PERFORMANCE-BASED SPECIFICATIONS FOR GRAVEL WEARING COURSES (BALANCED MIX DESIGN)

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2024 Michigan County Engineers

Manistee MI, February 6-8, 2024

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WARNING
GRAVEL ROADS
SURFACE CONDITIONS
CHANGE OFTEN
DRIVE CAREFULLY

Outline

- Introduction
- Understanding unpaved road materials
- Balanced mix design for unpaved roads
- Predicting unpaved road performance
- Material blending
- Conclusions

Overview

- Unpaved roads
  - Economically important
  - Lost art of unpaved road engineering
    - "Paved road aggregate base is ok" (It's NOT!)
  - Sustainability and management issues
- Improvement and preservation options:
  - Upgrade to paved standard
  - Rehabilitate (regravel and reshape)
  - Preserve fines (dust control)
  - Stabilize or "waterproof"

Engineered Unpaved Roads

Introduction

- Materials are selected to optimize all-weather performance
  - Good, year-round ride quality with minimal maintenance
  - No dust when dry
  - Passable when wet
- Numerous guides and specifications available worldwide
- Performance-related are the most useful, but not common
- Performance dependent on:
  - Particle size distribution (grading)
  - Plasticity (clay content)
  - Strength and thickness (bearing capacity)
  - Construction, shape/drainage, and maintenance
- Performance can be improved through mechanical stabilization and/or chemical treatments
  - Chemical treatments best for "keeping good roads good"
- Primary goal: safe; cost-effective to manage & maintain

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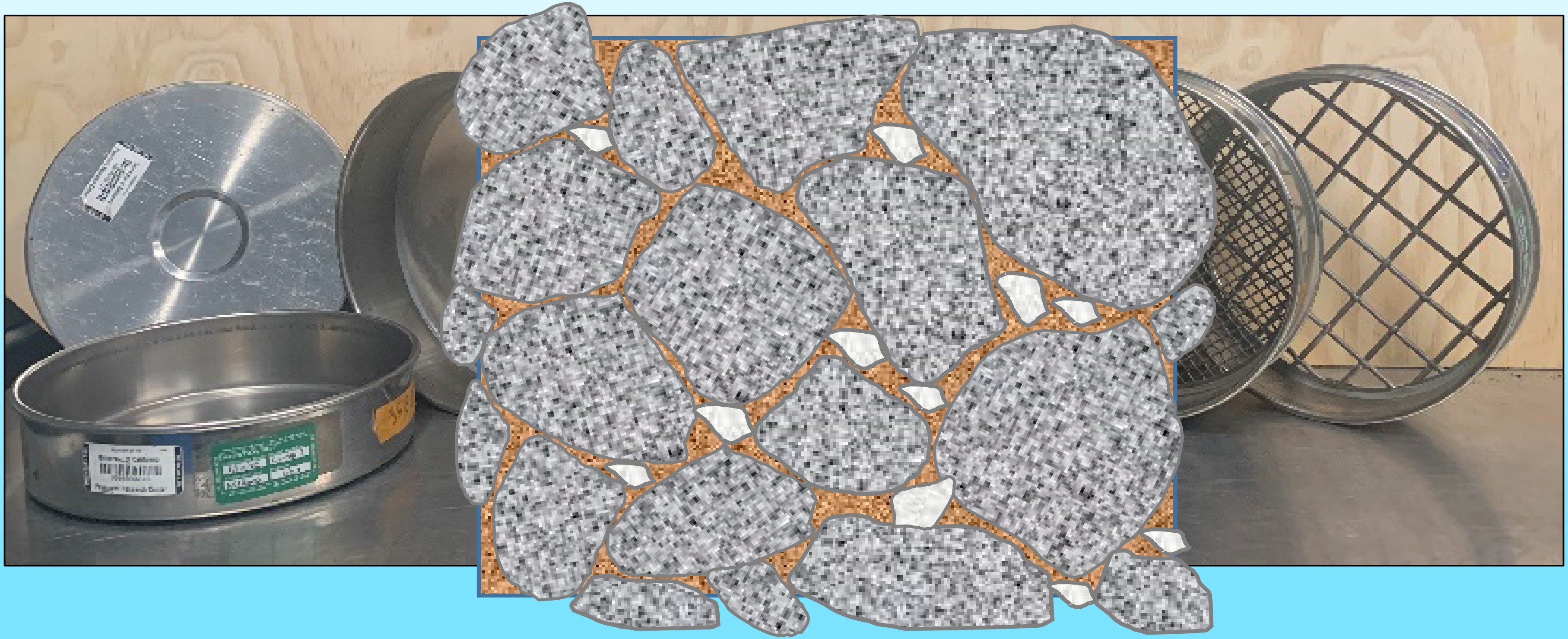
Understanding Materials

Materials - Grading



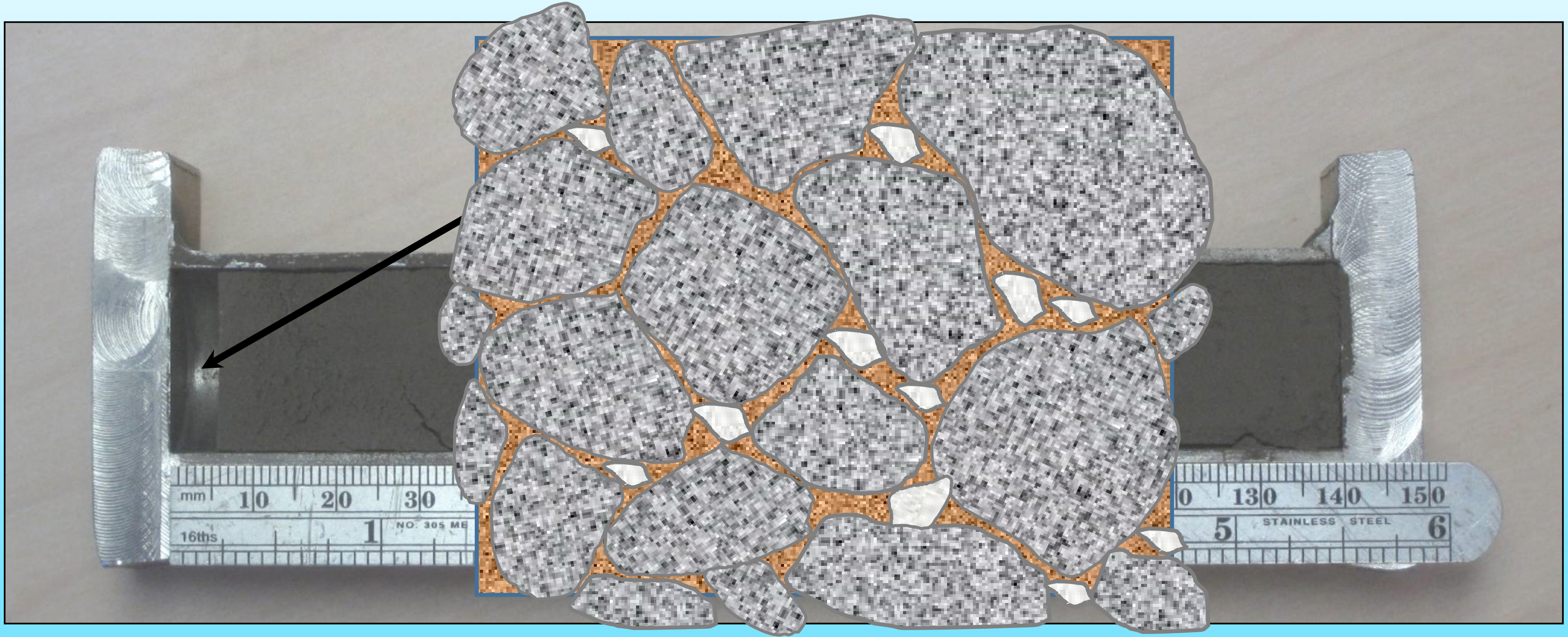
Aggregate interlock

The right ratio between coarse, intermediate, and fine particles (1in., #4, and #8 sieves)

Materials – Clay Content (Cohesion)

Liquid Limit - Plastic Limit = Plasticity Index

Materials – Clay Content (Shrinkage)



Some "glue" to hold everything together (weighted plasticity factor [linear shrinkage preferred])

Test Results (±$300)

ALLWEST Testing & Engineering

LABORATORY SUMMARY

PROJECT NAME:
CLIENT NAME:
LOCATION:
SAMPLE NUMBER:
LAB SAMPLE NUMBER:
SAMPLED BY:
DATE SAMPLED:
MATERIAL:
TEST DESCRIPTION

