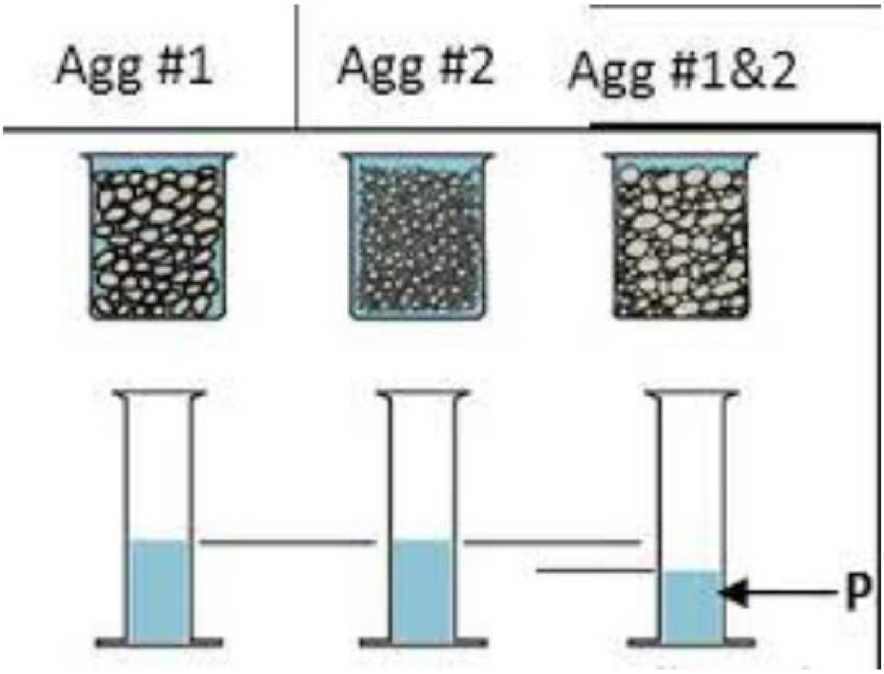
Optimized Aggregate Gradations

Technical Bulletin #23 - November 2023



What does optimized aggregate gradations mean?

If you recall Technical Bulletin #12 on Aggregates, one of the most critical assessments made of an individual aggregate is it's gradation. This is a measure of the percentages of different particle sizes in an aggregate sample. Selecting aggregates with acceptable gradations is half the battle for mix designing, the other half is using aggregates with complimentary gradations to achieve a quality mix design. In order to evaluate this, we combine the gradations, weighted by how much of each aggregate is used, to see how they interact when fully mixed in a concrete matrix. Often, an intermediate aggregate addition is necessary to optimize a mix design that already has a fine aggregate and coarse aggregate.

What are the benefits of optimizing the combined aggregate gradation?

For concrete pavements, it basically boils down to three things: concrete quality, workability and (potentially) economics. In a combined aggregate system, one of the main objectives is to pack as many aggregates into a mix design as possible, eliminating voids. A reduction in voids means we can reduce the paste content while maintaining our strength. Reduced paste content means lower shrinkage (less cracking), lower potential for alkali aggregate reactions, reduced permeability, and often cost savings. Another goal for optimized aggregate mixes is workability. An optimized aggregate mix will have more free paste (as less paste is used to fill voids) to allow for easier surface finishing operations. It will also hold together under vibration better, a key factor in slip form paving operations.

Sounds great, but how do we assess a combined aggregate gradation to know if it is optimized?

First some historical context: when concrete pavements first came about, typically two aggregates were used, but the combined gradation tended be be well graded. A standard was developed where a “haystack” shaped combined aggregate graph was desired to make the highest quality concrete.

