Congreso de Suelos Dispersivos y Sulfatados

Asunción, 24-25/10/19

SPG Sociedad Paraguaya de Geotécnia

APC Asociación Paraguaya de Carreteras

Comité Nacional Paraguayo

World Road Association Mondiale de la Route

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Sulfate Induced Heaving in Stabilized Sulfate Soils

Anand J. Puppala, Ph.D., P.E., D.GE., F.ASCE, F.ICE

Professor | A.P. and Florence Wiley Chair

Zachry Department of Civil and Environmental Engineering

Associate Director – Center for Infrastructure Renewal (CIR)

Texas A&M University, College Station, Texas, USA

&

Former University Distinguished Professor, UT Arlington, Texas, USA

Keynote Talk on October 24-25, 2019

ZACHRY DEPARTMENT OF CIVIL ENGINEERING
TEXAS A&M UNIVERSITY

Presentation Outline

My presentation focuses on the following aspects of sulfate induced heaving in soils:

I. Introduction and Sulfate Heaving Mechanisms

II. Select Case Studies

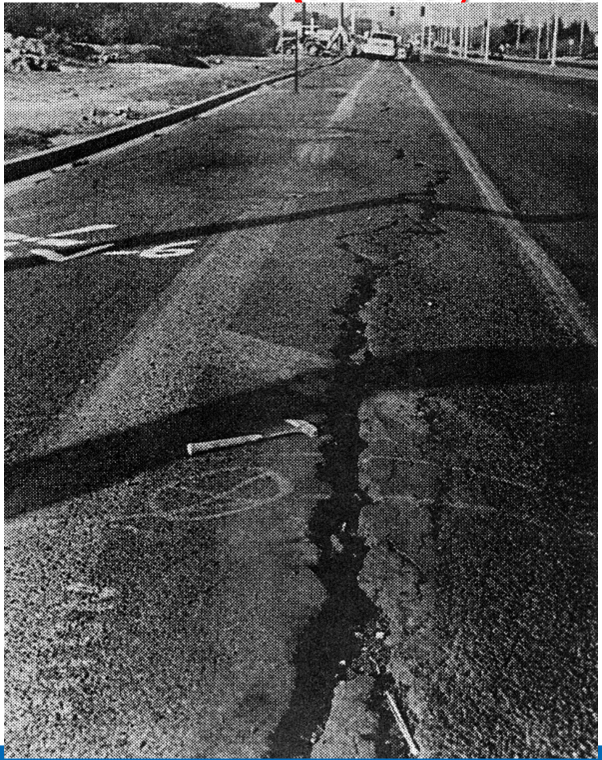
III. Sulfate Measurement Methods & Threshold Sulfate Levels

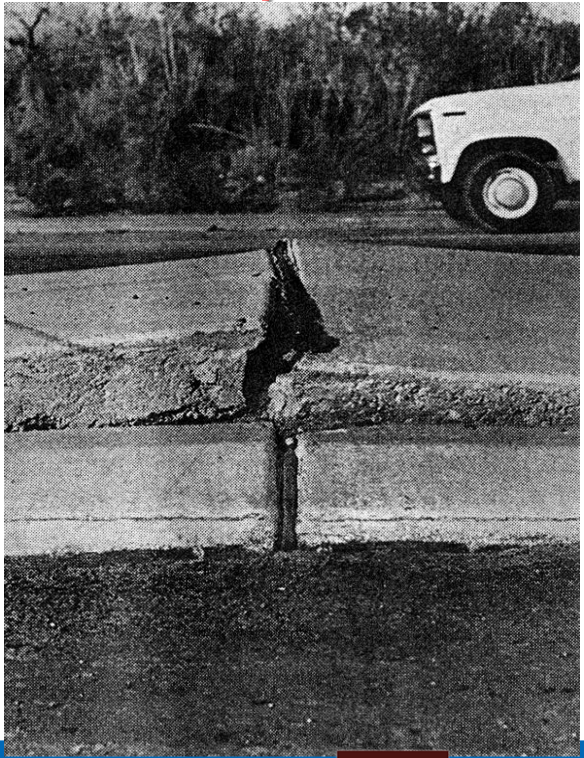
IV. Stabilization of Sulfate Soils

V. High Sulfate Soils Study and Field Implementation

VI. Summary Comments

Why Talk on Sulfate Soils?
A Prominent Case Study: Stewart Avenue, Las Vegas, Nevada
(Hunter, 1988 – ASCE JGGE)



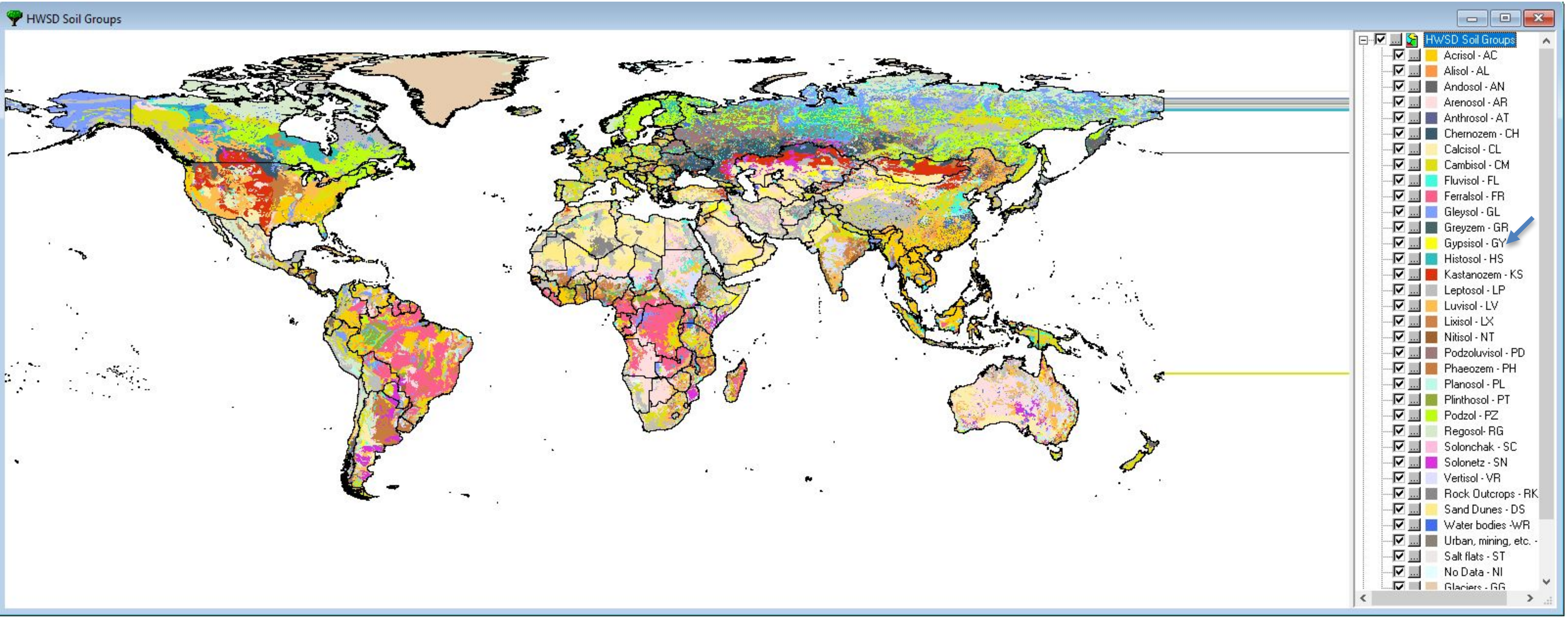


Longitudinal and Transverse Cracks on Stewart Avenue, Nevada

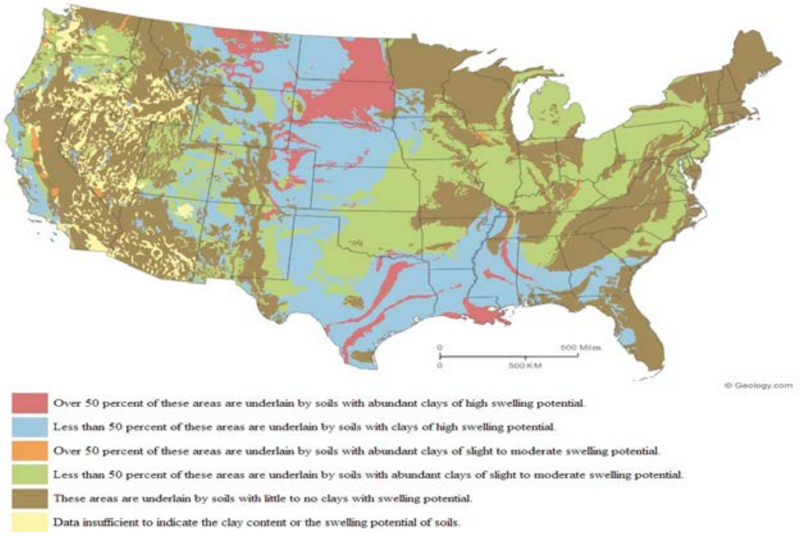
I. Introduction

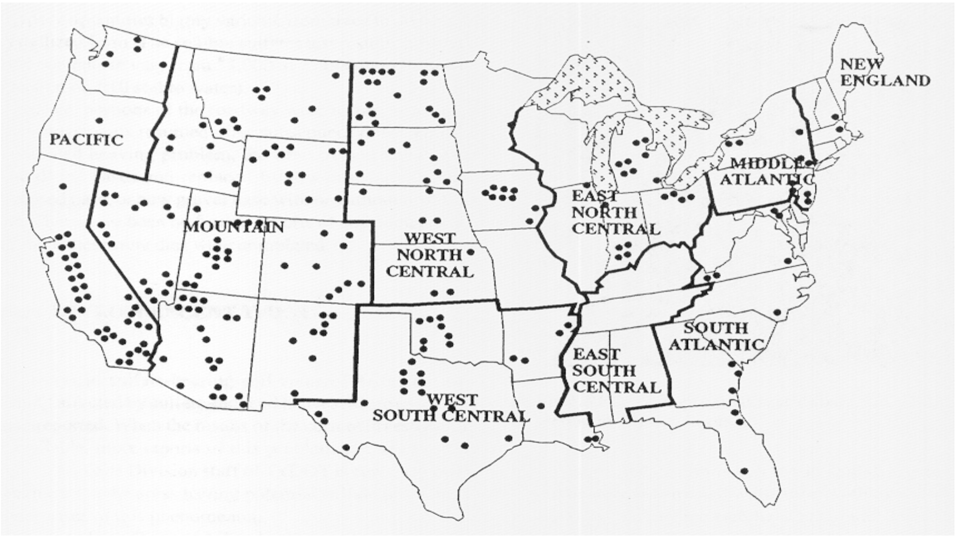
- Natural Expansive Soils
- Man-made Expansive Soil
  - Calcium based stabilizer treated sulfate soils
  - Sulfate induced heave - Ettringite
- Sulfate Heaving – Dr. Mitchell's 1986 Terzaghi lecture
- Sulfate Soil Problems in the World (USA, Paraguay, UK, Spain, India, Eastern Europe, Egypt, Saudi Arabia & Many Others)
- In USA
  - Initial focus was on southwestern states
  - More than 20+ states

