Best Practices for Steel Slag Usage in Unpaved Roadway and Shoulder Applications

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Presentation Objectives/Outline

1. Low-volume paved roads with unpaved shoulders – focus is MDOT SR 388 test sections
2. Unpaved roads using steel slag – focus is Noxubee County, MS

<u>Note:</u> a presentation was given to NSA at 101st Annual Meeting in 2019 discussing Mississippi market potential (water treatment, SMA, pavement bases.... the two applications above are most appealing market in view of presenters).

Why?
(Numerous Unpaved Roads and Shoulders in Mississippi)

- FHWA: MS has 73,000 centerline miles of highway
- MDOT: MS has 77,500 centerline miles of highway
  - 47,400 privately managed, municipalities….
  - 19,150 managed by OSARC (85% paved, 15% unpaved – 99% unpaved shoulders)
  - 10,950 managed by MDOT (80% unpaved shoulders)

Shoulder Aggregates Overview

- <u>Primary Objective:</u> Better understand how different shoulder aggregates perform on lower volume routes with asphalt surfaces and relatively narrow shoulders
  - Understanding properties or characteristics of aggregates and relating these properties to in service performance was of key interest
  - Gravel, limestone, steel slag, crushed concrete, & RAP were studied
- <u>A review of MDOT practices revealed:</u>
  - Multiple mentions of clay gravel problems, in particular blends without adequate plasticity
  - Limestone, crushed concrete, and RAP are mentioned, but (MDOT Standard Specifications) Red Book Section 320 doesn't have comprehensive specifications for multiple aggregate options
  - Overall consensus is MDOT specifications could benefit from possible updates

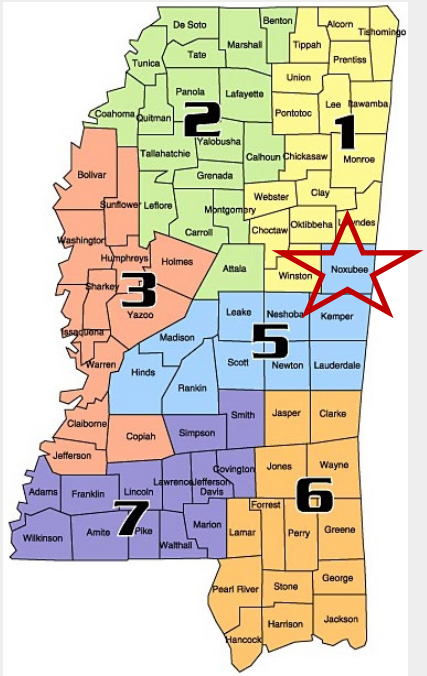
Literature Review Summary (± 70 References)

- There is not one universally approved method to evaluate shoulder performance
- 17 performance/property measures were identified and those used herein are highlighted: durability, **dry density**, load bearing capacity, **gradations**, **CBR**, resilient modulus, particle breakdown, self-cementation, particle emissions, rutting resistance, **edge drop-off (EDO)**, particle erosion, total crashes, fatal or injury crashes, related crashes
- EDO is defined as a vertical discontinuity or difference in elevation between two adjacent road surfaces – it is a key performance metric
  - 9 references were the primary basis for arriving at an EDO failure threshold range of 2 to 2.5 inches for this work

