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26-27 September 2019

EFFECTS OF SOIL PULVERIZATION LEVEL ON LIME STABILIZED CLAYS: IMPLICATIONS ON PAVEMENT DESIGN AND PERFORMANCE

Prof. İlknur BOZBEY



İSTANBUL ÜNİVERSİTESİ
C | E | R | R | A | H | P | A | Ş | A

OUTLINE OF THE PRESENTATION

Lime stabilization in pavements

Lime stabilization basics

My research on lime stabilization

My personal relationship with lime

LIME STABILIZATION IN PAVEMENTS

Expansive clays have always presented problems for lightly loaded structures, for example pavements

Without stabilization, they will consolidate under loads and change volumetrically during seasonal variations

Lime is one of the oldest additives to stabilize these soils



(Sawangsurinya et al, 2011)

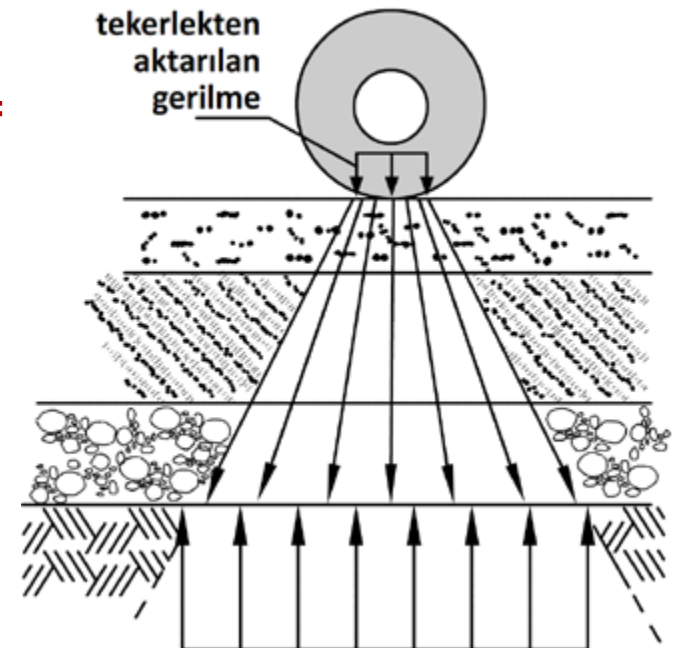


(Sebesta, 2005)

LIME STABILIZATION IN PAVEMENTS

Lime stabilization

- increases mechanical properties of reactive soils
- reduces thickness requirements
- reduces use of imported aggregates and
- increases savings associated with delays in rehabilitation costs



WHEN DO WE PREFER LIME STABILIZATION?

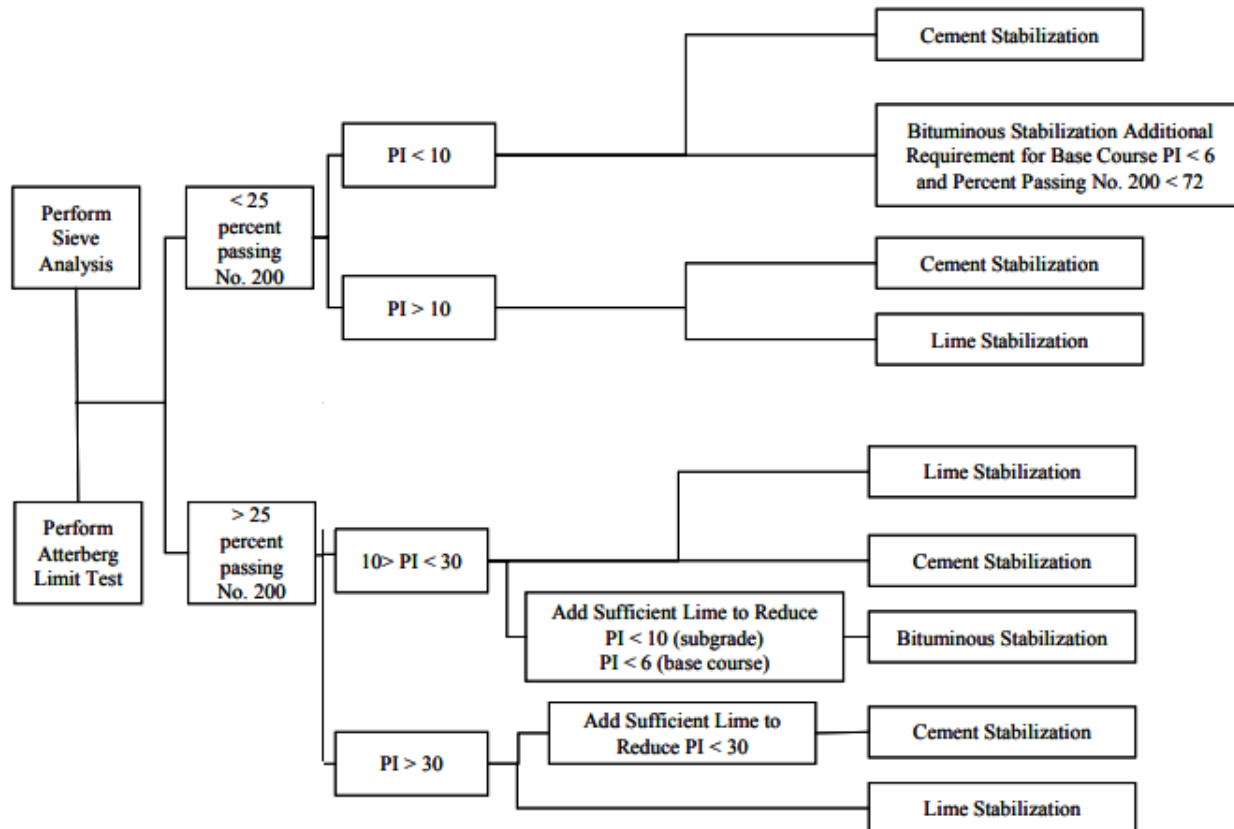


Figure 12. Determination of appropriate stabilizer type based on minus No. 200 content and plasticity index (after Currin et al., 1976).

HOW DOES LIME WORK?

Lime modification (short)

chemical alterations at the clay particles surface which decrease the volume change potential of the clay minerals

Lime stabilization (long term)

pozzolanic reactions btw lime and clay

is experienced more slowly, can progress over months and even years

Principles underlying lime-clay reactions

SHORT TERM/RAPID

Cation Exchange

Flocculation-aggregation

produce immediate improvements in

**soil plasticity,
workability,
uncured strength and
load deformation properties**

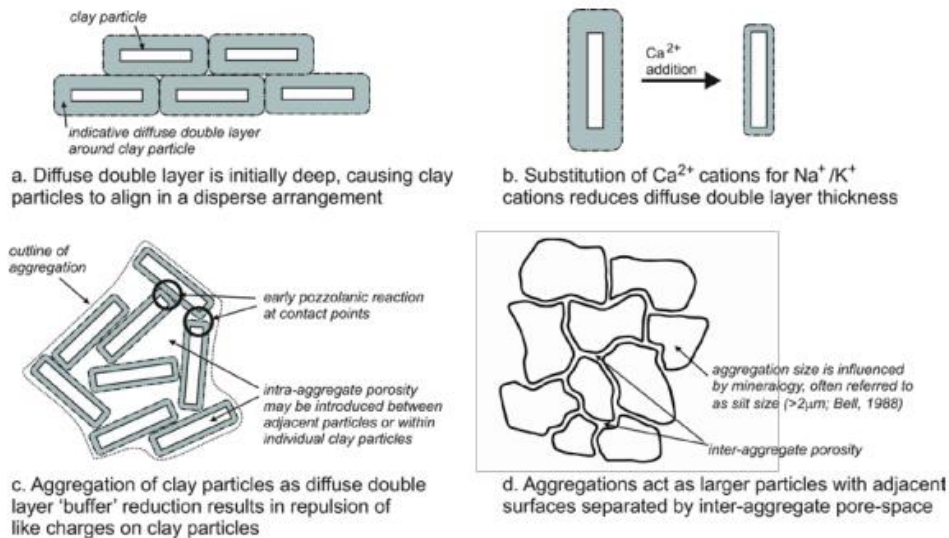
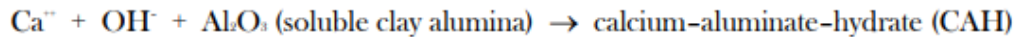
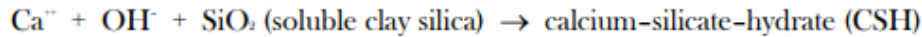
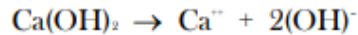


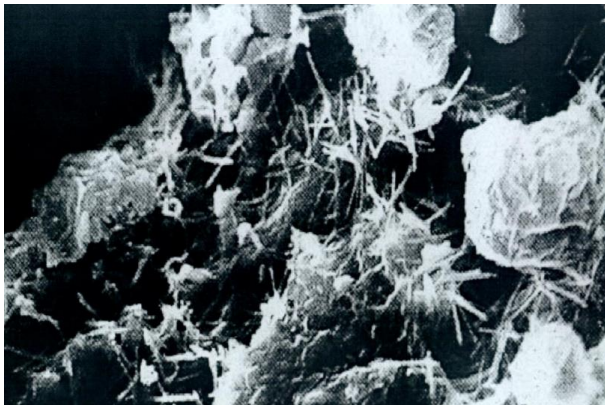
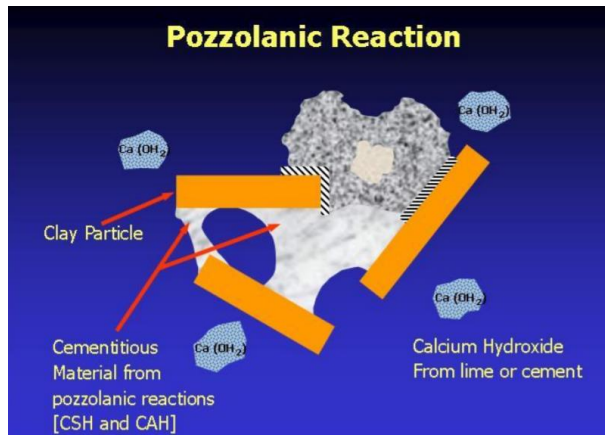
Figure 1 Sequence illustrating influence of early lime-clay reactions upon clay particle arrangements and soil structure

Principles underlying lime-clay reactions



LONG TERM

Pozzolanic reactions



Transportation of calcium hydroxide via water within the soil to combine with the alumina and/or silica in the clay minerals

Increase in strength, stiffness, durability

<http://www.dot.state.oh.us>

Issues for critical or key performance in pavements?

The material properties and characteristics of lime stabilized pavement layers can be divided into four categories;

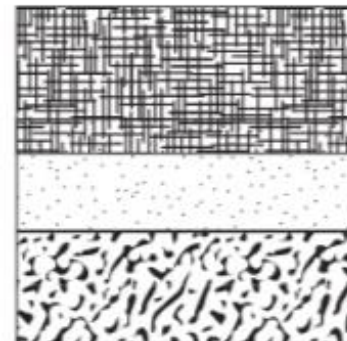
Strength and permanent deformation

Resilient properties

Fracture and fatigue

Durability

Subgrade stabilisation



Proposed pavement

Stabilised subgrade

in situ subgrade

Different protocols exist for laboratory testing



Procedures developed by Dr. Dallas Little, Texas A&M University

www.dot.state.oh.us

www.lime.org

Different protocols exist for laboratory testing

Laboratory Evaluations for Lime Stabilization

1. pH Determination for Minimum Lime Content:

- ASTM D 6276 (Eads – Grim Test)
- Min amount of lime to raise soil pH level to 12.4

2. Optimum Moisture Content

- ASTM D 698 (Standard Proctor Density)
- Generally increases with lime or LFA

3. Unconfined Compressive Strength

- ASTM D 5102
- Minimum of 100 psi
- Freeze-thaw durability

<http://www.dot.state.oh.us>

CONSTRUCTION OVERVIEW FOR LIME STABILIZATION

Basic steps for the field construction include the following steps

- scarifying or pulverizing soil,
- spreading lime,
- adding water and mixing,
- compacting and
- curing

CONSTRUCTION OVERVIEW FOR LIME STABILIZATION



CONSTRUCTION OVERVIEW FOR LIME STABILIZATION

Field and laboratory procedures differ and this may result in differences in the output, where the outputs are the lime stabilized soil properties.

Effects of different compaction types, effects of curing temperatures, etc..

One of the main differences that can occur between laboratory and field is soil pulverization level

CONSTRUCTION OVERVIEW FOR LIME STABILIZATION



Soil pulverization is a reduction process where the clay clods and bigger soil particles are pounded and ground into a range of finer particles, while the parent material properties remain the same.

ME AND LIME

I started studying with lime in my graduate studies and studied in the laboratory and in the field with lime. This was between 1996 and 2002.

After then I gave a long break for other more 'attractive' and 'trending' subjects.

But in 2007, I returned back to studying with lime and since then it has been one of my main research areas again.

So, my relationship with lime has had ups and downs, and I find this very normal because that is how the relationships are even if it is your relationship with your research topic.

RESEARCH OUTLINE

Garaisayev, 2007-2008

Sarikahya, 2009-2012

Muhammed Ibrahim, 2010-2012

Turkish General Directorate of Highways Project,
2013-2016

Turkish General Directorate of Highways, 2019-2021
on Deep Mixing

Review of Stabilization of Clays and Expansive Soils in Pavements and Lightly Loaded Structures—History, Practice, and Future

Thomas M. Petry, P.E., F.ASCE¹, and Dallas N. Little, P.E., F.ASCE²

Abstract: Expansive clay soils—those that change significantly in volume with changes in water content—are the cause of distortions to structures that cost taxpayers several billion dollars annually in the United States. Much has been learned about their behavior over the past 60 years, and relatively successful methods have been developed to modify and stabilize them. This paper reviews some of the key advances developed over the past 60 years in improving our understanding of the nature and methods of modifying and stabilizing expansive clay soils. The state of the practice in stabilization is presented, and practical and research needs to help improve the state of the practice are discussed.

DOI: 10.1061/(ASCE)0899-1561(2002)14:6(447)

CE Database keywords: Stabilization; Clays; Expansive soils; Earth structures; Distortion.

Two construction factors have strongly affected the quality of chemical stabilization: moisture and degree of pulverization. First, subgrades are rarely prewetted but are brought to the required water content during construction; often they are worked dry of optimum, resulting in incomplete chemical reactions due to lack of water. Second, the degree of pulverization is often substandard. Lime must react intimately with particles to enact the pozzolanic process; the larger the soil particles, the longer that process will take.

