CALIFORNIA DEPARTMENT OF TRANSPORTATION

REVIEW OF STATE HIGHWAY AGENCY QUALITY ASSURANCE PROGRAMS

June 2011

Review of State Highway Agency Quality Assurance Programs

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Review of State Highway Agency Quality Assurance Programs
Executive Summary

The California Department of Transportation's (Caltrans) existing construction quality assurance (QA) program for structural concrete does not clearly place the responsibility and accountability for quality on the contractor. On December 13, 2010, a decision document titled "Enhance the Quality Assurance Program for Structural Concrete Sampling and Testing" was approved (Appendix 1). The decision document provided overall direction to Caltrans staff to create a detailed delivery plan to develop specifications to "clearly assign the responsibility of quality control testing for structural concrete … from the Department to the contractor." The delivery plan was completed in January 2011 (Figure 1) and it was determined that liaison with industry groups would be achieved through the already established Rock Products Committee.[1]

	Last Update:	6/30/2011	
	Tasks	**Plan Start**	**Plan Finish**
	QC/QA Specification Development		
	2010 - 2011 Fiscal Year	Start	End
1	Establish Project Teams	15-Dec	31-Jan
2	Review Existing FHWA and Other State DOT Practices	1-Feb	30-Jun
3	Develop Outline for QC Program	15-Mar	30-Jun
4	Develop Outline for QA Program and IQA Guidelines	1-Apr	30-Jun
5	Define IA Roles and Responsiblities	15-Jun	15-Aug
	2011 - 2012 Fiscal Year		
1	Draft QC/QA Reference Specification	1-Jul	31-Aug
2	Pilot Project Identification and PS&E Approval	1-Jun	31-Aug
3	Internal & External Outreach and Guidance Docs	1-Jul	30-Nov
4	Advertise and Award Pilot Projects	1-Dec	31-Mar
5	Process/Review Feedback on Pilot Projects	1-Dec	31-Mar
6	Establish Full Implementation on All Projects	1-Apr	30-Jun

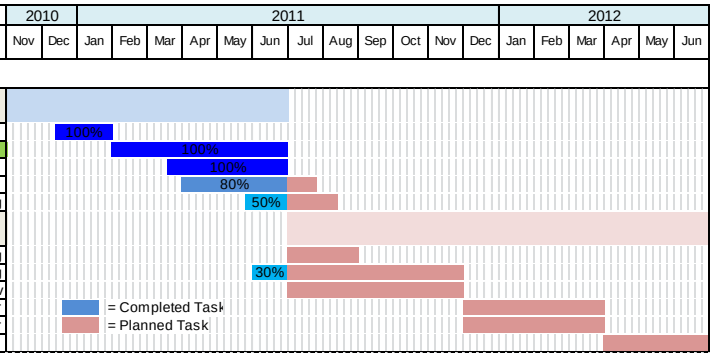

Figure 1 – Summary of Tasks from Delivery Plan Developed in Response to Approved Decision Document

In response to the second item of the delivery plan, Caltrans began a thorough review of Federal Highway Administration (FHWA) regulations and guidance documents and state DOT practices relative to QA specifications. This report is an attempt to document Caltrans' understanding of FHWA requirements as well as other DOT practices as it relates to structural concrete. This report provides a basis for creating sound Quality Control (QC) and QA outlines by allowing a thorough understanding of FHWA requirements and best practices from other DOTs.

This report also provides an overview of the types of QA programs used and lessons learned by state transportation agencies for control and acceptance of typical highway pavement materials and construction. Additionally, it highlights *how* these QA programs operate within the regulatory requirements of Title 23, Part 637, Code of Federal Regulations (23 CFR 637) as well as a "status of the States' implementation." This document briefly summarizes the methods and procedures used in state highway QA programs and demonstrate that Caltrans' proposed strategy of QA for structural concrete complies with FHWA guidelines and are consistent with the state-of-the-practice, as measured by other state highway agency (SHA) programs. Finally, the most recent FHWA quality assessment of Caltrans is included to demonstrate Caltrans' commitment to ensuring that the materials and workmanship incorporated into federal-aid highway construction projects conform to the requirements of the approved plans and specifications.

[1] The Rock Products Committee (RPC) is a cooperative effort of Caltrans, industry associations, and the Federal Highway Administration to address matters related to the production and use of aggregate, asphalt, and concrete in transportation projects. The RPC provides a forum for Caltrans and industry representatives to coordinate joint efforts aimed at improving construction methods, material specifications, and test methods utilized in the construction and preservation of transportation facilities. The Concrete Task Group deals with issues related to concrete materials and products on behalf of the Rock Products Committee.

1 INTRODUCTION

The California Department of Transportation's (Caltrans) current sampling and testing program for structural concrete is not ideally configured to "encourage" the contractor to monitor its production process such that it bears some responsibility for the quality of the end product. At the direction of the Rock Products Committee through the Concrete Task Group, the Concrete Materials and Quality Assurance (QA) Subtask Group was challenged to develop a framework for QA specifications for structural concrete and an implementation plan to remedy this situation. The goal is to shift responsibility for the quality control of material from Caltrans to the contractor, and allow Caltrans to more efficiently utilize its resources to ensure that the materials and workmanship conform to the requirements of the approved plans and specifications. To that end, Caltrans began this endeavor with a thorough review of Federal Highway Administration (FHWA) regulations and guidance documents, and state DOT practices relative to QA specifications.

PURPOSE AND SCOPE

The signed decision document (Appendix 1) established direction for Caltrans to develop clear guidance regarding roles and responsibilities of quality of materials related to structural concrete. The purpose of this document is to twofold: 1) to briefly summarize the methods and procedures used in state highway QA programs; and 2) to demonstrate that Caltrans' proposed strategy of QA for structural concrete complies with FHWA guidelines and is consistent with the state-of-the-practice, as measured by other state highway agency (SHA) programs.

BACKGROUND

Departments of transportation (DOT) have come to realize the importance of QA from the experience that failure to comply with either material or construction specifications can result in the premature failure of highway components. Construction QA programs are intended to ensure that the quality of the materials and construction incorporated in highway products is satisfactory.

Since the 1960s, QA programs have evolved into what are sometimes now second or third generation programs, all of which contain three main ingredients: quality control (QC); acceptance; and independent assurance (IA). This evolutionary process is reflected in the changes allowed by 23 CFR 637, the FHWA's *Quality Assurance Procedures for Construction*. This regulation was adopted in 1995 and requires each SHA to develop a QA program for the National Highway System (NHS). The program is designed to ensure that the materials and workmanship incorporated into each federal-aid highway construction project on the NHS comply with the requirements of the approved plans and specifications.

Not surprisingly, the strategies and practices used by state highway agencies to ensure quality employ a wide variety of QA approaches to meet the regulations as revised under 23 CFR 637. QA programs vary not only among but within agencies depending upon the material and construction area. Some agencies rely primarily on materials and methods provisions whereas other agencies routinely use contractor test results as part of the acceptance decision. Agencies tend to use materials and methods provisions for soils and embankment specifications to a greater extent than for other materials and construction, and to use contractor test results in the acceptance decision more often for hot-mix asphalt.

Many agencies require contractor QC for at least one material. Most agencies retain the acceptance function although the number using contractor test results in the acceptance decision is increasing. Although the QA concept calls for the separation of QC and acceptance, the separation is often unclear. Implementation of the IA function is as diverse among agencies as other aspects of the QA program.

Another example of the diversity can be found in the use of pay adjustment schedules. Most of the agencies use stepped pay schedules. Some use pay equations. One area of relative agreement is in training and certification. Most agencies tend to rely on in-house training and certification when either is required for all material and construction areas. Some agencies rely on regional and national accreditation programs such as Precast/Prestressed Concrete Institute (PCI) and American Concrete Institute (ACI).

When using contractor test results in the acceptance decision, 23 CFR 637 requires that verification testing be done by the agency. The type of verification varies greatly from agency to agency. Some agencies use a stronger statistical verification system than others. A considerable number of agencies use a weaker verification system that is less sensitive to differences between agency and contractor test results.

There is substantial agreement between the types of QA programs used for Portland Cement Concrete (PCC) structures and PCC paving. Almost 40 percent of the agencies use QA programs for PCC structures in which the contractor controls the quality and the agency performs acceptance. The other 60 percent are evenly divided between the practice of the agency controlling quality and performing acceptance, and the contractor controlling the quality and the agency using contractor test results in the acceptance decision. Gradation, air content, and slump are the most frequently used QC attributes. Almost 70 percent of the agencies establish the frequency for contractors to conduct QC tests and five agencies require control charts. Air content, cylinder strength, slump, and gradation are the most often used attributes for acceptance. More than 80 percent use the same test methods for QC and acceptance, and 60 percent use the same point of sampling. More than 60 percent of the respondents use pay adjustment procedures. Of the 14 agencies that use contractor tests in the acceptance decision, seven compare one contractor test result with one agency test result, one uses the *F*- and *t*-tests, and 10 use one agency test result compared with several contractor test results. For verification, two agencies use independent samples, four use split samples, and seven use both.

The use of consultants is widespread. Most agencies use the consultants in place of or as a supplement to agency acceptance testing, and a significant number use them in place of or as a supplement to contractor QC testing.

Caltrans most recent Quality Assessment score from the FHWA suggests that its performance is above average.

Although the concepts and strategies on QA specifications emerged from the pavements arenas and structural steel, of particular interest is the state-of-the-practice for structural concrete. Caltrans recognizes that this transition will require a carefully crafted plan to address the three key components of a QA program: QC, acceptance, and IA. Specifically, Caltrans recognizes that this plan for QA specifications for structural concrete must consider the following:

- The attributes to use for QC and for acceptance.
- The test methods to use for QC and for acceptance.
- The point of sampling to use for QC and for acceptance.
- Who establishes the frequency for QC tests.
- How to establish the QC tests.
- The quality measure to use for acceptance.
- Whether accept/reject or pay adjustment provisions will be used.
- What levels of risks are appropriate for the agency and contractor.
- Whether contractor tests will be used in the acceptance decision and, if they are, what type of verification system will be used, whether the agency will use split samples, independent samples, or both, and the purpose of the verification.
- If training and/or certification will be required; and, if required, who will do it.
- How the IA function will be administered.

Implementation of 23 CFR 637 has changed the way many agencies approach the measure of quality. It was this changing environment that precipitated another survey, the results of which described the wide range of methods and procedures that agencies used to ensure quality (Reference 2). The results of this survey as well as that of Caltrans, and the FHWA's Quality Assessment Stewardship Reviews are addressed in Sections 2, 3, and 4 of this report.

