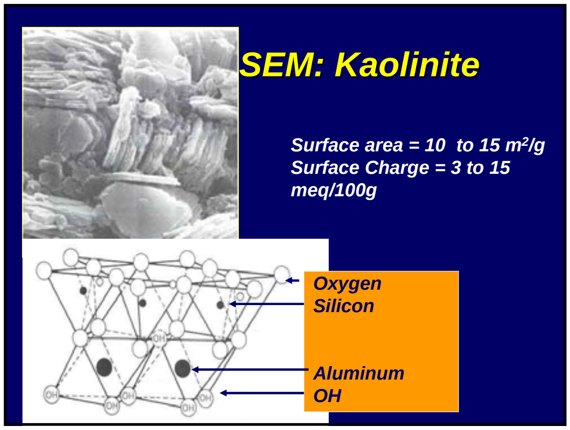
Soil Basics

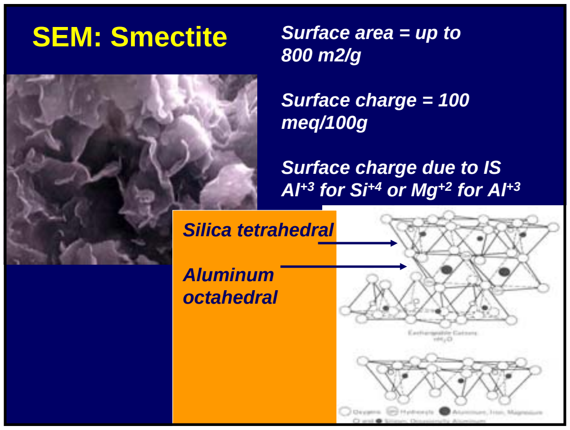


SEM: Kaolinite

Surface area = 10 to 15 m^2/g
Surface Charge = 3 to 15 meq/100g

Oxygen
Silicon

Aluminum
OH



SEM: Smectite

Surface area = up to 800 m2/g

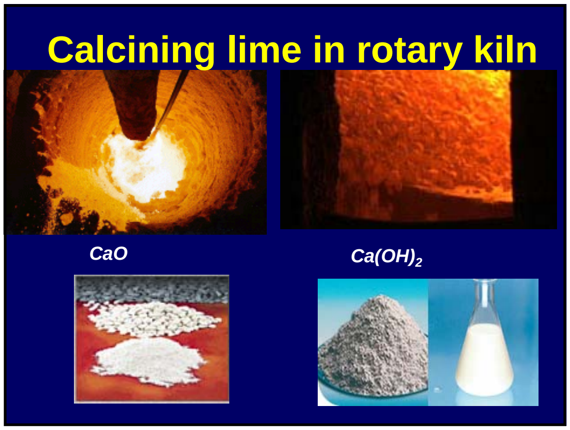
Surface charge = 100 meq/100g

Surface charge due to IS Al^{+3} for Si^{+4} or Mg^{+2} for Al^{+3}

Silica tetrahedral

Aluminum octahedral

Lime Basics



Calcining lime in rotary kiln

CaO

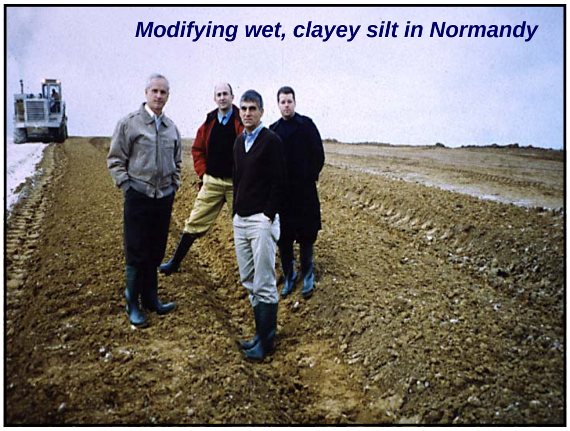
Ca(OH)$_2$

Reactions

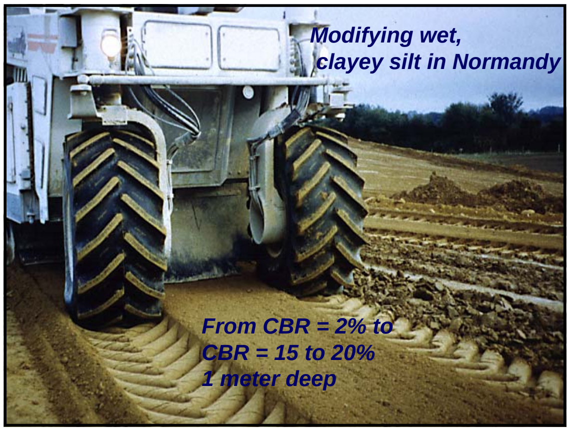
Lime slurry with 38% Solids at Denver International, 1990

