Full Depth Reclamation
Additive Selection Guidelines

In-Place Recycling Conference
Salt Lake City
June 3, 08

Outline

- FDR overview
- Soil tests and classification review
- Additive types and selection guidelines
  - Traditional additives
  - Less traditional additives
- Concluding remarks

Dull Depth Reclamation (FDR)

FDR*: Rehabilitation technique where full thickness of asphalt pavement & predetermined portion of underlying materials are uniformly pulverized & blended to an upgraded, homogenous base material

Asphalt Recycling & Reclamation Association

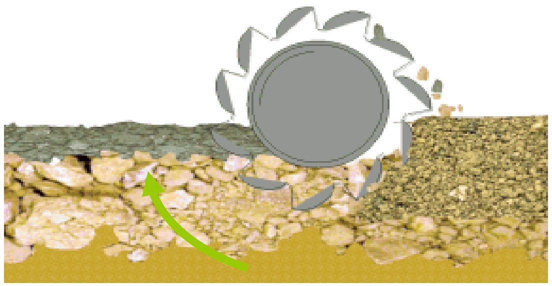
FDR Benefits

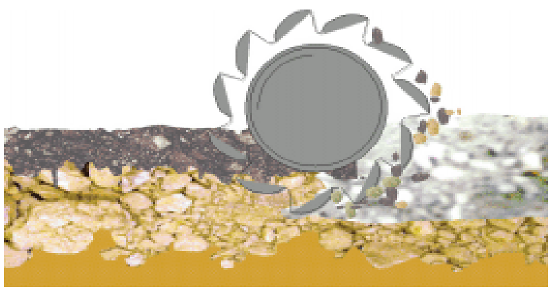
- Sustainability:
  - In place recycling/Preserve natural resources
  - Lower energy and carbon foot print
- Reduce construction time and user delays
- Maximize pavement performance through improved uniform support (long term strength and durability)
- Upgrade marginal base materials

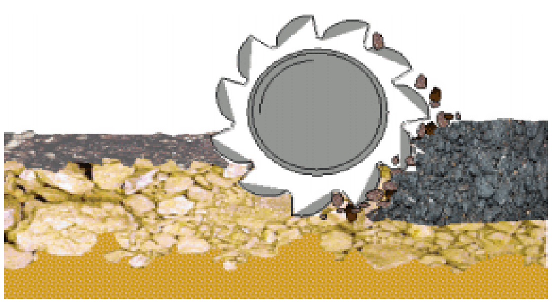
FDR Benefits (Cont.)

- Disrupt crack patterns minimizing potential for reflective cracking
- Profile and cross slope can be adjusted
- Limit utility interference
- Keep roadway opened during rehabilitation
- Cost effectiveness

Definitions







- <u>Mechanical</u> stabilization - **1st step in reclamation; also used to describe FDR without addition of binder (**Pulverization**)**
- <u>Chemical</u> stabilization - **FDR with chemical additive (Calcium or Magnesium Chloride, Lime, Fly Ash, Kiln Dust, Portland Cement, etc.)**
- <u>Bituminous</u> stabilization - **FDR with asphalt emulsion, emulsified recycling agent, or foamed / expanded asphalt additive**
- <u>Combination</u> stabilization - **Any 2 or more of above**

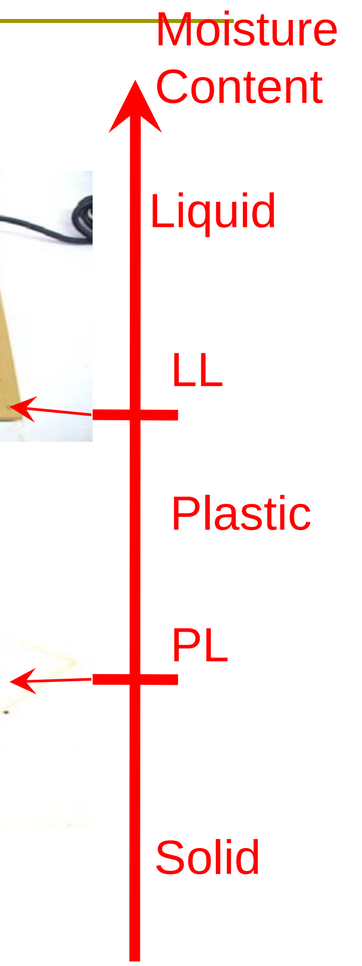
FDR Candidate

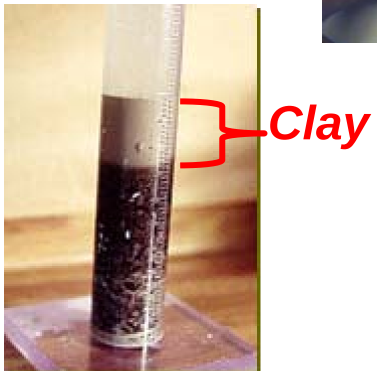
Additive Selection

- It is important to have a basic understanding of how the additives work:
  - Binding
  - Coating
  - Formation of new compounds
- It is necessary to characterize the materials to be treated:
  - Gradation
  - Plasticity (Liquid Limit, Plastic Limit and Plastic Index)
  - Soil classification