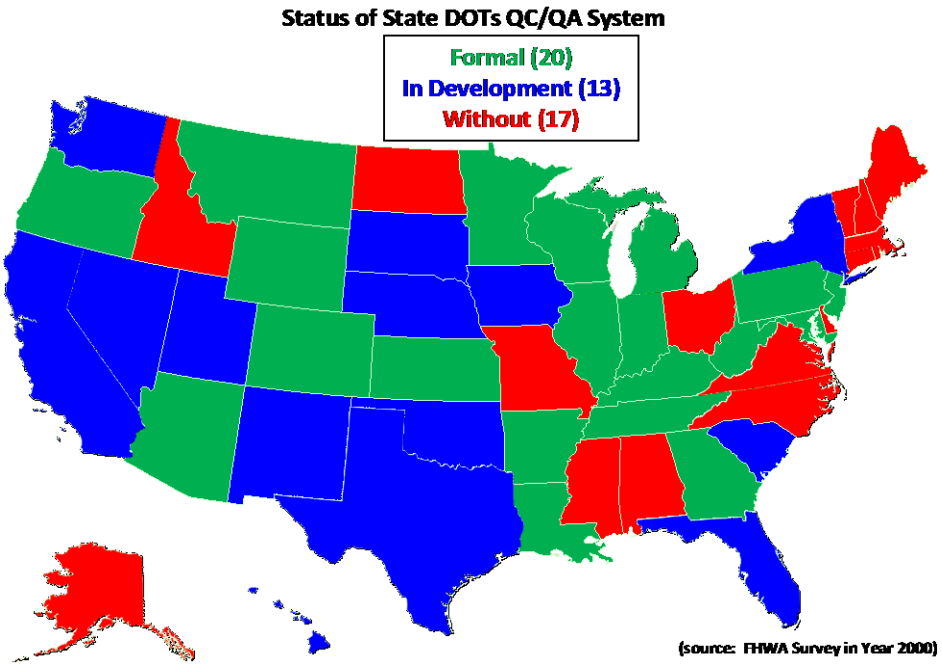

Figure 2 – Status of State DOTs QC/QA System

Because QA is viewed quite differently among (and sometimes within) the agencies, the QA methods and procedures, also differ significantly among agencies. The form of specification often varies within an agency depending on the material or construction item. Although there are many important elements of a QA program (for example, QC charts, pay adjustments, dispute resolution), the scope of this document is limited to the types and frequency of testing that Caltrans is proposing for structural concrete.

Highway QA programs began with the American Association of State Highway Transportation Officials (AASHTO) Road Test (1956 - 1958) and the analysis of the results. The evolution in QA programs in the past 50 years has produced several forms of specifications and was driven by several factors, two of which figure prominently: the AASHO Road Test which showed the importance of recognizing variability in the specifications; and the construction of the Interstate Highway System. This nationwide road-building program encouraged technological advances that increased construction speed, so much so that state highway agencies were motivated to implement QA specifications because they had too few inspectors to oversee the rapidly expanding system under traditional method specifications.

Statistically Based Specifications

Soon after the results of the AASHTO Road Test were published many agencies started measuring the variability of typical material and construction properties as a first step in establishing specification limits

for statistically based specifications. These specifications, developed during the 1960s, generally controlled the average product (or process) based on an "assumed" or sometimes "known variability."

About the same time as the implementation of statistically based specifications, the use of "disincentives" or penalties was initiated for products that did not meet the specifications. These "negative pay adjustments" were used instead of "remove and replace" or "shut-downs" of the operation. These pay adjustments received a less than enthusiastic reception from the contracting community.

QA Specifications

By the 1970s, the statistically-based specifications had been incorporated into QA programs with a strong dependence on statistical analysis (Reference 3). With the development of these programs came the recognition of a need for separate quality (process) control and acceptance functions. Specifying agencies recognized that the contractor, or producer, was in the best position to conduct the process control function because it depended on the contractor's personnel and equipment. The acceptance function was generally agreed to be an agency function to ensure that "satisfactory quality control has been exercised and that the proper degree of compliance to the specifications has been attained" (Reference 3). These QA-related definitions have been formalized and adopted in numerous publications including the AASHTO *Quality Assurance Guide Specification* (Reference 4).

23 CFR 637

In the 1980s, SHAs began taking a critical look at testing personnel assigned to contractor facilities. In many cases, the contractor had assumed the testing and inspection activities associated with QC. There was a growing perception that a duplication of testing was taking place: QC testing by the contractor and acceptance testing by the agency. In some states this was a primary reason for making the decision to remove the agency inspector/technician from the contractor's facility, and was coupled with the emphasis on reducing the number of agency personnel. Because the contractor was doing inspection and performing testing more frequently than the agency, the question was asked, why not use the contractor's test results in the acceptance decision? Although this could be done on state-funded construction at that time, federal regulation did not allow this. Consequently, in the early 1990s, the FHWA decided to review regulations that would allow for such test results to be used in the acceptance decision. An unpublished report, *Limits of the Use of Contractor Performed Sampling and Testing*, recommended that contractor sampling and testing be used in acceptance programs. In 1995, 23 CFR 637, which implemented this recommendation, was adopted (Reference 1).

Performance-Related Specifications

The evolution has continued to where performance-related specifications (PRS) are now being developed. In 1995, the topic of PRS was addressed in National Cooperative Highway Research Program *Synthesis of Highway Practice 212* (*10*). At that time, PRS were in their infancy and used infrequently. Prototype PRS now are available for both hot-mix asphalt (HMA) and PCC pavements (Reference 5).

Optimal Procedures for Quality Assurance Specifications

The 2003 publication, *Optimal Procedures for Quality Assurance Specifications* (OPQAS), was written under the auspices of the FHWA. This publication was intended to serve as a "how-to" manual for agencies interested in writing a new or modifying an existing QA specification (Reference 6). It is seen as part of the evolutionary process because of the cutting edge discussion of risk and risk analysis for acceptance plans.

DEFINITIONS

One problem associated with QA programs and specifications since their inception has been differing interpretations of the specialized vocabulary used in these programs. For ready reference, a side-by-side comparison of the primary definitions of interest — QC and QA — is shown in Table 1. Although there are

numerous sources (for example, ACI, 23CFR 637B and TRB), the additional terms related to QA programs and specifications included herein are those found in the Transportation Research Board (TRB) Transportation Research Circular, *Glossary of Highway Quality Assurance Terms* (Reference 7).

Table 1 — Various Definitions for Quality Assurance and Quality Control

Term	23CFR637B (1995)	ACI (ACI Concrete Terminology, August 2010)	TRB Glossary of Highway QA Terms (EC-137, 4th Update, May 2009)
Quality Assurance	*All those planned and systematic actions necessary to provide confidence that a product or service will satisfy given requirements for quality.*	*Actions taken by an organization to provide and document assurance that what is being done and what is being provided are in accordance with the contract documents and standards of good practice for the work*	*All those planned and systematic actions necessary to provide confidence that a product or facility will perform satisfactorily in service.*
Quality Control	*All contractor/vendor operational techniques and activities that are performed or conducted to fulfill the contract requirements.*	*Actions taken by an organization to provide control and documentation over what is being done and what is being provided so that the applicable standard of good practice and the contract documents for the work are followed.*	*Also called process control; those QA actions and considerations necessary to assess and adjust production and construction processes so as to control the level of quality being produced in the end product.*

Acceptance—sampling and testing, or inspection, to determine the degree of compliance with contract requirements.

End-result specifications—specifications that require the contractor to take the entire responsibility for supplying a product or an item of construction. The highway agency's responsibility is to either accept or reject the final product or to apply a price adjustment commensurate with the degree of compliance with the specifications.

Independence assurance (IA)—management tool that requires a third party, not directly responsible for process control or acceptance, to provide an independent assessment of the product and/or the reliability of test results obtained from the process control and acceptance testing. (The results of IA tests are not to be used as the basis of product acceptance.) This definition differs from that of 23 CFR 637, which defines IA programs as "activities that are an unbiased and independent evaluation of all sampling and testing procedures used in the acceptance program."

Lot (also called population)—specific quantity of similar material, construction, or units of product subjected to either an acceptance or process control decision. (A lot, as a whole, is assumed to be produced by the same process.)

Materials and methods specifications (also called method specifications, recipe specifications, or prescriptive specifications)—specifications that direct the contractor to use specified materials in definite proportions and specific types of equipment and methods to place the material. Each step is directed by a representative of the highway agency.

Performance-related specifications—QA specifications that describe levels of key materials and construction quality characteristics that have been found to correlate with fundamental engineering properties that predict performance. These characteristics (for example, air voids in asphalt concrete and compressive strength of PCC) are amenable to acceptance testing at the time of construction.

Performance specifications—specifications that describe how the finished product should perform over time.

Quality assurance (QA)—all planned and systematic actions necessary to provide confidence that a product or facility will perform satisfactorily in service. (This broad definition involves more activities than are covered in this report; however, the term is defined to provide a basis of reference.)

Quality assurance specifications—combination of end-result specifications and materials and methods specifications. The contractor is responsible for QC (process control), and the highway agency is responsible for acceptance of the product. (QA specifications typically are statistically based specifications that use methods, such as random sampling and lot-by-lot testing, which let the contractor know if the operations are producing an acceptable product.)

Quality control (QC) (also called process control)—QA actions and considerations necessary to *assess* and *adjust* production and construction processes so as to *control* the level of quality being produced in the end product (emphasis added).

Statistically based specifications (also called statistical specifications or statistically oriented specifications)—specifications based on random sampling and in which properties of the desired product or construction are described by appropriate statistical parameters.

Verification—process of determining or testing the truth or accuracy of test results by examining the data and/or providing objective evidence. (Verification sampling and testing may be part of an independent assurance program [to verify contractor QC testing or agency acceptance] or part of an acceptance program [to verify contractor testing used in the agency's acceptance decision].) This definition differs from that in 23 CFR 637 which defines verification sampling and testing as "sampling and testing performed to validate the quality of the product."

2 QUALITY ASSURANCE PROGRAMS

The development of quality assurance (QA) programs has been an evolutionary process and the forms and ingredients of QA programs vary appreciably from agency to agency. By definition, QA specifications combine end-result and materials and methods requirements. However, the way they are combined and the emphasis of each leads to the diversity. The nature of the materials and construction also affects the diversity in QA programs. For example, some agencies have found that, because of the relatively high heterogeneity of in-place soils and embankments, it is often more difficult to use statistically-based specifications for these materials than for plant-produced materials and, therefore, they rely more heavily on materials and methods specifications. The initiation of 23 CFR 637 further affected the diversity in QA programs. Although the rule allows the agency some flexibility, there are important requirements if contractor test results are used in the acceptance decision. Specifically, the preamble of the final rule making of 23 CFR 637 states the following:

> "The overall intent of the program is to provide adequate assurance that the public is receiving the desired quality in the product produced by the contractor. The first level of assurance is provided by qualified laboratories and testing personnel. This assures that the equipment and personnel are capable of performing the tests properly. The second level of assurance is by the IA program. This level assures that the testers and equipment remain capable of performing the tests properly. The third level of assurance is provided by verification sampling and testing. This level assures the quality of the product" (Reference 1).

