation in the event of a sudden thermal change, can lead to the surface layer becoming detached from the supporting structure.

Moisture permeability

Earth is a material which is easily penetrated by moisture. If the passage of water is blocked by a mortar, which will not even allow gases to pass through easily, this will lead to moisture accumulating up to the point of saturation, and thus result in gradual deterioration.

Absorption

Blocks will display a tendency to absorb some of the water contained in the mortar. When a mortar has been prepared using a hydraulic binder, which requires a certain amount of water for hydration to take place, care must be taken that the wall does not dry out the mortar too early, and thus cause it to be poorly cured.

Surface state

The sides of compressed earth blocks are generally flat, but with a smooth surface. It is, therefore, unnecessary and not usually recommended to apply very thick plasters to achieve a plane final surface, but the plaster has to be made to adhere to the blocks, for example by using a scratch coat to create a rough surface.

General Principles for Earth Construction Mortars

Considering the basic characteristics of earth as a building material, the selection of a mortar must give preference mainly to those that ensure

the capability to accept deformation;
good moisture permeability;
mechanical performances, which are compatible with those of the blocks.

In the application stage, care should be taken to ensure that

the application surface is properly prepared;

there is a good bond between the mortar and the compressed earth blocks;

the mortar is not allowed to dry out too quickly during and after

application;

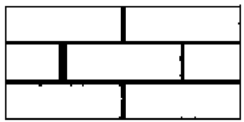
extremehygro-thermal conditions or too rapid variations are avoided; (and in addition, for plasters and renderings)

building shrinkage and settling movements have come to an end.

Principal Conditions of Using Mortars

Depending on the intended use, the aim will be to seek to enhance one or the other quality of a mortar. These new qualities will, however, sometimes entail a mortar mix which breaks the general rules for the composition of a mortar, which are necessarily dictated by the characteristics of the soil. An ideal mortar with all the desired qualities is difficult to achieve. Compromise solutions will have to be sought, taking into account the envisaged use and the local climatic constraints.

Bonding Mortars



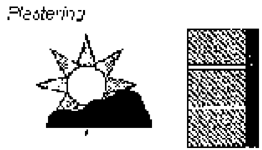
FIGURE

A bonding mortar must have adequate compressive strength and be

workable. Therefore, a lean hydraulic mortar, a sand mortar with high-calcium lime, or an earth mortar to which coarse sand and a stabilizer have been added, can all be used. A lean, unstabilized earth mortar can also be considered for well-sheltered walls. It should be noted that the masonry mortar should have the same compressive strength and resistance to erosion as the blocks. If the resistance of the mortar is less, erosion and infiltration of water will occur and the wall will deteriorate. Lime, which results in better workability and average mechanical strengths, is preferable to hydraulic binders. Only in the case of waterproof joints is it advisable to use a very compact mortar based on a hydraulic binder, with the addition of a high proportion of a water-repellent product wherever possible.

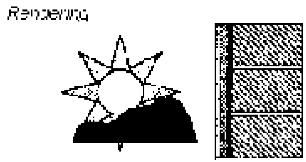
Mortars for Plasters and Renders

The composition of a plastering mortar will depend on whether the mortar has to be impermeable or not.



FIGURE

All that is necessary is good adherence and the ability to withstand cracking, as well as a pleasant appearance. Thus, very simple mortars, such as lean earth mortars with the addition of sand, lean mortars made with high calcium lime, gypsum plaster mortars, or lime and gypsum plaster mortars, are all suitable.



FIGURE

This must be both compact, in order to be impermeable, and must be able to withstand cracking - in other words, it must be supple. These qualities are very difficult to find united in a single mortar. That is why it is preferable to apply several layers and to change the composition of the mortar for each layer.

Main body of the rendering

The main layer should be fairly compact to ensure its impermeability and, therefore, should have a fairly high proportion of binder; at the same time, its mechanical performance must remain lower than that of

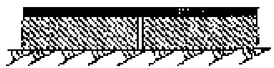
the material it is applied on. This is why pure hydraulic binders, which would impart high mechanical strengths, are not recommended. Mortars comprising a combination of different binders are preferable (eg high-calcium lime and Portland cement, with the proportion of lime being higher). What is important is to ensure that the modulus of elasticity is below that of the earth block. The proportion of binder can be lowered, or alternatively, the proportion of binder can be maintained, whilst the density of the aggregates is lowered, ie with a lightweight aggregate. The thickness of the main layer should be sufficient to prevent the passage of water, but at the same time it should not be too thick (in too heavy for the application surface), especially when it is made with mortars based on high-calcium lime (in which case, the carbon dioxide of the atmosphere, which is essential for the hardening process, cannot easily penetrate the mortar layer and curing is delayed).

In the finishing coat, small cracks are likely to appear after the main body of the render has dried out. These can be filled with a fine and very supple coat. The proportion of binder used in this final coat will, therefore, be lower than that used for the main layer.

Finally, in the scratch coat or key, it is important to ensure that the plaster adheres to the wall. However, increasing the ability of the main layer of mortar to withstand cracking (by amending the proportion of

binder), also reduces its ability to adhere. An intermediate scratch coat or key is, therefore, used very often. This does not contribute to impermeability, and cracks that may appear can be filled after the main layer and finishing coat have dried out. The scratch coat can, therefore, be made with a mortar containing a high proportion of hydraulic or mixed binder. The only constraints are that the passage of moisture should not be blocked and that excessive tensile stress should not be transmitted during drying out. This means that the coat must be thin and discontinuous to allow moisture to escape through the cracks and pores that appear during drying out. With application on surfaces that are brittle or damaged, the scratch coat should be replaced or complemented by the use of fixing points such as broken pottery or nails driven in at different angles over the whole surface.