SIEVE ANALYSIS			
AASHTO T27, T248 / ASTM C117, C136, C102, D1140			
1"		100	100
3/4"		100	100
1/2"		98	94
3/8"		84	80
#4		51	48
#8		31	31
#10		27	28
#16		20	21
#30		15	16
#40		13	14
#50		11	12
#100		9	10
#200		6.9	7.5
ATTERBURG LIMITS DETERMINATION		Non-Plastic	Non-Plastic
AASHTO T89, T90 / ASTM D4318			

FRACTURE COUNT
AASHTO TP61 / ASTM D5821

REVIEWED BY

This report shall not be repro

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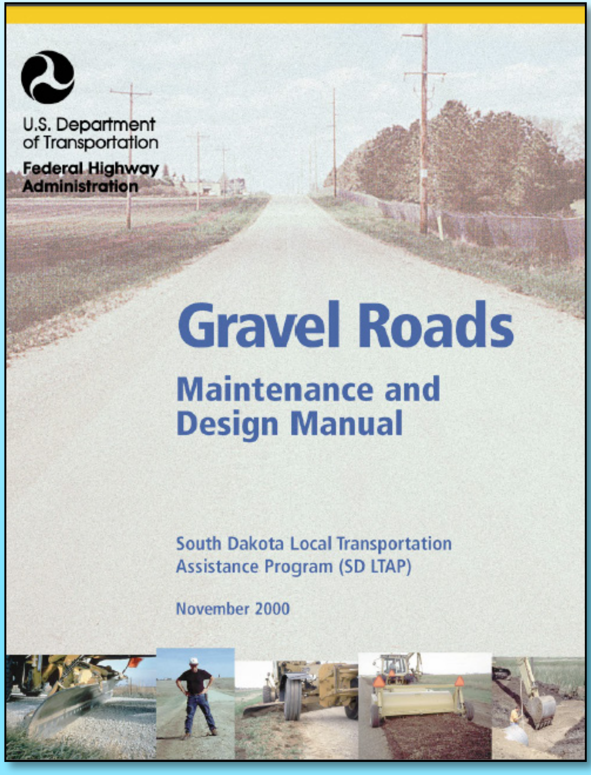
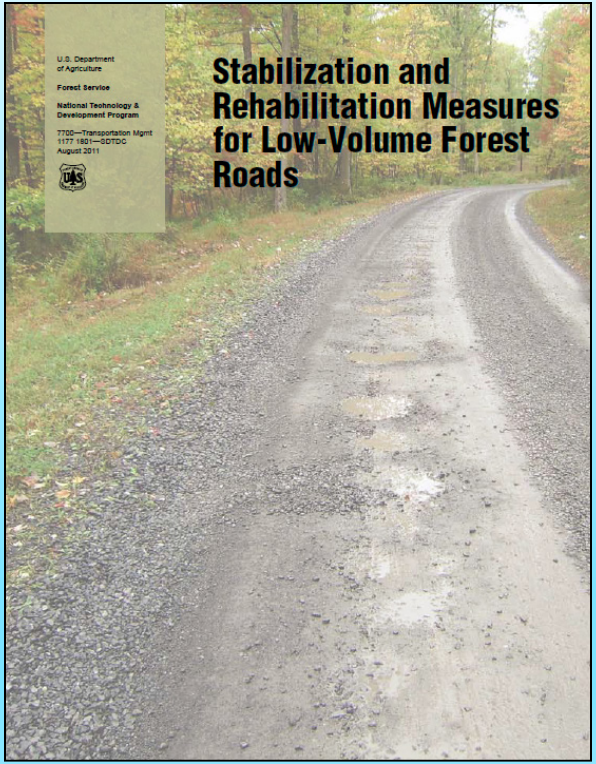
Revision #1- 03.20.12

US Guidelines & Specifications





Why Read Guidelines?

Example US Federal Specifications

Parameter			FHWA	USFS	
				Public Use	Haul
Sieve (mm [in.])	1	(25)	100	100	97 – 100
	3/4	(19)	90 – 100	97 – 100	76 – 89
	#4	(4.75)	50 – 78	51 – 63	43 – 53
	#8	(2.36)	37 – 67	28 – 39	23 – 32
	#40	(0.425)	13 – 35	19 – 27	15 – 23
	#200	(0.075)	4 – 15	10 – 16[1] or 6 - 12[1]	10 – 16[1] or 6 - 12[1]
Plasticity Index			4 – 12	2 – 9 if P#200 is <12% <2 if P#200 is >12%	

[1] Range for P#200 is 6.0 to 12.0% if PI is greater than zero

US vs. MDOT Specifications

Parameter		FHWA	USFS Public Use	Michigan (Table 902-1)
Sieve (in. [mm])	1 (25)	100	100	100
	3/4 (19)	90 – 100	97 – 100	–
	3/8 (9.5)	–	–	60 – 85
	#4 (4.75)	50 – 78	51 – 63	–
	#8 (2.36)	37 – 67	28 – 39	25 – 60
	#40 (0.425)	13 – 35	19 – 27	–
	#200 (0.075)	4 – 15	10 – 16[1] or 6 - 12[1]	9 – 16
Plasticity Index		4 – 12	2 – 9 if P#200 is <12% <2 if P#200 is >12%	Not specified

[1] Range for #200 is 6.0 to 12.0% if PI is greater than zero

Outline

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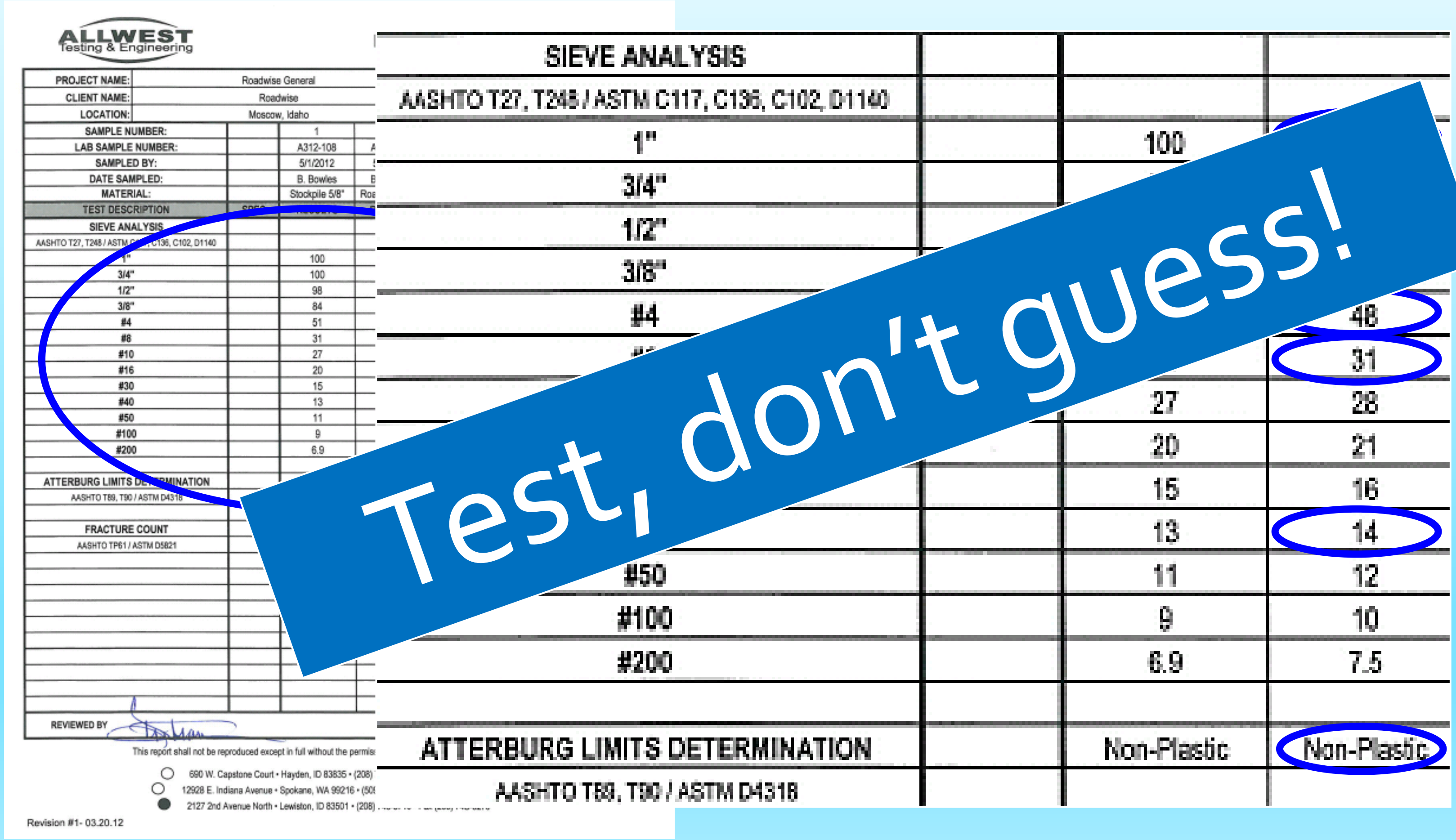
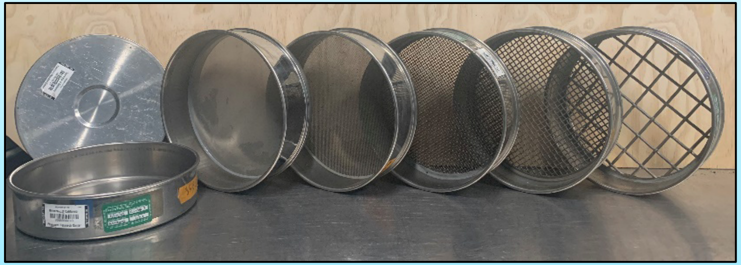
- **Balanced mix design for unpaved roads**
- Predicting unpaved road performance
- Material blending
- Conclusions

