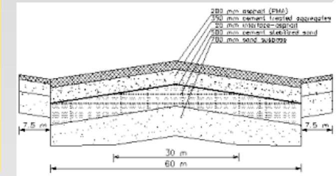
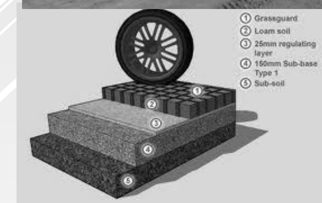
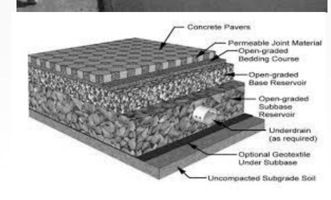
LECTURE 11:
Cement and lime treated bases







11.1 Introduction

In many countries, locally available materials are mixed with cement to obtain better characteristics with respect to stiffness, strength, moisture resistance etc. The backgrounds of modifying or stabilizing materials with cement or lime discussed in the lecture notes on Soil Stabilization [51]. Here only the most important issues with respect to pavement design will be discussed.

Before those issues are discussed, the reader should be aware of the fact that there is a distinct difference between a cement treated soil on one hand and a cement treated granular material or sand on the other. In general one could state that the less fines are present in the soil mixture, the more the cement treated material will behave like concrete. Furthermore one should realize that in most cases it is not feasible to treat a fine grained soil with cement. In such cases modification with lime is much more feasible than mixing it with cement.

One should also be aware of the fact that the characteristics of lime and cement treated materials strongly depend on aspects like:

- pulverization of the existing soil,
- homogeneity of spreading,
- homogeneity of mixing,
- homogeneity in moisture content,
- amount of lime or cement,
- compaction.

When mixing is done in place, a significant amount of variation in the characteristics of the treated material can occur due to variations in the above mentioned factors. One should therefore not be surprised when the characteristics determined on cores taken from the field are much less than the characteristics of the same material when mixed in the laboratory. A nice example of this is given in the table 24 [52] which shows the differences between the characteristics obtained on field and lab samples. These differences occurred in spite of the fact that the mixing procedure was regarded as very good.

Cement content	Unconfined compressive strength	Flexural strength	Modulus of rupture
3%	0.33 – 0.45	-	0.25 – 0.63
6%	0.55 – 0.6	0.69	0.13 – 0.54

Table 24: Comparison of field with laboratory strength data. Given are the ratios field : lab.

In another study differences in cement content of cores taken from the same project of up to 40% were reported. Based on this information it is therefore suggested to take as input for design, values which are 50% of the laboratory determined values.

Finally it should be mentioned that unlike for asphalt mixtures and granular materials, no relations exist that relate e.g. mixture composition to mechanical characteristics. The information given here therefore only provides rough estimates for the parameters needed as input for design purposes.

11.2 Lime treated soils

For design purposes, the following relations are suggested.

The **flexural strength and stiffness modulus in flexure** can be estimated from equations that were developed from test results obtained on laboratory produced specimens.

$\sigma_f = 13.78 + 101.2\ qu$

Where:

σ_f = flexural strength [psi] (1 psi = 7 kPa),

qu = unconfined compressive strength [ksi] (1 ksi = 1000 psi = 7000 kPa = 7 Mpa)

$E_f = 4.6\ \sigma_f - 139$

Where:

Ef = flexural stiffness [ksi]

- In the laboratory, a resilient modulus (determined by means of the repeated load CBR test) after 28 days curing of about 180 MPa was found for an Ethiopian black cotton clay when this material was mixed with 5% lime. When it was mixed with 7% lime a resilient modulus of about 400 Mpa was found.
- Keep in mind that for design purposes, it is wise to reduce these values to 50% of the estimated values.
- If no strength information is available, one has to rely on information given in literature about the stiffness modulus of lime treated soils. From the literature available and taking into account the difference between the results obtained on laboratory prepared specimens and field specimens, the author concluded that a stiffness value of 200 MPa seems to be a reasonable estimate to be used for design purposes.
- The **fatigue resistance** of lime stabilized materials is not only dependent on the amount of lime but also on the type of soil. Unfortunately very little information on the fatigue performance of lime stabilized materials can be found in literature. Nevertheless the following relationship is suggested by the author. It is based on information given in [51].

$$\text{Log } N = 16 - 16.67\ \sigma / \sigma_f$$

Where:

n = number of load repetitions to failure,

σ = applied flexural stress,

σ_f = flexural strength.