Regardless of which party to the contract performs the testing (agency, agency designee, or contractor) there are three critical components to an effective QA program: quality control (QC), acceptance, and independent assurance (IA). Agencies differ in the way they conduct these functions, not only from agency to agency, but within an agency, depending on the type of specification and material or construction area.

As part of the evolution of QA, the three functions have likewise evolved. Before 1960, little thought was given to any function except inspection and sampling and testing to determine if the specification limits were being met. The specifications used at that time were typically materials and methods specifications and, as such, sampling and testing were done by the specifying agency. Often, if the specification was not met, it was assumed that the test result was in error, and the material or construction was sampled and tested again. This assumption was made primarily because the agency was making the decisions concerning the contractor's operation, and the concept of variability was not well understood. At that time, there was no formal QC, and before 1962, no formal IA function. Following the American Association of State Highway Transportation Officials (AASHTO) Road Test analysis and a report from the Congressional House Committee on Oversights and Investigations, agencies sought better ways to determine if specifications were being met (References 3 and 8). A number of studies undertaken by the Bureau of Public Roads (predecessor to the FHWA) and the National Cooperative Highway Research Program (NCHRP) led to the requirement to conduct IA sampling and testing on FHWA funded projects and to the beginning of formal QC initiatives.

The intended function of each part of QA is important because each function should supplement the other. The analogy has been used of QA being similar to a three-legged stool: one leg QC; one leg acceptance, and the third leg IA (Reference 9). With any leg missing, the whole is unbalanced. The current concept of QA is that QC is the responsibility of the contractor, acceptance is the responsibility of the agency (although this responsibility may involve contractor test results), and IA is conducted by an independent third party. Note that the purpose of sampling and testing for QC and acceptance is to estimate the population being produced. Depending on the definition used, the purpose of IA is to

provide an independent assessment of either 1) the testing process or 2) of the product and/or the reliability of test results. Whichever definition is used, the emphasis is on *independent*.

QUALITY CONTROL

In early materials and methods specifications, there was often no formal QC requirement. The agency stipulated how the contractor was to perform the work and monitored the operations by inspection and testing. The testing done was a combination of QC and acceptance, although these terms were not generally used. That has changed somewhat with present day materials and methods specifications in that the QC function is often performed; sometimes by the contractor and sometimes by the agency. Regardless of who performs the QC function, the intent is the same; it is to assess and adjust production and construction processes so as to control the level of quality being produced in the end product. This should be a separate and distinct function from that of acceptance, which is to determine the degree of compliance with contract requirements.

However, in QA specifications that (by definition) contain ingredients of both end-result and materials and methods requirements, QC is designated as a function to be performed by the contractor. The assignment of this function to the contractor evolved from early materials and methods and statistically based specifications primarily for two reasons. First, it was found if the agency controls the contractor's process, the agency implicitly accepts responsibility for the product and "owns" it, regardless of the quality (References 9 and 10). Second, it is the contractor's production equipment and personnel that are used to produce the material and construction and, therefore, the best entity to control these items is the contractor.

With the shift of QC from the agency to the contractor, the concept and purpose of QC often became confused. This confusion apparently still exits. By definition, QC are "those QA actions and considerations necessary to assess and adjust production and construction processes so as to control the level of quality being produced in the end product" (Reference 7). The key word is control, not accept. The purpose of QC is not to sample and test for acceptance. Still, many agencies use the same test procedure and point of sampling for both QC and acceptance. If this is the case, the functions are not separated but, simply, conducted by different parties.

An important ingredient of QC is to develop a QC plan. Also, it is important that the plan realize that the purpose of QC is to measure those quality characteristics (for example, for structural concrete it should measure air content, slump gradation, and sand equivalent), and to inspect those activities that affect the production at a time when corrective action can be taken to prevent appreciable nonconforming material from being incorporated in the project (Reference 9). Although 28-day concrete compressive strength provides useful information to both the agency and the contractor, sufficient controls should be in-place to ensure quality material prior to placement of material.

A QC plan can be either contractor-specific or generic. Ideally, the plan should be contractor/operation-specific. However, many agencies choose to develop a generic plan to be used by all contractors or suppliers (Reference 11). In any case, the contractor should develop control limits based on the production capabilities of the specific operation. For effective QC actions, the control limits should not be based on the specification limits (Reference 6).

Other important ingredients in a QC plan are requirements of the use of qualified technicians and laboratories and the use of control charts. An example QC plan for structural concrete is shown in Appendix C of the AASHTO *Implementation Manual for Quality Assurance* (Reference 12).

Qualified Technicians

Clarification on the terms "qualified" and "certified" technicians is necessary. Regulation 23 CFR 637 uses the term qualified personnel, as opposed to certified. One reason that "qualified" was selected is that

some agencies are prohibited by law to certify technicians unless they are state employees. Also, technician certification usually implies the use of an ongoing recertification program, although technician qualification could be a one-time event. AASHTO *Standard Recommended Practice for Technician Training and Qualification Programs* (Reference 13) indicates that the terms "qualification" and "technician" are meant to be generic descriptions. The AASHTO *Quality Assurance Guide Specification* (Reference 8) uses the term "certified technicians." It is generally understood that technicians must be qualified and that one way to ensure this is to require them to have undergone some certification procedure.

If certification is required, most agencies either have an in-house certification program or participate in a regional (for example, Western Alliance for Quality Transportation Construction [WAQTC]) or national (for example, American Concrete Institute [ACI]) program. Several guidance documents are readily available on this topic(References 14 and 15).

Qualified Laboratories

23 CFR 637 defines qualified laboratories as "laboratories that are capable as defined by appropriate programs established by each state highway agency (SHA). As a minimum, the qualification program shall include provisions for checking test equipment and the laboratory shall keep records of calibration checks." (Reference 1).The June 29, 2000, date referenced in this section to qualified sampling and testing personnel also applied to the use of qualified laboratories. The requirement also states that "After June 30, 1997, each SHA shall have its central laboratory accredited by the AASHTO Accreditation Program or a comparable laboratory accreditation program approved by the FHWA." And furthermore, "After June 29, 2000, any non-SHA laboratory which performs IA sampling and testing shall be accredited in the testing to be performed by the AASHTO Accreditation Program or a comparable laboratory accreditation program approved by the FHWA." This date also pertains to any non-SHA laboratory used in dispute resolution sampling and testing (Reference 1). Suggestions on the requirements of qualified laboratories may be found on line at the following: *http://www.fhwa.dot.gov/pavement/materials/labqual.cfm*.

Statistical Process Control

One of the tools used by many manufacturing industries to help control the quality of their product is statistical process control (Reference 16); a tool that has not been readily accepted in the highway industry. One important tool in statistical process control is the use of control charts. Although many agencies require control charts to be plotted and maintained, contractors tend to comply reluctantly as evidenced by some of the following practices:

- Conducting only the minimum tests required.
- Plotting results on the charts at a convenient time rather than immediately, so as to react to out-of-control product.
- Using simplistic and less effective types of control charts, called "run charts."
- Not establishing effective control limits.
- Using specification limits for control limits (this is sometimes an agency requirement).
- Not reacting when product appears to be out of control.
- Using agency acceptance test results for their QC.

The purpose of a control chart is to provide a visual depiction of the population being produced. This means, ideally, that a control chart should provide estimates of the two population parameters — the average and the variability.

ACCEPTANCE

Because the acceptance function evolved from the earliest specifications, it is often considered the most important of the three. However, because QA is considered a system, all functions are important and should work together. The purpose of acceptance is to assess the quality of the product and, when appropriate, establish payment (Reference 6). Considerations involved in the acceptance function include the following:

- Acceptance procedures and requirements.
- Quality measures used.
- Possible use of contractor test results in the acceptance decision.
- Verification testing when contractor test results are used.
- Risks to the agency and the contractor.

Acceptance Procedures and Requirements

There are many important acceptance procedure issues that must be decided on when developing the acceptance plan. As with QC, there is no single prescription that works best, but several that have been used effectively by various agencies. It is important to determine what the agency wants to accomplish with the acceptance plan. If the primary function is to ensure that the contractors do not totally disregard quality, then the presence of an agency inspector accompanied by a minimal amount of acceptance testing may be sufficient. This limited effort, however, will not really allow the agency to distinguish between good and poor construction and material. To do this will require additional random sampling and testing along the lines of what has traditionally been done, or greater. If the agency wants a sound, statistically-based plan that will enable them to determine with a low degree of risk the quality levels that the contractor is providing, then even larger sample sizes will be required (Reference 6).

The evolution that has occurred in QA has affected not only the relationship among the QA functions, but has taken place within a function as well. For instance, acceptance testing once concentrated on those quality characteristics that were easiest to measure (for example, slump for Portland Cement Concrete [PCC]). More recently, quality characteristics are preferred that affect performance (for example, permeability for PCC).

Contractor Test Results Used in the Acceptance Decision

An important step in the evolution of QA programs occurred when 23 CFR 637 allowed contractor test results to be used in the acceptance decision. Recent history has indicated that, with the checks and balances required in 23 CFR 637, more testing in the acceptance function is being done using this alternative than would have been done solely by the agency under traditional acceptance testing. Studies have indicated that quality at least equal to that obtained under traditional specifications using only agency acceptance tests can be obtained with the use of contactor tests (Reference 17). However, a question still exists as to the validity and value of the use of contractor tests in the acceptance function. To answer this question, National Cooperative Highway Research Program (NCHRP) Project 10-58(02) *Using Contractor-Performed Tests in Quality Assurance* was undertaken. This research employed statistical procedures to evaluate whether state DOTs can effectively use contractor-performed test results in the QA process. The results of state DOT- and contractor-performed tests for hot-mixed asphalt concrete (HMAC), PCC, and granular base course were collected and statistically compared. Field projects were selected to allow evaluation of as many as possible of the QA variables that might affect the comparisons. The null hypothesis of this research was that the contractor-performed tests for use in the acceptance decision provide the same results as state DOT-performed tests. To test this hypothesis, contractor and state DOT results from six states were statistically compared to determine if differences between them in 1) variability, and 2) proximity to target or limiting values were significant at $\alpha = 0.01$.

For HMAC, the differences in means and variances found between the contractor and state DOT results are commonly significant. In general, the variability of state DOT quality assurance test results is larger than the variability of contractor quality control test results. Such differences might arise in part from

differences 1) in the number of specimens commonly tested by contractor and state agency technicians, and 2) in the time between sampling and testing of specimens often found between contractors and state agencies.