Interpreting Test Results



Balanced Mix Design for Unpaved Roads

- Replace grading envelopes with grading coefficient (G_c)
  - Ratio of coarse, intermediate, and fine
  - ((P1-P#8) × P#4) / 100
  - Target 15 to 35



- Replace plasticity index range with shrinkage product (S_p)
  - Weighted plasticity
  - Bar linear shrinkage (or ½PI) × P#40
  - Target 100 to 365; preferably 100 to 240

Balanced Mix Design for Unpaved Roads

Maximum size (in. [mm])	
Particle size distribution fa	
Weighted clay fa	65 (240)
Stren	>15
conditions and test methods!	
ependent on construction and maintenance quality!**	

Not rocket science, just rocks and a little arithmetic!

Calibrate for Local Use

Outline

- Introduction
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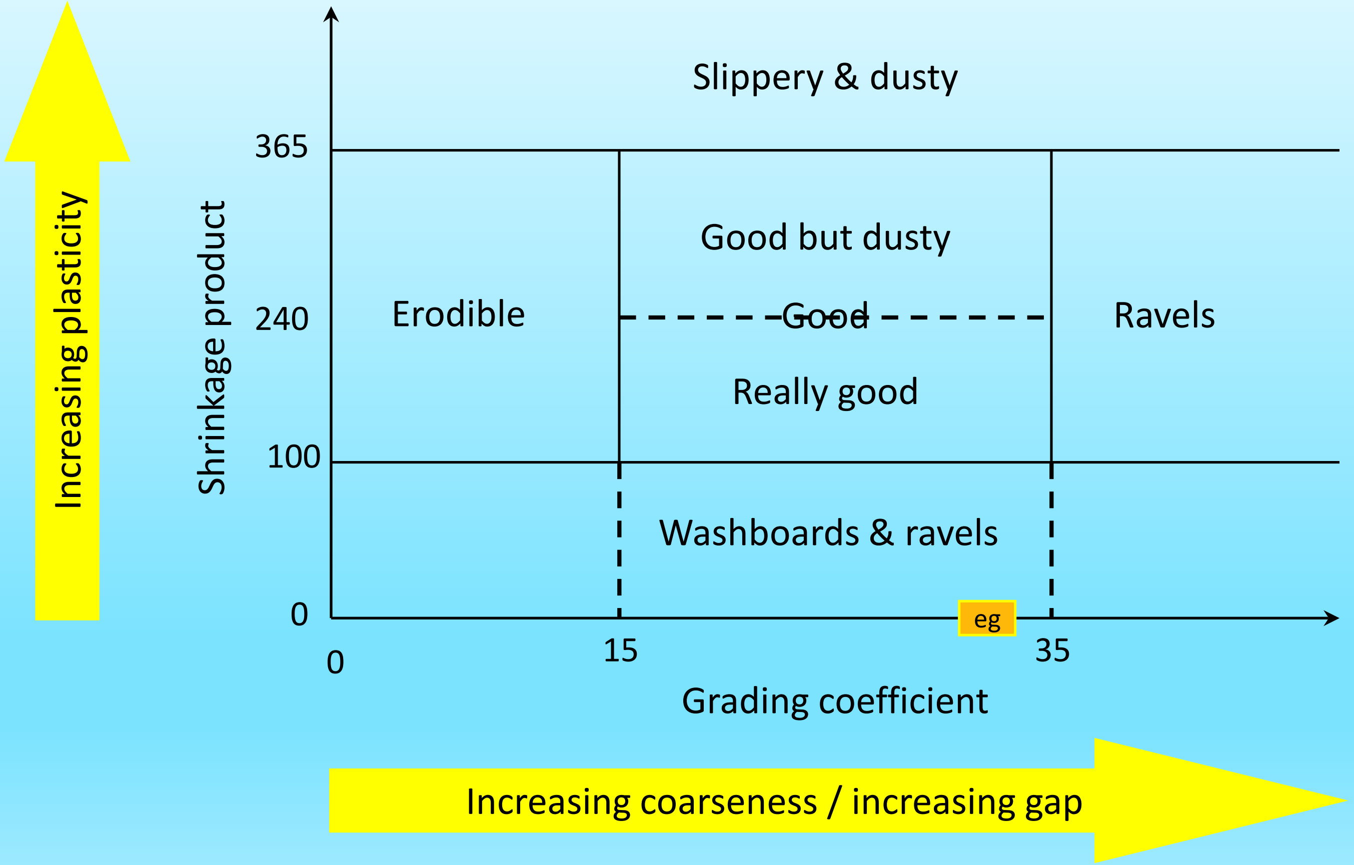
- Balanced mix design for unpaved roads
- **Predicting unpaved road performance**
- Material blending
- Conclusions

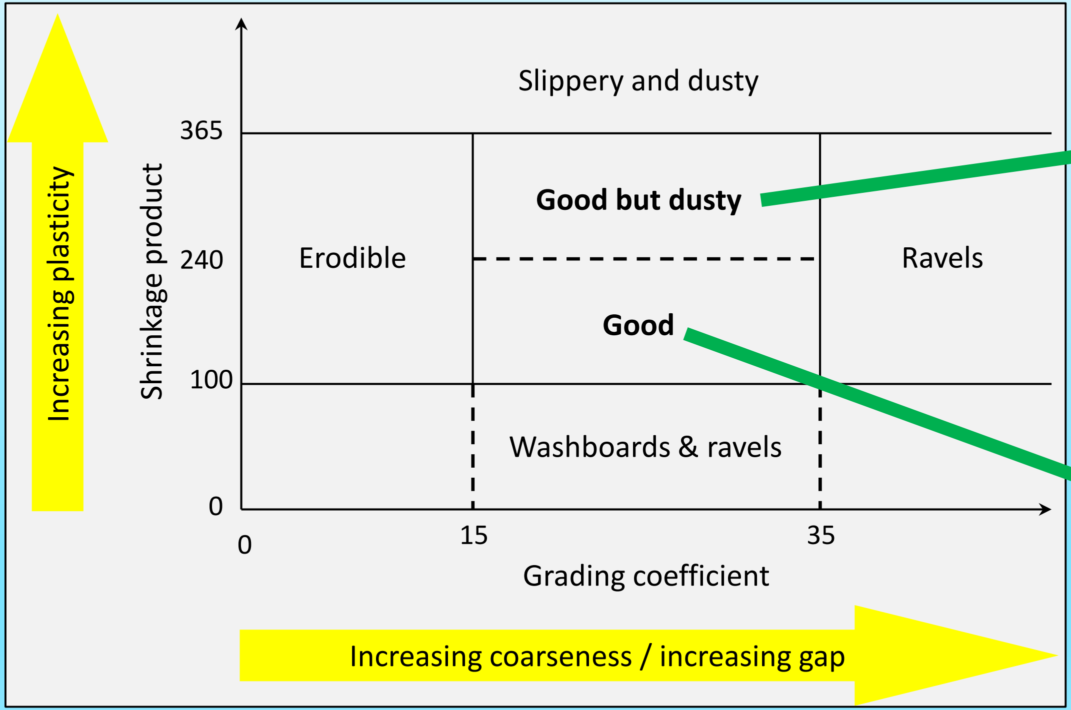
Predicting Road Performance

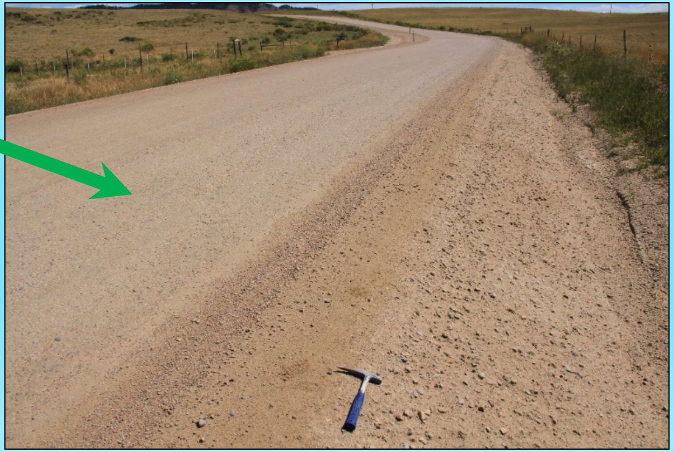
- Plot shrinkage product against grading coefficient to get expected performance
  - "Balancing" plasticity and gradation