The chances on fatigue failure are very low if the stress ratio is smaller than 0.5.

11.3 Cement treated materials

In this part attention will be paid to relationships that can be used for cement treated fine grained soils, cement treated sands and cement treated coarse grained materials.

11.3.1 Cement treated fine grained, cohesive soils

The **flexural strength and flexural stiffness** can be estimated using the following equations.

$$\sigma_f = -0.0042 + 0.1427\ \sigma_c$$

$$E_f = 1435\ \sigma_c^{0.885}$$

Where:

σ_c = compressive strength [MPa],

σ_f = flexural strength [MPa],

E_f = stiffness modulus in flexure [MPa].

- The relationship for the flexural stiffness was not developed for cement treated soils. Nevertheless reasonable predictions were made by the author using this equation and for this reason it is also proposed to be used for cement treated fine grained soils.
- Keep in mind that the relations are developed using results obtained on laboratory produced specimens. For design purposes it is recommended to use a value that is 50% of the predicted value.

If no strength data are available, the following suggestions can be helpful.

- A reasonable value for the laboratory stiffness of a cement treated A6 soil with 13% (m/m) cement compacted at optimum moisture content to a density of 1700 kg / m^3 is 3500 MPa. The field modulus would be approximately 1750 MPa and the field flexural strength would be around 0.48 MPa.

- At cement contents of 6%, 8%, and 10% the modulus is assumed to reduce to resp. 70%, 80% and 90% of the value obtained at a cement content of 13%.

- It should be noted that the modulus could reduce to 20% of the values given when compaction is done on the wet side of optimum moisture content.

Little information is available on the **fatigue resistance** of cement treated soils. For an A4 soil treated with 7% cement, the following fatigue relation was derived from information taken from literature.

$$\text{Log } N = -1.780 - 17.037 \log \sigma / \sigma_f$$

From this equation it appears that the probability that fatigue cracking will occur is very low if the stress ratio is reduced to 30%.

11.3.2 General comments with respect to lime and cement treated soils

From the information given on the stiffness and fatigue characteristics of lime and cement treated soils it becomes evident that their mechanical characteristics are not that "exciting". This implies that they should preferably not be used as base layer immediately under the asphalt layer.

Lime and cement treated soils act primarily as a working platform allowing good compaction of the layers placed on top of them. Furthermore the treated soil is far less sensitive to variations in moisture which otherwise could lead to swell and shrinkage.

One should never forget that cement treated soils will always crack as a result of shrinkage that occurs during hardening or a drop in temperature. Furthermore construction traffic might induce additional cracking making the cement treated material less stiff. When heavily cracked, the effective modulus can even reduce to 50% of the values recommended to be used for pavement design purposes.

11.3.3 Cement treated sands

In many parts in the world, sand is readily available while good quality crushed stone is not. Unfortunately the stiffness and strength characteristics of sands are not exceptionally good meaning that treating the material with cement is a viable option to improve those characteristics.

In this part of the notes attention will be paid to relationships that are helpful to estimate the mechanical characteristics of cement treated sands. Most of the available information is related to sand cement as used in the Netherlands. For that reason the presented equations hold particularly for that type of material.

In order to be able to estimate the **compressive and indirect tensile strength of Dutch sand cement**, a laboratory investigation [53] was carried out to determine the strength characteristics of this material. The sand was a fine grained sand typical for the sands used in the western part of the Netherlands for road construction. Some characteristics are given hereafter.

d10 = 125 μm,
d50 = 200 μm,
d60 = 230 μm,

dx = sieve size through which x% passes.