The statistical test results for PCC pavement and aggregate course construction are favorable toward pooling of contractor and state DOT results, although this finding is based on a smaller sampling of data than for HMAC. While there are no compelling reasons at this time not to use contractor-performed PCC tests for quality assurance, additional analyses would be prudent before this practice is generally adopted for PCC pavement and aggregate course construction.

Verification Testing

Verification Procedures

The ability of the comparison procedure to identify differences between two sets of test results depends on the number of tests that are being compared. The greater the number of test results in each set, the greater the ability of the procedure to identify statistically valid differences. Although a rule of thumb is a minimum agency rate of 10 percent of the contractor's testing rate, it is preferred to conduct a risk analysis to determine if a higher rate is warranted (Reference 11). It also must be decided whether it is the process or the test method that is to be verified. This relates to the use of independent or split samples.

Verification of Contractor Test Results

When contractor test results are used in the acceptance decision, the preamble of the final rule 23 CFR 637 requires, in addition to the IA program, a verification program including the use of independent samples for the verification sampling and testing. Rule 23 CFR 637 specifically states the following:

> "There are three sources of differences between two test results, differences in the material, differences in test procedures, and differences in sampling procedures. Split samples will only address the differences in test procedures and will only provide assurance that the contractor is performing the test properly. In a balanced system it is also necessary to assure that sampling of materials is performed properly. It is the FHWA's intent that the verification sampling and testing program be used to independently validate the quality of the material. Using independent samples will ensure that all sources of differences are measured. The FHWA recognizes the need to ensure that each contractor performs the tests correctly; that is the reason for extending laboratory and testing personnel qualification requirements and IA program requirements to the contractor if the contractor's test results are to be used in the acceptance decision. The FHWA expects the testing variability between the contractor and the State to be held to a minimum by requiring the contractor's program to be covered by an IA program and requiring the testing personnel and laboratories to be qualified. The FHWA has changed the definition of 'verification sampling and testing' and Sec. 637.207(a)(1)(ii)(B) to clarify the fact that the verification sampling and testing program is being used to validate the quality of the material." (Reference 1)

Even with the above explanation provided in 23 CFR 637, there exists misunderstanding about the difference in information provided by the use of independent versus split samples. To clarify the difference, the *Optimal Procedures for Quality Assurance Specifications* manual uses the terms "Test Method Verification" for the analysis using split samples, and "Process Verification" for the analysis using independent samples (Reference 6). A more detailed discussion of process and test method verification procedures is beyond the scope of this report but will be addressed as Caltrans transitions to its QA specification for structural concrete.

Risks and Operating Characteristic Curves

Establishing the limits to be used for acceptance is an important part of a QA program. Making the limits too restrictive deprives the contractor of a reasonable opportunity to meet the specification. If the limits are not sufficiently restrictive, however, they are ineffective in controlling quality. Selection of the limits relates to the determination of risks. The two types of risk encountered are the seller's (or contractor's) risk, α (alpha) and the buyer's (or agency's) risk, β (beta). A well-written QA acceptance plan takes these risks into consideration in a manner that is fair to both the contractor and the agency. Too large a risk for either party undermines credibility. Therefore, the risks should be both reasonably balanced and reasonably small.

The two types of risk, α and β, are very narrowly defined to occur at only two specific quality levels. β is the probability of accepting material that is exactly at the rejectable quality level, whereas α is the probability of rejecting material that is exactly at the acceptable quality level. To evaluate how the acceptance plan will actually perform in practice, it is necessary to construct an operating characteristic (OC) curve that is a graphic representation of an acceptance plan that shows the relationship between the actual quality of a lot and either 1) the probability of its acceptance (for accept/reject acceptance plans) or 2) the probability of its acceptance at various pay levels (for acceptance plans that include pay adjustment provisions) (Reference 7). The subjects of risks and OC curves are very important aspects of QA programs. A more detailed discussion of risks and OC curves is beyond the scope of this report but will be addressed as Caltrans transitions to its QA specification for structural concrete.

Quality Measures

Before listing the many quality measures used by agencies, a brief discussion of three of the most often used, individual values, average, and percent within limits (PWL) (or percent defective [PD]) is warranted. Although there are several quality measures that are used for acceptance, some are more effective than others in providing an estimate of the population. The earliest sampling and testing results relied on decisions based on individual values. There was no accumulation of values to determine an average, nor a measure of variability. The results of the AASHTO Road Test showed that this simple method of examining test results was inadequate. In the 1960s, with the initiation of statistically based specifications, acceptance specifications termed "Variability Known" were popular. These specifications measured only the average and assumed the variability to be known or constant. Several agencies quickly learned that in the highway industry this is an inaccurate assumption, because variability is rarely known or constant. That said, some agencies continue to use only the average as the preferred quality measure.

Significant advances in QA specifications were made in the 1970s. One was an understanding and analysis of risks, both to the contractor (seller) and to the agency (buyer). The advantages in the use of statistically based specifications had been recognized, logically, since their early development. However, with the introduction of the concept of risks, the advantages of a well-written statistically oriented specification to both the seller and buyer in terms of balanced risks became quantifiable (Reference 3).

Another advancement made in this decade was the adoption by some state agencies, such as New Jersey and Pennsylvania, of "Variability Unknown Specifications." In this type of specification, the average and variability are combined to estimate a quality level. Acceptance plans for this type of specification are based on procedures found in Military Standard 414 (Reference 18). The application of the specification is in the form of PWL or PD.

Typical quality measures used, in addition to the average, include the following:

- Individual values—the earliest form of acceptance. Because of the large variability associated with single values, this is one of the least-effective acceptance procedures.
- Range—the difference between the largest and smallest values in a set of data. It is the simplest measure of variability and is a reasonably effective measure for small sample sizes.
- Standard deviation—a measure of the dispersion of a series of results around their average. The standard deviation is the typical measure of variability and is a measure of precision.

- PWL—the percentage of the lot falling above the lower specification limits (LSL), beneath the upper specification limits (USL), or between the USL and LSL.
- PD—the percentage of the lot falling outside specification limits.
- Average absolute deviation (AAD)—for a series of test results, the mean of absolute deviations from a target or specified value. Because this quality measure uses a target value as a reference point, it is not usually applied with a quality characteristic with a single specification limit (for example, concrete compressive strength).
- Conformal index (CI)—a measure of the dispersion of a series of results around a target or specified value; this is a measure of accuracy. This quality measure is not usually applied with a quality characteristic with a single specification limit, for the same reason that AAD is not.

Training and Certification

Just as training and/or certification are necessary for QC purposes, they are also necessary for acceptance sampling and testing. Regulation 23 CFR 637, and the 1998 letter from the FHWA suggesting ways to implement 23 CFR 637, "requires that all sampling and testing of highway materials for Federal aid projects on the National Highway System (NHS), subsequent to June 29, 2000, must be performed by qualified technicians."

INDEPENDENT ASSURANCE

Because at least two different definitions of IA are used, there has been some confusion as to the following:

- The purpose of IA.
- How the IA program should be conducted.
- What the comparison of test results reveals.

Depending on which definition is used, the purpose of IA is to provide an independent assessment of the test results obtained from QC and acceptance or, in the broader context, to provide an independent assessment of the product and/or the reliability of test results obtained from the process control and acceptance testing. In both cases, the intended purpose of IA is to provide a connection to the acceptance plan. It involves a separate and distinct schedule of sampling, testing, and observation. In many agencies IA personnel perform other functions in addition to those related to IA. When statistical comparisons are made, they can provide an assessment of split-sample test results. The results from these comparisons are intended to reveal whether or not the test results from either QC or acceptance are statistically comparable to the independent test results.

It is important for the IA program to compare results and detect deficiencies, when they exist, in a timely manner. This improves the reliability of testing results. The timely comparison of data may be restricted by agency resources, including personnel, facilities, and geographic constraints. These resource needs must be considered in the IA program. The importance of qualified personnel to conduct the IA tests cannot be overstated.

Figure 3 shows how IA is organized in state DOTs. Twenty-eight agencies are organized statewide, 16 by district or region, 10 by project, and 10 by system. Figure 4 shows the source to which IA testing is applied. Forty-two agencies apply the IA function to agency testing, 26 to contractor testing, 15 to producer testing, 10 to supplier testing, and three to consultant testing.

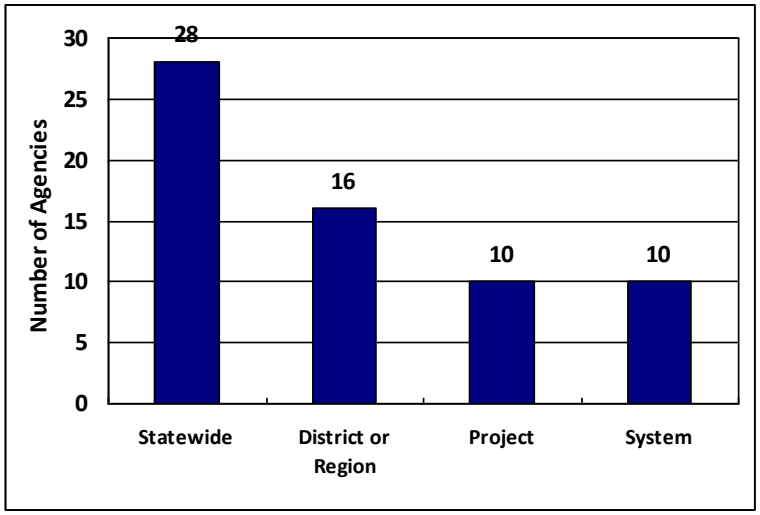

Figure 3 – Organization of Agency IA Testing (45 responses) (Reference 2)

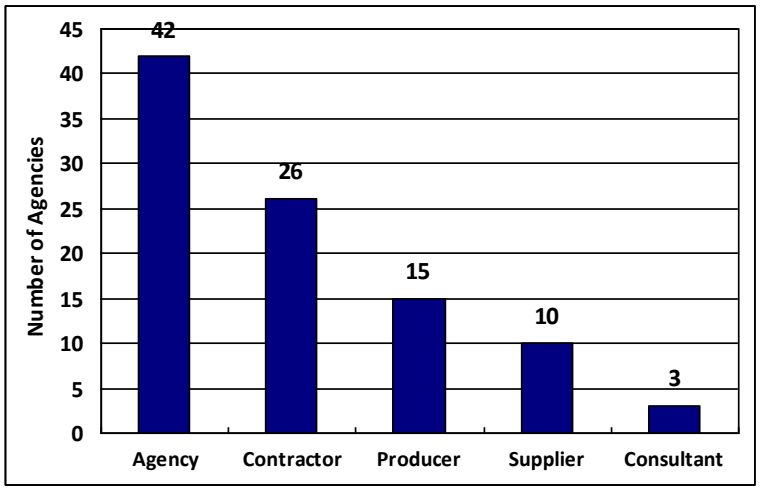

Figure 4 – Application of IA Testing (45 responses) (Reference 2)

The previous discussion provides an indication of the complexity of the IA function. Attempting to cover its many aspects is beyond the scope of this report. Note that internal Caltrans coordination, i.e., between OSM (Office of Structural Materials) and IA, is underway to assess what, if any changes, may be required to the current IA program to accommodate the transition to QA specifications for structural concrete.