Predicting Road Performance

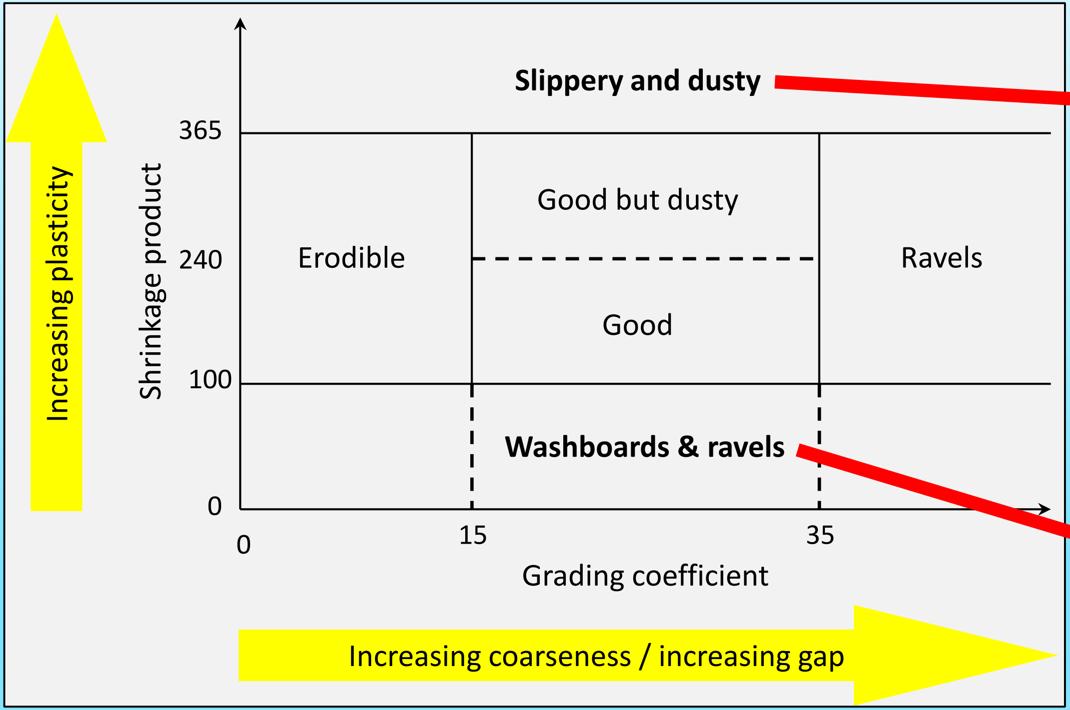


Predicting Road Performance

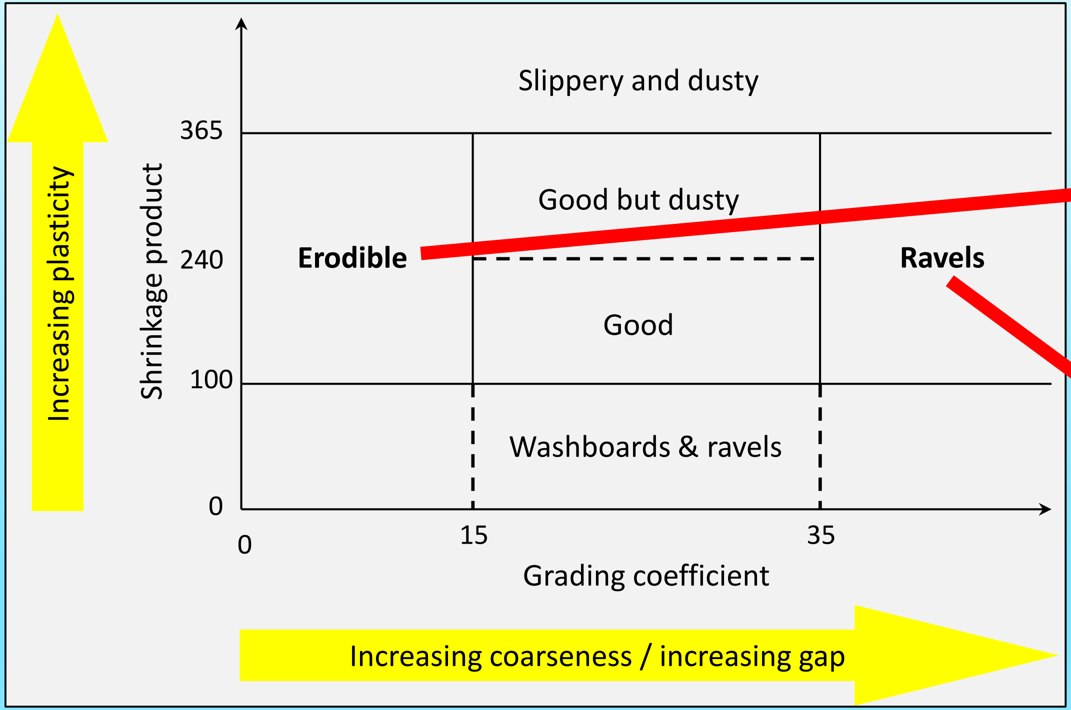




Predicting Road Performance



Predicting Road Performance



Deformation - Potholes

Deformation - Rutting

Shape + compaction + thickness!

How do US Guidelines Predict?

Parameter		FHWA	USFS	
			Public Use	Haul
Sieve (mm)	1	100	100	97 – 100
	#4	50 – 78	51 – 63	43 – 53
	#8	37 – 67	28 – 39	23 – 32
	#40	13 – 35	19 – 27	15 – 23
Plasticity Index		4 – 12	2 – 9 if P#200 is <12% <2 if P#200 is >12%	

How do US Guidelines Predict?

Parameter		FHWA	USFS	
			Public Use	Haul
Sieve (mm)	1 #4 #8 #40	100 50 – 78 37 – 67 13 – 35	100 51 – 63 28 – 39 19 – 27	97 – 100 43 – 53 23 – 32 15 – 23
Plasticity Index		4 – 12	2 – 9 if P#200 is <12% <2 if P#200 is >12%	
Grading Coefficient: (15 – 35)	Low range Mid range High range Worst case			
Shrinkage Product: (100 – 365)	Low range Mid range High range Worst case			