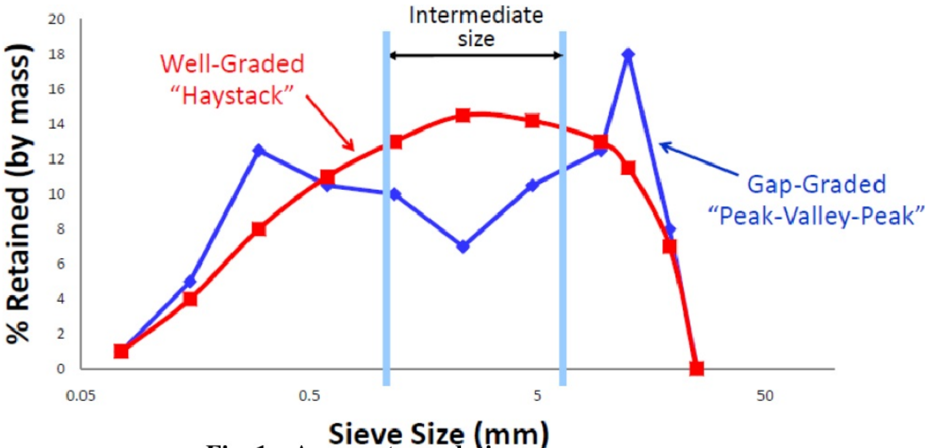
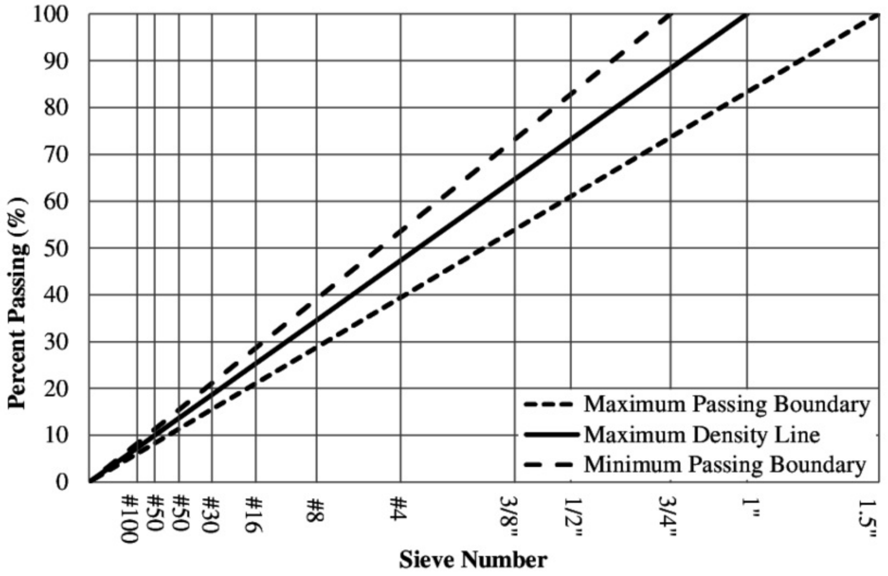
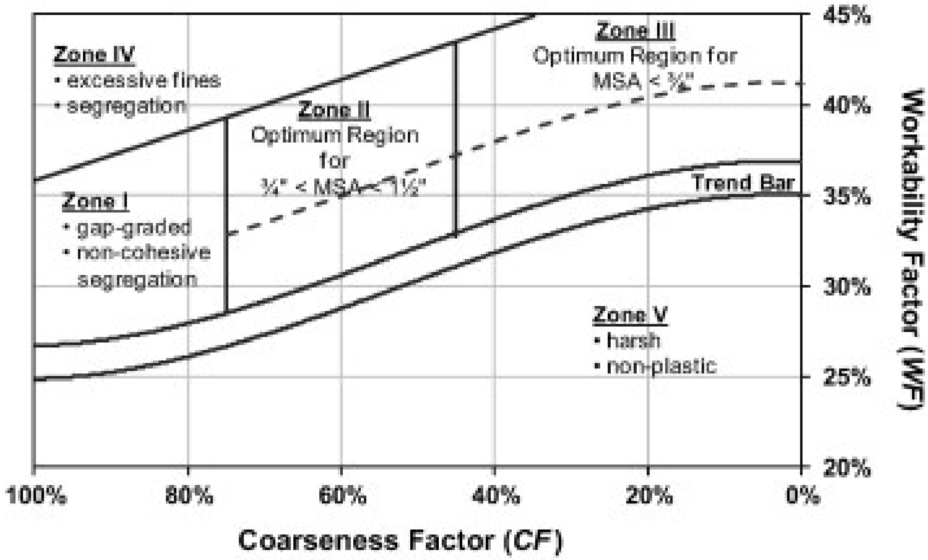


