Changing Needs In Sulfur Capacity For In-Ground Reinforced Concrete Sulfur Pits

April 13-16, 2010

League City, Texas, USA

SulfurUnit.com
MORE PRODUCTION - LESS RISK

STRUCTURAL PRESERVATION SYSTEMS

Thomas R. Kline **tkline@structural.net** **281.479.0391**

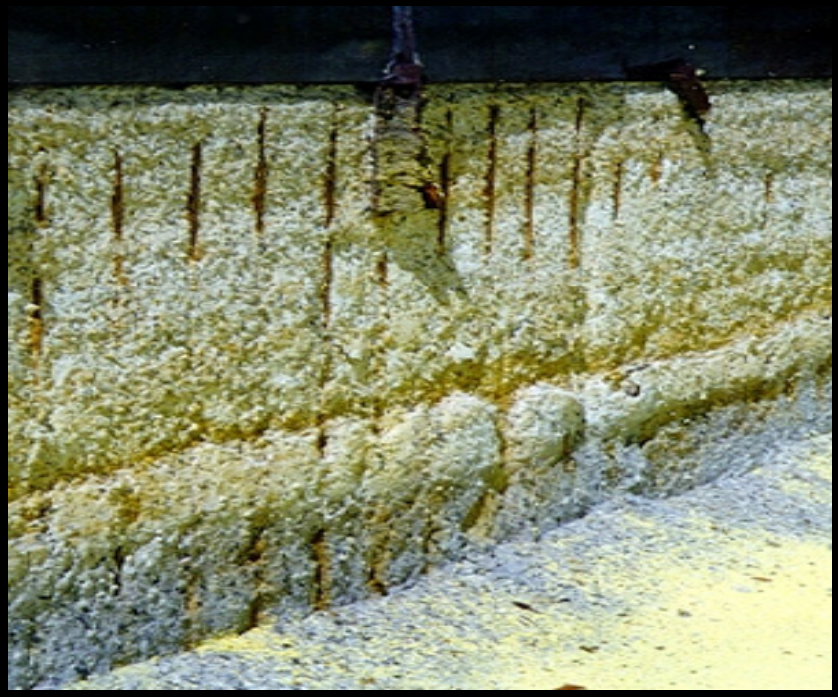
Concrete Problems

- Defects
  - Design, materials, construction
- Damage
  - Overload, fire, impact, chemical spill
- Deterioration
  - Metal corrosion, erosion, freeze/thaw, sulfate attack

Disintegration

Chemical Exposure

Attack matrix – sulfurous acid erosion exposing resistant large coarse aggregate



Matrix modification – sulfur contact alters Portland cement paste matrix into a semi-gelatinous state

