Quality Management for Concrete Pavement Under Performance Standards

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Alternative methods are being researched to develop ways to replace traditional highway contracting practices with performance standards. This will force major changes in both agency and contractor responsibilities for construction planning and quality management. Engineering formulas can be used to calculate structural solutions. These formulas do not resolve durability needs. There is no accepted means to define, in measurable terms, the characteristics of a concrete pavement that will be durable in typical highway environments. Methods are described whereby existing pavements with excellent and poor performance histories may be surveyed and used to define "durable concrete" and act as the basis for performance standards for durability. The methods for specifying, controlling, and verifying construction to meet the desired durability objectives are outlined.

The term "quality" is often discussed, universally supported, and everyone's acclaimed policy. "Quality" has become an idealized subject like motherhood, clean water, and zero pollution.

However, the Business Roundtable Construction Industry Cost Effectiveness Project Committee report opened with the statement, "By common consensus and every available measure, the United States no longer gets its money's worth in construction, the nation's largest industry." This appraisal was later echoed in the National Research Council report on the highway system (*1*). These findings reflect the failure of the traditional design-construction-inspection process to produce quality projects.

Two of the most respected leaders in the quality movement are W. Edwards Deming and Philip Crosby, but each defines quality in different terms. Deming describes it as "customer satisfaction," whereas Crosby refers to "conformance." The objectives are identical but each speaks to a different point in the chain of raw materials to the consumer. Deming speaks of the gap from manufacturer-supplier to buyer. Crosby addresses the subject from the worker with his tools to the product as designed.

Although zero defects (and assurance of quality) is a good objective, it is not realistic. During the 1983 National Conference on Quality Assurance in the Building Community, Geoffrey Fhronsdorff of the National Institute of Science and Technology described the Battelle Memorial Institute report of early product failures described as "fractures." The objective was to develop a correlation between "cost of prevention" and "cost of fracture."

It was reported that, for a nominal expenditure, 28 percent of unacceptable levels of quality can be prevented. For a higher cost, an additional 35 percent can be prevented. The remaining 37 percent can seldom be prevented regardless of the expenditure. Current state-of-the-art design and construction are not sufficiently advanced to cope with all problems, human errors, and technical factors that do not interface properly.

One problem is the terminology. The expression "quality assurance" creates a false impression of what is to be provided. By definition "assurance" means "the act of assuring; the state of being sure or certain." The only factors of which we can be assured are death and taxes. Even the high-level quality assurance program used in the U.S. space industry failed for one of the missions. How can the construction industry expect better success using its traditional practices?

A rational alternative term is "quality management." The responsibilities for management are well understood: someone is responsible for supervising and directing the work. "Quality management" is defined as all systems and methods needed to produce a product that will meet the assigned criteria with a predetermined degree of reliability. For highways that responsibility starts with the design engineer. A contractor cannot cast a high-quality pavement following a poorly conceived design or antiquated specifications.

Darrell W. Harp, Assistant Commissioner for the Office of Legal Affairs of the New York State Department of Transportation, said of this system:

> The contractor can't use his own initiative because he has little option when he is told precisely what he must do, what type of materials he must incorporate and exactly how it is to be put in place. Innovation is stymied. Another drawback is that the improvement of the product will be very slight and it is doubtful that you will see a reduction in overall cost. If we were to live forever with materials and methods specifications, I suppose we would still be driving around in Model 'Ts'. (*2*)

DEFINING THE PROBLEM

During the In Search of Excellence Conference in Hawaii, Damian Kulash identified three steps to quality:

1. Define what we mean,
2. Choose effective ways, and
3. Convince everyone of what is wanted and how to do it.

Once the first step has been accomplished, the second step can follow. Solutions to the third step will be difficult because it involves a paradigm shift requiring that old ways give way to the new. If a different result is wanted, something different must be done. The change will not be as difficult as some

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might believe, but all change is frightening and met with opposition. That is a problem of major proportions for the highway industry. One of the hurdles will be political leverage that may not be in the best interests of the driving, taxpaying public.

This paper provides a solution to the first two steps. Yogi Berra put Kulash's first step in a simpler way when he said, "If you don't know where you're goin', you might end up some place else." Despite decades of highway construction, there is no means to quantify, in technical terms, the characteristics of a durable concrete pavement. Millions of dollars are being spent to figure out how to design something that cannot be defined. Good design formulas do not ensure that a durable pavement will be put in place. More knowledge of how materials interface and how to cast a pavement to produce a dense, durable composite is needed rather than more design formulas.