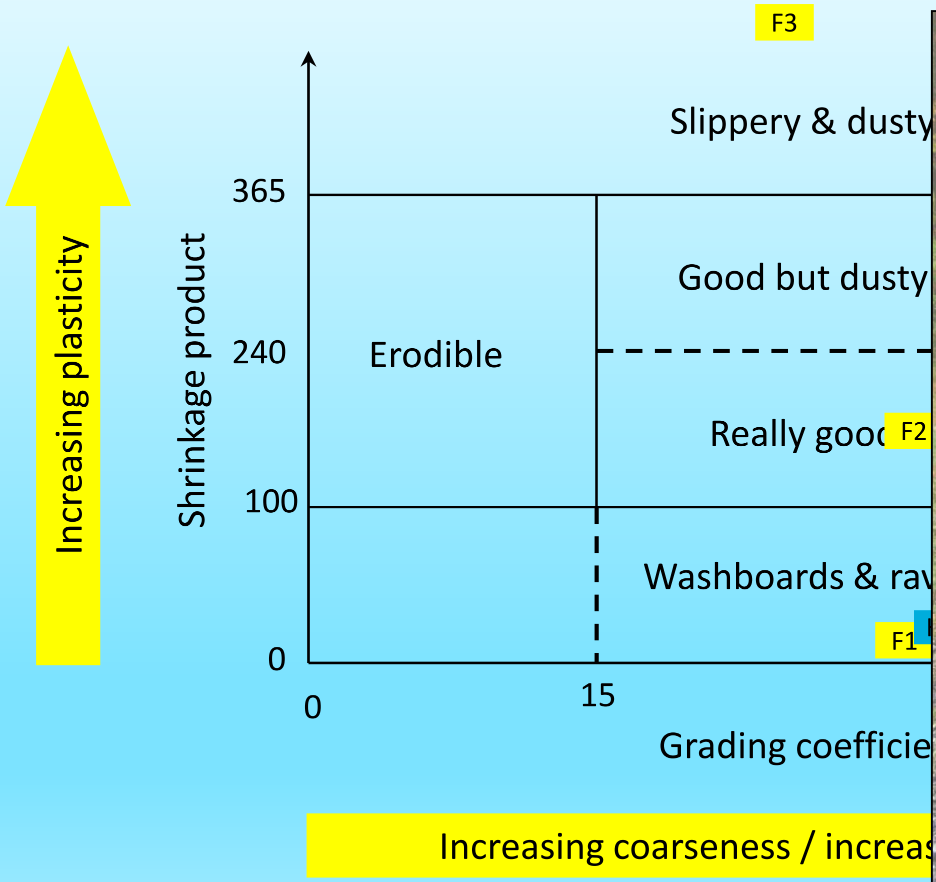
How do US Guidelines Predict?

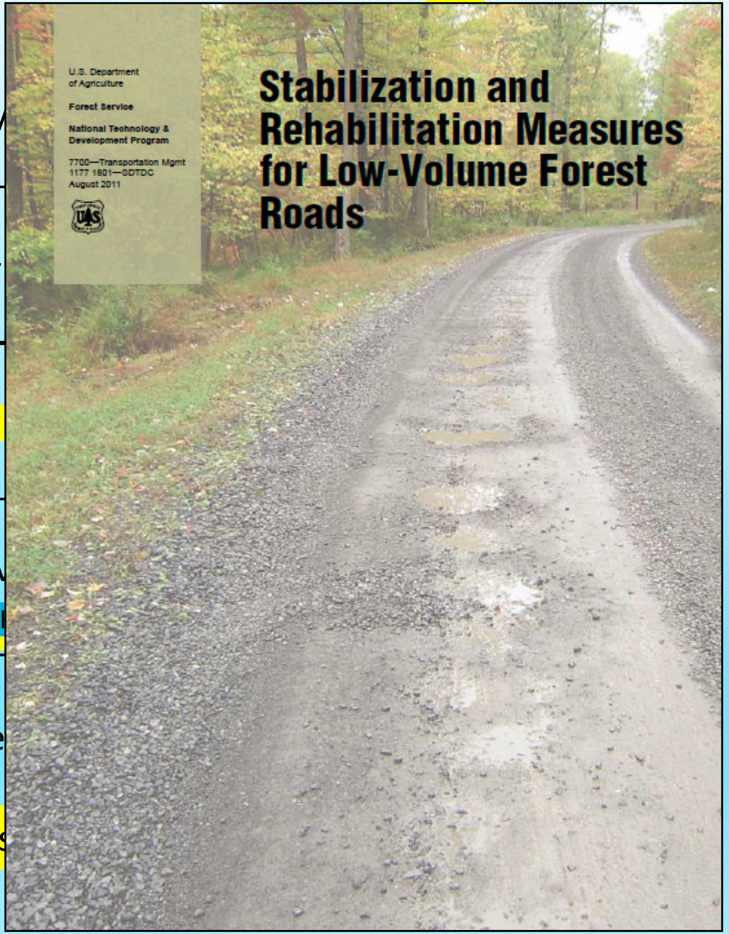
Parameter		FHWA	USFS	
			Public Use	Haul
Sieve (mm)	1	100	100	97 – 100
	#4	50 – 78	51 – 63	43 – 53
	#8	37 – 67	28 – 39	23 – 32
	#40	13 – 35	19 – 27	15 – 23
Plasticity Index		4 – 12	2 – 9 if P#200 is <12% <2 if P#200 is >12%	
Grading Coefficient: (15 – 35)	Low range	32	37	32
	Mid range	31	38	34
	High range	26	38	36
	Worst case	49	45	41
Shrinkage Product: (100 – 365)	Low range	26	38	30
	Mid range	192	126	105
	High range	420	243/27	207/23
	Worst case	420	27	23

How do US Guidelines Predict?

Parameter		FHWA	USFS	
			Public Use	Haul
Sieve (mm)	1 #4 #8 #40	100 50 – 78 37 – 67 13 – 35	100 51 – 63 28 – 39 19 – 27	97 – 100 43 – 53 23 – 32 15 – 23
Plasticity Index		4 – 12	2 – 9 if P#200 is <12% <2 if P#200 is >12%	
Grading Coefficient: (15 – 35)	Low range Mid range High range Worst case	32 31 26 **49**	**37** **38** **38** **45**	32 34 **36** **41**
Shrinkage Product: (100 – 365)	Low range Mid range High range Worst case	**26** 192 **420** **420**	**38** 126 243/**27** **27**	30 105 207/**23** **23**

How do US Guidelines Predict?





Discussion

Outline

- Introduction
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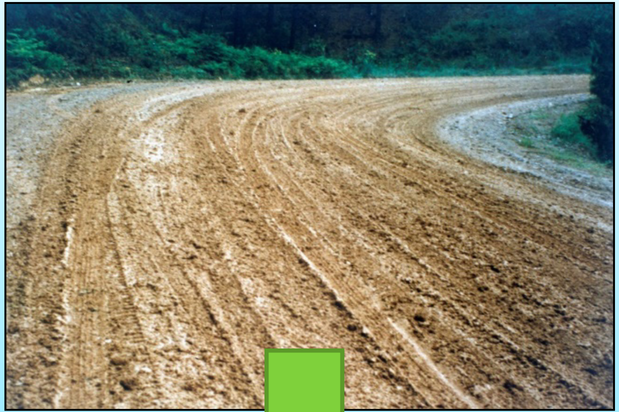
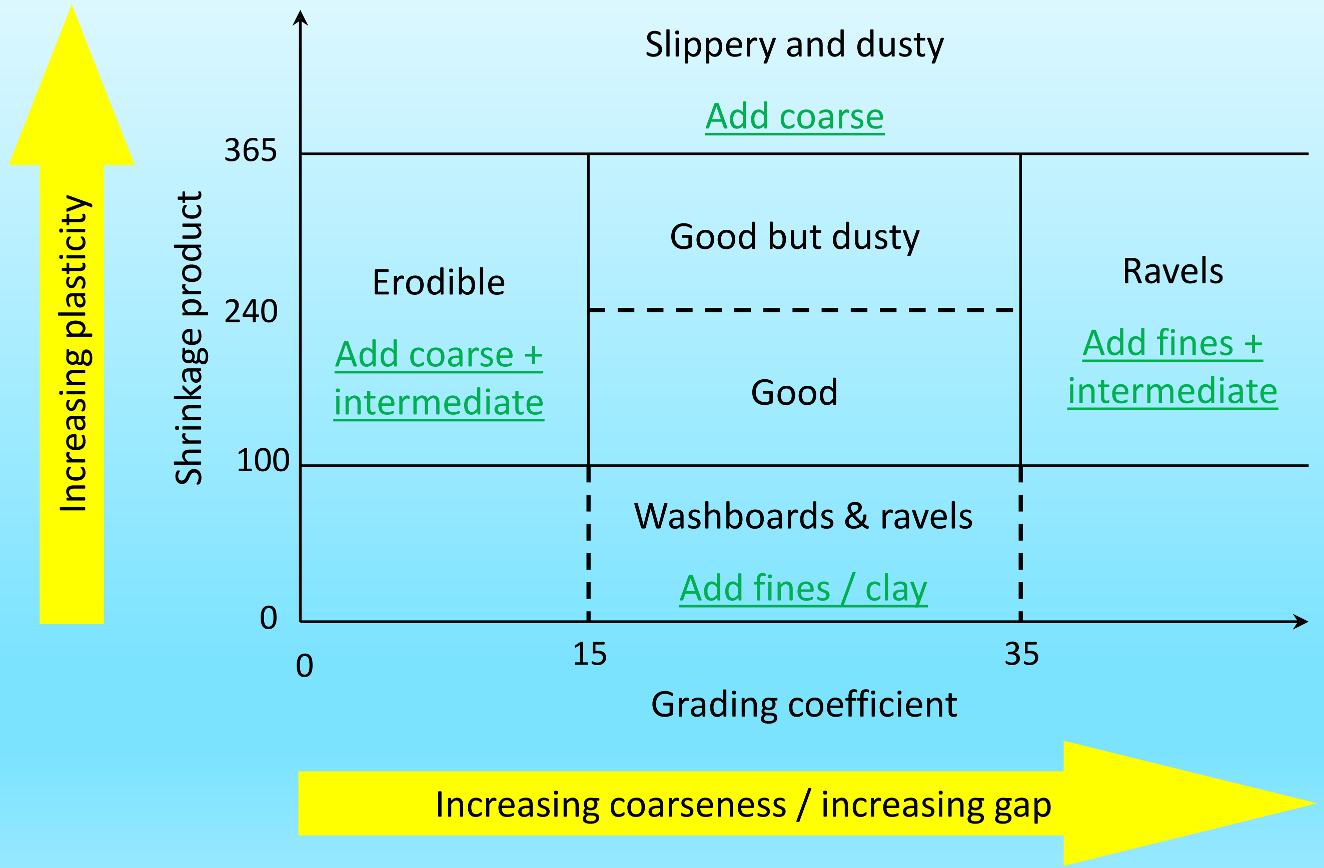
Two wrongs can make a right