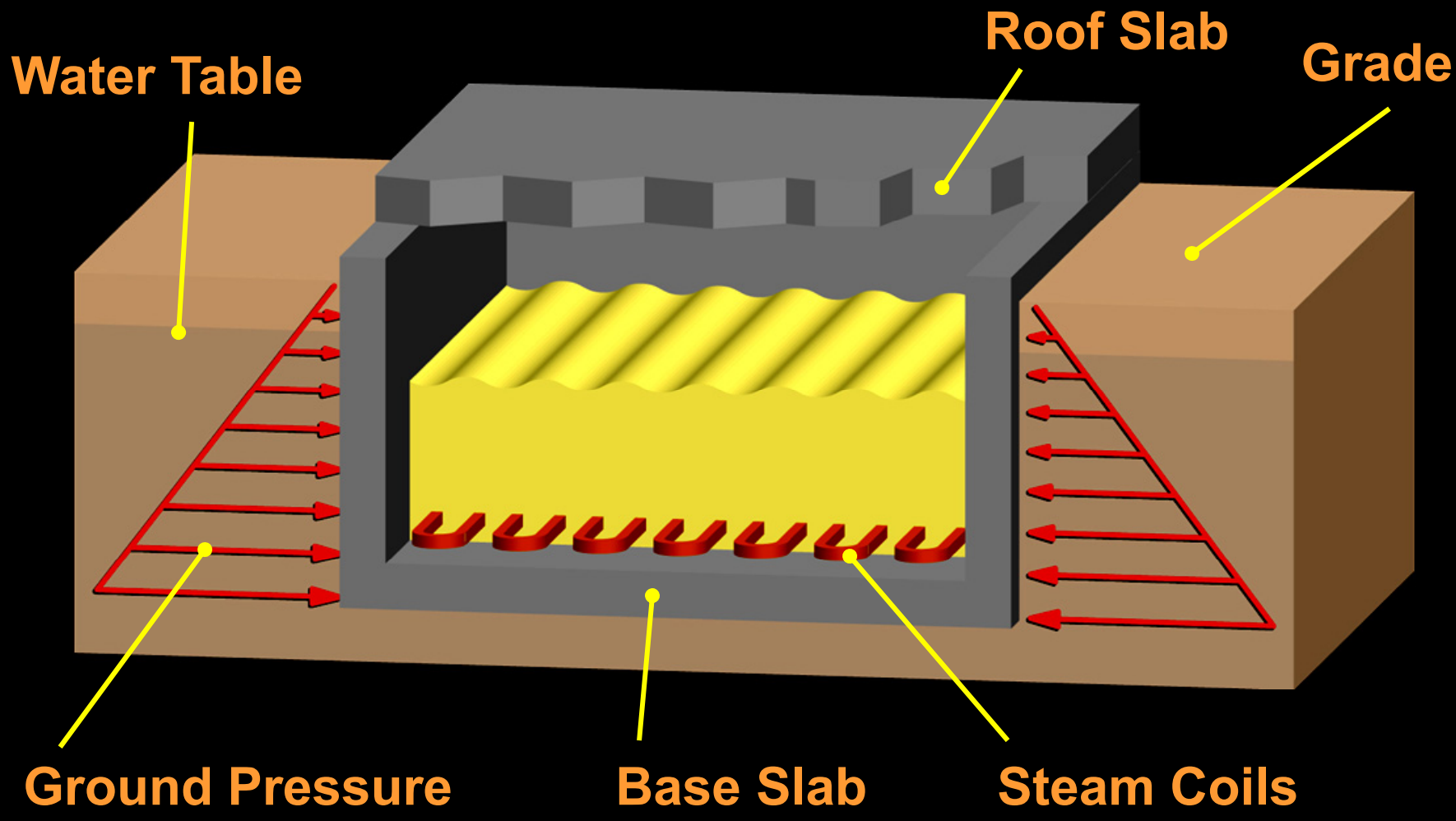
Operating Conditions

Operating Parameters

- Typically the sulfur pit concrete is exposed to operating temperatures of molten sulfur ranging between 285ºF to 315ºF.
- Temperature gradient exists within the wall mass extending from pit interior molten sulfur contact of 300ºF to pit exterior earth contact of 57 ºF. Actual exterior soil temperatures stabilized during operation reach elevated temperatures ranging between 120ºF to 130ºF.