Mixing lime slurry (5% CaO) With soils at opt. +5% Long mellowing to Accommodate high SO_4

Denver International Airport 5% wet of opt.

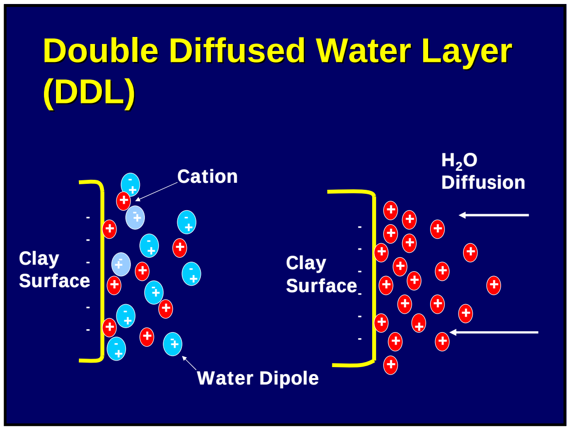


Modifying wet, clayey silt in Normandy

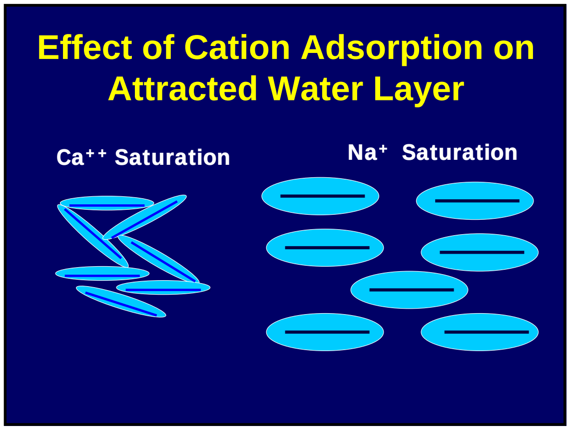


Modifying wet, clayey silt in Normandy

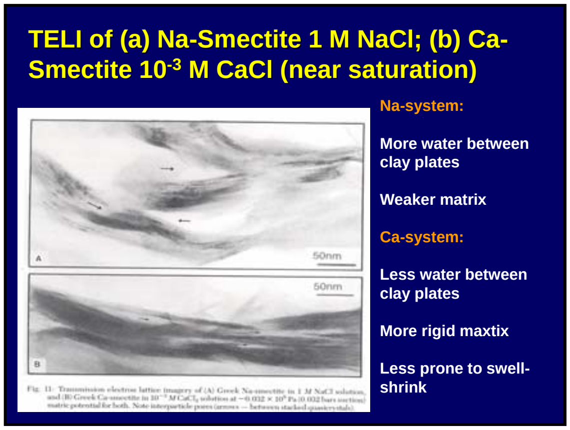
From CBR = 2% to CBR = 15 to 20% 1 meter deep



Double Diffused Water Layer (DDL)



Effect of Cation Adsorption on Attracted Water Layer



TELI of (a) Na-Smectite 1 M NaCl; (b) Ca-Smectite 10^{-3} M CaCl (near saturation)

Fig. 11: Transmission electron lattice imagery of (A) Greek Na-smectite in 1 M NaCl solution, and (B) Greek Ca-smectite in 10^{-3} M $CaCl_2$ solution at -0.032×10^5 Pa (0.032 bars suction) matric potential for both. Note interparticle pores (arrows — between stacked quasicrystals).