USE OF CONSULTANTS AND INNOVATIVE PRACTICES IN QUALITY ASSURANCE PROGRAMS

Many agencies continue to downsize and restructure their organizations, and, as a consequence, reduce personnel levels. To address these issues, agencies have taken several steps to relieve the pressure on their remaining personnel. Two such steps are the use of consultants for testing and inspection and the use of innovative practices. One of the innovative practices is the use of warranties (References 19, 20 and 21). Also, design-build is being tried by some agencies (References 22 and 23). Although these are different forms of contracting than the typical materials and methods or QA types, they still involve the control and acceptance of the materials and construction.

Hiring outside consultants to perform QA functions is a common practice. NCHRP *Synthesis of Highway Practice 263*, published in 1998, reported that 17 agencies of 39 responding (44 percent) indicated that they contracted some QA testing outside of their workforce (Reference 24). Results of the 2005 survey indicated that the number of agencies using consultants has increased to 35 of the 45 U.S. agencies responding (78 percent).

PAY ADJUSTMENT SYSTEMS

A significant advancement in the 1970s was the adoption of the concept of incentive pay clauses for product that was exceptionally better than required by the specifications. This concept was complementary to the concept of disincentive pay clauses previously used. Benefits of incentive pay clauses were viewed as improved quality, the positive psychological effect of being rewarded for excellent control, and fairness to the contractor (Reference 25).

One of the primary purposes of a payment schedule is to provide payment commensurate with the quality provided. Often this includes sufficient incentive to produce the desired level of quality at the time of initial construction. Effective payment schedules encourage contractors to apply appropriate QC measures to ensure that the finished product will equal or exceed the desired level of quality a high percentage of the time. The rationale of the agency is that the small additional cost of good QC practices expended in advance is better than being faced with the anticipated future costs of poor quality construction, which may lead to premature failure of pavements, excessive maintenance repairs, possibly unsafe driving conditions, etc. (Reference 6).

A secondary purpose of the payment schedule is to recoup at least part of the anticipated future costs that are likely to occur when poor quality is received. For a variety of reasons, there will occasionally be times when QC measures are absent or ineffective, leading to less than satisfactory work. Provided the work is not too seriously deficient, it usually is both impractical and unnecessary to require removal and replacement (accept/reject), and the better solution in these cases is to accept the work at a reduced price. This is consistent with the legal principle of liquidated damages, a well-established means for recovering losses that are difficult to quantify precisely at the time the contract is executed (Reference 6).

There are several types of acceptance procedures currently used, including pay adjustment schedules and the older accept/reject procedure. The accept/reject procedure is still used extensively for an entire material/ construction item, such as soils and embankments. However, it is also used extensively as "screening tests" for a material as it is incorporated in the construction; for example, air content for PCC.

For pay adjustment schedules either step pay factors or equations are typically used. The earliest payment schedules were usually stepped schedules, such as that shown in Table 2 and plotted in Figure 5. More recently, there has been a tendency to use continuous (equation-type) payment schedules. One is shown in Equation 1 and also plotted in Figure 5.

Table 2 — Typical Stepped Payment Schedule Based on PWL (Reference 6)

Estimated PWL	Payment Factor (percent)
95.0 to 100.0	102
85.0 to 94.9	100
50.0 to 84.9	90
0.0 to 49.9	70

Equation 1 – Payment Schedule Equation

$$PF = 55 + 0.5 \times PWL$$

where *PF = payment as a percent of the unit bid price, and*
PWL = estimated percent within limits.

Although risk analysis could show these two payment schedules to have very nearly the same long-term performance, especially for small sample sizes, there is a distinct advantage associated with the continuous form. When the true quality level of the work happens to lie close to a boundary in a stepped payment schedule, the quality estimate obtained from the sample may fall on either side of the boundary owing primarily to chance. Depending on which side of the boundary the estimate falls, there may be a substantial difference in payment level, which may lead to disputes over measurement precision, round-off rules, and so forth. This potential problem can be avoided with continuous payment schedules that provide a smooth progression of payment as the quality measure varies (Reference 6).

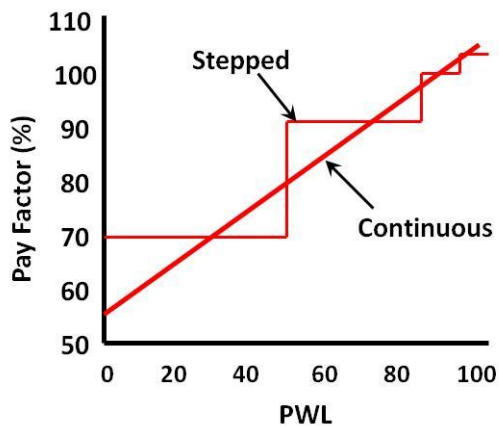

Figure 5 —Example of Stepped and Continuous Payment Schedules (6)

FUTURE OF QUALITY ASSURANCE PROGRAMS

Because QA programs are evolutionary, it was of interest to find out what changes were anticipated by the agencies. Twenty-three agencies reported that they anticipate significant changes in their QA programs in the near future and 22 indicated they did not anticipate any changes. Table 3 shows the products where changes are expected (Reference 2).

Table 3 — Products in QA Programs Where Changes are Expected

Product	Number of Agencies
Paving and/or PCC Structures	11
HMA and/or Binder	10
Soils, Embankments and/or Base	9
System	3
All	5
Manufactured Products	2
Precast and Prestressed Concrete	1
Pipe	1
Reinforcing Steel	1

Caltrans reported that it expected to make the following changes in its QA program:

1) For manufactured materials, when Caltrans implements a materials management system, Caltrans will no longer perform QA on a project-by-project basis, but will release material on a manufacturer's track record.
2) Implement requirement for contractors to develop a QC plan with minimum acceptable frequency and observations including identification of a quality manager. Caltrans QA will be "Did they follow the plan?" and perform statistically valid random sampling and separate tests.
3) Implement one-year workmanship and warrantee program.
4) Plan to aggressively move to performance/end-result specifications.

3 Quality Assurance Programs for Portland Cement Concrete Structures

As expected, the quality assurance (QA) programs for Portland Cement Concrete (PCC) structures are often similar to those of PCC pavements. Therefore, statistically based QA programs for PCC structures are not used by as many agencies as those for hot-mix asphalt (HMA); however, the use is increasing in this area (Reference 26).

TYPE OF QUALITY ASSURANCE PROGRAMS

Figure 6 show that 25 agencies use materials and methods provisions for PCC structures, with 14 agencies controlling the quality and performing acceptance. Seventeen agencies use QA programs with the contractor controlling quality and the agency performing acceptance, and 13 agencies use QA programs with the contractor controlling the quality and the agency using the contractor test results in the acceptance decision.

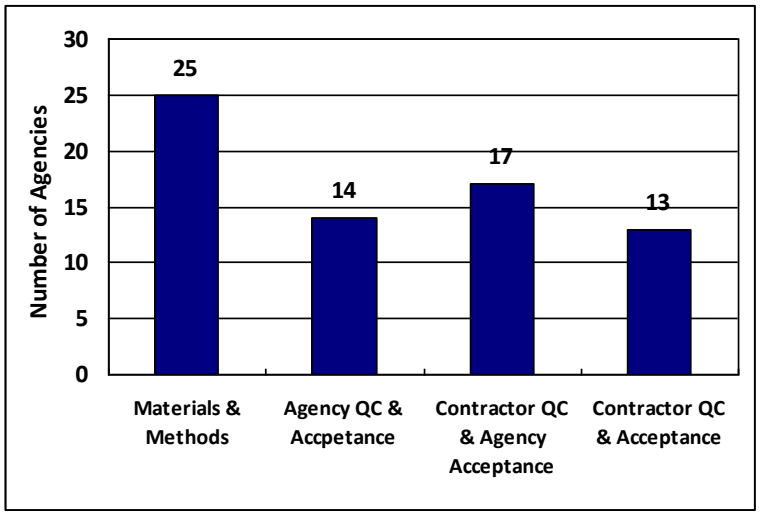

Figure 6 – QA Program for PCC (43 responses) (Reference 2)

Figure 7 shows that 36 agencies require the same test methods for quality control (QC) and acceptance, and 26 use the same point of sampling. One agency requires a different test method for QC and acceptance and 10 agencies specify test methods only for acceptance. Six use different points for sampling for QC and acceptance. Of those six, five use different independent random samples for QC and acceptance; and one samples for QC from the beginning of truck discharge and samples for acceptance from the middle of discharge.

QUALITY CONTROL

The attributes used for both QC and acceptance of PCC structures are shown in Table 4 and Figure 8. The attributes used most often for QC are gradation, slump, air content, and cylinder strength. Thirty agencies use gradation, 29 use slump, 28 use air content, and 21 use cylinder strength. Another often-used QC attribute is water–cement ratio, which is used by 15 agencies. Less frequently used are aggregate fractured faces and permeability.

For the frequency of QC tests, 30 agencies use an agency-established frequency and seven let the contractor choose the frequency. Five agencies require the use of control charts.

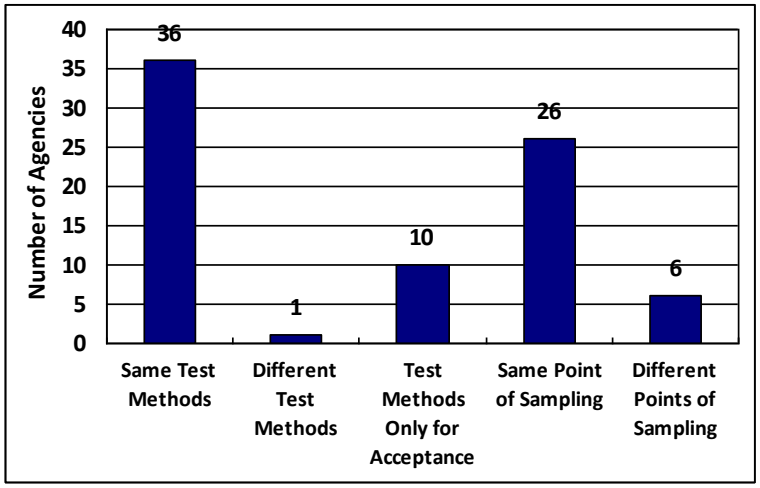

Figure 7 – Test Methods and Point of Sampling for PCC Structures (43 responses) (Reference 2)

ACCEPTANCE

Table 4 and Figure 8 show that the attributes used most often for acceptance of PCC structures are air content, used by 42 agencies; cylinder strength and slump, each used by 40 agencies; and gradation used by 30 agencies. Seventeen agencies accept PCC structures based on water–cement ratio, and 11 agencies accept PCC structures based on aggregate fractured faces. Some of the less frequently used acceptance attributes are permeability, temperature, sand equivalent, and beam strength.