Operating Conditions

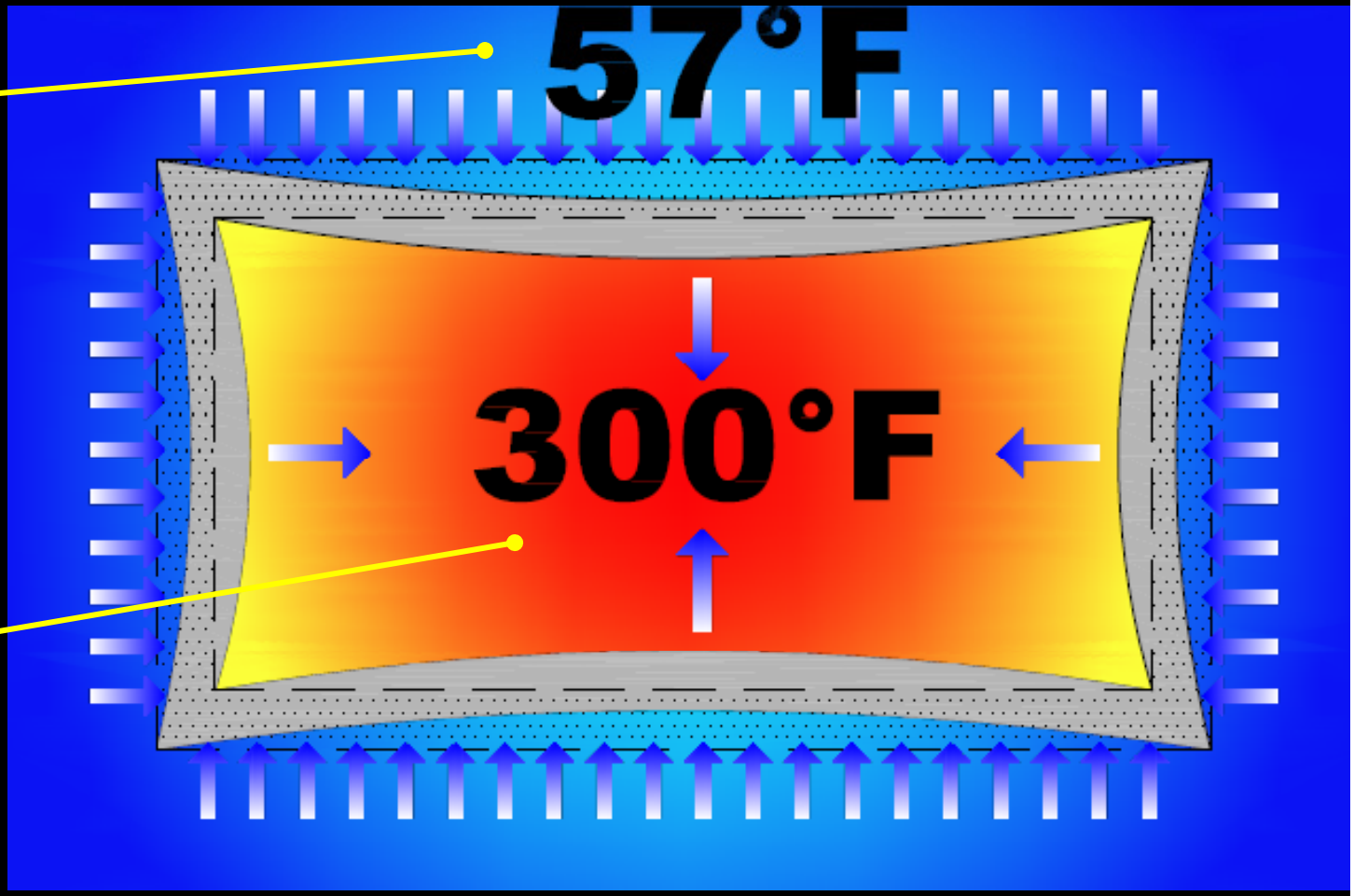
Operating Parameters



Operating Conditions

Operating Parameters

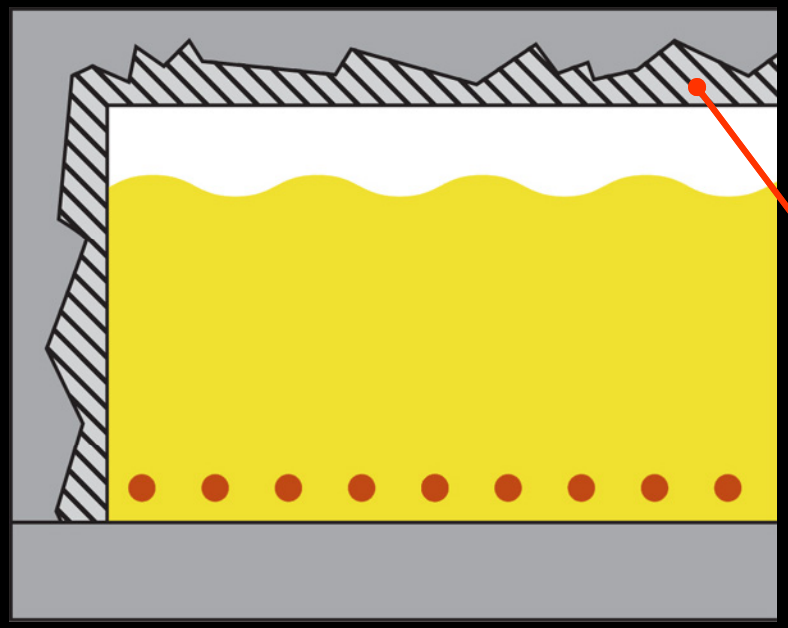
Exterior Earth (Actual Ranges 120°F to 130°F)



Molten Sulfur (Actual Ranges 285°F To 315°F)

