Controlling the Quality of Construction Aggregates Through Process Control

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The Georgia Department of Transportation and the Georgia Crushed Stone Association have worked together to develop a functional quality assurance system that requires the producer of construction aggregates to be responsible for process control and to certify to the state compliance with specifications. A state acceptance program maintains a check on the effectiveness of the program. A quality control program developed by the Vulcan Materials Company in support of the state program is described. This support program not only provides for proper sampling and testing but also includes a well-managed system of collecting and statistically analyzing test data through the computer, which can be used as an effective management tool. Eight computer printout reports are generated. Histograms provide valuable insight into the magnitude and causes of variations in product quality.

Historically, most contracting agencies have had specifications that provide for inspection and testing to be administered directly by the agency itself for controlling the quality of construction aggregates. Generally, these specifications have been punitive; thus, inspection and testing have become policing functions rather than a management tool to effect product quality. These types of specifications fail to provide the necessary incentives to aggregate suppliers to motivate them to accept their responsibility to effect aggregate quality through process control.

Although construction aggregates are a manufactured product and usually represent the greatest quantity of any material used on a project, they are uniquely different from other materials. Because of economic considerations, aggregates must be provided from local resources. Thus, once an aggregate resource has been selected through proper geological and engineering evaluations, the inherent physical properties (specific gravity, abrasion loss, sulfate loss, and so on) and chemical properties of the aggregates produced are essentially fixed. There are a few deposits in which selective mining and special processing procedures are required to improve the properties and upgrade the quality of the aggregate. These special considerations are not considered in this paper; rather, it is limited primarily to control of aggregate gradations and cleanliness. Fortunately, many of the concepts that apply to gradation control are also applicable to the control of other properties.

During the past few years, the construction industry, particularly the highway segment, has recognized the merits of the "end-result" specification concept, according to which the responsibility for quality control lies with the contractor and material suppliers. Through quality assurance concepts, criteria and methods are established by contracting agencies to assure them that the products they receive are produced under properly controlled conditions and in compliance with specifications. For a contractor to successfully operate under an end-result specification, he or she must be furnished from a reliable source with materials of the right quality. Thus, the concept of process control becomes very workable and necessary to an aggregate producer's operation when material is produced for a project under end-result specifications.

The Georgia Department of Transportation and the Georgia Crushed Stone Association have worked closely together to develop a functional quality assurance system for furnishing aggregates for use in state work. The system requires the producer to be responsible for process control and to certify to the state compliance with specifications. The state has established a quality acceptance program to maintain a check on the effectiveness of the producer's program.

Vulcan Materials Company, a major producer of construction aggregates, has developed a quality control program in support of the state program. The purpose of this paper is to describe this support program and some of the benefits that have resulted since it has been implemented.

BACKGROUND

The aggregate industry has traditionally been an unsophisticated business. The nature of the business, in general, is local because of the high transportation costs associated with the movement of materials and the low unit value of aggregate. Most of the existing aggregate processing plants have grown from small, family-owned businesses that were generally concerned with "how to get it out of the ground." The responsibility for sampling, testing, and accepting material was left to the customer—the highway department. Frequently, the highway department was required to resort to rather thorough inspection and testing programs to ensure acceptable quality and compliance with specifications. As a result, they found themselves in the position of running the aggregate business for the producer. This, of course, was undesirable and awkward for all concerned. Testing and inspection were costly to the state and, under such conditions, not too effective. For example, during the early 1970s, the state of Georgia had over 400 personnel assigned to aggregate testing.

Several years ago the aggregate industry was challenged to develop and implement an effective quality control program to effect better process control. It has taken considerable effort and encouragement by a few of the more progressive highway departments and the Federal Highway Administration to interest the industry in the concept.

QUALITY ASSURANCE BY THE STATE

The Georgia quality assurance program was developed through a cooperative effort between the Georgia Department of Transportation (DOT) and the Georgia Crushed Stone Association and was implemented in February 1975. The program is strictly voluntary, and participation by the producer is optional. Since its beginning, all producers of coarse aggregate have elected to participate. Since sand plants are generally much smaller and mostly operated by local contractors, only about 25 percent have elected to participate. If producers elect not to participate in the program, their material is sampled and tested by the state at the plant and project sites as it was before. To qualify for participation in the program, the source of material and the quality control program must meet the following criteria:

1. A mutually agreeable quality control program, between the DOT and the producer, must be established for each plant based on the characteristics of that plant

and its deposits as well as past performance.