Sanan Garaisayev, 2007-2008

Literature in 2007

Only a couple of papers

Felt, 1964

Grimer and Ross, 1957

Petry and Wohlegemuth, 1988

Laboratory testing is generally carried out with –No.4 sieve

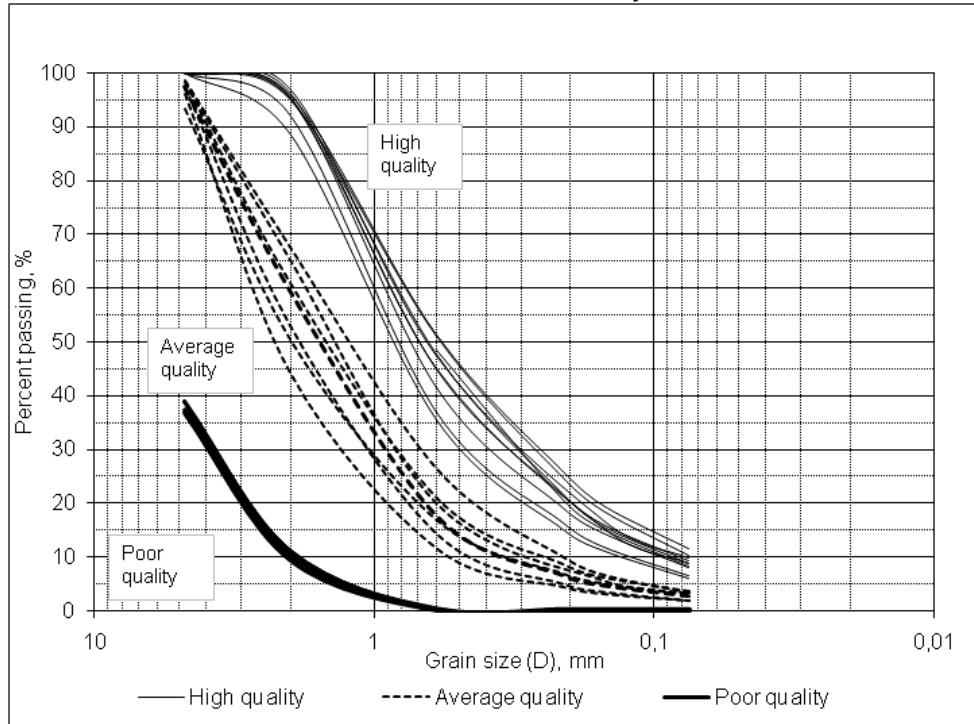
Manufacturers

In high plasticity clays, 12-22 passes may be required.



Effects of soil pulverization quality on lime stabilization of an expansive clay

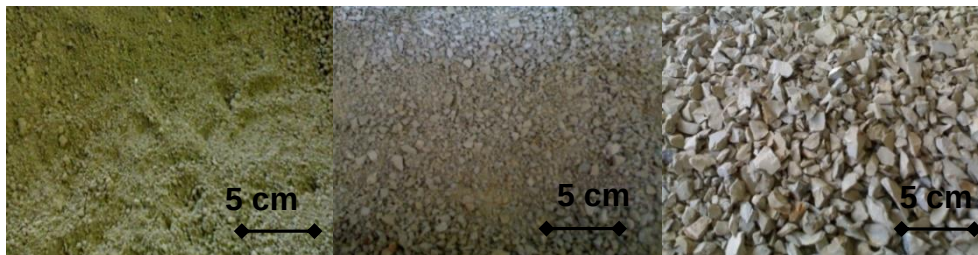
SANAN GARAI SAYEV, 2008



A laboratory investigation to determine the effects of soil pulverization quality on lime stabilization of a local expansive clay.

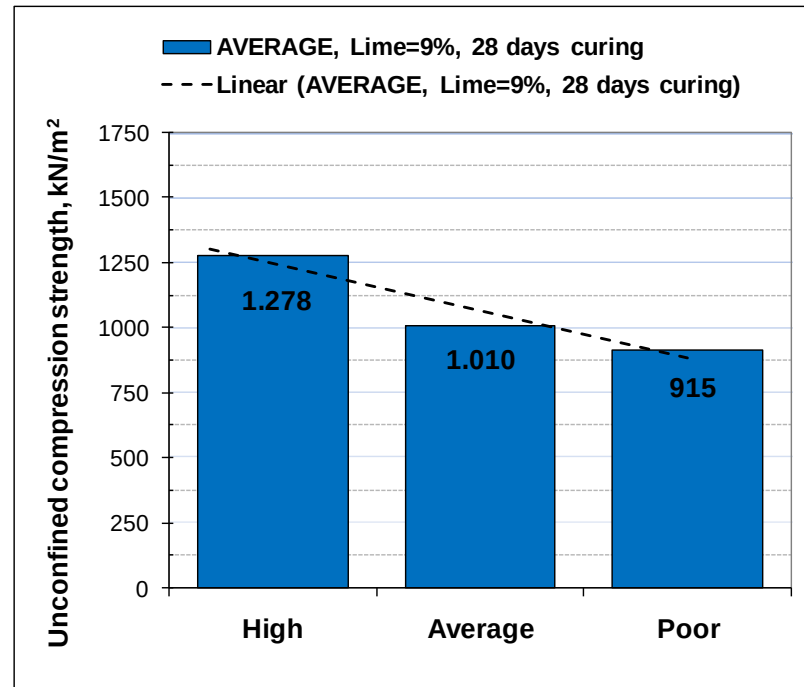
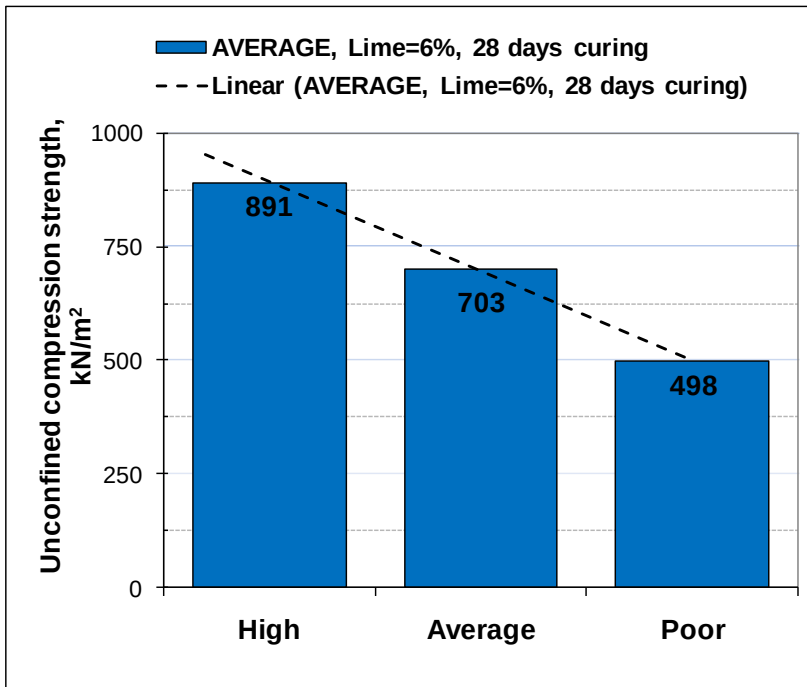
Three different pulverization levels, two lime contents, effects of mellowing

Unconfined compressive tests, microfabric investigations



Effects of soil pulverization quality on lime stabilization of an expansive clay

SANAN GARAI SAYEV, 2008



Effectiveness of lime treatment increased with increasing soil pulverization quality

Using higher lime contents could not fully compensate for poor pulverization ☹️

Effects of soil pulverization quality on lime stabilization of an expansive clay

SANAN GARAI SAYEV, 2008

Unconfined compressive strength is determined using ASTM D 5102. UCS can be used to approximate design parameters such as flexural strength, deformation potential and stiffness (resilient modulus) when these data are not available:

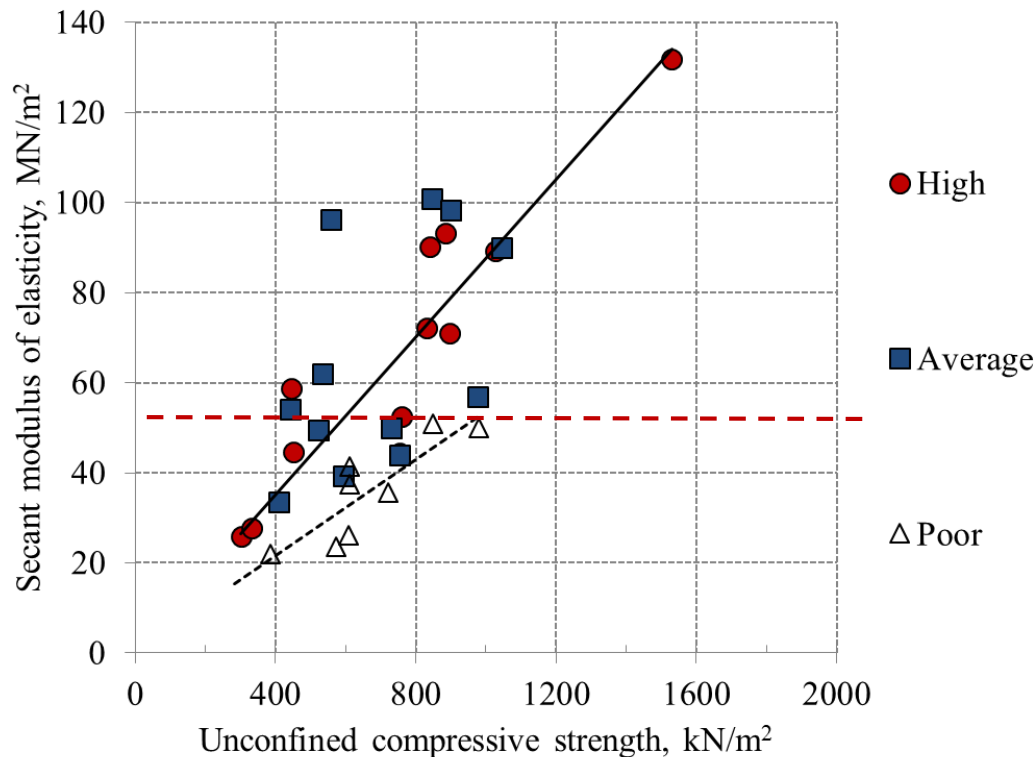
- Tensile strength can be conservatively estimated as 10 percent of the UCS, and flexural strength can be conservatively estimated to be twice the tensile strength or approximately 20 percent of UCS. (2)
- Several correlations have been developed between UCS and resilient modulus. One of the most conservative for lime-stabilized fine-granular subgrades was developed by Thompson (5) in which the resilient modulus $E_R = 0.124 (\text{UCS}) + 9.98$, where UCS is presented in psi and E_R in ksi. Comparisons in this example have shown this relationship to be overly conservative by approximately 50 percent.

www.lime.org

Can we have some correlations ?

Effects of soil pulverization quality on lime stabilization of an expansive clay

SANAN GARAI SAYEV, 2008



$$E_{sec} = 88q_u, \text{ High}$$

$$E_{sec} = 54q_u, \text{ Poor}$$

For poor soil pulverization, E values have an upper bound

qu-E correlation is a function of soil pulverization level

Thompson (1966) $E(ksi) = 10 + 0.124(q_u, psi)$

Effects of soil pulverization quality on lime stabilization of an expansive clay

SANAN GARAI SAYEV, 2008

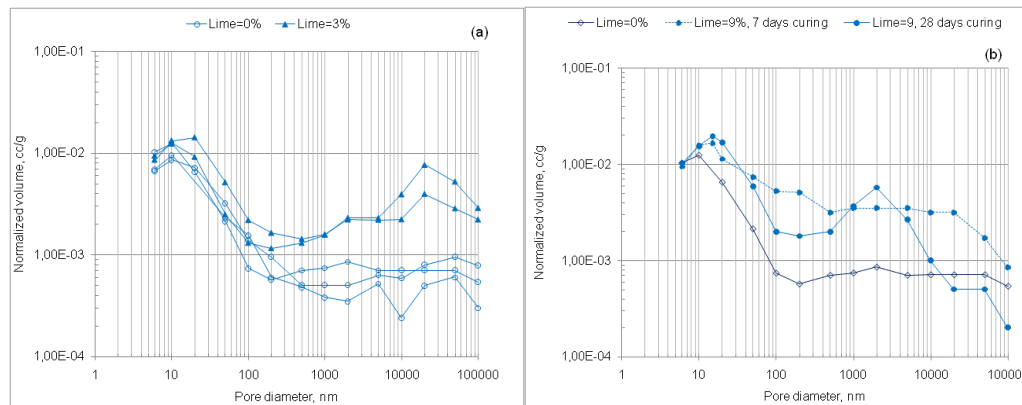


Fig 13. Pore diameter- normalized volume graph for a) natural and 3% lime added samples b) Natural sample and 9% lime added samples cured for 7 and 28 days

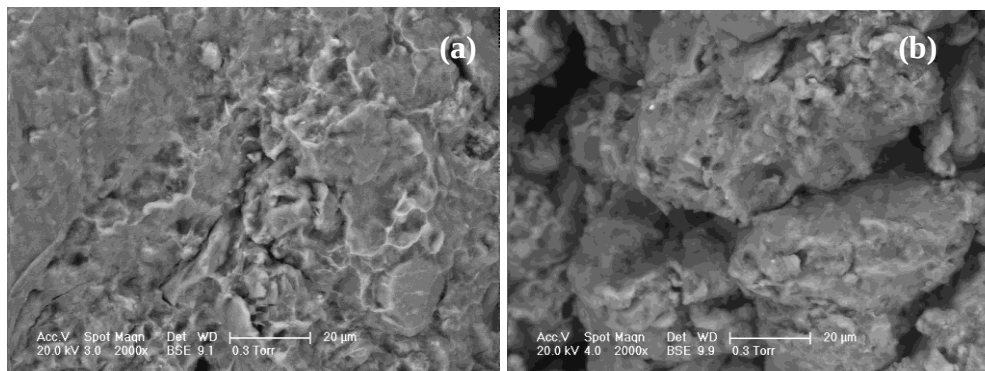
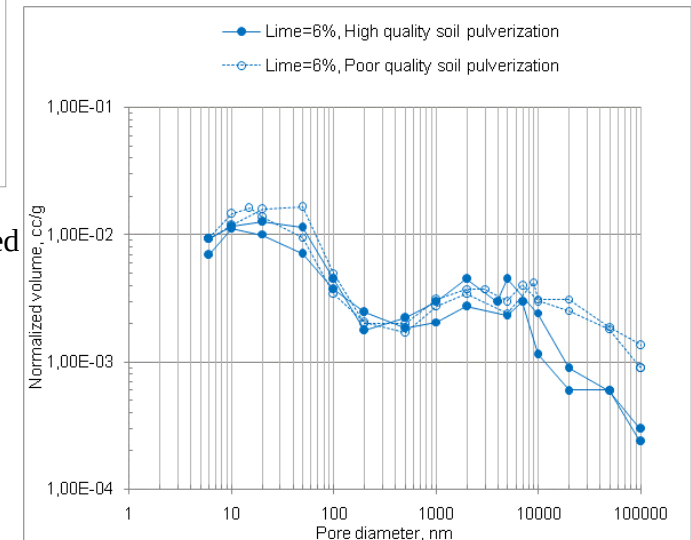


Fig 15. ESEM analyses of a) natural sample b) 3% lime treated sample



Led to further research

Soil pulverization level, q_u

Modulus, Correlations,
Microfabric

Other additives?
Durability?