Sulfate Soils in the World



Expansive and Sulfate Soils in USA

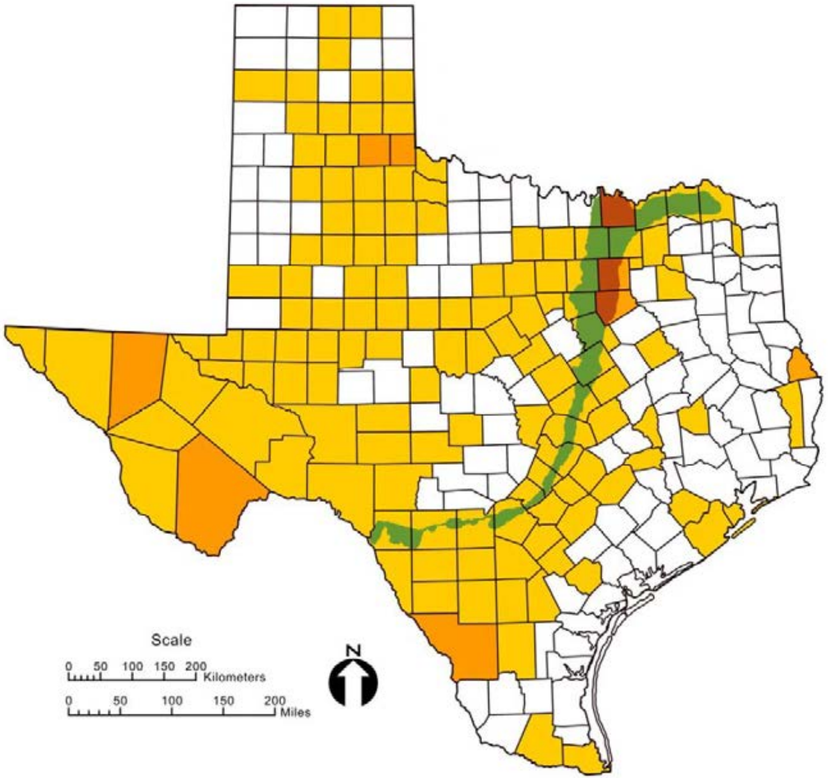




Source: USGS Surveys

Sulfate Soils

Sulfate Soils in Texas



Source: Harris et al. (2004)

Gypsum

- **Sources of Sulfates in Soil**
  - **Gypsum ($CaSO_4.2H_2O$)**
  - **Sodium Sulfate (Na_2SO_4)**
  - **Magnesium Sulfate ($MgSO_4$)**

Gypsum Crystals in Soil Formation

I. Sulfate Heave Mechanisms: Ettringite

$$CaO + H_2O \rightarrow Ca^{2+} + 2OH^-$$

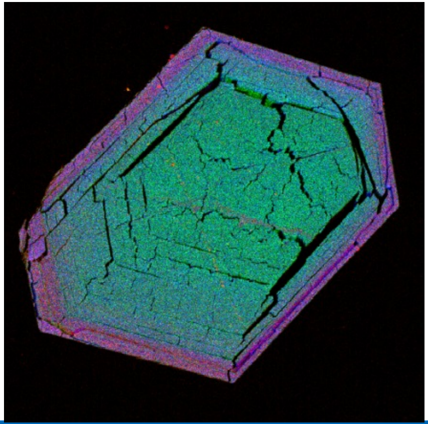
(Hydration of Lime – Free Calcium)

$$Al_2Si_4O_{10}(OH)_2 \bullet nH_2O + 2(OH)^- + 10H_2O \rightarrow 2Al(OH)_4^- + 4H_4SiO_4 + nH_2O$$

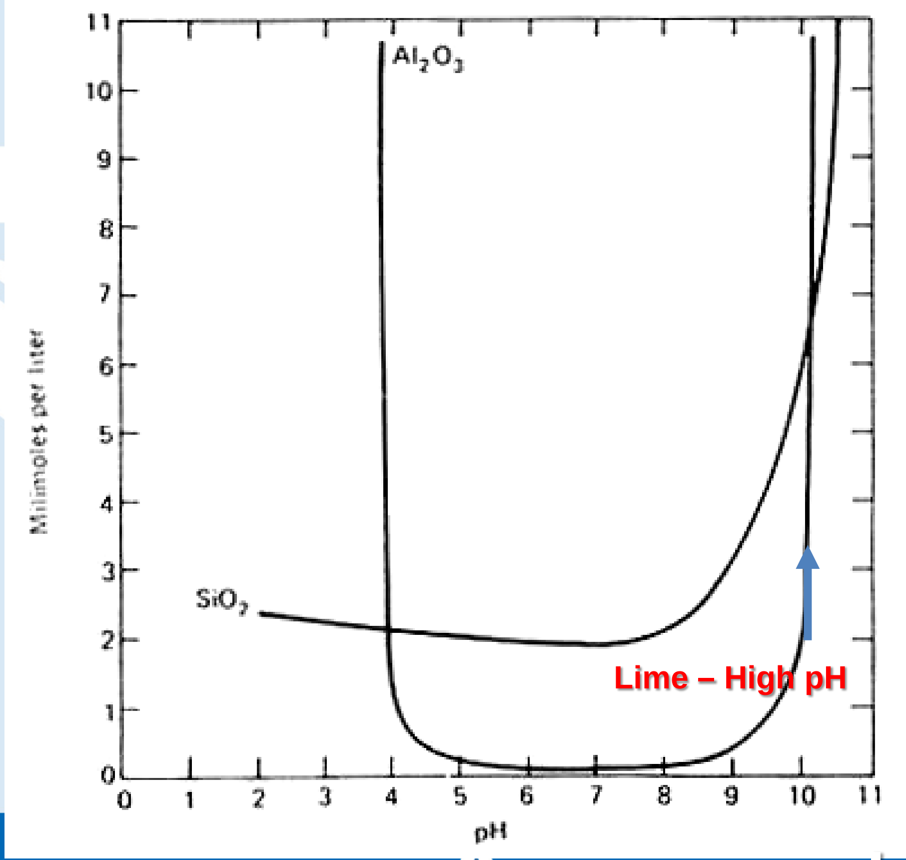
(Dissolution of clay mineral at pH>10.5, Free Alumina)

$$6Ca^+ + 2Al(OH)_4^- + 4OH^- + 3(SO_4)^{2-} + 26H_2O \rightarrow Ca_6[Al(OH)_6]_2 \bullet (SO_4)_3 \bullet 26H_2O$$

(Formation of Ettringite)



Solubility of Alumina and Silica in Water



I. Sulfate Heave Mechanisms: Thaumasite

$$CaO + CO_2 \rightarrow CaCO_3$$

(Carbonation of Lime)

$$CO_2 + H_2O \rightarrow H_2CO_3$$

(Formation of carbonic acid)

$$CaCO_3 + H_2CO_3 \rightarrow Ca^{2+} + 2H^{+} + 2CO_3^{2-}$$

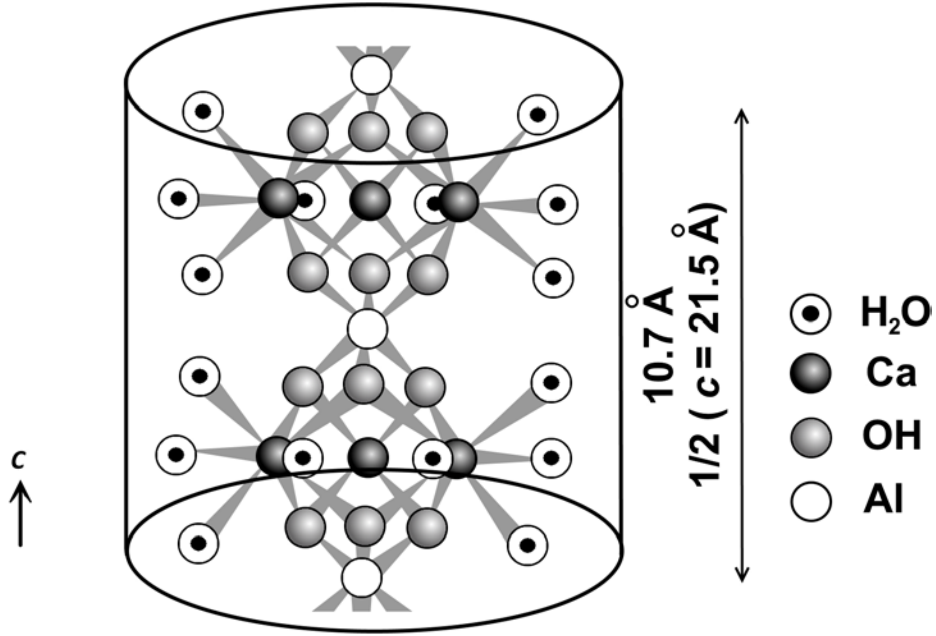
(Dissolution of calcite in carbonic acid)

$$Ca_6[Al(OH)_6]_2 \bullet (SO_4)_3 \bullet 26H_2O + 2H_2SiO_4^{2-} + 2CO_3^{2-} + O_2 \rightarrow$$

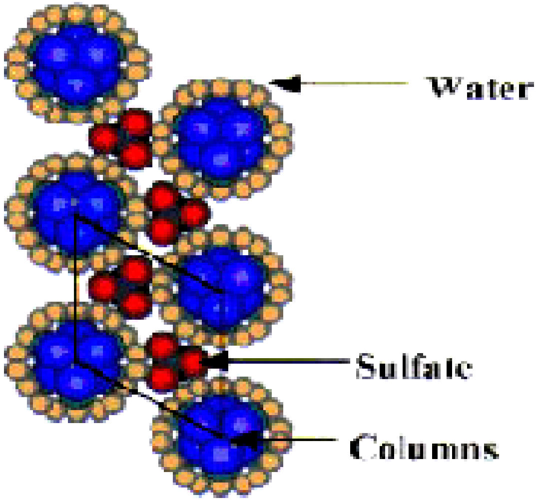
$$[Ca_3Si(OH)_6]_2(SO_4)(CO_3)_2 \bullet 24H_2O + 2Al(OH)_4^{-} + SO_4^{2-} + 4OH^{-} + 2H_2O$$

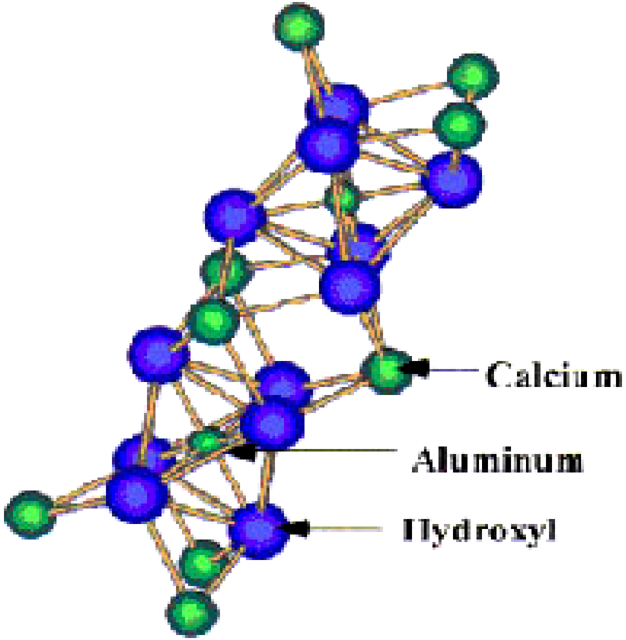
(Isostructural substitution of Ettringite to Thaumasite)