Fig. 1. Aggregate gradation

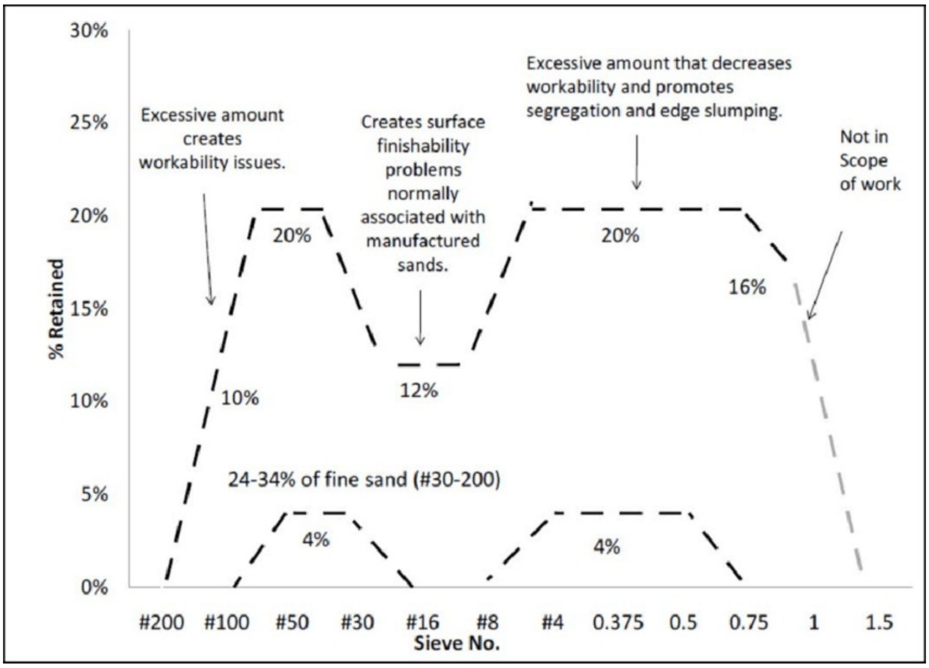
Over time, the 3/8" to #8 material began to be scalped away for use in asphalt or other materials leaving a “Peak-Valley-Peak” graph line that represented a gap in the gradation. Mix designs in the 60's through 80's didn't really address the change in aggregate gradations and left us with many concrete pavements that were not all that smooth, had vibration lines from segregation, and a myriad of other issues. In the late 80's, Jim Shilstone popularized two methods for assessing a combined aggregate gradation: the Power 45 Curve and what came to be known as the Shilstone Method.



The Power 45 Curve is a tool for assessing the particle distribution of all aggregates in a mix design. A line is drawn starting at 0 and raised to the .45 power. By proportioning aggregates to closely match the maximum density line we can ensure the minimum amount of voids in the matrix.



The Shilstone chart uses two equations from the combined aggregate gradation and graphs as a single point on a matrix. The “Coarseness Factor” is the % retained on the 3/8" sieve divided by the % retained on the #8 sieve. The "Workability Factor" is % passing the #8 sieve plus 2.5 times the cementitious content over 564lbs per yard. This chart helps ensure a workable mix design for the contractor if you make sure the mix design graphs in “Zone II” seen above.

