MDOT Requirements for Optimized Aggregates in Concrete

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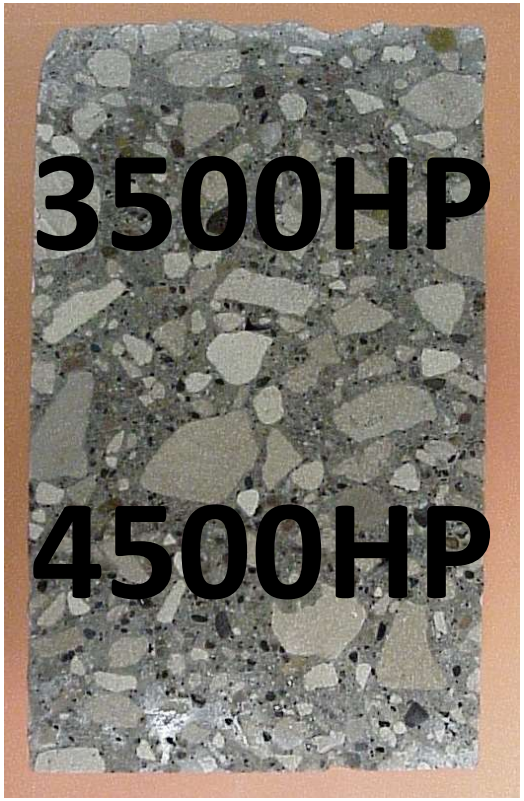
Michigan Concrete Association

What is an "Optimized Aggregate Gradation"?

- General
  - Optimized gradations are those that have been enhanced in some manner in order to enhance some property of the concrete.

- MDOT
  - Focuses on "Well-Graded" aggregate combinations

Optimized Aggregates



What?? If I pump the concrete, I have to use an Optimized Concrete Mixture?

- Yes
- This will continue to be discussed with MDOT
- Trade-off for changing sampling location

Goal of Optimized Aggregates

- Reduce permeability
  - Reduce mortar
    - Less shrinking
    - Cost savings related to less cementitious
- Better for pumping and finishing
- Lower w-cm ratio
- Greater durability

Improved Finishing

Less Handwork

Better Barrier Walls

Workability

Harsh initial appearance, but very workable once vibrated

Historically:

- MDOT generated mixture proportions
- Grade P1 paving concrete
  - Type I Portland cement (480 to 564 lbs./cu. yd.)
- Two aggregate blend
  - Coarse aggregate (potentially ½ inch max.)
  - Fine aggregate (often – lower spec limit)
  - QA often only checked at aggregate source…segregation likely
- ??? Consistency ???

Making Changes

- Challenges (late - 1990's),
  - Enhanced aggregate F-T durability.
  - Addition of third aggregate bin to portable plants allowing for three aggregate blend.
- But,
  - No formal optimization tool.
  - Inherited another "dead zone".
  - Harsh uncontrolled mixture.
  - Non-durable mixtures.

History of P1 Mod / P1M / Optimized / High Performance

- 1997 MDOT created the first P1Mod
  - Based on laboratory investigations
- 2004 MDOT retools the P1Mod Spec
  - Utilize three natural aggregates
    - Coarse – 1 inch to ¾ inch retained
    - Intermediate – 3/8 inch to No. 4 retained
    - Fine – No. 8 and finer
  - Optimizing of gradations based on "Shilstone" Method
- 2005 P1Mod upgraded with:
  - Requirement of detailed Stockpile Management Plan
  - Enhanced Process Control Requirements
  - Pay Items

High Performance Concrete Pavement (Grade P1M)

- Stand-alone P1Mod SP no longer utilized
  - Material Specs moved to 2012 Spec Book
  - Optimization procedure and QC/QA for optimized aggregates handled by section 3.09 of MDOT Materials Quality Assurance Procedures Manual
  - Concrete mix development covered in QC/QA Special Provision
- Optimized Aggregates are available for use in concrete mixes other than grade P1M (DM, S2M, other contractor-proposed mixes)

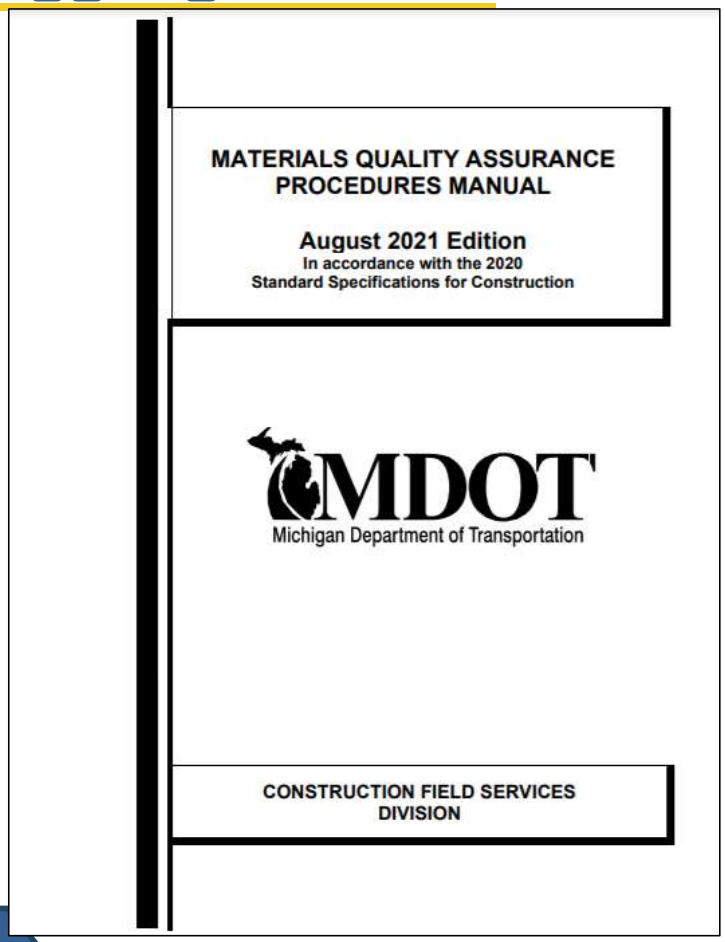
Section 1004 (Portland Cement Concrete Mixtures)

Nomenclature Changed in 2020 Spec Book:

New	3000	3500	3500HP	4000	4500	4500HP	P-NC
Old	S3, P2	P1, S2, T	P1M, S2M	S1	D	DM	P-NC
Used for	Sidewalks Shoulders	Pavement Curb & Gutter Driveways Bridge Substructure	High Performance Concrete Pavements High Performance Concrete Curb & Gutter	Foundations Piles	Bridge Decks Bridge Railing	High Performance Bridge Decks Concrete Barrier Wall	Full Depth Concrete Pavement Repairs

MQAP Section 3.09 – Optimized Aggregate Gradation

- Does not specify MDOT gradation series for aggregates
  - CA – retained on ½ inch sieve or greater
  - IA – retained on No. 4 and passing ½ inch
  - FA – passing No. 4 sieve
- Physical Requirements for each aggregate are located in subsection 902.03.C of the 2020 Spec Book
- LBW (P200) 2% CA, 3% IA & FA
- Max of 5% material with F-T >0.040 retained above ½" sieve



Testing Requirements – Commercial vs. On-Site Plants

- For ready-mix, if aggregates from Prequalified Aggregate Supplier:
  - Producer may utilize aggregate source's current weekly gradation analysis
  - Must QA these QC results weekly to confirm
- If not from Prequalified Supplier or gradations not supplied by aggregate sources
  - Requirements of On-Site batch plant apply (daily gradation testing)
- On-site – testing each day of production (on-site, paving)

Optimized Aggregate Gradation Acceptance Criteria

- One test per 5000 tons
- One test per 1000 tons –if not prequalified supplier material
- Use Mini -stockpile sampling protocol – MTM 107
- Use AASHTO method T 248 to
  - Reduce sample size by quartering –CA and IA
  - Miniature Stockpile sampling for FA