Ettringite Mineral Structure

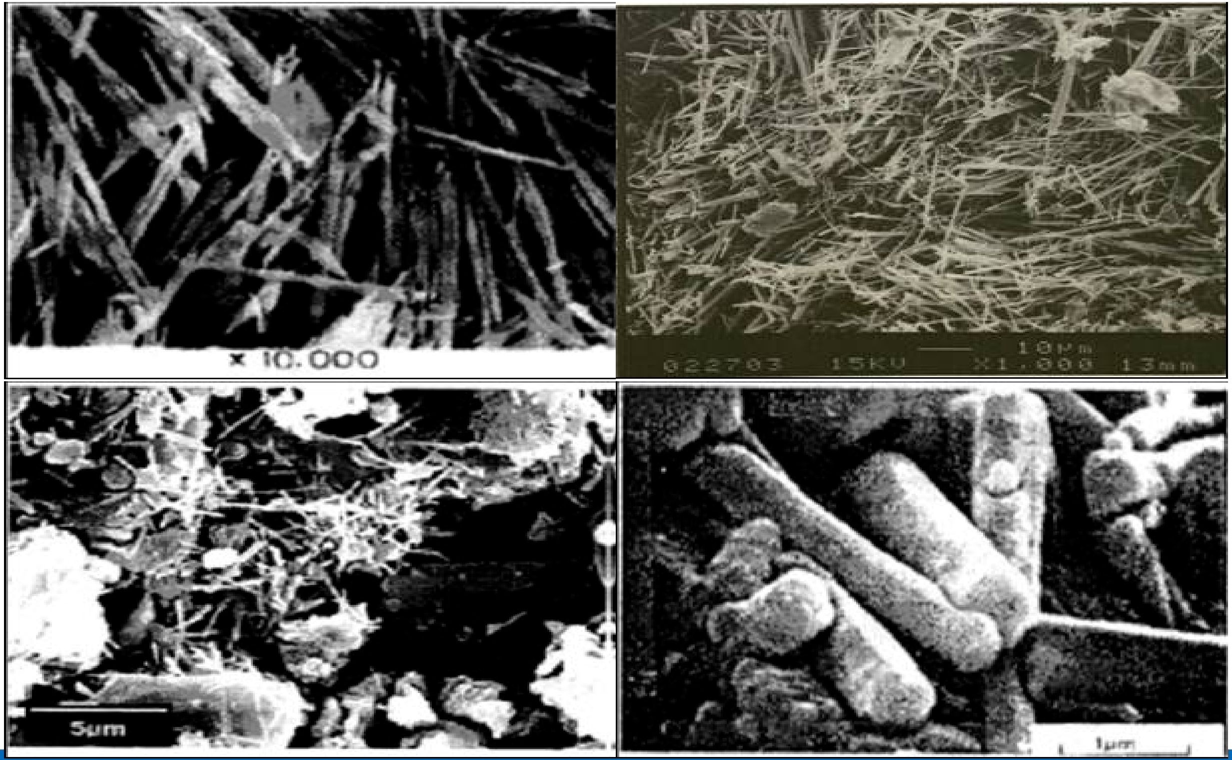


Ettringite



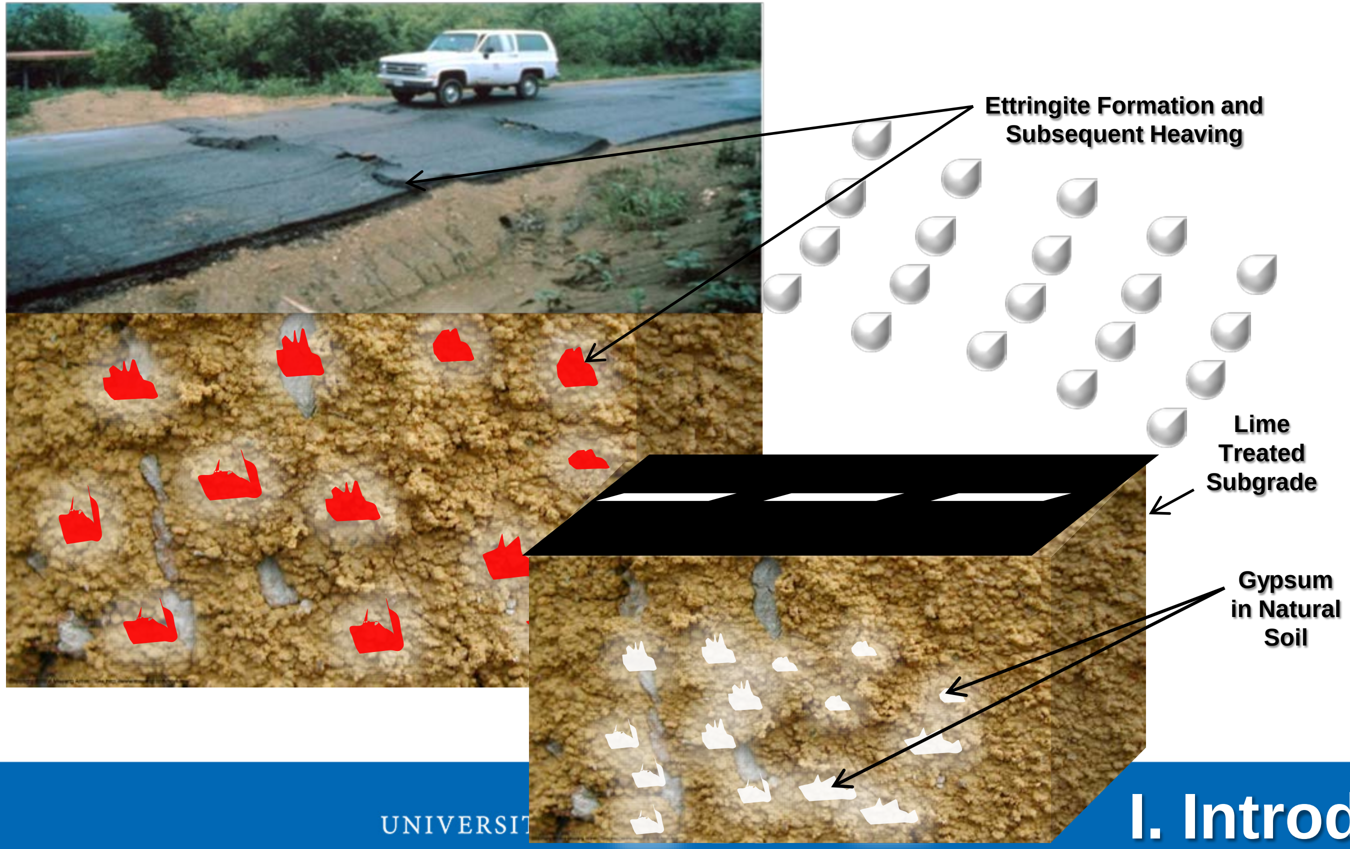


Various Forms of Ettringite: SEM Studies



Mitchell and Dermatas, 1992; Talero, 2002; Harris, 2004; Wang, 2004

Sulfate Heaving Phenomenon



Sulfate Heave Mechanisms

1. **Crystal Growth Theory: Ogawa & Roy (1982)**
   - Ettringite forms around calcium aluminum sulfate particles
   - Crystals grow due to entry of water
   - Expansion by intersection of adjacent reaction zones
   - Soil-lime system: Higher void ratio
   - Initial Ettringite is accommodated in soil voids
   - Additional Ettringite cannot be accommodated
2. **Hydration Theory: Mehta (1973)**
   - Expansion due to adsorption of water
   - Depending on hydroxyl concentrations
     - Large lath-like crystals
     - Small rod-like crystals
   - Small crystals cause expansion due to high surface area

II. Case Studies

Location	Soil Type	Nature of reaction products formed	Lime/ Cement Percent Level	Sulfate Content (mg/kg)	Heave Appearance after Construction
Parking Lots, Kansas, Southern California	N/A	Ettringite	NA	NA	NA
Stewart Avenue, Las Vegas, Nevada	Silty clay	Ettringite and Thaumasite	4.5% (L)	43,500	6 months
Lloyd Park, Joe Pool Lake, Dallas, Texas	OC Clays	Ettringite	5% (L)	2,000 – 9,000	Immediately
Auxiliary Runway, Laughlin AFB, Spofford, Texas	Clays	Ettringite	6-9% (L)	14,000 – 25,000	2 months
Cedar Hill State Park, Joe Pool Lake, Dallas, Texas	Highly plastic residual clays	Ettringite	6% (L)	21,200	2 months
Denver International Airport, Denver, Colorado	Expansive Clays	Ettringite	NA (L)	2,775	NA
SH-118, Alpine & SH-161, Dallas	Clayey Subgrades	Ettringite	4% (C) 6-7%(L)	>12,000	6 to 18 months
Dallas – Fort Worth International Airport, Irving, Texas	Clay	Ettringite	5% (L)	320 – 13,000	3 months
Near Shreveport, Louisiana	Aggregates	Ettringite	NA	NA	NA
Holloman Air Force Base, NM	Crushed Concrete	Ettringite	NA	NA	Several years
U.S.82,TX	N/A	Ettringite	6%(L)	100-27800	Immediately
Baylor Creek Bridge, Childress, TX	All soils	Ettringite	5%(L); 3%(C)	6800-35000	Several years
Western Oklahoma	Clays	Ettringite	0-5%(L)	194-84000	NA

Heaving on Joe Pool Lake Road, Grand Prairie, Texas

II. Case Studies

Source:
Les Perrin, USACE

II. Case Studies

Joe Pool Lake (Les Perrin, US Army Corps of Engrs)

II. Case Studies

Heaving on US 67, Midlothian, Texas

II. Case Studies

Source: Wimsatt, 1999

II. Case Studies:
Airport Taxiway, North Texas

Taxiway – Shoulders large number of cracks

Subsoils Near DFW Airport
Sulfate Contents > 30,000 ppm

Subgrade Soil with High Sulfates

Tests on Subsoils

- High Sulfates > 5000 ppm
- Gypsum – Main Source
- Taxiway Shoulders – Asphalt Concrete Section
  - Heave related cracking
- Taxiway – Concrete Pavement – No distress
- Heave varied from 2 in. to as high as 12 in.
- Water ditch close to section that heaved

Tunnel Case Study

Heaving on Tunnel Liners – Field Sampling

II. Case Studies: Tunnel Liner Cracking in Dallas

- Tunnel in Dallas Area Rapid Transit System
- Limestone Bedrock and Shotcrete Tunnel Liner
- Cracks at Several Location
- Was it Sulfate Heaving?
- Candidate for Further Deterioration?