Na-system:

More water between clay plates

Weaker matrix

Ca-system:

Less water between clay plates

More rigid maxtix

Less prone to swell-shrink

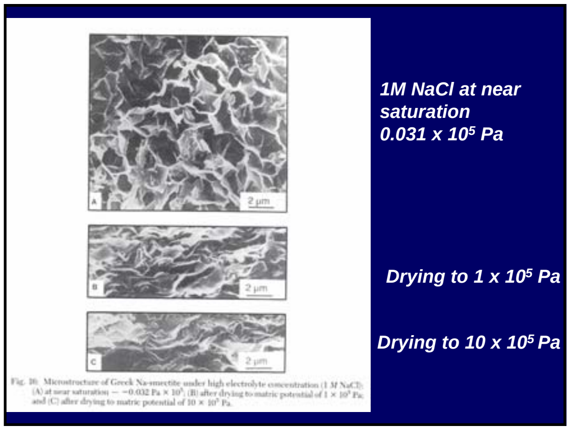


Fig. 10: Microstructure of Greek Na-smectite under high electrolyte concentration (1 M NaCl): (A) at near saturation — -0.032 Pa × 10^5; (B) after drying to matric potential of 1×10^5 Pa; and (C) after drying to matric potential of 10×10^5 Pa.

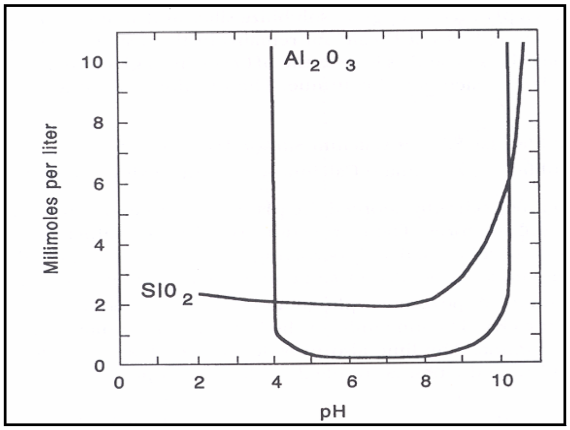
1M NaCl at near saturation
0.031×10^5 Pa

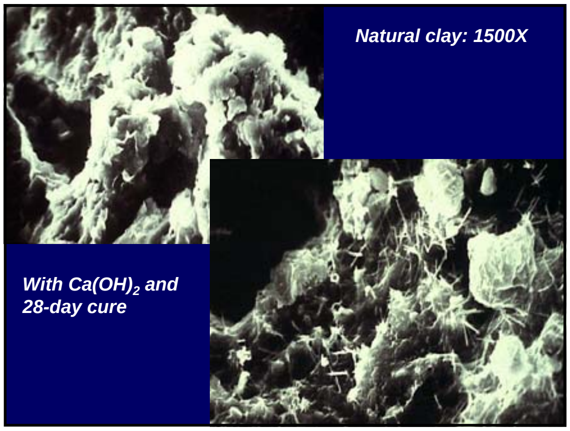
Drying to 1×10^5 Pa

Drying to 10×10^5 Pa

Pozzolanic Reaction

- **High pH (> 12) environment when water added to CaO**
- **SiO_2 and Al_2O_3 become soluble in high pH**
- **$Ca^{++} + SiO_2 + H_2O = CSH$**
- **$Ca^{++} + Al_2O_3 + H_2O = CAH$**





Natural clay: 1500X

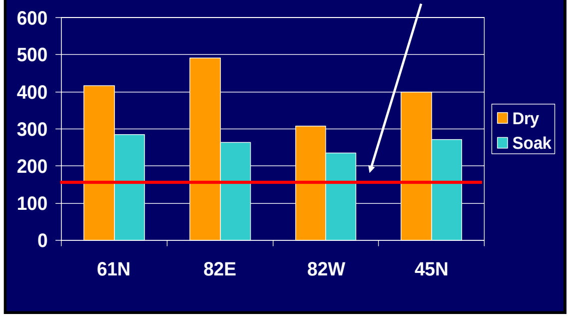
With $Ca(OH)_2$ and 28-day cure

Results

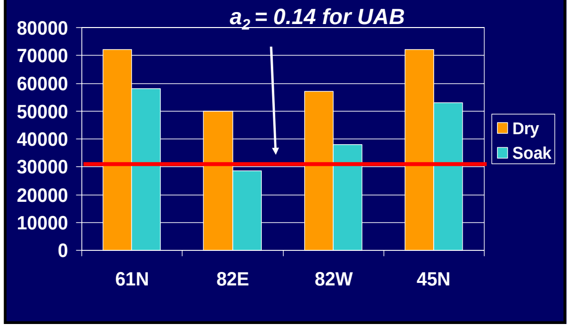
Mississippi Pavements

Highway	HMA (in.)	Yrs of Service
US 45 N	10	17
US 61 N	12	15
US 82W	13	20
US 82E	10	20