Mechanical Stabilization to Improve the Balance



Web-Based Blending Tool

- Coded manual procedure with simple user interface
- Determines proportion that each layer contributes to a target thickness as a percentage
- Includes:
  - Three layers plus subgrade
  - Up to three materials in a blend
  - User defined materials library
  - Blend verification
- Rubbish in, rubbish out
  - Use actual test results
  - Use actual layer thicknesses

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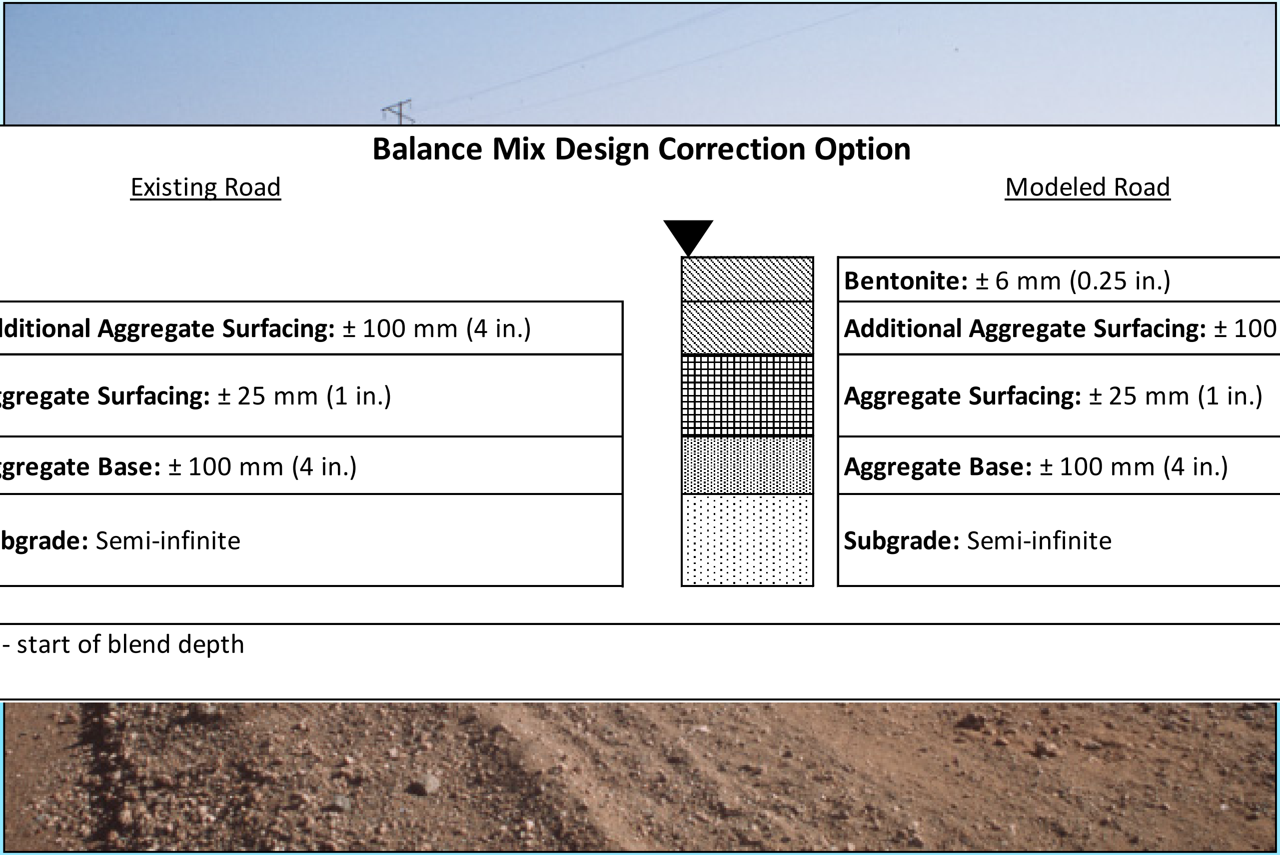
Recommended Thickness Designs (FHWA guide)

Estimated Daily Truck Traffic	Subgrade Shear Strength (CBR)	Suggested Minimum Gravel Thickness (in. [mm])
0 to 5	<3	7 (175)
	3 to 10	6 (150)
	>10	5 (125)
5 to 10	<3	9 (225)
	3 to 10	7 (175)
	>10	6 (150)
10 to 25	<3	12 (300)
	3 to 10	9 (225)
	>10	7 (175)
25 to 50	<3	15 (380)
	3 to 10	12 (300)
	>10	9 (225)
50 to 75	<3	18 (455)
	3 to 10	15 (380)
	>10	12 (300)

Example: Balanced Mix Design Correction



Balance Mix Design Correction Option

Existing Road

Additional Aggregate Surfacing: ± 100 mm (4 in.)	
Aggregate Surfacing: ± 25 mm (1 in.)	
Aggregate Base: ± 100 mm (4 in.)	
Subgrade: Semi-infinite	

Modeled Road

Bentonite: ± 6 mm (0.25 in.)	
Additional Aggregate Surfacing: ± 100 mm (4 in.)	
Aggregate Surfacing: ± 25 mm (1 in.)	
Aggregate Base: ± 100 mm (4 in.)	
Subgrade: Semi-infinite	

▼ Surface level - start of blend depth

Example: Balanced Mix Design Correction

Example: Balanced Mix Design Correction

Project ID: Balance Mix Design Correction

Existing road

Existing Structure

2 Layers | 3 Layers | 4 Layers | Delete All Layers

#	Type	Thickness (Inch)	Layer Sum (Inch)	Passing 1" (%)	Passing #4 (%)	Passing #8 (%)	Passing #40 (%)	Passing #200 (%)	BLS (or PI/2)	Actions
1	Aggregate base	4.0	4.0	100	64	52	24	10	2	Edit Delete Insert
2	Aggregate base	1.0	5.0	100	64	52	24	10	6	Edit Delete Insert
3	Aggregate subbase	4.0	9.0	100	78	60	41	15	10	Edit Delete Insert
4	Subgrade	∞	9.0	100	84	78	58	44	11	Edit Delete Insert

Design thickness

Recycle depth

Thickness Design: 7.0 Inch (Thickness Design Table)

Depth of Recycling: 5.0 Inch

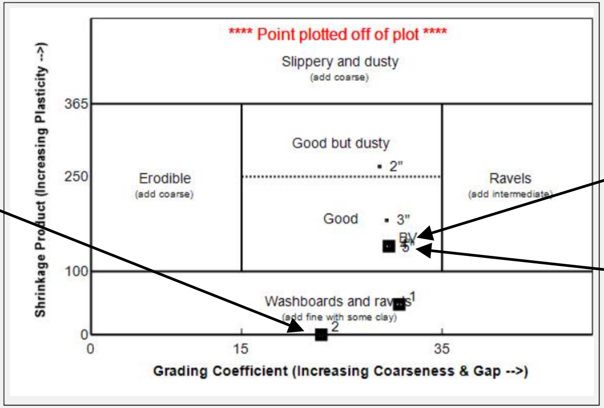
Predict Performance

Supplemental aggregate

☑ Add 0.3 Inch of Supplemental Material #: 4

☐ Add 0.0 Inch of Supplemental Material #: Select

☑ Plot Supplemental & Blend Validation Materials



Actual

Predicted

Materials library

Supplemental Material Library

#	Description	Passing 1" (%)	Passing #4 (%)	Passing #8 (%)	Passing #40 (%)	Passing #200 (%)	BLS (or PI/2)	Actions
1	Aggregate Surfacing	100	64	52	24	10	2	Edit Delete Insert
2	RAP	100	28	18	6	3	0	Edit Delete Insert
3	Clay	100	87	82	62	54	18	Edit Delete Insert
4	Bentonite*	100	100	100	98	95	50	Edit Delete Insert