II. Case Studies: Parameters Affecting Ettringite Induced Heaving

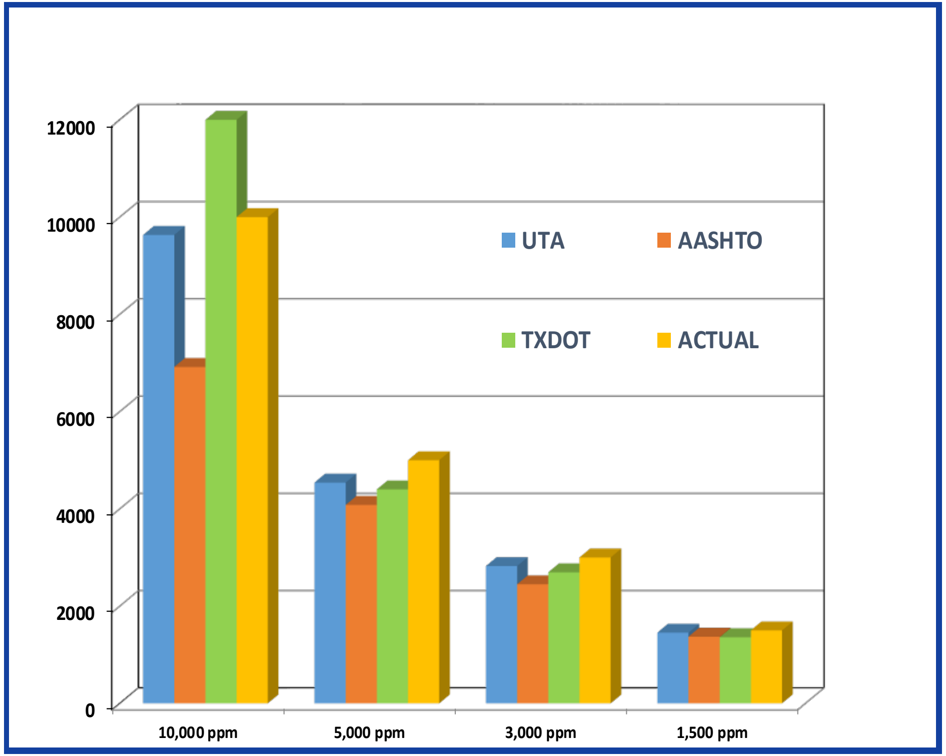
- Soil Type
- Soluble Sulfates
- Amount of Calcium Additives
- Curing Time and Temperature
- Availability of Water
- Compaction Moisture Content and Dry Unit Weight Condition

III a. Sulfate Measurement Methods

- Variability in Sulfate Levels
  - Measurement Technique (Puppala et al., 2002)
- Sulfate Measurement Techniques
  - Gravimetric methods
    - Modified UTA Method
    - AASHTO Method (T 290-95)
  - Turbidity Based
    - TxDOT Method (Tex-145-E)
    - ASTM Method (ASTM C-1580)

III a. Sulfate Measurement Methods

- **Modified UTA Method**
  - 1:10 Soil/Water Dilution Ratio
  - 0.1 µm Membrane Filter Paper
  - Sulfate is Precipitated as Barium Sulfate ($BaSO_4$)
- **AASHTO Method (T209-95)**
  - 1:3 Soil/Water Dilution Ratio
  - 0.45 µm Membrane Filter Paper (Coarser)
  - Barium Sulfate Weight
- **TxDOT Method (Tex-145-E)**
  - 1:20 Soil/Water Dilution Ratio
  - Filtration Using Whatman No. 42 Filter Paper
  - Colorimeter to Determine Sulfate Turbidity



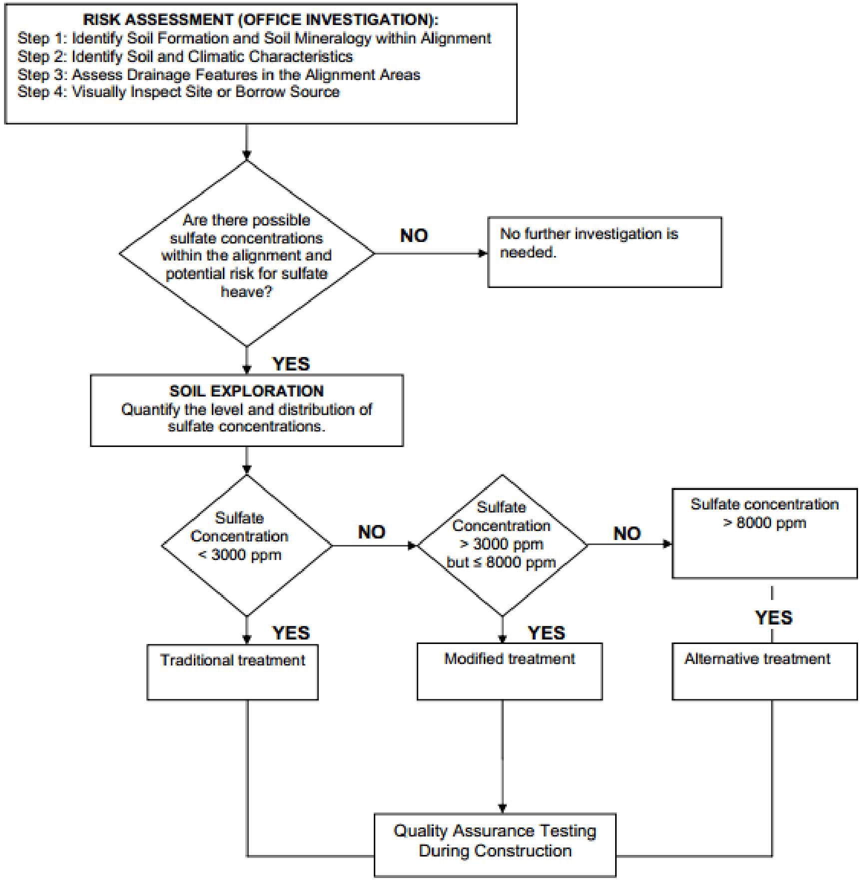
III b. Problematic Sulfate Levels

- In Most Sulfate Heave Case Studies (from Previous Slide)
  - Sulfate Levels Varied from
    - 320-43,500 ppm (Broad Range)
- Puppala et al. 2003 – NSF Funded Study
  - Sulfate Level ≤ 1,000 ppm: No Issues
  - 1,000-2,500 ppm: Lower Swell with Increased Lime Dosage
  - > 2,500 ppm: Problematic, Also dependent on compaction conditions

III b. Problematic Sulfate Levels

- **Sulfate Levels (TxDOT)**
  - **Low Risk: < 3000**
  - **Medium Risk: 3000 to 5000ppm**
  - **Moderate to High Risk: 5000-8000ppm**
- **Sulfate Levels > 8000ppm**
  - **<u>High Sulfate Soil</u>, Severe Concern**
  - **Remove and Replace Sulfate Soils or Blend in Non-Plastic Soils**
    - ***Economic and Sustainability Impacts***

IV. Stabilization of Sulfate Soils

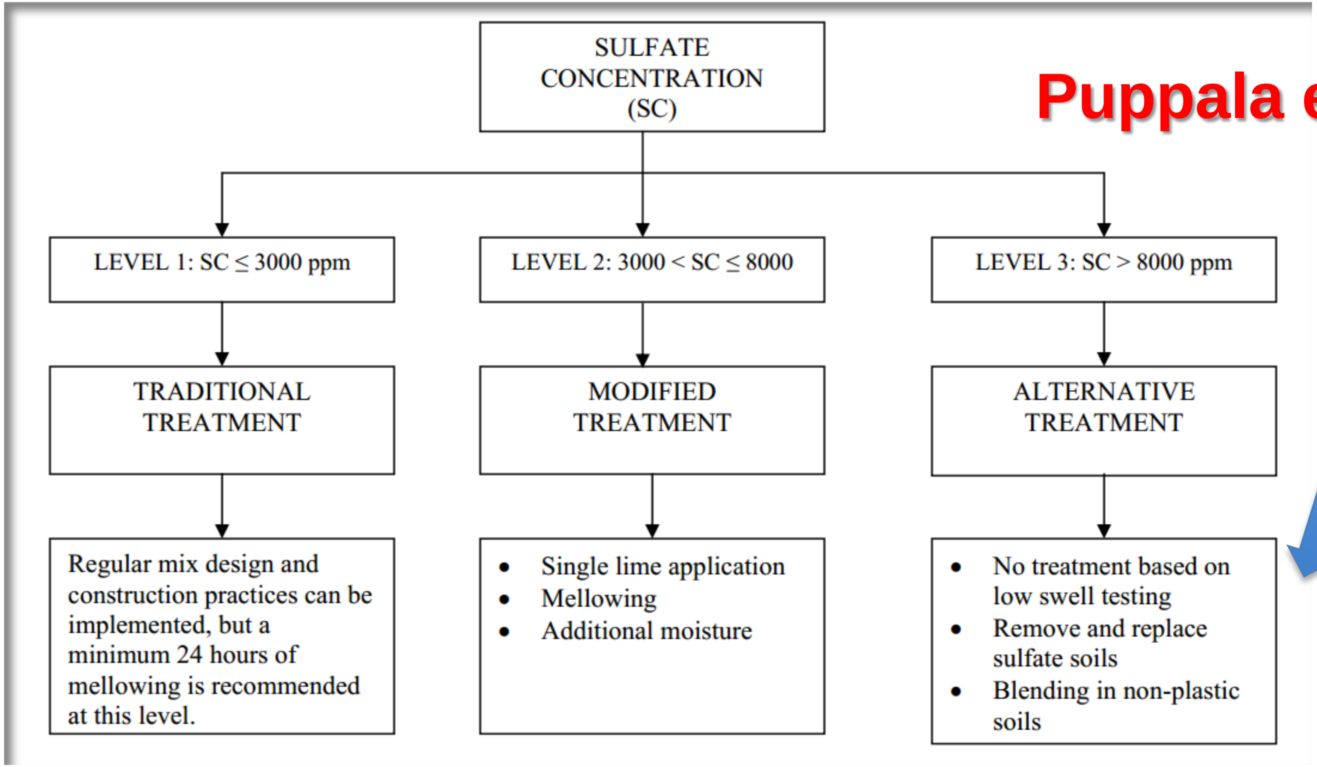


TxDOT Practice:

Drs. Little, Puppala, Petry, Harris and many others

(PLEASE NOTE - 1500 ppm Can Be Problematic)

IV. Stabilization of Sulfate Soils



Puppala et al. 2019

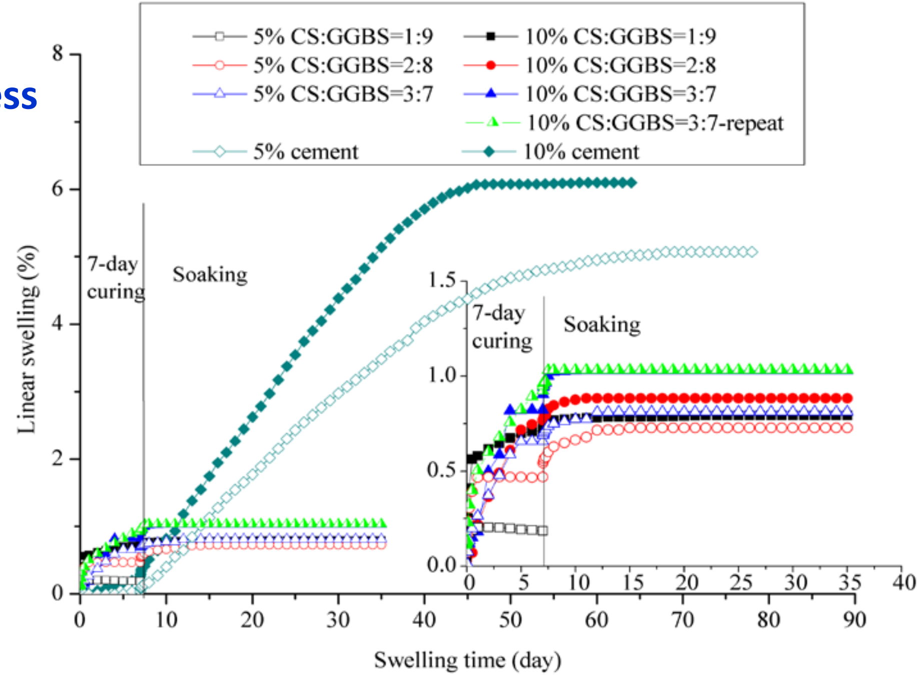
TxDOT Practice

IV. Stabilization of Sulfate Soils: Various Methods

- Ground Granulated Blast Furnace Slag (GGBS)
  - Shown to be Successful in US and UK
- Sulfate Resistant Cements: Type II and Type V
  - Laboratory Results Show Successful Stabilization
- Class F Fly Ash – Co-additive
- Double Lime Treatment
  - Mixed results
  - Heave will reappear