UCCS, psi (LSS)



Resilient Modulus, psi (LSS)



Visual Analysis of Soak Testing

Comparative Swell

After 12 hrs. of Capillary Rise

Field Data, DCP

Pavement	CBR, Subgrade (%)	CBR, LTS (%)	Ratio LTS: Subgrade
61N	15	200	33.3
82E	12	150	12.5
82W	4	47	11.8
45N	10	133	13.3

Field Data, FWD

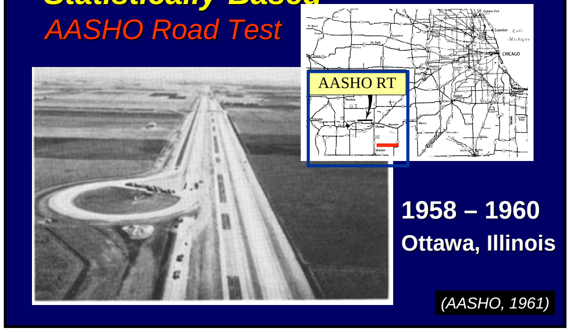
Pavement	Modulus, Subgrade (psi)	Modulus, LTS (psi)	Ratio LTS: Subgrade
61N	13,000	61,000	4.38
82E	17,000	352,000	20.72
82W	17,600	193,000	10.98
45N	17,900	211,000	11.86

Field Data, GPR

Pavement	LTS Thickness	Dielectric Value
61N	150-mm	9 – 13
82E	150-mm	6 – 8
82W	150-mm	7 – 10
45N	250-mm	No Data

The AASHTO Empirical Design Example "Statistically-Based"

AASHO Road Test

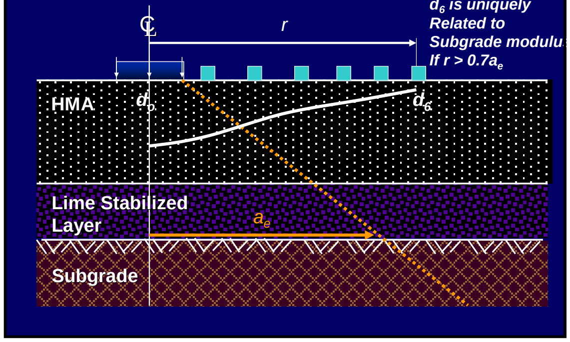


1958 – 1960

Ottawa, Illinois

(AASHO, 1961)

Falling Weight Deflectometer



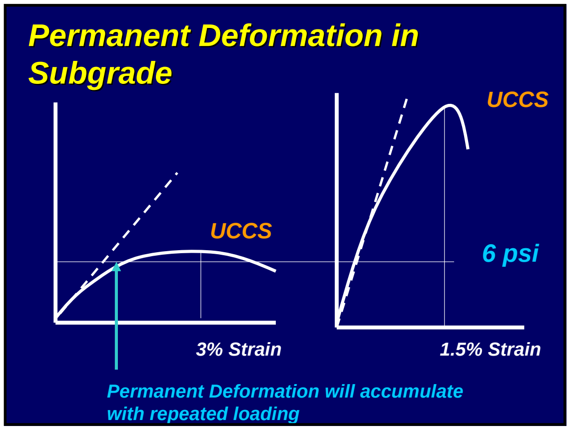
d_6 is uniquely Related to Subgrade modulu

If $r > 0.7a_e$

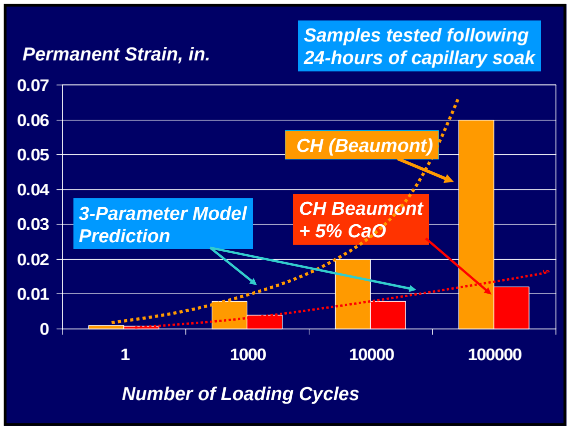
Comparison of Design Values

Pavement	Lab UCCS, psi	Lab M_R, psi	Field CBR, %	Field a_2
US 61N	285	50,000	200	0.13
US 82E	264	28,500	150	0.16
US 82 W	235	38,600	47	0.12
US 45N	271	53,000	133	0.14

