

Lime Use For Soil & Base Improvement

*Application
Design
Testing*



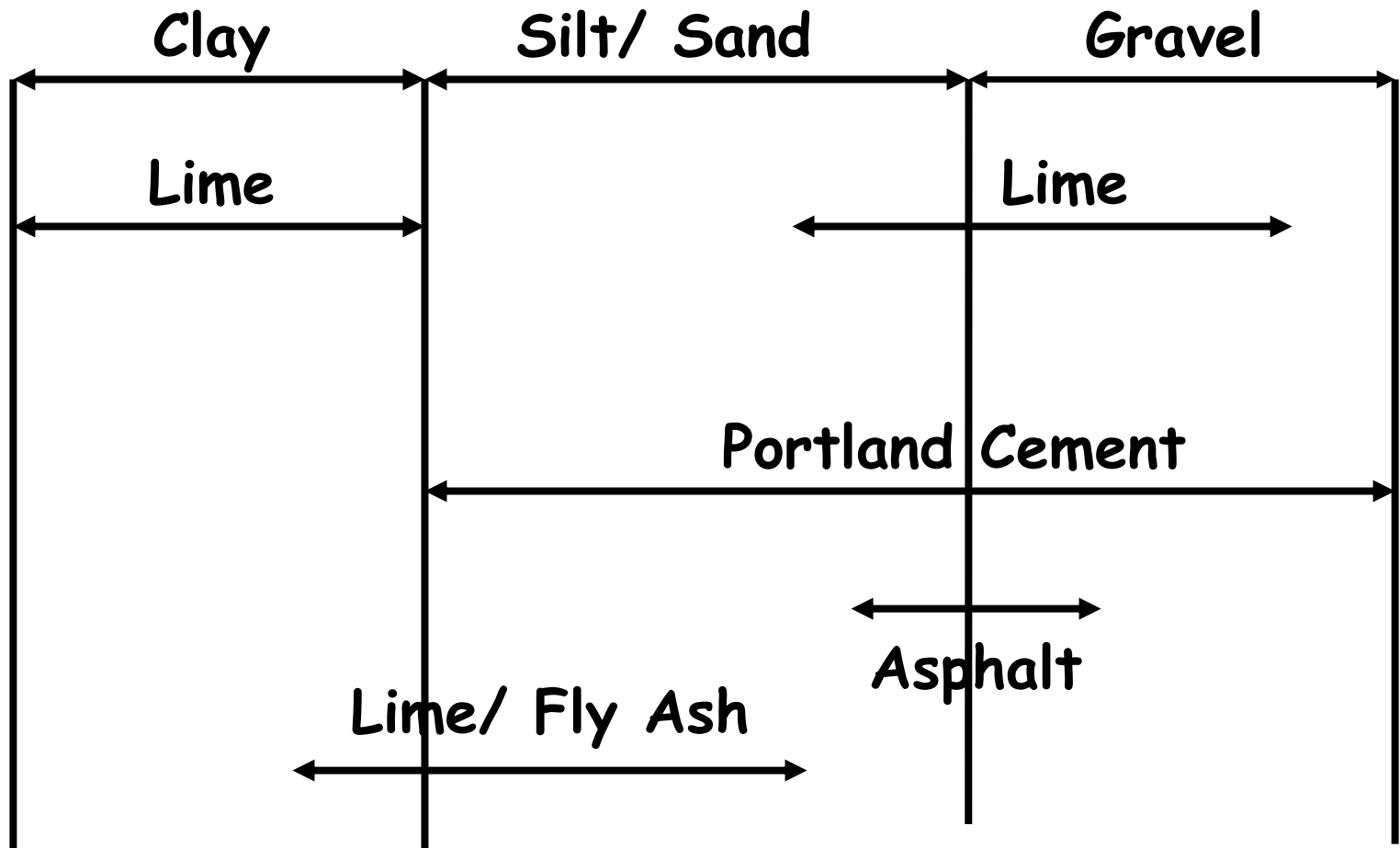
Appian Way

*P3 Symposium
July 19, 2007*

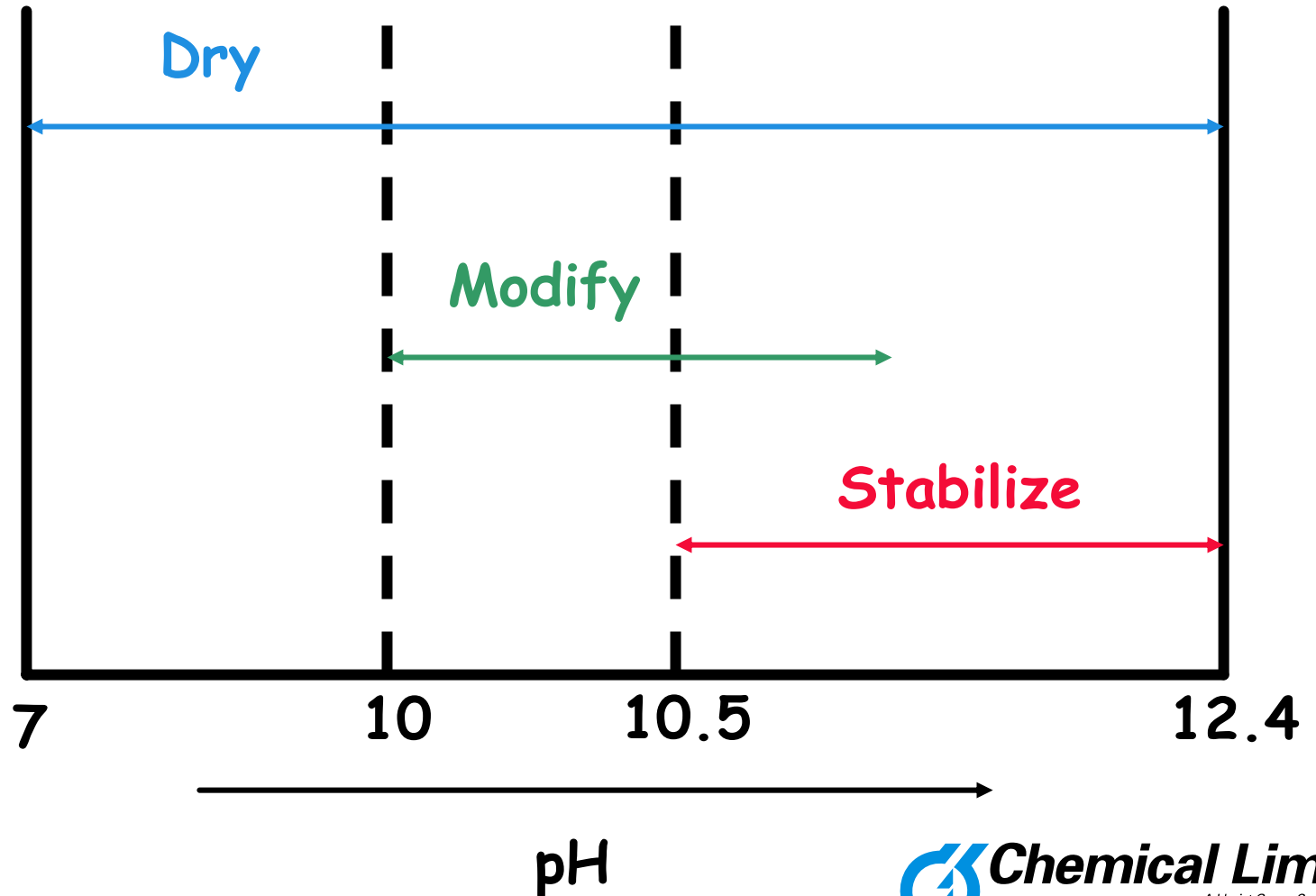
Eric Berger

 **Chemical Lime**
A Lhoist Group Company

Common Additives for Soil Treatment



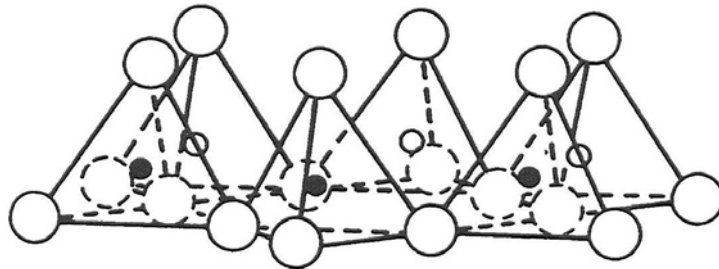
Many Uses of Lime



Clay Soils

- Typically moisture sensitive
 - Expansion potential & swell pressure
- Exhibit poor pavement support
 - Low R-values, CBRs, & unconfined compressive strengths
- Constructibility problems
 - Highly plastic - poor workability
 - Hard to compact
 - Yield or pump when wet

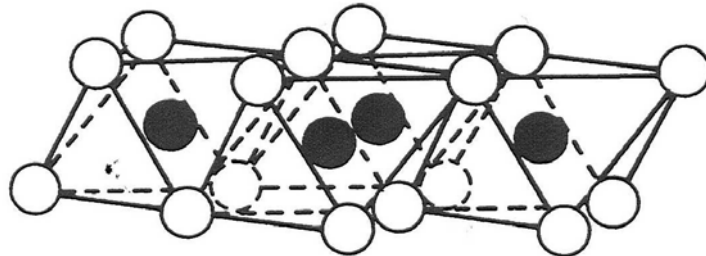