Effects of soil pulverization level and freeze and thaw cycles on fly ash and lime stabilized high plasticity clay

NASHAT A. KAMAL (2009-2012)

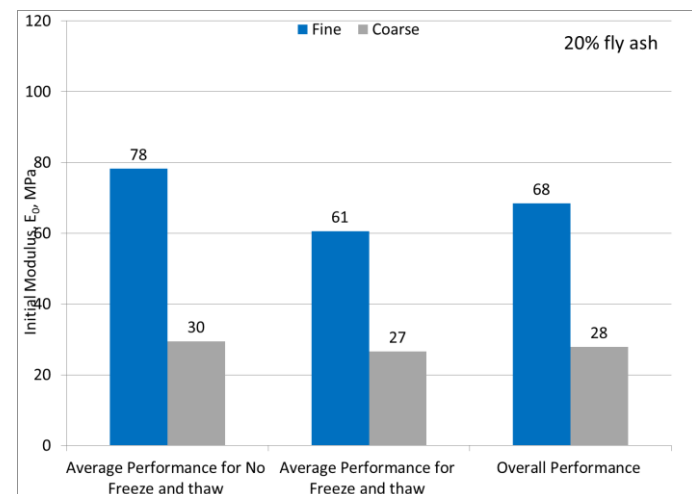
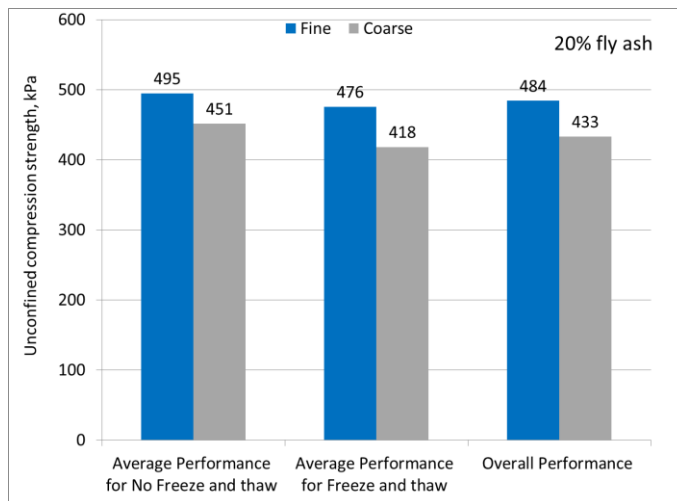
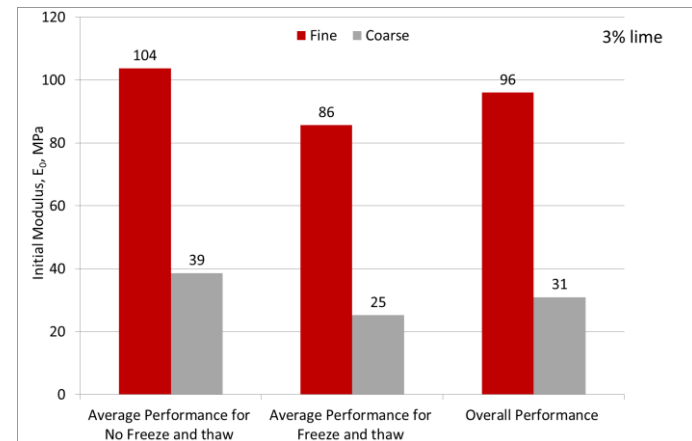
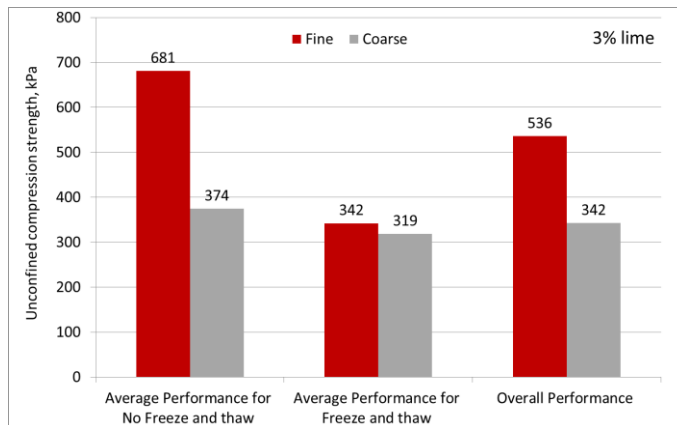
Effects of durability through freeze and thaw cycles

Hydrated lime and Class F fly ash stabilization



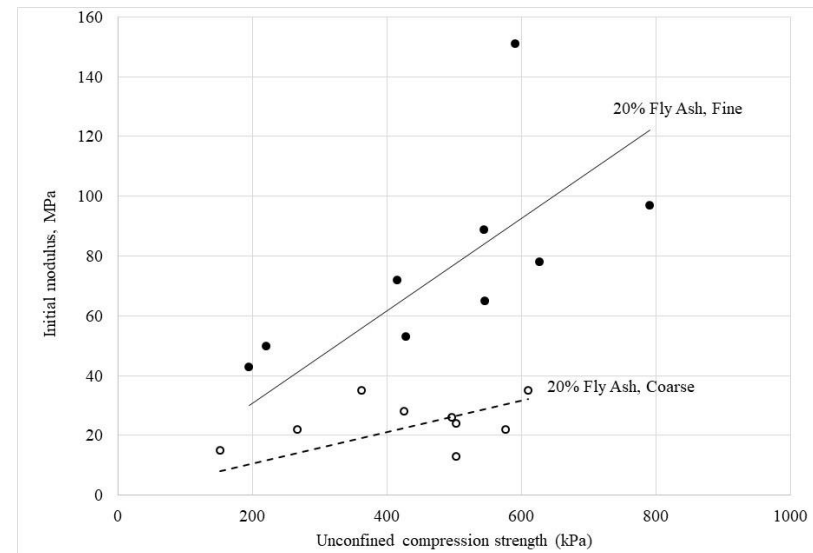
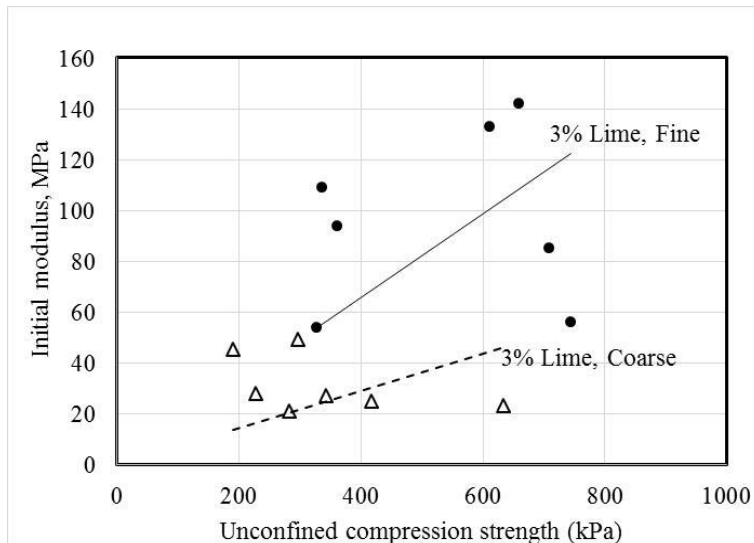
Effects of soil pulverization level and freeze and thaw cycles on fly ash and lime stabilized high plasticity clay

NASHAT A. KAMAL (2009-2012)



Effects of soil pulverization level and freeze and thaw cycles on fly ash and lime stabilized high plasticity clay

NASHAT A. KAMAL (2009-2012)



Effects of soil pulverization level and freeze and thaw cycles on fly ash and lime stabilized high plasticity clay

NASHAT A. KAMAL (2009-2012)

Similar strength values may result in different modulus values for different soil pulverization levels

Design based on strength improvements might be misleading ?

Laboratory Evaluations for Lime Stabilization

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- ASTM D 6276 (Eads – Grim Test)
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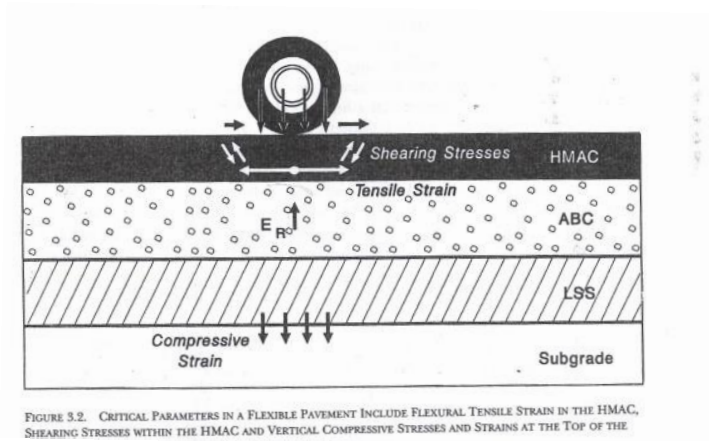
3. Unconfined Compressive Strength

- ASTM D 5102
- Minimum of 100 psi
- Freeze-thaw durability

Implications on pavement design ?

Effects of soil pulverization level and freeze and thaw cycles on fly ash and lime stabilized high plasticity clay

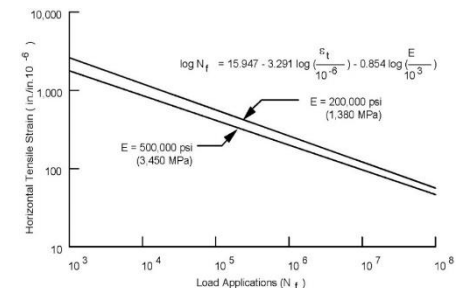
NASHAT A. KAMAL, YAVUZ ABUT (2009-2012)



Mechanistic-empirical approach,

- critical stresses or strains are calculated
- these are linked to pavement performance by transfer functions.

- Horizontal tensile strain at the bottom of HMAC layer
- Vertical compressible strain at the top of the subgrade



RESILIENT MODULUS OF LIME STABILIZED SOILS

were not considered. Many expressed concerns about this approach, including Professor A. Casagrande (Burmeister, 1943):

“Irrespective of the theoretical method of evaluation of load tests, there remains the important question as to what extent individual static load tests reflect the results of thousands of dynamic load repetitions under actual traffic. Experience and large-scale traffic tests have already indicated that various types of soils react differently, and that the results of static load tests by no means bear a simple relation to pavement behavior.”

Resilient modulus defines the efficiency of a pavement to distribute load induced stresses within the pavement system and is a part of mechanistic-empirical approach

RESILIENT MODULUS OF LIME STABILIZED SOILS

Level 1. At input level 1, M_r of the lime stabilized soils is determined in accordance with a mixture design and testing protocol (MDTP) (Little, 2000). The AASHTO T-307 test protocol or an equivalent test can be used to estimate the resilient modulus. The MDTP requires the resilient

Level 2. At input level 2, M_r of the lime stabilized soils can be estimated from unconfined compressive strength (q_u) of the cured soil-lime samples performed in accordance with the MDTP (Little, 2000). The 28-day q_u is measured and determined in accordance with ASTM D 5102 as part of the MDTP. The MDTP should be adopted for the determination of lime demand for the soil, fabrication, curing, and soaking prior to determining the unconfined compressive strength. M_r can subsequently be estimated from q_u as follows (Thompson, 1966):

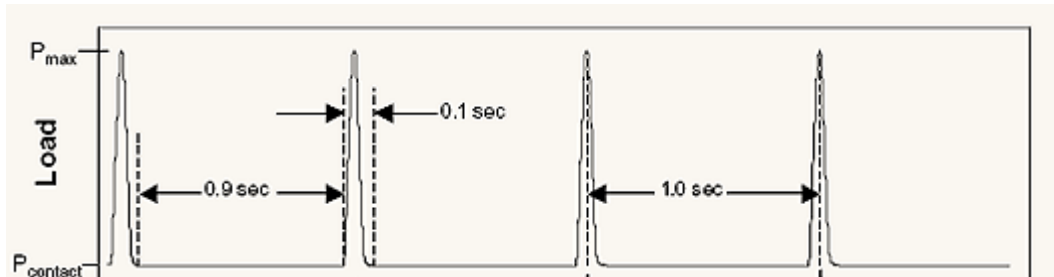
$$M_r = 0.124(q_u) + 9.98 \quad (2)$$

where,

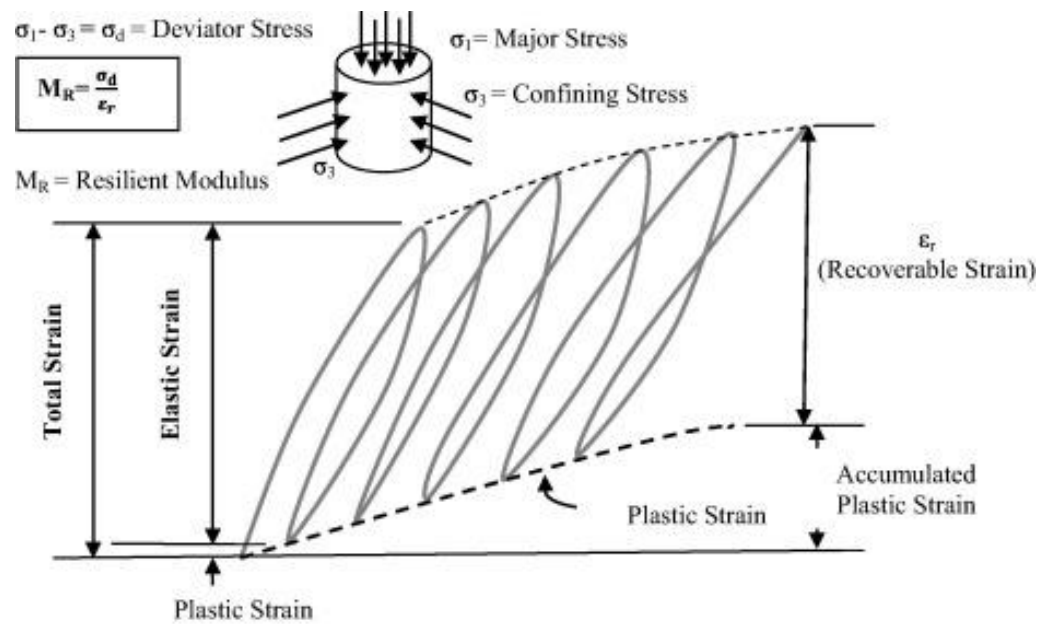
M_r = resilient modulus, ksi.

q_u = unconfined compressive strength, psi.

Level 3. At input level 3, M_r is estimated from experience or historical records. The literature demonstrates that resilient moduli of 30,000 to 60,000 psi can be readily achieved for reactive soils (with 25 percent passing No. 200 sieve and PI of at least 10). However, the exact extent of increase is a function of the soil mineralogy and lime content.