Test Review

- Atterberg Limits (LL, PL, PI)
  - PI = LL-PL
  - AASHTO T89 and 90
- Gradation
- Soil classification
  - AASHTO (A-1 to A-7)
  - Unified soil classification
- Sand Equivalent
  - Clay content of passing #4





AASHTO Soil Classification

----269.0503 Tc 40 max 064(N)41 min 9(ar-0.9 .*[40 max 9(x ma)-64(x 41 min 78x0267 Tc 40 max -11(-41 min[1x)9(mi40 max)]TJ 0.7-41 min 0593 T

10 max	10 max	11 min	11 min	10 max	10 max	11 min	11 min

Usual Types of Significant Constituent Materials	Stone Fragments Gravel and Sand	Fine Sand	Silty or Clayey Gravel and Sand	Silty Soils	Clayey Soils
General Rating as Subgrade		Excellent to Good		Fair to Poor	

Plasticity index of A-7-5 subgroup is equal to or less than LL minus 30. Plasticity index of A-7-6 subgroup is greater than LL minus 30

Unified Soil Classification

UNIFIED SOIL CLASSIFICATION AND SYMBOL CHART

COARSE-GRAINED SOILS (more than 50% of material is larger than No. 200 sieve size.)		
	Clean Gravels (Less than 5% fines)	
GRAVELS More than 50% of coarse fraction larger than No. 4 sieve size	GW	Well-graded gravels, gravel-sand mixtures, little or no fines
	GP	Poorly-graded gravels, gravel-sand mixtures, little or no fines
	Gravels with fines (More than 12% fines)	
	GM	Silty gravels, gravel-sand-silt mixtures
	GC	Clayey gravels, gravel-sand-clay mixtures
	Clean Sands (Less than 5% fines)	
SANDS 50% or more of coarse fraction smaller than No. 4 sieve size	SW	Well-graded sands, gravelly sands, little or no fines
	SP	Poorly graded sands, gravelly sands, little or no fines
	Sands with fines (More than 12% fines)	
	SM	Silty sands, sand-silt mixtures
	SC	Clayey sands, sand-clay mixtures
FINE-GRAINED SOILS (50% or more of material is smaller than No. 200 sieve size.)		
SILTS AND CLAYS Liquid limit less than 50%	ML	Inorganic silts and very fine sands, rock flour, silty of clayey fine sands or clayey silts with slight plasticity
	CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays
	OL	Organic silts and organic silty clays of low plasticity
SILTS AND CLAYS Liquid limit 50% or greater	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts
	CH	Inorganic clays of high plasticity, fat clays
	OH	Organic clays of medium to high plasticity, organic silts
HIGHLY ORGANIC SOILS	PT	Peat and other highly organic soils

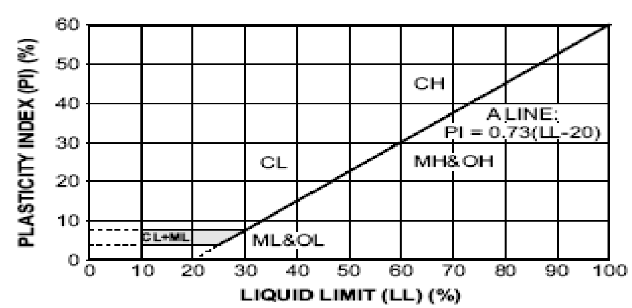
LABORATORY CLASSIFICATION CRITERIA

GW	$C_u = \frac{D_{60}}{D_{10}}$ greater than 4; $C_c = \frac{D_{30}}{D_{10} \times D_{60}}$ between 1 and 3	
GP	Not meeting all gradation requirements for GW	
GM	Atterberg limits below "A" line or P.I. less than 4	Above "A" line with P.I. between 4 and 7 are borderline cases requiring use of dual symbols
GC	Atterberg limits above "A" line with P.I. greater than 7	
SW	$C_u = \frac{D_{60}}{D_{10}}$ greater than 4; $C_c = \frac{D_{30}}{D_{10} \times D_{60}}$ between 1 and 3	
SP	Not meeting all gradation requirements for GW	
SM	Atterberg limits below "A" line or P.I. less than 4	Limits plotting in shaded zone with P.I. between 4 and 7 are borderline cases requiring use of dual symbols.
SC	Atterberg limits above "A" line with P.I. greater than 7	