Treating Gypseous Soil Using Carbide Slag (CS)-Ground Granulated Blastfurnace Slag (GGBS)

- CS is by-product from acetylene gas production, GGBS is by-product from steel making
- Swell significantly less
- Cease swell earlier



Collaborator: Dr. Yaolin Yi, Nanyang Technological University (NTU), Singapore

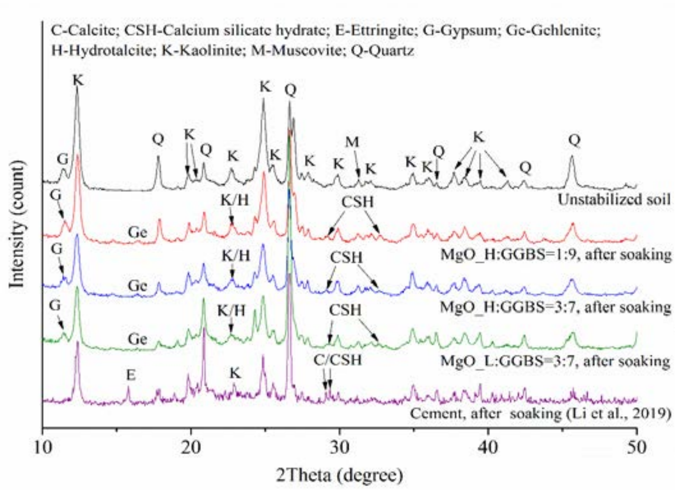
yiyaolin@ntu.edu.sg

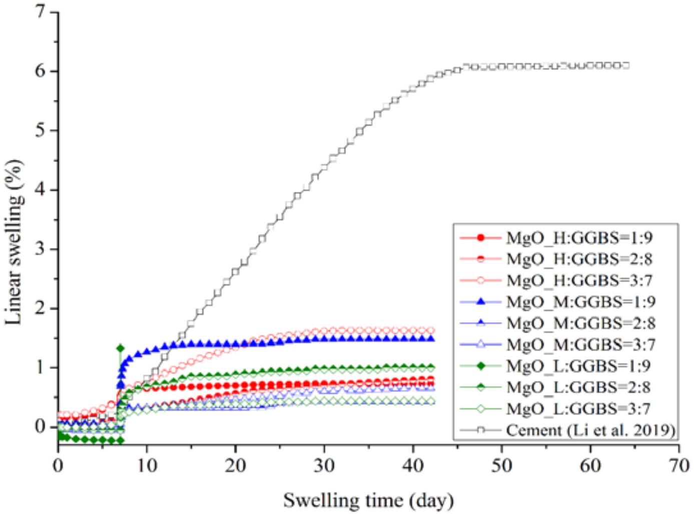
IV. Stabilization...

Li, W., Yi, Y. & Puppala, A.J. (2019). Utilization of carbide slag-activated ground granulated blastfurnace slag to treat gypseous soil. Soils & Foundations, 10.1016/j.sandf.2019.06.002.

Treating Gypseous Soil Using Reactive Magnesia- (MgO)- Ground Granulated Blastfurnace Slag (GGBS)

- Reactive MgO is calcinated at low temperatures of 700–800° C
- Gypsum remain unreacted, NO ettringite produced
- Swell less, cease swell earlier



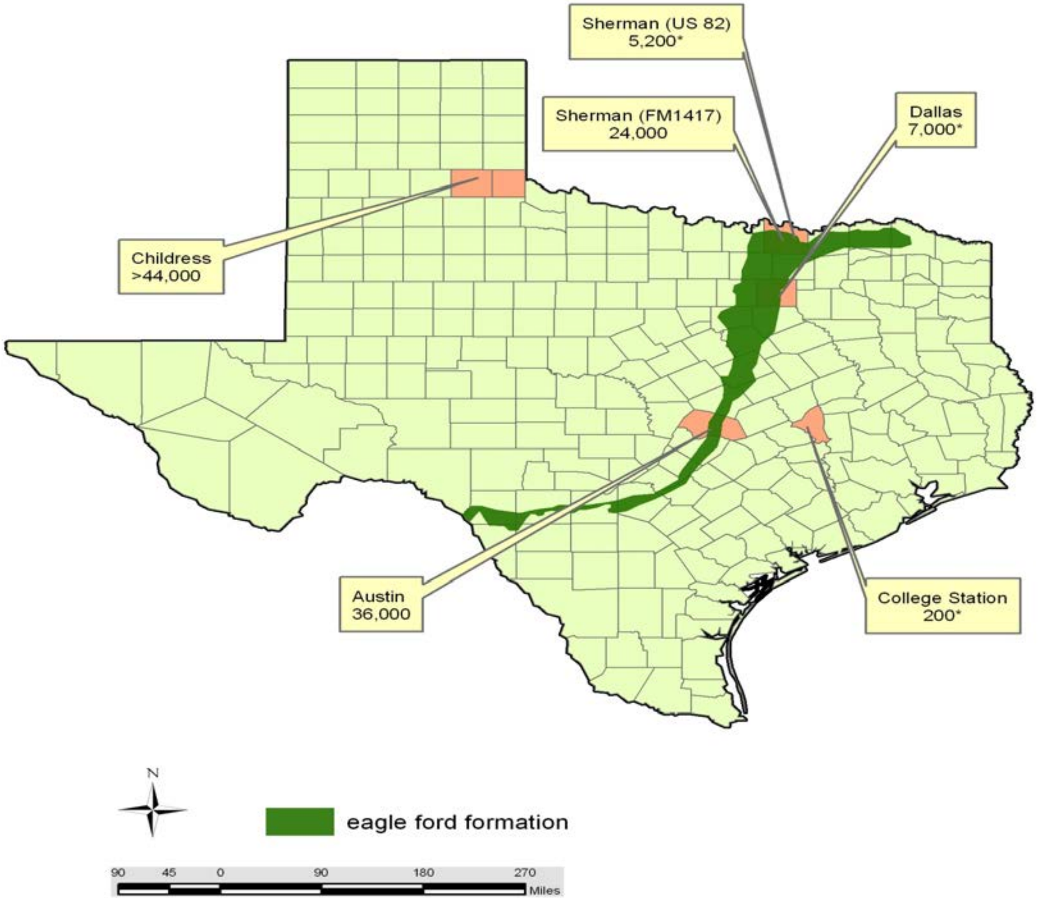


Treatments for High Sulfate Soils (Sulfates > 8000 ppm)

- Extended Mellowing Period
- Lime and Fly Ash
  - Research Project with Texas DOT
  - Lab and Field Studies

IV. Stabilization...

V. High Sulfate Soils Study – TxDOT Funded

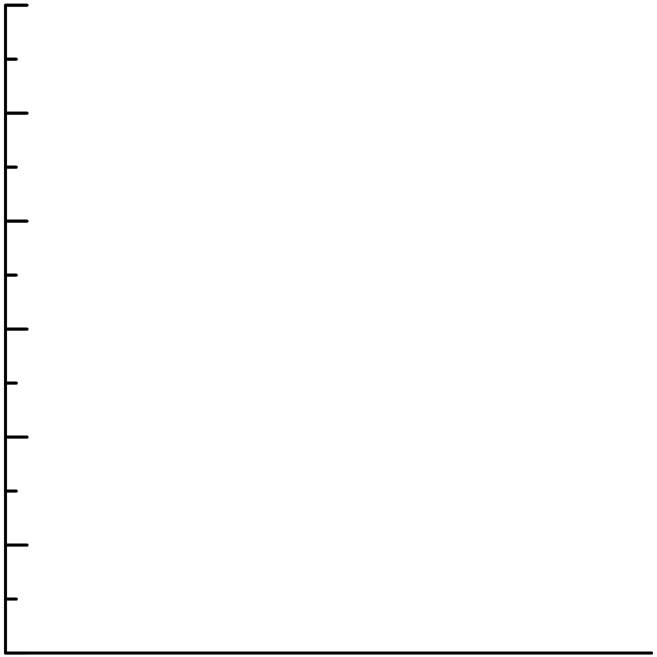


Soil Classification and Testing Variables

Soil	Atterberg Limits			USCS Classification	Soluble Sulfates, ppm
	LL	PL	PI		
Austin	76	25	51	CH	36,000
Childress	71	35	36	MH	44,000
Dallas	80	35	45	CH	7,000*
Sherman	72	30	42	CH	24,000
Riverside	35	11	24	CL	200*
US-82	75	25	50	CH	5,200*

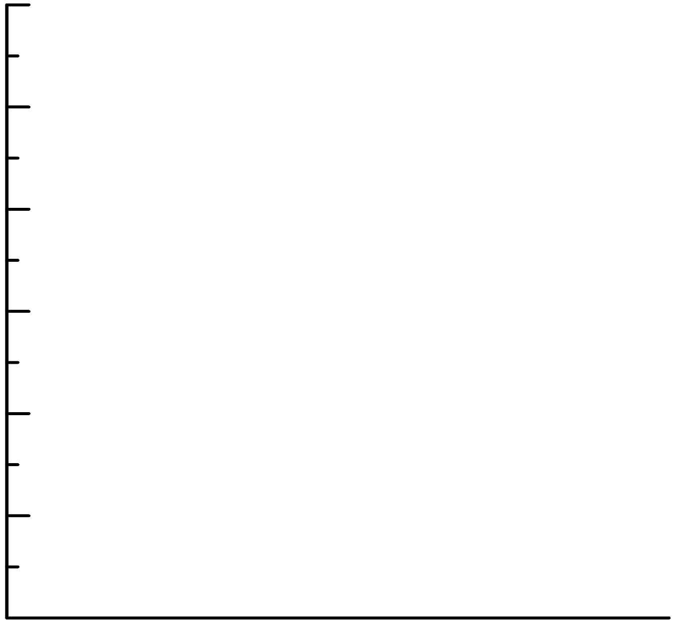
Description	Variable
Soils	Six (Austin, Childress, Dallas, Sherman, Riverside, and US-82)
Sulfate Contents	Five (12,000 ppm; 20,000 ppm; 24,000 ppm; 36,000 ppm; and 44,000 ppm)
Stabilizer	One (Lime)
Dosage	One (6%)
Compaction Moisture Contents	Two (Optimum, OMC and Wet of optimum, WOMC)
Mellowing Periods	Three (0, 3 and 7 days)

3D Volumetric Swell Tests - Cont'd..