2. Each plant must have an approved laboratory. Laboratory equipment and facilities must be certified.

3. Sampling and testing personnel must be trained and certified.

4. To ensure uniformity of testing between the DOT and the producer, one sample per quarter is tested at the producer's laboratory and then shipped to the state's laboratory for comparison testing.

5. Correct load-out of materials, including cleanliness of all haul units and accurate identification of products, are recognized as producer responsibilities and are considered an integral part of the quality control program.

6. Delivery of aggregate from a source that has an approved quality control program is certified by the producer to comply with the specification and need not be tested at the project or at the plant before use unless nonuniform or nonspecification material is suspected by the DOT.

7. To substantiate the quality of the material actually incorporated in the work and to evaluate the quality assurance program, certain evaluation procedures are followed. The DOT samples and tests on a regular but random basis at the source of production and on occasion at the project site. Sampling and testing are done as often as required to evaluate the effectiveness of the producer's quality control program.

8. The producer is required to sample and test at an agreed frequency for each type of material being furnished to the DOT. Producer certification is made on an approved DOT form. The producer's records are sent to the DOT for their records. Each load of material need not be tested, but the shipments represented by a particular sample should be indicated on the reports by a project number and other necessary identification.

9. The producer is responsible for keeping separate, if necessary, the different materials used for different purposes by the DOT, such as material for asphalt concrete, portland cement concrete, graded aggregate base, and other mixtures.

10. Regular samples are taken at the project at frequencies prescribed by the DOT.

11. Certification of facilities and personnel is the responsibility of the DOT. Certification is made at the request of the producer. Subsequent recertification is required annually or based on personnel changes or problems detected in the system.

This is a summary of what is required by the Georgia DOT for a producer to participate in a product certification program. This system thus far has been most effective. As previously mentioned, before implementation the DOT had approximately 400 people sampling, testing, and inspecting aggregates in the state of Georgia; now there are 12. In addition, before implementation the state experienced frequent problems with material that did not meet specifications; since implementation, the number of problems has been reduced significantly.

PROCESS CONTROL BY THE PRODUCER

Initially, the producers were somewhat reluctant to participate in the program because they felt they were being required to add personnel to their staff to inspect and maintain a quality control program for the state, thus adding to their operating costs. Experience has shown that it takes about 1 person/909 000 Mg (1 person/ 1 000 000 tons) of capacity to properly maintain a quality control program. Depending on the size of an operation, the cost to a producer will be between $0.01 and $0.02/ Mg (ton). This is a significant cost and a very tangible one, and any good business would require a justification before such an expenditure was approved. Unfortunately, the benefits of a producer quality control program are not readily apparent, and some are intangible in nature, much like technical services or research and development activities.

However, soon after the Georgia program had been implemented, the industry recognized that the program offered many advantages that certainly overshadowed the costs of the program. The most significant contribution was that the responsibility of producing quality, and therefore the mechanisms to effect quality, were given to the producer. Flexibility of plant operation, less rejected material, technical services, and goodwill are but a few of the advantages that have emerged from this program. Obviously, the quality of the material has to be controlled at the plant, and the producer is in the best position to perform this function.

VULCAN QUALITY CONTROL PROGRAM

During the early 1960s, when Vulcan was emerging as a leader in the aggregate industry, its management recognized that a research and development capability merited attention. Thus, they formed one of the first research and development groups in the industry. A part of the defined function of the newly formed research and development section was quality control, but it was not until 1972 that this program became fully functional. The program has assisted measurably in improving the quality of material being produced in those divisions that are using it. The development of Vulcan's quality control program has been closely related to and associated with the evolution of the certification and end-result specification program of the Georgia DOT.

Vulcan's program has had the support and encouragement of its top management, which is an essential aspect of the success of a quality control program. The following items have been identified as contributing to a good, functional quality control system:

1. Qualified personnel;
2. A well-planned, written system approved by management;
3. Good housekeeping and preventive maintenance practices;
4. Correct sampling and testing procedures;
5. Proper data analysis; and
6. Use of the results in engineering and management decisions.

Vulcan has now implemented its quality control program in about one-third of its plants. It is functioning in those states in which highway departments encourage producers to maintain their own quality control programs. In three of these states, the highway departments now accept product certification from the producer in lieu of state testing.