Determine percentages of sand and gravel from grain-size curve. Depending on percentage of fines (fraction smaller than No. 200 sieve size), coarse-grained soils are classified as follows:

Less than 5 percent .... GW, GP, SW, SP
More than 12 percent .... GM, GC, SM, SC
5 to 12 percent .... Borderline cases requiring dual symbols

PLASTICITY CHART



Additive Selection Guidelines

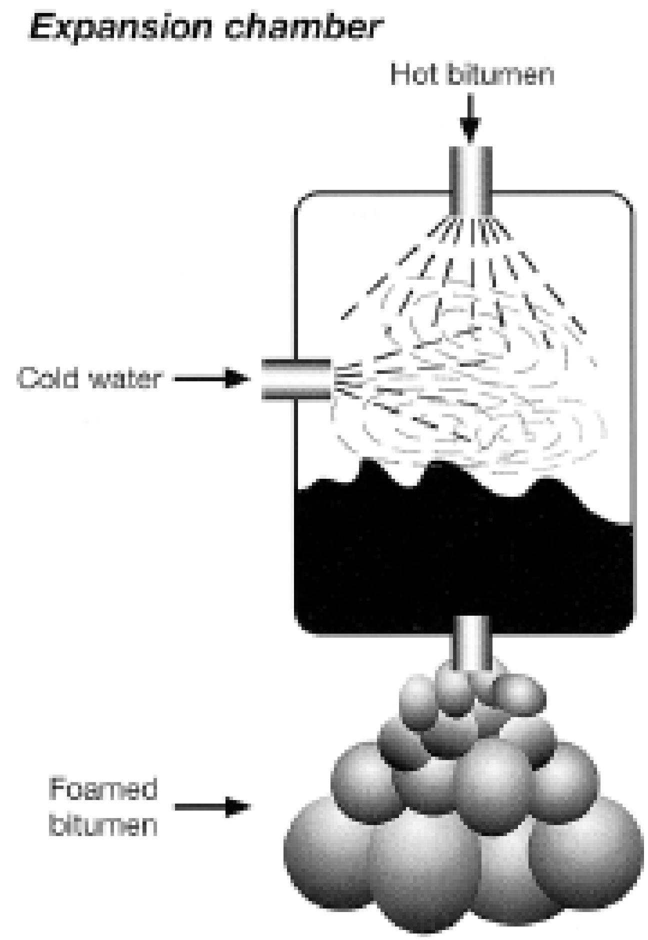
- Lime (3 to 6%)
  - Formed by the decomposition of limestone at elevated temperatures (Calcium carbonate)
  - Cation exchange and flocculation/agglomeration
  - Chemical reaction from Lime, Water, Silica and Alumina in clay results in new cementicious compounds
  - Selection: PI>10 and P200<25 <u>or</u> PI 10-30 and P200>25, SO_4 in clay < 3000 ppm

Additive Guidelines (Cont.)

- Portland Cement (3 to 6%)
  - Finely ground calcium silicates and aluminates with small percentages of magnesium oxide, gypsum and uncombined oxides
  - Hydration of the calcium silicates produces a cementicious paste predominatly in the form of calcium silicate hydrate (CSH)
  - Type II cement typically used
  - Selection: PI<10

Additive Guidelines (Cont.)

- Foamed asphalt (1 to 3%) (+cement)
  - High temperature asphalt (>300F) is injected with a small amount of water (about 2% BWA)
  - Foaming and increase of surface area temporarily allows for coating of the fines
  - 5%<#200<20%



Additive Guidelines (Cont.)