Table 4 – Attributes Used for QC and Acceptance of PCC Structures

	QC	QA
Gradation	30	30
Air Content	28	42
Slump	29	40
Cylinder Strength	21	40
Water-Cement Ratio	15	17
Aggregate Fractured Faces	7	11
Permeability	5	8
Temperature	1	2
Sand Equivalent	0	2
Beam Strength	0	2

43 responses (Reference 2)

Nineteen agencies use accept/reject acceptance plans and 28 use pay adjustment systems. Of the 28 that use pay adjustment, 14 use a stepped pay schedule and 10 use equations. No one single agency uses only an incentive, whereas 19 use only a disincentive, and nine use both. Fourteen agencies use contractor test results as part of the acceptance decision. For procedures where the contractor test results are used in the acceptance decision, 10 agencies use all attributes, one agency uses only attributes based on accept/reject, and two use only attributes that do not involve pay.

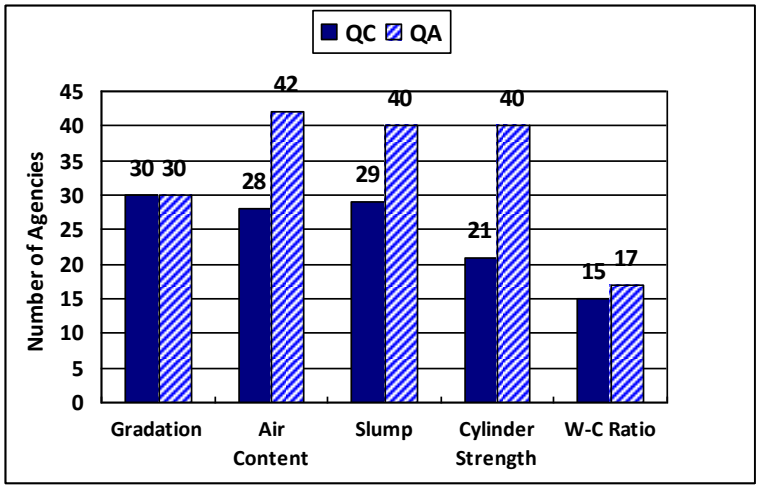

Figure 8 – Attributes Used Most Often for QC and Acceptance of PCC Structures (43 responses) (Reference 2)

Seven agencies use a verification system based on one contractor test to one verification test. Of those, one uses American Association of State Highway Transportation Officials (AASHTO) D2S, two use American Society for Testing and Materials (ASTM) D2S tolerances, two use agency-established tolerances, and two use other verification procedures. This number indicates that some agencies use more than one source. One agency uses *F*- and *t*-tests for a comparison of accumulated tests and one uses only the *t*-test. Ten agencies use one agency test compared with several contractor tests. Three agencies use a comparison of accumulated test results based on a lot, three use a completed project, and two use production over an extended period of time. Two agencies use independent samples, four use split samples, and seven use both.

QUALITY MEASURES USED FOR ACCEPTANCE

Table 5 and Figure 9 show the quality measures used for acceptance of PCC structures. The most common quality measures, used by 16 agencies, are the average and range. Ten agencies use the percent within limits (PWL) or percent defective (PD), eight use individual values, and six use the standard deviation.

Table 5 – Quality Measures Used for PCC Structures

Quality Measure	Number of Agencies
Average	16
Range	16
PWL	8
Individual Values	8
Standard Deviation	6
PD	2

43 responses (Reference 2)

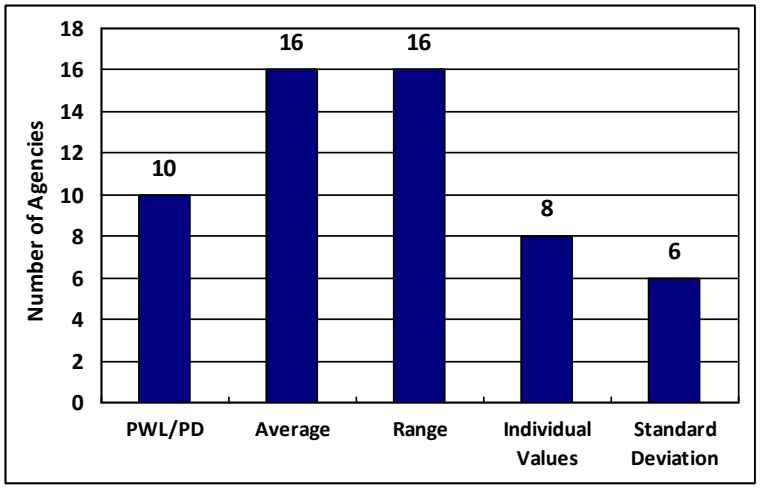

Figure 9 – Quality Measures Most Often Used for PCC Structures (43 responses) (Reference 2)

TRAINING AND CERTIFICATIONS

Figure 10 shows that training and certification for agency personnel involved in inspection, sampling, and testing of PCC structures uses mostly in-house, American Concrete Institute (ACI), or regional programs. Twenty-five agencies require in-house training and 24 require in-house certification. Eleven agencies use ACI for training and 16 use certification from ACI. Six agencies use regional programs for agency personnel training and 10 use regional certifications. University, college, American Concrete Pavement Association (ACPA), and Precast/Prestressed Concrete Institute (PCI) training and certification, and state board certification are also used. For contractor personnel, 11 agencies require in-house training and 14 require in-house certification. Also, 12 agencies use ACI for training and 15 for certification. Four allow contractor personnel to receive regional training, and seven use regional certification. University, college, ACPA, and PCI training and certification, and state board certification are also used for contractor personnel.

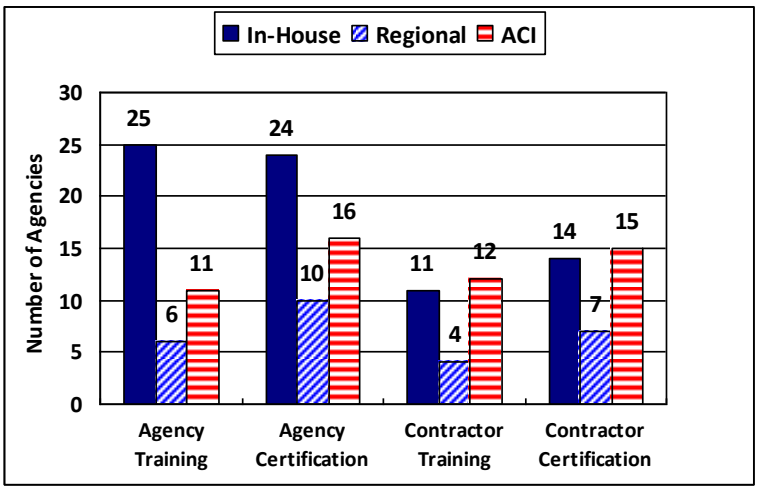

Figure 10 – Training and Certification Requirements Most Often Used for PCC Structures (43 responses) (Reference 2)

CALTRANS SURVEY ON QUALITY ASSURANCE FOR STRUCTURAL CONCRETE

In August 2008, Caltrans began its study of the possible shifting of its structural concrete sampling and testing from State forces to the private sector and/ or contractors. Caltrans began with a survey (attached as Appendix 2) of the state highway agencies (SHA) and District of Columbia, and Puerto Rico and Canadian provinces. Of the 31 agencies that responded, 11 states and one Canadian province reported that they required the contractor to perform QC testing. As shown in Table 6, nearly two-thirds of the agencies still play a significant role in sampling and testing. Also shown are the materials tested by agencies with QA programs for structural concrete.

Table 6 — Selected Results of Caltrans Survey on Sampling and Testing of Structural Concrete

Responsibility for	State Forces	Private Sector or Contractor
Sampling and Making Cylinders	20	9
Testing for Consistency (Slump)	18	11
Testing Cylinders for Compressive Strength	19	9

State DOT	QA Testing for Structural Concrete		
	Concrete Only	Concrete and Aggregate	Data Not Available
Arizona	✓		
Colorado	✓		
Connecticut			✓
Florida	✓		
Indiana			✓
Iowa		✓	
Kentucky	✓		
Michigan			✓
Montana	✓		
Nebraska		✓	
Tennessee	✓		
Texas		✓	
Virginia	✓		

4 FEDERAL HIGHWAY ADMINISTRATION QUALITY ASSURANCE STEWARDSHIP REVIEWS (Reference 27)

The objective of these activities was to review the state agency quality assurance (QA) program practices and procedures, and to ascertain the status of the states' implementation of the 23 CFR 637 QA regulations. These reviews were conducted by the Office of Infrastructure as part of the Federal Highway Administration's (FHWA) overall stewardship activities for state agency QA programs.

The reviews considered the entire QA program in each state. Prior to the start of the reviews in FY 2004, there was some concern expressed over the use of contractor supplied test results in the acceptance decision. As shown in Figure 11, 33 states currently allow the use of contractor testing in the acceptance decision. As a result of this fact, the review focused on states that use contractor tests results in the acceptance decision. Twenty of the 24 reviews were conducted in states using contractor test results in the acceptance decision.

Figure 11 — SHAs Using Contractor Test Results in Acceptance Decision (Reference 27)

The assessments were a joint effort involving the state agencies and FHWA Headquarters, Resource Center, and Division Office personnel. Material practices involving the regulation were examined at the states' headquarters, region/district, and construction project level.

As shown in Figure 12, 24 stewardship reviews were completed between FY 2003 and 2008. California was reviewed in FY 2004.

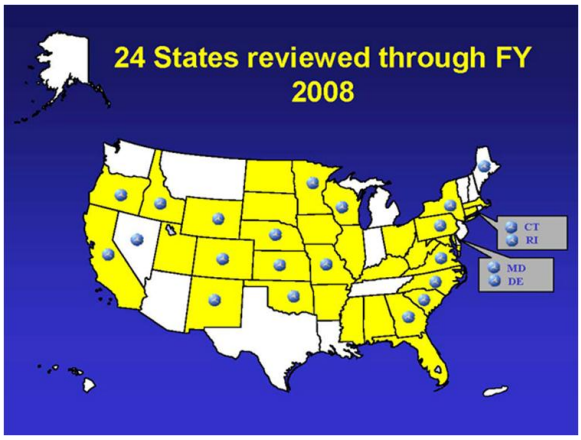

Figure 12 — QA Stewardship Reviews: FY 2003 -2008 (Reference 27)

The most recent QA assessment data provided by the FHWA are shown in Table 7 and indicate that Caltrans score improved from 66.6 in 2008 to 77.2 in 2010.