Loading



$$M_R = \frac{\sigma_d}{\epsilon_r}$$

Strain



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| C | E | R | R | A | H | P | A | Ş | A |



KARAYOLLARI
GENEL MÜDÜRLÜĞÜ

A joint venture project

**Istanbul University-Cerrahpasa (IUC)-Turkish General
Directorate of Highways (KGM)-Research Center**

Bozbey and Kelesoglu (2013-2016)

Effects of soil pulverization level on

Strength, resilient modulus and durability

Implications on design and performance

Istanbul University-Cerrahpasa (IUC) -



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C E R R A H P A Ş A

Turkish General Directorate of Highways (KGM)-
Research Center



KARAYOLLARI
GENEL MÜDÜRLÜĞÜ

- Includes laboratory extensive testing
- CBR, Resilient modulus, UCS
- Correlations based on this data, q_u -E, M_R - q_u , CBR- M_R
- Freeze and thaw cycles, extended soaking for durability
- A design guide for lime stabilized pavements for General Directorate of Highways
- Recommendations for the current lime stabilization specification for General Directorate of Highways

Table 1. Index properties of the soil

Measured property	Value	Measured property	Value
Gravel (ASTM), %	9	Plasticity Index	41
Sand (ASTM), %	20	Soil Classification, USCS	CH
Fine percent (ASTM), %	71	Soaked CBR- Swell percent, %	3 - 6,6
Liquid Limit, %	69	Sulfate content, %	0,01
Plastic Limit, %	28	Organic content, %	0,14

All the soil passed through 20 mm sieve.

For fine pulverization, the soil was pulverized so that all the soil passed through No. 4 sieve.

For coarse soil pulverization, 60% passed the No. 4 sieve.

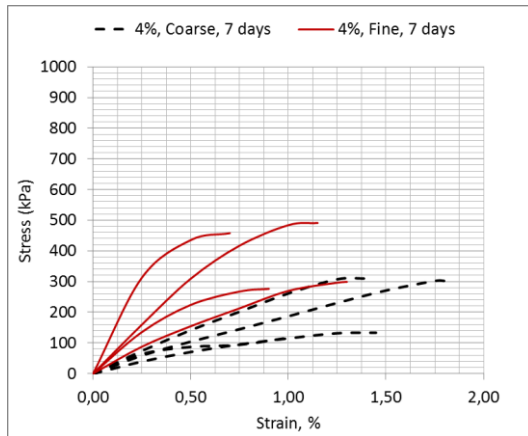
Both soil gradations met the soil gradation criteria in relevant recommendations, eg. Turkish lime specification.



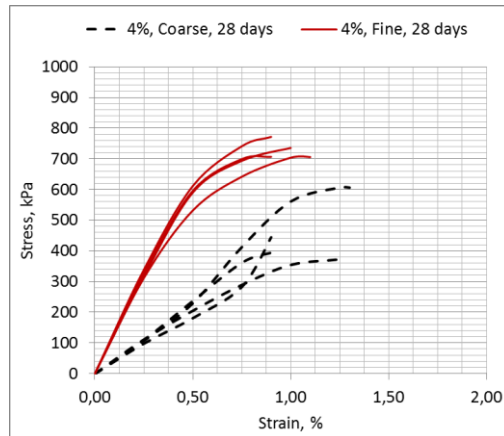


UNCONFINED COMPRESSION STRENGTH TESTS – 4% LIME

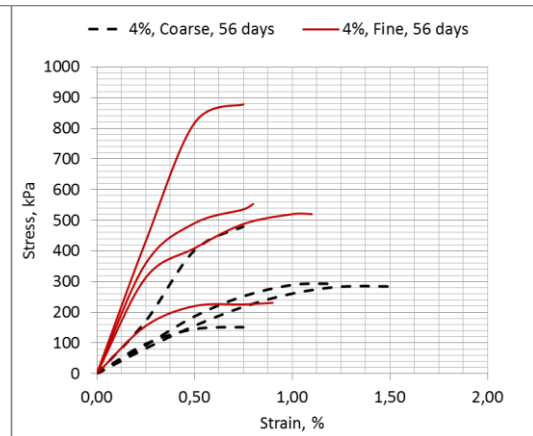
7 days



28 days



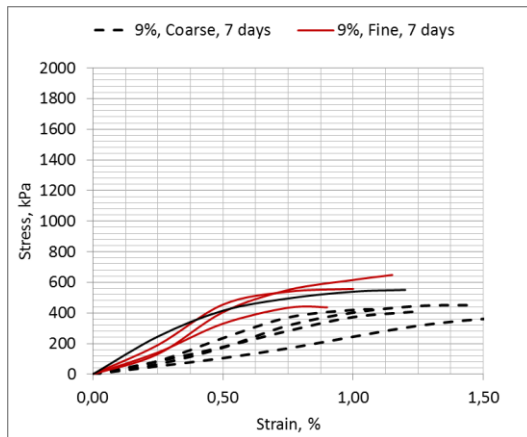
56 days



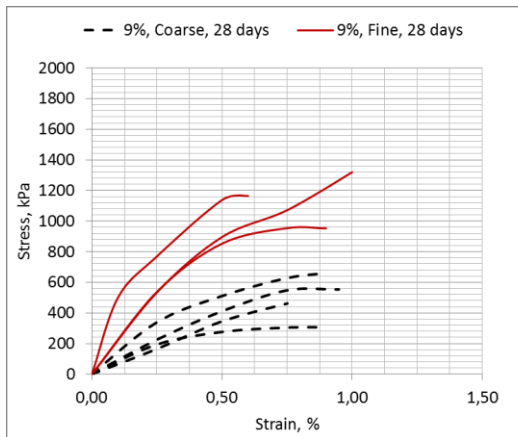
Strength with fine pulverization >> Strength with coarse pulverization

UNCONFINED COMPRESSION STRENGTH TESTS – 9% LIME

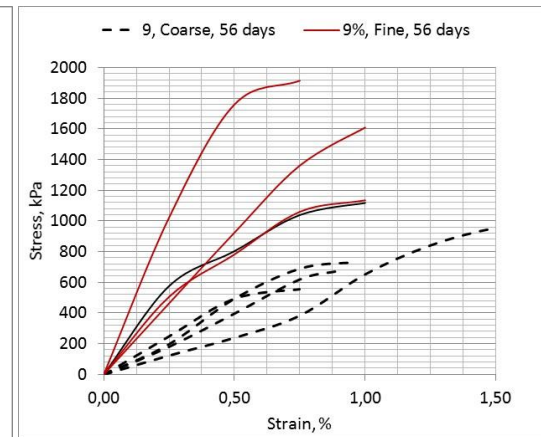
7 days



28 days

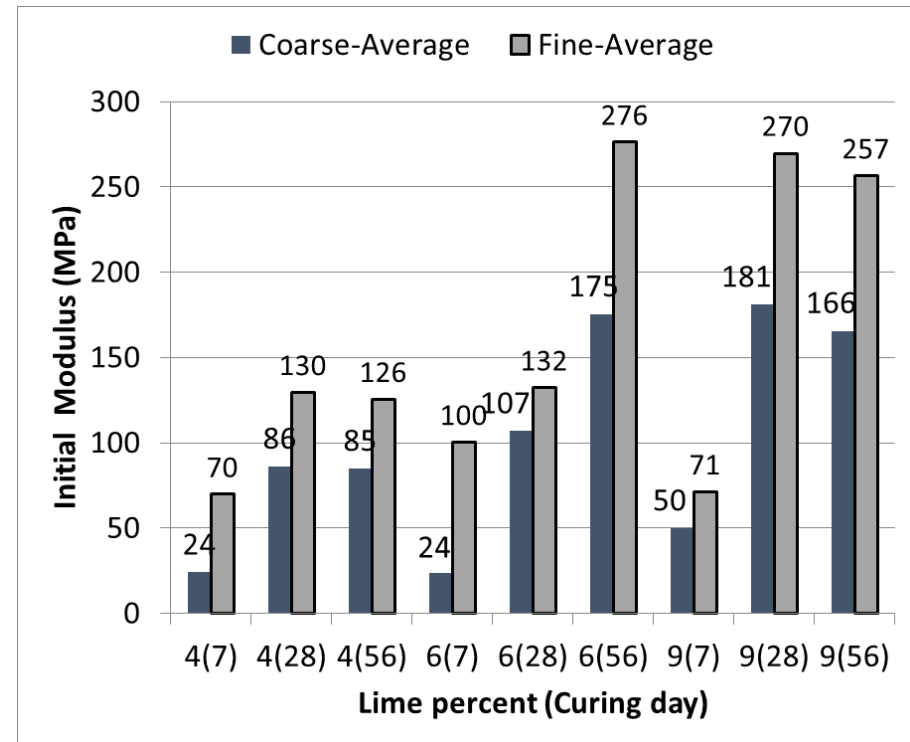
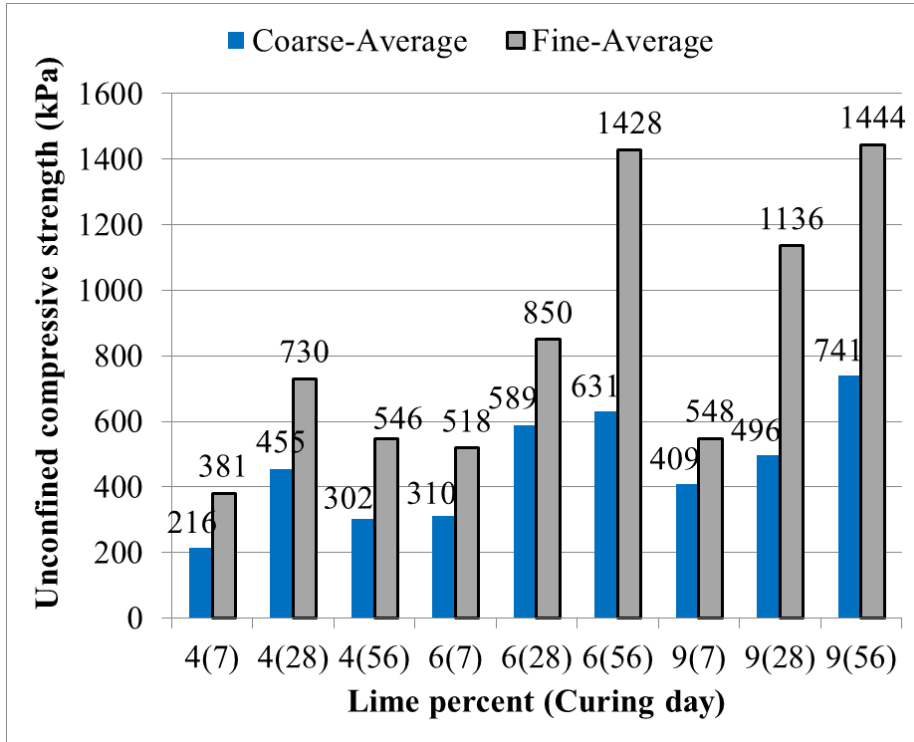


56 days



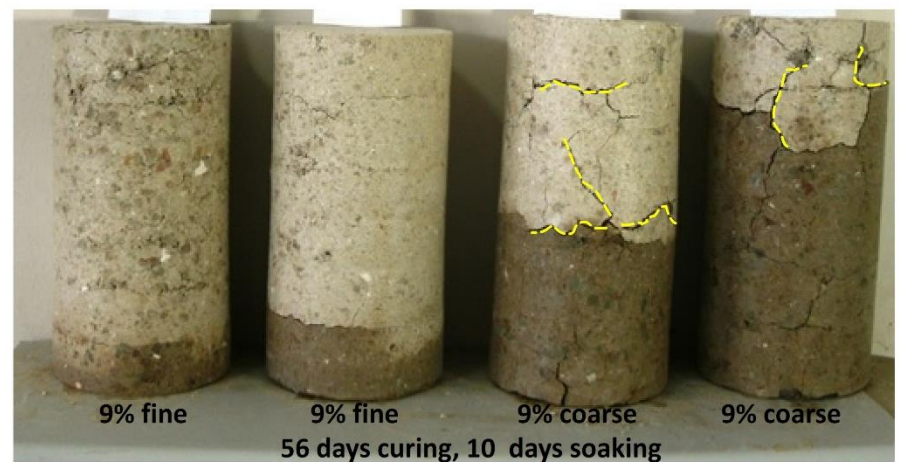
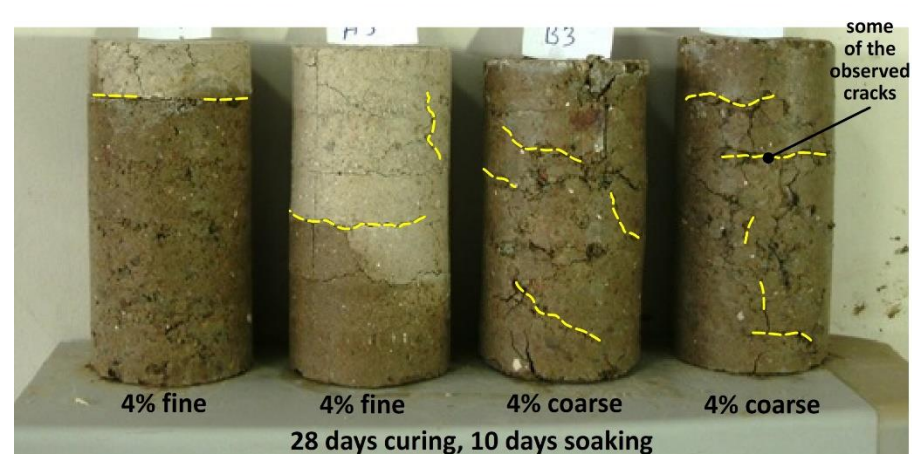
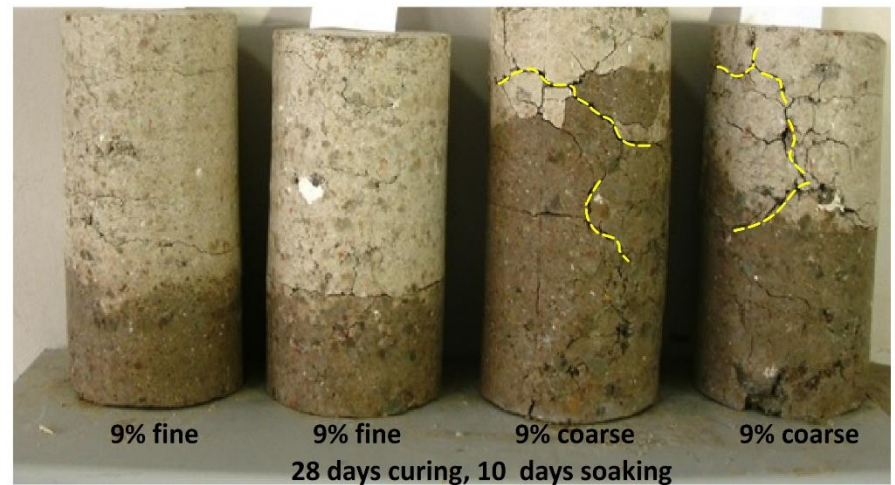
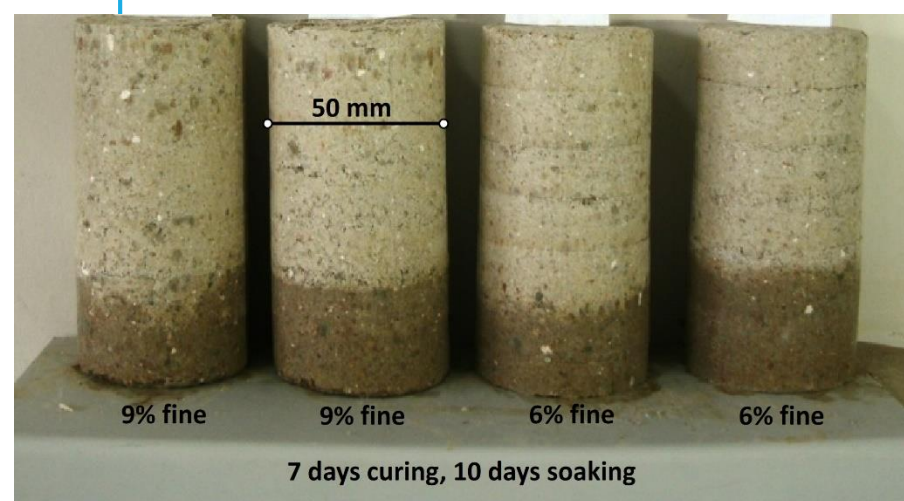
Strength with fine pulverization >> Strength with coarse pulverization

AVERAGE VALUES



SOIL PULVERIZATION LEVEL IS AS IMPORTANT AS LIME CONTENT AND CURING DAYS....