Permanent Deformation in Subgrade



Permanent Deformation will accumulate with repeated loading

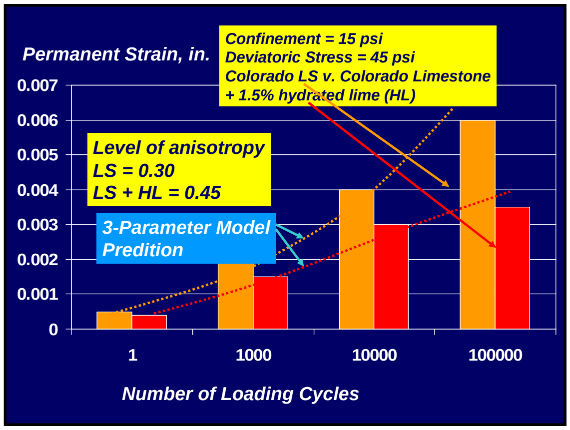


Samples tested following 24-hours of capillary soak

CH (Beaumont)

3-Parameter Model Prediction

CH Beaumont + 5% CaO



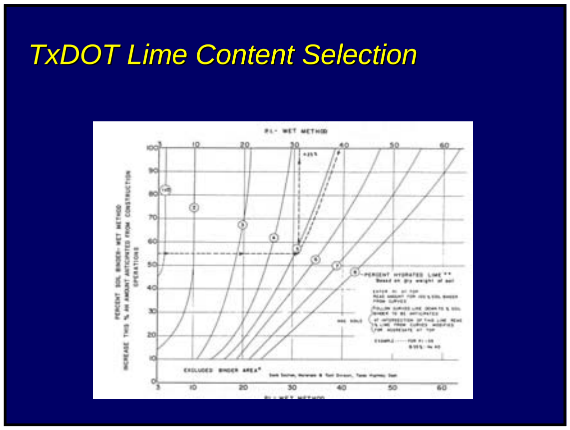
Confinement = 15 psi
Deviatoric Stress = 45 psi
Colorado LS v. Colorado Limestone + 1.5% hydrated lime (HL)

Level of anisotropy
LS = 0.30
LS + HL = 0.45

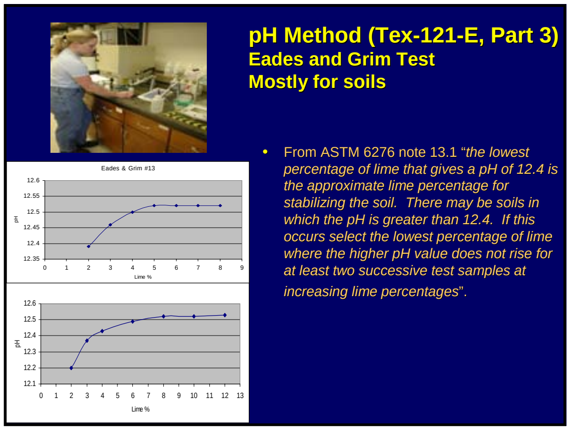
3-Parameter Model Predition

Mix Design

TxDOT Lime Content Selection



pH Method (Tex-121-E, Part 3)
Eades and Grim Test
Mostly for soils



- From ASTM 6276 note 13.1 "*the lowest percentage of lime that gives a pH of 12.4 is the approximate lime percentage for stabilizing the soil. There may be soils in which the pH is greater than 12.4. If this occurs select the lowest percentage of lime where the higher pH value does not rise for at least two successive test samples at increasing lime percentages*".