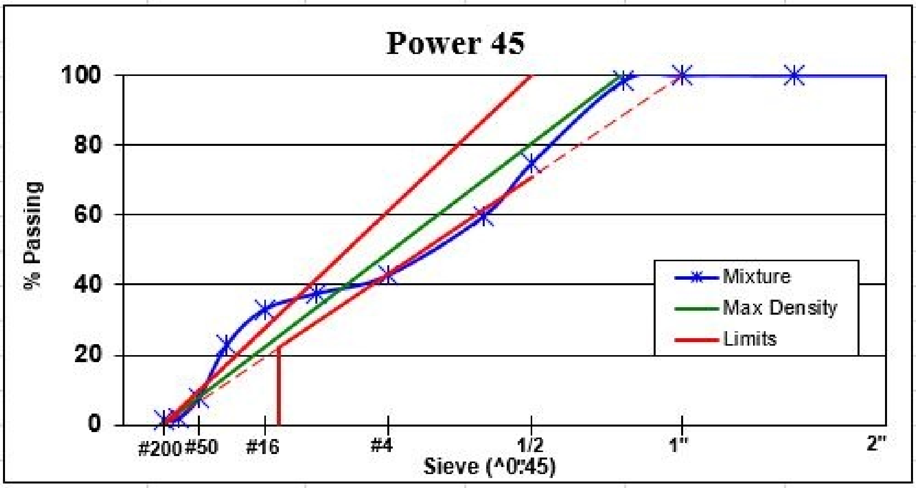


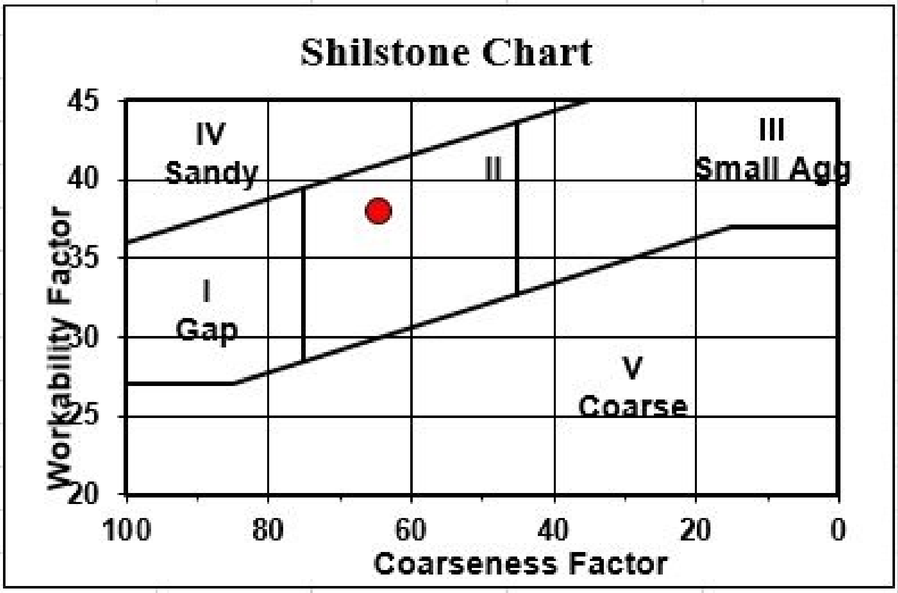
Finally, a great deal of research was done by Tyler Ley and others to determine a replacement to the old “Haystack” chart as many were still using that for a target curve. They found a slightly altered chart was necessary, out of which was born the Tarantula Curve. Here we chart the individual percent retained of the combined aggregate sample gradation at each sieve and make sure they are within the control lines.

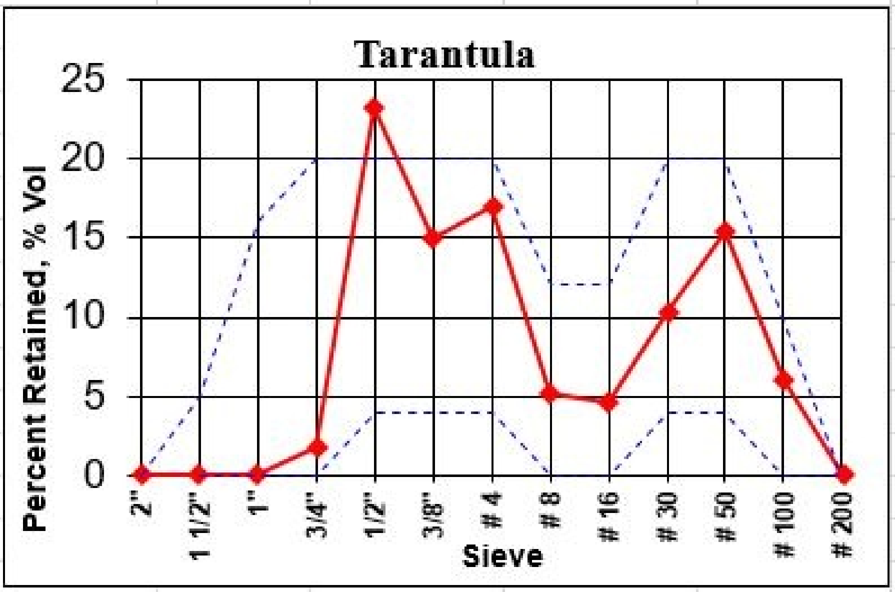
If we can develop a mix design that closely follows the Power 45 curve, maps in zone II of the Shilstone Chart and fits in the control lines of the Tarantula curve we can be reasonably certain of a workable mix with minimal voids. It is important to consider that aggregate options are not always plentiful and sometimes the ready mix supplier must make the best of the gradations they have available to them. In this instance, it may not be possible to achieve the goals of all three charts. However, the charts can still be used to make the very best of those aggregates as possible.