In FHWA Publication FHWA/RD-87/095 on the relationship between concrete consolidation and performance, the summary includes the following statement:

> A concrete pavement is a manufactured item. Therefore, it is necessary to ensure that quality control is exercised at all critical phases of production. Presently, quality control specifications exist to assure a quality product through all phases of construction up to delivery of concrete at a site. However, there are no direct specifications available to monitor concrete quality after the concrete is placed in front of the paver. (*3*)

Quality of the constructed project, in terms of both strength for loads and durability for the environment, must be defined in measurable terms. Engineering design formulas provide solutions for structural needs but not for durability. Concrete pavements that meet design criteria for thickness and strength may not be durable or produce a smooth ride. Therefore, good design must include both good engineering design and sound technology.

Today construction is controlled on the basis of input with the expectation that output will be consistent. The paving industry buys sand, stone, cement, asphalt, steel, and other products that have broad producer-oriented tolerances. The result is cumulatively variable based on the effects of the tolerances. It is like expecting the sum of 16 + 22 + 12 to produce a total of 50. Actually the sum can vary between 41 and 59 when each of the factors is allowed to function within variables such as $16\ (\pm 3) + 22\ (\pm 4) + 12\ (\pm 2)$. This is what happens with most building materials. Acceptance of the broad tolerances allowed for input items ensures variable output.

The quality management concept suggests that control be based on recognition of output objectives and that adjustments be made as materials vary during production to deliver the desired quality. In simpler terms, become performance oriented and manage the production to produce the desired results. This was the policy followed by highway department project engineers years ago when bidding was by line item. The engineer monitored progress and directed changes in midcourse to produce the intended result.

DEFINING THE QUALITY STANDARD

The quality process involves determining the desired qualities of the constructed project, translating those qualities into measurable terms, and managing the work to produce those qualities.

Like beauty, quality is measured in the eyes of the beholder. Three major groups are interested in the quality decision: the public, the agency-engineer-inspector, and the contractor and his suppliers. Each looks upon quality in different terms. Once the quality objectives of each are understood, a plan can be developed to pay the bill for and produce the needed quality.

- The public wants personal comfort, minimal interference with their lives, and low cost. These do not translate to mathematical formulas. Although low initial cost is always of concern, long-term durability is also important. If the work is not durable, the repairs interfere with traffic and raise taxes. Therefore, the engineer-agency's customer is the driving public who wants a better ride, flat pavements, and no roller coasters. The public measures quality by comfort and durability—that is Deming's "customer satisfaction."
- The engineer is responsible for planning the public's measure of quality. The problem is that an engineer thinks in terms of mathematical formulas. On the basis of tests and theories, the engineer calculates loads and loading cycles and comes up with a solution to satisfy the public. Then bid documents are prepared that describe everything and how to do it in engineering terms. Often high, costly safety factors are used to overcome what is perceived to be poor potential execution of the work. Physical tests are made to verify only a minimal level of ingredient quality. To the engineer, quality is measured by numbers.
- Finally, contractors and suppliers must follow Crosby's objective for conformance but are forced by the bidding process to make price-oriented decisions. They bid the least cost to meet the minimum requirements of the contract. If they bid to provide solutions that meet the engineer's and the public's intent, they are not competitive. Therefore, the construction team measures quality by conformance at the least cost.

Failure in the quality system derives from these divergent means of measuring quality. The conflict is among the public's desire for personal comfort, the engineer's love for numbers, and the contractor's concern for dollars. The actual bottom line is dollars, although that does not always contribute to customer satisfaction for the taxpaying public.

If there are problems on a project and resolution is through litigation, the contractor generally prevails. Contractors are protected by the 1918 U.S. Supreme Court decision *U.S. versus Spearin*, under which an owner warrants that the plans and specifications will achieve the results intended. The contractor is not bound to use the most desirable of all the options and can do anything within the limits of the contract. If the contract specifies tolerances that can be combined to produce an unacceptable product, the owner—not the contractor—is responsible.

