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"Moving Advancements into Practice"

MAP Brief March 2014

Describing promising technologies that can be used now to enhance concrete paving practices

Mixture Design and Proportioning for Concrete Pavements

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ROAD MAP TRACK 1

PROJECT TITLE
Mixture Design and Proportioning

TECHNICAL WRITER
Peter Taylor
National Concrete Pavement Technology Center

EDITOR
Sabrina Shields-Cook

SPONSOR
Federal Highway Administration

MORE INFORMATION
Peter Taylor
National Concrete Pavement Technology Center
ptaylor@iastate.edu
515-294-8103

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Moving Advancements into Practice (MAP) Briefs describe innovative research and promising technologies that can be used now to enhance concrete paving practices. The Jan-Feb 2014 MAP Brief provides information relevant to Track 1 of the CP Road Map: Materials and Mixes for Concrete Pavements

This MAP Brief is available at www.cproadmap.org/publications/MAPbriefMarch2014.pdf.

Why are we talking about this?

The topic of mixture design and proportioning is gaining attention recently, despite the relatively small number of people actually involved in doing mixture proportioning with any regularity. Traditionally, specifications for mixtures tended to be prescriptive and restrictive, meaning that concrete providers had little freedom or incentive to optimize or improve their products. It was generally sufficient to use the same mix as yesterday, last year, or the last project.

Education is this field has also been limited, with many misconceptions being accepted as fact, potentially leading to inappropriate responses to failures or problems.

The push toward performance-based specifications, however, combined with tighter budgets and greater attention to sustainability, there is a growing pressure to better understand the parameters that influence critical performance for concrete mixtures. This tech brief summarizes research currently underway with the aim of improving this understanding.

Definitions

The phrase "mixture design" is often used to describe a sheet that lists the amount of each material in a batch by pounds per cubic yard. The definitions being adopted in the paving community separate "design" from "proportioning," roughly along the lines of responsibility.

Mixture design is the process of determining the required and specifiable characteristics of a concrete mixture; i.e., choosing what is required to survive the environment and provide the required service life. That means the engineer or owner will select the performance needed from the mixture to meet structural and durability requirements. Such parameters will generally include a required strength, permeability, air-void-system, and shrinkage.

Some prescriptive limitations may still be imposed (such as supplementary cementitious materials content) to ensure that a long life will be achieved. These are normally selected because they are easier to measure than the associated performance metric.

Mixture proportioning is the process of determining the quantities of concrete ingredients; i.e., choosing what and how much to use to meet the requirements of the design. This is where individual products are selected and their relative amounts are calculated.

There is a perception that proportioning is simply a computational exercise. While numerical approaches provide a good starting

point, the state of technology is still that trial batches, both in the laboratory and in the field, are needed to be sure that a given mixture is performing as required.

Who needs what

The demands on a mixture depend on the parties involved. The owner will primarily be concerned with the long-term performance—strength and durability. While the owner may be interested in the fresh properties, this is largely because of their impacts on constructability and, indirectly, longevity.

On the other hand, the contractor is primarily concerned with constructability issues—workability, setting, and early strength—so that the next phase of work can begin. The contractor's concern with longer-term factors is generally limited to those with a bonus or penalty attached.

Some of these requirements may be mutually exclusive: for example, adding water to a mix makes it more workable but compromises all other properties and decreasing the water to cementitious materials ratio (w/cm) improves permeability but increases cracking risk.

The art of good mixture proportioning is to find compromise among the many demands on the system.