At each of the participating plants, an adequately equipped laboratory is maintained and manned by a trained quality control technician. This technician is under the supervision of the quality control manager, who, in turn, reports to division management. All quality control activities are overseen and monitored by the corporate quality control manager, who is a professional engineer.

More than a policing activity was desired. One of the basic premises of the program was that information developed from testing, if obtained and analyzed correctly, could be a valuable asset to management.

To assist in the management of Vulcan's quality control program, a computerized statistical quality control

system was developed. The system consists essentially of input data collected from the sampling and testing activities of the plants. The information is routed to the computer on a routine basis, and at defined points in time the data are statistically analyzed and reduced to a usable format. Currently, access to eight different reports is available each month. A brief description of each report follows.

Exception Report

The exception report is prepared as a tool to enable management to make a quick assessment of any significant problems. It lists all tested samples of a product that are outside specification limits and provides, through statistical concepts, information on potential problems that may require corrective attention.

Frequency of Sampling Report

The sampling report provides information on the total number of samples tested at a plant by day and by month for each product.

Time-Sequenced Values Report

The values report is basic. It shows all the samples tested at a plant as well as the date, time of day, and gradation for each product.

Product Uniformity Report

The report on product uniformity provides information for comparing the quality of a particular product from one plant to another. It may be used to compare the uniformity of the mean percentage passing and standard deviation for a given product between plants and to compare the monthly performance of a plant with year-to-date performance.

Control Chart Limits Report

The control chart limits report provides data for the purpose of preparing quality control charts that are used by the inspector and superintendent at the plant to control quality during production.

Average Gradation Analysis and Standard Deviation Report

The report on average gradation analysis and standard deviation provides for sales personnel and customers a listing of mean percentage passing and standard deviation for all products produced at a plant.

Yearly Statistical Comparison Report

The yearly statistical comparison report lists the average gradations and standard deviations by month for all products sampled during the previous 12 months. Seasonal patterns and fluctuations can thus be identified and anticipated.

Histograms

For each sampled product for which sufficient data are available, a histogram is plotted for each sieve size tested. If samples are properly selected and tested, a "bell-shaped" curve is generated. If the plots do not approach such a shape, it is an indication that some procedure may be incorrect and corrective action may be required.

Information obtained from these reports is providing valuable insight into the type and cause of variation that occurs in the various products. For example, it has been found, as would be expected, that the point of sampling makes a considerable difference in the magnitude of the variation. If an ASTM No. 57 aggregate (typical concrete-sized coarse aggregate) is sampled from the production belt just before it is discharged into stock or a loading bin, the variation on the 13-cm (0.5-in) control screen may be as low as 2 to 4 percent. If this same material is sampled under controlled conditions from a railcar or a truck, the variation will be in the range of 4 to 6 percent. If it is sampled from a stockpile, it can be as high as 10 percent. We believe that this type of information is extremely valuable in establishing specification limits, methods of sampling, and tolerances in specifications and in assisting in the mix design for portland cement concrete, asphaltic concrete, and crushed-stone base.

SUMMARY

Vulcan's statistical quality control system has been a very effective aid in controlling quality and in knowing what is being produced. It is a valuable management tool. Among the advantages the program provides are the following:

1. It documents in a concise and orderly manner the quality of all products;
2. It satisfies the record-keeping requirements of state highway departments that are using or considering product certification programs in lieu of their present inspection procedures;
3. It optimizes the amount and timing of sampling;
4. It provides effective information to sales personnel and services to customers;
5. It reduces the amount of material shipped that does not meet specifications;
6. It provides a valuable library of information that may be adapted to research and development programs;
7. It provides an effective tool for operating, maintaining, and upgrading plant control;
8. It makes it possible to identify and anticipate seasonal fluctuations;
9. It maximizes product quality commensurate with operations, sales, and marketing conditions; and
10. It provides a more competitive atmosphere in the construction materials industry.

Vulcan's system has been designed to provide dependability and accuracy. It ensures a high probability of valid data and is flexible and adaptable to all aggregate plants operated within the company. Simplicity and clarity have been prime considerations throughout the development of the quality control system.

Even though significant progress has been made by a few states in the implementation of producer quality control systems and product certification, several factors are still deterring the concept from being widely accepted by highway departments and producers. Many producers see the program as costing them money and feel that there are no ways for them to recover incurred costs. Quality control is one of those functions that are somewhat intangible: The cost and effort of the activity are easily identifiable but the benefits are not. These obstacles can be overcome only by educating the producers and through experience.

