7. CEMENT AND LIME STABILIZED MATERIALS

7.1 Introduction

This chapter gives guidance on the manufacture and use of cement and lime-stabilized materials in base course, subbase, capping and selected fill layers of pavements. The stabilizing process involves the addition of a stabilizing agent to the soil, mixing with sufficient water to achieve the optimum moisture content, compaction of the mixture, and final curing to ensure that the strength potential is realized.

Many natural materials can be stabilized to make them suitable for road pavements but this process is only economical when the cost of overcoming a deficiency in one material is less than the cost of importing another material which is satisfactory without stabilization.

The primary use for cement and lime stabilization in tropical countries like Ethiopia has so far been with gravelly soils to produce roadbases. The processes can also be used with more clayey soils to make the upper layer of sub-bases.

Stabilization can enhance the properties of road materials and pavement layers in the following ways:

- A substantial proportion of their strength is retained when they become saturated with water.
- Surface deflections are reduced.
- Materials in the supporting layer cannot contaminate the stabilized layer.
- Lime-stabilized material is suitable for use as a capping layer or working platform when the in situ material is excessively wet or weak and removal is not economical.

Associated with these desirable qualities are several possible problems:

- Traffic, thermal and shrinkage stresses can cause stabilized layers to crack.
- Cracks can reflect through the surfacing and allow water to enter the pavement structure.
- If carbon dioxide has access to the material, the stabilization reactions are reversible and the strength of the layers can decrease.
- The construction operations require more skill and control than for the equivalent unstabilized material.

Methods of dealing with these problems are outlined in Section 7.6.

The minimum acceptable strength of a stabilized material depends on its position in the pavement structure and the level of traffic. It must be sufficiently strong to resist traffic stresses but upper limits of strength are usually set to minimize the risk of reflection cracking. Three types of stabilized layer have been used in the structural design catalog (Chapter 10) and the strengths required for each are defined in Table 7-1.
Table 7-1: Properties of Cement and Lime-Stabilized Materials

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
<th>Unconfined compressive strength* (Mpa) (Cement Stabilized)</th>
<th>Minimum CBR value* (%) (Lime stabilized)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CB1</td>
<td>Stabilized base course</td>
<td>3.0 - 6.0</td>
<td>100</td>
</tr>
<tr>
<td>CB2</td>
<td>Stabilized base course</td>
<td>1.5 - 3.0</td>
<td>80</td>
</tr>
<tr>
<td>CS</td>
<td>Stabilized sub-base</td>
<td>0.75 - 1.5</td>
<td>40</td>
</tr>
</tbody>
</table>

* Strength tests on 150 mm cubes (see Section 7.4)

7.2 The Stabilization Process

When lime is added to a cohesive soil, calcium ions replace sodium ions in the clay fraction until the soil becomes saturated with calcium and the pH rises to a value in excess of 12 (i.e. highly alkaline). The quantity of lime required to satisfy these reactions is determined by the initial consumption of lime test (ICL), (British Standard 1924).

The solubility of silica and alumina in the soil increase dramatically when the pH is greater than 12 and their reaction with lime can then proceed producing cementitious calcium silicates and aluminates. Amorphous silica reacts particularly well with lime. The cementitious compounds form a skeleton that holds the soil particles and aggregates together.

The primary hydration of cement forms calcium silicate and aluminate hydrates, releasing lime, which reacts with soil components, as described above, to produce additional cementitious material.

The gain in strength associated with the formation of calcium silicates and aluminates occurs slowly. It is accelerated by heat, an advantage when using lime stabilization in hot climates.