Structure of Clay Minerals (1)



○ and ○
Oxygen

○ and ●
Silicons

(1)



○ and ○
Hydroxyls

●
Aluminum or similar
metallic cation

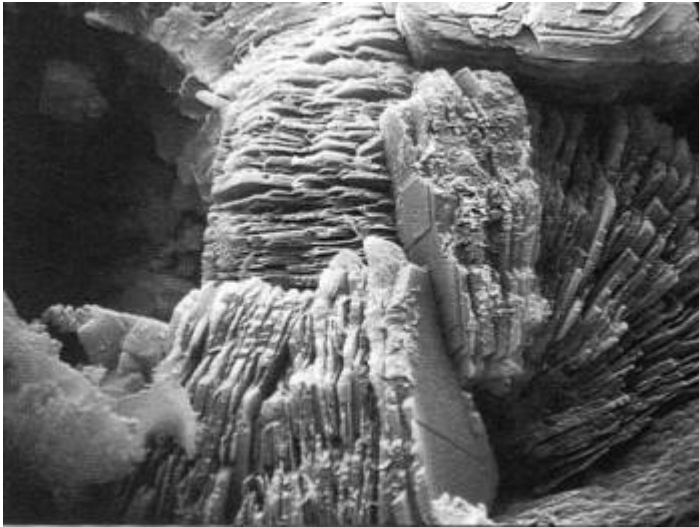
(2)

›Basic units of silicate clay minerals are Silicon tetrahedrons and Aluminum (or Magnesium) octahedrons. Thousands of these basic units are connected to make up tetrahedral sheets (1) and octahedral sheets (2).

›Different combinations of tetrahedral and octahedral sheets are called layers (i.e. Kaolinite: 1:1; Smectite: 2:1).

›In some clays, these layers are separated by interlayers in which water and different adsorbed cations are found

Structure of Clay Minerals (2)



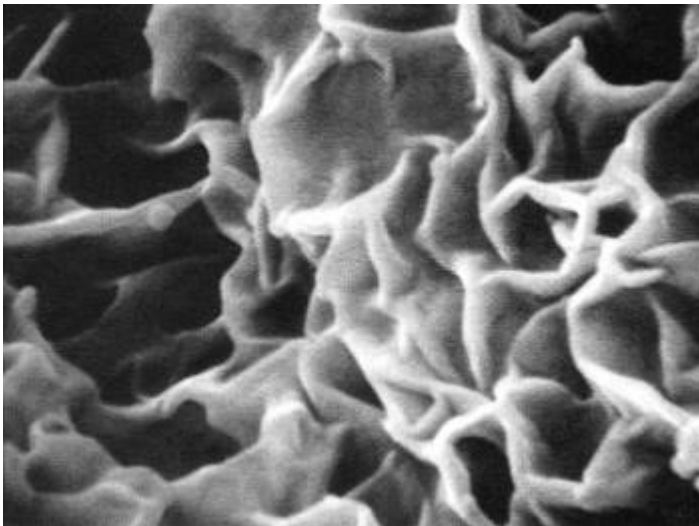
Kaolinite:

Hexagonal crystals

Size: 0.2 - 2 μm

Surface Area: 10 - 30 m^2/g

[Magn: 2000 x]



Montmorillonite:

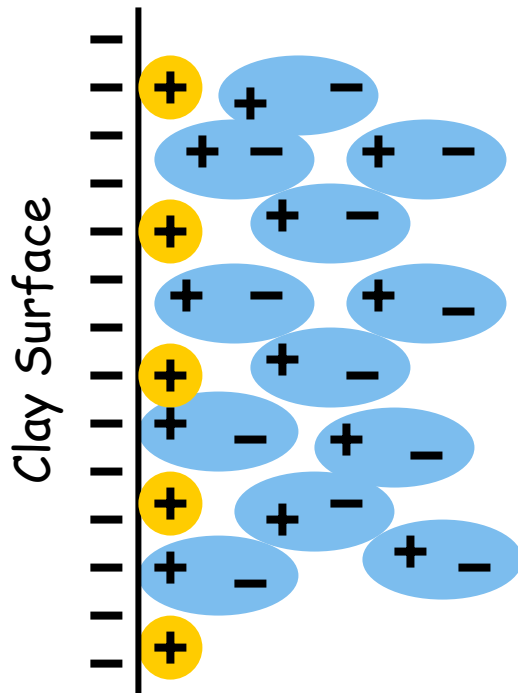
Flakes

Size: 0.01 - 1 μm

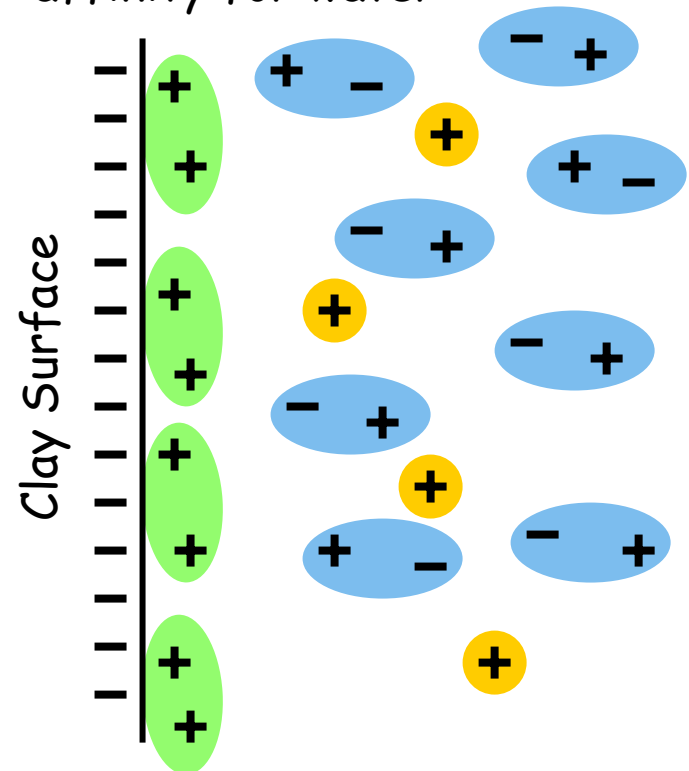
Surface Area: 650 - 800 m^2/g

[Magn: 20000 x]

The System: Clay - Water - Calcium



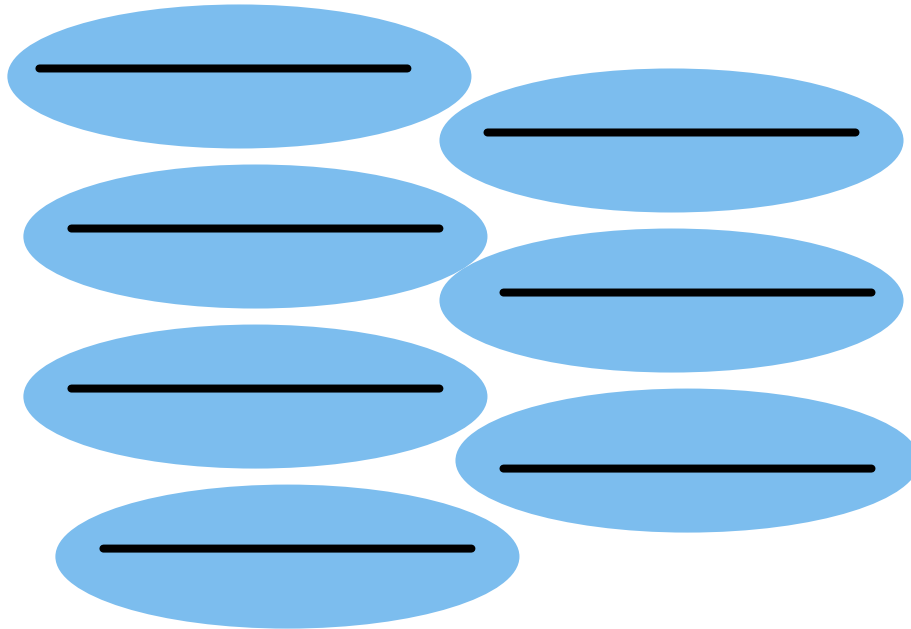
Calcium cations (++) replace weaker bonds reducing clay affinity for water



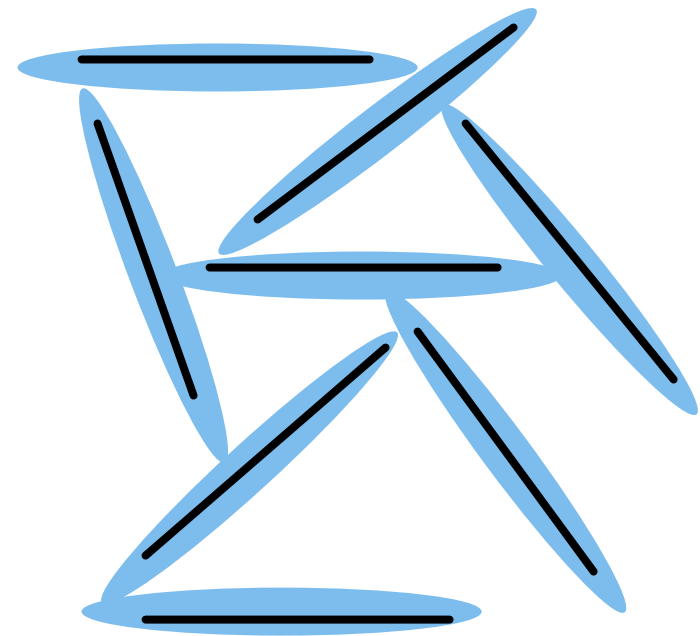
Negatively charged clay surface attracts cations (+) & water molecules (dipole), causing formation of a 'double diffused water layer'