Table 7 — Caltrans Quality Assessment Scores

	2008		2010	
	National	Caltrans	National	Caltrans
High	86.8		98.2	
Low	17.9		51.6	
Average	60.0	66.6	71.8	77.2

Findings

The most recent stewardship review report highlights "best practices" as well as "opportunities for improvement" in the following areas: acceptance; independent assurance (IA); and laboratory and technician qualification. Report highlights pertaining to acceptance and IA are shown herein. The complete report is available at the following:
http://www.fhwa.dot.gov/pavement/materials/stewardship2008.pdf

Acceptance - Use of Contract Test Results

In most states it was found that the state's validation system needed to be strengthened. Deficiencies included:

a. Not using independent samples for state verification samples.
b. No statistical comparison of contractor and state data.
c. Low state-to-contractor test comparison ratio of one vs. 10 results, and one vs. one comparisons of test results for validation.
d. Lack of control of contractor supplied data.
e. Lack of a defined time for comparing test results.
f. Not increasing testing frequencies when test results do not compare.
g. States not controlling the sampling location and timing.
h. States allowing biased retesting provisions.
i. Lack of security for samples.
j. Lack of random sampling.

Independent Assurance Program Issues

a. Many states should review their test result comparison tolerances. In some instances tolerances were developed in the early 1970s and have not been thoroughly examined since then. In many cases the testing variability has improved due to certification programs and improvements to test procedures. Therefore, the tolerances may be too large.
b. Some IA inspectors take independent samples. IA should consist of a program of split sampling and testing or reference sample testing to help ensure that the testing is being performed correctly on properly calibrated equipment. Independent samples do not efficiently isolate issues or detect problems associated with sampling, testing, and equipment, unless large numbers of independent samples are taken.
c. IA forms refer to specification compliance. IA is specifically intended for determining testing competence, not specification compliance.
d. Gyratory compaction is not included in the state's IA program. The IA program should cover all test procedures that are used in the acceptance decision.
e. The state's IA program does not cover technicians in the QC laboratories. All technicians including state personnel, contractor personnel, and consultant personnel that are performing testing that is used in the acceptance decision must be qualified.
f. Methods need to be developed to standardize comparison of IA and acceptance test results including having both test results on the IA form.

g. Timely resolution of discrepancies in IA, specification, compliance, and validation need to be documented and included in the project files.
h. A goal of 90 percent coverage of the active testing personnel per year should be established when the system approach is used for IA.
i. States should require technicians to calibrate the air meters used for testing air content on Portland Cement Concrete.
j. Comparison tolerances should be developed for all tests that are covered by the IA program. Additionally, the steps to be taken once an IA sample result does not compare should be documented.
k. IA programs should include some observation of test procedures.

5 CONCLUSIONS AND RECOMMENDATIONS

This report provides an overview of the types of quality assurance (QA) programs used by state transportation agencies for control and acceptance of typical highway pavement materials and construction. Additionally, it highlights *how* these QA programs operate within the regulatory requirements of the Federal Highway Administration's 23 CFR 637 as well as a "status of the States' implementation." Finally, the most recent FHWA quality assessment of Caltrans is included to demonstrate Caltrans' commitment to ensuring that the materials and workmanship incorporated into federal-aid highway construction projects conform to the requirements of the approved plans and specifications. This report is the first step in Caltrans' transition to QA specifications for structural concrete.

CONCLUSIONS

With respect to state-of-the-practice of QA programs in general and to structural concrete in particular, the following conclusions are noteworthy (References 2, 26, 27, 28).

As expected, the state QA programs are quite varied. Some types of programs are used more frequently than others within a material type; for example, materials and methods for soils and embankments, and agency use of contractor test results in the acceptance decision for hot-mix asphalt (HMA). Therefore, although some definite trends were reported, each agency generally has its own ideas and reasons as to how and why its QA program operates as it does. An example of the diversity can be found in the use of pay adjustment schedules. Most of the agencies use stepped pay schedules that, naturally, vary appreciably from state to state. Some agencies use pay equations, and, for those agencies, no single equation is used appreciably more than another. One area of relative agreement is in training and certification. Most agencies tend to rely on in-house training and certification when either is required for all material and construction areas. Some agencies rely on regional and national accreditation programs such as Precast/Prestressed Concrete Institute (PCI) and American Concrete Institute (ACI).

Two practices were found that indicated that QA programs were not being used to their optimum capability. The first is that, although the concept of QA calls for the separation of the functions of quality control (QC) and acceptance, it is not clear that the majority of agencies clearly separate them. For all material and construction areas surveyed, both QC and acceptance functions often overlap by the use of the same test methods and point of sampling, regardless of whether the agency or the contractor performs the test. Many agencies use simpler but statistically weaker procedures for the type of verification system when the agency uses the contractor test results as part of the acceptance decision. This procedure is less sensitive in measuring differences between agency and contractor test results.

There is substantial agreement between the types of QA programs used for Portland Cement Concrete (PCC) structures and PCC paving. As for PCC paving, almost 40 percent of the agencies use QA programs for PCC structures in which the contractor controls the quality and the agency performs acceptance. The other 60 percent are evenly divided between the practice of the agency controlling quality and performing acceptance, and the contractor controlling the quality and the agency using contractor test results in the acceptance decision. Twenty-five agencies use materials and methods-type provisions. Gradation, air content, and slump are the most frequently used QC attributes. Almost 70 percent of the agencies establish the frequency for contractors to conduct QC tests and five agencies require control charts. Air content, cylinder strength, slump, and gradation are the most often used attributes for acceptance. More than 80 percent use the same test methods for QC and acceptance and 60 percent use the same point of sampling. More than 60 percent of the respondents use pay adjustment procedures. Fourteen of those using pay adjustments use stepped pay schedules, with nine using both an incentive and disincentive and 19 using only a disincentive. The average, range, and percent within limits/percent

defective (PWL/PD) are the quality measures most often used. Of the 14 agencies that use contractor tests in the acceptance decision, seven compare one contractor test result with one agency test result, one uses the *F*- and *t*-tests, and 10 use one agency test result compared with several contractor test results. For verification, two use independent samples, four use split samples, and seven use both.

The implementation of the independent assurance (IA) function is as diverse among agencies as other aspects of the QA program.

The use of consultants is widespread, with more than 75 percent of the responding agencies reporting that they use consultants. This is not surprising considering the general downsizing that has taken place within state highway agencies (SHA). Most use the consultants in place of or as a supplement to agency acceptance testing, and a significant number use them in place of or as a supplement to contractor QC testing.

Caltrans most recent quality assessment score from the FHWA suggests that its performance is above average.

RECOMMENDATIONS

Although the concepts and strategies on QA specifications emerged from the pavement arena, of particular interest is the state-of-the-practice for structural concrete. Caltrans recognizes that this transition will require a carefully crafted plan to address the three key components of a QA program: QC, acceptance, and IA. Specifically, Caltrans recognizes that this plan for QA specifications for structural concrete must consider the following (References 2 and 28):

- The attributes to use for QC and for acceptance.
- The test methods to use for QC and for acceptance.
- The point of sampling to use for QC and for acceptance.
- Who establishes the frequency for QC tests.
- How to establish the QC tests.
- The quality measure to use for acceptance.
- Whether accept/reject or pay adjustment provisions will be used.
- What levels of risks are appropriate for the agency and contractor.
- Whether contractor tests will be used in the acceptance decision, and, if they are:
    - What type of verification system that will be used;
    - Whether the agency will use split samples, independent samples, or both; and
    - The purpose of the verification.
- If training and/or certification will be required, and, if required, who will do it.
- How the IA function will be administered.

It is recommended that Caltrans continue its transition to QA specifications for structural concrete through careful internal (Headquarters Office of Structural Materials, Construction and IA, and District) and external (FHWA and industry) coordination.

Decision Document

Enhance the Quality Assurance Program for Structural Concrete Sampling and Testing

1. Problem Statement

The Department's existing construction quality assurance (QA) program for structural concrete does not clearly place the responsibility and accountability for quality on the contractor.

Although the contractor is required to control the quality of the material entering the work, the appropriate quality control (QC) tests are at the contractor's discretion. As a result, the QA testing performed by the Department is so frequent that the contractor often does very little testing during construction, creating a reliance on the Department's tests in lieu of the contractor's QC. This frequency of testing by the Department causes an increase in Capital outlay support (COS) costs.

With recent changes to *Standard Specifications*, Section 90, "Portland Cement Concrete," there is a focus on allowing the contractor greater control of a concrete mix design. The contractor's goal would be to fully utilize the options available to produce cost effective concrete that meets their needs in construction, and delivers the quality and performance characteristics required by the Department. However, with the current QA program, there is no incentive for the contractor to develop an effective (robust) QC program necessary to reach this goal.

In addition, there is a need to review current Portland Cement Concrete tests for relevancy given that concrete produced today involves more than the basic components of aggregate, cement and water. For tests that are deemed necessary to control the quality and measure performance, appropriate QC, QA, and independent quality assurance (IQA) responsibilities must be defined. The QC, QA and IQA[1] responsibilities should be clear regardless of procurement method (e.g. design-bid-build, design-build or Public-Private Partnerships (P3)) or where different implementing agencies[2] are responsible for delivery.

[1] As defined in Deputy Directive DD-90, "Funding of Quality Management Work on State Highway Project", Independent Quality Assurance entails the activities performed by the Department at a project level to ensure that the implementing agency's quality assurance activities result in projects being developed in accordance with Department standards, policies and practices and the quality control plan provided by the project sponsor. In the construction phase, a QC plan will be developed and provided by the contractor. QC and QA are also defined in DD-90 at the project development stage.

[2] The implementing agency is that entity charged with successful completion of each project component as defined in Government Code Section 14529 (b) per Deputy Directive DD-23-R1, "Roles and Responsibilities for Development of Projects on the State Highway System", February 2007.

2. Recommendation

Alternative B. Clearly assign the responsibility of quality control testing for structural concrete as outlined under 4.2 Alternative B from the Department to the contractor. The implementing agency (the Department for most state highway projects) becomes responsible for the QA program. The Department remains responsible for IQA as well as the independent assurance (IA) program.