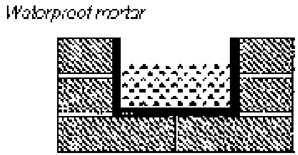
Mortars for floor finishes



FIGURE

To withstand impact and continuous abrasion, a "working surface" mortar for floors should contain a very high proportion of binder. This high binder content would result in a low capacity to accept deformation. An earth floor, however, is very susceptible to movement

by swelling or settling. Therefore, it is highly contradictory to put a rigid working surface on an earth floor. A cement screed laid directly on an earth floor will crack and deteriorate very rapidly and is, therefore, not recommended. Instead it is better to place a dry stone pitching between the floor and the screed, or treat the floor directly by compaction (tamping), possibly using a stabilizer. In the latter case, regular maintenance must be ensured, or the surface must be protected by another kind of covering (ceramic tiles laid on a bed of sand, for example). Earth block pavements would need to be stabilized throughout, in order to be able to withstand normal stresses without a protective coating.



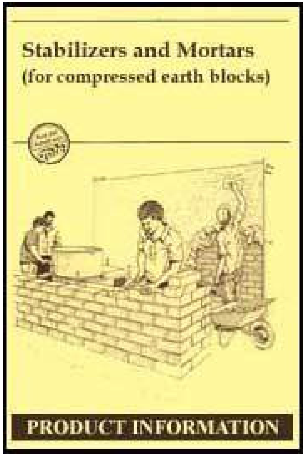
FIGURE

This type of mortar must have an even higher proportion of binder than the preceding type in order to be compact and to ensure that it is totally impermeable. A strong hydraulic binder would make it especially impermeable to the passage of moisture. However, its rigidity would not allow it to resist the inevitable movements in the earth-built structure

and it would crack very quickly, allowing water to pass into the structure. This kind of mortar has, therefore, to be both very supple and impermeable at the same time, requirements which are very difficult to achieve in combination. The fact, that it is impossible to reliably protect a drain or cistern made of earth, explains why building them in earth is not recommended unless the question is thoroughly understood and unless certain fairly specialized products, natural or artificial, are available.

Equipment for Mixing, Applying and Testing Mortars

Equipment for mixing earth with stabilizers and other additives are described in the GATE Product Information portfolio Soil Preparation Equipment. The methods of applying earth construction mortars, plasters and renders are principally the same as for any other type of mortar. Hence the equipment required- eg trowel, splatterdash, float- is also the same. Similarly, the equipment for testing the quality of hardened earth construction mortars, plasters and renders - eg using a pocket penetrometer or pendulum scleroscope (as illustrated below) is the same as for all other mortars.



Natural products

I. INTRODUCTION

Description

The term "natural products" covers a wide range of stabilizers of animal, vegetable and mineral origin. The products on which we will concentrate are chose obtained directly from nature or those subject to a simple preparation process, rather than chose which are the product of involved processing, which are more like synthetic products, such as agricultural wastes. Accurate scientific information about such natural stabilizers, the use of which depends largely on traditional skills, is sparse and research into them virtually non-existent.

The main advantage of these stabilizers is their local availability. Despite this, they are rarely available in sufficient quantities to be used on anything more than an individual basis. On the other hand, because of their rarity and the fact that they are produced by very simple processes, their market value is higher than chat of industrial products. Often, they have other uses, such as for agricultural processes or even as food, so chat their use as stabilizers is not always a priority.

Conditions of use

These products are often only effective in very specific conditions of preparation and environment. Even so, they have certain advantages,

for example by increasing water resistance and slowing deterioration. The water absorption of a treated wall will be slower than that of an untreated wall, allowing deterioration to be remedied (between two rainy seasons, for example), while an untreated wall would deteriorate very rapidly. It should be remembered chat natural products are not as effective as industrially manufactured products such as cement, lime, bitumen, and so on.

II. FIELD OF APPLICATION

Origin and uses of products

MINERAL PRODUCTS

Some types of sands, silts and clays belong to this category, as a variety of special mineral deposits found only in certain regions. They are excavated in quarries or even directly on the building site.

ANIMAL PRODUCTS

These products can be produced by animals drawn from animals, or be produced by simple natural or artificial processes from their corpses.

VEGETABLE PRODUCTS

These products can be drawn from plants or result from simple transformation processes.

Natural products, with the exception of a few products of geological origin, are in most cases not available to be used as a stabilizer within the mass of compressed earth blocks. In general their use therefore remains restricted to use as stabilizers for plasters and renders.

Their role varies widely: some are used to correct the grain size distribution of soils (for example, sands can be added to clays and vice versa); some give an attractive pigmentation and are sought after as decorative renders. Others help to stabilize earth mortars by making them water resistant, and are used to improve the durability of external renders. Some display considerable adhesion and prevent internal plasters from powdering.

Nature and applications of products

MINERAL PRODUCTS

> **BENTONITE: This is added in small quantities to the soil being treated. This type of clay has powerful degreasing properties and expands in the presence of water, thus preventing the passage of water.**

POZZOLONAS: Some soils (volcanic sands in particular) have natural pozzolanic properties. They can be used for stabilizing clayey soils but often require the addition of at least 25% lime or 50% cement to make them an effective binder which in turn will stabilize clay when added at a rate of about 8%. Pozzolana-based renders are, however, far more flexible than cement-based ones. They are often used for finishing flat earth-brickwork roofs and for vaulting.

ANIMAL PRODUCTS

EXCREMENT: All sorts of excrement are used. Cow dung is undoubtedly the most widely used, although it is better used as manure or fuel. Other traditions make use of horse or camel dung, or of pigeon droppings. The action of these kinds of excrement is probably due to the presence of fibre (mixed straw) phosphoric acid and potassium. The use of animal urine can also be found. Horse urine used to replace mixing water effectively eliminates cracking and results in a marked improvement in the ability of the soil to withstand erosion. Surprisingly good results can be obtained when it is combined with lime.

ANIMAL BLOOD: The use of bull's blood has been known since

Roman times. When combined with lime or polyphenols, stabilization with cow's blood is effective. The blood must be fresh and not in powder form.