Effect of Cation Adsorption on Attracted Water Layer

Na⁺ Saturation



Ca⁺⁺ Saturation



Lime - Soil Reactions:

Immediate Reactions (within hours)

- **Reduction in Water Content**

chemical reaction ($\text{CaO} + \text{H}_2\text{O} \rightarrow \text{Ca(OH)}_2 + \text{heat}$)* and mixing effect
*: not for Hydrated Lime

- **Flocculation / Agglomeration of Clay particles**

textural change leads to decrease in PI & increase in workability

Medium & Long Term Reaction (days, weeks, months, years)

- **Pozzolanic reaction between lime and clay particles**

Rate of pozzolanic reaction depends on

- amount and type ('stability') of clay minerals
- temperature (increase by $10^\circ\text{C}/50^\circ\text{F}$ doubles speed of reaction)
- high pH (> 12 , "OH⁻") and availability of Ca^{2+} and water

- **Recarbonation of Lime**

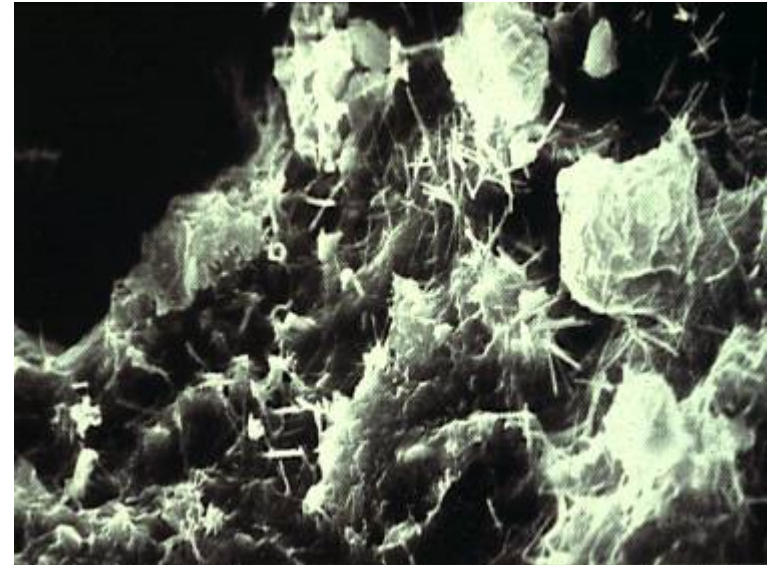
decreases amount of Lime available for pozzolanic reaction

Pozzolanic Reaction (1)

Hydrated lime (Ca(OH)_2 \longrightarrow pH > 12)
+ water (H_2O)
+ Clay (SiO_2 & Al_2O_3 become soluble)
= Cementitious material (CSH & CAH)