It is important that the program be simple to administer and require a minimum of paperwork. An effective program need not be complicated and bureaucratically burdensome. A producer is much more receptive and

responsive to a program that is simple to administer and that keeps costs down.

Producer-managed quality control and product certification have proved to be effective methods of improving product quality and reducing inspection and testing costs. Vulcan believes that quality control can be an effective cost control activity and that it will, if properly administered, bring a profitable return to the company on its investment.

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Process Quality Control in the Crushed-Stone Industry

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Selected producers of crushed stone were surveyed on their attitudes toward setting up structured quality control systems that might largely replace much of the conventional testing of aggregates by state inspectors. Their responses are summarized. The overall response was clearly in favor of the concept. Most producers felt that such a system would eliminate many problems and pay off in terms of customer confidence. The essentials of workable, statistically valid specifications that would be appropriate to the producer control concept are outlined. Such specifications should define acceptable variations from approved target gradations for given end uses but should permit considerable latitude to the producer in establishing the target gradation. Good gradation control requires careful processing; the desired consistency is seldom if ever found in materials taken from natural deposits with little or no processing. The importance of close adherence to sound, standardized sampling techniques is emphasized. Both process control samples and samples monitored by state or other agencies should be taken from the "as-produced" material. Test portions for monitoring should be split from routine process control field samples to provide a valid statistical comparison of the producer's control program.

The crushed-stone industry is clearly in favor of specifications based on concepts that recognize the fact that bulk materials are inherently variable and that place realistic limits on the degree of variability that is acceptable. The old, outmoded practice of acceptance or rejection is no longer used in most areas of the country. Specifications must define reasonable limits within which the great majority of quality measurements should fall. However, in view of the many sources of variation in test results, it is unrealistic to expect every sample to "pass" in all respects.

Specifications should also require a measurable degree of consistency in gradation. The old axiom, "We can use a wide variety of gradations, but we cannot tolerate too much variation," should be recognized. This is more important in some end uses than in others.

Specifications for crushed-stone base material, similar in principle to ASTM D 2940, exemplify this concept. They establish a rather wide master range and give producers considerable leeway in selecting a gradation that best fits their operations but require a job mix formula that places more strict limits on deviations from the target gradation selected.

Consistent gradations are important in the case of aggregate base materials, which rely on good compaction and accurate measurement of compaction for maximum load-supporting power. They are extremely important in the case of bituminous mixtures, where variability may affect not only compaction but also void content, both of which strongly influence stability and durability, and in the case of portland cement concrete, where variability may affect water demand to achieve a given slump and thus also affect strength and yield. But in none of these cases is it necessary to require that every aggregate producer who bids on a given job meet a single, narrow gradation band.

Commercial producers of aggregate have found that good quality control programs pay off in a number of ways, especially in producing aggregates to meet this type of specification. Because they produce aggregates that are consistent in gradation and other important characteristics, their products are sought and are more readily accepted by contractors who work in the private sector and for public agencies. In recognition of the fact that crushed stone is generally processed under good quality control procedures, a number of state agencies are reducing their emphasis on sampling and testing of stone by state personnel. The growing tendency is to place greater reliance on the producer's quality control records as the basis for routine acceptance.

On learning that the Federal Highway Administration (FHWA) has been pursuing research in its federally coordinated program (FCP) to "promote the takeover by producers of the job of process control" and thus relieve state inspectors of much of their testing load (1), the National Crushed Stone Association (NCSA) undertook a survey of its members to determine the attitude in the industry toward such a development. The membership was advised that a shift from state test data to producers' data as the basis for quality assurance might involve making available to the state all quality control records on the specified materials. The following sections summarize the responses from NCSA member companies.

SURVEY OF INDUSTRY ATTITUDE

Members of NCSA represent a wide range of company sizes as well as quarry sizes. At some quarries, highly sophisticated plants may be found that are designed to produce annually millions of megagrams of stone of a wide variety of sizes and blends. Other quarries are operated only intermittently, and portable plants are moved in and out to produce just enough material for a specific project or a year's supply of maintenance stone. With very few exceptions, all members who responded to the survey showed a favorable attitude toward the concept of producer control as the basis for quality assurance. Some, in fact, urged that this paper reflect an NCSA policy of actively promoting the concept al-