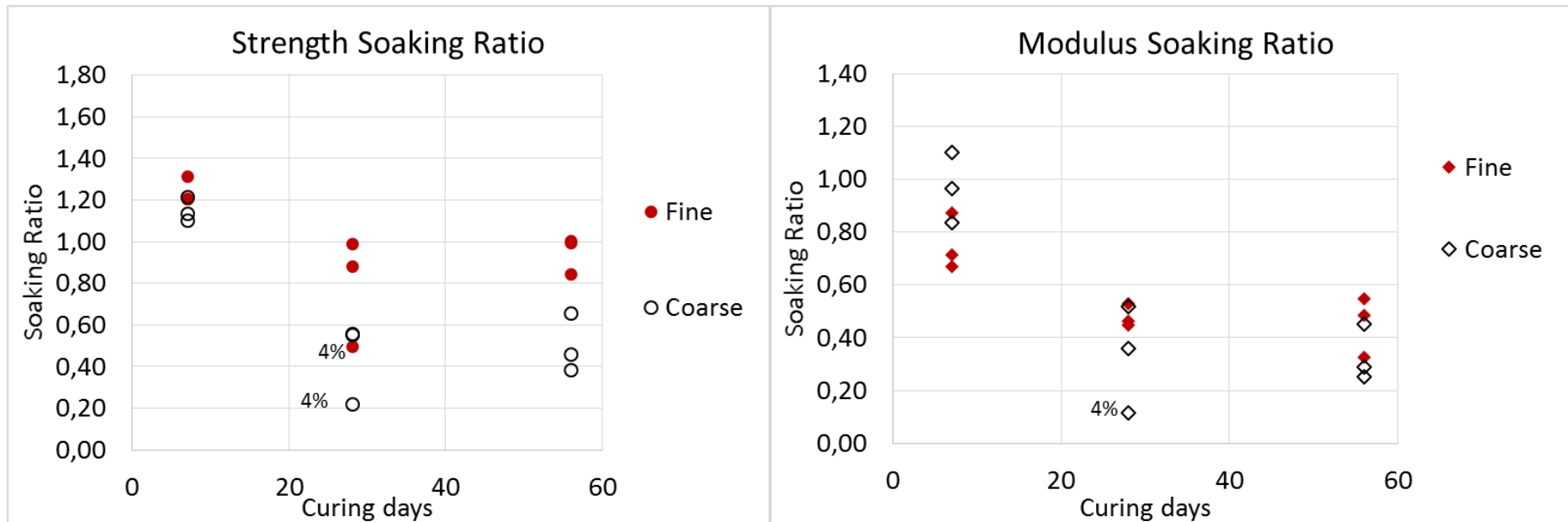
WHAT HAPPENS UNDER EXTENDED SOAKING (10 DAYS)



PERFORMANCE BETTER WITH FINE PULVERIZATION

SOAKING RATIO: REDUCTION IN STRENGTH OR MODULUS

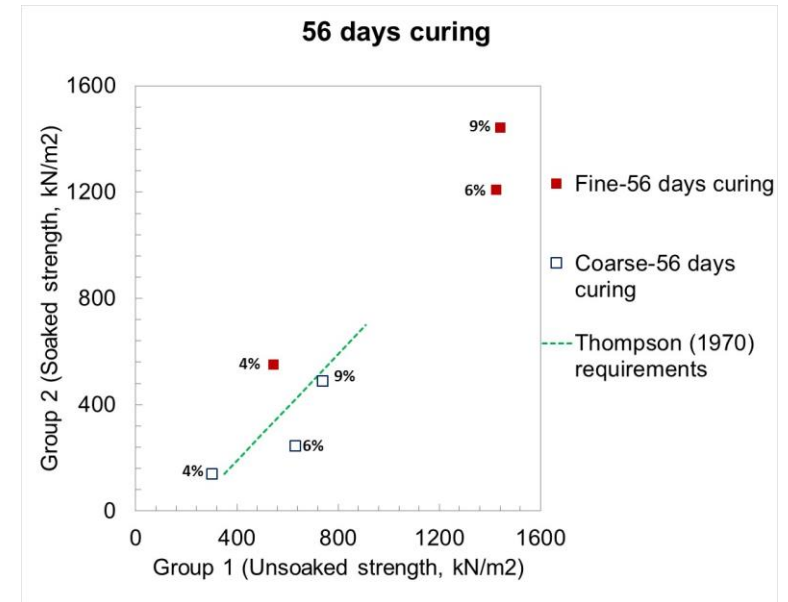
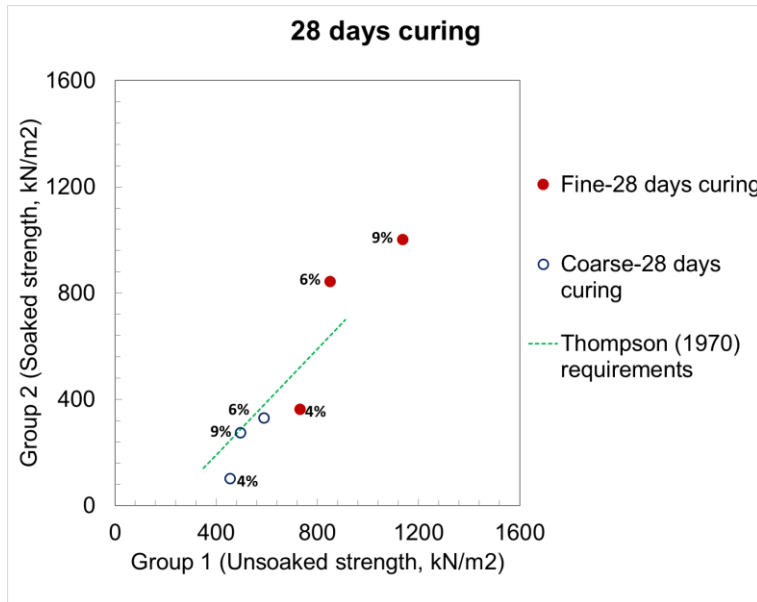
$$\text{SoakingRatio} = \frac{\text{Strength}(\text{Modulus})\text{aftersoaking}}{\text{Strength}(\text{Modulus})\text{beforesoaking}}$$



WHAT DO WE HAVE IN THE LITERATURE FOR COMPARISON, THOMPSON (1970)

Anticipated use	Residual strength requirement (kPa) ^a (Soaked)	Strength requirements (kPa) ^b (Unsoaked)
		Extended soaking for 8 days
As Modified subgrade	140	350
As Subbase		
Rigid pavement	140	350
Flexible pavement, 254 mm ^c	210	420
Flexible pavement, 200 mm ^c	280	490
Flexible pavement, 130 mm ^c	420	630
As Base	700	910

COMPARISON WITH THOMPSON (1970)



Superiority of fine soil pulverization to satisfy the criteria



Figure 2. Resilient modulus sample preparation process; compaction and curing

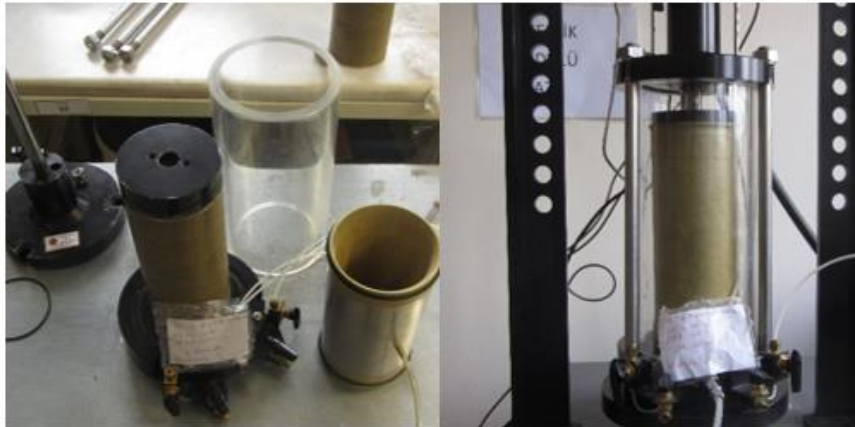
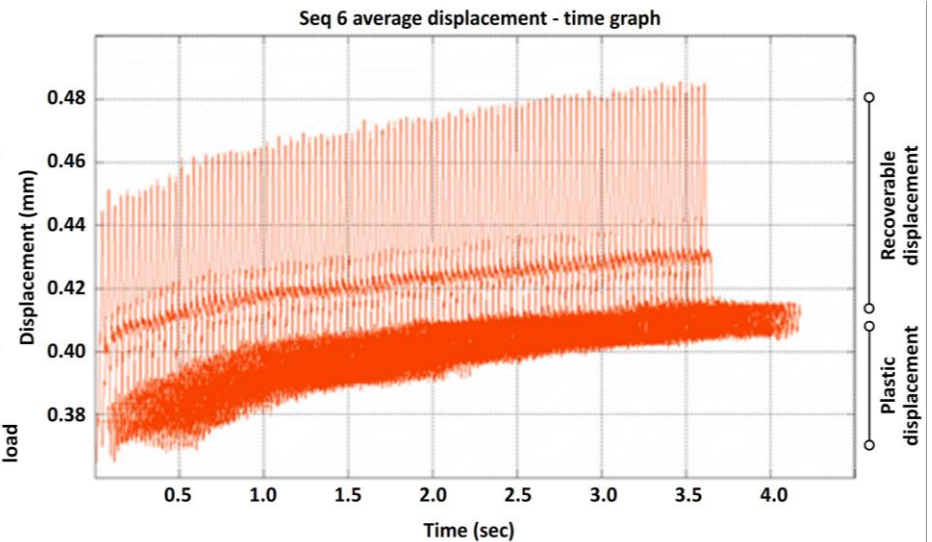
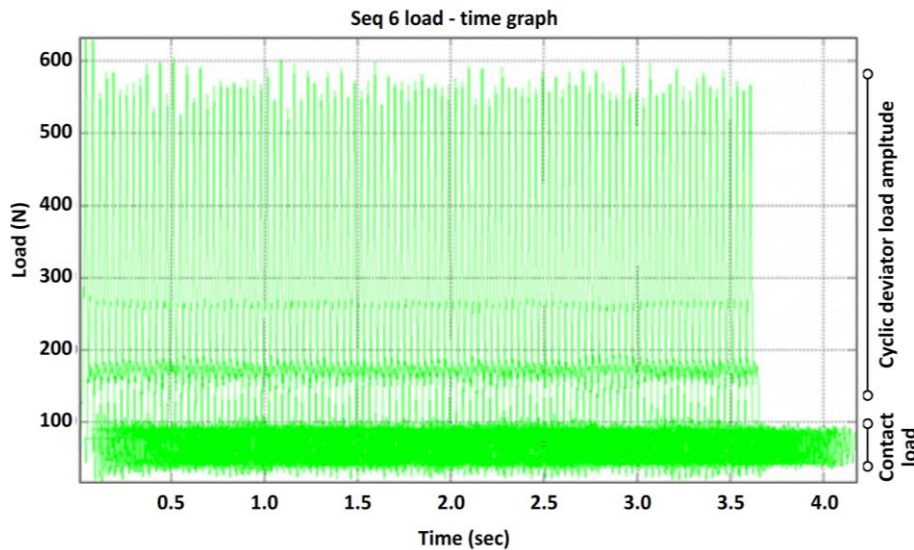


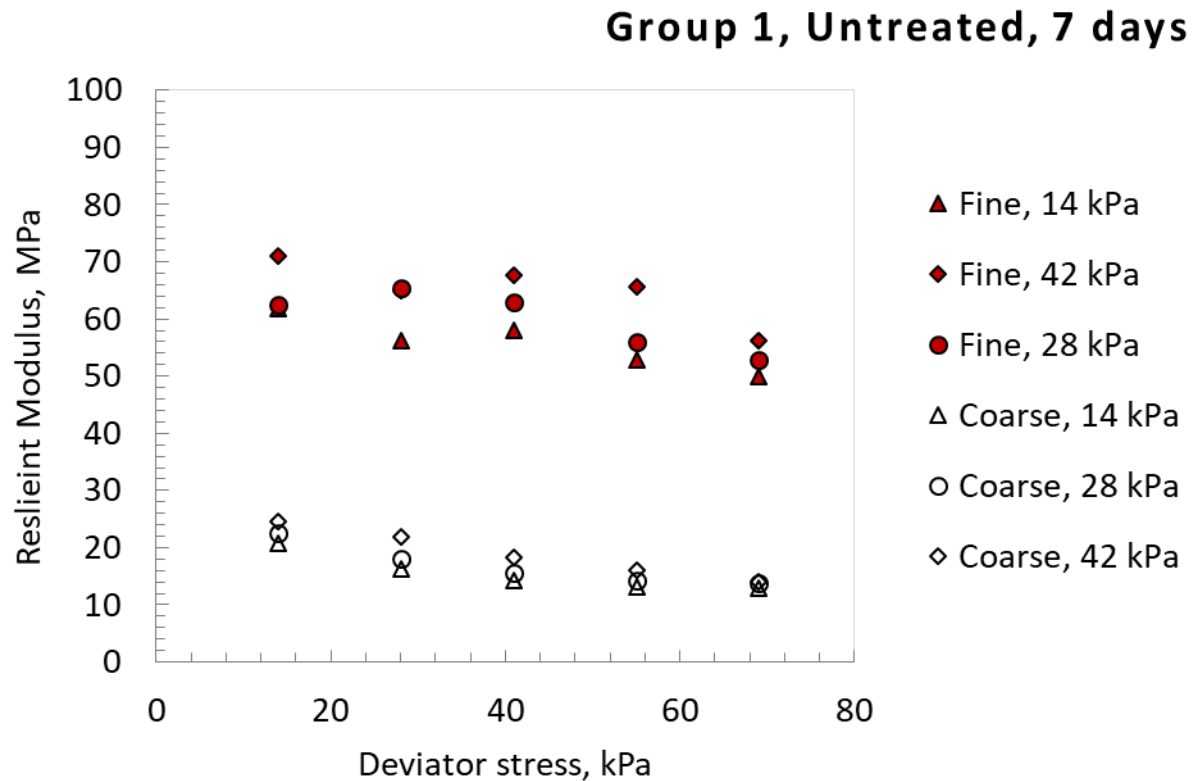
Figure 3. Resilient modulus test stages

Loading Stage	Confining stress, kPa	Deviator stress, kPa	Number of loading	Loading Stage	Confining stress, kPa	Deviator stress, kPa	Number of loading
0	42	28	1000	8	28	42	100
1	42	14	100	9	28	55	100
2	42	28	100	10	28	69	100
3	42	42	100	11	14	14	100
4	42	55	100	12	14	28	100
5	42	69	100	13	14	42	100
6	28	14	100	14	14	55	100
7	28	28	100	15	14	69	100