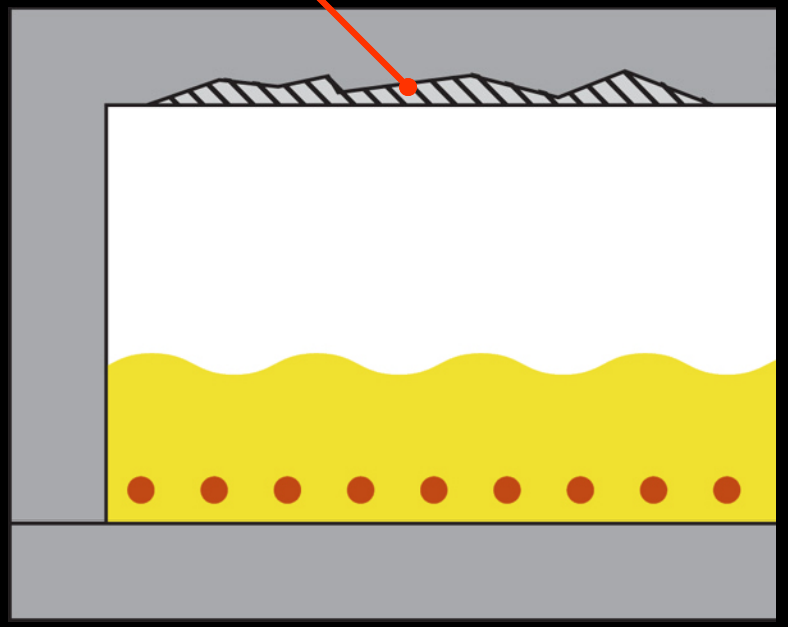
Operating Conditions

Operating Parameters



Small Pit
Fluctuating Levels

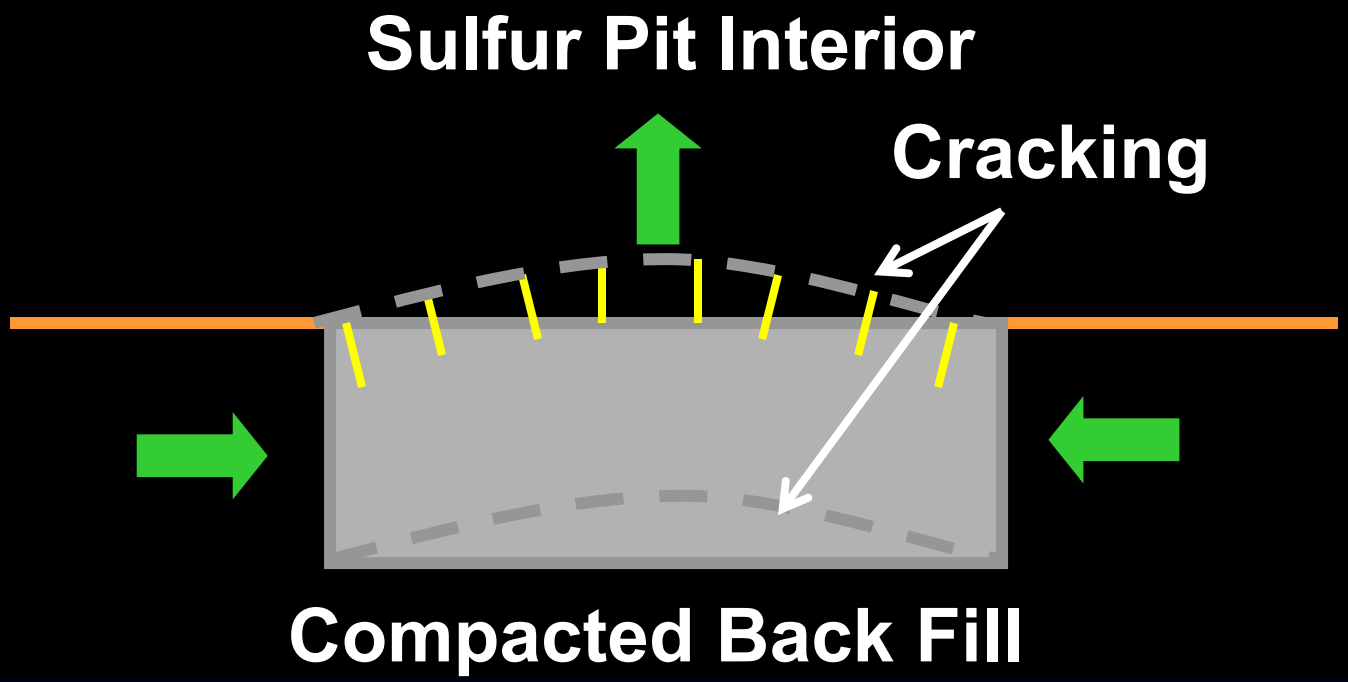
Deterioration



Large Pit
Constant Level

Sulfur Pit Structural Issues

- An irresistible force (i.e., thermal growth) meeting an immovable object (i.e., densely compacted soils and rock).