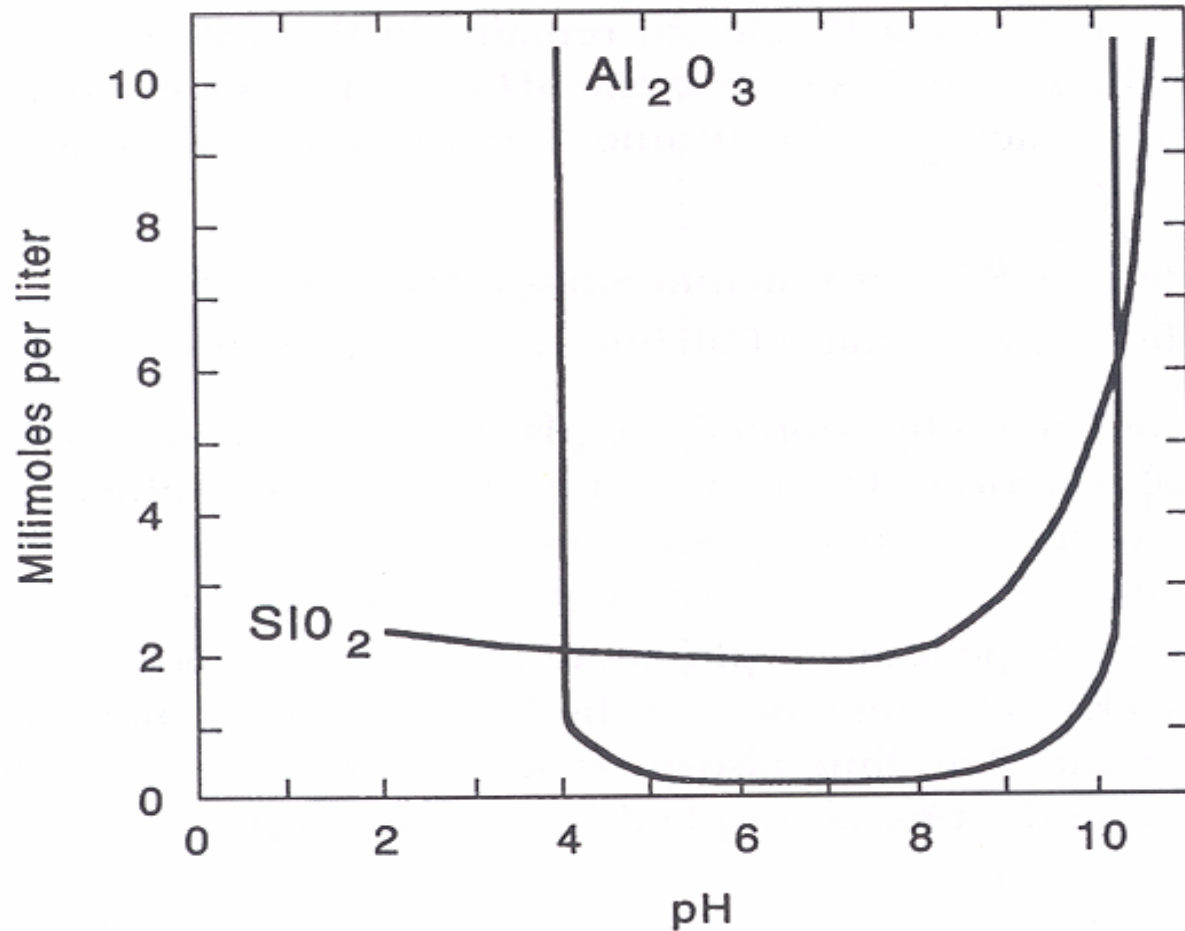
Natural Clay: 1500X



With Ca(OH)_2 & 28 day cure
 **Chemical Lime**
A Lhoist Group Company

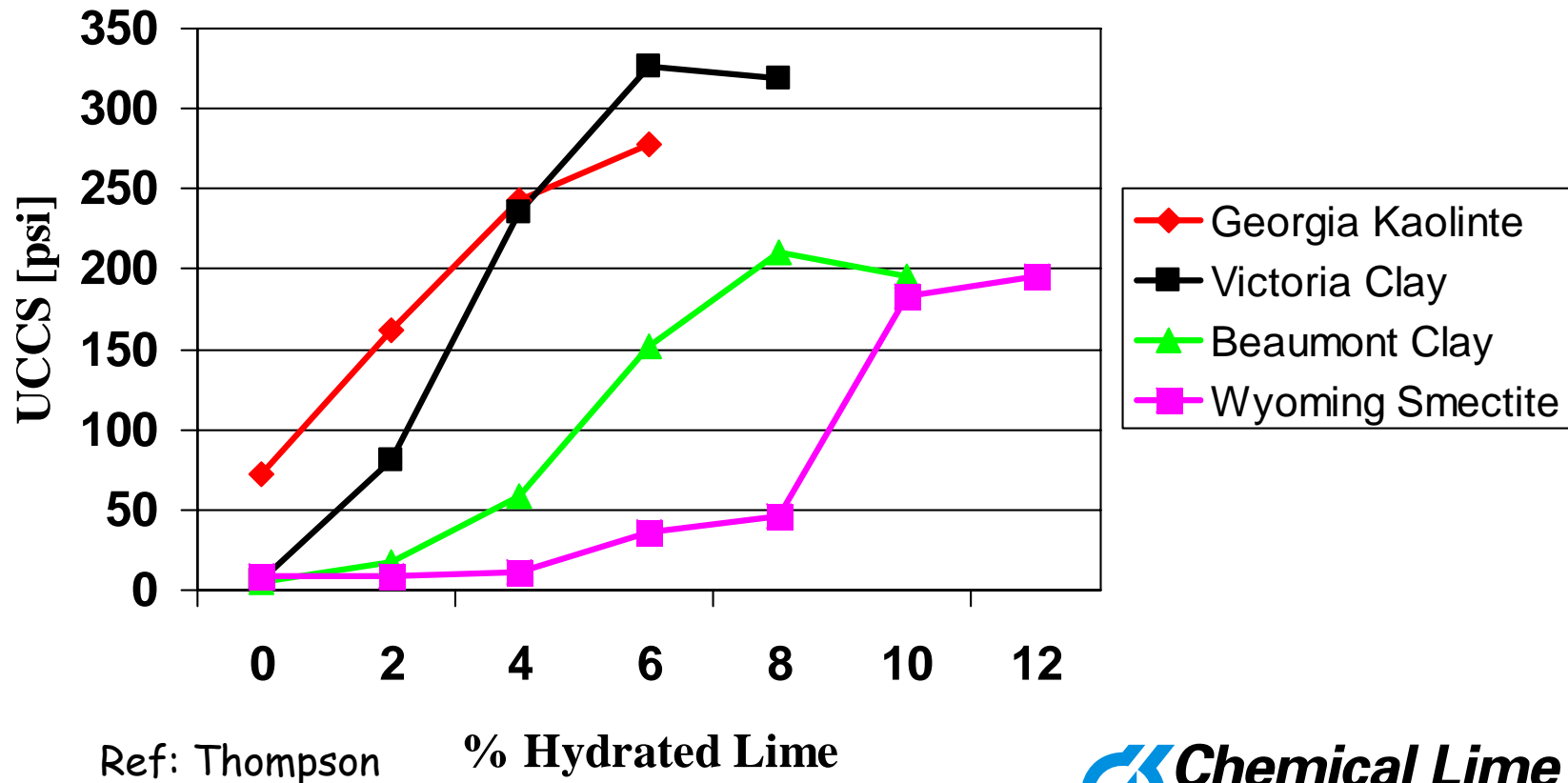
Pozzolanic Reaction (2)