ANIMAL FUR AND HAIR: Animal hair and fur play much the same role as some vegetable fibres.

CASEIN: Proteinic casein (the middle fraction of milk protides) is sometimes used in stabilization in the form of whey combined with bull's blood. Certain milk powders have been tried and give good results. "Poulh's soap" is also used. Prior to being added to the soil, this diluted casein is beaten to a paste after first being mixed with brick dust.

LIME: Lime can be prepared from shells or coral. This is skill done in some countries such as Somalia and Senegal.

ANIMAL GLUES: These can be used for stabilization, particularly for renders. Animal glues are produced from horn, bone, hooves and hides.

TERMITE HILLS: Termites secrete an active substance, which appears to be a non-ionic cellulose polymer of the polysaccharide type. Termite hills stand up well to rain and their

soil can be mixed with another for the production of blocks. The substance has been synthesized by research workers in South Africa, but costs three times as much as cement.

SHELLAC: Covering the twigs of trees in India and the Far East this is a resin secreted by the female lac-insects (Coccus lacca). It confers excellent strength on sandy soils, but the stabilized material does not stand up well to water.

OILS AND FATS: Fish oils and animal fats can serve as waterproofing agents. Similarly, the stearates contained in animal fats play the same role.

VEGETABLE PRODUCTS

ASHES: Hardwood ash is rich in calcium carbonate and has stabilizing properties, but is not always suitable for soils which may be suited to lime stabilization. Ash additions is suggested in proportions of 5 to 10%. This improves dry compressive strength, but does not reduce sensitivity to water.

VEGETABLE OILS AND FATS: If these are to be effective, vegetable oils must dry quickly, so that they harden on contact with air and are insoluble in water. The use of castor oil is highly

effective, but it is extremely expensive because it is also used in aviation. Coconut, cotton, and linseed oils are also used. Kapok oil prepared first by roasting kapok seeds, turning them into a flour which can then be transformed into a paste (20 to 25 1 of water to 10 kg of powder) can be effective. This depends on the quality of the seeds and the roasting process, which increases the yield, as well as the length of time it takes to prepare the paste (6 hours boiling). There is also palmitic oil which is obtained from saponified palm oil precipitated by 25% HCI. About 1 kg of palmitic acid is obtained per kg of palm soap in solution. Palmitic acid mixed with lime gives calcium palmitate, which is used in stabilizing renders. Shea (karite) oil or butter is also used for renders.

TANNINS: Tannins often act as dispersants and improve the coating of the grains by clays. They are also a good compaction acid (breaking up lumps) and reduce permeability. The amount of tannin required varies from a small percentage of the mixing water when tannin decoctions (solutions obtained by boiling) are used. The most commonly known are tannin from the bark of nere, oak, chestnut, and scorpioid acacia. The Hausa of Africa use the natural potash which accumulates in dying trenches, or an infusion of carob-bean husks, or even of mimosa, which the most

wealthy import from Egypt.

HUMIC ACID OR POLYPHENOLS: These are derived from lignin (a by-product of the wood and paper industries) and form hard stable compounds, particularly in ferralitic soils.

SAP AND LATEXES: The juice of banana leaves precipitated with lime improves erosion resistance and slows water absorption. The latex of certain trees, such as euphorbia, reduces permeability slightly. The same applies to hevea rubber, and concentrated sisal juice in the form of organic glue. Latexes mix with acid soils (coagulation), but mix better with neutral soils.

GUM ARABIC: This is obtained from the acacia tree. Its ability to waterproof is low, because it is soluble in water. It acts primarily as a floccullent, helps to increase dry compressive strength, and slows the capillary absorption of water by acting on the kinetics of this phenomenon. When added to the soil, or even better to sand, gum arabic produces good protective coatings, which are hard, do not crack, and adhere well to earth walls. This product does not stand up well to water, hence it is better to use it on the inside of buildings. The colour obtained is a pastel red ochre. Gum arabic is used as a render chiefly in the Sudan, but is

becoming increasingly expensive.

PALMO-COPAL: Copal is a resin obtained from certain tropical trees. Palmo-copal is a solution of copal obtained by heating palm oil. The amount required varies from 3 to 8% for sandy soils. Another variety, manilla copal, is the only copal resin which has a waterproofing capacity.

COLOPHANE This is obtained during the distillation of turpentine essences from oily pine resins. Soluble in organic solvents and in aqueous alkaline solutions, colophane resin forms a gel after reacting with certain metallic salts (iron and aluminium) and reduces the water absorption of soils.

VINSOL: This is also obtained during the production of turpentine. It is used in acid soils at critical control rates (+ 1%). Water repellent, it improves cohesion, but does not affect compressive strength.

LIGNIN: This is a by-product of the paper industry. It is a sort of alkaline resinous liquor with a waterproofing capacity. It is soluble and can become insoluble when reacting with chrome. Unfortunately, chromo-lignin is expensive.

MOLASSES: Sugar aldehydes from dehydrated molasses can be polymerized at high temperatures with phenolic catalysts. The resinous material obtained has characteristics similar to that of the naturally occurring asphalt and synthetic resins.

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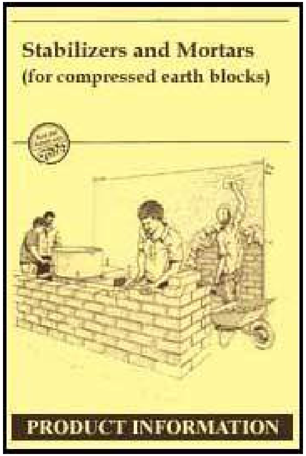

Lime

I. INTRODUCTION

Description

There are there main types of lime: high calcium limes (which we will subsequently refer to simply as "limes"), hydraulic limes and dolomitic limes.

> **HYDRAULIC LIMES gain greater strength, and at a faster rate, than high calcium limes. They also set under water and produce a generally more durable product. Their behaviour, the way they work and their characteristics closely resemble those of a lower strength Portland cement. This material will therefore not be further explored here and the Portland cement sheet may usefully be consulted. Their use should not be considered unless**

other types of lime are not available. Natural hydraulic limes are more effective stabilizers than artificial hydraulic limes.