Until recently highway departments, and civil engineers in general, worked by line item for bidding and construction. They controlled quality by making adjustments in the field to meet their objectives. That system has been changed to one of hard dollar bids. Despite the change, the department of transportation manuals are essentially the same for materials and provide broad, often politically motivated tolerances. The construction engineer no longer has the power to require adjustments to control the process and guide the work to produce the intended quality. The contractor can use the worst of all combinations, and the public is forced to accept the results. The fault does not lie with the contractor, who is forced by the low bid practice to survive in the price jungle.

INNOVATIVE CONTRACTING AND PERFORMANCE STANDARDS

TRB's Task Force on Innovative Contracting Practices has been evaluating ways to overcome past problems and meet the needs of the future. One of the major problems facing the agencies is the reduction in personnel. Figure 1 is an FHWA graphic representing the projected relationship between federally funded projects and available agency personnel based upon assumptions that the 1991 highway act would be passed as originally planned. Clearly shortages in personnel will make it impossible in the future for agencies to control work in the same manner as they do today.

There is no question that agencies are losing many of their most experienced personnel. Most replacements have had little training in basics, much less innovations in materials technology. A state concrete engineer who was to retire within 2 years said, "You must remember I am a product of my agency. I have worked here 30 years and been taught only to follow the Manual. I don't know any technology other than what I was told by the department." An interested, younger man was assigned as his replacement but was reassigned after several years because he was performing well and he could fill an immediate need. There is no qualified replacement for that concrete engineer, although he will retire this year. How will someone be able to take his place?

Many officials also admit that a major objective is to develop a program to prevent agencies from losing so many claims. Obviously alternative contracting and quality management practices must instituted.

DEFINING OBJECTIVES

It will not be a complex task to determine the characteristics of a good concrete pavement. There is no need for laboratory research to reinvent good concrete. Hundreds of miles of highways are performing extremely well. Some have been in place up to 100 years. What is known about why they have done well? There are also hundreds of miles that are deteriorating at a faster rate than that expected. These two extremes are ideal research specimens. They have been affected by the real-world conditions. No accelerated, artificial laboratory tests are needed. The in-place construction is there to be examined for clues as to what made each perform as it did.

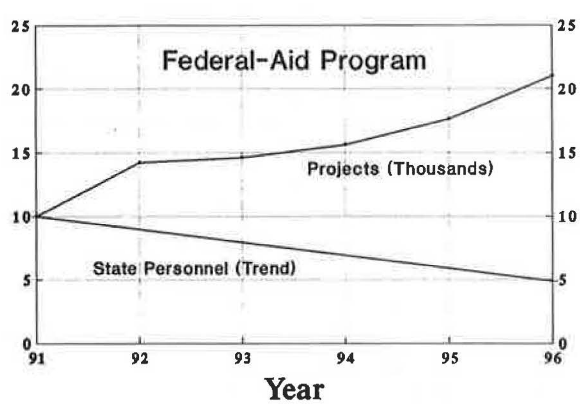

FIGURE 1 FHWA projected relationship of federally funded projects and available public agency personnel under the proposed 1991 highway bill.

The investigators should be technologists who understand the concrete process. They need know little about engineering design formulas but much about concrete-making materials and the concrete construction process. They will have to correlate the effects of materials, mixtures, placement practices, consolidation, curing, and testing with performance. Textbooks do not explain the problem. The investigators must have inquisitive minds and be ready to report that some of the highly respected books written 40 years ago do not necessarily relate to today's materials and needs.

Concrete forensic engineers with whom I have discussed this approach say that it is innovative. The senior petrographer for a major federal agency said that in his many years of work with that agency, he had been asked on only one occasion to find out why a certain concrete performed well, yet he had studied thousands of failures. The profession is conscious of failures but takes little time to study and accentuate quality.

The study program should proceed as described in the following sections.

Identification of Subject Pavements and Background Material

Identify old and new, good and bad pavements and assemble records about each. If available, include mixture proportions, adjustments, mixer types, placement methods, consolidation equipment and methods, reinforcing details, joint details, finishing methods, curing, and climatological conditions at the time of casting.

Specific information—not just reference to compliance with a standard—is needed. Contract documents may be helpful, but they do not provide the detail needed. Assumptions will have to be made for very old projects. Retired personnel and old documents might provide needed background. Investigators must persevere in their search for project information and the practices of the time.

Surface Study

Perform a surface study of the selected projects and observe and record overall and detailed conditions. Identify deterioration that may be based upon engineering design, excessive loading cycles, or base failures. These should not be allowed to interfere with the study of the concrete portion.

The study should reflect the occurrence of scaling, D-cracking, carbonation cracking, aggregate reactivity, abrasion, erosion, or other concrete deterioration. Special attention should be given to variations in measurable qualities of work done under the same contract. Investigators must be prepared to ask such questions as whether concrete permeability was high or low where D-cracking occurred. This can possibly be answered by finding portions of a pavement where the same materials were used but one did not show D-cracking.

Photograph area and typical surface conditions. The surface details should be shown within an 8-in. (±) square framed by a grid cut in grey card stock with 3/8-in. hatch marks around the edge. Figure 2 shows the setup used in a study for the city of Dallas.

Figure 3 is a closeup of a 1922 cast pavement still in service. It has a high density on the surface of particles passing the 3/8-in. and retained on the No. 16 sieve. That aggregate distribution appears to be in conformance with ASTM C 33 and the Portland Cement Association (PCA) recommendations of the period. The 1923 issue of ASTM C 33 required that the sand consist primarily of coarse particles. *Design and Control of Concrete,* Issue 1, recommended that only 65 percent of the fine aggregate be allowed to pass the No. 8 sieve.

The American Concrete Institute reports from Committee 201, Guide to Durable Concrete (*4*), and 210, Erosion of Concrete (*5*), cite the need for the intermediate aggregate particles to minimize abrasion and erosion. Intermediate-sized particles have other beneficial effects on the concrete, such as improvement in rheology during placement, resulting in increased density and decreased permeability.

Figure 4 shows a new pavement that was wearing rapidly. The gap between the 1/2-in. particles and the mortar is distinct. The aggregate gradation is acceptable under current standards. The 1989 ASTM C 33 gradations provide for coarser coarse aggregate and finer sand. Gap grading of aggregates appears to contribute to durability problems in many ways.

Correlation of Data and Definition of Pattern

Correlate data and photographs from the projects studied and attempt to define a pattern from the study. In most cases, trends will be found during the detailed examination. Data can help identify the causes of performance differences. From that study, representative locations should be selected for physical testing and petrographic study.

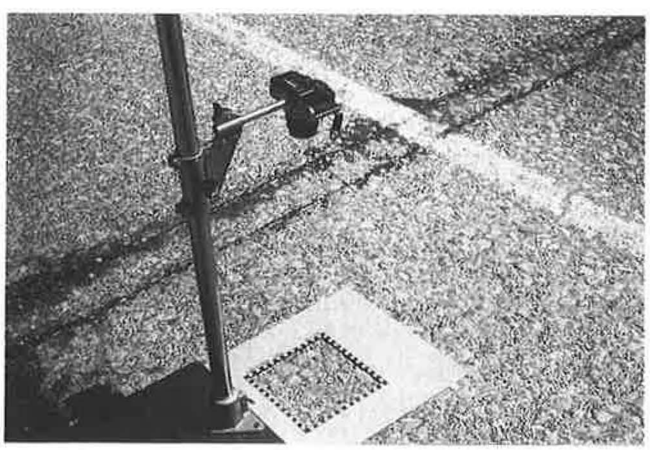

FIGURE 2 Photographic setup for Dallas study.

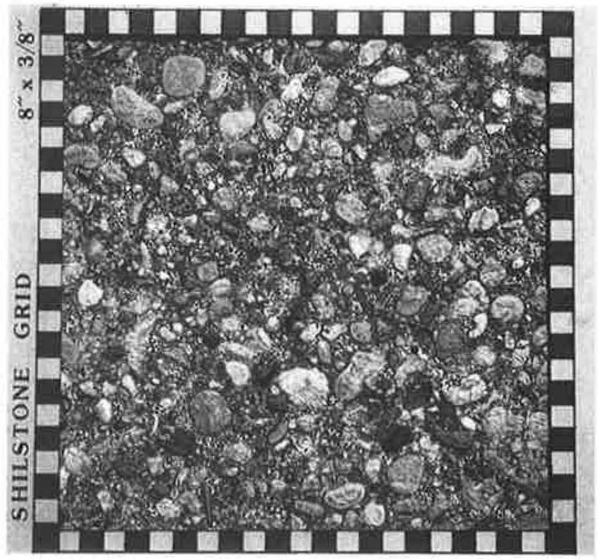

FIGURE 3 1922 cast concrete pavement with high aggregate density.

Physical Testing

At each selected sample site, drill parallel holes and use a nuclear density gauge similar to Troxler 2376 (see Figure 5) to measure variations in pavement density from the bottom to the top at 1-in. intervals. Cut 8-in.-diameter cores between the drilled holes to include the concrete evaluated by the nuclear gauge.

Take sufficient 4-in. or 6-in. cores to make physical tests, tests of permeability by the boil or chloride penetration method, and petrographic studies.

Examine the base under the core location to assess its potential effect upon the concrete condition.

Cut the 8-in. core into 1-in. (±) plates and evaluate each plate petrographically and by other means to determine variations in permeability, relative density, and trapped and entrained air.

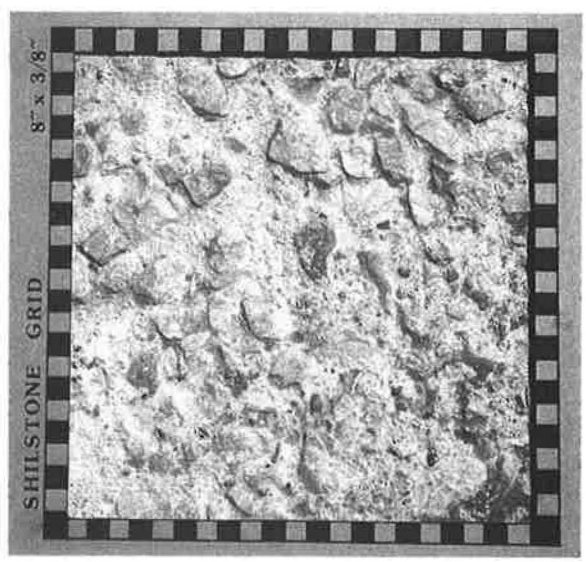

FIGURE 4 Poorly performing gap-graded mixture.

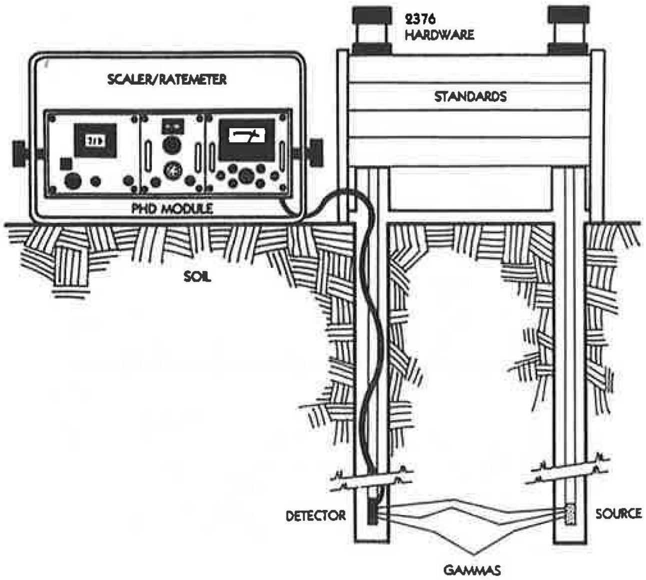

FIGURE 5 Nuclear gauge to measure variations in relative density.

Determine compressive strength, split core strength, and permeability for the other cores. Figure 6 is a regression analysis comparing permeability and compressive strength of companion cores from the Dallas study. The pavements with data in the upper left quadrant are performing well. Those in the lower right quadrant are performing poorly. Those in the other two quadrants have special features to overcome deficiencies in one of the measured results.

Petrographic Studies

Perform petrographic studies of some of the cores, not only to assess the quality of the paste and mortar, but also to identify reactive aggregates that may have contributed to problems. Describe the aggregate particle shape, texture, and distribution by individual sieve sizes to determine the combined gradation. Describe the aggregate distribution by particle size, not just as "coarse" and "fine." The extremes will

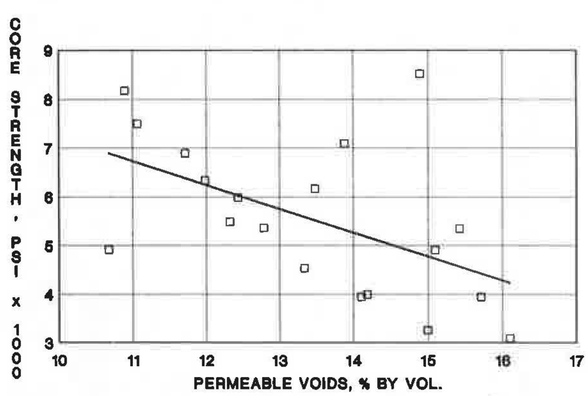

FIGURE 6 Regression analysis: permeability versus core strength.

be (a) those that are well graded with dense distribution and (b) those with a high incidence of one or two coarse aggregate particle sizes and fine mortar.

Analysis and Report

Analyze and report the data. The report should provide a picture of the difference between the good and the poorly performing pavements. It is anticipated that the following factors will be found to influence performance:

1. Relative density difference between the top and bottom of the cores, with the lower density on the bottom. It is anticipated that uniform, high-density concrete will perform better.
2. Permeability will play a significant part in the durability, especially where water penetration has contributed to D-cracking or sulfate problems.
3. The balance between large (trapped) and small (entrained) air will be influenced by aggregate shape and the amount of coarse aggregate in the mixture.
4. Freeze-thaw resistance will be improved by both the relative density of the concrete and the type of air. It is expected that pavement with lower than normally specified air content will perform well. This will be accentuated in concrete cast before air entrainment was used. A lesser amount of purposely entrained air with a low spacing factor will assure better durability than will a large amount of trapped air.
5. Well-graded mixtures perform better than gap-graded mixtures. The high incidence of ⅜-in. to No. 16 particles helps block capillary pores and improve abrasion resistance.

PERFORMANCE SPECIFICATION

On the basis of the research, specifications should be developed that describe the performance required (*6*). They should be brief and results oriented and avoid defining how the contractor should do the work. Current state manuals should not be referenced. It is not possible to change results while keeping the recipe the same.

The contractor's responsibility for quality management must be defined. Only the organization performing the work can control the quality. That function must include in-process controls and in-place verification of hardened concrete quality. The contractor should be required to plan and organize the construction process using technical skills to assemble materials, equipment, and labor in compliance with the performance standards. This planning will ensure that primary attention is given to results, rather than resources.

The contractor should not have to labor under the constraints of prescriptive requirements but should have the maximum latitude to produce the pavement at the lowest cost.

The following performance objectives can be used as a guide for details to be covered in the performance specification:

Engineering: strength, thickness, and jointing;
Construction: compacted density, surface texture, and ride;

Durability: entrained air; sulfate resistance, D-crack controls, or both; abrasion or erosion resistance, or both; and permeability limits;

Quality: responsibilities, planning, materials, equipment, methods, personnel, and control practices;

Other: incentives and disincentives;

Verification: owner methods.

The tendency to revert to traditional methods must be avoided. The fewer words, the better. If the document describes "how," it is not a performance document. It must describe "what" as an end product, but not its components. For example, the qualities of potentially reactive aggregates can be described for durability, but stockpile gradation must defer to combined gradation in the mixture if that is found to be a key to performance.

Incentives and disincentives are important for success. The past practice has been to assess penalties and give no credit for higher quality, even though that quality may extend pavement life. There are many examples in which the lack of provision for incentives costs the taxpayer benefits. The following is an example.

A new technology allowed a contractor to increase flexural strength by more than 150 psi. Since he was paid for only the lower strength and a cement factor was not specified, he reduced the cement content by 50 lb to save about $1.50/yd^2. The added strength could have extended the life of the pavement because of the lower water-cement ratio. The higher quality was of more importance than the $1.50/yd^2 that the contractor saved. The taxpayer is the loser.

Some might respond to this by advocating the specification of a high cement factor, "to be safe." This can be counterproductive. The contractor has no incentive to produce a strength higher than that specified. He can use more sand (which is often cheaper) and still meet strength. High-sand mixtures require more water. Durability is influenced more by total water than by the water-cement ratio. In the end, durability and the taxpayer suffer.

CONTRACTOR QUALITY CONTROL

The president of an international construction firm contacted Shilstone & Associates on the subject of quality while bidding on a project in Saudi Arabia. He said that he wanted a program set up on the job so that when the superintendent wanted to do something under a tight schedule, the correct materials, equipment, and trained personnel would be there to "do it right" the first time.

The contractor is, as is any manufacturer, the only one who can control the quality of his work. If he is to have responsibility for furnishing a product, he needs the authority to control how it is done. In the late 1800s, John Ruskin said, "Quality is never an accident. It is always the result of intelligent effort." The "intelligent effort" starts with an approved quality control program and qualified people assigned to perform the work. Deming agrees with that concept and said, "Quality must be built into the work. It cannot be inspected in."

The first step in quality management is to develop a plan of action. Most planning starts with the resources—the baseline items. Quality planning works in reverse. It starts with the constructed product and the question, "What are the factors that affect attainment of the primary objective and those that will produce incentive pay?" This forces the planner to consider all of the variables and how to best mesh them to meet his objective. The principal factors are materials, equipment, methods, and people. Books have been written on the subject, but the following are a few of the major factors.

Materials include not only mix ingredients, but also the methods of curing, joint sealants, and other products. Not all cements are equal. It must be known which will produce not only the long-term strength, but also the early strength to allow access to completed castings. The same is true for admixtures and fly ashes. The chemically active ingredients should be evaluated to determine their chemical compatibility. The admixture suppliers should be asked if a special sequence of addition should be followed.

Aggregate distribution has a major effect on water demand. A well-graded mix requires less water and is more responsive to vibrators and finishing. Since only the combined gradation is to be considered, the most economical, locally available materials can be combined without the need for stockpiles to meet arbitrary gradation requirements.

Colorado Department of Transportation engineers replaced 500 lb of ¾-in. gravel and 300 lb of sand with 800 lb of waste "squeegee" (⅜ in. to No. 30) aggregate (*7*). This reduced the water by 5 percent, increased the strength by 10 percent, and changed a difficult-to-finish bridge-deck mix into one that "finished like butter." A materials supplier in another state reported wasting 1,000 tons per day of nonstandard-gradation aggregate. This material now accounts for 32 percent of the combined aggregate for an excellent mix.

Occasionally a cheap sand may be acceptable but will require more mix water and produce an acceptable but lower strength. With an incentive clause in mind, the quality manager may find that a more expensive coarse sand or blend of other materials may be more expensive, but it can

1. Reduce water and produce higher strength,
2. Increase relative density,
3. Improve mix mobility,
4. Make finishing easier,
5. Produce a better ride, and
6. Ensure incentive pay.

Equipment includes that for batching, mixing, placing, compacting, finishing, and testing. The more bins or means to use multiple aggregates, the better. The United States is the only industrial nation that allows use of a single coarse aggregate and a single fine aggregate. Such a system makes it impossible to blend materials to improve mix characteristics. This can be partially rectified by use of cold feed systems (as used for asphalt) to blend aggregates before placing the mixture on the hopper loading belt. In my opinion, a minimum of three aggregate bins is necessary to manage mixture proportions, but four are helpful.

Mixer quality affects strength and mixture workability. Placing, compacting, and finishing equipment must be compatible with the mixture, because it is key to producing high relative density and low permeability. The desired degree of consolidation must be uniform throughout the casting. A mixture that responds well can be compacted with good, but lighter equipment working at a higher speed to improve productivity. The contractor must demonstrate that the performance standards will be met by casting and testing a trial section before start of the work.

Testing equipment must be appropriate, calibrated, and in working order. The FHWA demonstration program is reporting that modern testing procedures, including maturity meters and ultrasonic equipment, provide more information than the traditional physical tests. Questions about entrained versus trapped air content are being heard. The conventional pressure and volumetric test equipment must be in good working order. Wet unit weight should always be checked, because it can identify problems with air meters and verify yield. The physical testing equipment and test practices should be in conformance with ASTM standards.

Methods used must be compatible with the objectives. It is anticipated that the recommended investigation will uncover some current methods that do not work. Even the previously quoted FHWA report on consolidation (*3*) indicates that the industry has little quality control over concrete once it has been placed ahead of the spreader. Performance standards will make it essential that the methods used work. If they do not, the disincentives will be costly for the contractor.

Tests should be meaningful. Although the slump test has been used for many years, it describes only the consistency of a batch and has little or no relationship to strength potential. The wet unit weight in a ½-ft^3 bucket is the best all-around test. The weight is affected by both water and air content.

The methods for casting test specimens are important. ASTM Standard C 31 provides that specimens cast at a slump of 1 in. or less must be consolidated by vibrator. Slumps from 1 to 3 in. may be consolidated by a vibrator or a rod. Vibrated specimens are more representative of in-place concrete placed using modern paving equipment.

The effects of vibration versus rodding can be significant. To confirm this and the applicability of vibration at any slump, a series of 50 sets of companion cylinders was field cast using both puddling and vibrating methods. The slumps ranged to 6½ in. A statistical analysis of the data revealed that slump was immaterial. The compressive strength of vibrated cylinders averaged 450 psi higher than that for rodded cylinders.

Personnel is critical to success. Many of the most experienced agency and construction supervisors are retiring. There has been little effort to train others to fill the technical gap. In terms of quality management, the loss of the technical skills is more important than loss of operational experience.

Technology is the engine that will drive quality in the future. Instead of an increasing number of personnel in the technical pipeline, the number is shrinking and the pipeline is almost closed. Most engineering universities are almost entirely eliminating the study of materials from their curricula. Who is teaching the future leadership? Who is teaching advanced concrete technology? Most technologists have gained their experience in the school of hard knocks. Few of the young, more skilled quality control personnel stay with that part of the industry because the pay is better in other segments.

The smart contractor of the future will apply not only operational, but also technical expertise to maintain a strong position. He will apply the correct technology to do it better at a lower cost and also get full incentive pay. His problem lies with the lack of trained personnel to fulfill the need and the few places where his own personnel can go to be trained in the practical applications of construction technology. The American Concrete Institute technician program is good, but it doesn't go far enough.

Field personnel must be trained and not just hired to do a limited job. Video provides an excellent opportunity for training. Even the economical Camcorder can produce an adequate training tool. From experience, I have great faith in the American worker. Given an opportunity to learn and improve his position, he will do so. Lend him a video tape to help him better understand and hold his job, and he will find a way to watch it.

The less formal the presentation, the better. It should not be a military-style presentation or a "rah-rah-we-are-a-great-company" motivator. It should be a personal, one-on-one, factual description of what the workers can expect. Show them what makes a pavement good and what they can expect to see. Help them identify tell-tale signs and teach them how to do their job. Learning from others who probably do not have the right answers is not the way to get started.

Ask the workers their opinions. That process, known as Quality Circles, has been extremely effective in Japan and the United States. Feedback from those doing the work is a more effective means to improve the quality of the work than an idea generated by someone far from the work. Books have been written on the subject, and the American Society for Quality Circles has done much to advance the applications.

Rewards and incentives to workers should be part of the quality program. Some rewards should be published and others, spontaneous. If a worker knows that management can receive incentive pay, but he gets none of it, he will respond as do the contractors who do not have incentive clauses. Yes, a share of the benefits in dollars is important, but not the only thing workers seek. According to many studies of worker psychology, nonmonetary personal rewards are high motivators. A Gold Hat Club could signify that the wearers have been recognized for their quality work. There should not be many of those, because it would weaken the image. An unexpected barbecue and beer supper halfway through the job will create a better attitude. The best and easiest motivator is a pat on the back and a thumbs-up sign. Good human relations improves quality and should be an integral part of the quality system.

AGENCY RESPONSIBILITIES

Once work gets under way, the agency must audit quality control. Acceptance testing should be done during construction and after completion. Performance contracts require the agency to undertake their work from a new point of view. They will have to review submittals and judge their adequacy to meet both short- and long-term objectives. Performance warranties probably will not exceed 5 years, although the objective may be 40-year durability.

Those who review submittals will not be able to rely on formulas similar to those used for design. Their concern must be durability, and be based upon technical factors. For example, a given combination of materials may produce adequate concrete strength for load-carrying capability for the pavement. However, that combination may contribute to long-term problems due to poor rheological properties and experience rapid wear in high-traffic or turning lanes. Those reviewing the documents must be knowledgeable in construction and not those who follow a checklist based on manual limits.

CONCLUSIONS

There is no simple method to implement this important subject. Quality is the product of hard, properly directed work. This program offers a new venture into the unknown but one that can result in construction that meets the needs both now and in the long term. The benefits of a properly established and managed quality program are clear:

1. The objective, proven from 50 years of testing and field experience, will be defined, targeted as a goal, the center of the planning process, and verified by measurement.
2. Litigation will be reduced.
3. Innovation will be expanded to increase productivity, improve quality, and reduce costs.
4. Higher-quality pavement will be better able to span base materials problems.
5. Quality in the form of customer satisfaction will be provided for the taxpaying public.

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