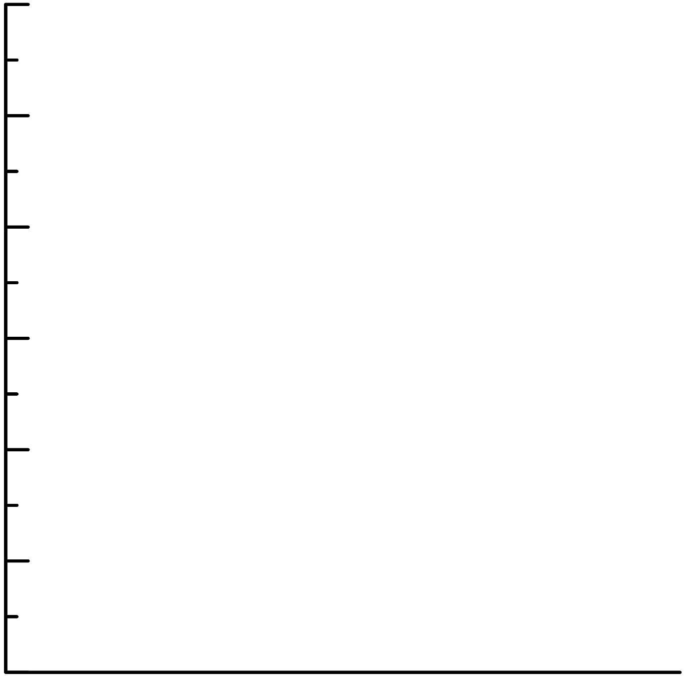


Sherman Soil ('CH'; 24,000 ppm sulfates)

Riverside Soil ('CL', 20,000 ppm sulfates)



3D Volumetric Swell



Childress Soil
(‘MH’; 44,000 ppm sulfates)

Reactive Alumina and Silica Measurements

Soil	Natural		0 day mellowing		3 day mellowing	
	Al	Si	Al	Si	Al	Si
Austin	**58.9**	**15.4**	22.8	6.1	18.9	5.1
Childress	**75.8**	**12.6**	28.1	5.9	32.2	7.2
Dallas	289.9	231.2	87.6	68.2	122.2	69.2
Sherman	279.2	137.3	115.9	47.1	131.9	50.3
Riverside	297	379.8	108.8	42.8	183.7	49.4
US-82	323.3	187.1	94.2	19.9	135.6	27.3

Relatively Lower Reactive Alumina/Silica in Austin and Childress Soils

Compaction Void Ratios

Soil Type	Sulfate Content, ppm	Void ratio, e @ OMC
Austin	36,000	**0.54**
Childress	44,000	**0.52**
Dallas	12,000	0.84
Sherman	24,000	0.86
Riverside	20,000	0.61
US-82	12,000	0.82

Low Compaction Void Ratios – Less Space for Ettringite

Analysis of Test Results

- Effects of Pre-Compaction Mellowing
  - Swell Behavior
    - Effective in 4 of the 6 soils (Dallas/Sherman/Riverside/US-82)
    - Reduced swell magnitudes at 3 and 7 day mellowing
      - All 4 soils have sulfates < 30,000ppm
    - Ineffective in Austin and Childress soils
      - Sulfate levels > 30,000ppm
  - Shrinkage Behavior
      - Not a Concern in Treated High Sulfate Soils

Analysis of Test Results (Cont’d..)

- **Reactive Alumina/Silica**
  - **Lowest reactive alumina/silica**
    - **Ettringite formation favored at low alumina levels**
    - **Low Silica contents result in lower stabilization reactions**

- **Effect of Void Ratio**
    - **Lowest Void Ratios in Austin/Childress**
    - **Low Void Space for Ettringite Accommodation**

V. High Sulfate Soils - Field Studies

Development of Design and Construction Guidelines for High Sulfate Soils

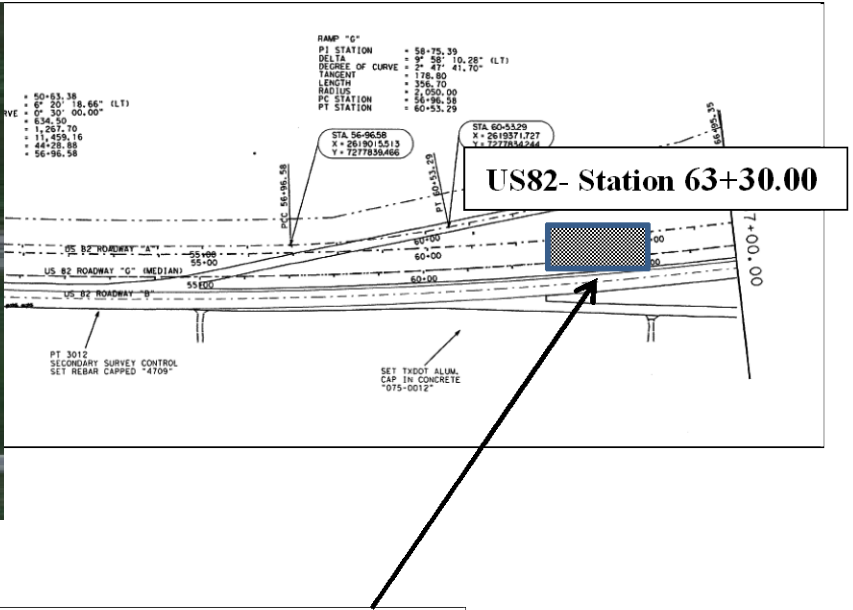
- **Test Sections for field Monitoring (US-82)**
  - **Station 1 – Lime + FlyAsh with extended mellowing**
  - **Station 2 – Lime with extended mellowing**
  - **Station 3 – Lime with no mellowing (control site)**
- **Field Studies**
  - **Elevation Surveys**
  - **UAV Surveys**
  - **FWD and surface profiling**
  - **Laboratory studies**

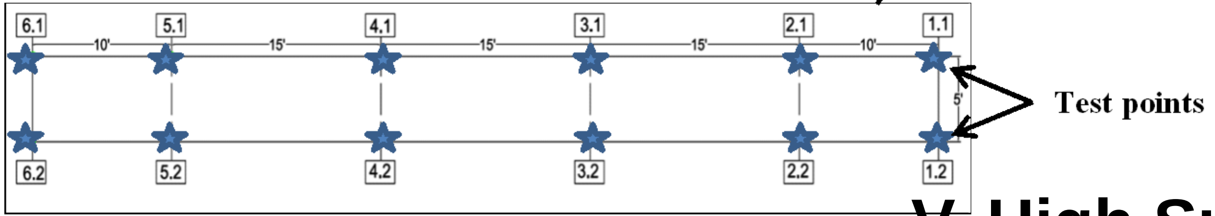
V. High Sulfate Soils- Field Studies

Days	3 Sections		
	Lime + Fly Ash Extended mellowing	Lime Extended mellowing	Lime – mellowing: Control
1	Lime Treated subgrade (6%) light compact	Lime Treated subgrade (6%) light compact	Lime Treated subgrade (6%) light compact
2-3	Mellowing period	Mellowing period	Mellowing & Final Compact
4	Recut & Light Compact	Recut & Light Compact	-
5	Mellowing period	Mellowing period	-
6	Recut & Light Compact	Recut & Light Compact	-
7	Mellowing period	Remix & Final Compaction	-
8	Fly ash treatment (3%) & Light Compact	-	-
9	Mellowing period	-	-
10	Remix & Final Compaction	-	-

V. High Sulfate Soils - Field Studies

Stations 1, 2 and 3 (3 is Control)

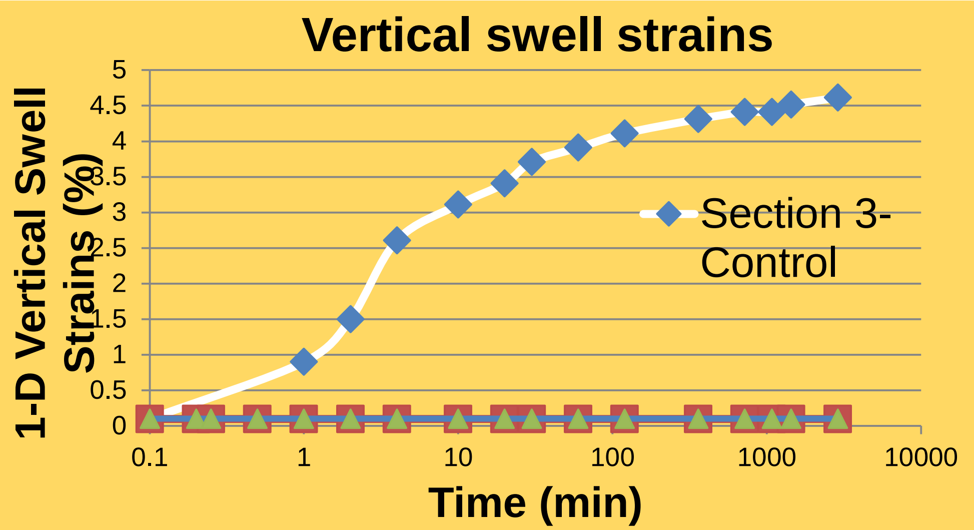


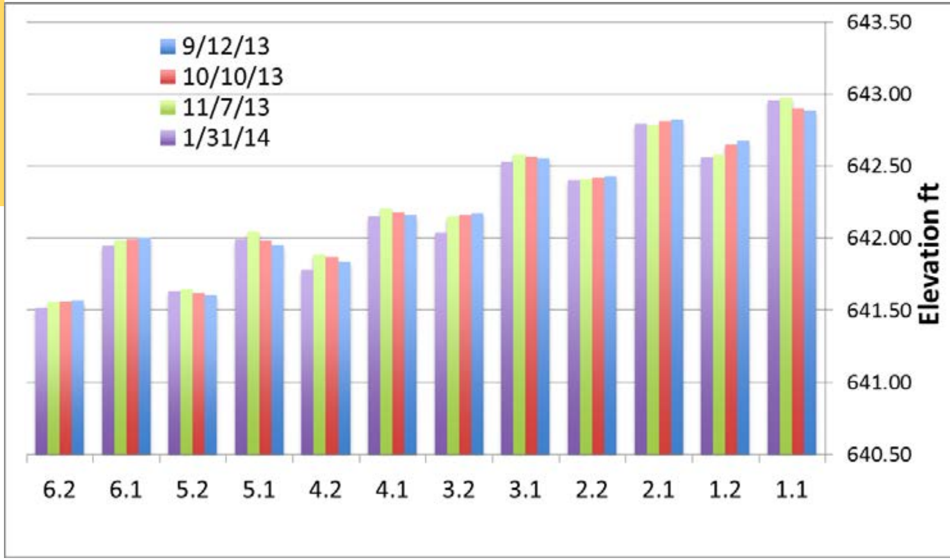


V. High Sulfate Soils - Field Studies

Stations 1, 2 and 3

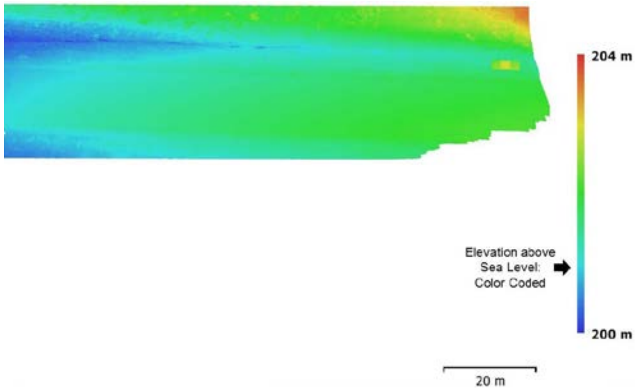
V. High Sulfate Soils
- Field Studies





V. High Sulfate Soils: Field Studies

V. Field Studies – Conclusions



Dr. Congress Presentation Covers These

1. **Mellowing technique worked for Sherman soil whereas In Childress soil volumetric swell increased with mellowing. Low initial reactive alumina and high sulfate contents are the reasons for ineffectiveness of mellowing in Childress soils**
2. **In soils with high compaction void ratios initial Ettringite growth can be accommodated within the soil matrix**
3. **Field implementation studies studied three methods including Lime with extended mellowing, Lime and fly ash treatments and control lime treatment. Field data collection showed that both lime-fly ash and lime with extended 7+ day mellowing methods provided improvements to high sulfate soils with less heaving**