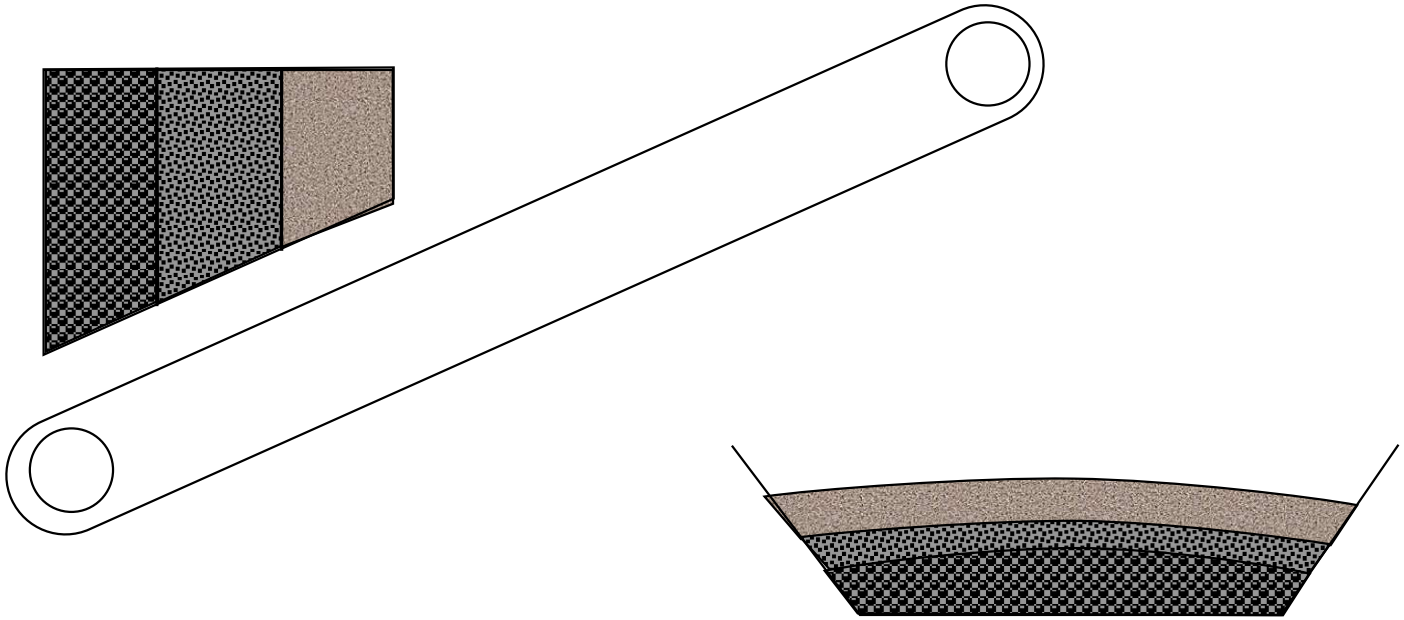
MQAP Section 3.09

- Stockpile Management Plan
  - Process controls for shipping, handling, and storage
- Two different max aggregate sizes
  - Pavements > 6 inches = 2 inch max size
  - Pavements ≤ 6 inches = 1½ inch max size
  - All other applications = 1½ inch max size

Custom size material (not an MDOT standard gradation)

6AA / 6AAA size

Handling/Batching/Timing Aggregate



The "Shilstone" Method

- Utilizes:
  - Fineness Modulus
  - Power 0.45 Charts
  - Percent Retained Charts
    - ~~5-15 or 8-18 Rule~~
  - Coarseness Factor
  - Workability Factor

To determine "Optimized" Gradations

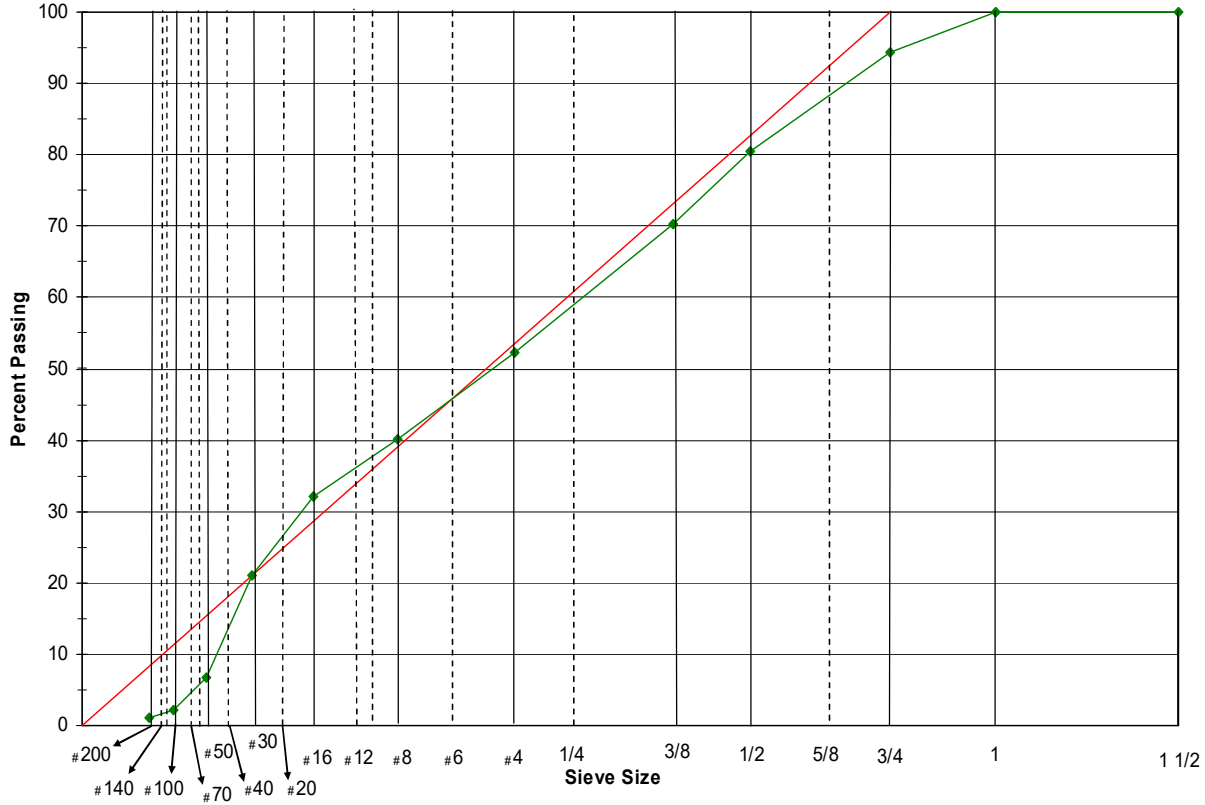
Jim Shilstone, Sr., 1923-2010

Combined Gradation

6								
7								
8			6AA	26A	2NS		Combined	Percent
9		% Blend ⇨	50.0%	10.0%	40.0%	0%	100%	Retained
10		Sieve Size	Percent Passing					
11	50 mm	2	100.0	100.0	100.0	0.0	100.0	0.0
12	37.5 mm	1 1/2	100.0	100.0	100.0	0.0	100.0	0.0
13	25 mm	1	98.6	100.0	100.0	0.0	99.3	0.7
14	19 mm	3/4	77.7	100.0	100.0	0.0	88.9	10.5
15	12.5 mm	1/2	41.6	99.5	100.0	0.0	70.8	18.1
16	9.5 mm	3/8	22.7	79.4	100.0	0.0	59.3	11.5
17	4.75 mm	#4	2.7	9.8	99.0	0.0	41.9	17.4
18	2.36 mm	#8	1.4	3.2	84.0	0.0	34.6	7.3
19	1.18 mm	#16	1.4	2.1	66.0	0.0	27.3	7.3
20	600 µm	#30	1.3	1.8	47.0	0.0	19.6	7.7
21	300 µm	#50	1.3	1.7	19.0	0.0	8.4	11.2
22	150 µm	#100	1.2	1.6	4.0	0.0	2.4	6.1
23	75 µm	#200	0.8	1.6	0.3	0.0	0.7	1.7
24								
25		Coarseness Factor		62.3			34.6	Workability
26								