Operating Conditions

Concrete Material Alterations

Sulfate & Calcium Ions form Gypsum
($CaSO_4 \cdot 32\ H_2O$) - expands 124% in volume

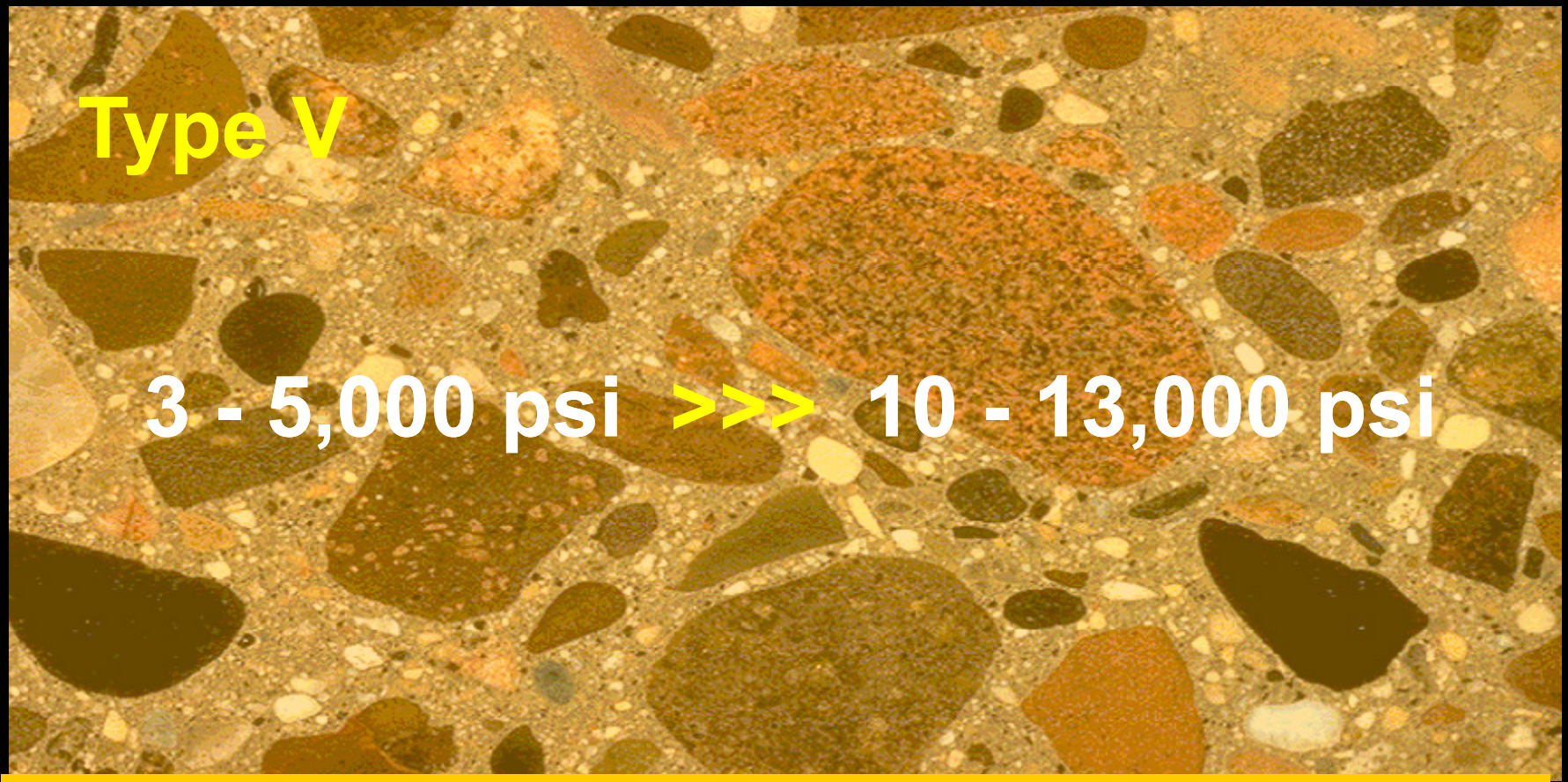
Sulfate & Calcium Aluminate form Calcium Sulfoaluminate (ettringite) ($3CaO \cdot Al_2O_3 \cdot 3CaSO_4 \cdot 3H_2O$) - expands 227% in volume