The cement contents used were: 6%, 8%, 10% and 12% by weight. The moisture contents used were also 6%, 8%, 10% and 12%. The unconfined compressive strength after 28 days could be predicted using:

$$UCS = 40.5 - 23\,X_1 - 13.6\,X_2 + 20.7\,X_3 - 108.5\,W^2 + 123.2\,D\,W^2 - 35\,W^2 D$$

The indirect tensile strength could be predicted using:

$$\sigma_t = 32.17 - 3.81\,X_1 - 1.91\,X_2 + 2.02\,X_3 + 0.097\,W - 15.98\,D$$

In these equations:
UCS = unconfined compressive strength [kgf / cm^2]
Xi = dummy variable,
W = moisture content [% m/m],
D = dry density [gr / cm^3],
1 kgf / cm^2 = 100 kPa.

The dummy variables are defined as follows:

Cement content [% m/m]	X_1	X_2	X_3
6	1	0	0
8	0	1	0
10	0	0	0
12	0	0	1

No equations were developed to estimate the **stiffness modulus** of the cement treated sand. Therefore the author tested two equations that were available in literature for the prediction of the stiffness modulus from the compressive strength of the material. The used equations are:

$E_f = 1435\ \sigma_c^{\ 0.885}$ (1) and $E_f = 1284\ \sigma_c$ (2)

When used together with the Dutch specifications, the following results were obtained.

Strength requirement	Stiffness modulus [MPa] using	
	Equation 1	Equation 2
Lab. specimens after 28 days mean compressive strength 5 MPa	5963	6420
Field specimens after 28 days minimum compressive strength 1.5 MPa	2054	1926

The estimates obtained by means of both equations are considered to be very reasonable and therefore it is believed that both equations can be used for design purposes.

The fatigue relation as determined for a particular sand cement in the Netherlands is:

$$\log N = 10 - 0.08\ \varepsilon$$

Where:
ε = tensile strain at the bottom of the sand cement layer [µm / m].

An extensive analysis was made of the performance of a number of road sections in the SHRP-NL database that have a cement treated sand base [54]. It was possible to derive from this analysis a field fatigue relation which, together with the laboratory determined fatigue relation, is shown in figure 110. From this picture one can conclude that a design made using the laboratory determined fatigue relation is on the save side because that fatigue line more or less corresponds with the field line indicating a 85% probability of survival. Furthermore it is quite clear that there is a significant amount of variation around the mean fatigue line.

The field fatigue relation can be written as:

$$\text{Log } N = 8.5 - 0.034\ \varepsilon$$

Where:

N = allowable number of equivalent 100 kN axles (probability of survival is 50%),
ε = tensile strain at the bottom of the cement treated base [µm / m].