Example

Let's make an example. For two non-optimized mix designs, we are going to use an Illinois DOT PV/SI and an Iowa DOT C3WR, both with two aggregates. Then we'll compare to an optimized QMC mix design. We'll use real gradations of aggregates we have at our disposal.
First, a two-agg Illinois DOT PV/SI: This is a mix with 580 pounds cementitious and a 60%-40% blend of coarse aggregate to fine aggregate.

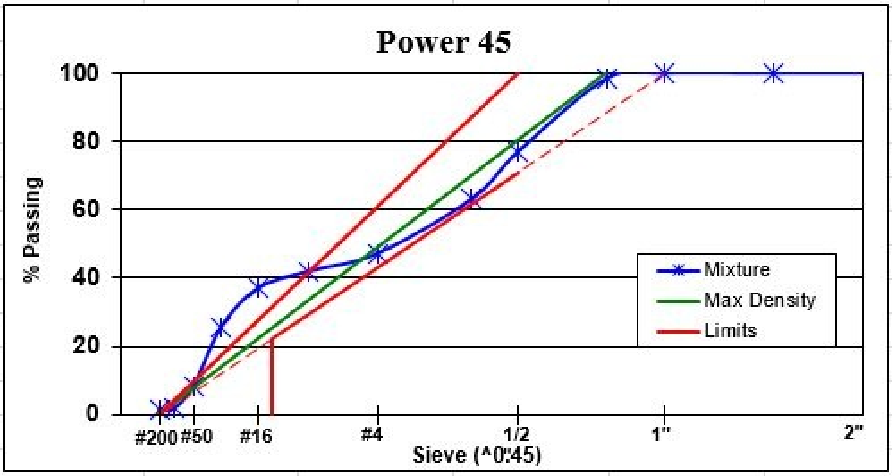


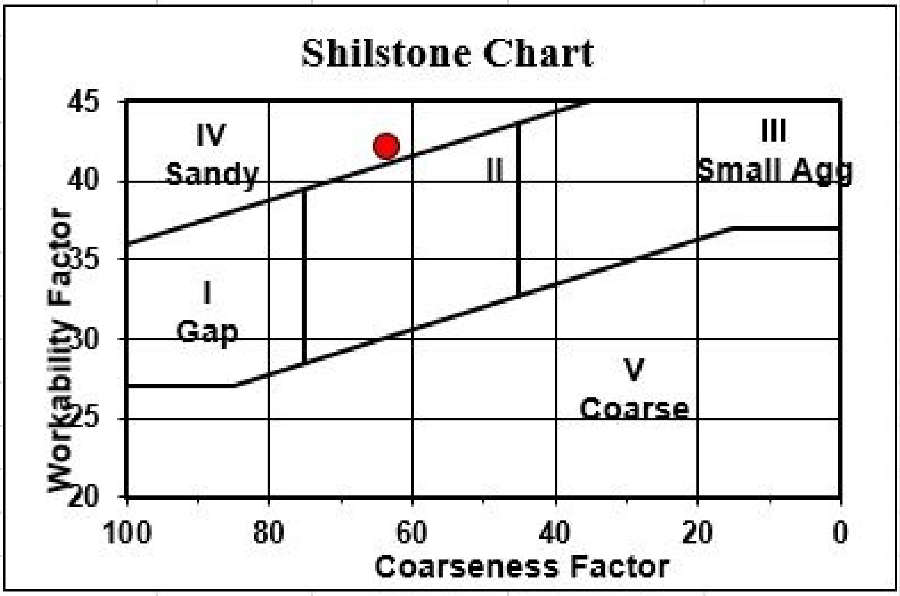


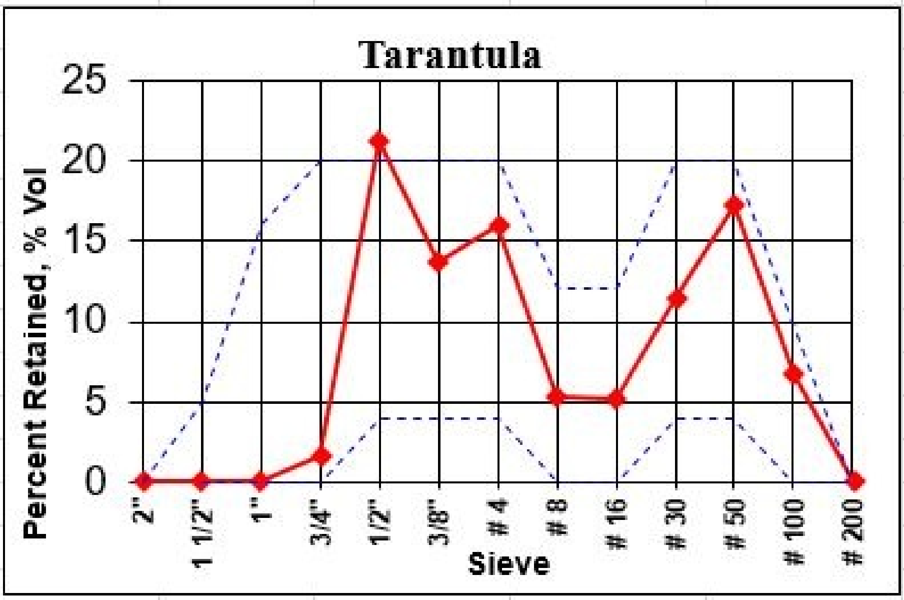


As you can see, the PV/SI mix design does not closely follow the power 45 and breaks the limits on the tarantula on the ½" sieve. This tells us there will be excessive voids and the mix is somewhat gap graded. It does score well on the Shilstone, suggesting it will finish well through a paver.

Now let's see an Iowa DOT C3WR: This is a mix with 571lbs of cementitious, and a 55%-45% aggregate blend.