HIGH CALCIUM LIME is obtained by calcination at 900° to 1,000°C of a relatively pure, clay-free calcareous rock. A calcium carbonate content of 97% would normally be considered the minimum for production of high calcium limes. During baking, this carbonate dissociates and part of it escapes in the form of carbon dioxide CO2. This leaves only calcium oxide CaO, known as quicklime, the proportion of which determines the quality of the final product. Pure high calcium lime will contain more than 97% CaO; fat lime, more than 85%; and a lean lime, less than 85%. When it is placed once more in contact with the carbon dioxide present in the atmosphere, the lime again becomes calcium carbonate.

DOLOMITIC LIME is similar to a high calcium lime, except that it contains a proportion of magnesium oxide (MgO) combined with calcium oxide (CaO). This lime needs more care in usage compared with a high calcium lime and it is particularly important to ensure that it has been properly burned and slaked, chat is, it is burned at a lower part of the temperature range for lime production and a longer time is allowed for slaking it. A

good proportion of the world's limestone is dolomitic limestone.

There are two main forms of lime: quicklime and hydrated lime.

QUICKLIME (CaO): Quicklime is produced directly by firing the stone in kilns. The sensitive conditions of storage and maintenance it requires can limit its use. Quicklime is extremely hygroscopic (ie it attracts water) and must be protected from moisture. It is a caustic material, becoming very hot during the hydration stage (up to 150°C), and must be handled with great care. On an equal weight basis, it is more effective than hydrated lime, because it can supply greater quantities of calcium ions.

HYDRATED LIME ($CaOH_2$): Since quicklime is a chemically unstable and slightly hazardous product, it is normally hydrated, becoming not only more stable but also easier and safer to handle. Hydrated lime is produced by adding water to quicklime in a process called "hydration" or "slaking", where the calcium oxide and water combine chemically to form calcium hydroxide. Fat slaked limes do not have to be very finely crushed to be effective. Industrial qualities contain between 90 and 99% of "active lime' while artisanal lime may only contain between 55 and 75%, the rest consisting of unburnt or excessively burnt

material.

Conditions of use

The setting of lime, which is in fact the recarbonation of the product when exposed to the carbon dioxide present in the air, implies that prolonged storage of the product after manufacturing is harmful, since setting begins naturally. In addition, while it is being used, if the thickness of the product is too great, the carbon dioxide in the air will penetrate to the bottom of the product slowly and incompletely, and the lime will therefore set only in part.

In the case of artisanal production of lime, the quality varies widely and can differ very significantly from theoretical limits (less carefully chosen raw material poorly monitored firing, partial extinction, etc). In this event, a few preliminary tests are always recommended to gauge the quality of the product and the proportions used should be adapted in the light of their results.

After mixing lime with soil, it is preferable to leave the mix for a while before use, to make best use of the plasticising qualities of the lime.

For stabilizing compressed earth blocks, lime is always used in powder form. For mortars, however, the use of lime in the form of a paste

presents certain advantages, but makes calculations of amounts to be used more inaccurate, as the exact proportion of lime in the paste is not well-known beforehand; the mix of sand or soil for the mortar must then be carried out well to ensure that it is uniform.

II. STABILIZER

Historical background

It appears chat the large scale use of lime for stabilizing soils is fairly recent, and was pioneered in the nineteen-twendes in the USA. Since then millions of m² of roads have been constructed in lime-stabilized soil and immense experience has been gained. The construction of the Dallas - Fort Worth airport, covering some 70 km², in 1974 is one of the most spectacular applications of this technique. Indeed more than 300,000 tonnes of lime were used for the stabilization works. Lime has also been, and still is, used for constructing buildings and there is an increasing interest in lime stabilization in this field.

How stabilization occurs

The theory of lime stabilization suggests that stabilization occurs in 5 basic ways.

WATER ABSORPTION: Quicklime undergoes a hydration reaction in the presence of water or in moist soil. This reaction is strongly exothermic with the release of about 300 kcal for every kg of quicklime.

CATION EXCHANGE: When lime is added to a moistened soil, the latter is flooded with calcium ions. Cation exchange then takes place, with calcium ions being replaced by exchangeable cations in the soil compounds, such as magnesium, sodium, potassium, and hydrogen. The volume of this exchange depends on the quantity of exchangeable cations present in the overall cation exchange capacity of the soil.

FLOCCULATION AND AGGREGATION: As a result of the cationic exchange and the increase in the quantity of electrolytes in the pore water, the soil grains flocculate and tend to accrete. The size of the accretions in the fine fraction increases. Both grain size distribution and structure are altered.

CARBONATION: The lime added to the soil reacts with carbon dioxide from the air to form weak carbonated cements. This reaction uses up part of the lime otherwise available for pozzolanic reactions.

POZOLANIC REACTION: This is by far the most important reaction involved in lime stabilization. The strength of the material results largely from the dissolution of clay minerals in an alkaline environment produced by the lime, and the recombination of the silica and alumina in the clays with the calcium to form complex aluminium and calcium silicates, thus cementing the grams together. The lime must be added to the soil in sufficient quantities in order to proceed and maintain a high pH, which is necessary for the dissolution of the clay minerals for long enough to allow an effective stabilization reaction.

Proportions of lime to be used

When 1 % quicklime is added to the soil the exothermic hydration reaction dries the soil, removing between 0.5 and 1% of water. The addition of 2 to 3% quicklime immediately causes a reduction of the plasticity of the soil and the breaking down of lumps. This reaction is called the fixing point of the lime. This reaction is not part of the stabilization process, but should rather be considered a "modification". For ordinary stabilization work, between 3 and 20% quicklime is used, the difference - in comparison with cement stabilization - being that, with lime, there is an optimum quantity for each soil. Generally speaking

quantities of 8 to 10% lime are required in order to obtain satisfactory results.