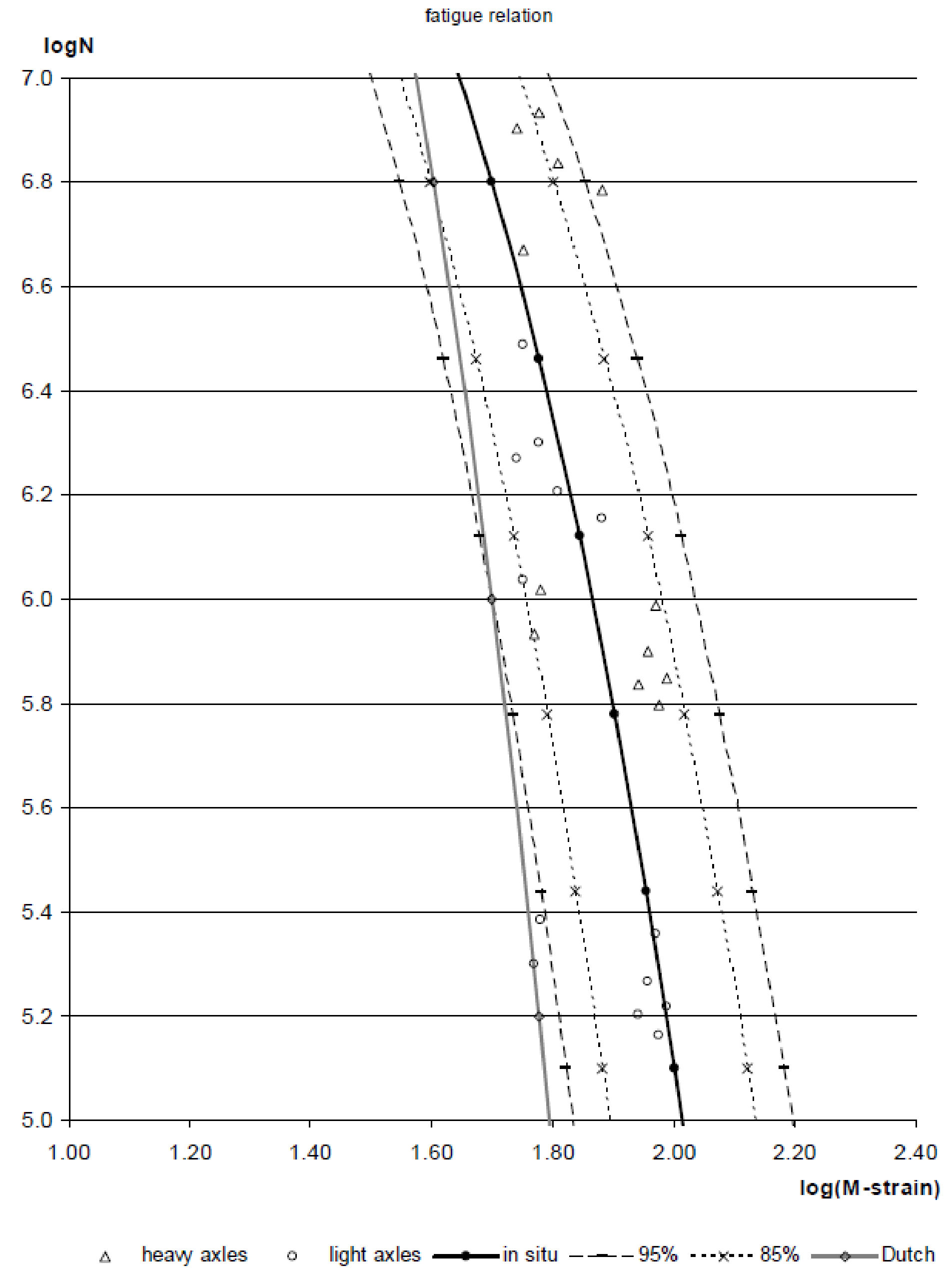


Figure 110: Field fatigue relation for sand cement base courses.

11.3.4 Cement treated granular materials

For granular materials, much lower cement contents are used than for cement treated soils and cement treated sands. The Portland Cement Association gives the following estimates for cement requirements for different soil groups.

AASHO soil group	Usual range in cement requirements [% m/m]
A-1-a	3 – 5
A-1-b	5 – 8
A-2	5 – 9
A-3	7 – 11
A-4	7 – 12
A-5	8 – 13
A-6	9 – 15
A-7	10 – 16

Table 25: Cement requirements in relation to soil group.

The following equations have been proposed to estimate the **stiffness modulus** of these materials.

$Ef = 1435\ \sigma c^{0.885}$

$Ef = 1284\ \sigma c$ for cemented fresh crushed aggregates (South Africa)

$Ef = 1784\ \sigma c$ for cemented natural weathered gravel (South Africa)

In all cases [E] = [MPa] and [σ] = [MPa].

Typical **fatigue** relations that are reported are given below.