Influence of pH on solubility of Silica and Alumina



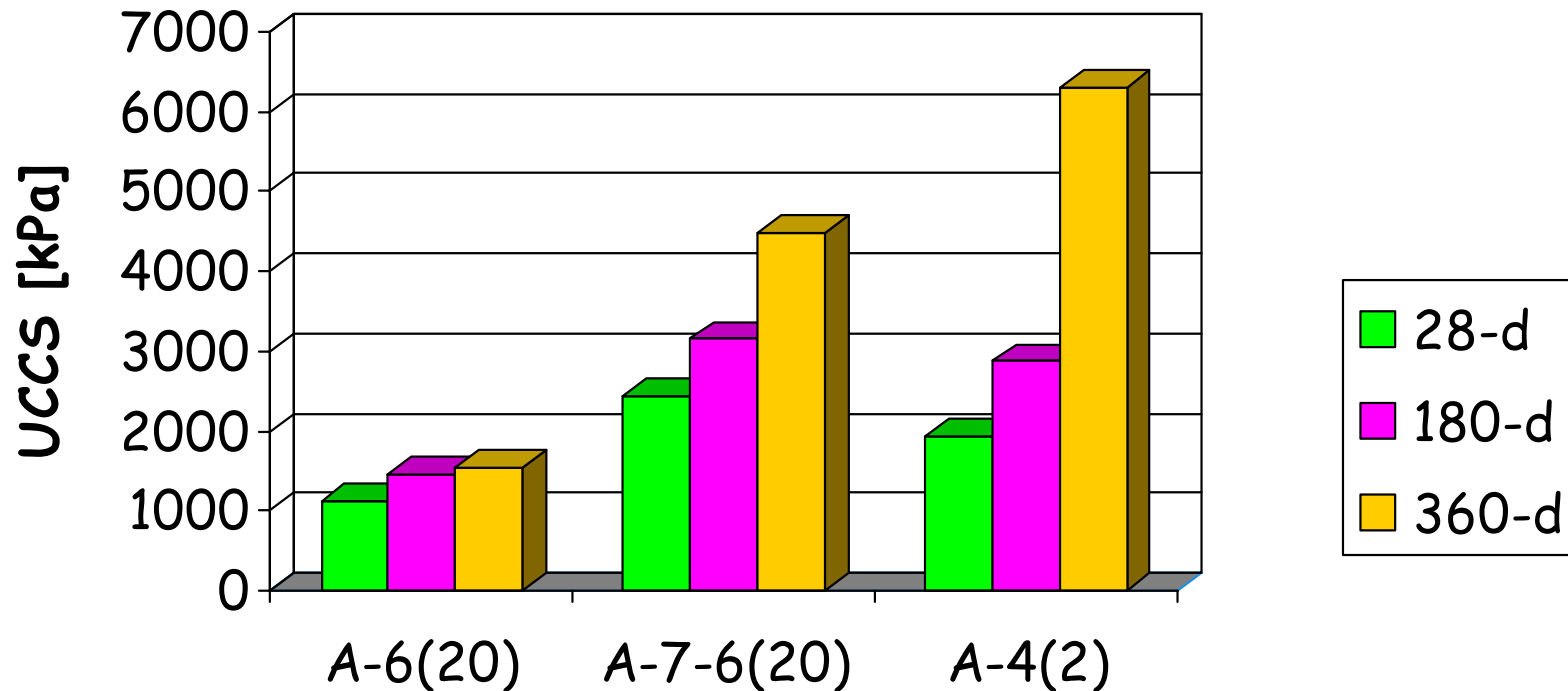
Pozzolanic Reaction (3)

Influence of clay-mineralogy on amount of Lime required to produce the pozzolanic reaction:



Strength Increase with Lime Stabilization

Effect of Curing Time on Strength Development:
(unconfined compressive strength (UCCS) for different California soils)



Ref: Doty

Soil Classification

1 PSI = 6.89 kPa



Case Studies

Mississippi Pavements Study

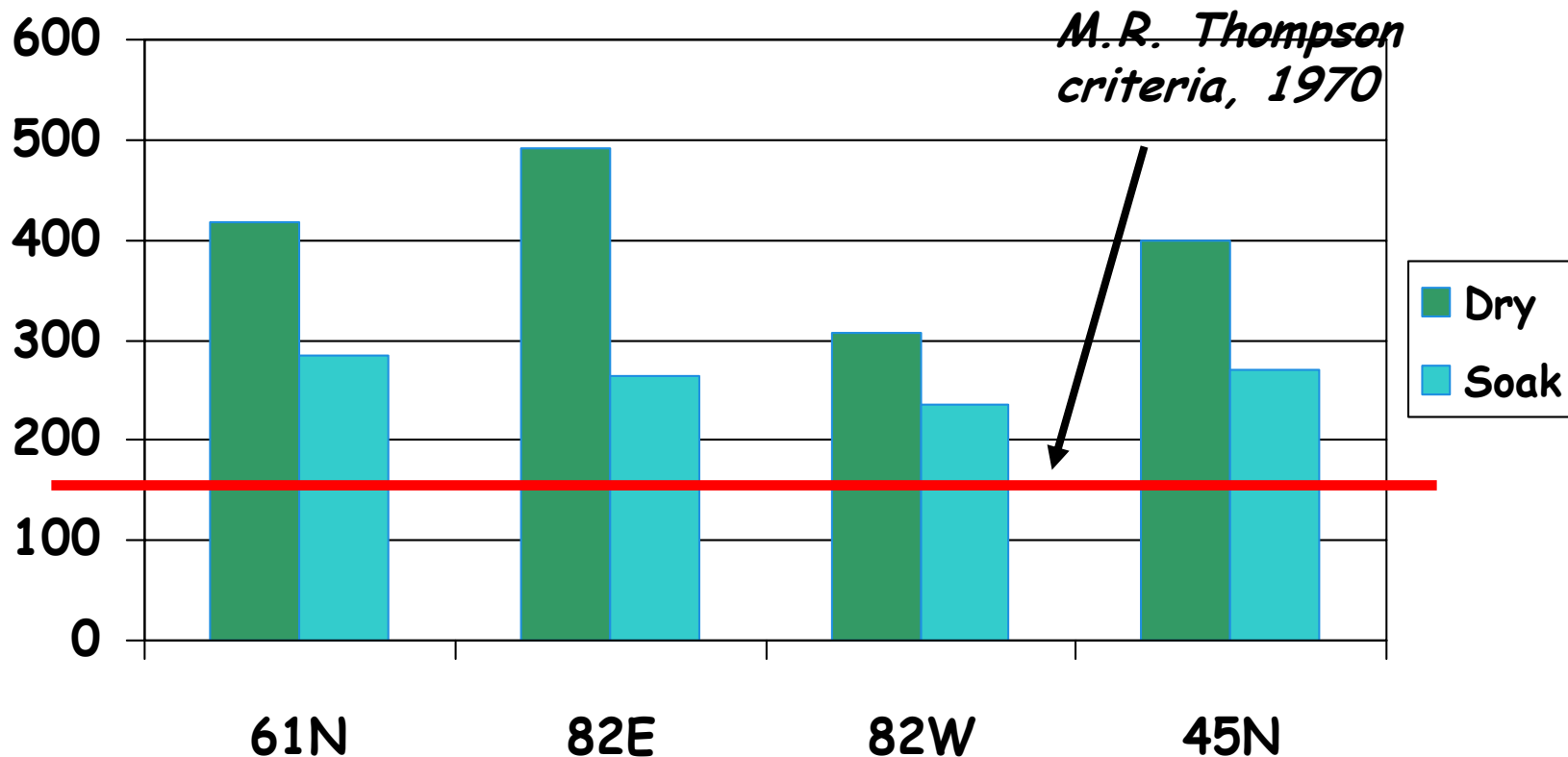
| Highway | HMA (in.) | Yrs of Service |
|---------|-----------|----------------|
| US 45 N | 10 | 17 |
| US 61 N | 12 | 15 |
| US 82W | 13 | 20 |
| US 82E | 10 | 20 |

