Customize every concrete batch with computers

Computerized mix management system will vary proportions to meet varying needs

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Traditionally, concrete mixture proportions are selected, tested, and approved by the engineer. The result is a design mix that gives ingredient weights for cementitious materials, water, admixtures, and fine and coarse aggregates. Once established, batch weights for water and aggregates may be adjusted to account for moisture content in stockpiled aggregates. Otherwise, ingredient weights are fixed. Any change in design weights must again go through the approval process.

But ingredient properties vary. Site conditions such as temperature vary. How the concrete is placed—by pump, chute, or crane and bucket—varies too. A fixed-ingredient mix design doesn't account for these variations that affect concrete properties such as water demand, workability, and finishability. Using fixed weights of variable ingredients under variable conditions yields a predictable result—a variable product.

For example, broad aggregate grading tolerances allowed by ASTM C 33 are major contributors to placing and finishing problems. Telltale signs of these problems are pumping difficulties or finishers reporting either that troweling is like rubbing stones or that they're carrying too much fat ahead of the trowel.

To avoid problems caused by keeping ingredient weights constant, concrete should be produced to meet performance requirements in accordance with a design formula for the composite mixture. This can be done by applying computer technology.

Mixture design management

Scheduled for release this year, a new software system will allow the producer to store a mixture design formula instead of batch weights in the plant control computer. This will permit using the most economical materials available to meet varying construction needs. The mixture design formula will be supported by four sets of information (databases):

- Ingredient properties
- Concrete mix performance history
- Construction needs
- Weather conditions and delivery times

Changes in information within these databases, such as aggregate grading, cement source, mix temperature, or placing method, would trigger a mix proportion change. This proportion change would still produce a batch matching the mixture design formula while taking into account variations in materials and jobsite conditions. This will enable the supplier to produce more uniform concrete better meeting construction needs.

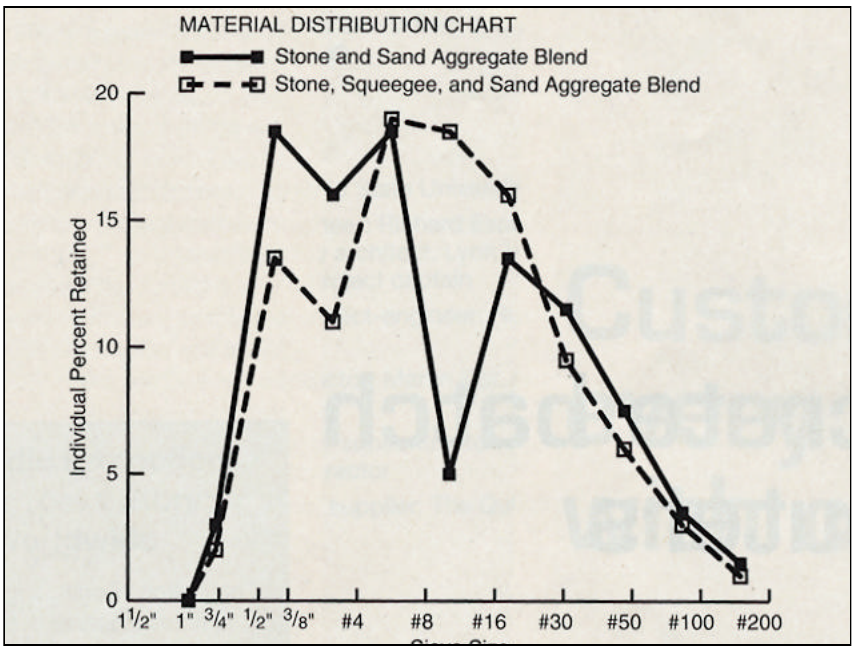
Database development

The database for ingredients has separate sets of information for aggregates, portland cement, fly ash, and admixtures. Information from in-plant tests on the ingredients or from mill test reports can be entered into the database regularly. The computer will use the most recent data or running averages as a basis for changes in proportions. For instance, seasonal changes in river sand fineness might dictate a change in sand content to maintain constant workability while controlling water content to produce constant strengths. Sieve analysis results entered into the database will reflect the gradation changes and the computer program will automatically adjust sand content to correct for the changes.

The database for concrete mix performance history is a statistical program into which results of tests on plastic and hardened concrete are entered. Statistics are a technical means for recording valuable experience and using that experience to better control operations. Using this data, the computer software program examines relationships between plastic and hardened concrete properties. For instance, graphs can be plotted showing strength versus air content, slump, mix temperature, time between batching and sampling, and wet unit weight. A "what if. . ." function will permit the software user to study the individual or combined effects of one or more properties on strength. Time line charts generated by the program also will indicate trends in properties such as strength. A sudden rise in moving average for standard deviation of strength test results, for example, is an early warning of mix control or testing problems.

Experience in pumping and fin-

The Importance of Gradation: A Tale of Two Mixes



The concrete mix for bridge deck projects in Denver was difficult to use. Finishers had a hard time closing the surface of the 3-inch-slump concrete made with a 3/4-inch-top-size coarse aggregate and a concrete sand. Using principles from Shilstone's mix design software program, CDOT concrete engineer Alan Eastwood modified the mix by simply replacing part of the sand and stone with a third aggregate—a fine pea gravel that didn't meet pea gravel specs. Called squeegee, it's a waste product from the manufacture of sand that the city of Denver uses for ice control.