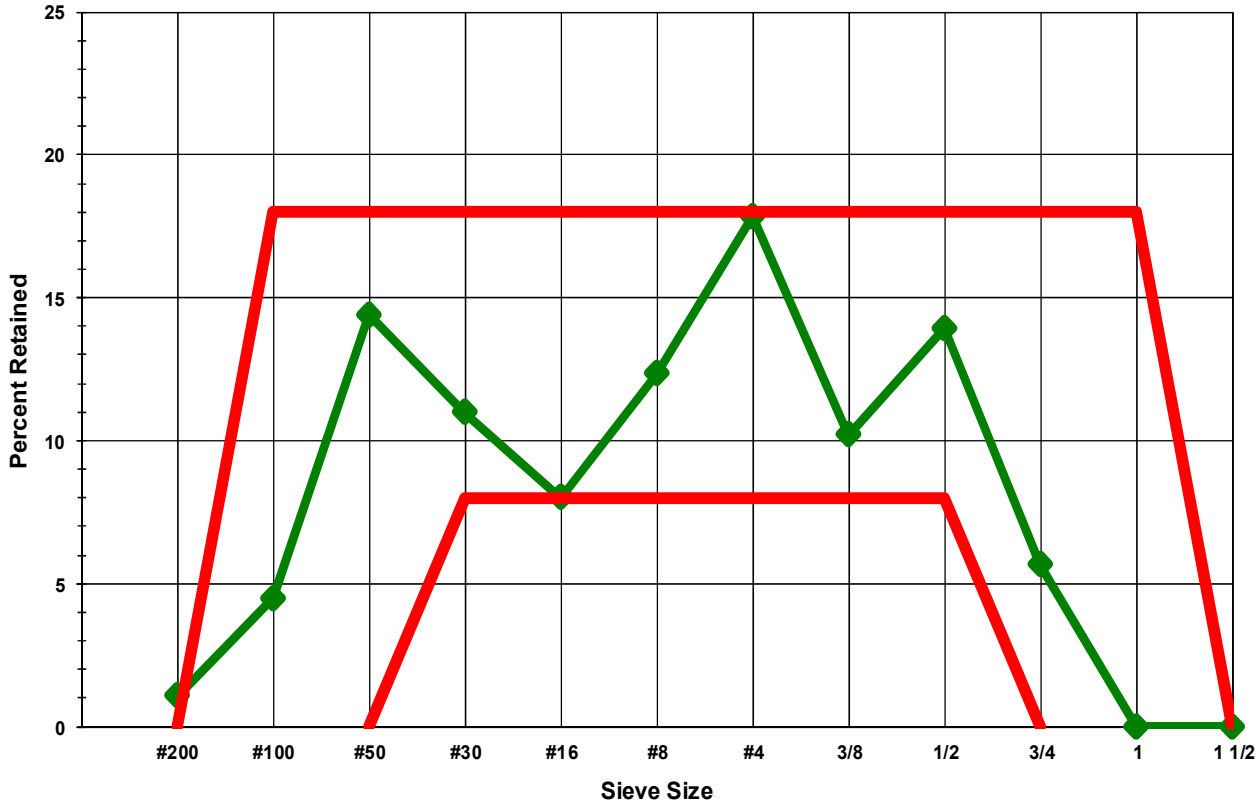
Power 0.45 Chart

Ideal gradation line representing the maximum aggregate density



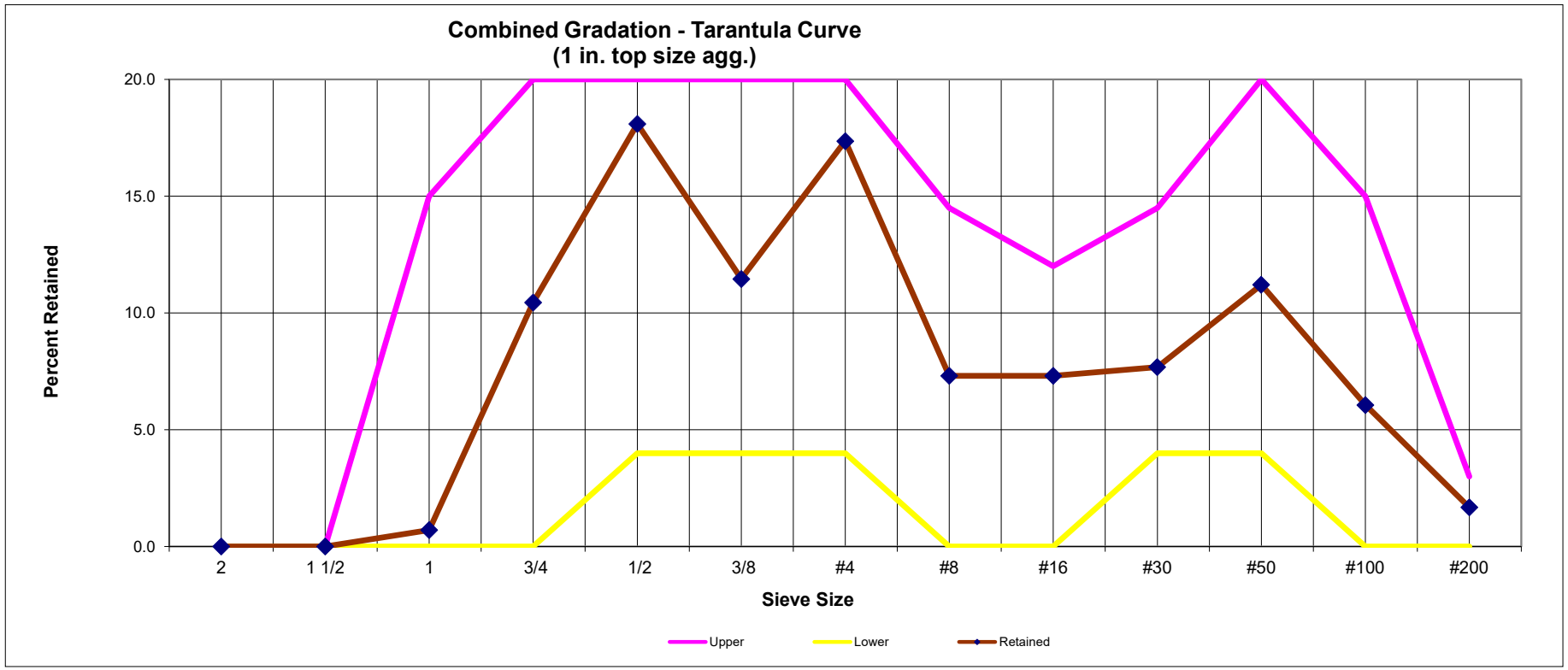
Percent Retained Charts

"Haystack" graph



The *TARANTULA* curve!!!!

Tarantula Example

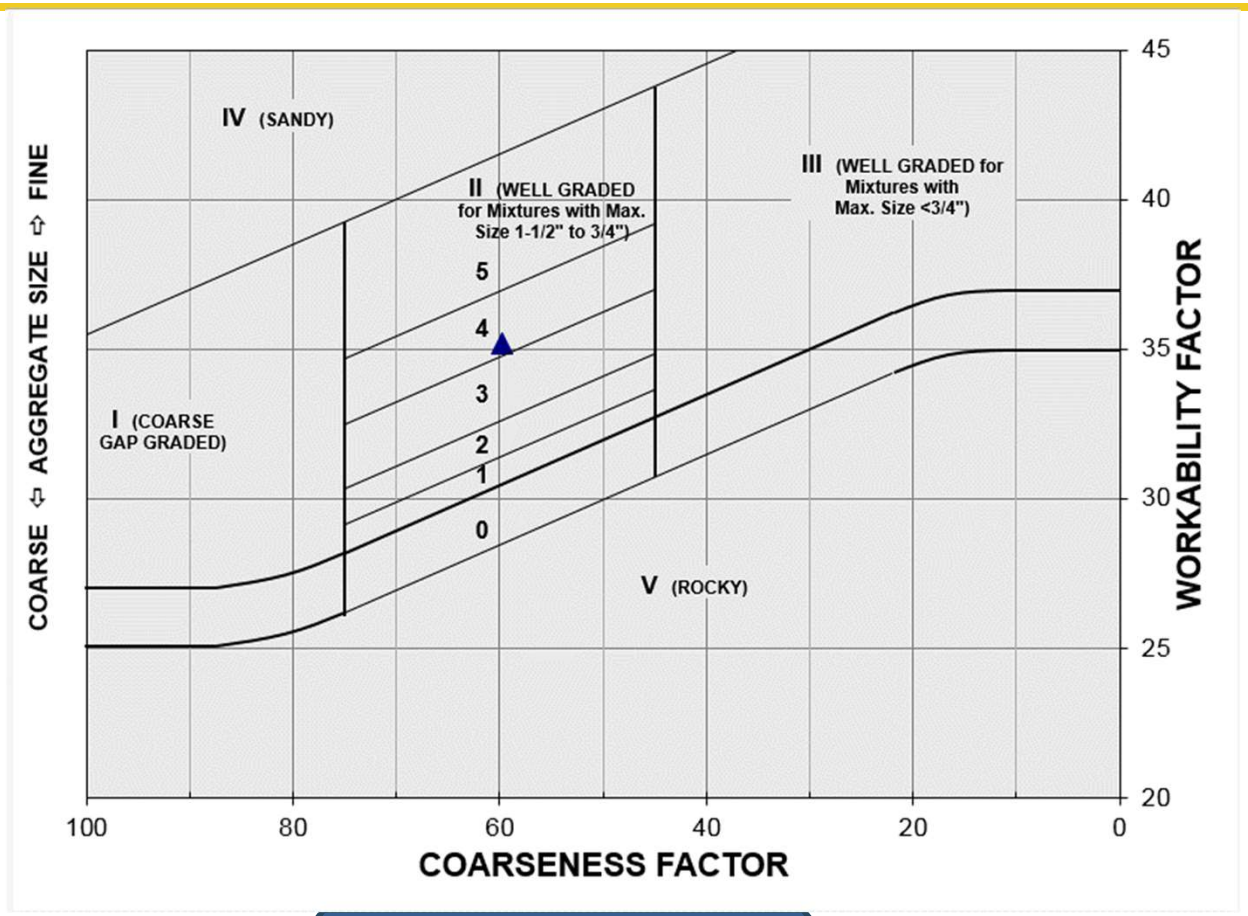


Coarseness vs. Workability Chart

- $$CF = \frac{\text{[combined \% retained above 3/8 inch sieve]}}{\text{[combined \% retained above No.8 sieve]}} \times 100$$