To remedy and reduce the effects of these chemical reactions - Use cements with low C_3A

- **Type V Sulfate resisting Portland cement**
- **Blends of Hydraulic/Portland cements**
- **Cement replacements with supplemental Cementitious materials (Flyash, Microsilica, etc.)**

Operating Conditions

Operating Parameters



Sulfur

Operating Conditions

Operating Parameters

- Sulfur impurities and by-products form “Carsul”
- “Carsul” settles along crevices and base regions
- May be mistaken for concrete

Operating Conditions

Deterioration Mechanisms

- "Desiccation" of the concrete mass (i.e., removal of excess moisture by high service temperatures) causing cracks
- Sulfurous acid attack – "acid" generated by water leakage into the pit from cracks, failed penetration seals or jacketed pipe/coils leaks
- Corrosion of reinforcing steel bar above molten sulfur levels in the Vapor Zone
- Scouring effect of fluctuating molten sulfur levels in daily "working pits"

Operating Conditions

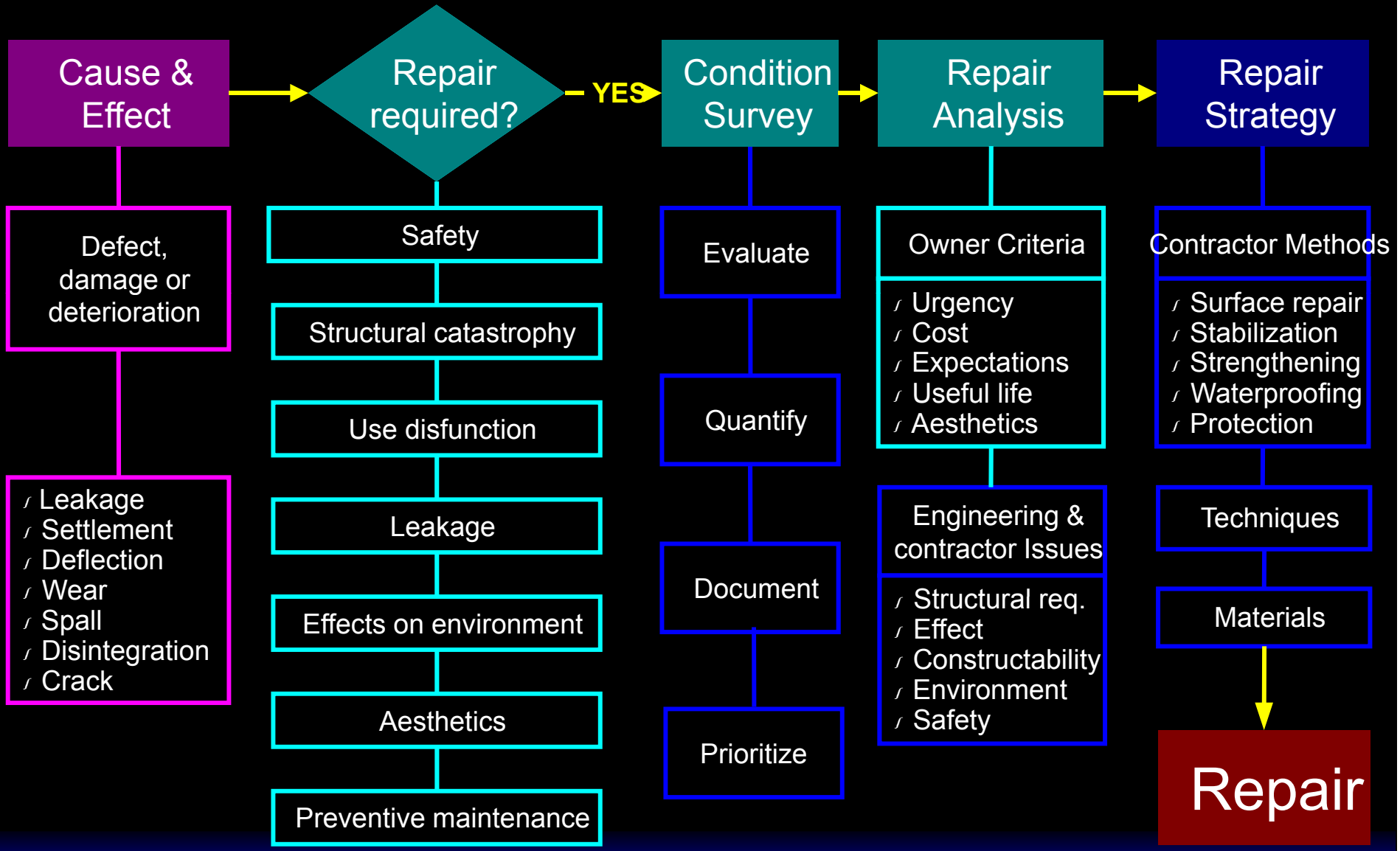
Deterioration Mechanisms






Sulfur Pit Repair Failures

Concrete Repair Is A Process!



Repair Process

Condition Survey

Field Investigation

- Visual Inspection and Site Survey
- Acoustic Impact Testing
- Mapping of Significant Features

Condition Survey

Field Investigation

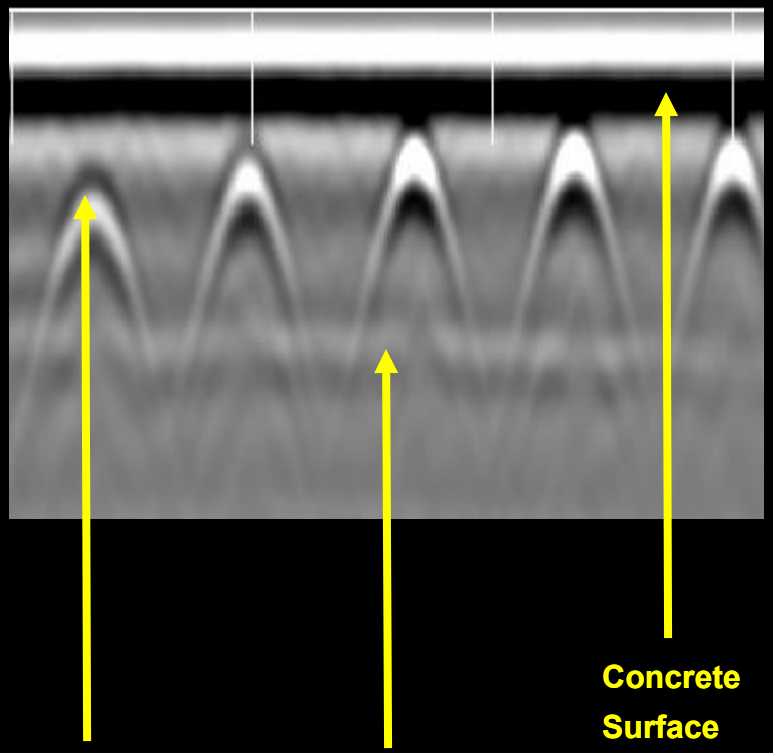
- Ferroscan & Standard Rebar Pachometer Survey