Comparative Swell



Ref: Little

Unconfined Compressive Strength (psi) Lime Stabilized Soil



Ref: Little

Field Data with 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 |

Ref: Little

Field Data with 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 |

Ref: Little

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 |

Ref: Little

Pavement Design - Added Strength

Benefits:

- A structural value is given to the stabilized subgrade

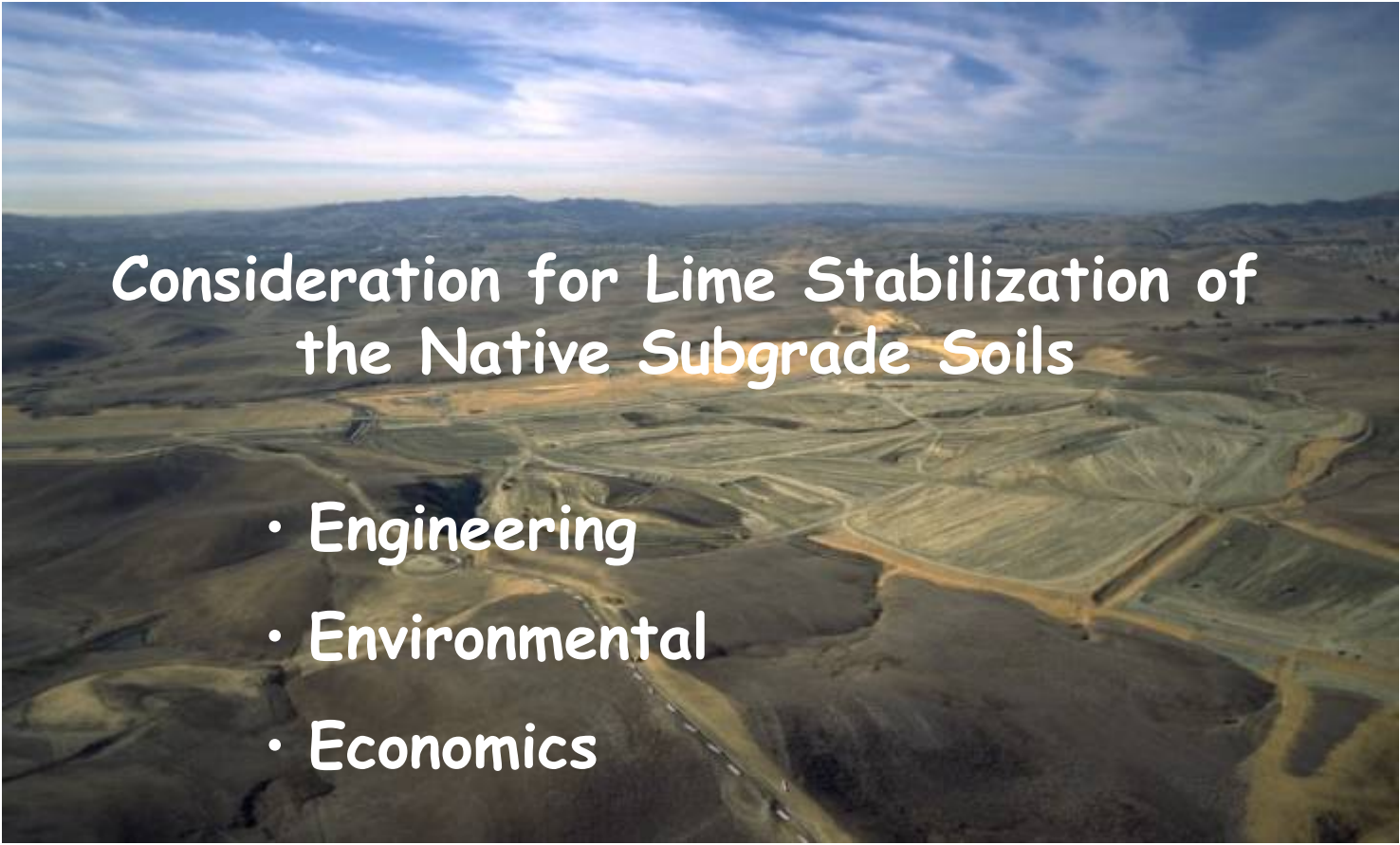
AASHTO Equation:

$$-S_N = a_1 D_1 + a_2 D_2 + a_3 D_3$$

where $a_3 = 0.11 - 0.17$

e.g. Figure 2.8, AASHTO Guide for
Design of Pavement Structures

Dougherty Valley



Consideration for Lime Stabilization of the Native Subgrade Soils

- Engineering
- Environmental
- Economics

Ref: ENGEO, Inc.

Engineering Benefits

- Reduction of shrink/swell potential of the native clay soils
- Increase load bearing capabilities of the subgrade
- Increase of subgrade R-Value from native 5 to treated +70
- Increased longevity of roadway by continued strength gains of the treated soil, creating a permanent pavement foundation

Environmental Benefits

- Reduction in the amount of trucking from approximately 6,000 Truck loads of aggregate base to 2,300.
- Reduction in the amount of wear and tear of existing roadways leading into the site.
- Reduction in the maintenance cost of the existing roadways
- Reduction in further quarry depletions and less air pollution due to trucking requirements

Economic Benefits

- Reduction of the pavement section
- Initial design section for a TI 8 required 4.8 inches of AC, 20.4 inches of AB, over compacted subgrade
- Treated section for a TI 8 required 4.8 inches of AC, 8.4 inches AB, over 15 inches of 4 percent lime treated subgrade soils.
- Total reduction of 12 inches of Class 2 Aggregate Base.
- Reduction in the amount of grading required for roadway construction.
- A schedule savings of up to 30 percent during the winter months.