3. Background

The current construction quality assurance (QA) program requires the Department's personnel to perform various sampling and testing of concrete materials to provide confidence that the contractor has fulfilled contract requirements for quality. Sampling and testing of concrete materials require close coordination with contractor's construction activities, especially when considering aggressive construction schedules and potential delay costs. Sampling and testing coordination with other construction activities are critical in completing projects on time.

With the exception of precast concrete, the Department currently does most of the field sampling and testing of structural concrete. The contractor is only required to do testing necessary to qualify their mix designs for the concrete specified by compressive strength either with certified test data or trial batch test reports.

The Department also tests and qualifies many aggregate sources, to determine whether they meet the specifications prior to incorporation into the contractor's design. This is accomplished by sampling the aggregates at their source and testing for compliance with the specifications at regular intervals.

Once a mix design is approved, the Department assumes responsibility for testing the aggregate and cementitious material used during production of the concrete mix. The Department also performs testing and sampling of fresh concrete at the jobsite, e.g. air content, yield tests and producing concrete cylinders for compressive strength testing.

During placing operations, per section 4-90 of the *Construction Manual*, the Department also sends inspectors to concrete batch plants to monitor the mixing of the concrete. These inspectors confirm aggregate moisture and the proportioning of cement, water, and aggregates into transit mixers. At regular intervals, and before any mixing operations, batch plants are inspected by Department inspectors to certify that batching equipment used to weigh the aggregate, water, and cement is calibrated.

Though the contractor is required under *Standard Specifications*, Section 6, "Control of Materials" to control the quality of the material entering the work, the tests required are left up to the contractor to determine. The specifications do not require the contractor to submit the results of these tests to the Engineer. In addition, the *Construction Manual* currently states, "For acceptance of materials or work, resident engineers must not use as documentation any tests the contractor performs to control

the work." However, there are various instances where contractor's QC data are accepted for QA purposes: Precast concrete, cement, curing compound, chemical admixtures, etc.

The Federal Highway Administration's (FHWA's) quality assurance requirement described in Title 23, Code of Federal Regulations, Chapter I, Part 637, "Construction Inspection and Approval" (23 CFR 637, attached Appendix A) states that "Each STD [state transportation department] shall develop a quality assurance program which will ensure that the materials and workmanship incorporated into each Federal-aid highway construction project on the NHS [National Highway System] are in conformity with the approved plans and specifications, including approved changes." Furthermore, 23 CFR 637, Subpart B, "Quality Assurance Procedures for Construction," makes STDs responsible for developing, maintaining, and administering a quality assurance program that includes an approved IA program.

Under the FHWA requirements, the IA program is responsible for:

- Evaluating testing equipment by using calibration checks and proficiency samples.
- Evaluating testing personnel by observation and proficiency samples.
- Evaluating proficiency test results and developing guidelines, including tolerance limits, for the comparison of test results.
- Reporting annually to the FHWA summarizing the efforts of the IA program if the STD uses a system approach.

The Department does maintain an IA program that has the responsibility of routine evaluation of all testing personnel, testing equipment, and laboratories for competency to perform specific tests on construction materials. Department personnel are routinely certified through the IA program on specific test methods to ensure material testing is properly performed. The Department's IA program is available to commercial and local agency laboratories, and participation in this program is required for those laboratories and testers providing test results for contract acceptance considerations on the Department's and NHS projects.

The Department's practices and IA program are consistent with FHWA regulations and other state transportation departments.

23 CFR 637 also allows contractor's QC sampling and testing to be used in the acceptance decision under specific conditions. For the past year, the modified *Standard Specifications* Section 40, "Concrete Pavement" has been in use to give contractors a greater responsibility in QC testing. A list of the specific QC tests is in the *Standard Specifications*. However, except for air content test for air-entrained concrete, these tests are not used as part of the acceptance decision per 23 CFR 637. Other currently approved QC/QA specifications include: precast concrete, hot mix asphalt and rapid strength concrete.

In 2008, the Department conducted a survey of all other state highway departments to assess the practice of their QC/QA program for structural concrete. Thirty one (31)

responded, of which eleven (11) required the contractor to perform varying degrees of concrete sampling and compressive strength testing. Incidentally, Canada requires that the contractor be responsible for sampling and making cylinders as well as testing for concrete consistency.

Proposed structural concrete QC/QA specification guidelines were presented to the California bridge construction industry at the June 2009 California Bridge Construction Forum held in San Diego. The industry expressed concern whether the Department was ready to make the cultural shift with contractor's performing most of the tests. At the same time, they would question a program where contractors and the Department did duplicate testing.

4. Alternatives

4.1 Alternative A ("No Action" Alternative)

Continuing the current practice of Department personnel performing concrete sampling and testing during construction is not desirable because it creates an atmosphere where the contractor may hinge their product quality on the Department's testing. Because of contractors' dependency upon the Department to determine product quality, contractors have less incentive to develop innovative practices to improve product quality. In addition, confusion and disputes on charges of time and materials may then arise from the timeliness of these test reports resulting in additional project costs.

4.2 Alternative B (Recommended Alternative)

In order for the contractors to successfully be given flexibility and responsibility in developing their product, they must have an effective QC program that ensures they are achieving the required performance per *Standard Specifications*. In turn, the Department must have an effective QA program that does not duplicate the contractor's QC process but rather assesses its effectiveness.

The proposed specification requirements described herein are consistent with federal regulations and other state highway departments that are currently implementing similar programs. Current practice and documentation on QC/QA specification such as FHWA report *FHWA-RD-02-095 Optimal Procedure for Quality Assurance Specifications* as well as FHWA *Technical Advisory T 6120.3 Use of Contractor Test Results in the Acceptance Decision, Recommended Quality Measures, and the Identification of Contractor/Department Risks* will be used as reference guides to develop the actual specifications. *Standard Specifications* Section 40, "Concrete Pavement" will be used as a starting point in the specification development.

The new concrete quality control specification will require the contractor to prepare and submit a quality control plan (QCP) and be responsible for testing and reporting concrete quality control test results at specified frequencies. Payment for QC testing

would be included in the contract price for structural concrete and in effect the costs of quality control would shift from COS to project capital.

The QCP submitted by the contractor would include, at a minimum:

- Identifying a Quality Control Manager (QCM).
- Providing an accredited independent testing facility.
- Names of the trained and certified sampling and testing technicians.
- Sampling, testing, decision making, and reporting procedures.

The QCM reviews, approves and forwards their QC test reports to the Engineer for review and material documentation. An example of the proposed QC tests and their testing frequency is in Appendix B.

The Department would maintain a QA program that would perform sampling and testing to verify and validate the quality of the material. The frequency would in part be based on consequence of failure associated with a specific test. Results from the QA tests would be reported to the contractor. Results from QC, QA tests or a combination thereof may be used to determine material acceptance and/or administrative deduction for out of compliance concrete (e.g. *Standard Specifications* Section 90-9, "Compressive Strength").

Construction Manual section 3-609 states, "For acceptance of materials or work, resident engineers must not use as documentation any tests the contractor performs to control the work. Perform and record acceptance tests as required by section 6-1, 'Sample Types and Frequencies,' of this manual." This section will need to be revised to reflect the direction of this decision document (i.e. any verification test(s) by the Department, in addition to the contractor's QC test results, may be used by the Department as a part of the acceptance of materials). For projects administered by others, verification sampling and testing would be the responsibility of the implementing agency.

This revision is necessary to conform to 23 CFR 637 which states that the quality control sampling and testing may be used in the acceptance program if the following is satisfied:

- QC sampling and testing performed by qualified laboratories and personnel and evaluated by an IA program.
- QA sampling and testing performed to validate product quality.
- STD must establish a dispute resolution system. The dispute resolution system shall address the resolution of discrepancies occurring between the QA sampling and testing and the QC sampling and testing.

A process and specifications will be developed to address common discrepancies between QC and QA results for structural concrete. Besides the Department's dispute resolution process outlined in section 5-403 of the *Construction Manual*, the manual may need to be amended to include procedures for resolving disputes arising from structural concrete testing and sampling results.

Regardless of the implementing agency, the Department has the responsibility of the IQA function. The proposed IQA process would require a well defined audit of the project records to verify the frequencies, results, and resolutions of discrepancies between the QC and QA tests. It is recommended that this audit be regularly performed on all projects. Section 5-102 of the *Construction Manual* outlines the sixty three (63) categories of project documents. The categories pertinent to this decision document are: 37 Initial Tests and Acceptance Tests; 38 Quality Control and Quality Assurance; 41 Report of Inspection of Material; 43 Concrete Records. *Bridge Construction Memo 4-0.0* also outlines the scope of the project record review for structures construction items.

All personnel engaged in sampling and testing of concrete to comply with acceptance criteria will require certification. All associated testing facilities will require accreditation. To meet this increase in demand for certification and accreditation, nationally recognized programs such as AASHTO Material Reference Laboratory (AMRL), Cement and Concrete Reference Laboratory (CCRL), and the American Concrete Institute (ACI) may be used in lieu of the Department's IA Program. Where possible, the use of well developed and broadly accepted national standards for sampling and testing should be considered to ensure consistency and to ease implementation.

In summary, the main benefits of the proposed option are:

- Increase project efficiency and contractor accountability by requiring the contractor to be responsible for structural concrete QC. The contractor can better control the schedule and efficiency of testing and can use the quality control process to produce the most cost-effective mix design that achieves the required performance.
- The costs of quality control testing will primarily be captured in project capital rather than COS as it is today.
- Provide for a consistent level of QC/QA/IQA testing on all projects regardless of the procurement mechanism or the implementing agency.

5. Fiscal Impact

This change would likely reduce COS costs while increasing capital costs on projects. Generally, the reduction in COS would be the result of fewer tests performed by Department staff. The precise impact will depend on how the QC/QA and responsibilities are defined and how IQA is implemented.

Corporate resources are needed to affect this change.

6. Organizational Impact

This change would likely reduce the number of tests performed by Department staff and shift their focus onto QA and IQA responsibilities.

7. Other Affected Documents

Other documents that are affected and will require changes include:

- *Standard Specifications* (Section 6, Section 90).
- *Construction Manual.*
- Construction Procedure Directives.
- *Concrete Technology Manual.*
- *Bridge Construction Records and Procedure Manual.*
- *Independent Assurance Manual.*
- California Test Methods (as needed).

8. Risk(s)

Identified risks include:

- Internal and external resistance to transferring a portion of test responsibility to industry.
- Inability of industry to effectively manage this increased responsibility.
- Potential for fraudulent testing or test results.
- Developing and maintaining a robust QA program supported by management.
- Internal challenge in agreeing to a scope for the QA program.
- A laborious specification development process.
- Implementation delay due to moratorium on specification development due to development of the 2010 specification.

9. Proposed Implementation

General

- Begin implementing new specifications in July 2011. