Managing Concrete by Computer

JAMES M. SHILSTONE, SR.

The production and quality control of concrete have been based on the establishment of a mix recipe for ingredients fixed by weight or, for liquids, by volume. During progress of the work, materials characteristics are verified and judged on the basis of broad limits set in the project specifications. The original recipe is adjusted during production to compensate for the moisture in the aggregates. Field tests are made of the plastic concrete to determine that certain characteristics are met. The ultimate judgment of mix quality is based on strength. Fallacies occur in the existing system and field tests of concrete produced under the current system seldom provide a reliable basis for forecasting performance as measured by strength. Methods for mix adjustments to produce uniform concrete during production and as recommended by Duff Abrams in 1918 and Delmar Bloem in 1956 plus new technology are described as being possible when mixtures are managed by computer.

Computers are widely used to aid in engineering calculations and production of concrete structural drawings. Despite their power, they have seen limited use for concrete production and quality control. Those used at batch plants are little more than mix weight storage vaults. Even when controlling production operations, the programs are relatively simple.

There are eight functions by which an IBM-PC-compatible computer and available software can aid the concrete industry to produce better, more economical concrete and to improve communications within the industry:

1. Providing better methods for selecting, evaluating, and adjusting concrete mixture proportions;
2. Adjusting mixture proportions to meet project engineering criteria and construction needs;
3. Aiding in the more efficient utilization of aggregate resources;
4. Adjusting mixture proportions to compensate for variations in ingredient characteristics and statistical data;
5. Calculating from a database the combined influences of field tests of plastic concrete to forecast ultimate strength;
6. Training concrete technicians to efficiently use varying materials resources despite their lack of math skills;
7. Providing means for educating everyone from construction workers to engineers in the technology of concrete mixtures and the influences of materials variations upon the work they will perform; and
8. Providing terminology and procedures for better communication between design, construction, and supply personnel.

To appreciate the opportunities and potential benefits to be derived from using the computer for concrete technology and mixture management, current practices must be reviewed. A typical procedure for fixing mixture proportions is as follows:

- Proposed aggregates are tested for compliance with the specifications. Material data such as specific gravity, gradation, dry rodded unit weight, and fineness modulus are recorded.
- Mixture proportions, measured by weight, are selected using various table, charts, rules of thumb, and historical local practices.
- Proportions are tested in trial mixtures and the potential strength for differing cementitious materials factor is determined.
- Final proportions are selected from a chart representing the relationship between cementitious materials content or water/cement ratio and test strengths.
- The selected proportions are transmitted to the project engineer for approval.
- Because there are no standard practices for evaluating mixture proportions, the mixture is approved based only upon strength and consistency as measured by slump.

Consideration is seldom given to the potential effects of the approved proportions on the construction or engineering properties other than strength and consistency. There are many times when answers to the following questions should be provided:

- Will the mixture tend to produce high or low shrinkage?
- Is this the best combination of materials to facilitate placement using the pump or other placing equipment proposed for the construction?
- Do the proportions provide sufficient mortar in the mixture to satisfy construction needs and produce the slab or formed finishes specified?
- Do the proportions provide too much sand that increases surface tension of the concrete to the form, increases bugholes on the vertically cast concrete, inhibits the action of the vibrator, or causes slab or pavement finishing problems?
- Do the proposed mixture proportions represent the median characteristics of materials to be used in the work or are they representative of isolated combinations?

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- If the materials characteristics change during progress of the work, how and when should proportions by weight be changed and by what standards should the changes be made?

Unfortunately, these questions are seldom raised. The proposed mixture is accepted and the materials proportions, by weight, are duly recorded and established as the criteria for the work. As the construction progresses, the components to the mixture are allowed to vary within the broad tolerances of ASTM, AASHTO, U.S. Army Corps of Engineers, a state department of transportation, or other standards. Tests are made on materials but the results are used only to determine if each ingredient complies with the appropriate standard and not to determine how the new characteristics will affect the concrete. The fact that the materials in use in the construction may differ widely from those used in selection of initial proportions is seldom considered.

PRINCIPLES VERSUS PRACTICES FOR MIXTURE PROPORTIONING

Fundamental principles of concrete mixture proportions are analogous to those for constructing a laid-up field stone wall; they have long been known but are seldom described in the literature. They are as follows:

- A maximum number of large particles should be used in the mixture;
- A sufficient number of intermediate particles should be provided to fill the major voids between the large particles;
- Sufficient fine particles should be available to fill the remaining larger voids and coat the two larger sizes to provide the needed mobility; and
- The paste should coat the aggregate particles, fill the fine voids, and provide lubrication during placement and strength after hydration.

In practice, the industry violates these principles, in particular the reference to three aggregate sizes. Instead of the aggregates' being divided into three size ranges, concrete is produced from stockpiles referred to as coarse and fine aggregates divided at the No. 4 sieve. The intermediate aggregate is material that passes the 3/8-in. sieve and is retained on the No. 8 sieve. In practice, these particles can occur as part of the coarse aggregate or as part of the fine aggregate, or comply with their own classification—frequently referred to as pea gravel. Some researchers refer to the intermediate sizes as interference because of the adverse effect of their variability on concrete mixture characteristics.

A special problem arises for the concrete industry when aggregate producers scalp the intermediate aggregate sizes from their production to supply them to the more profitable asphalt concrete (AC) or block markets. Like the stone wall without intermediate sizes, more mortar must be used to fill voids and hold the wall together. When asphalt demand is down, the intermediate sizes are more abundant in the concrete. This type of variation has an adverse effect upon concrete strength, durability, and workability.

Many treatises have been written concerning procedures by which portland cement concrete (PCC) mixture proportions should be selected. Unfortunately, little has been written concerning adjustments during construction to compensate for the variables that occur. Even less has been written upon the target relationships of particles within the mixture and the optimization of their distribution. The historical practice of maintaining weights constant has produced acceptable concrete for many years. As resources have been depleted, the cost of hauling increased, engineering requirements advanced, quality control reduced, and construction processes become more demanding, past practices are not meeting the needs of specification concrete today nor will they meet the needs of the future. The practice of maintaining material weights constant while allowing those materials to vary widely produces nonuniform concrete.

The asphaltic concrete industry uses a different procedure for selecting and maintaining mixture proportions to produce a uniform product. The combined materials distribution, to include liquid, makes up the mix design. When ingredients vary from the original characteristics, weights are adjusted to reproduce, as near as possible, the original particle and asphalt distribution. The same approach can be used for PCC. This has not been done in the past because of the time required and difficulty to make those calculations. The computer can perform the necessary calculations in seconds.

MIXTURE ADJUSTMENT METHODS

Fuller and Thompson (*1*) recommended a procedure whereby the aggregate proportions were selected from the blend that produced the highest unit weight by test. The effect of this procedure was to optimize the aggregate proportions, thereby reducing voids to be filled by paste.

The fact that mixtures should be adjusted for variations in aggregate gradation was advanced by Abrams (*2*) and confirmed by Bloem (*3*). This work was republished by the National Ready Mixed Concrete Association (*4*). Abrams (*2*) recommended that the combined aggregate fineness modulus be kept constant. This process was carried out by Bloem (*3*) who obtained excellent correlation with differing sand gradings. Unfortunately, this method is seldom applied because of the time required to make the adjustments. The principles are sound but the problem has been that it has not been possible to do the calculations and make the adjustments while work has been in progress.

ACI-211 (*5*) provides for aggregate proportions to be selected based on variations in grading for both coarse and fine fractions. These are measured by nominal coarse aggregate size, dry-rodded unit weight, and fine-aggregate fineness modulus. Though not so stated, the primary need for making adjustments is based on the amount of intermediate particle size (pea gravel) included in each aggregate size. The amount of sand needed to provide workability must be increased as the amount of intermediate particles, in either coarse or fine fraction, is increased. A gap-graded combined aggregate with no materials between the 3/8-in. and No. 8 screens requires a minimal amount of fine particles to provide a given consistency. As intermediate particles are added to the gap-graded mix, the need for fine particles is increased.

The relationship between the sizing of the two larger fractions and the needed fine particles has been described graphically (Figure 1) by Shilstone and Voelker in the coarseness factor chart. The trend bar has been established based on experience and mix confirmation. The bar represents an approximate optimization of particle distribution when the aggregates are rounded, uniformly graded natural gravel or cubically crushed stone and well-graded natural sand. The relative coarseness of the two larger fractions is shown on the *X*-axis and can be expressed as the fraction of the particles retained on the No. 8 sieve that are also retained on the 3/8-in. sieve, multiplied by 100. The *Y*-axis represents the percentage of the combined aggregate that passes the No. 8 sieve. The latter particles are those that provide mobility for the mixture and workability necessary for placement and finishing.

Another factor introduced with the coarseness factor chart was the influence of the amount of cementitious materials in the concrete mixture. The chart was based upon 564 lb of cement (six bags) per cubic yard. As cement varies from that amount, the need for fine aggregate varies. An increase in cement results in a decrease in the need for fines and vice versa. The absolute volume of a U.S. bag of cement is equal to approximately 2.5 percent of the combined aggregate. Therefore, if 30 percent of the combined aggregate is sand that passes the No. 8 sieve, the adjusted amount of workability particles for a seven-bag mix would be 32.5; for a five-bag mix it would be 27.5. *W* represents the percentage of the combined aggregate passing the No. 8 sieve; *W-Adj* (adjust) represents the equivalent workability factor corrected for the amount of cementitious materials in the mixture.

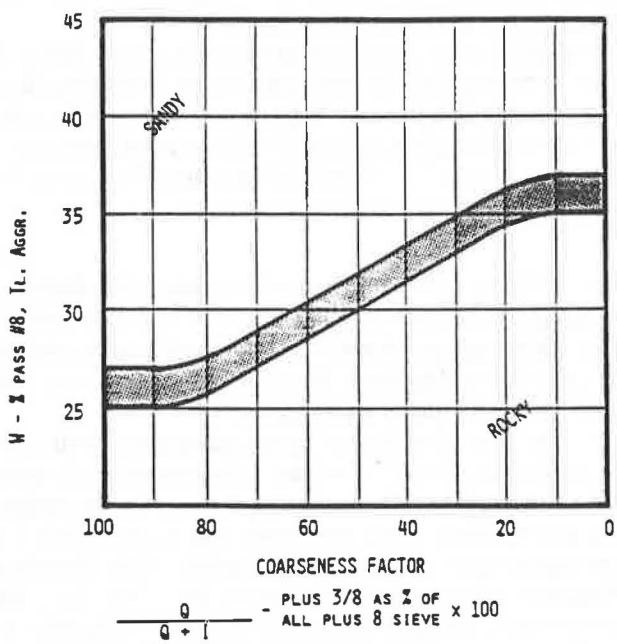

FIGURE 1 Relationship between fraction passing and fraction retained on No. 8 sieve.

Once the relationships desired for certain materials, construction needs, and engineering requirements are established, the coarseness factor chart can be used to adjust ingredient weights as gradations vary. Despite the use of aggregates with differing gradations, mixtures will be nearly comparable when they are proportioned to plot on the chart at nearly the same location as the original mixture.

Another, easily handled method for maintaining mixtures uniform is to maintain the mortar factor constant. Mortar is defined as all material passing the No. 8 sieve. Mortar content has a major effect upon strength, shrinkage, durability, wearability, placeability, finishability, and cost. Particles larger than the No. 8 sieve are inert filler. The mortar factor procedure makes adjustments for sand gradation variations. There are no provisions for adjustments to compensate for variations on the 3/8-in. sieve. When there are significant changes on the 3/8-in. sieve, adjustments should be through use of the coarseness factor chart.

There is no one method for determining the desirability of a mixture. The percentage of aggregate retained on each screen as shown on the gradation chart in the appendix is being found to be one of the best guides for mix performance during placement and finishing. Too much (more than about 20 percent of the combined aggregate) on one sieve, such as the 1/2-in., and not enough (less than approximately 6 percent) on another sieve, such as the Nos. 4 or 8, can be expected to cause finishing problems.

MIX MANAGEMENT COMPUTER PROGRAM

Computers provide an ideal means for selecting initial mix proportions, analyzing concrete mixtures, and adjusting mixtures as materials and statistical data vary. When a program is menu driven, its use can be simplified to the degree that responsible results can be produced by even nontechnical personnel. A desirable feature of the computer is its ability to rapidly perform the calculations to mathematically combine the ingredients into the design volume and analyze that combination of materials. After all, the characteristics of the combined materials are what is important.

The combined materials should be separated at the No. 200 sieve. Materials passing are paste. Those retained are aggregate. The aggregate should be subdivided, regardless of source, into the large, intermediate, and fine particles with the division at the 3/8-in. and No. 8 sieves.

An analysis of the combined materials should be displayed in charts, tables, and graphs so that the user can assess the characteristics of the mixture before it is batched. The user can be alerted to changes of objective and evaluate the effect of those changes. In the event that undesirable changes have occurred, proportions can be adjusted to closely approximate the desired characteristics.

The screen display and printed report should include the following:

- Mix volume;
- Water/cement ratio;
- Statistical data, if used as the basis for the design;
- Minimum average recommended strength to satisfy statistical design;
- Combined fineness modulus;
- Coarse aggregate as percent of total aggregate;

- Percent mortar;
- Individual, combined aggregate, and total mix gradations;
- Gradation charts for both total mix and combined aggregate;
- Materials distribution charts by sieve size for aggregate and total mix; and
- Wet unit weight.

If the coarseness factor chart is used, the following additional data should be provided:

- Coarseness factor,
- Percentage of the combined aggregate passing the No. 8 sieve,
- Effective minus No. 8 particles adjusted for cement factor, and
- A graphical representation of the chart and the plotted points.

A copy of a report prepared using one commercial program is shown in the Appendix. This report demonstrates how the computer can be used to select proportions using nonstandard aggregates. It is felt that the mixture described would produce excellent results for heavily reinforced, vertically cast elements or 3- to 6-in. flatwork. The proportions for the two fine aggregates were determined by the computer as that blend that would be the closest to the median ASTM C-33 (*6*) grading. The combined grading of the mix shown incorporates more intermediate aggregate than if the mix were produced with two aggregates with gradations complying with ASTM C-33 (*6*) for size 57 stone and concrete sand.

Entries and options for the program are as follows:

Cement Factor. Cement can be determined in accordance with ACI-211 (*5*), ACI-301 (*7*) statistical data, water/cement ratio, or manual entry. Water/cement ratio required for severe environments will override other entries.

Cementitious Admixtures. Fly ash and pulverized slag can be used and calculated as cement replacement, addition, manual entry, or none. Provisions will be made in the next modification for the inclusion of silica fume.

Water. Water can be selected in accordance with the ACI-211 (*5*) tables or manual entry. A reduction from ACI-211 (*5*) can be made based upon the type and effectiveness of the admixture.

Air Entrainment. The entrained air recommended in ACI-211 (*5*) for varying environmental conditions is displayed for the user. Selection of air content is by manual entry.

Coarse Aggregate. Coarse aggregate can be selected based on the ACI-211 (*5*) recommended practice based on dry-rodded unit weight and fineness modulus, percentage of aggregate (not recommended), combined fineness modulus, workability factor for the coarseness factor chart, and percentage of total mixture that is mortar, or manual entry. The manual entry option should be used to make adjustments when undesirable conditions are observed or when analyzing an existing mixture.

Fine Aggregate. Fine aggregate can be selected based on ACI-211 (*5*) recommended practices to produce a given total mixture weight or absolute volume, or by manual entry.

Capability for handling two or more coarse aggregates will be essential for future work. Concrete produced with two sizes of coarse aggregate can be adapted easily to differing needs, produce more consistent results, and afford the opportunity to make the best use of available resources. It is desirable to make provision for blending two fine aggregates. When the user can enter gradations of two differing materials, the computer should calculate (a) the least and most percentages of aggregate No. 1 that can be used to comply with ASTM C-33 (*6*) grading limits, and (b) the percentage of aggregate No. 1 that will produce the closest to the median ASTM C-33 (*6*) sand gradation and that will display that gradation. The user should be able to enter any sand ratio and the computer report the combined gradation.

The next step is to put the program into the concrete production process. The ultimate use of the complete program described will be as a part of dispatch controls and to manage the production of performance concrete. The computer will store the mathematical formula by weight for the desired mixture particle distribution rather than by batch weights.

The database for the materials in process at a plant can be maintained by the producer's quality control organization. Statistical data, cementitious materials, use efficiency, specific gravities, and aggregate gradations will be entered in a database. When a mixture is to be produced, the computer will search the database for the materials in process and calculate the weights of each ingredient. The saturated-surface-dry (SSD) mix weights will be transmitted to the batch controls where adjustments for moisture in the aggregates and size of batch can be made. The concrete will be uniform from day to day regardless of materials variations. The process will take but a few seconds. Concrete will finally be produced as Abrams (*2*) recommended in 1918. The computer has made this process possible.

A good program can serve as an educational tool. Although most of the analytical methods are not new, they have seldom been calculated in the past. When a user sees data day after day, the user soon recognizes the effects on the concrete of variations in materials. Early findings derived from use of one program include

- ASTM C-33 (*6*) grading limits are restricting the use of available natural resources in the 3/8-in. to No. 16 particle sizes. These sizes can be used to produce well-graded concrete mixtures that will facilitate the use of desirable construction practices and assure better durability.
- The method of describing aggregate sizes based upon the maximum allowable particle size does not always describe the character of the mixture that may evolve. An aggregate of 1-in. size may have no material on the 1-in. sieve and only 2 to 3 percent of the combined aggregate on the 3/4-in. sieve while 25 percent or more may be retained on the 1/2-in. sieve. The size identified and the effective size may be entirely different and thereby create a false impression of the effect of aggregate size on engineering properties of a mixture.
- An option should be provided to waive the ASTM C-33 (*6*) grading specifications to allow the concrete producer to blend, by weight, more than two sizes of available materials to provide a combined gradation comparable with that that

would result in the production of dense and durable concrete that will also meet the strength criteria. Subsequent tests of aggregate should verify that the combined gradations are consistent.

- The ASTM C-33 (*6*) grading standards accept the supply of varying aggregate gradations that can create mix problems. The practice of scalping the intermediate aggregate sizes results in gap-graded combined aggregate mixes that cause pumping and slab finishing problems. The practice can also cause an undue amount of larger sizes to be retained on one sieve. It appears that not more than approximately 20 percent of the combined aggregate should be retained on a single sieve but as much as 35 percent has been found.
- The computer can aid in the use of nonstandard materials for the production of good-quality concrete. This will reduce the cost of concrete as well as make better use of available natural resources. Cost reductions of a dollar or more per yard are possible with no sacrifice in quality.

STATISTICAL ANALYSIS BY COMPUTER

The quality of concrete is influenced by many factors. The factors can be classified into two groups: (a) those that can be measured by tests before casting, and (b) those that are production variables unknown to the user. Tests and production data that serve as indicators include slump, entrained air content, mixture temperature, time in transit, and wet weight. The hidden factors include cement, fly ash and admixture chemical variations, aggregate variations, and testing irregularities. No single test provides the information regarding acceptability of a batch.

For simplicity, only two factors at a time may be considered. For example, slump is often related to strength or air content to strength. Both factors are indicators of potential strength but their combined effect is more important. A computer program applying the principles of statistics beyond standard deviation can provide a means to assess the relationship of the combined influences upon the quality of the concrete. It has been calculated that it is possible to produce more than 100,000 tables, charts, trend lines, and distribution curves from a single database using one available program.

Data entry involves responding to questions concerning field data and results of both flexural and compressive strength tests. User options can be selected to identify different conditions. The user options allow test data to be entered in the database from different projects. Each test series entry can be identified as being used in a certain segment of a project, by varying supervisors or by an identified testing agency or inspector. Differing production plants, contractors, and projects can be identified. This feature allows for later examination of the mix as a whole or by influences identified by user code.

The program can report the following:

- Tabular results of all recorded and computer data. Twenty-eight columns of data can be printed. The data entered or calculated can be printed.
- Frequency distribution can be plotted for 12 variables from recorded or calculated data. Where strength is concerned, the age can be identified.
- Time-line charts can be provided for the same 12 variable tests and computed data. It is especially helpful in the time-line graph to indicate the results as moving averages so as to smooth out the line and define trends rather than try to interpret erratic individual results.
- Regression analysis is probably the most important innovation for concrete to come from the program. Bivariate regression analysis can be calculated for any 2 of the 12 items and results can be plotted on X-Y charts for all information in the database. All points and the first and second degree trend lines should be plotted. The trend lines formulas should be provided along with coefficients of correlation and standard errors.

Multiple regression analysis can show the combined effect of multiple factors upon any one factor. The most frequently used comparison is for the influence on strength of slump, entrained air, wet unit weight, mix temperature, water added on the job, and age at time of sampling. Each of these factors partially describes influences that appear related to the water/cement ratio and the ultimate strength of the concrete. The computer can calculate the formula and report the coefficient of correlation and the standard error.

The computer-generated report should include the trend lines, formulas for the calculations, the coefficients of correlation, the standard errors, and the standard deviation for each one of the factors. The user should be able to use the what-if feature with results shown on the screen. Example data can be input to the computer and the report of the projected strength and standard error shown.

The data developed by multiple regression analysis can be used in the field by recording the formula in a hand-held programmable calculator. The technician can input his test data and determine the acceptability of a batch from the formula and the standard error. The practice used today is to make judgment upon each individual test procedure. Good concrete is being rejected and undesirable concrete is being accepted.

For example, a concrete cast with a 6-in. slump after 90 min of mixing at a mix temperature of 90° F will not produce the same results as when the mix temperature is 50°. Because the hydration process is slowed at the cooler temperature, why should that mix be rejected in 91 min? The answer is, "Because that's the specification requirement." A better specification would be one based upon multiple regression data gained from experience rather than an arbitrary written statement. The two mixtures might produce the same results when the age of the former is 62 min and that of the latter is 128 min.

Based upon results of data evaluated, there is little correlation between slump and compressive strength. In the majority of cases, the coefficient of correlation is less than 0.40. That level of correlation is judged in math texts to be very small to negligible. Figures 2-7 represent data from a major structure for which over 200 tests were made of the mixture described here. The supplier, contractor, and testing agency are highly respected organizations.

Figures 2-5 show the relationship of strength to slump, entrained air, mix temperature, and age after water is added to the cement. Correlation is poor, standard errors are high, and the correlation between entrained air and strength is better than that for slump and strength. It is felt that the standard error describes variables that are unknown to the user. Figure 6 is the multiple regression analysis of all four of the tests. Correlation is somewhat better but the standard error is still large.

Figure 7 shows the relationship between 7-day strengths and 7-day strengths as a percentage of 28-day strengths. The coefficient of correlation is relatively large. The finding was that 7-day strength as a constant percentage of 28-day strength is not valid. The trend shown in Figure 7 has been

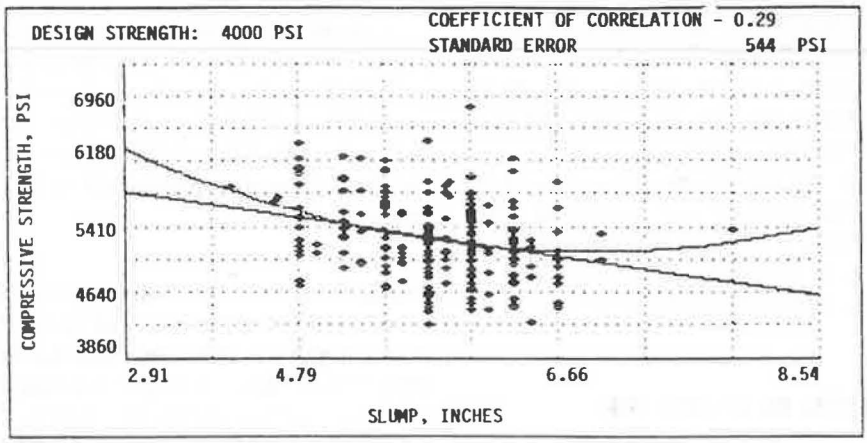

FIGURE 2 Regression analysis showing relationship between slump and strength.

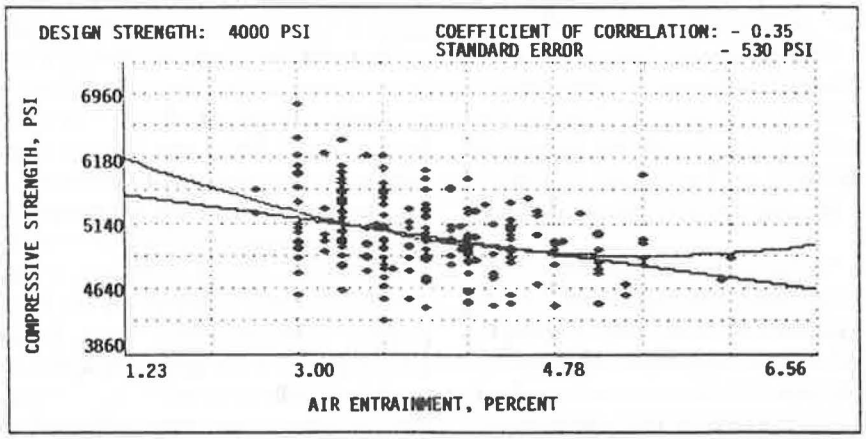

FIGURE 3 Regression analysis showing relationship between entrained air and compressive strength.

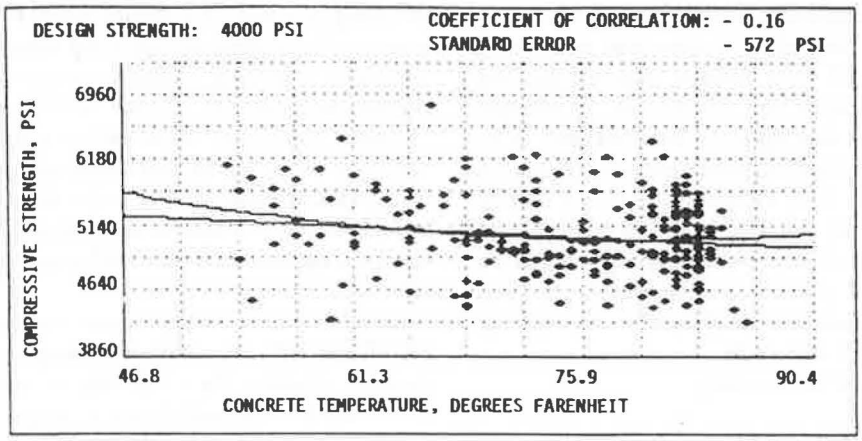

FIGURE 4 Regression analysis showing relationship between concrete mix temperature and compressive strength.

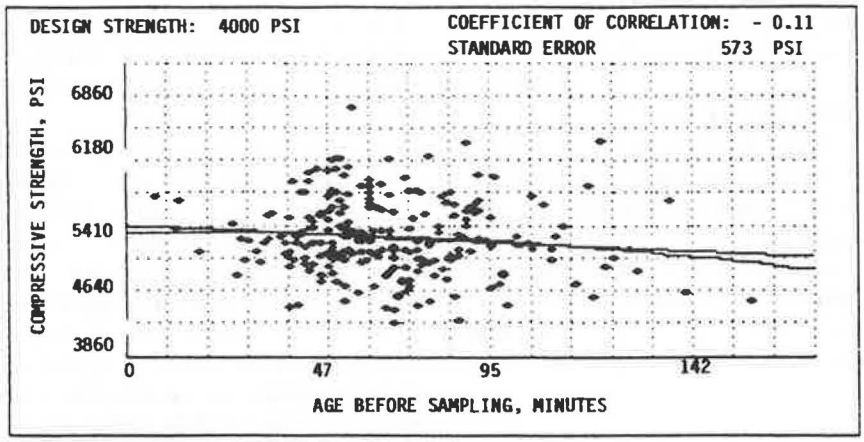

FIGURE 5 Regression analysis showing relationship between mixing time in transit and compressive strength.

REGRESSION ANALYSIS [Y = B0 + (B1 x X1) + . . . (Bn x Bx)]

Number of Tests = 205 Standard Deviation = 563

						Correlation
Y	=	28 Day Comp				
			B0	=	8366.485067	
X1	=	Slump	B1	=	-213.323579	0.27
X2	=	Concrete Temperature	B2	=	-10.010686	0.13
X3	=	Air Entrainment	B3	=	-201.796902	0.35
X4	=	Age Before Sampling	B4	=	-4.759930	0.11

Standard Error of Estimate = 486.463780
Coefficient of Correlation = 0.518236

FIGURE 6 Multiple regression analysis showing combined relationship between slump, air, mix temperature, and mixing time on strength.

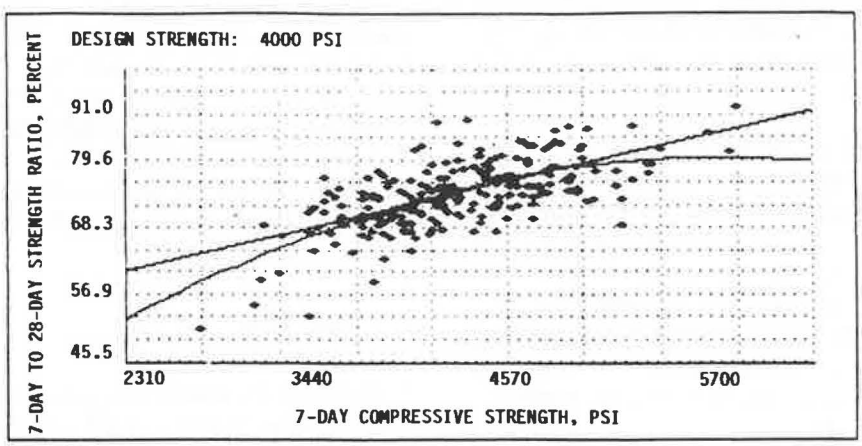

FIGURE 7 Regression analysis showing relationship between 7-day and 7-day as a fraction of 28-day strength.

confirmed on the basis of extensive data from three projects. Each project involved coarse aggregate with different geological characteristics composed of granite, gravel, and limestone.

THE RESULTS

Computer-based statistics will change the way the industry evaluates concrete. Though lines have been established for relationships between mixing time, slump, air content, and other factors, these are individually relatively unimportant. The program value lies in its ability to interrelate the combined test results and define the degree of value of each factor.

Many of the variations from theory of the relationship of tests to results are due to variations in aggregate gradations. As the aggregate gradings change, water demand changes to produce a constant slump and it, in turn, causes variations in air content. Construction is adversely affected by variations in concrete mixture characteristics. Computer control of

concrete production can help producers cope with the variations in aggregate gradings and produce consistent concrete.

If the quality and uniformity of concrete are to be improved, there must be changes in the way that it is currently produced and monitored. There are two options: (a) provide better controls at the points of production of concrete mix ingredients (e.g., tighter aggregate gradation restrictions or limitations in ranges of sizes), or (b) provide improved means of making adjustments at the point of concrete production to cope with the variables. The variables are so complex that it is impossible to calculate timely adjustments without the aid of a computer.

WHAT MANAGING CONCRETE BY COMPUTER CAN DO FOR THE INDUSTRY

It was claimed at the onset that computer programs will impact on eight major areas. The following is how this will be done:

1. The mix management program will provide an accurate and rapid method for selecting, evaluating, and adjusting concrete mixture proportions because it targets the combined materials in the cubic yard of concrete and manages available materials to produce the desired objectives.
2. Strength and slump should no longer be considered the sole basis for establishing mixture characteristics. For example, mix characteristics should be different for a 4,000-psi mass concrete footing and a 4,000-psi pan joist slab with a 2-in. deck. The difference is more than maximum aggregate size. The user can quantify the mortar needs for varying construction processes and put an end to disputes relative to mixture workability.
3. It will be possible to use multiple and nonstandard aggregates. The computer calculated combined gradations and particle distribution charts that can be studied and used to determine the effect of the combined aggregate on workability and performance. The ability to review the characteristics before production makes it possible to more efficiently utilize aggregate resources and aid in the recognition of the effects of differing gradations and particle shapes. The use of nonstandard aggregate can ensure the most efficient use of the natural resources.
4. Uniform concrete can be produced by adjusting ingredient proportions when variations occur. The statistical data ensure the most economical use of the cementitious materials. The computer programs can take a giant step towards the production of true-performance concrete.
5. The statistical program provides data that can be used to better understand the combined effect of field tests upon the performance of concrete. The results of multiple field tests and batch records can be used by individual inspectors to make judgments of batch acceptability. The ultimate effect will be an improved procedure for forecasting strength.
6. Mathematics skills of new entrants to the concrete technology field are sometimes low. There are three options: (a) Keep everything simple so mathematics is not necessary, but accept the fact that the concrete quality will not be as consistent as desirable. (b) Conduct mathematics classes for new entrants into the industry. (c) Show new entrants how to use a computer and programmable calculator that contain more mathematics than most would learn and use during their work. Even if mathematics were taught, it would take too long to do by other than a computer.
7. The computer can be used to teach mix and materials technology. Education in concrete technology, even at the university level, is limited in scope and modern technology. It is often restricted to the casting and testing of trial mixtures plus an overview of the antiquated ACI-211 (*5*) procedure, which dates back to 1938. Computer programs can be used to graphically show the students the difference between mixtures that have proven excellent and those that have caused problems. Later they will be able to evaluate profiles.
8. Communication within the concrete industry is difficult. When concrete mixtures are better understood and all parties speak the same language after undergoing similar training, there will be communication, and slump will not have to be discussed. When a contractor knows his construction needs and calls for a mixture with a certain mortar factor, the concrete producer will be able to translate that into a product and the engineer will know why that mortar factor is necessary. Should there be a significant adjustment in fine aggregate content and more water needed, the mixture could be adjusted in seconds to maintain the water/cement ratio constant.

Advantages can be enjoyed by engineers, contractors, and concrete producers. Each has a major stake in concrete construction. Because of their lack of knowledge in the science of concrete mixtures, they have left responsibilities for selecting proportions to others who may not know their needs beyond strength. Now there are tools for them to use.

It is time for the concrete industry to turn to the computer. With it, costs can be reduced and a better product will be produced.

ACKNOWLEDGMENTS

The two programs used for illustrative purposes were seeMIX for mix management and seeSTAT for statistics. Both were developed to meet consulting needs by Shilstone & Associates but were sold to and expanded by Shilstone Software Co., 8577 Manderville Ln., Dallas, Tex. 75231, for commercial distribution. To the best of the author's knowledge, seeMIX is unique. Based upon studies of literature, the closest program to seeSTAT in data generated is by Questar Software, 3600 N. 19th Ave., Phoenix, Ariz. 85015; the package uses a spreadsheet format.

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APPENDIX

SHILSTONE & ASSOCIATES, INC.

8577 MANDERVILLE RD. DALLAS, TEXAS 75231-1001 214/361-9681

CONCRETE MIX DESIGN

TRIAL 1 [1] 650 PSI 01/04/88

CONTRACTOR : FAST TRACK PAVERS, INC.
PROJECT : DEMONSTRATION
SOURCE OF CONCRETE : SITE PRODUCTION, INC.
CONSTRUCTION TYPE : STRUCTURES
PLACEMENT : BUCKET

WEIGHTS PER CUBIC YARD (SATURATED, SURFACE-DRY)

		YIELD, CU FT
Excellent Portland Inc, ASTM C-150, II, LB	558	2.84
My Plant Power, ASTM C 686 Type F, LB	19	0.12
Silica Fume, LB	30	0.21
Natural Sand Inc., ASTM C-33, LB	899	5.46
Crushed Stone Co., ASTM C-33 Size 4, LB	258	1.57
Crushed Stone Co., ASTM C-33, Size 5, LB	792	4.88
Crushed Stone Co., ASTM C-33, Size 6 -, LB	738	4.58
Natural Gravel Co., ASTM C-33, Size 8 -, LB	247	1.49
WATER, LB (GAL-US)	290 (34.7)	4.64
AIR ENTRAINMENT, %	4.5 +/- 1.5	1.22
	TOTAL	27.00
Chemical Co. ASTM C-494, OZ-US	24.3	
Air Plus, Co., ASTM c-260, OZ-US	3.0	
WATER/CEMENT RATIO, LBS/LB	0.48	
SLUMP, IN	4.00	
CONCRETE UNIT WEIGHT, PCF	141.9	

This is a demonstration program. Note 4 coarse and 1 fine aggregate are used. Observe aggregate trend line is generally straight and particles (last chart) are fairly uniformly distributed. Lines in last two charts were drawn by hand.

PREPARED BY :

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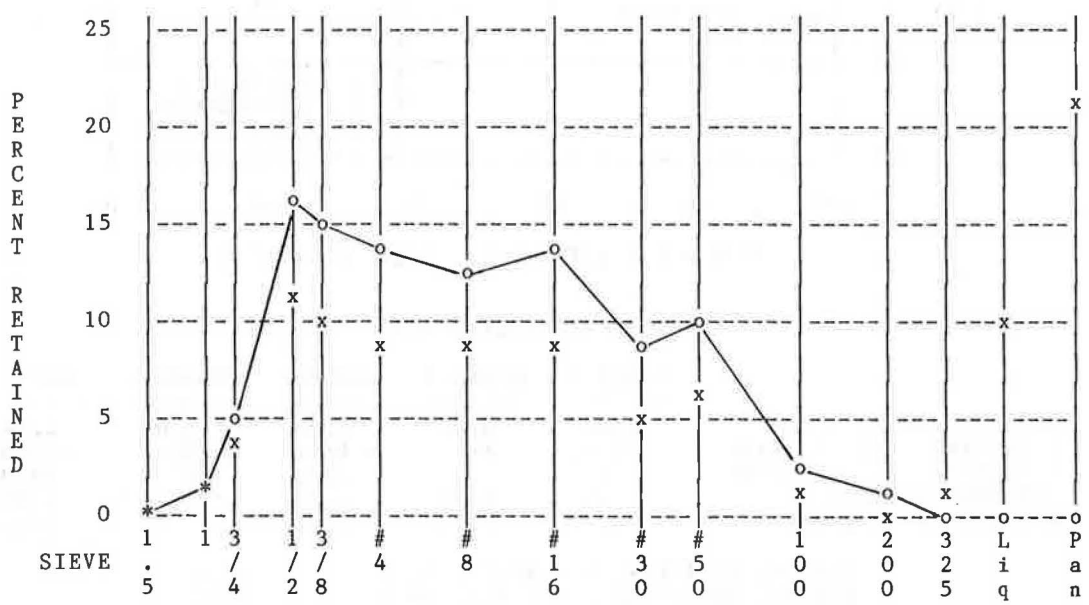
Quality Control Supervisor

Demonstration Mix - Trial 1

MATERIALS DISTRIBUTION

SIEVE	STONE 1	STONE 2	STONE 3	STONE 4	SAND	PASTE	TOTAL	AGGR
1-1/2 "	100.0	100.0	100.0	100.0			0.0	0.0
1 "	85.0	98.0	100.0	100.0			1.2	1.8
3/4 "	50.0	90.0	100.0	100.0			3.5	5.2
1/2 "	23.0	46.0	90.0	100.0			11.2	16.8
3/8 "	5.0	19.0	68.0	90.0	100.0		10.2	15.3
# 4	-	6.0	40.0	69.0	99.0		8.8	13.1
# 8	-	-	21.0	30.0	89.0		8.5	12.7
# 16	-	-	5.0	4.0	65.0		9.0	13.5
# 30	-	-	-	-	43.0		5.5	8.3
# 50	-	-	-	-	12.0		6.3	9.4
# 100	-	-	-	-	3.0		1.8	2.7
# 200	-	-	-	-	0.5	100.0	0.5	0.8
# 325	-	-	-	-	-	95.1	1.7	0.2
Liquid	-	-	-	-	-	65.0	10.1	-

MATERIALS DISTRIBUTION CHART BY SIEVE

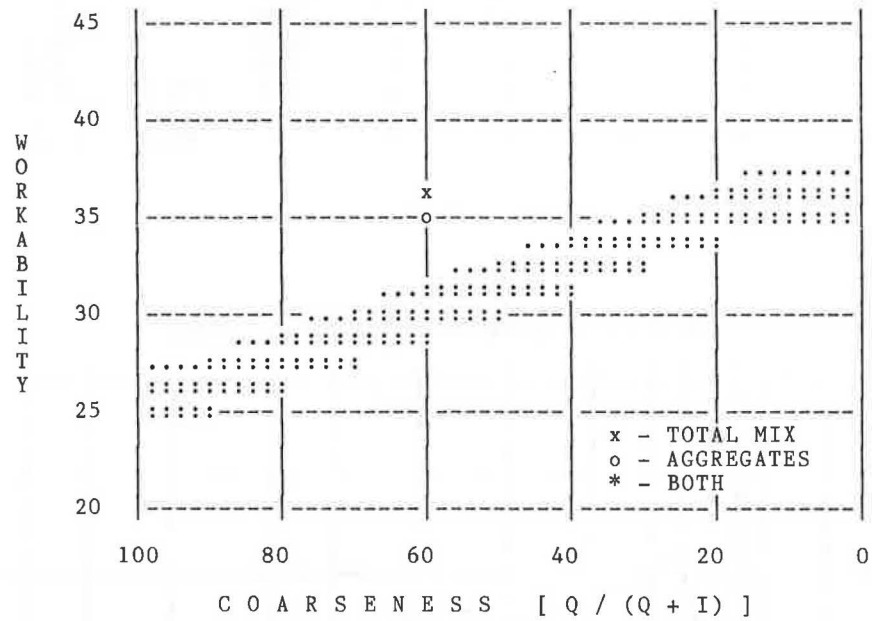


x - ALL COMPONENTS o - AGGREGATES * - BOTH

Demonstration Mix - Trial 1

MIX ANALYSIS

MIX VOLUME, CU FT	27.00
COARSENESS (Q / (Q + I))	60.3
WORKABILITY	34.9
W - ADJUST	36.0
PERCENT MORTAR	56.6
TOTAL FINENESS MODULUS	5.25



MIX CHARACTERISTICS

	STONE 1	STONE 2	STONE 3	STONE 4	SAND
DENSITY, SP G	2.64	2.60	2.58	2.66	2.64
% PASSING 3/8 " SIEVE	5.0	19.0	68.0	90.0	100.0
% PASSING # 8 SIEVE	-	-	21.0	30.0	89.0
FINENESS MODULUS	7.45	6.85	5.66	5.07	2.89
PERCENT OF AGGREGATE	8.7	27.2	25.5	8.3	30.4

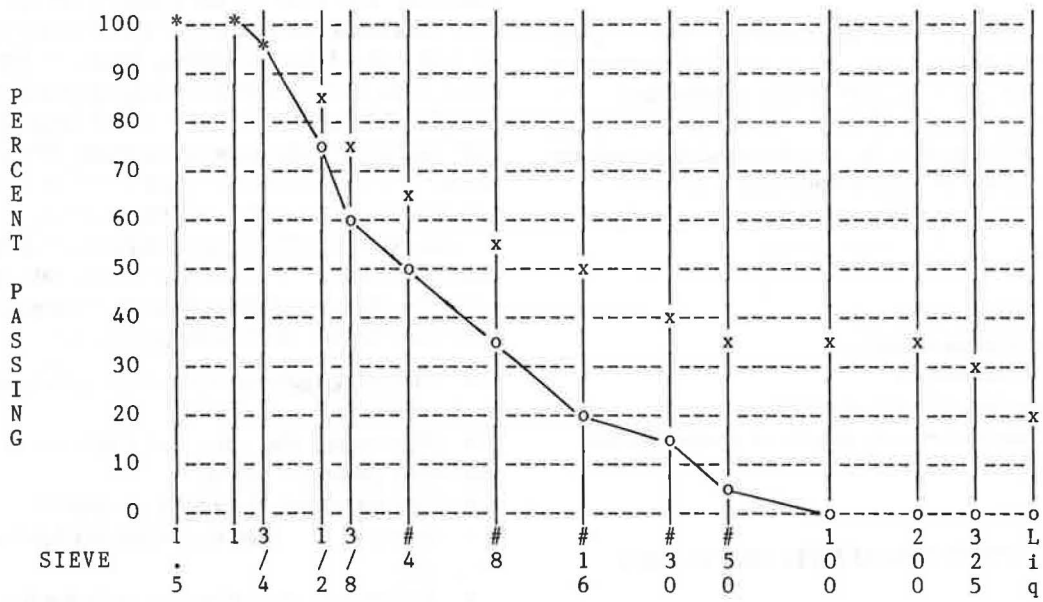
MINERAL ADMIXTURE 1 DENSITY, SP G	2.60
MINERAL ADMIXTURE 2 DENSITY, SP G	2.33

Demonstration Mix - Trial 1

FULL GRADATION ANALYSIS

SIEVE	STONE 1	STONE 2	STONE 3	STONE 4	SAND	PASTE	TOTAL	AGGR
1-1/2 "	100.0	100.0	100.0	100.0			100.0	100.0
1 "	85.0	98.0	100.0	100.0			98.8	98.2
3/4 "	50.0	90.0	100.0	100.0			95.3	92.9
1/2 "	23.0	46.0	90.0	100.0			84.1	76.1
3/8 "	5.0	19.0	68.0	90.0	100.0		73.9	60.7
# 4	-	6.0	40.0	69.0	99.0		65.1	47.6
# 8	-	-	21.0	30.0	89.0		56.6	34.9
# 16	-	-	5.0	4.0	65.0		47.6	21.3
# 30	-	-	-	-	43.0		42.1	13.1
# 50	-	-	-	-	12.0		35.8	3.6
# 100	-	-	-	-	3.0		34.0	0.9
# 200	-	-	-	-	0.5	100.0	33.5	0.2
# 325	-	-	-	-	-	95.1	31.8	-
Liquid	-	-	-	-	-	65.0	21.7	-

GRADATION CHART



x - ALL COMPONENTS o - AGGREGATES * - BOTH