7.3 Selection of Type of Treatment

The selection of the stabilizer is based on the plasticity and particle size distribution of the material to be treated. The appropriate stabilizer can be selected according to the criteria shown in Table 7-2:

Table 7-2: Guide to the Type of Stabilization Likely to be Effective

<table>
<thead>
<tr>
<th>PP ≤60</th>
<th>More than 25% passing the 0.075 mm sieve</th>
<th>Less than 25% passing the 0.075 mm sieve</th>
</tr>
</thead>
<tbody>
<tr>
<td>PI ≤10</td>
<td>PI &lt; 10</td>
<td>PI &gt; 20</td>
</tr>
<tr>
<td>Cement</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Lime</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Lime-Pozzolan</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Notes. 1. * Indicates that the agent will have marginal effectiveness
2. PP = Plasticity Product (see Chapter 6).
Except for materials containing amorphous silica, e.g. some sandstones and chert, material with low plasticity is usually best treated with cement. However, reactive silica in the form of pozzolans can be added to soils with low plasticity to make them suitable for stabilization with lime. If the plasticity of the soil is high there are usually sufficient reactive clay minerals which can be readily stabilized with lime. Cement is more difficult to mix intimately with plastic materials but this problem can be alleviated by pre-treating the soil with approximately 2 per cent of lime to make it more workable. When lime is added to a plastic material, it flocculates the clay and substantially reduces the plasticity index.

If possible, the quality of the material to be stabilized should meet the minimum standards set out in Table 7-3. Stabilized layers constructed from these materials are more likely to perform satisfactorily even if they are affected by carbonation during their lifetime. Materials not complying with Table 7-3 can sometimes be stabilized but more additive will be required and the cost and the risk from cracking and carbonation will increase.

Table 7-3: Desirable Properties of Material before Stabilization

<table>
<thead>
<tr>
<th>Test sieve (mm)</th>
<th>Percentage by mass of total aggregate passing sieve (mm)</th>
<th>CB1</th>
<th>CB2</th>
<th>CS</th>
</tr>
</thead>
<tbody>
<tr>
<td>53</td>
<td>100</td>
<td>100</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>37.5</td>
<td>85 – 100</td>
<td>80</td>
<td>100</td>
<td>-</td>
</tr>
<tr>
<td>20</td>
<td>60 – 90</td>
<td>55</td>
<td>90</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>30 – 65</td>
<td>25</td>
<td>65</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>20 – 50</td>
<td>15</td>
<td>50</td>
<td>-</td>
</tr>
<tr>
<td>0.425</td>
<td>10 – 30</td>
<td>10</td>
<td>30</td>
<td>-</td>
</tr>
<tr>
<td>0.075</td>
<td>5 - 15</td>
<td>5</td>
<td>15</td>
<td>-</td>
</tr>
<tr>
<td>Maximum allowable value</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LL</td>
<td>25</td>
<td>30</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>PI</td>
<td>6</td>
<td>10</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>LS</td>
<td>3</td>
<td>5</td>
<td></td>
<td>-</td>
</tr>
</tbody>
</table>

Note: It is recommended that materials should have a coefficient of uniformity of 5 or more.

Some aspects of construction must also be considered in selecting the stabilizer. It is not always possible to divert traffic during construction and the work must then be carried out in half-widths. The rate of gain of strength in the pavement layer may sometimes need to be rapid so that traffic can be routed over the completed pavement as soon as possible. Under these circumstances, cement stabilization, with a faster curing period, is likely to be more suitable than lime stabilization.

Certain types of organic compounds in soils can affect the hydration of cement and inhibit the gain in strength. It is recommended that the effects of organic matter are assessed by strength tests as outlined below.

Recent experience has shown that soils in which sulphates are present should be avoided. Examples have been reported of lime stabilized clays swelling to a marked degree in the months following construction. The cause of this swelling has been traced to a reaction between sulphates in the soil and the calcium silica-alumina hydrates formed as the lime reacts with soil. This reaction can occur in the presence of as little as 0.3 per cent of sulphate in the soil and is reported to be activated in situations where the soil is in or near a saturated condition.
7.4 Cement Stabilization

7.4.1 SELECTION OF CEMENT CONTENT

The cement content determines whether the characteristics of the mixture are dominated by the properties of the original soil or by the hydration products. As the proportion of cement in the mixture increases, so the strength increases. Strength also increases with time. During the first one or two days after construction this increase is rapid. Thereafter, the rate slows down although strength gain continues provided the layer is well cured. The choice of cement content depends on the strength required, the durability of the mixture, and the soundness of the aggregate.