Add Material

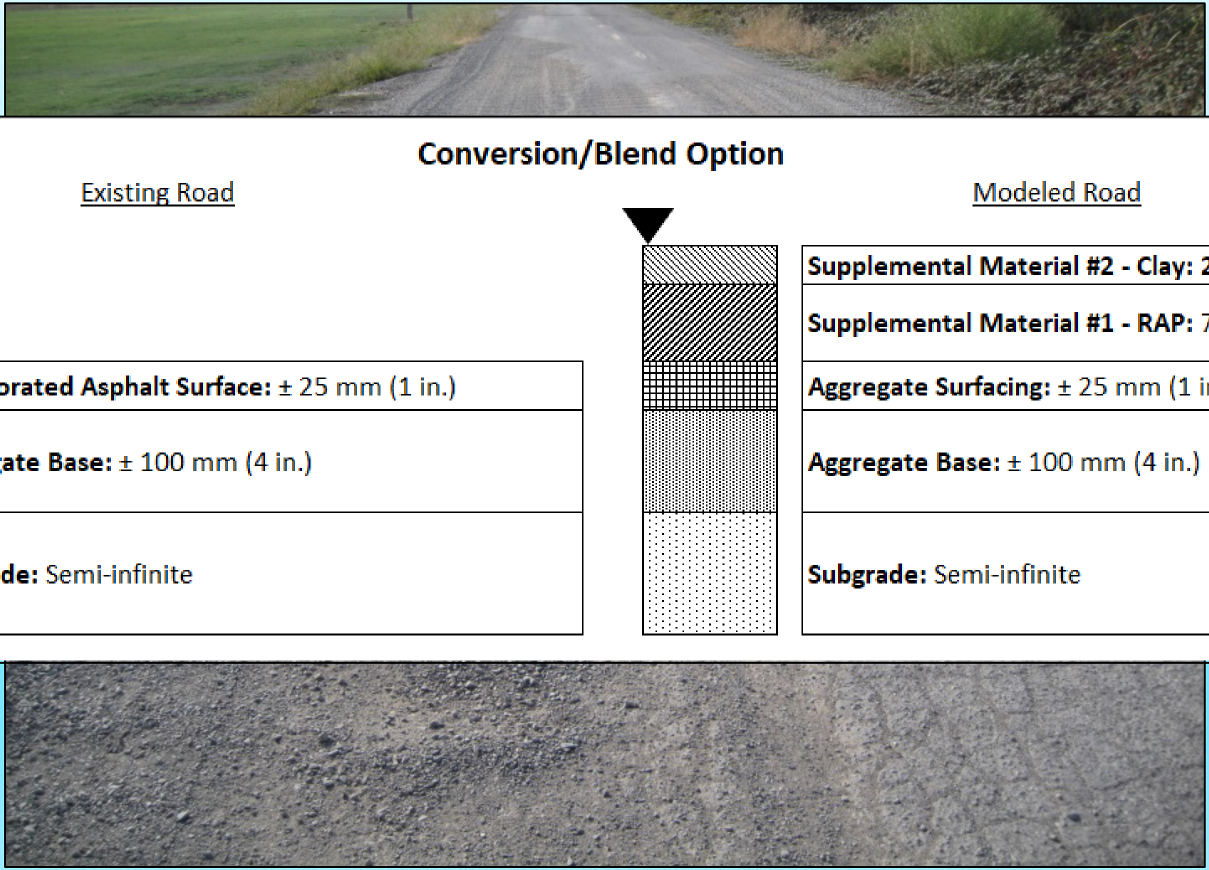
Chemical Treatment Selection Tool

Verification

Blend Validation

Description	Passing 1" (%)	Passing #4 (%)	Passing #8 (%)	Passing #40 (%)	Passing #200 (%)	BLS (or PI/2)	Actions
Blend Validation	100	66	55	28	15	5	Edit Clear

Example: Unpaving / Regraveling



Conversion/Blend Option

Existing Road	Modeled Road
	Supplemental Material #2 - Clay: 25 mm (1 in.)
	Supplemental Material #1 - RAP: 75 mm (3 in.)
Deteriorated Asphalt Surface: ± 25 mm (1 in.)	**Aggregate Surfacing:** ± 25 mm (1 in.)
Aggregate Base: ± 100 mm (4 in.)	**Aggregate Base:** ± 100 mm (4 in.)
Subgrade: Semi-infinite	**Subgrade:** Semi-infinite

Example: Unpaving / Regraveling

Existing road

Design thickness

Recycle depth

Supplemental aggregate

Materials library

Verification

Actual

Predicted

Project ID: Unpaving Project

Existing Structure

2 Layers | 3 Layers | 4 Layers | Delete All Layers

#	Type	Thickness (Inch)	Layer Sum (Inch)	Passing 1" (%)	Passing #4 (%)	Passing #8 (%)	Passing #40 (%)	Passing #200 (%)	BLS (or PI/2)	Actions
1	Asphalt concrete	1.0	1.0	100	28	18	6	3	0	Edit Delete Insert
2	Aggregate base	4.0	5.0	100	78	60	41	15	10	Edit Delete Insert
3	Subgrade	∞	5.0	100	84	78	58	44	11	Edit Delete Insert

Thickness Design: 7.0 Inch (Thickness Design Table)

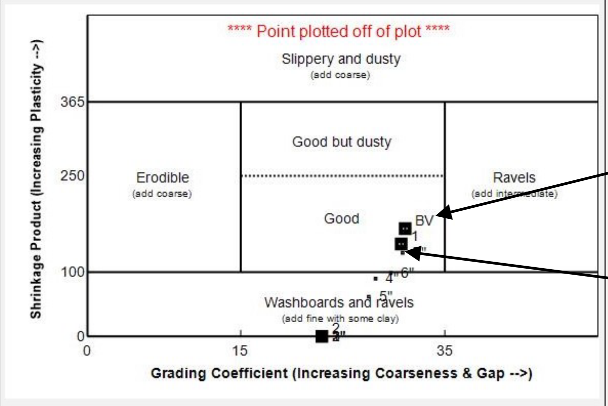
Depth of Recycling: 7.0 Inch

Predict Performance

☑ Add 3.0 Inch of Supplemental Material #: 2

☑ Add 1.0 Inch of Supplemental Material #: 3

☑ Plot Supplemental & Blend Validation Materials



Supplemental Material Library

#	Description	Passing 1" (%)	Passing #4 (%)	Passing #8 (%)	Passing #40 (%)	Passing #200 (%)	BLS (or PI/2)	Actions
1	Aggregate Surfacing	100	64	52	24	10	6	Edit Delete Insert
2	RAP	100	28	18	6	3	0	Edit Delete Insert
3	Clay	100	87	82	62	54	18	Edit Delete Insert

Add Material | Chemical Treatment Selection Tool

Blend Validation

Description	Passing 1" (%)	Passing #4 (%)	Passing #8 (%)	Passing #40 (%)	Passing #200 (%)	BLS (or PI/2)	Actions
Blend Validation	100	51	39	24	14	7	Edit Clear

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Unpaved Road Chemical Treatment Selection Tool

UCPRC City and County Pavement Improvement Center

Home | Instructions | Treatment Selection | Results Interpretation | About

Language & Units
English Spanish
US SI

Welcome to the UCPRC's Unpaved Road Chemical Selection Tool Site

There are millions of kilometers/miles of unpaved roads around the world managed by numerous authorities, land owners, and public and private organizations. Common to all of these roads are unacceptable levels of dust, poor riding quality and/or impassability in wet weather, and expensive maintenance and gravel replacement activities. Over the last 100+ years, a range of different chemical treatments have been developed to overcome these issues. Most of these are proprietary, which can complicate selection of an appropriate treatment for a specific set of conditions. There is also no single product that will solve all problems under all conditions.