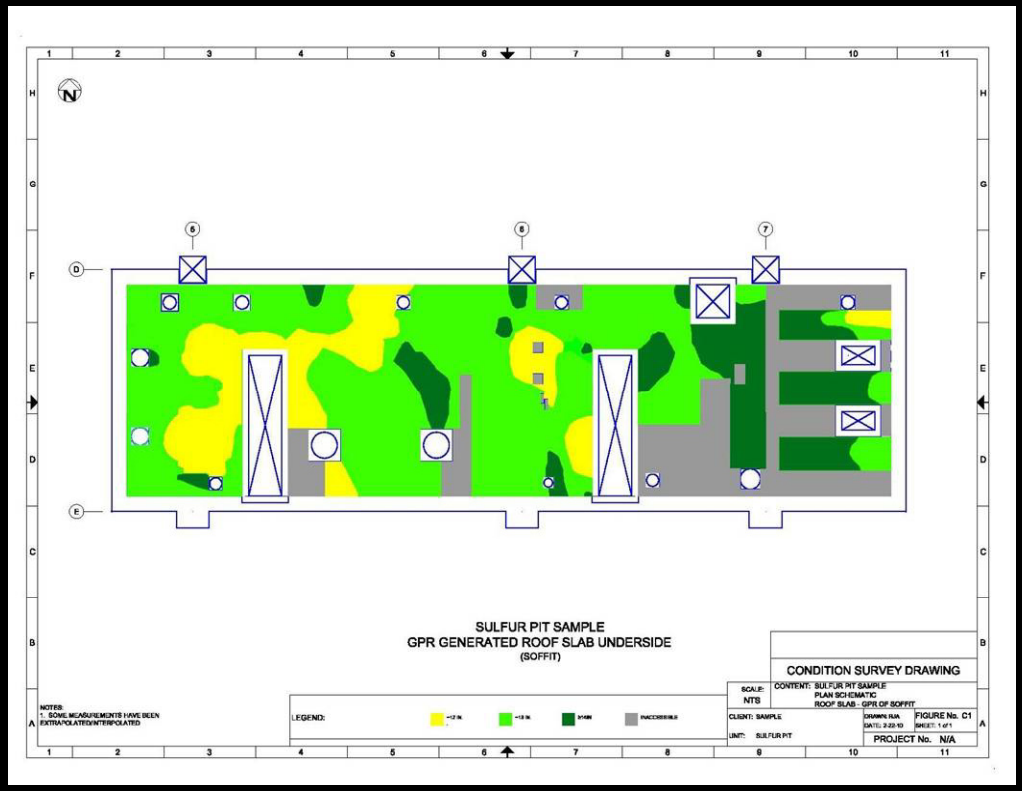
Repair Process

Condition Survey

Field Investigation

Ground Penetrating Radar Line Scan





Repair Process

Condition Survey

Field Investigation

- Sample Extraction

Core Extraction

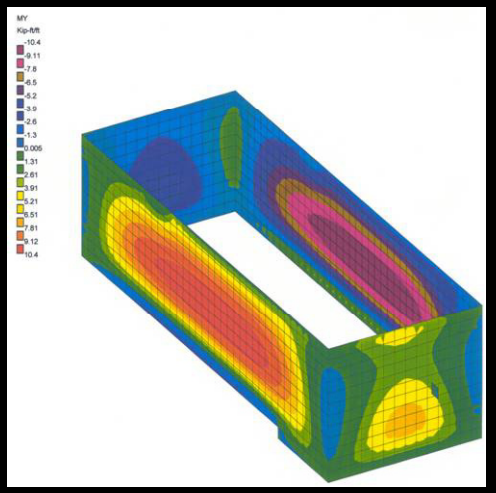
Chloride Sampling

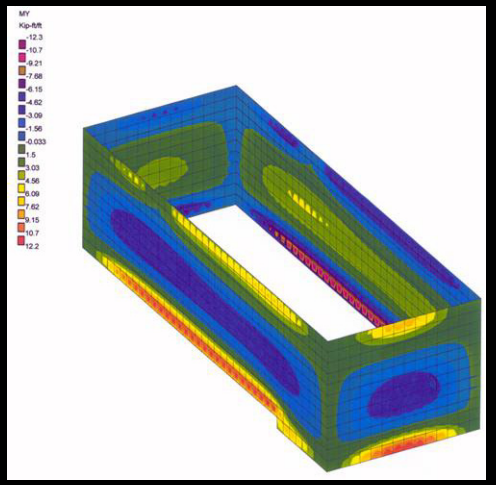
Sulfur Pit Repair Scenarios

- Leaking Cracks
  - Cementitious grouting
  - “Chinking”
  - Well-points
- Surface Erosion
  - Partial and full-depth removal and replacement
  - Installation of a “new skin” (i.e., durability liner)
  - Installation of a new structural liner
- Corroding Reinforcing
  - New rebar replacement & integration with repair couplers
  - Incorporation of corrosion inhibiting admixtures into repair materials

Engineered Repair Design

- Each Sulfur Pit is a unique structure and should be engineered as such
- Soil sampling and analysis
- Structural modeling and analysis
- Partnering between contracting and engineering





Surface Repair

Material Selection Criteria

- Repair material similar to original substrate…
  - Modulus of elasticity (loads)
  - Thermal expansion (Δ temp)
  - Low drying shrinkage (crack-free)
  - Chemically resistant to service environment
- Repair like with like!
  - So the repair will behave compositely ("as-one") with the substrate under load

Placement Techniques

Roof Slab Soffit – Form & Pump

- Shoring required to support roof slab as flexural steel lacks bond with concrete
- Excavation requiring undercutting of rebar & new bars added as necessary due to corrosion losses
- Soffit forms installed and concrete placed under pressure into formwork cavity