The minimum cement content, expressed as a percentage of the dry weight of soil, should exceed the quantity consumed in the initial ion exchange reactions. It is recommended that the percentage of cement added should be equal to or greater than the ICL.

7.4.2 PREPARATION OF SPECIMENS

The optimum moisture content and the maximum dry density for mixtures of soil plus stabilizer are determined according to British Standard 1924 for additions of 2, 4, 6 and 8 per cent of cement.

Samples for the strength tests should also be mixed and left for two hours (to account for delays in practice) before being compacted into 150 mm cubes at 97 per cent of the maximum dry density obtained, after a similar two hour delay, in the ASTM Test Method D 1557 (Heavy Compaction). These samples are then moist cured for 7 days and soaked for 7 days in accordance with BS 1924.

When the soaking phase is completed, the samples are crushed, their strengths measured, and an estimate made of the cement content needed to achieve the target strength.

As an alternative, the strength of stabilized sub-base material may be measured by the CBR test after 7 days of moist curing and 7 days of soaking. A minimum CBR of 70 is recommended.

7.5 Lime Stabilization

7.5.1 PROPERTIES OF LIME-STABILIZED MATERIALS

By lime-stabilization, both the ion exchange reaction and the production of cementitious materials increase the stability and reduce the volume change within the clay fraction. It is not unusual for the swell to be reduced from 7 or 8 per cent to 0.1 per cent by the addition of lime. The ion exchange reaction occurs quickly and can increase the CBR of clayey materials by a factor of two or three.

The production of cementitious materials can continue for ten years or more but the strength developed will be influenced by the materials and the environment. The elastic modulus behaves similarly to the strength and continues to increase for a number of years. Between the ages of one month and two to three years there can be a four-fold increase in the elastic modulus.
7.5.2 TYPES OF LIME

The most common form of commercial lime used in lime stabilization is hydrated high calcium lime, Ca(OH)$_2$, but monohydrated dolomitic lime, Ca(OH)$_2$, MgO, calcitic quick lime, CaO, and dolomitic quicklime, CaOMgO are also used.

For hydrated high calcium lime the majority of the free lime, which is defined as the calcium oxide and calcium hydroxide that is not combined with other constituents, should be present as calcium hydroxide. British Standard 890 requires a minimum free lime and magnesia content (CaO + MgO), of 65 per cent.

Quicklime has a much higher bulk density than hydrated lime and it can be produced in various aggregate sizes. It is less dusty than hydrated lime but the dust is much more dangerous and strict safety precautions are necessary when it is used. For quicklime, British Standard 890 requires a minimum free lime and magnesia content, (CaO + MgO), of 85 per cent. ASTM C977 requires 90 per cent for both quicklime and hydrated lime.

Quicklime is an excellent stabilizer if the material is very wet. When it comes into contact with the wet soil the quicklime absorbs a large amount of water as it hydrates. This process is exothermic and the heat produced acts as a further drying agent for the soil. The removal of water and the increase in plastic limit cause a substantial and rapid increase in the strength and trafficability of the wet material.

In many parts of the world, lime has been produced on a small scale for many hundreds of years to make mortars and lime washes for buildings. Different types of kilns have been used and most appear to be relatively effective. Trials have been carried out by TRRL in Ghana (Ref. 11) to determine the output possible from small kilns and to assess the suitability of lime produced without commercial process control for soil stabilization. Small batch kilns have subsequently been used to produce lime for stabilized layers on major road projects.

7.5.3 SELECTION OF LIME CONTENT

The procedure for selecting the lime content follows the steps used for selecting cement content and should, therefore, be carried out in accordance with British Standard 1924. The curing period for lime-stabilized materials is 21 days of moist cure followed by 7 days of soaking. If the amount of lime exceeds the ICL, the stabilized material will generally be non-plastic or only slightly plastic.

The temperature of the samples should be maintained near the ambient temperature. Accelerated curing at higher temperatures is not recommended because the correlation with normal curing at temperatures near to the ambient temperature can differ from soil to soil. At high temperatures the reaction products formed by lime and the reactive silica in the soil can be completely different from those formed at ambient temperatures.