RESILIENT MODULUS TESTING



RESILIENT MODULUS VALUES



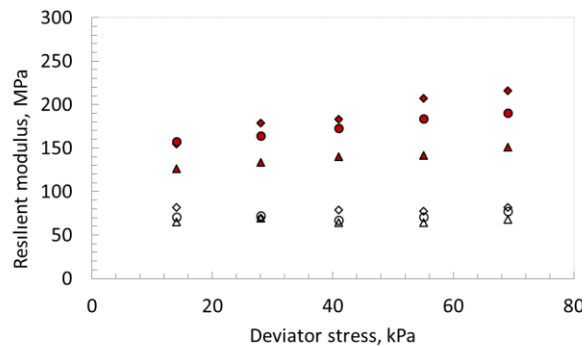
RESILIENT MODULUS VALUES

7 DAYS

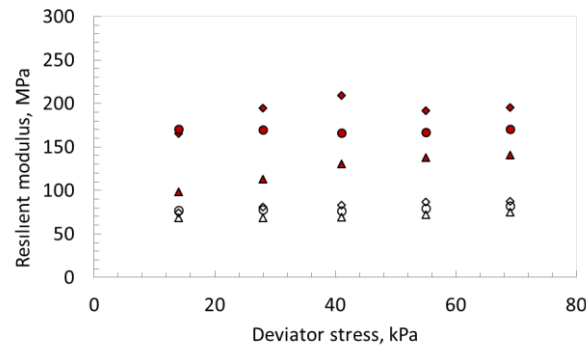
28 DAYS

56 DAYS

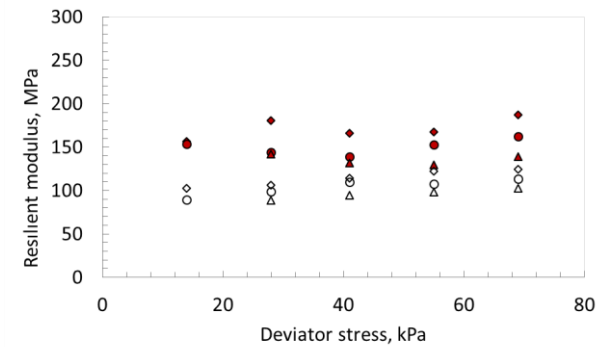
Group 1, 4% lime, 7 day



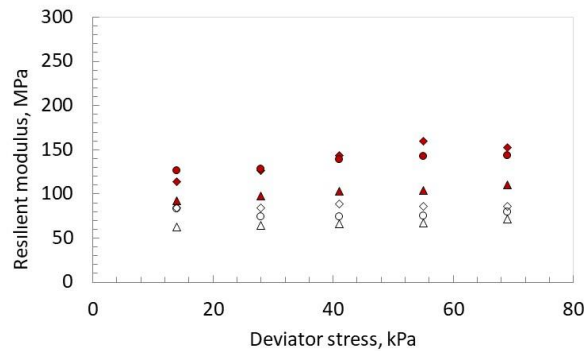
Group 1, 4% lime, 28 days



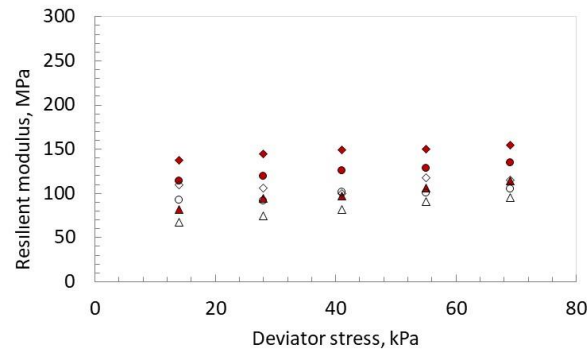
Group 1, 4% lime, 56 days



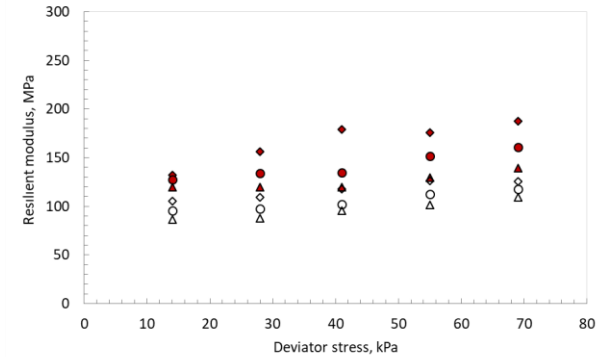
Group 1, 6% lime, 7 days



Group 1, 6% lime, 28 days



Group 1, 6% lime, 56 days



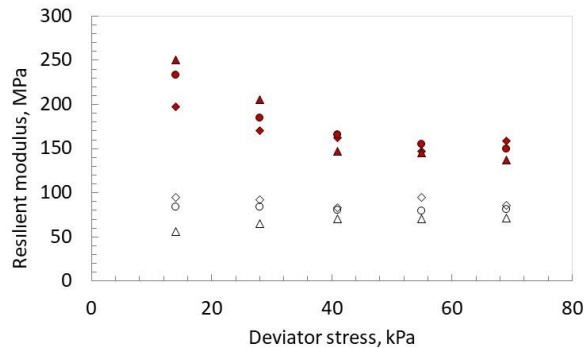
RESILIENT MODULUS VALUES

7 DAYS

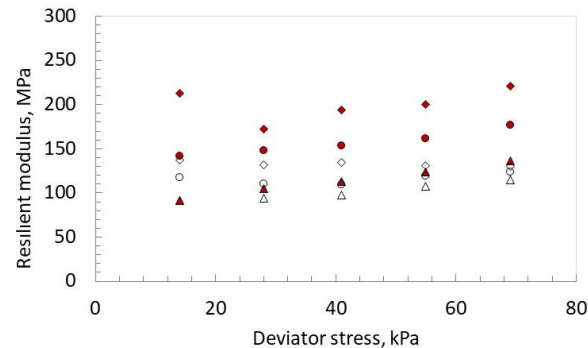
28 DAYS

56 DAYS

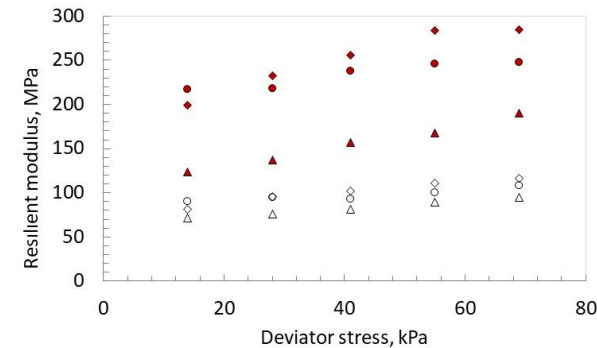
9% lime, 7 days



9% lime, 28 days



9% lime, 56 days

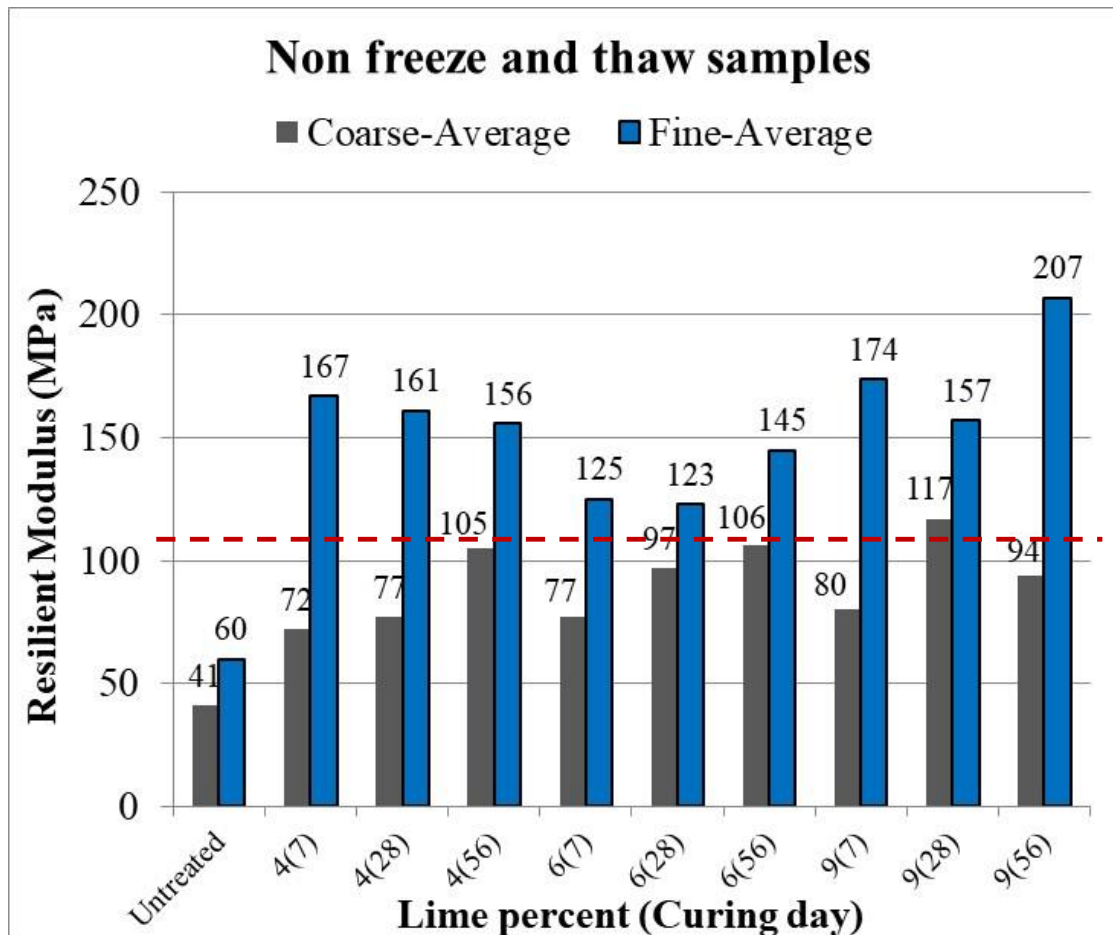


Dependency of resilient modulus to stress state

Increases in resilient modulus values depended on not only on lime content, curing duration but soil pulverization level as well.

So it is a part of the story....

AVERAGE VALUES



For COARSE soil pulverization, higher lime contents MAY not bring any additional benefits to the stabilized soil in terms of AVERAGE resilient modulus values.

FREEZE AND THAW CYCLES

12 freeze and thaw cycles

One cycle consists of one freezing and one thawing period

Freezing period consists of 24 hours of freezing at -23°C where the samples are placed on water-saturated felt pads about 6 mm thick.

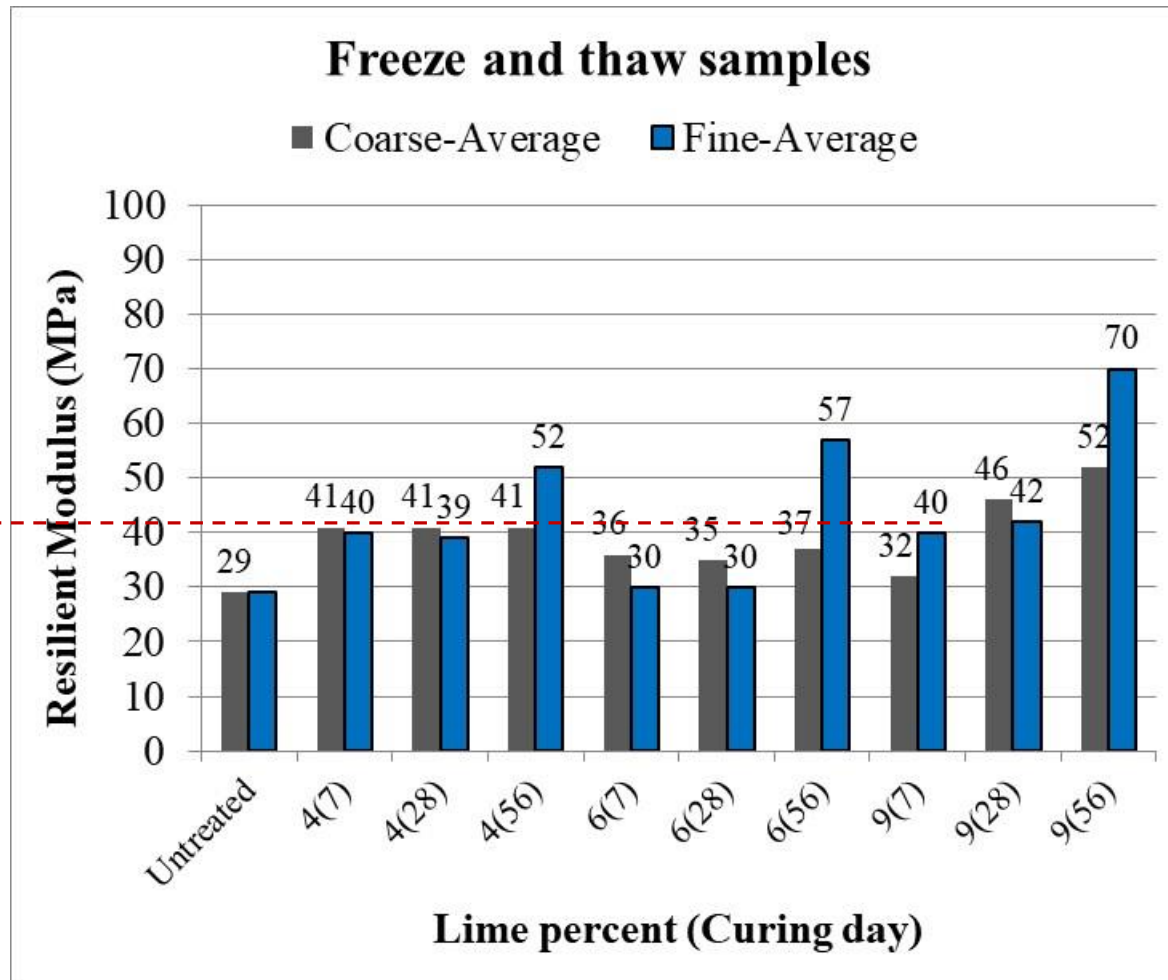
After the freezing period is over, the samples are left to thaw for 23 hours at a temperature of 23°C and a relative humidity of 100%.