Soils that can be used

Lime has only every limited effect on soils with a high organic matter content (content higher than 20%) and on soils short of clay. It is more effective and can be more effective than cement on clay-sand soils and especially on very clayey soils. The effects of lime are thus highly dependent on the nature of the soils involved but a comparison with the effects of cement can, in many cases, be attempted. It has been observed that lime reacts far more quickly with montmorillonite clays than with the kaolinites, reducing the plasticity of the montmorillonites and having only aslight effect on the plasticity of the kaolinites. Water content has a significant effect on clay soils which can be stabilized with lime, particularly in the pulverization and compaction stage. Natural pozzolanas react particularly well with lime.

Note that proportions of lime quoted are for industrial quality lime containing between 90 and 99% quick lime. For lime produced by less sophisticated methods, which may contain only 55% quick lime (the rest being made up of unfired or over-fired components), the proportion must be increased. The two main methods of improving the

performance of soil with lime are summarized below:

Modification of the soil: the lime is added until a setting point is reached. This operation reduces the plasticity of the soil and improves its flocculation.

Stabilization of the soil: the proportions are much higher. Reference monograms on the suitability of soils and the proportion of lime must be interpreted with a great deal of care.

Effects of lime stabilization

Some of the effects of lime stabilization on the soils are:

DRY DENSITY: For a given compression, lime reduces the maximum dry density, and raises the optimum moisture contents, because of flocculation.

COMPRESSIVE STRENGTH: The optimum proportion of lime should be determined by preliminary tests. Compressive strength tends to increase dramatically with the age of the product; therefore tests should be carried out only after allowing a curing period of 3 months. Values between 2 end 5 MPa can easily be obtained and when sophisticated industrial procedures are

employed values of between 20 and 40 MPa can be expected.

TENSILE STRENGTH: This is highly influenced by the quantity and quality of clays contained in the soil, which reacts with the lime.

DIMENSIONAL STABILITY: Just I to 2% Iime can reduce shrinkage from 8 or 10% to 1% and eliminate swelling.

ABRASION: The proportion of lime should reduce material lost to 3% after 50 cycles - an excellent performance;

EROSION: The proportion of lime should reduce the mean depth of holes to 15mm - an excellent performance for this extremely severe test.

WETTING-DRYING: The proportion should reduce material losses to 10% - an excellent performance for this extremely severe test.

FREEZE-THAW: The proportion of lime should reduce material losses to 10%: an excellent performance for this excessively severe test.

Effects of certain products on lime-stabilization

ORGANIC MATTER: These can block ionic exchange in clayey soils without, blocking the pozzolanic reaction. Soils containing up to 20% organic matter can be stabilized with lime, but care is essential.

SULPHATES: Calcium sulphates are less dangerous than magnesium sulphates, when dry. When moist, all sulphates are harmful.

PORTLAND CEMENT: In quantities of up to 100% of the lime content will increase compressive strength.

BITUMEN: Between 0 and 2% of bitumen added as emulsion or cutback makes the limestabilized soil waterproof. Potassium sulphate (K_2SO_4) can also be used.

III. MORTAR

Bonding mortar

High calcium lime is one of the most suitable binding agents for the preparation of mortar for earth buildings: its does not shrink too much, it is moisture-permeable, its mechanical performance is not too high and it lends a degree of elasticity to the mortar. It is plastic, and it is

slow to set.

Depending on the mechanical characteristics of the background, mortars are prepared with greater or lesser proportions of lime. For surfaces which have fairly good mechanical strength, such as stabilized compressed earth blocks, a mixed lime-cement mortar - however, with a predominance of lime-can even be used. Combining high calcium lime with cement is also common practice, because lime sets very slowly and at least 6 months must be allowed before a fat lime reaches its final mechanical performance. Cement enables one to attain a minimum level of strength quickly.

There are some possibilities of additives to improve the basic qualities of lime: pozzolanic materials (rice husk ash, fly ash powdered brick, etc) to give a degree of hydraulicity, marble dust to increase hardness, and oil to quicklime to give a waterproof composite.

In an earth mortar, the effectiveness of lime as a stabilizer is debatable, as high calcium lime has an affect only on soils with a high clay content For mortars, therefore, one tends to use thinned soils which arc not very active. In fact, lime reinforces the binding action of clay a little and gives an earth mortar a plasticity and workability which improves its application.

Plasters and renders

The best results are obtained with hydrated limes, in the form of extremely fine-ground powder or a paste prepared be forehand. Theuse of hydrated lime as a surface rendering or plaster for soil structures is old and well established in many countries. It must be remembered that the hardening of a rendering based on slaked lime is the result of slow carbonation by carbon dioxide in the air, and as a result these dressings should not be too thick. The long hardening process makes these renders sensitive to atmospheric conditions. particularly frost and great heat. In many regions, lime renderings arc modified during preparation, with various additives which can improve their quality. For example, fresh bull's blood, leaving aside its importance in magical practice improves the waterproofing qualities of the renderings. Other practices include the addition of natural soft soap, which improves workability and waterproofing, and facilitates polishing. The addition of a little molasses helps to harden the render. When hydrated lime renders are exposed to considerable stressing, hydraulic lime or cement can be added. However, only a small proportion may be added to avoid excessive hardening or reduction of permeability. Experimentation has made it possible to specify proportions for lime or sand based multi-layer renders and mixed renders based on lime, cement and sand.

The lime-stabilization of soil renders and plaster has its greatest affect on clayey soils, when lime is used in large quantities, often over 10% A lime-stabilized render is best applied to astabilized wall. The addition of animal urine or dung can have truly astonishing effects on the render (less shrinkage, hardness and good permeability). The main drawback is the strong ammonia smell during mixing, which some people find disagreeable.