Tests for Lime Stabilization

Mixture Design & Testing Protocol:

- **Classify Soil & determine Lime Demand**
 - 25 % passing #200 & $PI \geq 10$
 - Organics < 1 %
 - Eades & Grim pH test (ASTM D 6276) to determine Lime demand
 - Establish moisture-density relationship
- **Fabricate, Cure & Soak Samples**
 - mimic field conditions
 - normal curing at 72°F (21°C) for 28 days; accelerated curing at 120°F (49°C) for 48 hours
 - critical for freeze-thaw zones: time to first winter
- **Determine Strength & Stiffness**
 - Unconfined Compressive Strength (ASTM D 5102)

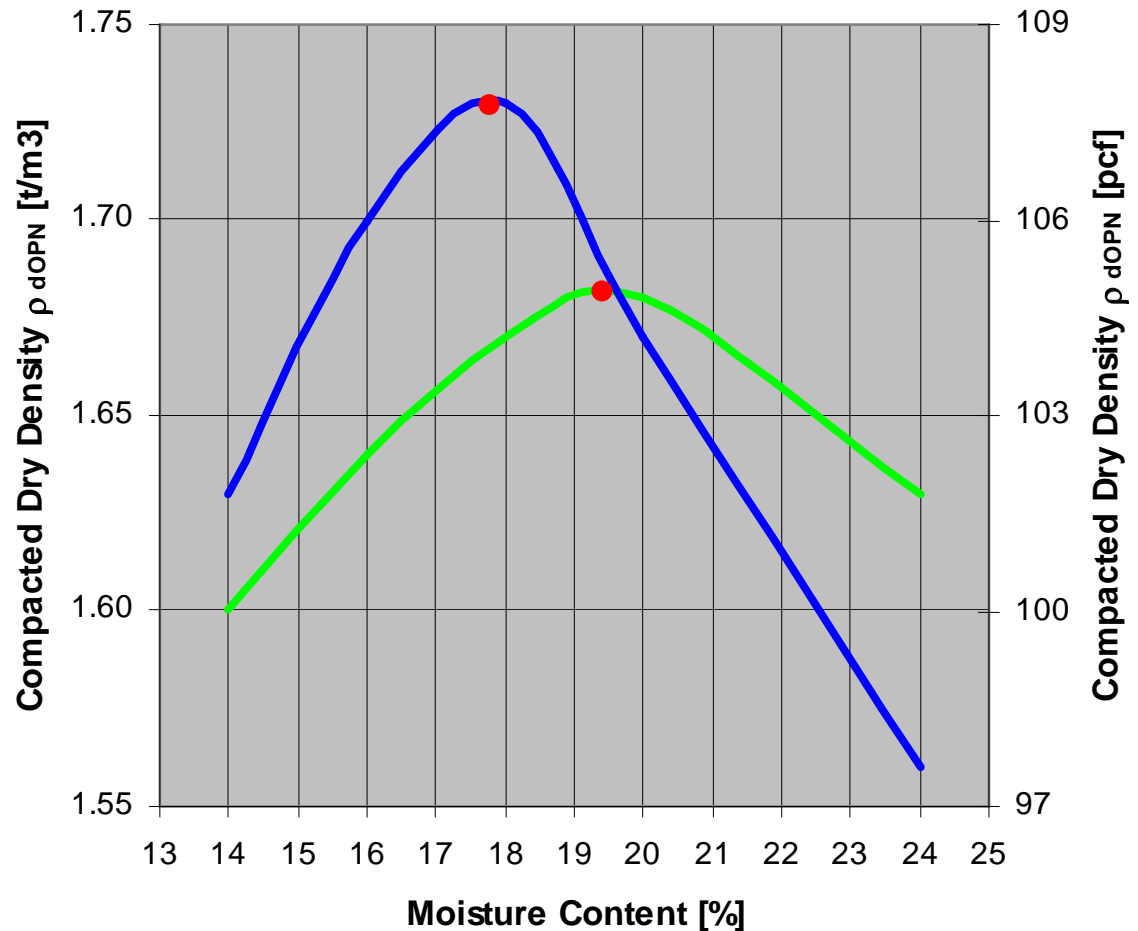
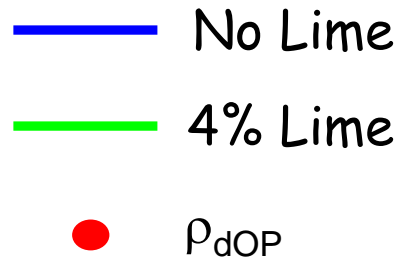
Rapid Change in Soil Texture



Native Clay

Lime Treated Clay

Influence on Moisture-Density Relation:



Lime treated Soil:

- Lower ρ_{dOP} at high moisture contents
- Proctor-Curve gets "flatter"

Aggregate Base Modification

Why Modify Aggregate Base Material?

Improves engineering properties of marginal or unstable aggregates

Enhances performance of aggregate as a structural material in pavements

Increases source utilization and improves economics of aggregate operation

Aggregate Base Modification

- Plasticity or excess fines of treated aggregate are reduced to non-plastic or “acceptable” level
- Clay content is stabilized and particle size increased to become important, marketable part of aggregate
- Strength is gained through pozzolanic reactivity or particle cementation (particularly notable in caliches)
- Production life of pits and quarries can be extended for years by better utilization of marginal materials

Aggregate Modification Testing

- Amount of lime will vary by the amount of clay or fines in the material and their plasticity
- Obtain a representative sample of the material to be modified
- Identify material problems
 - Recommended tests: Plasticity Index, Sand Equivalent
- Determine quantity of lime needed to reduce plasticity/ increase particle size of fine fraction
 - Eades Grim pH Test
 - 1-2% commonly needed

Modify Aggregate Plant

- Simple process - components often on hand
- Silo and vane feeder to apply lime to belt
 - 1-2% commonly needed - quicklime, hydrate, slurry
- Water spray to hydrate lime so that it reacts with clay or other fines
- Pug mill or belt plows to mix lime and aggregate insuring complete reaction

Benefits of Soil Stabilization

- Eliminates excavation & export costs
- Provides a stable & impermeable layer below base or paving section
- Expansion or swell is decreased & foundation support is increased
- A structural value can be assigned to stabilized subgrade: $a_3 = 0.11 - 0.17$
- Long term strength & performance is achieved

National Lime Association Publications

- Available for download from: www.lime.org
 - Lime Stabilization & Mechanistic-Empirical Pavement Design - Mallela, et al
 - Mixture Design & Testing Procedures for Lime Stabilized Soil
 - Lime-Treated Soil Construction Manual: Lime Stabilization & Lime Modification
 - Evaluation of Structural Properties of Lime Stabilized Soils & Aggregates - Little
 - Volume I - Structural Performance of Lime Stabilized Layers
 - Volume III - Mixture Design