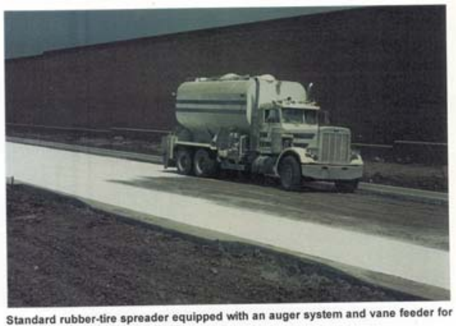
Soil-Lime Mix Design – Tex-121-E Part 1

- Minimum Strength Method
  - Develop M-D relationship in accordance to Tex-113-E
  - Mold 3 specimens (6 by 8") at varying percentages of lime
  - Place in triaxial cell and cure at room temp for 7 days
  - Remove cell, air dry at 140F for 6 hours (or loss 1/3 moisture)
  - Subject sample to capillary for 10 days
  - Determine the average UCS at each lime percent
  - Determine the minimum lime content the desired strength is achieved = Target Lime Content
  - Minimum UCS recommended for base is 150 psi and for subgrade is 50 psi

National Lime Association Procedure (Little, 1998) – Yusuf, Little, & Sarkar, TRR 1757, pp. 22 – 31

- Step 1: Classify and assess suitability for lime stabilization
- Step 2: Perform Eades & Grim pH test (ASTM D 6276) to determine approximate optimum lime content
- Step 3: Determine moisture/density AASHTO T-99, TEX 113A) relationship for lime treated soil and determine strength gain following accelerated cure at approximate optimum lime content
- Step 4: Verify optimum lime content and determine unconfined compressive strength (UCCS – ASTM D 5102) following capillary soaking
- Step 5: Determine resilient modulus (Rapid Test or AASHTO T 307 – 99 at 6 psi deviatoric – **Er-ksi = 0.124 (UCCS-psi) + 10** following capillary soaking
- **Step 6: Tube suction - discontinued**

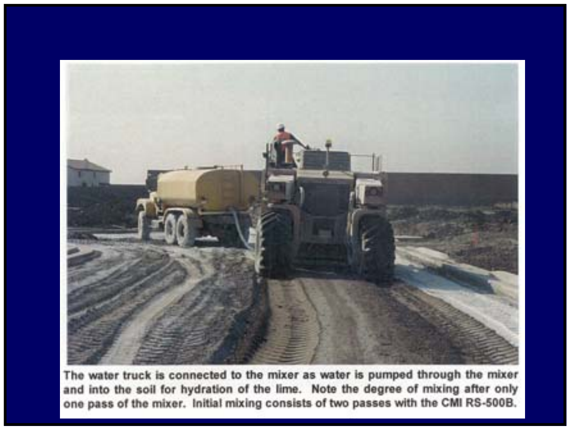
Construction



Standard rubber-tire spreader equipped with an auger system and vane feeder for controlled dry product distribution.

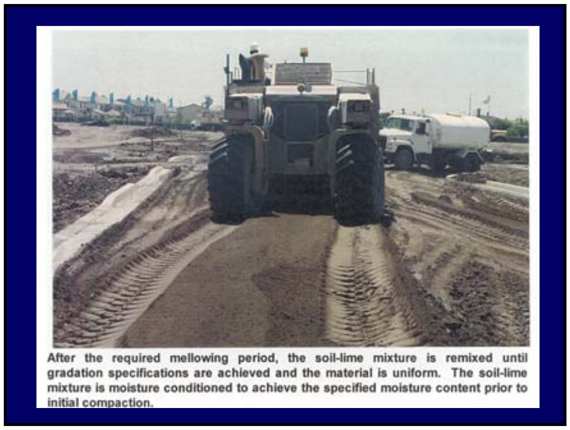
Dry lime is spread with the distribution truck at the engineer's design rate of application.

The CMI RS-500B traveling rotary mixer is capable of uniformly blending lime and soil to a depth of 20 inches. The mixer is designed specifically for soil stabilization and asphalt pulverization. The CMI RS-500B is equipped with an on-board computer that controls the mixing depth and flow of water through the pump system.



The water truck is connected to the mixer as water is pumped through the mixer and into the soil for hydration of the lime. Note the degree of mixing after only one pass of the mixer. Initial mixing consists of two passes with the CMI RS-500B.