Free potable water is made available to the absorbent pads under the specimens to permit the specimens to absorb water by capillary action during the thawing period.

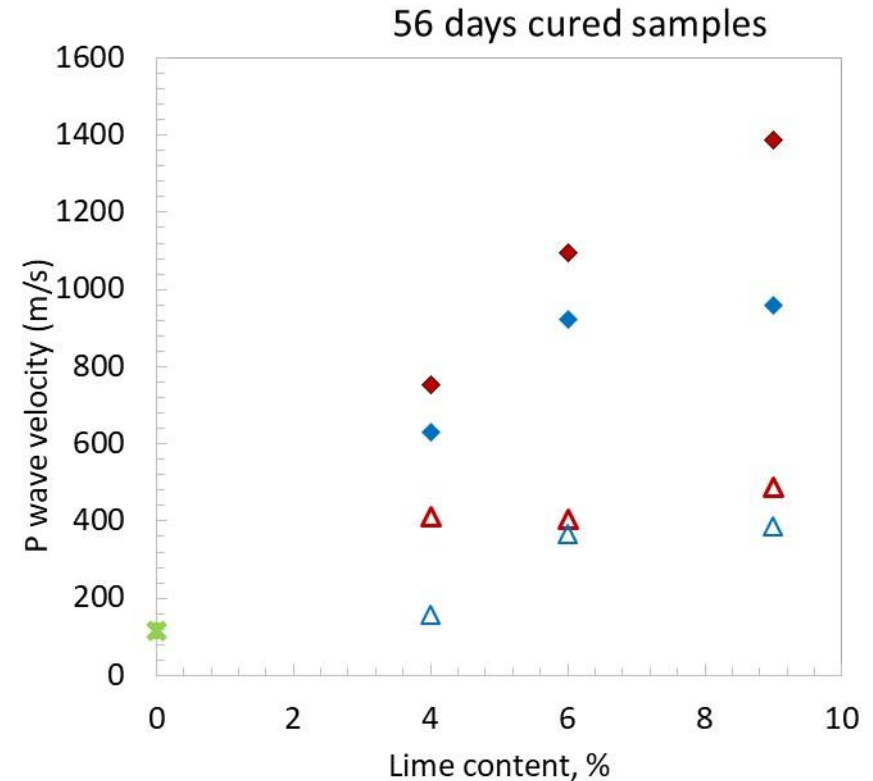
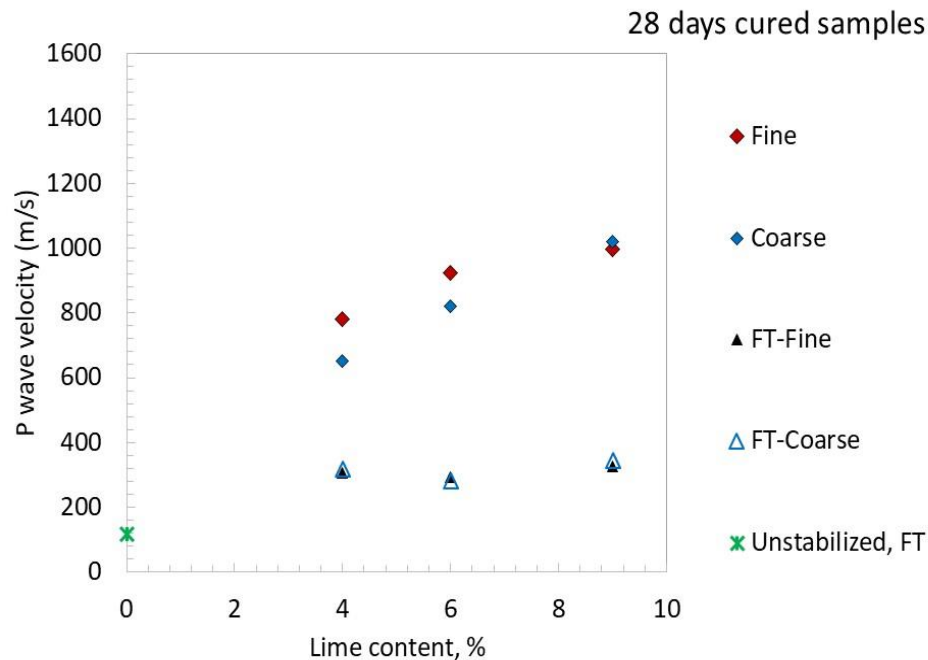


Figure 4. Freeze and thaw cycles application on resilient modulus samples

AVERAGE VALUES FOR FREEZE AND THAW SAMPLES



P WAVE VELOCITY



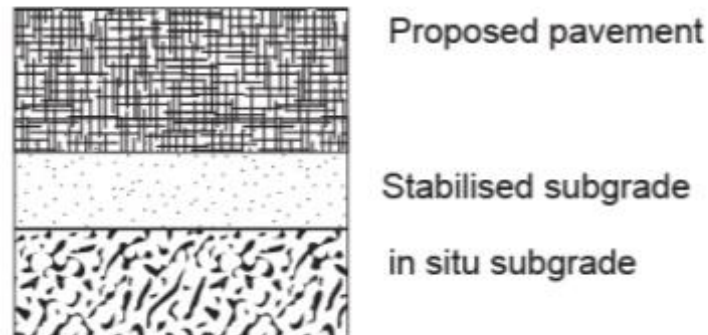
P wave measurements were found to be promising for understanding the effects of curing and freeze and thaw cycles and even for soil pulverization level effects.

IMPLICATIONS ON DESIGN AND PERFORMANCE

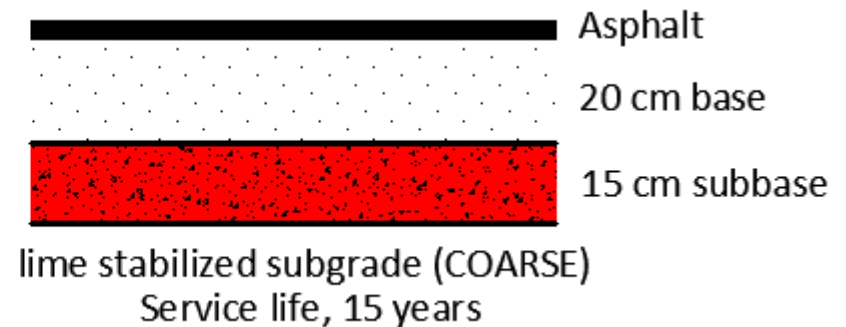
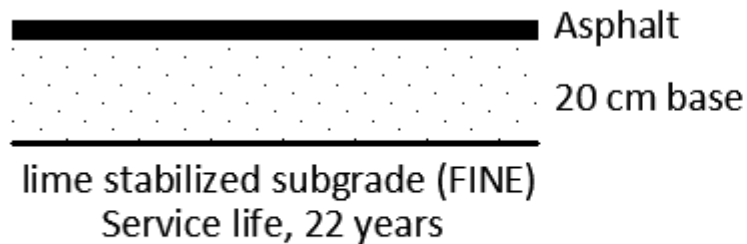
A typical design procedure was carried out according to Turkish Pavement Design Guideline and then comparative analyses were carried out using Kenpave Software.

In this paper, for the sake of comparison, a case study was chosen where the subgrade was stabilized with lime.

Subgrade stabilisation



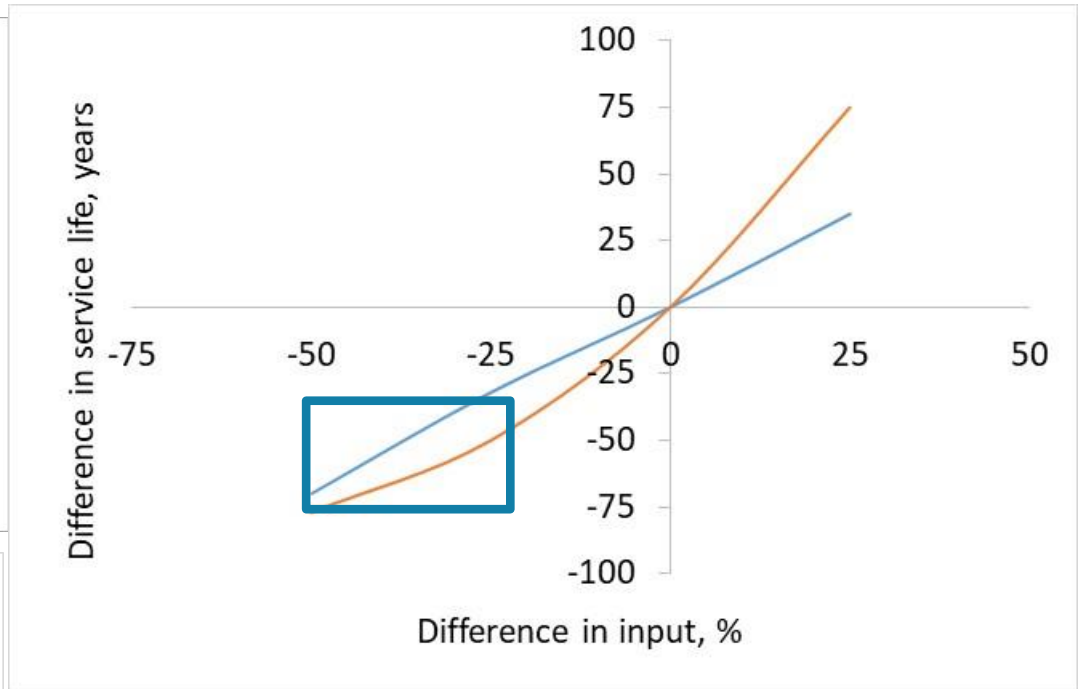
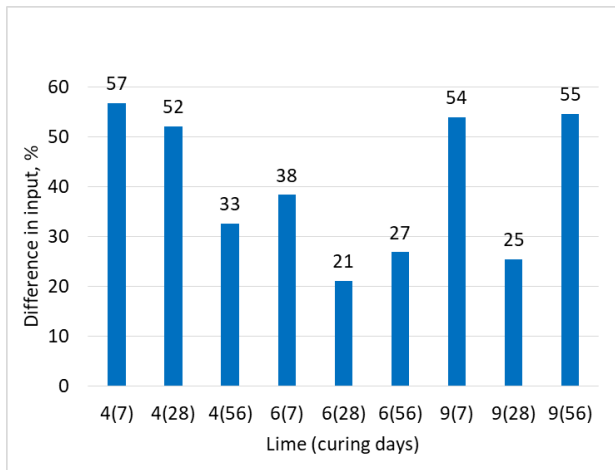
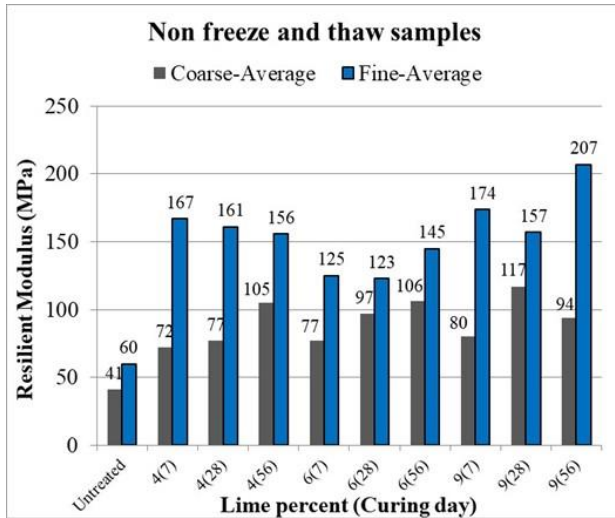
AN EXAMPLE



Turkish Design Guide : **15 cm subbase** needed for coarse soil pulverization

KENLAYER: Service life decreases from 22 years to 15 years

IMPLICATIONS ON DESIGN AND PERFORMANCE



Christopher ve diğ. (2010)
Schwartz (2016)

Cost analysis carbon footprint sustainability evaluation



Advances in Ground Modification with Chemical Additives: From Theory to Practice

Anand J. Puppala, Ph.D., P.E., D.GE.

Associate Dean-Research - College of Engineering
Distinguished University Professor - Department of Civil Engineering
Sustainable and Resilient Civil Infrastructure Center (SARCI)
University of Texas at Arlington



I. Pipeline Project Cost Analysis

USING NATIVE MATERIAL (W/O TREATMENT) AS BEDDING AND EMBEDMENT

Total costs for using in situ material without treatment	\$ 1,266*
--	-----------

USING IMPORTED MATERIAL AS BEDDING AND EMBEDMENT

Total costs for using imported material	\$ 8,168*
---	-----------

USING NATIVE MATERIAL (With TREATMENT) AS BEDDING AND EMBEDMENT

Total costs for using in situ material without treatment	\$ 1,318*
--	-----------

*Per 100 ft of pipe length



I. Pipeline Project Carbon Footprint Analysis

USING NATIVE MATERIAL (W/O TREATMENT) AS BEDDING AND EMBEDMENT

Total CO ₂ emissions for using excavated material without treatment, kg	1,515*
--	--------

USING IMPORTED MATERIAL AS BEDDING AND EMBEDMENT

Total CO ₂ emissions for using imported material, kg	10,190*
---	---------

USING NATIVE MATERIAL (With TREATMENT) AS BEDDING AND EMBEDMENT

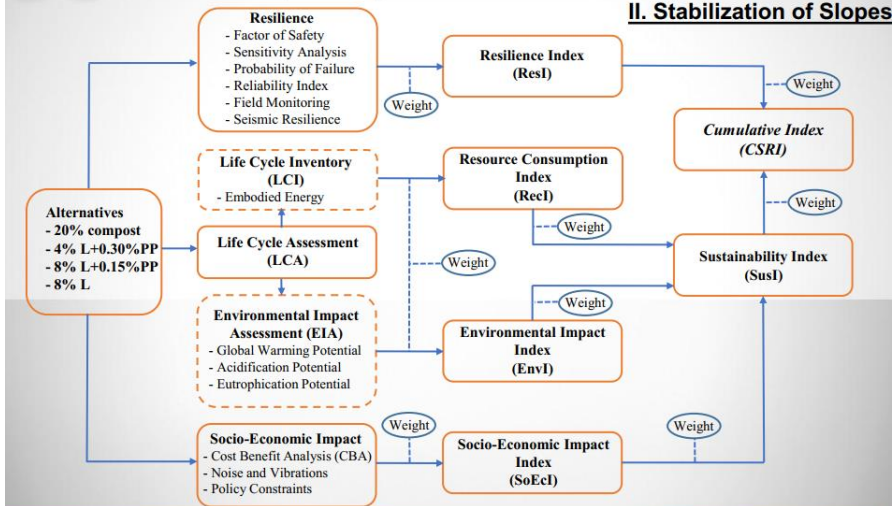
Total CO ₂ emissions for using excavated material without treatment, kg	7,751*
--	--------

*Per 100 ft of pipe length



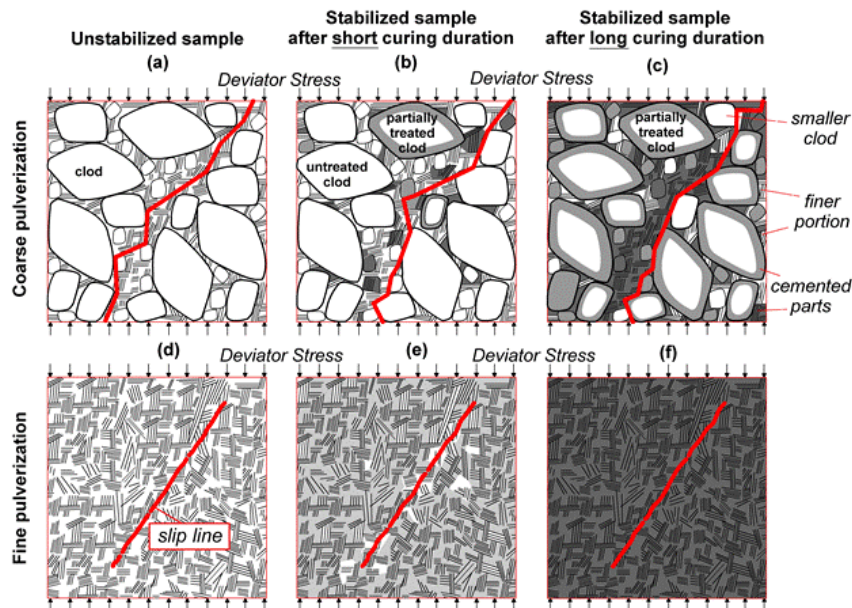
Sustainability Evaluation: Proposed Analysis Framework

II. Stabilization of Slopes



MICROFABRIC

For coarse soil pulverization, access of lime particles to clay in the clods is prohibited and therefore the only way that lime can reach the soil particles within the clods through diffusion.