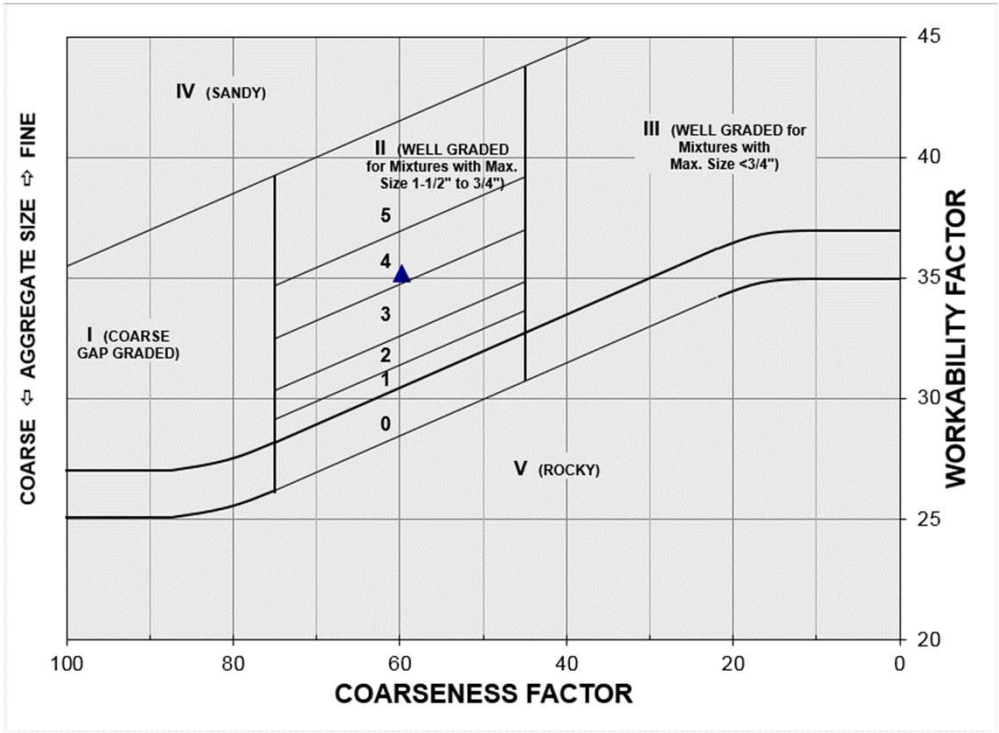
- WF = Combined % Passing No.8 Sieve

Coarseness vs. Workability Chart



Zone I Coarse Gap Graded

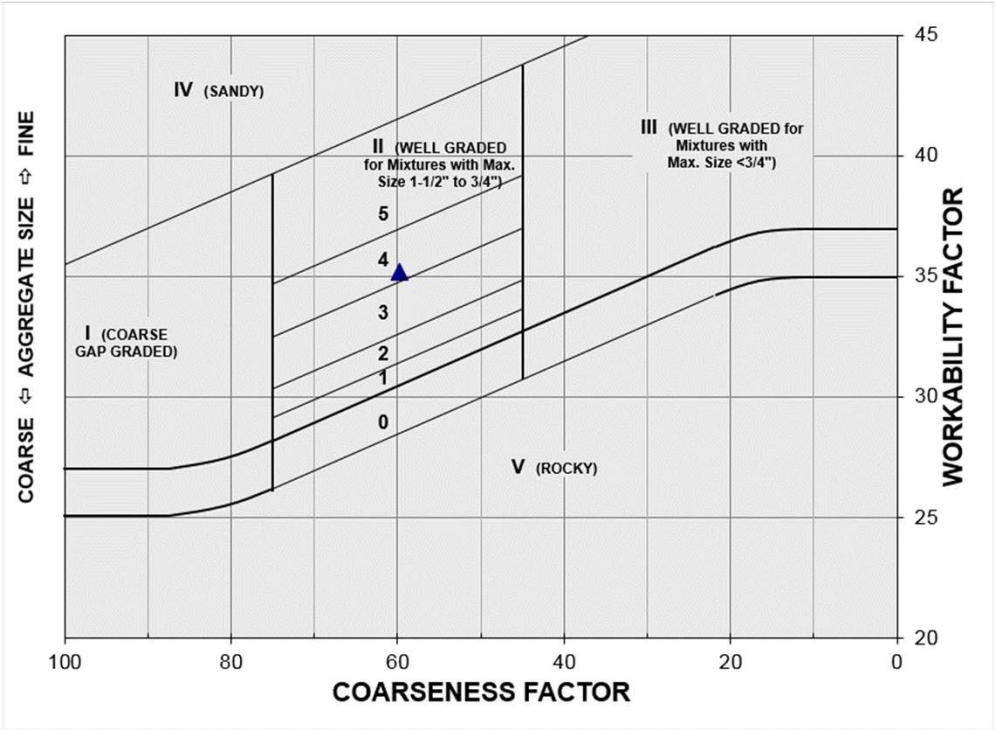
- High potential for segregation
- Deficient in intermediate material (passing 3/8" and retained on #8)
- Uncontrolled voids
- Excessive "cream" or paste



Zone II Well Graded (for most mixes)

Subzone 0

- Optimum for rounded gravel or cubically crushed stone and natural coarse sand.
- Requires excellent control of aggregate grading and prevention of segregation in the stockpile or bin. If segregation occurs, may fall into Zone V and become non-plastic.



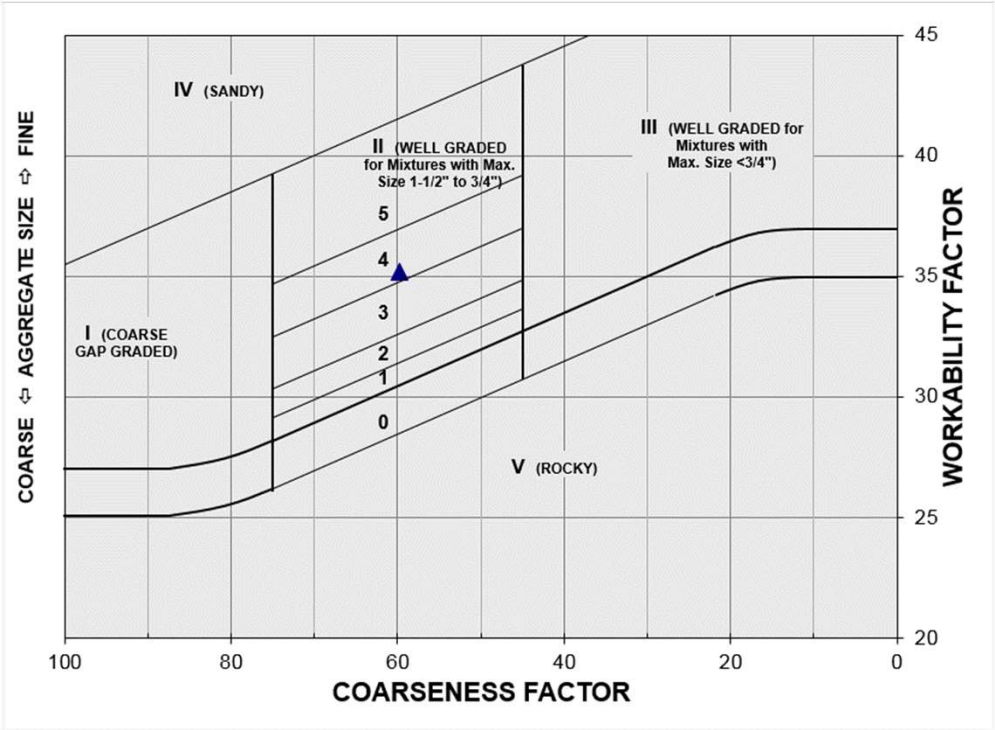
Zone II Well Graded (for most mixes)

Subzone 1

- Similar to subzone "0" but is more flexible.