For an A-1-a soil treated with 5.5% cement (moisture content 7.5% and a density of 2200 kg / m^3) the following relation was given:

$$\log N = 9.110 - 0.0578\,\varepsilon \quad [\varepsilon] = [\mu m / m]$$

In South Africa the following relationship is used.

$$\log N = 9\,(1 - \varepsilon / \varepsilon t)$$

In both equations:
ε = applied strain level,
εt = strain at break

For fresh crushed rock material the strain at break varies between 100 and 250 µm/m. The mean value was reported to be 160 µm / m. For natural weathered material, the strain at break seems to be dependent on the stiffness modulus following the trend shown below.

E [MPa]	Strain at break [µm / m]
2500	188
5000	141
7500	118
10000	112
15000	106

One should however be aware of the large amount of scatter around the trend line. At a stiffness of 3000 MPa, strain at break values ranging between 120 and 280 μm/m have been reported while at a stiffness of 6000 MPa the range is still between 100 and 200 μm/m. At high stiffness values, the variation in strain at break values is less.

In Australia a fatigue relation was developed for cement treated base courses using the results of accelerated load testing experiments and laboratory testing. The fatigue relation is given below.

$$N = \{(A\,E^{-B} + C) / \varepsilon t\}^{D}$$

Where:
E = stiffness modulus [MPa],
εt = tensile strain at the bottom of the cement treated base [μm / m],
A = 112664
B = 0.804
C = 190.7
D = 12

11.3.5 Cement treated secondary materials

In the Netherlands large amounts of secondary materials have to be recycled. Re-use of these materials in road constructions is very feasible and quite often those materials are cement treated to give them the required mechanical characteristics and to prevent leaching of contaminating material. Given the wide variety in composition of those recycled materials and given the limited amount of research that is done to obtain mechanical characteristics of these materials, it is very difficult to propose guidelines how to estimate values for these characteristics.

A material for which some characteristics are available is **cement treated asphalt rubble**. A typical value for the **compressive strength** of cement treated crushed asphalt rubble is 3.1 MPa. This value is obtained for an asphalt rubble treated with 3.3% cement [m/m] having a density of approximately 1970 kg/ m_3. By means of falling weight deflection measurements **stiffness values** of around 4500 MPa were obtained for a mixture that was subjected to construction traffic. On areas that were not subjected to construction traffic stiffness values of 6000 MPa were obtained.

Stiffness values of 11000 MPa were obtained on beams that were tested in the laboratory using a four point bending test set up. This value was obtained at a temperature of 0 ^{0}C and a load frequency of 30 Hz.

At 20 ^{0}C and 30 Hz a stiffness of 8000 MPa was obtained. Also **fatigue tests** were performed at the same temperatures and using the same loading frequency. The results are presented below.

For 0 ^{0}C and 30 Hz: $\log N = -38.69 - 11.42 \log \varepsilon$

For 20 ^{0}C and 30 Hz: $\log N = -24.95 – 7.72 \log \varepsilon$

In both cases [ε] = [m / m].

11.3.6 Design considerations cement treated base courses

In the previous sections ample attention has been paid to the fatigue characteristics of cement treated materials. Fatigue cracking is however a type of cracking that appears after many load repetitions. In reality transverse shrinkage cracks due to hardening and thermal movements might already develop shortly after the pavement has been constructed. Depending on the load transfer across these cracks, significant traffic induced tensile strains might develop parallel to these cracks resulting in longitudinal cracking. This phenomenon is schematically shown in figure 111.

In [54] some practical design guidelines have been develop to analyze the occurrence of these longitudinal cracks. It was shown that in winter time when the transverse cracks are usually open and the load transfer across the crack is limited, the tensile strain along the transverse crack is about 1.46 times the tensile strain that is calculated for an undamaged area. In summer time when the crack is closed, this multiplication factor amounts 1.2.

Furthermore it was shown that the probability of traffic induced cracking in sand cement bases like the ones used in the Netherlands is very low when the strain level is below 60 μm/m.