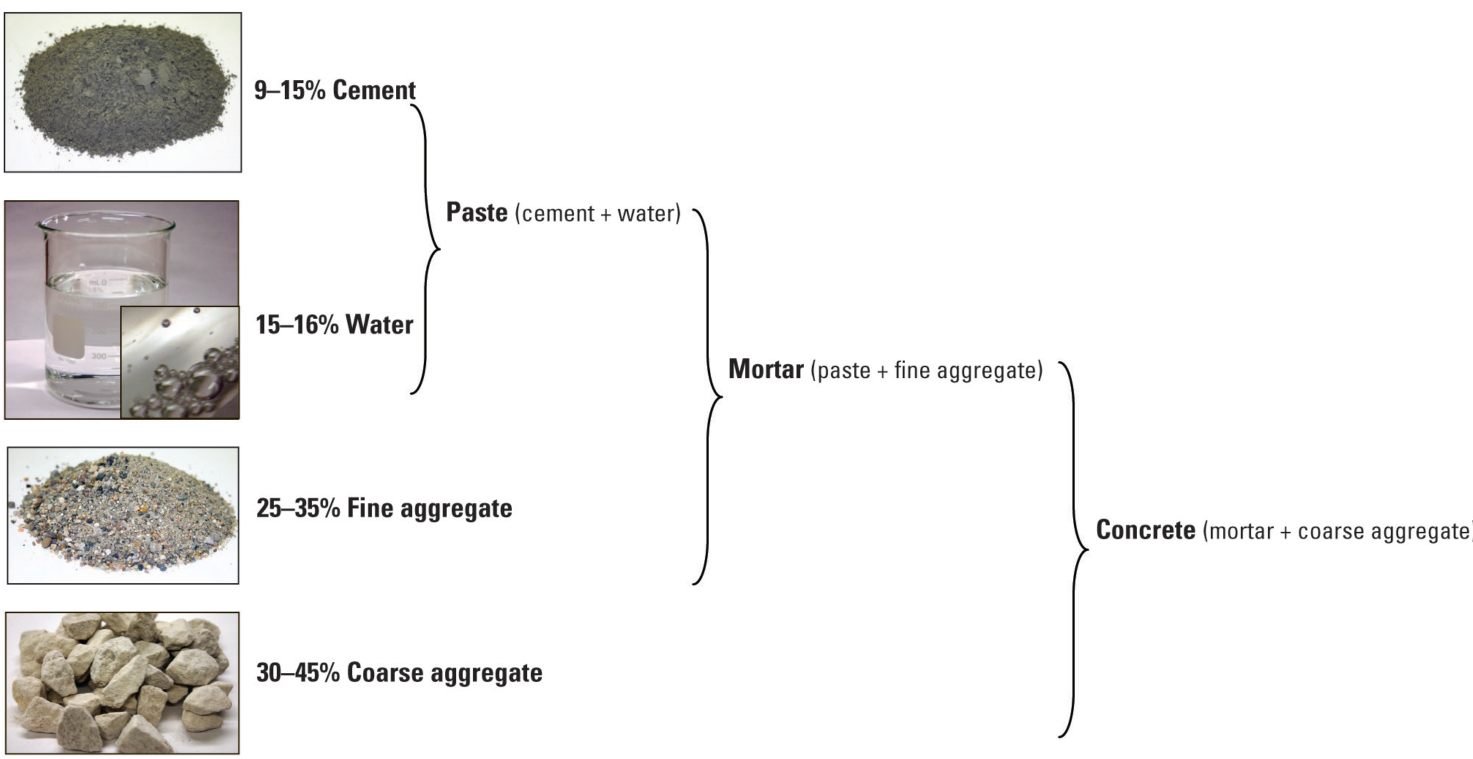
Design decisions

Design decisions should be limited to the longer term parameters and may include the following:

- W/cm, because this parameter controls performance
- Binder type and dosage where necessary; for instance, to obtain resistance to alkali silica reaction
- Permeability to improve potential durability
- Air void system to ensure resistance to cold weather
- Strength for structural purposes, although experience has shown that if durability concerns are addressed, delivered strength often exceeds the required minimum
- Shrinkage to control cracking

Properties such as slump should not be specified, because the specifier is unlikely to know the workability needs of the equipment used by the contractor. Limitations on variability may be considered because they may indicate errors in batching.

Many specifications include a minimum binder content. Recent work is demonstrating that the amount of paste required in a system to achieve a given performance is influenced by the gradation of the aggregate system. Excess paste beyond



Components of concrete mixtures

a certain amount provides no measurable benefit and may reduce performance in terms of permeability and even strength. This is a large change in perspective and is driven by the increasing use of chemical admixtures and supplementary cementitious materials that nullify long-held rules of thumb.

Proportioning

Proportioning in the United States is generally based on ACI 211.1. However, the ACI 211.1 document was prepared

- Primarily for mixtures with 4 in. slump and 4000 psi.
- Before supplementary cementitious materials (SCM) were common.
- Before chemical admixtures were common.
- Before computers were readily available.

The document was last revised in 1991. The original concept was cunning, and worked well for the intended product. By nature, it was also very conservative, often leading to much richer mixtures than necessary.

Therefore, researchers are currently working on developing alternative approaches. One such approach is based on work by Kohler and Fowler (2013) and sets the problem up in three stages: select an aggregate system, select a paste system, and select paste quantity.