Literature Review – Shoulder Aggregates

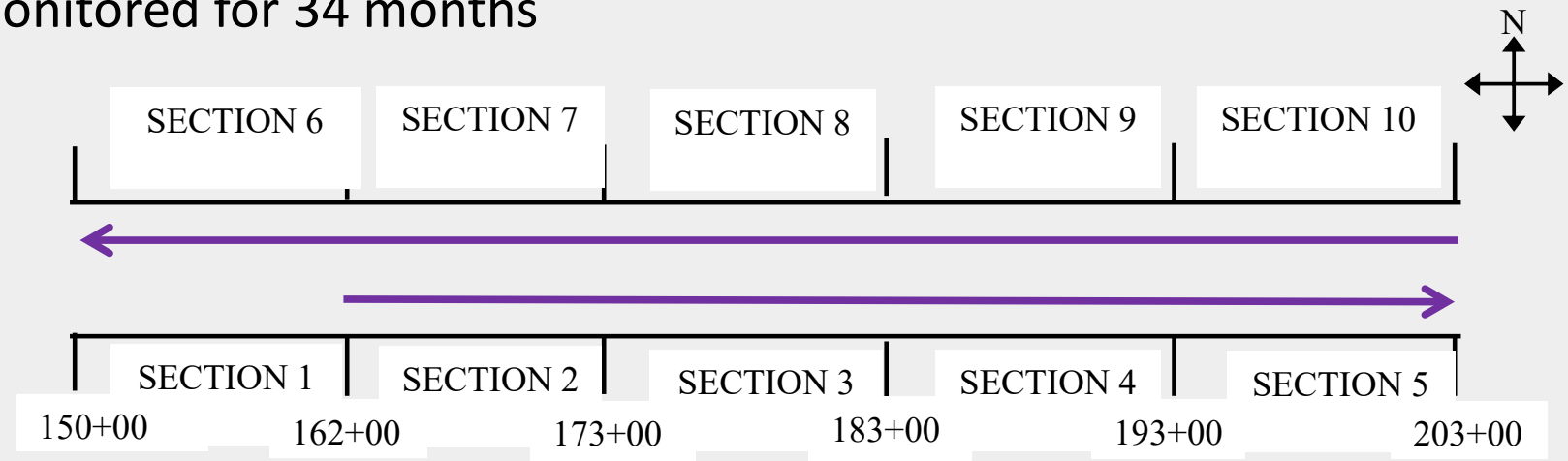
- Literature has varying information about various aggregates, but shoulder aggregates specific studies are not especially common
  - Steel Slag: 2013 synthesis showed only Indiana and West Virginia using slag for shoulders
  - Crushed Concrete: Iowa State's tech center has some fairly detailed guidance for gradations and other possibly specifications
  - Gravel: Literature can be hard to quantify in some cases "gravel" sometimes just means aggregate – larger gravels tended to break down in service, 4 to 15% fines, and a plasticity index of 4 to 12 were general suggestions/requirements
  - Limestone: Not too much shoulder specific content, but limestone has proven record in numerous base or comparable applications
  - RAP: A 1990's synthesis reported only Indiana and Vermont using RAP on shoulders, and a 2019 Minnesota reference reported 50 to 100% RAP use generally working well on shoulders

State Route 388 Test Section



- A low volume road is usually defined as less than 400 to 2,000 VPD (MDOT uses 2,000 and for reference SR 388 is 1,500)
- 8.8 mile project with 2-inch asphalt overlay
- Shoulder width on plans was 6 ft wide and variable, and widths on site were typically ± 1.5 ft to slope break in shoulder

- Project Let Jan 2019, built Aug 2019, monitored for 34 months



Section	Material	% Passing ¾ in	% Passing No. 8	% Passing No. 200
1	---	---	---	---
2	Steel Slag	100	30	2.6
3	Limestone – ¾ Down	96	46	9.7
4	Limestone – 610	97	41	6.4
5	Limestone – 825B	76	41	11.3
6	Crushed Concrete	85	25	3.9
7	Gravel – 5E (PI of 21)	89	60	9.9
8	Gravel – 5C	96	52	9.2
9	RAP – Cold Milled	100	37	2.0
10	RAP – Fine Milled	98	38	3.0

SR 388 Construction and Monitoring

SR 388 Data Collection and Analysis

- Field Sampled Aggregates
  - Proctor, CBR (T193, no soaking, less compaction), Gradation, Atterberg Limits
- Site Visits: Pre-Construction, Construction, 5 Field Visits:
  - Visual evaluations with photos, Edge drop-off (EDO), other…
- Overarching goal was to use one property at a time to rank sections (i.e., aggregates), and then collectively look at all rankings for specification suggestions
  - Visual evaluations, general trends, plots of properties vs. time
  - Statistics at 5% level: *t-grouping* for means to chain results and evaluate change over time along with linear regression to statistically relate changes in two variables

Edge Drop-Off Results

		Section 2	Section 3	Section 4	Section 5	Section 6	Section 7	Section 8	Section 9	Section 10
<0.25	Pass									11.9
0.25	Pass					1.6	1.6	1.6	0.8	4.0
0.50	Pass				6.3	7.1	7.1	4.0	0.8	6.4
0.75	Pass	7.8		8.6	3.9	20.5	10.2	5.6	3.9	8.7
1.00	Pass	19.6	5.2	23.4	14.8	40.9	23.6	19.8	26.0	25.4
1.25	Pass	13.7	8.3	13.3	14.1	15.8	22.8	8.7	15.8	9.5
1.50	Pass	24.5	10.3	25.0	15.6	10.2	15.8	19.1	20.5	23.0
1.75	Pass	14.7	13.4	16.4	12.5	3.2	10.2	14.3	11.0	7.1
2.00	Pass	10.8	11.3	11.7	20.3	0.8	6.3	11.1	10.2	3.2
2.25	Pass	5.9	7.2	0.8	3.1		1.6	5.6	2.4	
2.50	Fail	1.0	18.6	0.8	6.3		0.8	5.6	3.9	0.8
2.75	Fail	2.0	11.3		2.3			0.8	3.9	
3.00	Fail		10.3		0.8			2.4	0.8	
3.25	Fail		2.1					3.3		
3.50	Fail		1.0							
3.75	Fail							0.8		
4.00	Fail		1.0							
Note		Failed on V4	Failed on V4	Passed	Failed at V5	Passed	Passed	Failed at V5	1/2 Failed at V5	Failed at V5

- $P_{2.25}$ (or percent of measurements that exceeded 2.25 inches) proved useful to evaluate sections and was a technique not found in literature – 2.25 inches was midpoint of 2 to 2.5 inch range from literature

Edge Drop-Off (EDO) Rankings

EDO Rank	EDO_1	EDO_{Max}	$P_{2.25}$
1 (Best)	RAP FM (8.6)	C.C. (37.1)	C.C. (0.0)
2	825 LS (22.8)	S.S. (46.2)	RAP FM (0.8)
3	C.C. (23.7)	RAP FM (49.7)	610 LS (0.8)
4	5C (23.8)	610 LS (52.4)	5E (0.8)
5	5E (30.3)	5C (57.9)	S.S. (3.0)
6	610 LS (31.5)	825 LS (60.8)	RAP CM (8.6)
7	S.S. (34.8)	5E (63.3)	825 LS (9.4)
8	¾ LS (37.8)	¾ LS (72.2)	5C (12.9)
9 (Worst)	RAP CM (43.9)	RAP CM (78.3)	¾ LS (44.3)

- EDO was evaluated as a percentage of shoulder depth at construction and prior to aggregate placement
- EDO_1 is drop-off after first 2.8 months of service
- EDO_{Max} is maximum drop-off observed during monitoring

CBR Rankings

CBR Rank	CBR_{4D}-56_B	CBR_{0D}-56_B	CBR_{4D}-25_B
1 (Highest)	C.C. (154)	5C (146)	825 LS (89)
2	825 LS (135)	610 LS (145)	C.C. (80)
3	610 LS (116)	825 LS (138)	610 LS (62)
4	5C (109)	C.C. (121)	¾ LS (58)
5	¾ LS (103)	¾ LS (98)	5C (55)
6	S.S. (85)	S.S. (54)	S.S. (50)
7	RAP FM (26)	5E (39)	RAP FM (15)
8	5E (19)	RAP FM (27)	RAP CM (12)
9 (Lowest)	RAP CM (17)	RAP CM (18)	5E (8)

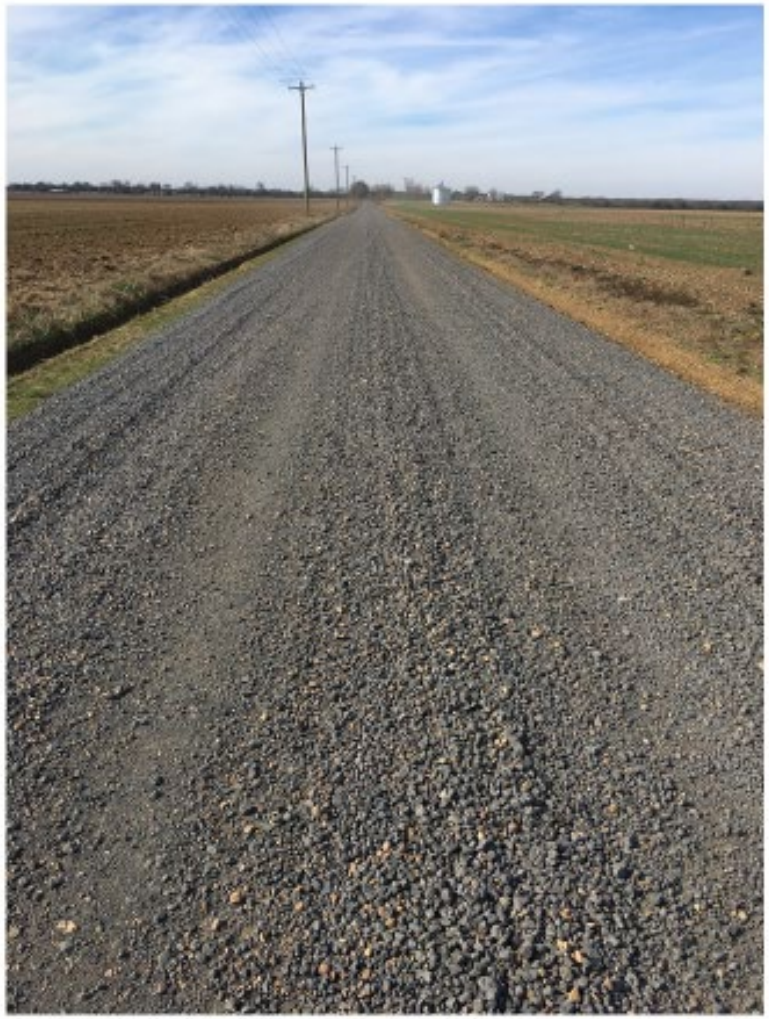
- Gradations, Proctors, and Atterberg Limits mostly met expectations – some slight cases of gradations being out of range, but they were not deemed meaningful
- CBR somewhat related to EDO, but not statically (*p-value* = 0.09 above)

Visual Observation Results and Rankings

Visual Rank	Material
1 (Best)	5E (Tier 1) [Passed]
2	C.C. (Tier 2) [Passed]
3	610 LS (Tier 3) [Passed]
4	RAP CM (Tier 1) [Half Passed, Half Failed]
5, 6, 7 {Tie}	825 LS (Tier 2) [Failed]
5, 6, 7 {Tie}	5C (Tier 3 to 4 – Mostly Failed) [Failed]
5, 6, 7 {Tie}	RAP FM (Tier 3) [Effectively Failed]
8, 9 {Tie} (Worst)	S.S. (Tier 4 – Failed) [Failed]
8, 9 {Tie} (Worst)	¾ LS (Tier 4 – Failed) [Failed]

- Tiers were defined on site by visual evaluators
- Agricultural traffic believed to be major factor – (sections 2 to 5 – steel slag and limestone) received more agricultural traffic based on visual observations
- Deeper shoulders were believed to be more challenging – steel slag was in a deep section
- Overall, steel slag behaved in a manner worthy of shoulder aggregate use consideration

Lots of Successful Uses For Low Volume Unpaved Roads in Mississippi

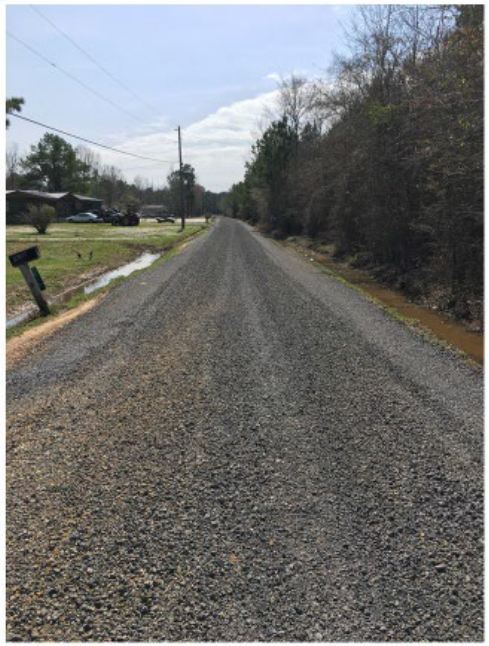


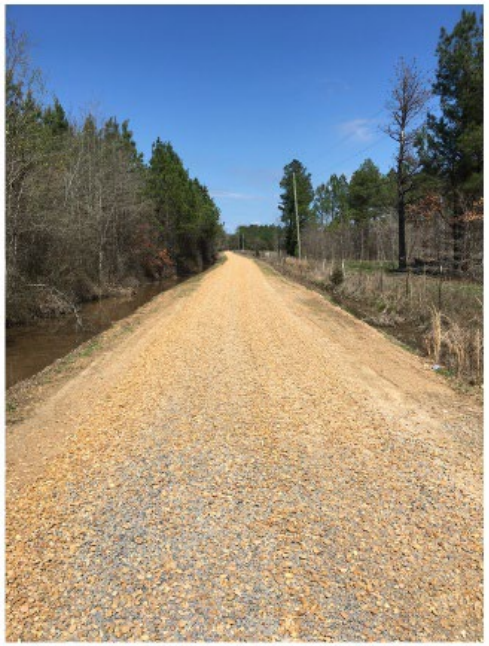
Edw C. Levy GTMS Market Spring 2019 Approximate Nmbers

GTMS = Golden Triangle Mill Service

4 x 1.5 Ballast	2 x 0.75 Ballast	1.5 x 0 DuraBerm	0.75 x 0 Commercial
40% Base	**50%** Base	**50%** Driveway & Low Volume Roads	**80%** Driveways & Walkways
30% Logging Roads	**30%** Heavy Haul Roads	**40%** Parking Lots & Laydown Yards	**20%** Heavy Use Pads
30% Erosion Control & Washout	**20%** Chicken Houses	**10%** Shoulder Aggregate	

Glenn Road – Side By Side Gravel vs. Slag



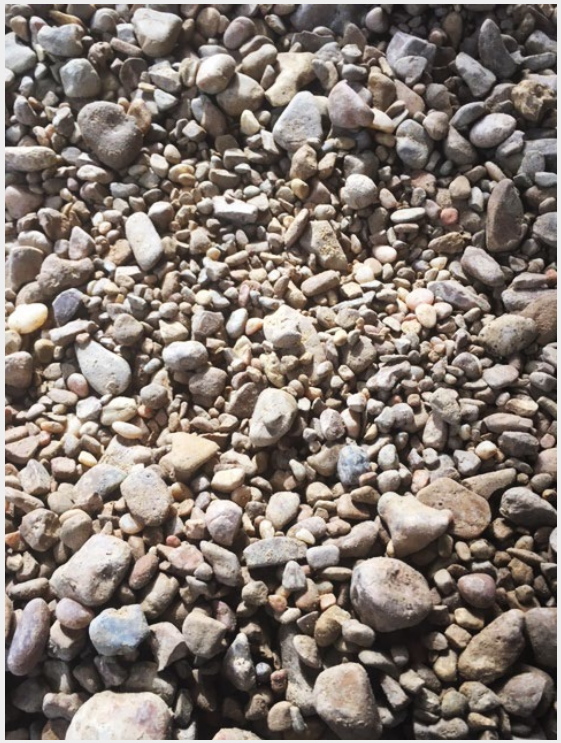


Just After Placement

Two Years Old

California Bearing Ratio (CBR) Testing

- **Dura-Berm**
- From Golden Triangle Mill Service
- Material above 3/4” discarded



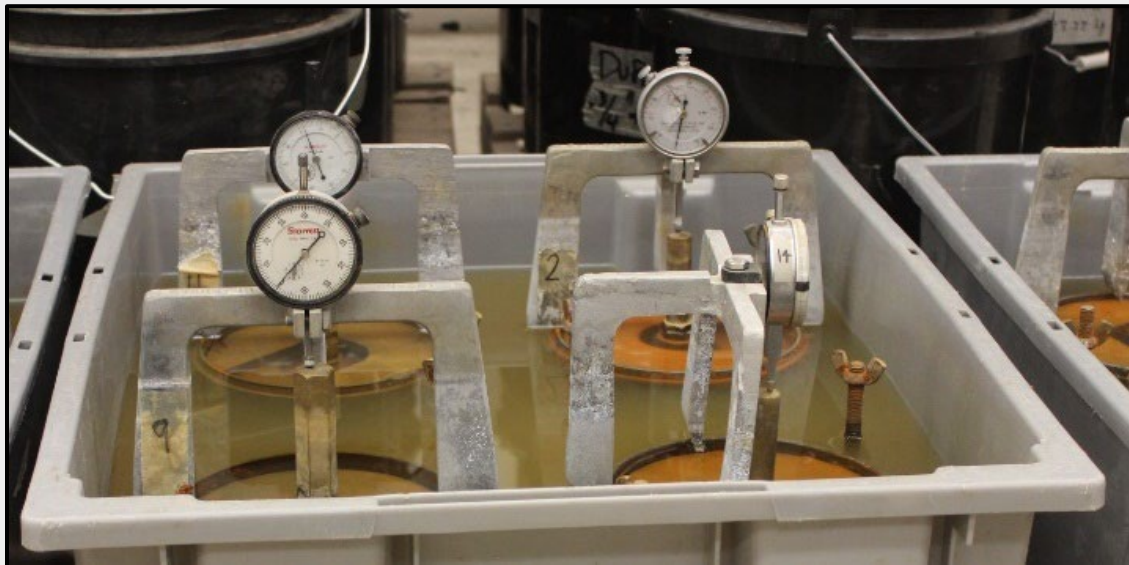
- **Gravel**
- From Glenn Road
- Material above 3/4” discarded

- **Sand**
- SM, A-2-4, 9B, 9C level sands from north Mississippi

CBR Results

DuraBerm-Sand %	CBR
100-0	43
88-12	169
75-25	228
63-37	176
50-50	106
38-62	68
25-75	43

DuraBerm-Gravel %	CBR
100-0	43
75-25	49
50-50	44
25-75	35
0-100	37

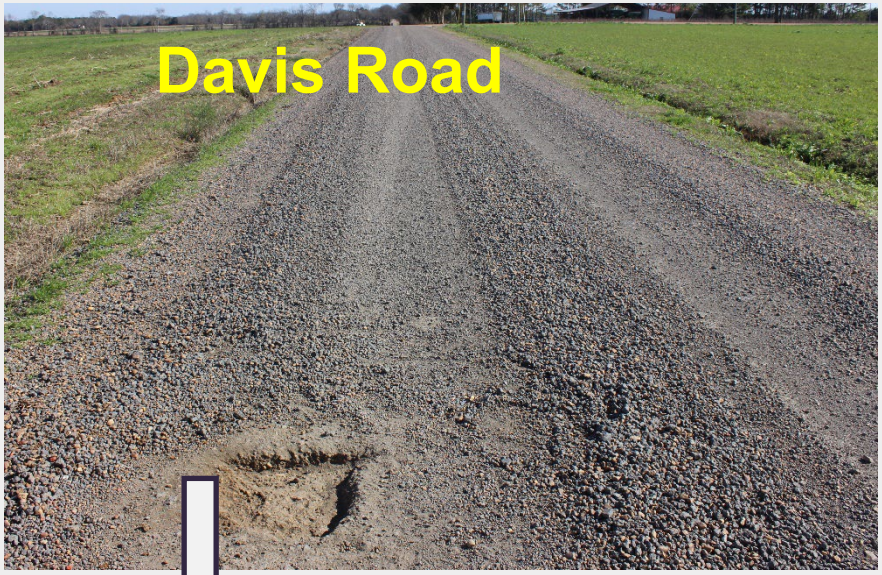



Davis Road

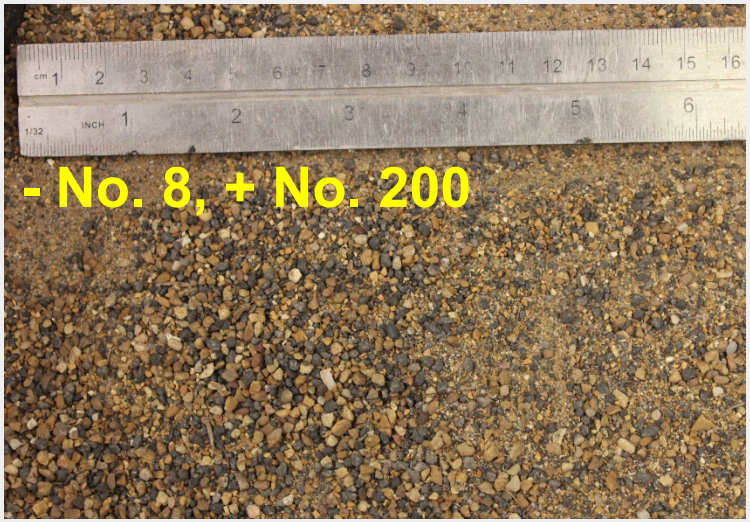

Dwelling Place


County
Line Road


Glenn Road


Davis Road


+ No. 8


- No. 8, + No. 200

Property	Glenn	Davis	Dwelling	County Line
Steel Slag (in +No. 8) (%)	50	50	10	0
Liquid Limit (%)	16	34	39	17
Plastic Limit (%)	13	19	19	16
Plasticity Index - PI (%)	3	15	20	1
Passing 0.75 in Sieve (%)	98	92	97	99
Passing No. 4 Sieve (%)	50	43	52	62
Passing No. 8 Sieve (%)	40	33	34	47
Passing No. 30 Sieve (%)	34	24	23	34
Passing No. 200 Sieve (%)	14	15	16	12
CBR (AASHTO T 193)	211	181	10	73

Noxubee County District 5 – 50 to 75% reduced grading from steel slag, no road failures with steel slag, and favorable customer reviews – Glenn and Davis roads reported as best performing routes

Summary / Best Practices - Shoulders

1. CBR measurements were only modestly informative toward predicting edge-drop off performance (no soaking but traditional compaction was best)
2. While crushed concrete outperformed all other aggregates, other shoulder aggregates (including steel slag) evaluated at State Route 388 have at least a reasonable case for being included in further specification processes (MDOT is currently evaluating their shoulder specifications)
3. A good blend of finer particles is desirable, but this can be hard to find with crushed steel slag – look for applications where steel slag can be blended with existing materials (e.g., shoulder re-shaping)

Summary / Best Practices – Unpaved Roads

1. Sample existing road, measure gradation, PI
2. Consider steel slag quantity available from local mills when establishing ranges of material to use per unit of unpaved roadway being managed
3. Select steel slag percentage based on gradation of steel slag, gradation of roadway blend, PI of existing roadway, and CBR of blend (100 should be sufficient)
4. Don’t expect much bearing capacity increase below steel slag levels of about 25% for roadways with an existing fine gradation

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Questions?