Subzone 2

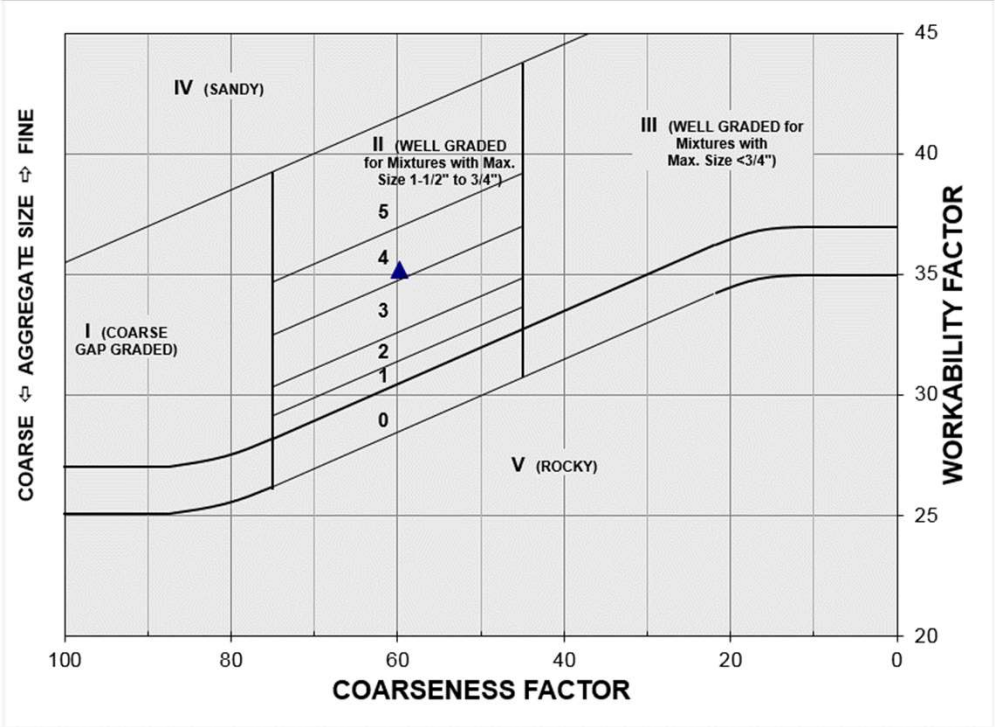
- Excellent for slipform construction with good particle shape aggregates and good control.



Zone II Well Graded (for most mixes)

Subzone 3

- Good slipform concrete.
- Highly workable for gravel or cubically crushed stone mixtures and good pumpability for bridge decks.
- May be used for formed flatwork.



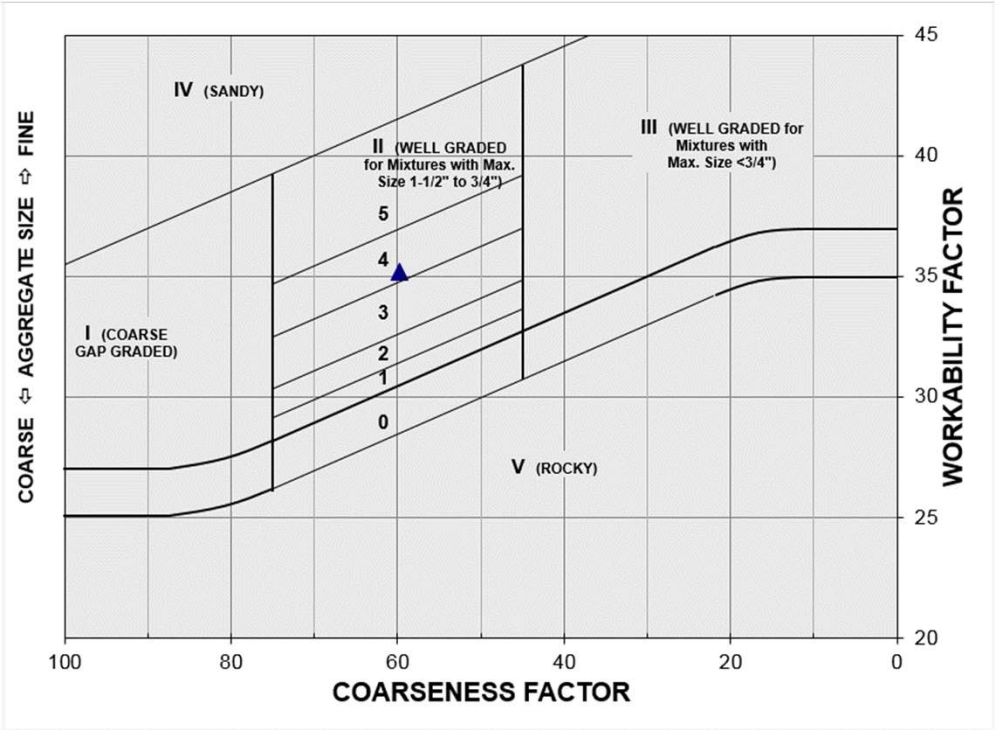
Zone II Well Graded (for most mixes)

Subzone 4

- All-around mixture for many purposes including placement in reinforced vertical construction.

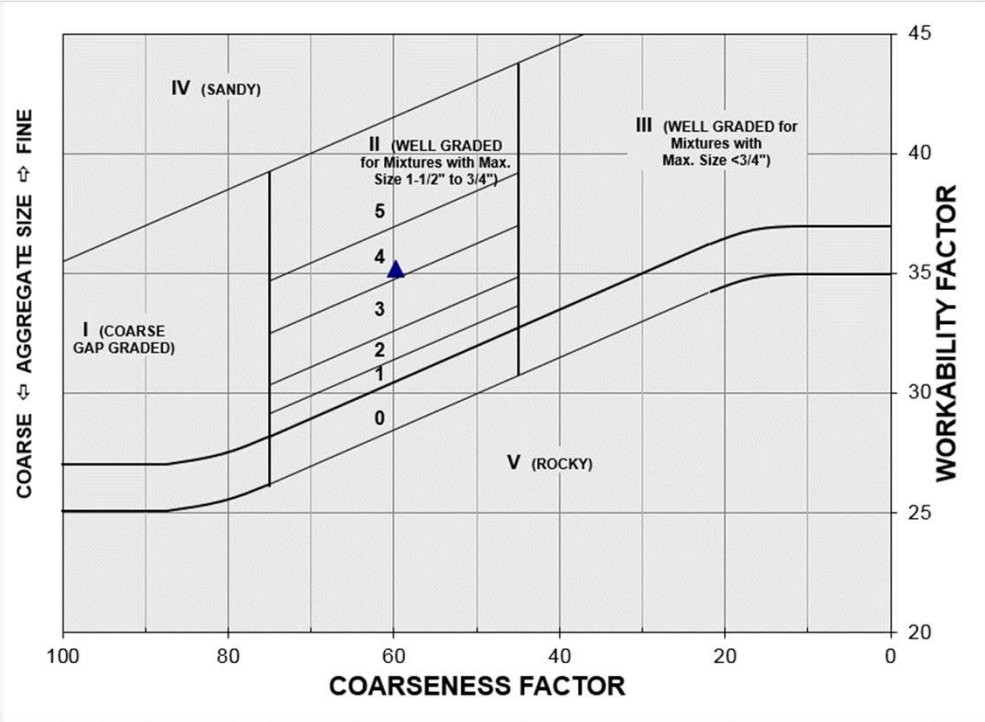
Subzone 5

- A zone where problem aggregates or equipment problems make it necessary to have more than the desirable amount of fine mortar in a mixture.



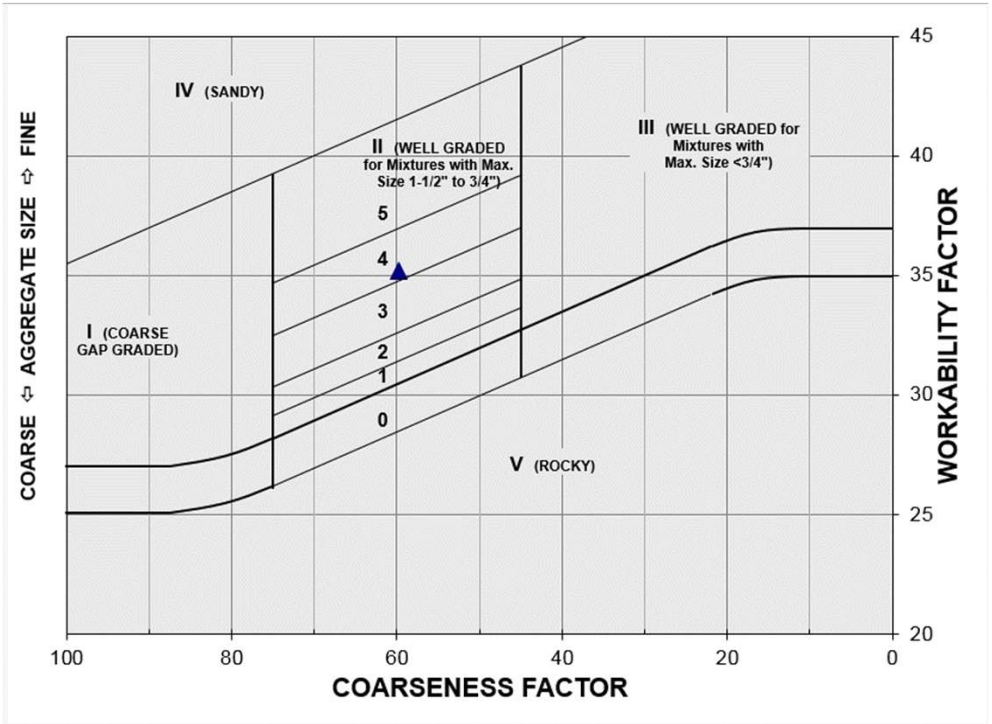
Zone III Well Graded (only for small top size)

- An extension of Zone II for 1/2" and finer aggregate mixtures.