Renders	Lime	Cement	Sand
Scratch coat	1		1- 2
Main layer	1		2.5 - 3
Finishing coat	1		3.5 - 4
or			
Scratch coat	2	1	3 - 4
Main layer	2	1	6
Finishing coat	2	1	8

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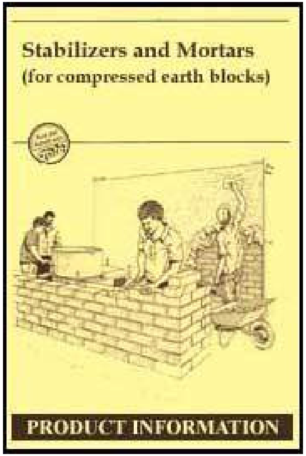

Stabilizers and Mortars (for compressed earth blocks) (GTZ, 1994, 20 p.)

Portland cement

I. INTRODUCTION

Description

Portland cement is obtained by firing at 1500°C a precise mix of ground calcareous rock and clayey materials. The mix which emerges as lumps at the end of the firing period is known as clinker; this clinker is then cooled and finely ground, and a small quantity of gypsum - which delays setting time - is added, to give Portland cement itself. Depending on the nature of the raw materials, the proportions used and the way the process is carried out, the final characteristics of the cement and, above all, its mechanical performances will vary.

Various products can be added to the clinker obtained at the end of the firing stage. The most common of these is slag, which is a by-product of the metallurgical industry. Slag is the gangue of iron ore and is obtained by separation at the moment of fusion of the ore. The various products obtained by mixing clinker and ore each have their own strength characteristics and also the capacity to withstand chemical corrosion especially sulphates.

Other cements are produced for special purposes: cements with a very high sulphate content (supersulphated cements) which are highly resistant to sulphates in sea-water, aluminium cements obtained by firing calcium carbonate and bauxite which have very slow setting times; pozzolanic Portland cements, obtained by mixing clinker and pozzolana - a volcanic rock - in order to prepare durable mortars; white

cement prepared with raw materials containing no iron oxide.

Conditions of use

Portland cement without retardants begins to set fairly quickly (1 hour). Reworking a mortar which has started to set merely breaks down the links which have begun to be formed; a mortar containing Portland cement must therefore be used without fail within an hour of being prepared. Hardening begins 3 to 12 hours after setting has started and takes 4 weeks. While it is setting, the cement takes up a certain amount of water (hydration); the mortar must therefore retain sufficient humidity, especially during the beginning of the hardening stage. When using a cement mortar on a dry, porous surface, this will rapidly absorb part of the water contained in the mortar and the cement will no longer have enough moisture to harden. This phenomenon is known as "grilling" the mortar and should be avoided by wetting the surface before applying the mortar.

Since cement goes off in damp conditions, dry storage is essential.

Cement shrinks as it hardens; using it neat would result m

cracks.

Cement lends itself well to mixing with other binders, notably limes, but on the other hand it cannot be mixed with gypsum.

II. STABILIZER

Historical background

The first attempts to use cement as a stabilizer were made for road-building purposes in the USA in 1915. Cement stabilization developed independently in Germany in the Since about 1935, cement stabilization has been increasingly used in the USA for both road and runway construction. The applications of cement-stabilized material have multiplied enormously since then and it is used world-wide for infrastructure works as much as for building construction. Today, our understanding of cement stabilized soils is very comprehensive.

How stabilization occurs

Hydrated cement reacts in two different ways in a soil:

a. By conventional hardening of the cement by hydration and bonding with the sandy "skeleton" of the soil.

b. By undergoing a 3-phase reaction with clay:

1 Hydration triggers the formation of cement gels on the surface of the clay aggregates. The lime, which is released during the hydration of the cement, tends to react with the clay. The lime is quickly used up and the clay starts to change its character.

2 Hydration proceeds and encourages the clay aggregates to break down. The latter are deeply penetrated by the cement gels.

3 The cement gels and the clay aggregates become intimately interlinked. Hydration continues, but more slowly.

In effect, three combined structures are obtained:

an inert sandy matrix bound with clay;
a matrix of stabilized clay
a matrix of unstabilized soil.

Stabilization does not affect all the aggregate. A stabilized matrix covers the composite aggregations of sand and clay.

Suitability of different cements

Ordinary Portland cement or similar cements are very suitable. There is nothing to be gained by using very high-strength cements, as these bring no particular benefits and are moreover very expensive. Higher-strength cements require very specific curing conditions and are liable to deteriorate, making them unsuitable for use on work sites far removed from the factory producing them. Portland cements of class 250 or 350 is preferred. Cements containing other materials such as slag, fly-ash and other pozzolanas can also be used, although these will only be available close to steel plants power stations and similar localities. In contrast, cements with high contents of other materials should not be used, because they need a precisely controlled curing environment. These include iron Portland cement, blast-furnace cement, mixed metallurgical cements and slag clinker cements.

Proportions of cements to be used

Excellent results can be obtained with between 3 and 16% by weight. Some soils require only 3%, while the same proportion in others makes them perform less well than if no cement at all had been used. Generally speaking, depending on the composition of the soil (determined by testing), at least 6 to 8% cement is required to get satisfactory results.

Soils that can be used

Nearly all soils, except those containing an excessive amount of organic material, can be treated with cement, which significantly improves their properties. Salt-rich soils are also difficult to stabilize with cement, but increasing the proportion of cement can often yield good results. Soils with a high clay content mix only with difficulty and require large amounts of cement. When the mixing process is very closely controlled under laboratory conditions, good results can be achieved with clayey soils. In practice, however, cement is not used for stabilizing clay when the liquid limit is greater than 50% and the clay content is higher than 30%. Preliminary treatment of these extremely clayey soils with lime may improve the chances of obtaining good results when cement is added later on. Numerous tests give indications about the suitability and proportion of cement.

The table overleaf gives an idea of the cement requirements of various soils.

Effects of cement stabllization

Some of the effects of cement stabilization on soils are the following:

- **DRY DENSITY: This is lower for soils which compact well and**

higher for soils which compact less well.