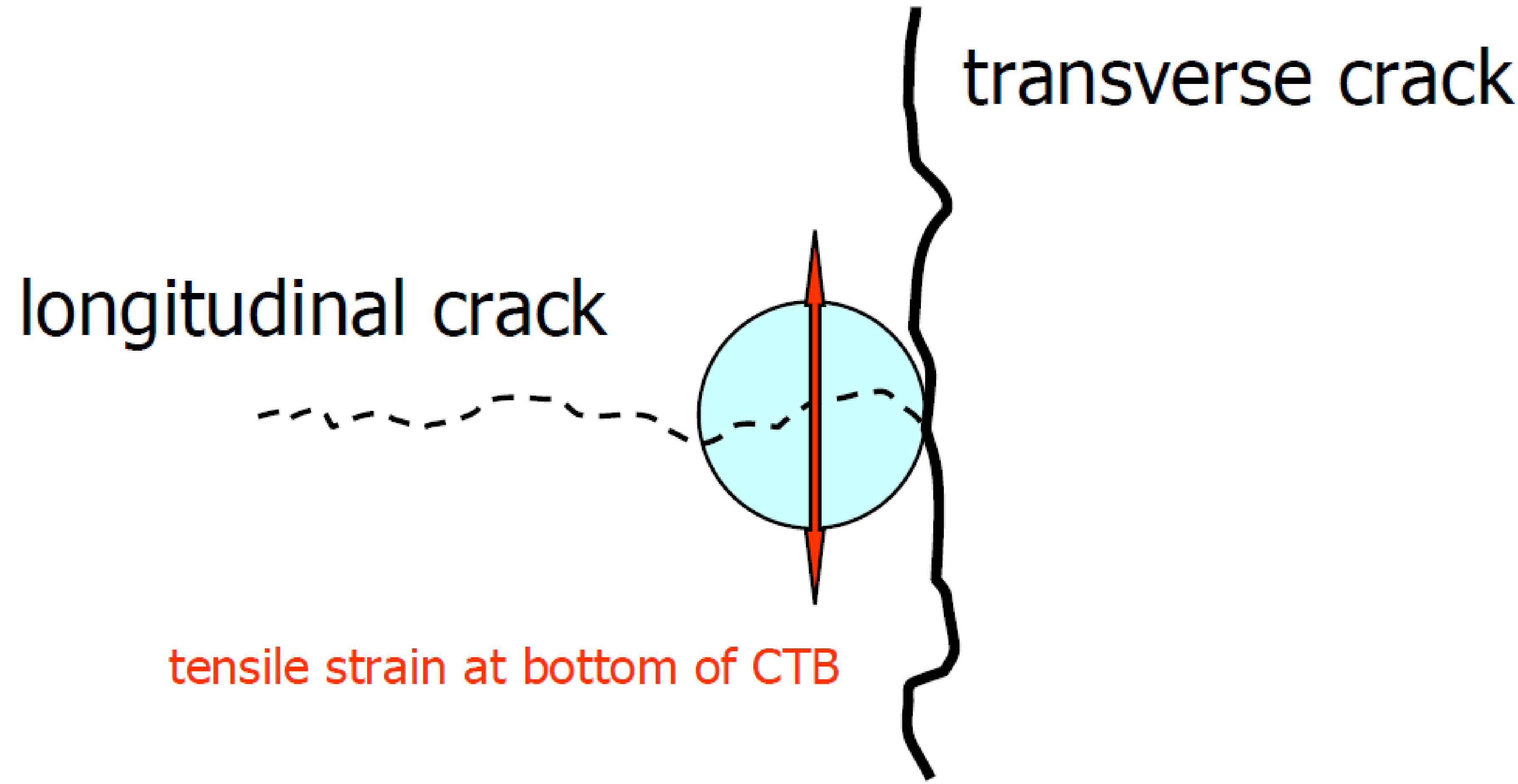


Figure 111: Principle of the development of a longitudinal crack in a cement treated layer near a transverse crack.