Loss of fines (as dust) on an untreated road

A procedure has therefore been developed to guide practitioners in the selection of an appropriate treatment. This procedure, based on the 1999 US Forest Service Guide (*Dust Palliative Selection and Application Guide*), and updated with new research and experience, factors traffic, climate, material properties, and road geometry into the most appropriate treatment selections for a given set of input values. The procedure is based on the philosophy of using chemical treatments to keep good roads in good condition, rather than attempting to use chemical treatments to "fix" bad roads. This unpaved road chemical treatment selection tool and information related to it is fully described in the UCPRC guideline entitled "Guidelines for the Selection, Specification, and Application of Chemical Dust Control and Stabilization Treatments on Unpaved Roads." This web-based chemical treatment selection tool can be considered as a companion to the guideline.

The photo on the left shows loss of fines on an untreated road while the photo on the right shows the results of applying a fines preservation treatment.

Stable fines preservation on a treated road

Disclaimer

This unpaved road chemical treatment selection procedure has been developed to guide selection of an appropriate treatment. It is based on the experience of practitioners and documented field experiment results. It is a guide only and does not replace engineering practice and judgment. Before initiating a treatment program, users should check actual performance for their particular materials and conditions with appropriate laboratory performance tests and/or short field experiments and/or seek guidance from other experienced practitioners and treatment suppliers. The University of California does not endorse the use of any specific product for dust control and stabilization of unpaved roads. In no event shall the University of California be liable to any party for direct, indirect, special, incidental, or consequential damages, including lost profits, arising out of the use of this system, even if the University of California has been advised of the possibility of such damage. The University of California specifically disclaims any warranties, including, but not limited to, the implied warranties of merchantability, fitness for a particular purpose and noninfringement.

☐ **Accept**

Treatment selection for BMD

Unpaved Road Chemical Treatment Selection Tool

Home | Instructions | Treatment Selection | Results Interpretation | About

Road ID CR18 **Details** km 1 to km 1

Material Test Results

%Passing 25	100	%Passing 0.425	25
%Passing 4.75	45	%Passing 0.075	15
%Passing 2.36	35	PI (or BLSx2)	10

Objective

- Short-term dust control (spray-on)
- Long-term fines preservation (spray-on)
- Long-term fines preservation (mix-in)
- Long-term stabilization (mix-in)

Roadway Parameters

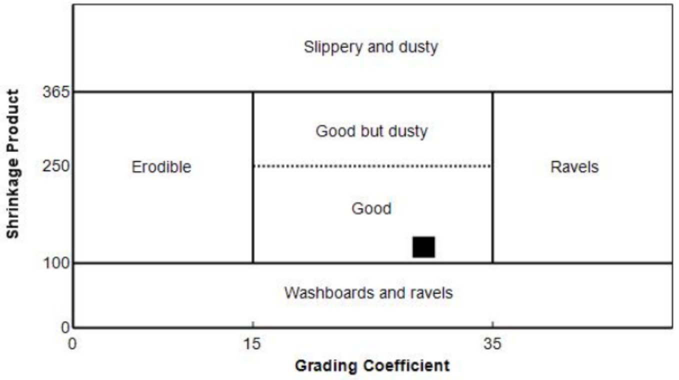
Traffic (AADT): < 100

Climate: Damp

- More Than 10% Trucks
- Steep Grades
- Sharp Curves

Compute Ratings | Environmental & Other Influences

Predicted Material Performance for Untreated Road



Treatment Ratings

Treatment	TR	CL	PI	FC	HV	SG	SC	Rating
Calcium Chloride	1	1	1	1	0	0	0	1.0
Magnesium Choride	1	1	1	1	0	0	0	1.0
Glycerin Based	1	1	1	1	0	0	0	1.0
Lignosulfonate	1	1	1	1	0	0	0	1.0
Molasses/Sugar	1	1	1	1	0	0	0	1.0
Plant Oil	1	1	1	1	0	0	0	1.0
Tall Oil	1	1	1	1	0	0	0	1.0
Base Oil	1	1	1	1	0	0	0	1.0
Petroleum Resin	1	1	1	1	0	0	0	1.0
Synthetic Fluid	1	1	1	1	0	0	0	1.0
Synthetic Fluid + Binder	1	1	1	1	0	0	0	1.0
Sodium Chloride Brine	1	2	1	1	0	0	0	2.0
Asphalt Emulsion	1	1	2	2	0	0	0	2.1
Synthetic Polymer	2	2	2	2	0	0	0	2.4
Water	3	3	3	3	0	0	0	NA
Water + Surfactant	3	3	3	3	0	0	0	NA
Concentrated Liquid Stabilizer	3	3	3	3	0	0	0	NA
Bentonite	3	3	3	3	0	0	0	NA

TR: Traffic; **CL:** Climate; **PI:** Plasticity; **FC:** Fines Content; **HV:** More Than 10% Trucks
SG: Steep Grades; **SC:** Sharp Curves; **Rating:** Treatment Performance Ratings

Suppliers | Print

Treatment selection for UBMD

Unpaved Road Chemical Treatment Selection Tool

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Road ID CR18 **Details** km 1 to km 1

Material Test Results

%Passing 25	100	%Passing 0.425	25
%Passing 4.75	45	%Passing 0.075	10
%Passing 2.36	35	PI (or BLSx2)	0

Objective

- Short-term dust control (spray-on)
- Long-term fines preservation (spray-on)
- Long-term fines preservation (mix-in)
- Long-term stabilization (mix-in)

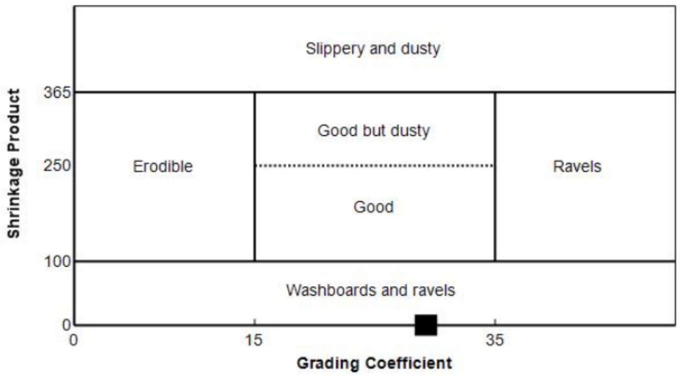
Roadway Parameters

Traffic (AADT): < 100 Climate: Damp

- More Than 10% Trucks
- Steep Grades
- Sharp Curves

Compute Ratings | Environmental & Other Influences

Predicted Material Performance for Untreated Road



Treatment Ratings

Treatment	TR	CL	PI	FC	HV	SG	SC	Rating
Asphalt Emulsion	1	1	2	1	0	0	0	2.0
Calcium Chloride	1	1	2	2	0	0	0	2.1
Magnesium Choride	1	1	2	2	0	0	0	2.1
Glycerin Based	1	1	2	2	0	0	0	2.1
Lignosulfonate	1	1	2	2	0	0	0	2.1
Tall Oil	1	1	2	2	0	0	0	2.1
Base Oil	1	1	2	2	0	0	0	2.1
Petroleum Resin	1	1	2	2	0	0	0	2.1
Synthetic Fluid	1	1	2	2	0	0	0	2.1
Synthetic Fluid + Binder	1	1	2	2	0	0	0	2.1
Synthetic Polymer	2	2	2	2	0	0	0	2.4
Plant Oil	1	1	3	2	0	0	0	3.0
Sodium Chloride Brine	1	2	3	2	0	0	0	3.0
Molasses/Sugar	1	1	3	3	0	0	0	3.1
Water	3	3	3	3	0	0	0	NA
Water + Surfactant	3	3	3	3	0	0	0	NA
Concentrated Liquid Stabilizer	3	3	3	3	0	0	0	NA
Bentonite	3	3	3	3	0	0	0	NA

Suppliers | Print

TR: Traffic; **CL:** Climate; **PI:** Plasticity; **FC:** Fines Content; **HV:** More Than 10% Trucks
SG: Steep Grades; **SC:** Sharp Curves; **Rating:** Treatment Performance Ratings

Outline

- Introduction
- Understanding unpaved road materials
- Balanced mix design for unpaved roads
- Predicting unpaved road performance
- Material blending
- Conclusions

Conclusions

- Unpaved roads are managed with very constrained budgets, but high user expecatations
- Using performance-based specifications can reduce maintenance/extend regraveling intervals
- Difficult to source good unpaved road wearing course materials from commercial sources
- Relatively easy to blend supplemental aggregates to meet that performance specification
- Adopting an "engineered" unpaved road management strategy will be most cost-effective
- It's proven technology - give it a try!

Thank-you!

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