WET COMPRESSIVE STRENGTH: Under good conditions, the wet compressive strength equals or attains values over 50% of dry compressive strength.

TENSILE STRENGTH: This varies from 1/5 to 1/10 of compressive strength values.

The following tests can be performed to evaluate the effects of cement stabilization.

ABRASION: The proportion of cement should reduce material lost to 3% or less after 50 cycles of brushing, which is an excellent performance.

EROSION: The proportion of cement should reduce the mean depth of pitting to 15mm or less-an excellent performance as this is an extremely severe test.

WETTING-DRYING: An optimum proportion should reduce material losses to 10% or less - an excellent performance as this is an extremely severe test.

FREEZE-THAW: An optimum proportion should reduce material losses to 10% or less an excellent performance as this is an extremely severe test.

Effects of certain products on cement-stabilization

ORGANIC MATTER: This is generally recognized as being harmful, particularly if it contains nucleic acid, tartaric acid, or glucose. Its effect is to slow down the setting of cement and to lower its strength. As a general rule, an organic matter content in excess of 1% represents a hazard and soil containing more than 2% should not be used

Some organic products (amine acetate, melamine, aniline) and certain inorganic products (ferrous chloride! reduce the sensitivity of some soils to water.

Lime (2%) can reduce the harmful effects of organic matter, as does calcium chloride (0.3 to 2%), which also accelerates setting. Lime also serves to modify the plasticity of the soil and to limit the formation of nodules.

When the pH value is > 7 (alkaline or neutral): calcareous soils, brown alkaline soils, and some gley soils can be stabilized with 10% cement,

and rates of between 1 and 2% of organic matter are in general not a problem.

When the pH value < 7 (acid): gley soils can be successfully stabilized with 10% cement if the organic matter content is less than 1%. Podsols and acidic brown soils can sometimes be stabilized successfully if they contain less than 1% organic matter. If anomalies are found to exist, preliminary treatment with calcium chloride (1 to 2%) may bring about a certain improvement.

SULPHATES: These have very harmful side-effects, calcium sulphate (anhydrite and gypsum) in particular, and are often encountered. They result in the destruction of the hardened cement from the inside of the cement-soil, an increase in the sensitivity of the clay to moisture. For soils with a sulphate content of more than 2 to 3%, a special study is essential.

OXIDES AND METALLIC HYDROXIDES: These are basically iron and aluminium oxides. They rarely exceed 5% of the soil, and thus have little effect.

WATER: In principle, water containing organic matter and salts should not be used as these may cause efflorescence. Water with

a high sulphate content may also have harmful effects.

BITUMEN: Between 2 and 4% bitumen added as an emulsion or cutback makes the soil waterproof.

III. MORTAR

Bonding mortar

The texture of a good bonding mortar is generally more sandy than that of compressed earth blocks, with a maximum particle diameter of 2 to 5 mm Cement-stabilized mortar must always be used with cement-stabilized compressed earth blocks. In this event, the proportion of cement used should be increased by a factor of 1.5 or 2 to achieve the same strength as that of the earth blocks.

Plasters and renders

Cement mortars are too rigid and suffer from the defect of not adhering well to compressed earth block walls. Cracking, blistering and falling off in sheets are frequently observed symptoms .Their use is not recommended and should at best be a temporary solution, with Proportions of the order of 1 part cement to 5 or 10 parts soil or sand. Preferably a little lime should be added: 1 part lime to 1 part cement, or

1 part lime to 2 parts cement if at all possible. Cement renders should be applied on a wire netting. This reduces cracking and falling off in slabs, but does not improve adhesion, Usually this solution is fairly expensive and not very satisfactory.

Cement-stabilization of plasters and renders is only really effective if the soil is very sandy. Proportions may vary from 2 to 15% cement, depending on whether a mild improvement or genuine stabilization is required. Cement-stabilized renders should preferably be applied to stabilized walls. It is also possible to add between 2 and 4% bitumen. This mixture tends to darken the dressing without spoiling the colour, but greatly improves water resistance.

The Unified Soil Classification System (USCS) is based on the size of the soil particles, the amounts of the various sizes and the plastic characteristics of the very fine grains. This system takes into account the engineering properties of the soils. It is descriptive and easy to associate with actual soils, and it has the flexibility of being adaptable both to the field and to the laboratory. Probably its greatest advantage is that the soil can be classified readily by visual and manual examination based on the results of simplified grain size distribution tests and plasticity tests.

The table can be found at the back of the leaflet on "Gypsum", in this Product Information folder.

AASHO SOIL CLASP BY WEIGHT (%)	USCS SOIL CLASS FOR VARIOUS SOILS (3)	CEMENT REQUIREMENTS
A-1-a	W, GP, GM, SW, SP, SM	3 - 5
A-1-b	GM, GP, SM, SP	5 - 8
A-2	GM, GC, SM, SC	5 - 9
A-3	SP	7 - 11
A-4	CL,ML	7 - 12
A-5	ML, MH, CH	8 - 13
A-6	CL, CH	9 - 15
A-7	OH, MH, CH	10 - 16

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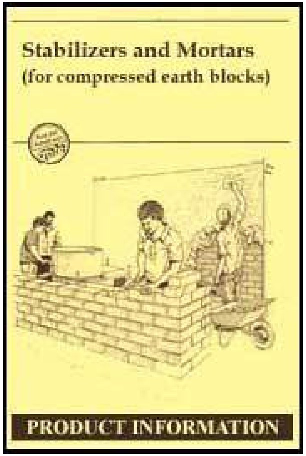
Stabilizers and Mortars (for compressed earth blocks) (GTZ, 1994, 20 p.)

(introduction...)