Before and after mixes are shown in the table below. Aggregate gradings are compared in the figure. Adding 800 pounds of squeegee and removing 300 pounds of sand and 500 pounds of gravel produced remarkable changes in the mix. Less water was needed to give the same slump. Unit weight and strength increased. And, best of all, workability improved dramatically, saving money on labor and finishing.

Effect of Blended Aggregate on Concrete Properties

Material	Amount per cubic yard	
	Original mix	Mix with blended aggregates
Type II cement	528 pounds	528 pounds
Fly ash	132 pounds	132 pounds
CDOT concrete sand	1,100 pounds	800 pounds
CDOT ¾-inch gravel	1,800 pounds	1,300 pounds
Squeegee	—	800 pounds
Mixing water	265 pounds	250 pounds
Water-reducing admixture	20 ounces	20 ounces
Air-entraining agent	3 ounces	3 ounces
Water-cement ratio	0.40	0.38
Slump	3 inches	3 inches
Concrete unit weight	140.9 pcf	141.4 pcf
Finishability	poor	excellent

Eastwood says there are three lessons to be learned from this example:

- Some (but not all) mix problems can be solved by changing mix proportions to achieve a better aggregate grading
- It's not necessary for the grading of each blending aggregate to meet ASTM C 33 grading requirements. Only the combined aggregate grading is important.
- Blending three aggregates instead of two gives producers a greater chance of achieving the best combined aggregate grading.

Unfortunately, many concrete producers have only two aggregate bins available. Using three aggregates with only two bins can be done. But it requires preblending two of the aggregates at the quarry and ensuring that no segregation occurs when the blend is shipped to the plant. That's risky and doesn't give the producer leeway for making adjustments once the blend is in the bins. A three-bin setup gives the producer and the contractor customer greatest flexibility.

By blending from several bins, producers can use aggregates that by themselves don't meet ASTM C 33 grading requirements but in combination produce good-quality concrete. That's essentially what the people in Colorado did. They wrote their own specifications and discarded all references to ASTM C 33 for aggregate grading. Other engineers and agencies are following that trend and turning to combined gradation objectives. Duff Abrams recommended this approach in 1918 when he introduced the water-cement ratio versus strength relationship.

With at least three aggregates and a software program that quickly makes aggregate blending calculations, a plant can use the most economically available aggregates and still produce a better product.

ishing provides input for the database of construction needs. Different levels of workability are needed for concrete placed by chute and concrete that's pumped. There's also a difference in workability requirements between concretes pumped through 4- and 5-inch-diameter lines.

In this software system, mixture designs for different placing and finishing conditions are based on field experience generated from worldwide projects. For instance, concrete made with a crushed stone coarse aggregate requires about 54% to 55.5% mortar content if it's to be pumped through a 5-inch line. (Mortar consists of cement paste plus sand passing the No. 8 sieve.) But to pump it through a 4-inch line, you need 55.5% to 57% mortar. This kind of information can be entered into the construction needs database

The database of weather conditions relates particularly to the problem of strength drop during summer months. This drop is partly due to cement hydration during transit, which causes slump loss and may result in more water being added at the jobsite. The database provides information that permits mix adjustments to compensate for variations in temperature and time of haul.

Plant control software

Software for the mix management system will work on many computer systems. For batch plant control systems operated by MS-DOS-compatible computers, it can run in the batch plant computer itself. If the batch plant is set up to run under Microsoft Windows, the system can run simultaneously with the batch plant program on a 386 computer and concurrently (with task switching) on a 286 AT-compatible computer. This means that 386 batch plant control systems can maintain constant communications with the mix management system. The 286 computers can switch back and forth from batch control to mix management system with the push of a button.

For non-MS-DOS-compatible batch plant computers, the mix management system resides in an outside box—a stand-alone computer that can send and receive information from the batch plant computer. The batch plant computer requests mixture proportions through the RS-232 port, but any change in mixture designs will have to be entered directly into the stand-alone computer.

With either batch plant control system, the mix management system calculates proportions to meet a mixture design formula, displaying the particle distribution analysis and ingredient weights on the plant controller's screen. If the controller sees a problem, he or she can still reject the batch and make adjustments. In effect, a mix management system will customize every batch of concrete to produce a consistent product that meets varying engineering, construction, and durability needs.

The software program is now being developed for use with current batch plant computer control systems. But the technology already exists. Software for mix management, performance history, and materials database components is in use manually around the world today. Use of the mix management program has already contributed to a new recognition of the importance of the effect of aggregate gradation on construction needs and mix quality. A statistics program for performance history has shown that slump and strength are not necessarily related. And a program for blending aggregates makes blend calculations in seconds.

A glimpse of the future

The U.S. Army Corps of Engineers is currently performing a technical review of the software as part of its Construction Productivity Advancement Research (CPAR) program. It will also conduct field testing and analysis of the mix management system. The Corps will share what it's learned with industry and other government agencies to aid in overall improvement in U.S. construction productivity.

With widespread use of computer-assisted mix management systems, other changes in the concrete production industry will occur. Instead of using only coarse and fine aggregate, plants will blend three, four, or even five aggregates to produce high-quality concrete with inexpensive aggregates that don't have to meet standard grading requirements. On-line sampling devices will frequently monitor gradation, and some plants may use final screening at the batching bins as is done at asphalt plants.

Data from tests on plastic and hardened concrete will come to the plant computer by wire directly from testing laboratory computers. So will test results from cements, admixtures, and pozzolans. This will reduce time lag between data acquisition and use of the data for adjusting the mix.

By emphasizing uniform output rather than uniform batch weight inputs, high-quality concrete and fewer field problems will result.

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