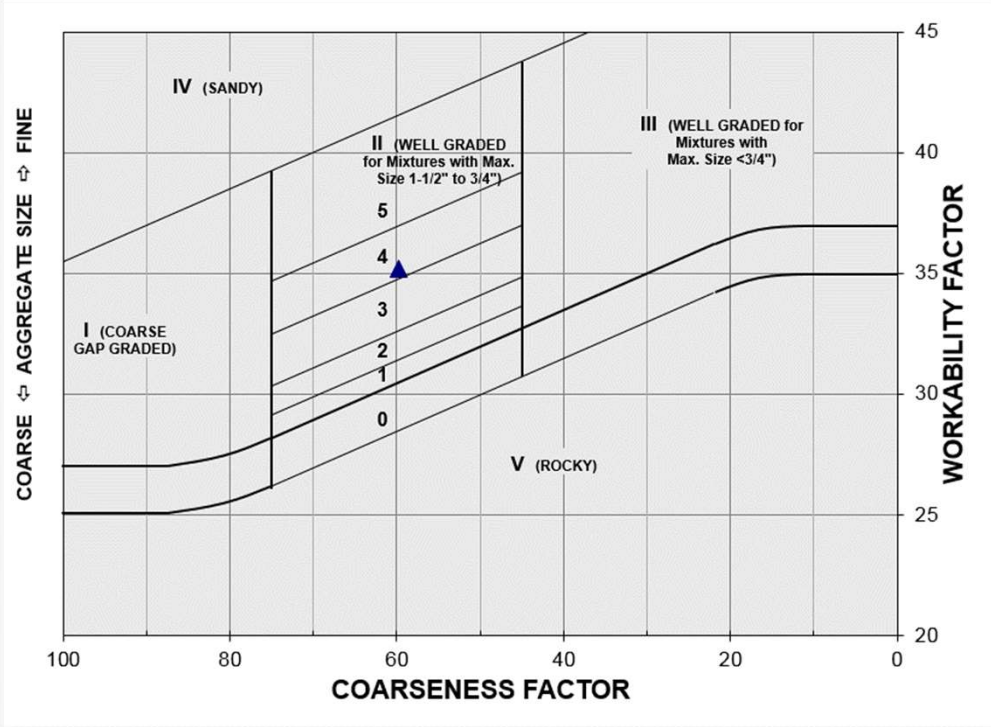
Zone IV Sandy

- Excessive fines in the mixture.
- Commonly referred to as the "Courthouse" due to potential problems.
- High potential for segregation during consolidation and finishing.

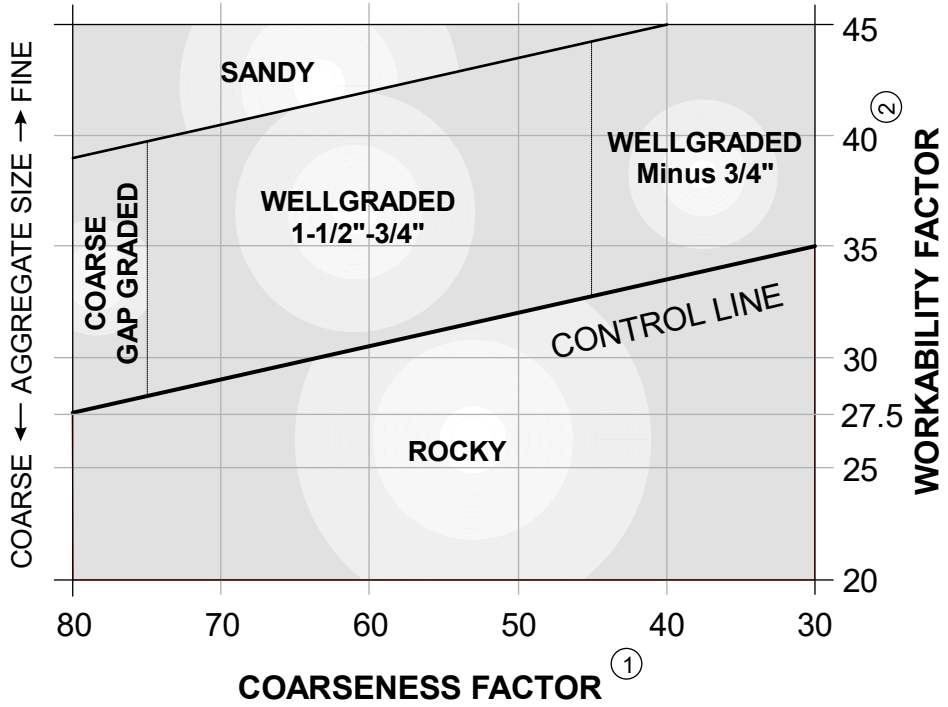


Zone V Rocky

- Too much coarse aggregate - non plastic.



Coarseness vs. Workability – USAF CESA Chart

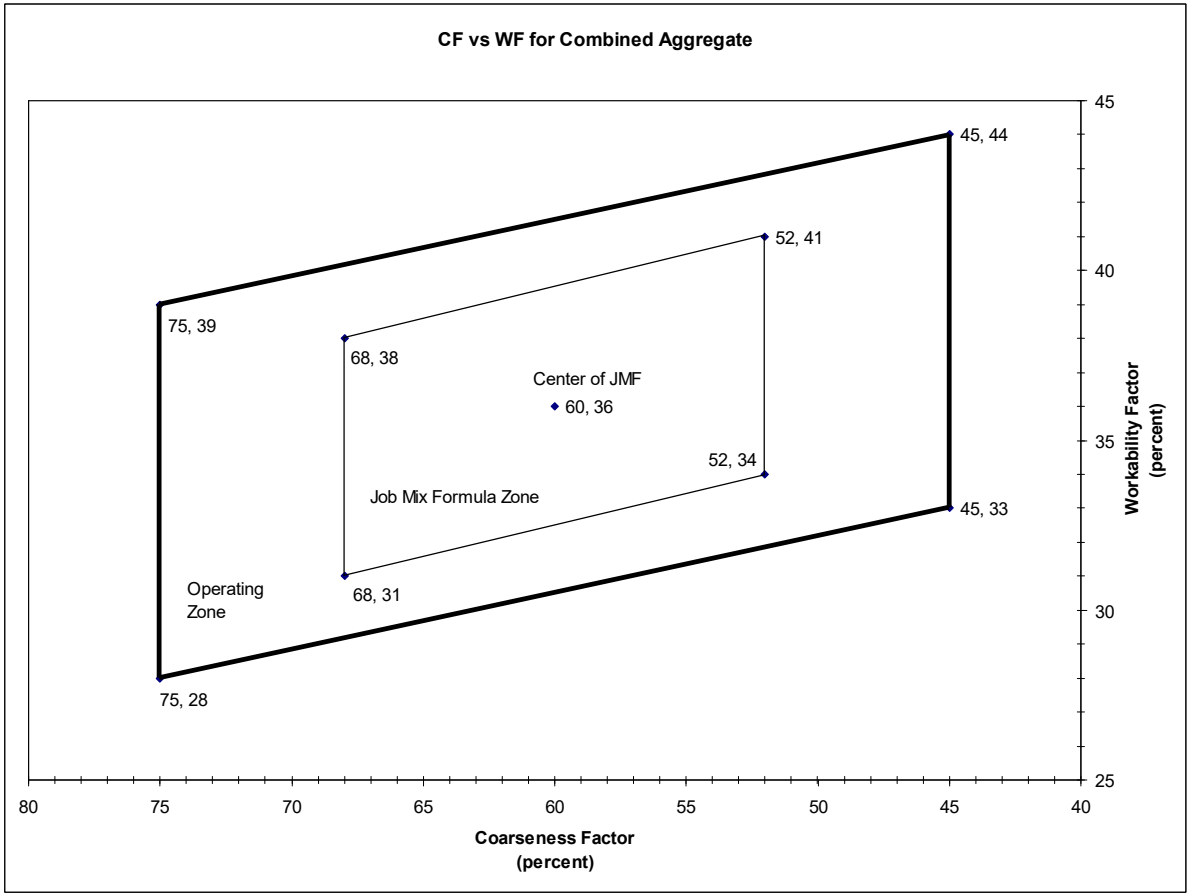


NOTES:

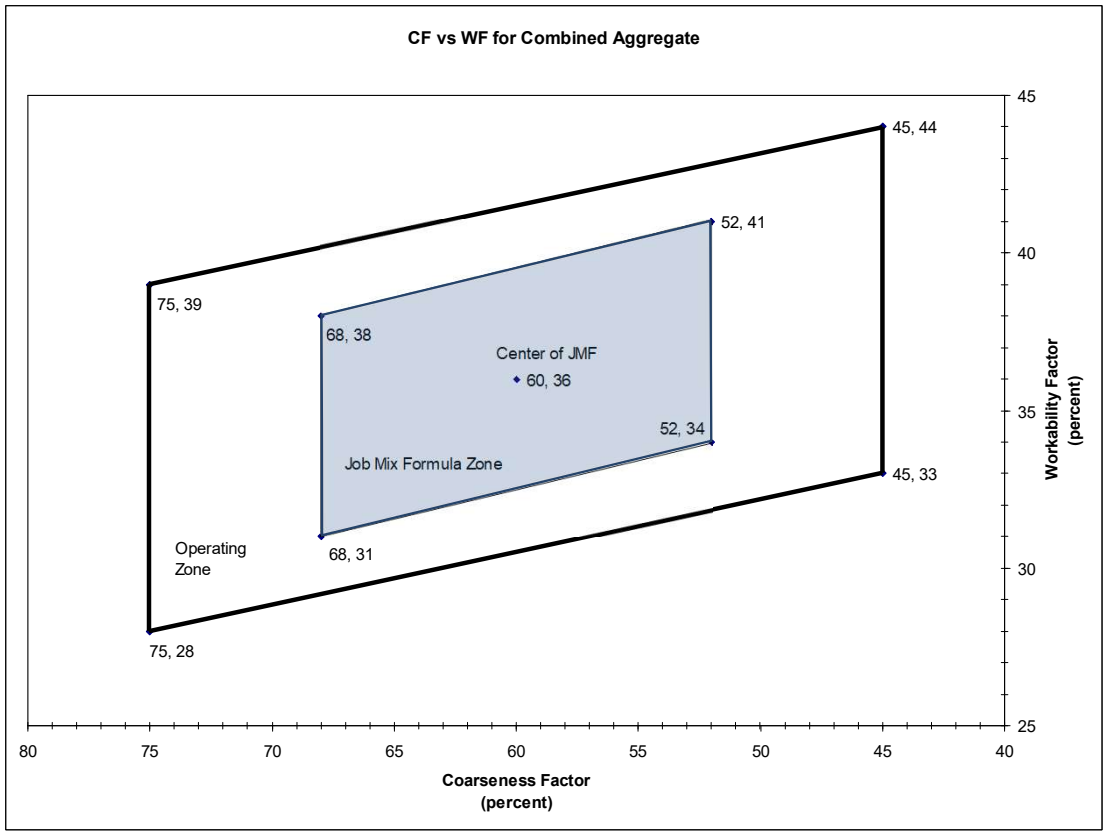
① **COARSENESS FACTOR =** $\frac{\text{\% RETAINED ABOVE 9.5mm SIEVE}}{\text{\% RETAINED ABOVE \#8 SIEVE}}$ X 100

② **WORKABILITY FACTOR =** % PASSING #8

MDOT Chart


CF vs WF for Combined Aggregate
45, 44
52, 41
75, 39
68, 38
Center of JMF
60, 36
52, 34
Job Mix Formula Zone
45, 33
Operating
Zone
68, 31
75, 28
45
40
35
30
25
Workability Factor
(percent)
80
75
70
65
60
55
50
45
40
Coarseness Factor
(percent)

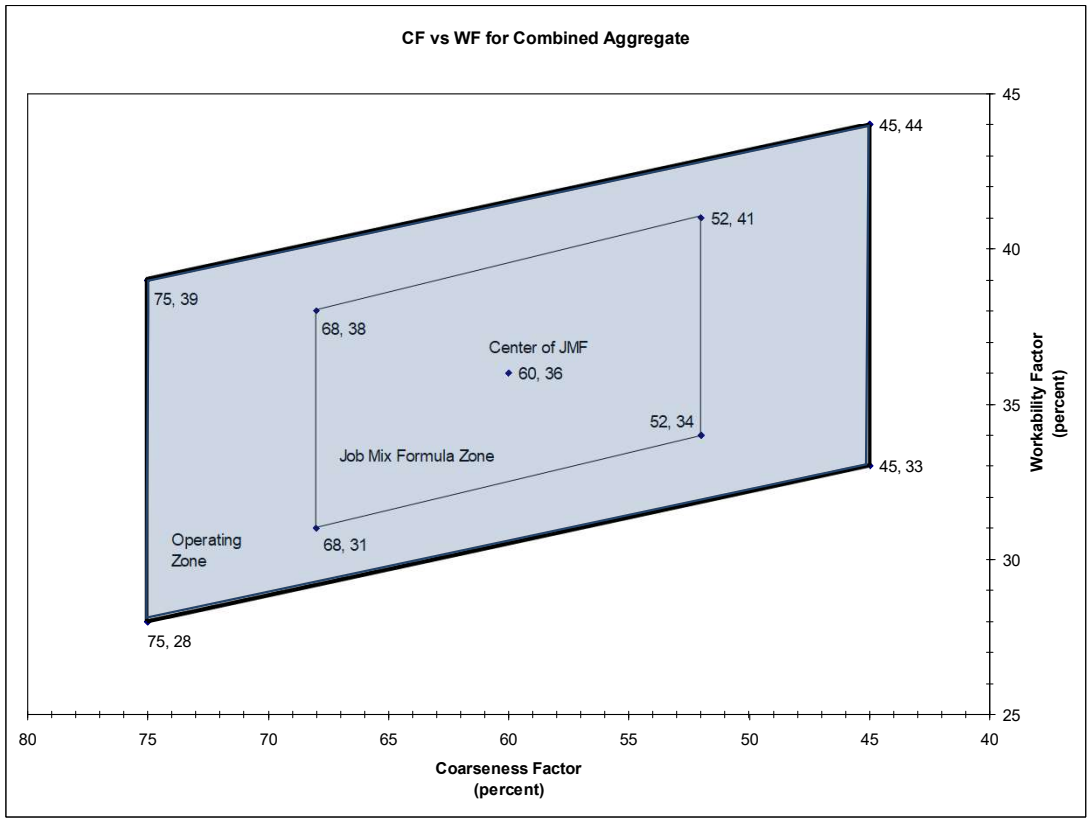
Zones in MDOT Chart



Job Mix Formula (JMF) Zone

- Contractor's proposed optimized gradation for production, as submitted to the Engineer in the Initial Mix Design, must plot within this zone

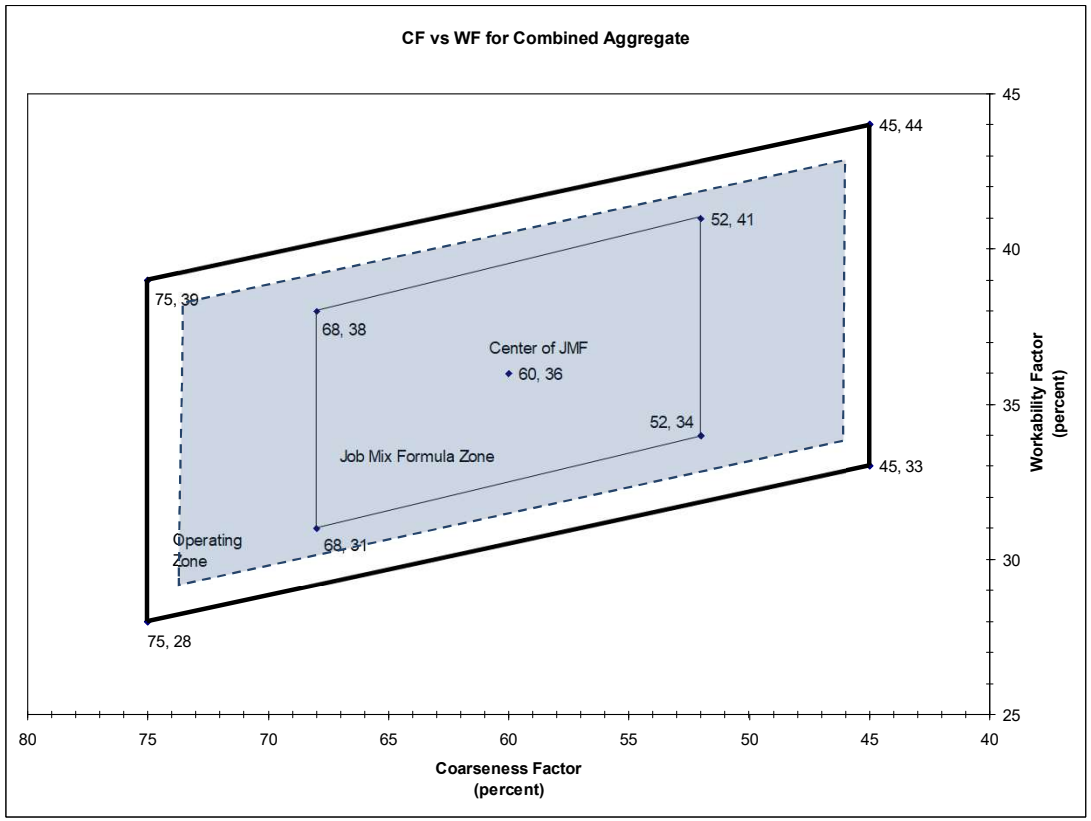
Zones in MDOT Chart



Operating Zone

- Contractor must ensure that the optimized gradation for production plots within this zone