Placement Techniques

Roof Slab Replacement – In Kind

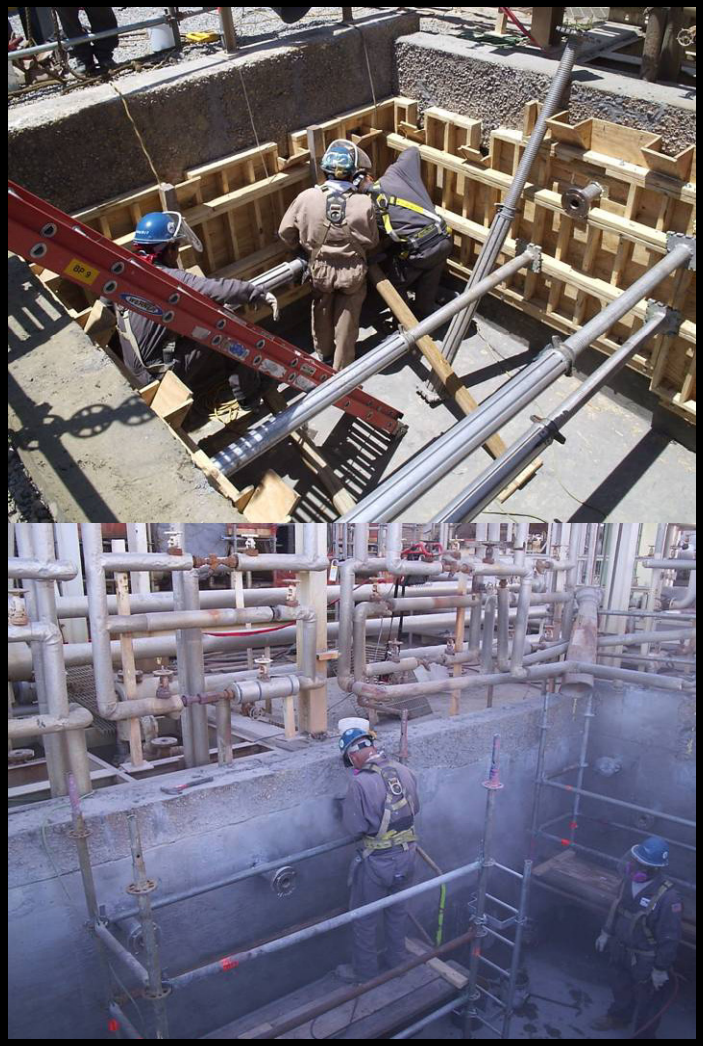
Full-Depth Repair

- Remove deteriorated roof slab
- Formwork at base of roof slab and dowel walls to roof reinforcing

Placement Techniques

Form & Pour Wall Repairs

- Form & pour partial-depth wall repairs via “birds-mouth” ports employing external form vibrators to assemble formwork and internal vibrators to address concrete consolidation within formwork cavity



Placement Techniques

Precast Roof Slab Panels

Sulfur Pit Repair Construction Environment – Innovative Techniques To Accelerate Repair Construction Schedule

- Use of site-built modular formwork adjusts to as-built Sulfur Pit site conditions with roof in-place (atypical Pits)
- Port locations & spacing assure “port-to-port communication” during repair material placement & adequate consolidation

Sulfur Pit Repair Construction Environment – Innovative Techniques To Accelerate Repair Construction Schedule

- Use of panelized modular formwork adjusts to Sulfur Pit metrics (typical Sulfur Pits)
- Panelized forms are externally braced (i.e., form-ties not required) works best with roof slab removed allowing internal & external consolidation

Sulfur Pit Repair Construction Environment – Quality Is Job 1

STRUCTURAL GROUP

SULFUR PIT INSPECTION PROGRAM (SPIP)

Contractor: Structural Preservation Systems	Work Scope / Application:	INSPECTION LEVELS
Project No. / Title / Location: Motiva Enterprises Port Arthur, Texas	SULFUR PIT #2 REPAIR	Level 1 – 100% Verification / Inspection. Level 2 - Random In-Process Verification / Inspection. Level 3 – Prior to Start of Work. Level 4 – Upon Completion of Work. Level 5 – Document Review.
AFS / WO / PO No: 12668		
SPIP Number: 1		

Rev.	Description	Contractor Approval	Date	Owner Approval	Date

Item No.	Attribute / Activity Description	Acceptance Criteria (Codes, Std., Spec.)	Applicable Y / N	INSPECTION REQUIREMENTS				Forms / Records / References
				Inspect	Hold	Witness	Review	
1	Remove Loose Concrete Materials from Sulfur Pit Wall Areas	ASTM, ACI, P. Emmons Rep./Maint. as Appl.						
2	Verify existing Concrete Wall at repair areas is free of Sulfur Cake deposits	ASTM, ACI, P. Emmons Rep./Maint. as Appl.						
3	Verify reinforcing steel is noted on as-builts construction drawings	ASTM, ACI, P. Emmons Rep./Maint. as Appl.						
4	Verify existing reinforcing steel has been cleaned on all sides and augmented if necessary	ASTM, ACI, P. Emmons Rep./Maint. as Appl.						
5	Install Reinforcing Steel Bars as specified and verify rebar cover	ASTM, ACI, P. Emmons Rep./Maint. as Appl.						
6	Verify Dowel Holes are 2" in Dia. 12" deep and Clean	ASTM, ACI, P. Emmons Rep./Maint. as Appl.						
7	Verify 5 Star Grout is mixed and consolidated according to manufacturers recommendations	ASTM, ACI, P. Emmons Rep./Maint. as Appl.						
8	Verify forms are built and secured to withstand the concrete pour pressure	ASTM, ACI, P. Emmons Rep./Maint. as Appl.						
9	Verify mix water is appropriate for Emaco S-66 product being used and maintaining a consistent slump for placement and testing	ASTM, ACI, P. Emmons Rep./Maint. as Appl.						
10	Verify placement procedures are in accordance with ACI 304.2R & 304R-89	ASTM, ACI, P. Emmons Rep./Maint. As Appl.						

* = OPTIONAL QC = CONTRACTOR'S QC INSPECTOR *QA = OWNER'S QA REPRESENTATIVE S/C = SUBCONTRACTOR OTL = OWNER'S TECHNICAL LIASON FE = CONTRACTOR'S FIELD ENGINEER/SURVEYOR

- Implementing an SPIP (Sulfur Pit Inspection Program) provide owner & contractor a verifiable audit trail of accountability with designated milestones & hold points - assuring no important details "fall-through-the-cracks"

Conclusion

- "Devil-is-in-the-Details"
- Even small amounts of deterioration require specific detailing so things aren't made worse while in-service
- Each Sulfur Pit is unique and requires a thoughtful enlightened approach in order to implement an enduring repair