Select an aggregate system

Aggregates comprise the bulk of the volume and mass of a mixture, and as such are normally obtained from sources close to the batch plant. Care should be taken to ensure that they are not prone to alkali aggregate reaction or d-cracking.

If use of "at risk' materials is unavoidable then other actions may have to be taken to compensate such as the use of appropriate amounts of supplementary cementitious materials.

In principle, the more aggregate that can be put into a mixture, the lower the amount of paste required. This is beneficial because paste is generally the most expensive component. It also generates heat and is the component that is most prone to drying shrinkage.

It is accepted that the "better" the gradation of the combined aggregate system, the greater its density will be. Some approaches seek to force the gradation to follow a so-called "power 45" line.

On the other hand, a counter argument states that if the aggregate system is too dense, then it will become unworkable. A recent report by Cook et al. (2013) has indicated that for paving, a good aggregate gradation should fall within the limits of a so-called "Tarantula curve" plotted using the amount of material retained on individual sieves. Systems within this envelope can be close to a theoretical maximum density yet still allow good workability and finishing characteristics.

It should be noted that good concrete can still be made even if the gradation is less than ideal. It just means that more paste may be required, and that greater attention may have to be paid to workmanship to ensure that the mixture is well consolidated and finished.

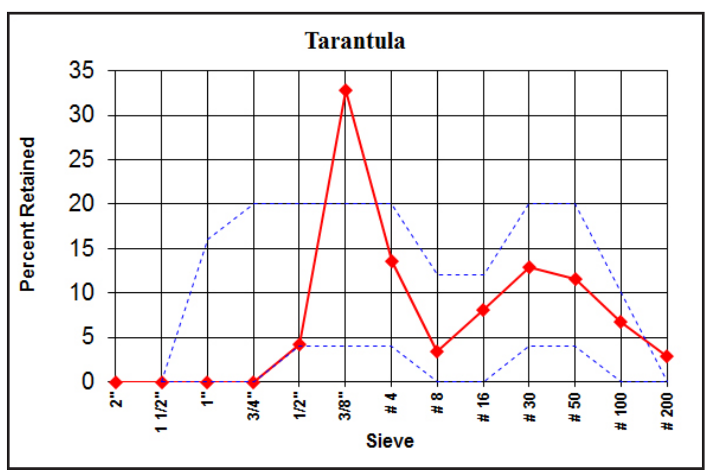
Having determined the aggregate sources and desired/achievable gradation, the volume of voids between the consolidated aggregate particles should be determined in accordance with ASTM C 29.

Select a paste system

Many of the decisions that govern the quality of the paste in the mixture have been made as part of the design:

- W/cm – for pavements a range of 0.38 to 0.42 is suggested in cold climates
- Target air content – 5% air volume behind the paver in cold climates
- SCM type and dose – this decision is influenced by local availability, time of year and cracking risk, and needs such as alkali silica reaction prevention

Target admixture dosages may be estimated at this stage but will have to be verified in trial batches.



Tarantula curve

Select the paste quantity

For a concrete mixture to both be workable and meet hardened performance requirements, it should contain a minimum amount of paste that is sufficient to fill all of the voids between the aggregate particles. An additional amount is also required to separate the aggregates slightly and so lubricate movement between them and make the mixture workable. This “excess paste” also acts to glue the aggregate particles together.

Experimentation has shown that the volume of paste should be about 1.75 times the volume of voids in the consolidated combined aggregate system. Greater amounts will increase workability; for self-consolidating concrete, the amount is about 2.5 times.

A minimum amount is required to achieve any workability, below which water-reducing admixtures provide no benefit and little workability can be achieved. This amount is about 1.5 times the void space, based on work completed to date, but may vary with a wider range of aggregate systems.

Once some workability has been achieved by adding sufficient paste, then final slump can be controlled using water reducing admixtures as needed.

Iterate

Noting that some of the decisions made in later stages may impact factors from earlier stages, it is recommended that the process be iterated to find a good balance between conflicting demands.

Trial batches

As noted above, all of this numerical work is still insufficient without trial batches being made in the laboratory and in the field. The type and size of mixer will influence the final workability and admixture requirements, as will the temperature at the time of batching and the state of moisture in the aggregates.

Adjustments may also be needed with changing seasons. In warm weather, increasing SCM dosages may be desirable to help cool the mixture and reduce the risk of early age cracking, but in cold weather the opposite is true.

For more information

For more information, contact Dr. Peter Taylor, Associate Director, National Concrete Pavement Technology Center, ptaylor@iastate.edu, 515-294-8103.

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