- Emulsified asphalt (3 to 6%)
  - Cationic or anionic
  - Typically 60-65% residue and 35-40% water, emulsifiers and chemicals
  - Selection: SE >30 and Passing#200 < 20% (100% base to 100% RAP)

Suggested Additives for Various Aggregate Bases and Soils – Blend of existing bituminous and base / soil

Material Type	Well-graded gravel	Poorly graded gravel	Silty gravel	Clayey gravel	Well-graded sand*	Poorly graded sand	Silty sand	Clayey sand	Silt, Silt with sand	Lean clay	Organic silt / organic lean clay	Elastic silt	Fat clay, fat clay with sand	Pros	Cons
USCS	**GW**	**GP**	**GM**	**GC**	**SW**	**SP**	**SM**	**SC**	**ML**	**CL**	**OL**	**MH**	**CH**		
AASHTO	**A-1-a**	**A-1-a**	**A-1-b**	**A-1-b or A-2-6**	**A-1-b**	**A-3 or A-1-b**	**A-2-4 or A-2-5**	**A-2-6 or A-2-7**	**A-4 or A-5**	**A-6**	**A-4**	**A-5 or A-7-5**	**A-7-6**		
Emulsion FDR / GBS Best if SE > 30 and P200 < 20* (100% base to 100% RAP)														Project / material selection, engineered design/emulsion, field support, same day return to traffic, quick overlay	Cannot handle high clay content
Foamed asphalt P200 5 to 20% and follow max. density grad.														Same day return to traffic, quick overlay	Safety, gradation, maintain high asphalt temperature
Portland cement PI<10														Quick set, high strength, compatible with many soils	Dust, early cracking, little overlay bonding
Lime PI>10 and P200<25 <u>or</u> PI 10-30 and and P200>25, SO_4 in clay < 3000 ppm														Quick set, high strength	Dust, early cracking, potential sulfate heave

*Some projects that do not meet these material recommendations have been successfully built

Additive Guidelines (Cont.)

- Magnesium or Calcium chloride (1%)
  - Salts
  - Can result in increased pore water surface tension, producing an increase in apparent cohesion, resulting in strength improvement
  - Susceptible to leaching
  - Selection: 3 to 5% clay beneficial, 8%<#200<12%

Less Traditional Additives

- Ionic
  - Acid and alkaline additives
  - Loss of double-layer water in clay (this is more important for montmorillonite clay where the double-layer water is larger than the clay sheets)
  - Reactions occur over long time periods
  - Most suitable to silts and clays, where the electrical charges of the particles and the pore fluid significantly affect soil behavior

Less Traditional Additives (Cont.)

- Enzymes
  - Organic molecules that catalyze very specific chemical reactions if conditions are right
  - Reactions can take long time periods
  - Only small dosages are needed
  - Very soil specific – likely clay with some organic content

Less Traditional Additives

- Lignosulfonates
  - Derived from lignin that binds cellulose fibers together
  - Coats individual particles with a thin adhesive-like film
  - Primarily cementing agents with possible minor chemical effects
  - Capacity for ion exchange
  - Water soluble and susceptible to leaching

Less Traditional Additives (Cont.)

- Petroleum Resins
  - Asphalt emulsions and synthetic isoalkane fluids
  - Primary binding mechanism is physical bonding
  - Generally not used in fine-grained materials
- Tree Resins
  - Relatively unprocessed by-products of timber and paper industries
  - Act similar to lignosulfonates but are less susceptible to leaching

Less Traditional Additives (Cont.)

- Polymer Stabilizers
  - Typically vinyl acetates or acrylic copolymers suspended in an emulsion
  - Excellent waterproofing potential
  - Increased benefit if a small percentage of Portland cement is used
  - Generally not used in fine-grained materials

Stabilization Additive	Proposed Primary Stabilization Mechanism	Material Compatibility	Strength Improvement	Volume Stability	Waterproofing
Ionic	Cationic exchange and flocculation	Fine-grained soils	Low-medium	Low-medium	Low-medium
Enzymes	Organic molecule encapsulation	Fine-grained soils	Low	Low-medium	Low
Ligno-sulfonates	Physical bonding / cementation	Granular soils	Medium	Low-medium	Low
Salts (Calcium, Magnesium)	Hygroscopy / cation exchange and flocculation / cementation	All	Low-medium	Low	Low
Petroleum resins	Physical bonding / cementation	Granular soils	Medium	Medium	High
Polymers	Physical bonding / cementation	Granular soils	Medium-high	Medium	Medium-high
Tree resins	Physical bonding / cementation	Granular soils	Medium-high	Medium	Medium-high

Summary

- FDR additive selection is based on:
  - Materials type (at the representative depth)
  - Gradation
  - Plasticity
- Manufacturer's recommendations and additional testing and are suggested for less traditional additives
- Combination of additives can be used

Summary (Cont.)

- Other important considerations for successful FDR applications
  - Safety, reliability, ease of construction
  - Performance objectives
  - Additive loading, design and testing
  - Specifications
  - QC/QA requirements

Questions?

Thank you for your interest in FDR

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City of El Centro, CA

2008 FDR Project