Gypsum

I. INTRODUCTION

Description

Gypsum plaster is obtained from a saline sedimentary rock- gypsum - a calcium sulphate with two water molecules ($CaSO_4$. $2H_2O$), which is

ground and then fired. The water present in the rock evaporates. Depending on how high a temperature is used for firing, different products are obtained: first a semi-hydrate ($CaSO_4$. ½ H_2O) at a firing temperature of 100° to 180°C, which is the most common form of plaster, above 180°C, a soluble anhydrite is obtained ($CaSO_4$) which is a highly reactive but unstable plaster. At temperatures of 1000° to 1100°C, an anhydrated plaster is obtained; this has a longer setting time and gives harder products with very little shrinkage.

Conditions of use

In the presence of water, the plaster reverts to the original stable composition which it had in the rock after a recrystallisation reaction during which heat is given off and there is an increase in volume. The proportion of water used during mixing is very important in determining the final characteristics of the product. Too much water leads to considerable porosity which significantly lowers mechanical performance.

It is most commonly used as a pure paste without adding any aggregate. But additives are sometimes added to speed up or slow down setting times. High calcium lime is quite frequently used, its effect being sometimes to accelerate and sometimes to slow down setting

times, but it gives better workability and therefore a better application. This paste is used mostly for rendering walls which are not exposed to rain.

The plaster must be protected from any moisture. It has a corrosive effect on iron, if the latter is not protected. When preparing a plaster render paste or a mortar, care must be taken to optimize the dosages and avoid using too much water. The plaster is always added to the water and never the other way around to avoid lumps forming. The plaster sets very rapidly, and therefore the paste or mortar must be used immediately; once a paste has begun to set, there is no point in trying to remoisten it. Prepare small quantities at a time to avoid waste.

II. STABILIZER

Only very little research has been carried out on the use of gypsum as a stabilizer for compressed earth blocks. Although some successful prototypes have been built, scientific evidence is too scarce to recommend the use of gypsum as a CEB stabilizer on a large scale.

III. MORTAR

Bonding mortar

Gypsum can be used as a bonding mortar, but its use cannot be

recommended, as scientific data is too scarce. The plaster allows mortars to harden rapidly. This fast setting of plaster is sometimes sought after for special uses, such as building earth block vaults and domes.

Plasters and renders

Once it has been used, gypsum plaster remains very sensitive to moisture, which makes it lose many of its qualities with regard to compressive and bending strengths, as well as its hardness. By penetrating the pores, water affects its crystalline structure. This explains why gypsum plaster is mainly used in situations where it is less likely to get wet, that is, as an interior plaster.

Gypsum plasters are fairly compatible with earth walls. They have very good moisture permeability and a very low modulus of elasticity, and therefore are able to follow the swelling and shrinkage movements of an earth support well. It is best to improve the adhesion of gypsum to the earth by first applying a diluted wash of lime or cement.

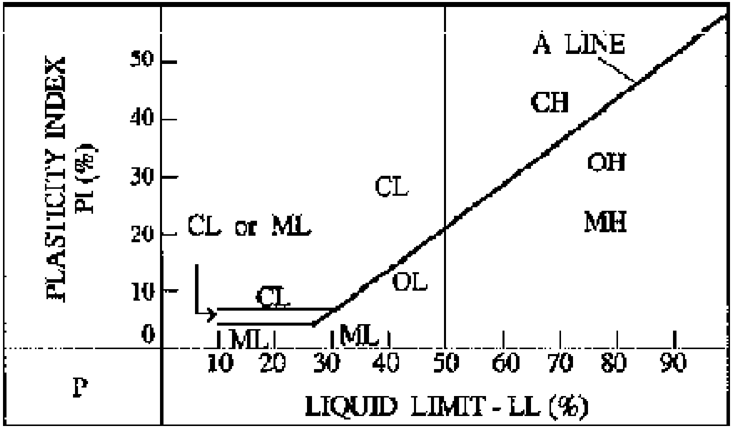
On outside walls, slaked lime can be added to the gypsum. This hardens the rendering and improves its water resistance. The rendering can be applied in 2 layers, with 1 to 1.5 parts of slaked lime added to 10 parts

of plaster and 7.5 to 10 parts of sand for the first layer. The same proportion of binder, but without sand, can be used for the second layer. Waterproofing the surface with a fluoro-silicate solution after a period of a few days is desirable.

GEOTECHNICAL CLASSIFICATION USCS SYSTEM LABORATORY PROCEDURE			**SYMBOLS**	**DESCRIPTION**
More than half the elements have a diameter greater than 0.08 mm GRANULAR SOILS	More than half the elements >0.08 mm have a diameter >2 mm GRAVELY SOILS	All diameters are represented, none predominates	GW	Clean gravel Well graded
		One grain size or one grain fraction predominates	GP	Clean gravel Poorly graded
		Fine elements have no cohesion	GM	Silty gravel
		Fine elements have	GC	Clayey gravel

		Fine elements have cohesion	GC	Clayey gravel
	More than half the elements >0.08 mm have a diameter < 2 mm SANDY SOILS	All diameters are represented none predominates	SW	Clean sand Well graded
		One grain size or one grain fraction predominates	SP	Clean sand Poorly graded
		Fine elements have no cohesion	SM	Silty sand
		Fine elements have cohesion	SC	Clayey sand
More than half the elements have a diameter less than 0.08 mm FINE	Liquid Limit LL <50% CLAY AND SILT SOILS		CL	Low plasticity clay

SOILS-CLAY AND SILT				
		Inorganic	ML	Low plasticity silt
		Organic material	OL	Organic silt and clays with low plasticity
	Liquid Limit LL >50% CLAY AND SILT SOILS		CH	Highly plastic clay
		Inorganic	MH	Highly plastic silt
		Organic material	OH	Highly plastic organic silt and clay
		Organic matter predominates. Can be recognized by smell, dark colour, fibrous texture, low moist density	Pt	Peat and other highly organic soils


PLASTICITY INDEX
PI (%)
50
40
30
20
10
0
A LINE
CH
OH
MH
CL
CL or ML
CL
ML
ML
OL
P
10 20 30 40 50 60 70 80 90
LIQUID LIMIT - LL (%)

FIGURE