This takes time, it can never be guaranteed that it will be completed even in the long run.

MICROFABRIC

14 *I. Bozbey et al.*

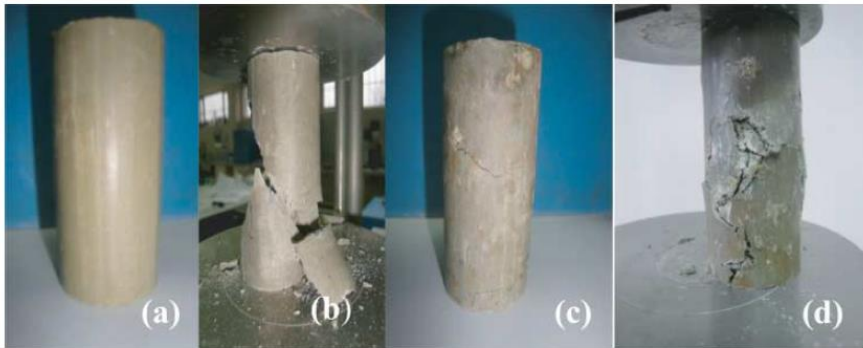
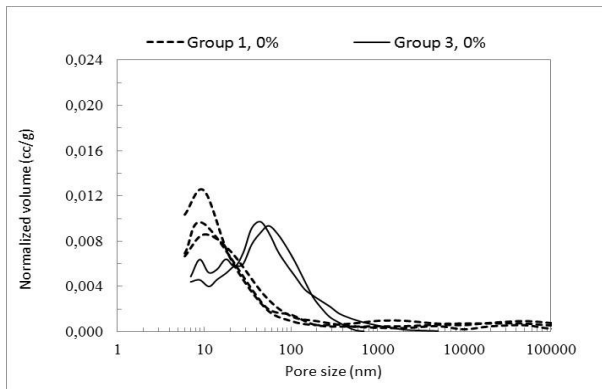


Figure 2. Fine pulverisation (a and b) and coarse pulverisation (c and d) samples.

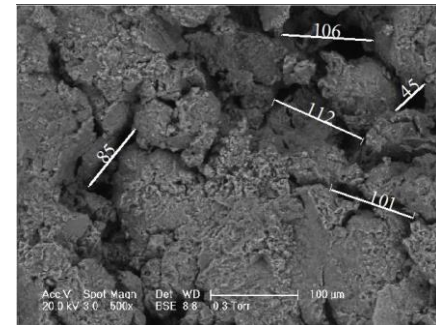
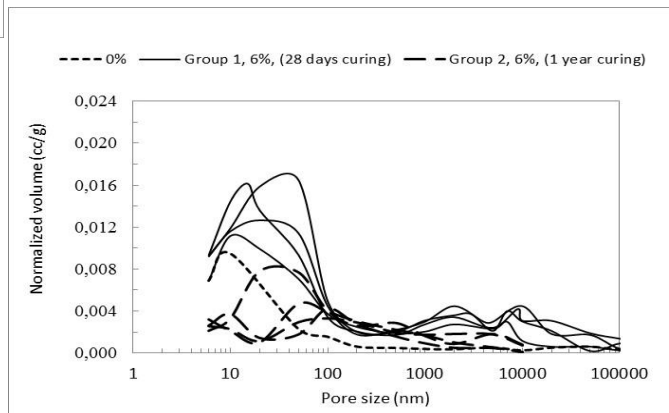
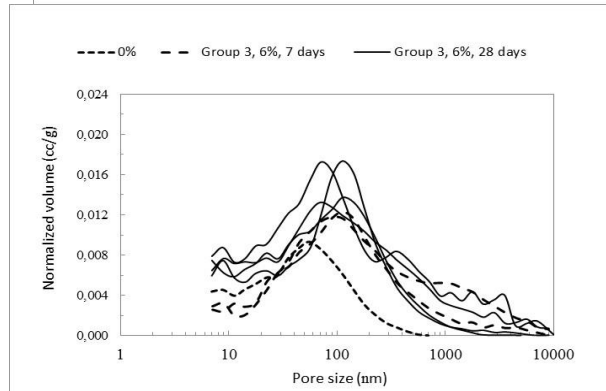
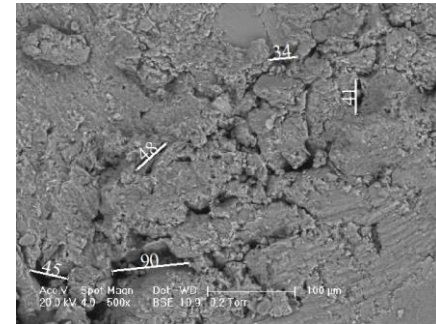
With increasing stresses and strains as in the unconfined compression tests,

the strains become localized at weak planes and therefore the strength is controlled by these weak planes.

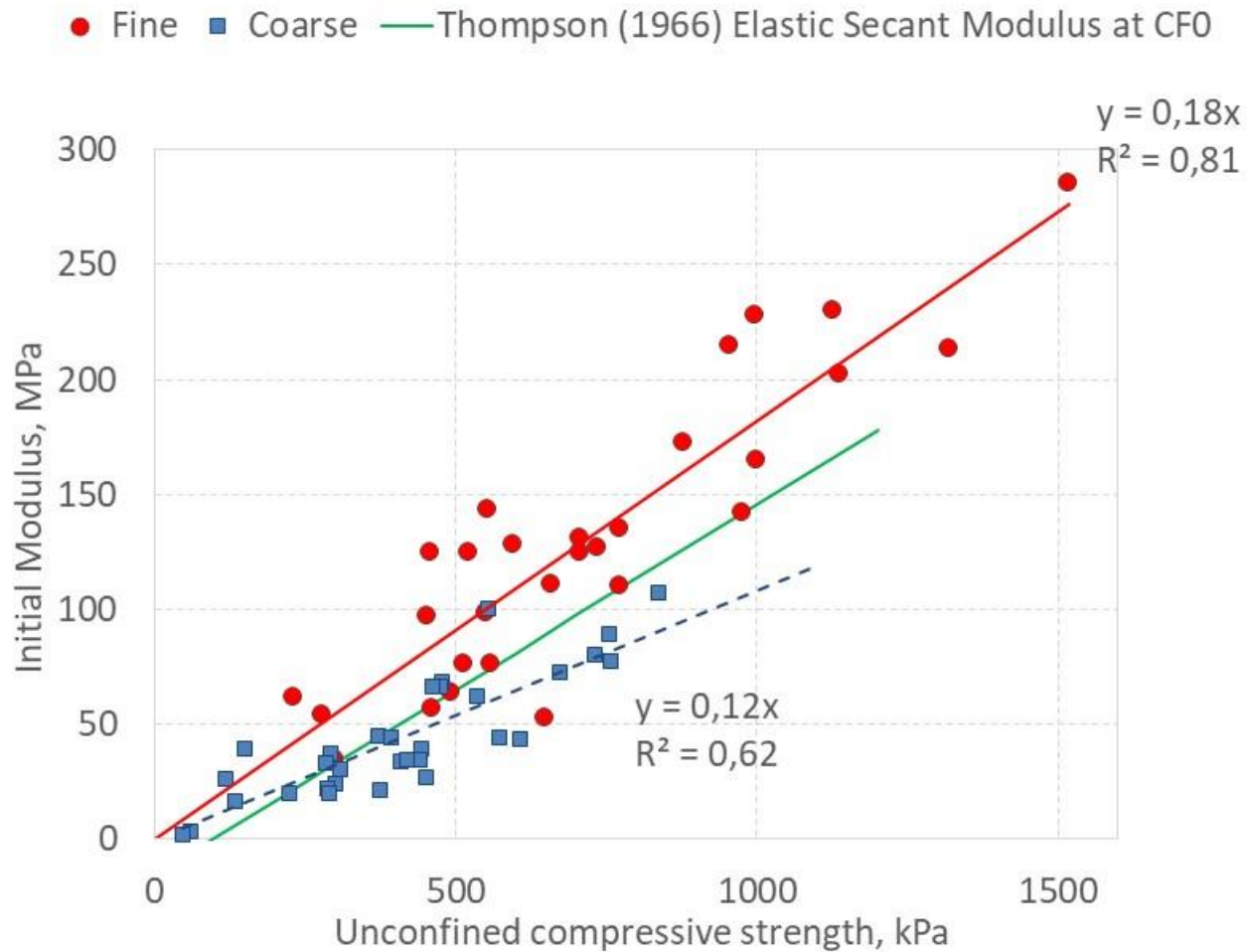
BOZBEY (2017), Microfabric Evaluation of Lime-treated Clays by Mercury Intrusion Porosimetry and Environment Scanning Electron Microscopy



A novel “Pore Size Amplification Factor”, (PSAF) was calculated to determine the amplification and/or deamplification of different pore size ranges compared to the untreated soil.

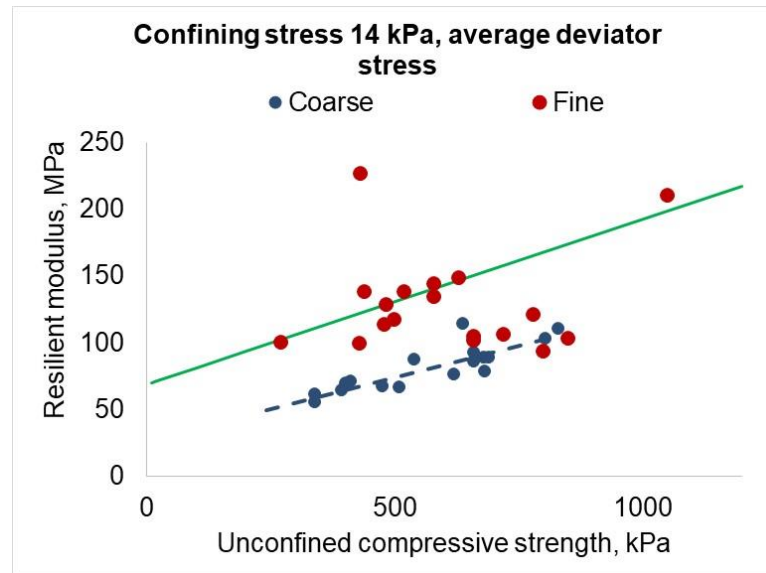


CORRELATIONS

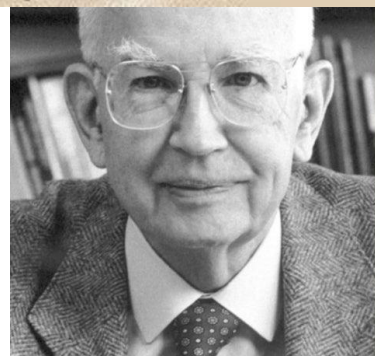


CORRELATIONS

$$M_R = 0,124 * q_u + 68,8$$



CORRELATIONS



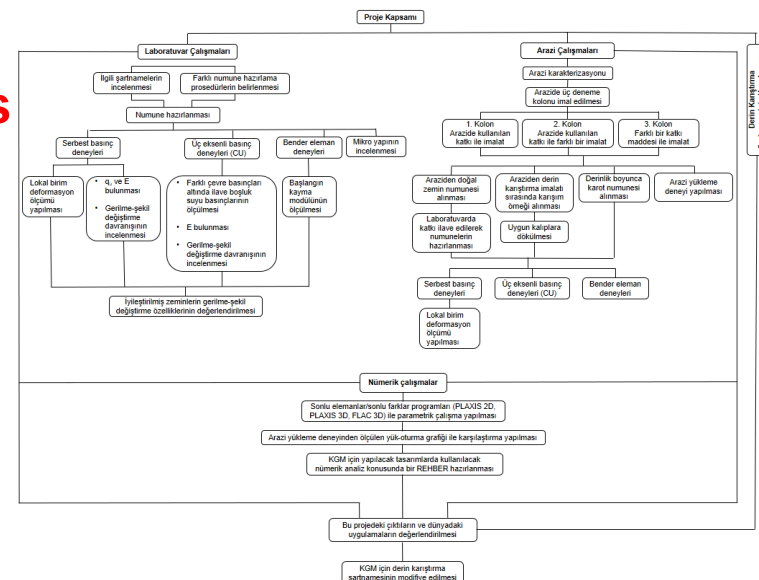
If you torture
the data long
enough, it will
confess to anything.

Ronald Coase

İSTANBUL ÜNİVERSİTESİ
C E R R A H P A Ş A



Specification studies



CONCLUSIONS

- Lime can be used to stabilize high plasticity clays. Proven protocols for laboratory and field should be followed.
- Level of benefit gained from lime stabilization depends not only on lime content, curing duration and stress state but on **soil pulverization level** as well.
- Significant economic and environmental problems may be associated with low quality soil pulverization levels in the field. This should be further studied.

CONCLUSIONS

- For durability considerations, use of high lime contents coupled with fine soil pulverization and extended curing durations is necessary.
- Laboratory testings should be carried out with anticipated field gradations.
- Correlations should include the anticipated field soil pulverization level.
- A lime stabilized pavement approach should include a comprehensive investigation of both resilient modulus and strength.

MY STUDENTS



Sanan Garaisayev from Azerbaijan and
his daughter **ilknur**



Nashat Sarikahya



Muhammed İbrahim



Yavuz Abut



Akin Gokgoz

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THANK YOU