Mitigation of High Sulfate Soils in Texas

Anand J. Puppala, Ahmed Gaily, Aravind Pedarla, Aritra Banerjee
Department of Civil Engineering, The University of Texas at Arlington, Arlington, Texas, 76019

Concept

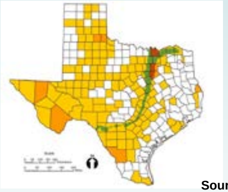
- Pavement distress in chemically stabilized sulfate bearing soils is a growing concern for highway agencies

Source: Les Perrin, USACE

- Researchers have conducted studies on heave mechanisms in chemically treated soils containing sulfate levels below 10,000 ppm
- In most of the heave cases the sulfate contents were reported to be as high as 50,000 ppm
- The main intent of the research is to understand heave mechanisms in soils with sulfate contents above 10,000 ppm

Background & Innovation

- Sulfate Bearing Expansive Soils



Source: Harris et al. (2004)

- Lime/Cement treated bases are used to support the pavement infrastructure
- Some of these expansive soils contain sulfate minerals such as Gypsum ($CaSO_4.2H_2O$) in their natural formation
- $6Ca^{+} + 2Al(OH)^{4-} + 4OH^{-} + 3(SO_4)^{2-} + 26H_2O \rightarrow Ca_6[Al(OH)_6]_2 \bullet (SO_4)_3 \bullet 26H_2O$

(Formation of Ettringite)

Gypsum Crystals in Natural Soil

Laboratory Testing Program

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Performance Evaluation Studies

FWD and Surface Profiler Studies

Acknowledgements

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- Pat Harris, Sam Houston State University

VI. Summary Comments

- Sulfate Heave Problems – Man made expansive soil problem – problems to pavement infrastructure
  - Sulfate Measurements in Soils – Common test in geotechnical site characterization investigations
- Problematic Sulfate threshold levels – Varies
- Treatment Methods: Low to Moderate Sulfate soils (< 8000 ppm)
  - Sulfate Resistant Cements & Blast Furnace Slag Showed Promise
  - Class F-Fly Ash - Co-additive with low calcium additives
- Treatments: High Sulfate Soils (> 8000 ppm)
  - Lime and Fly Ash Additives with Mellowing
  - Lime with Mellowing

Laboratory Mix Design & Field Trial Section – Strongly Recommended

Acknowledgements

National Science Foundation (PD: Dr. Fragaszy)
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Texas DOT (Multiple Projects)
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Colleagues: Drs. Raj Vempati, Pat Harris, Laureano Hoyos and Bhaskar Chittoori

&

Dr. Dallas Little of TAMU

Related Papers

- **Puppala, A. J., Congress, S. S.C., Talluri, N., & Wattanasanthicharoen, E. (2019). Sulfate-Heaving Studies on Chemically Treated Sulfate-Rich Geomaterials. ASCE Journal of Materials in Civil Engineering, 31(6), 04019076.**
- **Puppala, A. J., Talluri, N., Congress, S. S. C., & Gaily, A. (2018). Ettringite induced heaving in stabilized high sulfate soils. Innovative Infrastructure Solutions, Springer, 3(1), 72.**
- **Puppala, A. J., Pedarla, A., & Gaily, A. (2016). Implementation: Mitigation of High Sulfate Soils in Texas: Development of Design and Construction Guidelines (No. Final Report 5-6618). Texas. Dept. of Transportation.**
- **Harris, P., Harvey, O., Jackson, L., DePugh, M., & Puppala, A. J. (2014). Killing the Ettringite Reaction in Sulfate-Bearing Soils. Journal of Transportation Research Record, 2462(1), 109-116.**
- **Puppala, A. J., Talluri, N., Gaily, A., & Chittoori, B. (2013). Heaving mechanisms in high sulfate soils. In Proceedings of the 18th International Conference on Soil Mechanics and Geotechnical Engineering, Paris, France.**
- **Talluri, N., Puppala, A. J., Chittoori, B. C., Gaily, A. H., & Harris, P. (2013). Stabilization of high-sulfate soils by extended mellowing. Journal of Transportation Research Record, 2363(1), 96-104.**
- **Congress, S. S. C., & Puppala, A. J. Evaluation of UAV–CRP Data for Monitoring Transportation Infrastructure Constructed over Expansive Soils. Indian Geotechnical Journal, 1-13.**

Related Papers

- **Puppala, A. J., Viyanant, C., Kruzic, A. P., and Perrin, L., (2002). "Evaluation of a Modified Soluble Sulfate Determination Method for Fine-Grained Cohesive Soils." *Geotechnical Testing Journal*, Vol. 25, No. 1, pp. 85–94.**
- **Puppala, A. J., Intharasombat, N., Vempati, R. (2005). Experimental Studies on Ettringite Induced Heaving in Soils. ASCE Journal of Geotechnical and Geoenvironmental Engineering, Vol. 31, No. 3, pp. 325-337.**
- **Puppala, A. J., Kadam, R., Madhyannapu, R., and Hoyos, L. R. (2006). "Small-Strain Shear Moduli of Chemically Stabilized Sulfate-Bearing Cohesive Soils." ASCE *Journal of Geotechnical and Geoenvironmental Engineering*, ASCE, pp.322-336.**
- **Puppala, A. J., Wattanasanticharoen, E. and Punthutaecha, K. (2003). "Experimental Evaluations of Stabilization Methods for Sulphate-rich Expansive Soils." Ground Improvement Vol. 7, No. 1, pp. 25-35.**
- **Puppala, A. J., Talluri, N. S., Gaily, A., and Chittoori, B. S. (2013). "Heaving Mechanisms in High Sulfate Soils." Proceedings of the 18th International Conference on Soil Mechanics and Geotechnical Engineering, Paris 2013.**
- **Puppala, A. J., Talluri, N. S., Chittoori, B. S., and Gaily, A. (2012). Lessons Learned from Sulfate-Induced Heaving Studies in Chemically-Treated Soils. Proceedings of the International Conference on Ground Improvement and Ground Control. Research Publishing, 1, 85-98.**
- **Bheemasetti, T. V., Chittoori, B., Zou, H., Puppala, A. J., & Thomey, J. (2016). Spatial mapping of soluble sulfate concentrations present in natural soils using geostatistics. ASCE Journal of Geotechnical and Geoenvironmental Engineering, 143(2), 04016090.**

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trwd Tarrant Regional Water District

UNIVERSITY OF TEXAS ARLINGTON

Center for Integration of Composites into Infrastructure

TENCATE GEOSYNTHETICS

US Army Corps of Engineers

Thank You

Pres. Jose Mendoza
Alejandro Quiñónez Samaniego
Eduardo Bitter, José Cattaneo
& My Friend Prof. Consoli

Congreso
de Suelos Dispersivos
y Sulfatados

Asunción, 24-25/10/19

Sociedad Paraguaya de Geotécnia

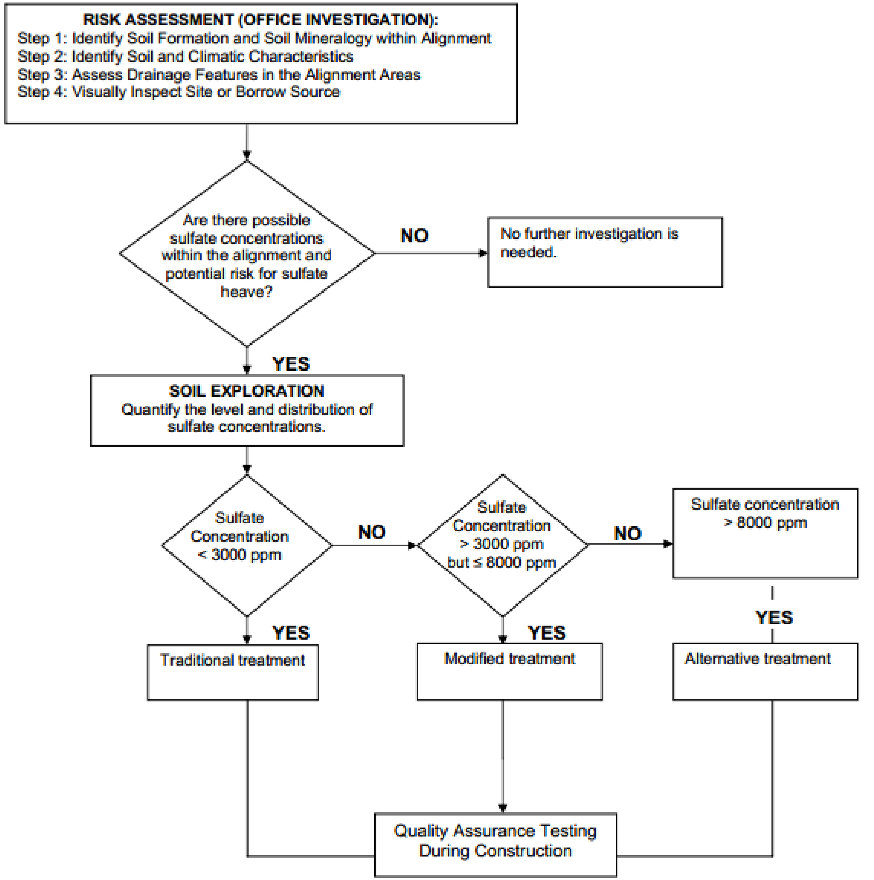
APC
ASOCIACIÓN PARAGUAYA DE CARRETERAS

COMITÉ NACIONAL PARAGUAYO
WORLD ROAD ASSOCIATION MONDIALE DE LA ROUTE

Anand J Puppala’s Closing Comments on Sulfate Soils

Stabilization of Sulfate Soils

TxDOT Practice:



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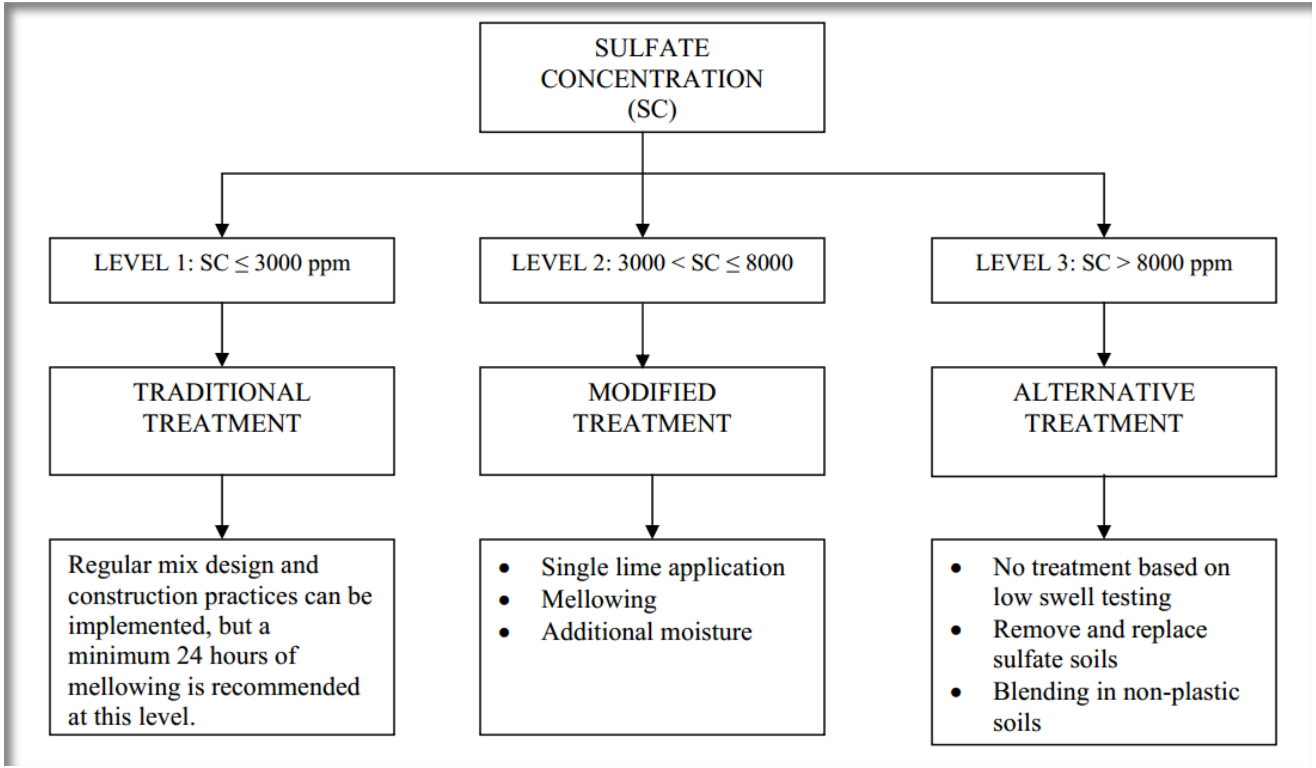


TxDOT Practice

Stabilization of Sulfate Soils

- Ground Granulated Blast Furnace Slag (GGBS)
  - Shown to be Successful in US and UK
- Sulfate Resistant Cements: Type II and Type V
  - Laboratory Results Show Successful Stabilization
- Class F Fly Ash – Co-additive
- Double Lime Treatment
  - Mixed results
  - Heave will reappear

Mitigation of High Sulfate Soils in Texas

Anand J. Puppala, Ahmed Gaily, Aravind Pedarla, Aritra Banerjee
Department of Civil Engineering, The University of Texas at Arlington, Arlington, Texas, 76019

Concept

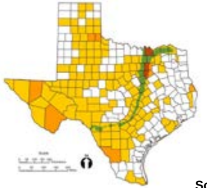
- Pavement distress in chemically stabilized sulfate bearing soils is a growing concern for highway agencies

Source: Les Perrin, USACE

- Researchers have conducted studies on heave mechanisms in chemically treated soils containing sulfate levels below 10,000 ppm
- In most of the heave cases the sulfate contents were reported to be as high as 50,000 ppm
- The main intent of the research is to understand heave mechanisms in soils with sulfate contents above 10,000 ppm

Background & Innovation

- Sulfate Bearing Expansive Soils



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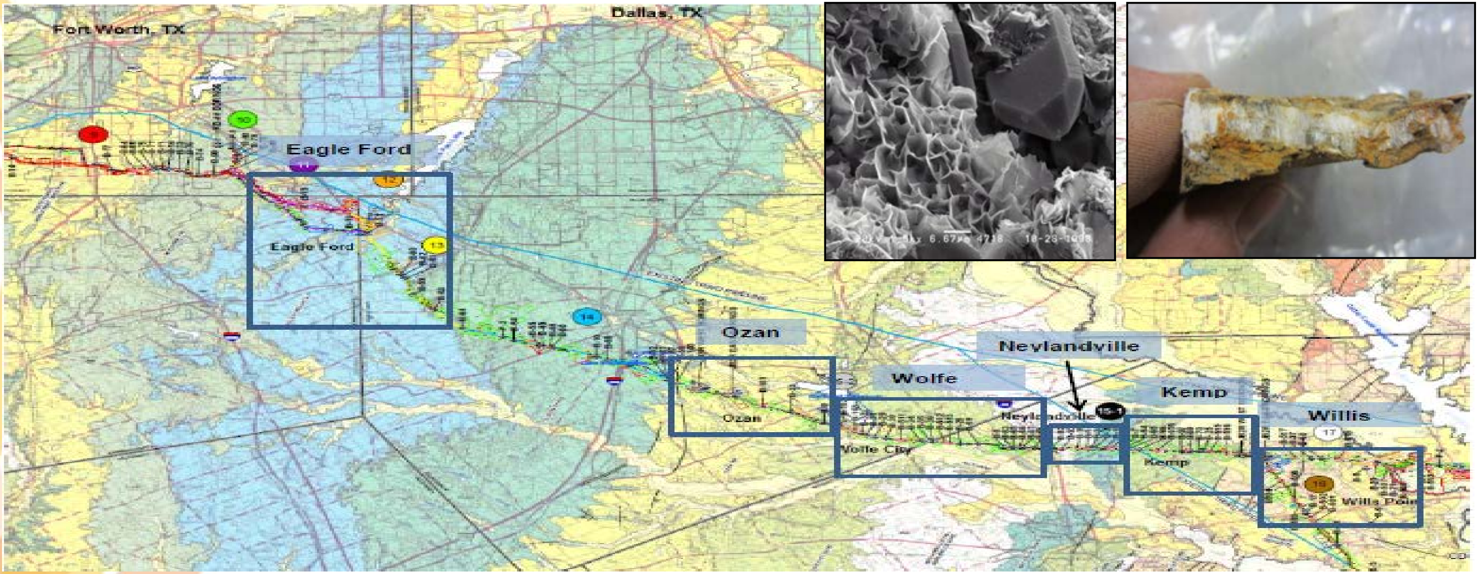
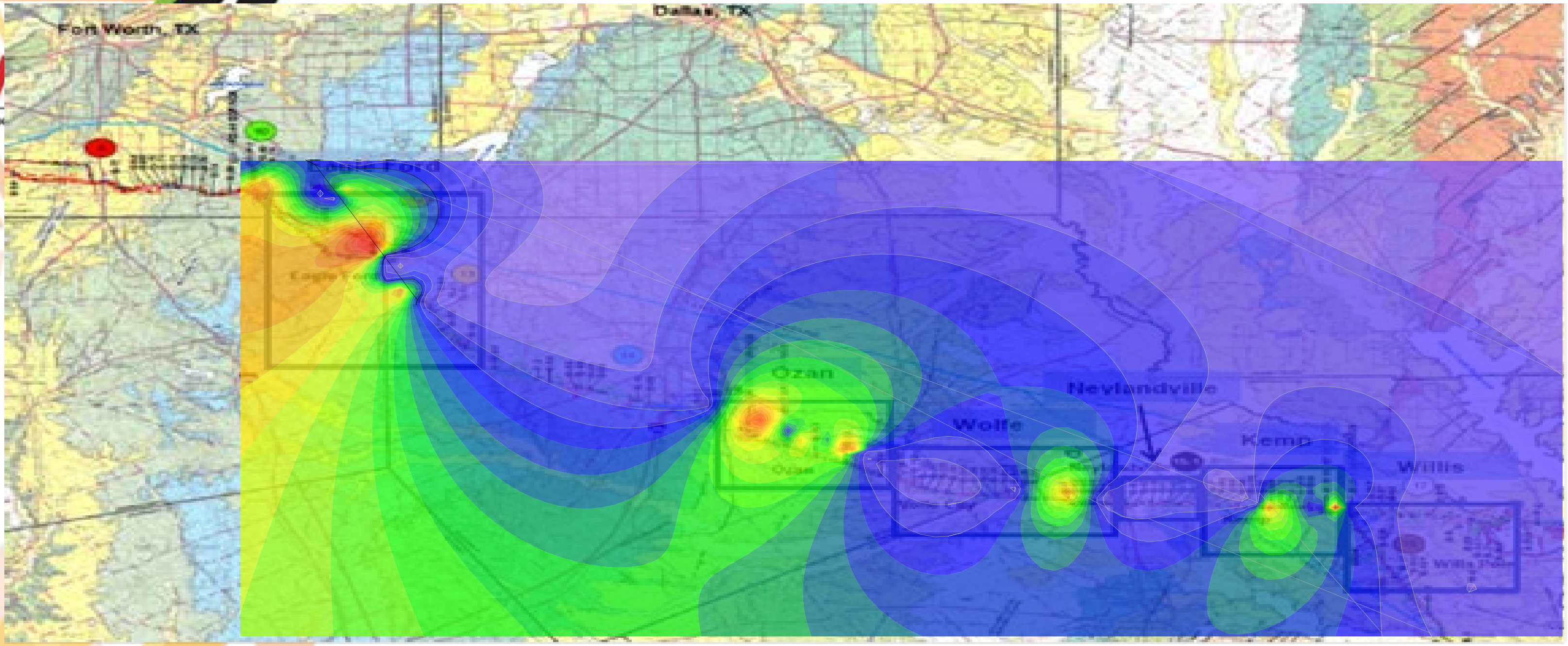
Visualization Approach – Site Characterization

- Dallas and North Texas Geological Formations
- Laboratory Studies - **Natural Sulfates**
- Aim – To develop visualized sulfate contour maps for the region




Fort Worth, TX
Dallas, TX
Eagle Ford
Ozan
Wolfe
Neylandville
Kemp
Willis

Stabilization of High Sulfate Soils

Mellowing technique worked for Sherman soil whereas In Childress soil volumetric swell increased with mellowing. Low initial reactive alumina and high sulfate contents are the reasons for ineffectiveness of mellowing in Childress soils; In soils with high compaction void ratios initial Ettringite growth can be accommodated within the soil matrix

Field implementation studies showed that <u>Lime with extended mellowing and Lime and fly ash treatments</u> provided improvements to high sulfate soils with less heaving

<u>Laboratory Mix Design & Field Trial Section – Strongly Recommended</u>

Clay Mineralogical Distribution

Soil Region	Soil Classification	% Illite	% Kaolinite	% Montmorillonite
Austin	CH	14.5	**48.6**	36.9
Childress	MH	18.3	**65.9**	15.8
Dallas	CH	15.2	34.6	50.2
Sherman	CH	13.2	20.3	66.5
Riverside	CL	21.2	58.7	20.1
US-82	CH	13.7	39.2	47.1

Kaolinite Dominance in Austin and Childress Soils