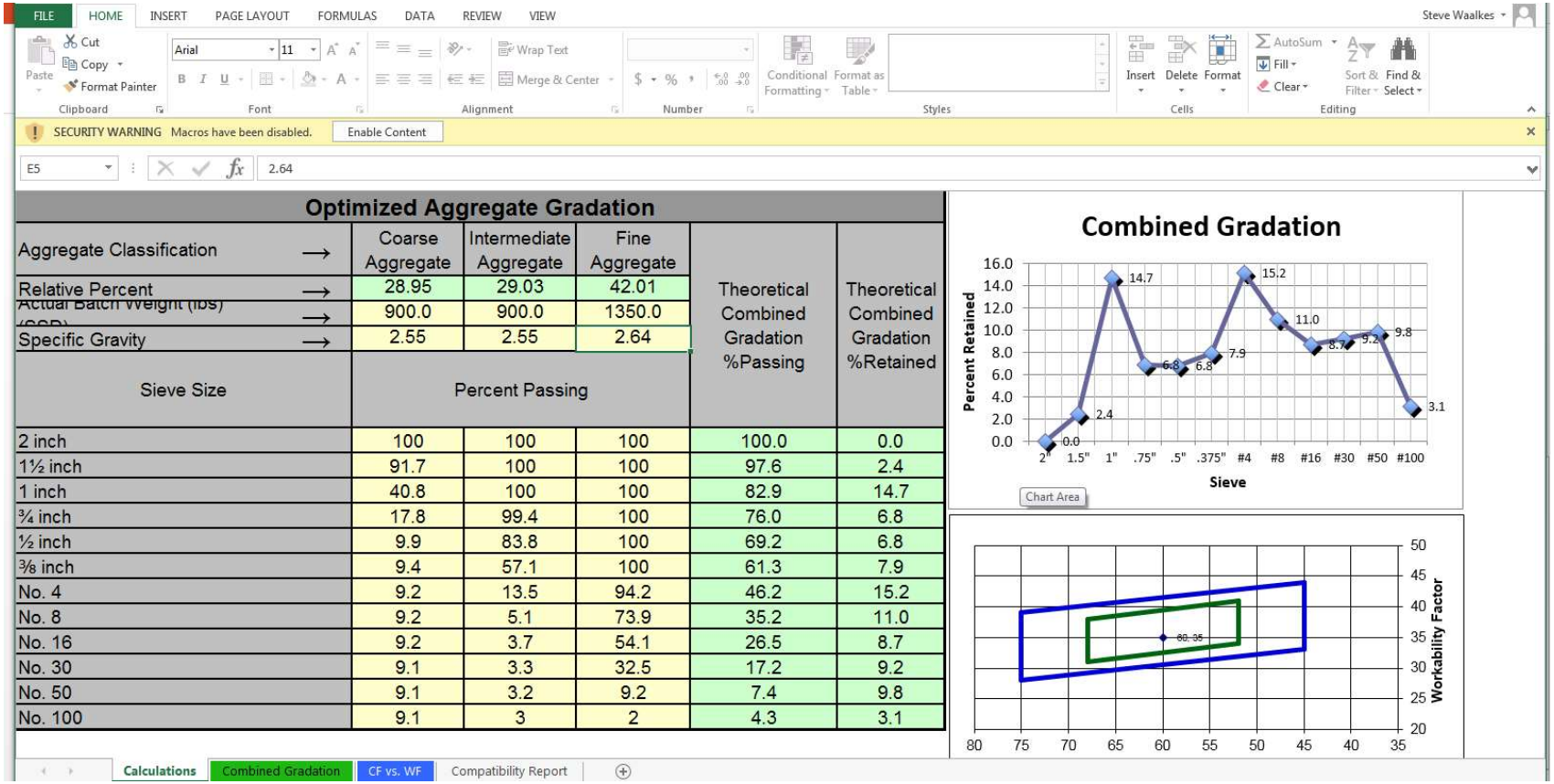
Zones in MDOT Chart



Action Limits

- Contractor's proposed action limits; if production gradation plots outside this zone, steps taken to bring back within this zone. This is NOT a stop production criteria.

MDOT Spreadsheet



FILE HOME INSERT PAGE LAYOUT FORMULAS DATA REVIEW VIEW — Steve Waalkes

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Optimized Aggregate Gradation

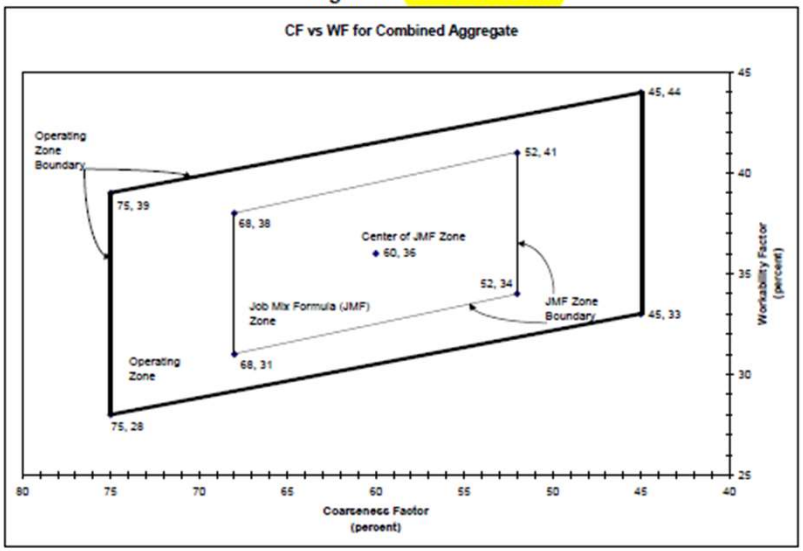
Aggregate Classification →	Coarse Aggregate	Intermediate Aggregate	Fine Aggregate	Theoretical Combined Gradation %Passing	Theoretical Combined Gradation %Retained
Relative Percent →	28.95	29.03	42.01		
Actual Batch Weight (lbs) →	900.0	900.0	1350.0		
Specific Gravity →	2.55	2.55	2.64		
Sieve Size	Percent Passing				
2 inch	100	100	100	100.0	0.0
1½ inch	91.7	100	100	97.6	2.4
1 inch	40.8	100	100	82.9	14.7
¾ inch	17.8	99.4	100	76.0	6.8
½ inch	9.9	83.8	100	69.2	6.8
⅜ inch	9.4	57.1	100	61.3	7.9
No. 4	9.2	13.5	94.2	46.2	15.2
No. 8	9.2	5.1	73.9	35.2	11.0
No. 16	9.2	3.7	54.1	26.5	8.7
No. 30	9.1	3.3	32.5	17.2	9.2
No. 50	9.1	3.2	9.2	7.4	9.8
No. 100	9.1	3	2	4.3	3.1

Calculations | Combined Gradation | CF vs. WF | Compatibility Report

Optimized Aggregates – QA

- Acceptance (3.09.08)
  - Acceptance of the combined aggregate gradation will be based on the ability of the combined aggregate gradation to plot within the Operating Zone Boundary
  - Loss by Wash ≤ Spec Requirement

Figure 1: CF vs WF Chart



How To Implement Optimized Mixtures for Paving?

- Three bins on the plant
- "Coarse" limestone, 6AAA quality (0.040 F/T), crushed to "custom" size/gradation
- "Intermediate" agg, 0.067 F/T, crushed to "custom" size/gradation
  - Particles >½ inch must meet quality specs for coarse aggregate (F-T dilation); anything >½ inch that doesn't meet F-T limited to less than 5% of total aggregate
- Daily gradation testing

How To Implement Optimized Mixtures for DM & S2M?

- Possibly extra or dedicated bin
- 6AAA quality limestone, 0.040 F/T, 6AA size
- "Intermediate" agg, 0.067 F/T, (26A or 29A)
  - Particles >½ inch must meet quality specs for coarse aggregate (F-T dilation); anything >½ inch that doesn't meet F-T limited to less than 5% of total aggregate
- Weekly gradation testing

Questions?

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Thank you!!