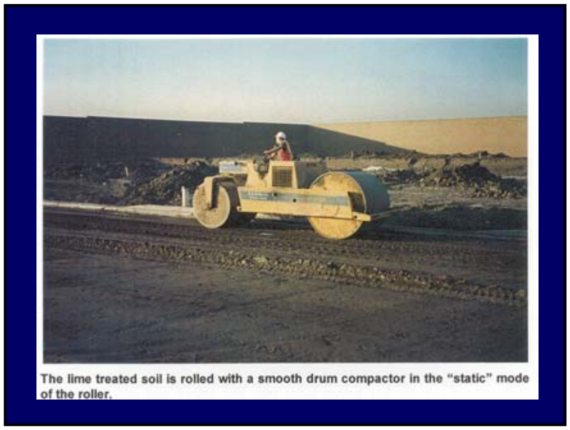
Water is a key ingredient in each stage of the lime stabilization process. Moisture is added to the lime treated soil after initial mixing and the soil is allowed to "mellow" in an uncompacted state overnight to allow for complete hydration of the lime and breakdown of the clay soil.



After the required mellowing period, the soil-lime mixture is remixed until gradation specifications are achieved and the material is uniform. The soil-lime mixture is moisture conditioned to achieve the specified moisture content prior to initial compaction.

Initial compaction is achieved with a Rex self-propelled padfoot compactor. The Rex compactor has the capacity to compact 12 inches of lime treated soil in-place. Typical specifications require 90 to 95 percent relative compaction.

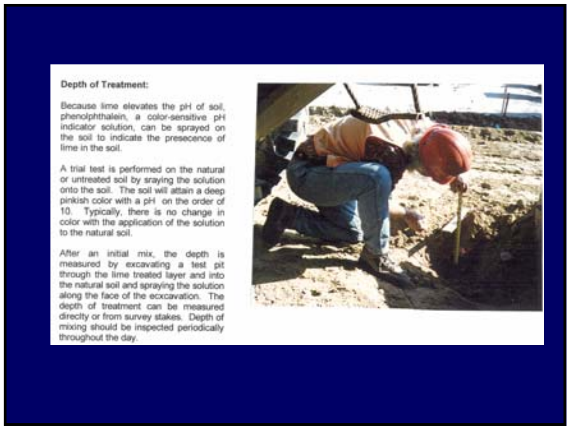
The lime treated soil is then fine graded by the paving or grading contractor to within the paving elevation tolerances.



The lime treated soil is rolled with a smooth drum compactor in the "static" mode of the roller.

The lime treated soil after completion of final compaction with the smooth drum roller.

Engineer's specify curing of the lime treated soil with asphalt emulsion, as seen above, or with periodic water applications - "moist cure" as seen below. Subsequent pavement layers, such as aggregate base or asphalt may now be placed over the lime treated layer.



Depth of Treatment:

Because lime elevates the pH of soil, phenolphthalein, a color-sensitive pH indicator solution, can be sprayed on the soil to indicate the presecence of lime in the soil.

A trial test is performed on the natural or untreated soil by sraying the solution onto the soil. The soil will attain a deep pinkish color with a pH on the order of 10. Typically, there is no change in color with the application of the solution to the natural soil.

After an initial mix, the depth is measured by excavating a test pit through the lime treated layer and into the natural soil and spraying the solution along the face of the ecxcavation. The depth of treatment can be measured direclty or from survey stakes. Depth of mixing should be inspected periodically throughout the day.

Degree of Pulverization:

The phenolpthalein solution is again used to determine the degree of uniformity and pulverization. After final mixing, the solution is sprayed onto the soil-lime mixture and observations of the color changes are made. The prescence of streaks or pockets of lime or non-uniformity of color reaction is considered evidence of inadequate mixing.

Altenatively, the degree of pulverization can be measured using selected sieve sizes. Most specifications are based on the 1 in. and the No. 4 sieve. The processed material is dry sieved to determine the percent passing

Density

Conventional procedures, such as nuclear gage and sand cones are used to determine the in-place density of the compacted treated layer.

When dealing with lime stabilized soil, it critical that the moisture density relations are determined from a field mixed sample of the soil-lime mixture. The moisture density relations generally undergo changes consisting of reduce maximum dry densities and increased optimum moistures. These changes are also time dependent and may change relative to such factors as curing time.

Typically, in-place density is controlled relative to the wet density of the laboratory determined moisture density relation. Because moisture is a critical element in the soil stabilization process, testing by this method allows for relative compaction to be achieved at higher moisture contents.

Moisture

Conventional procedures such as oven dry and nuclear methods are used. Nuclear devices have a tendency to give higher moistures than the in-place moisture. As a result, moistures obtained from nuclear devices should be correlated to oven dry moistures and the device adjusted accordingly.

Hydrated Lime Slurry