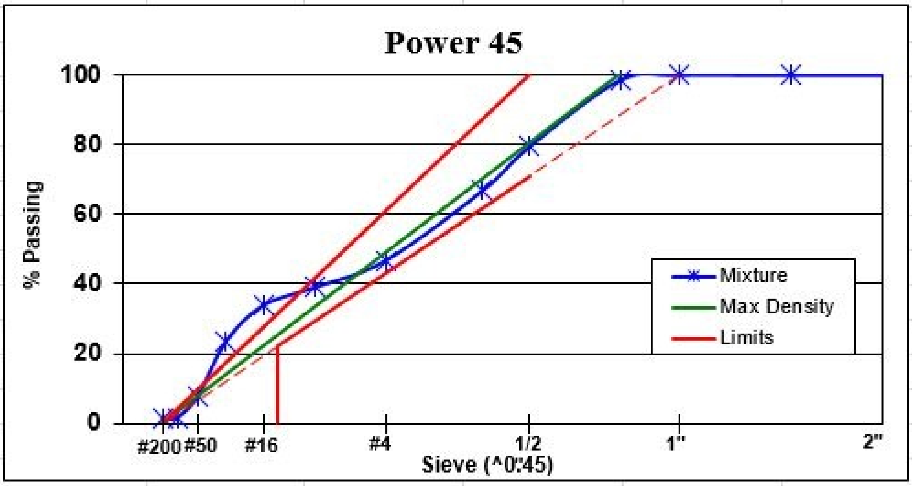


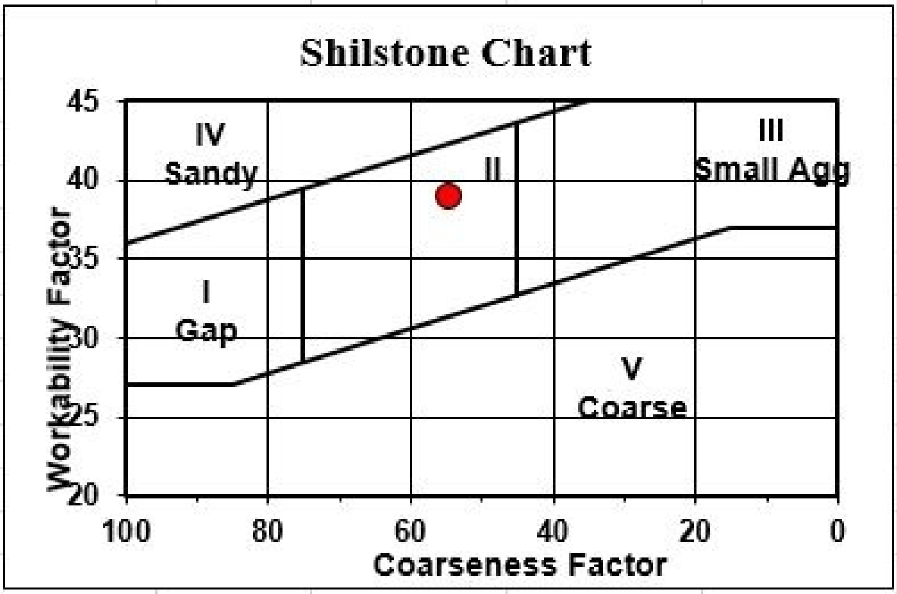


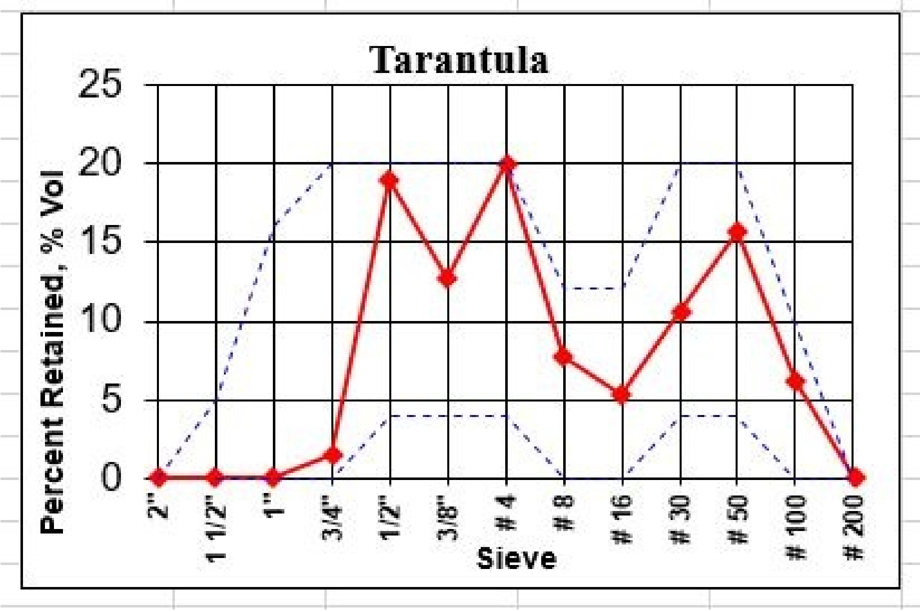


This mix is slightly improved on the Power 45 and Tarantula, but now it sits just outside the sweet spot on the shilstone, and may be more prone to segregation.

Finally, lets look at a QMC mix that can be used with the Iowa DOT. QMC mixes are uniquely created for the aggregate gradations that will be used in the mix. This one has 555lbs of cementitious, and a 49-10-41 split on Coarse-intermediate-fine aggregates.







This mix performs much better on the Power 45 and Tarantula (the little hump on the fine end of the power 45 is unavoidable with the relatively fine sands in the area). It also scores well on the Shilstone. We would describe this combined gradation as optimized. We also saved 25lbs of cementitious material compared to the PV/SI mix and 16lbs compared to the C3WR mix. Experience tells us that the optimized gradation effect more than makes up for the lost reactive material in terms of strength and durability.

As the other Tech Bulletins can attest, there are a great many factors to making quality concrete. Optimized aggregate gradations are just one more piece of the puzzle, allowing us to get the very best out the materials at our disposal.

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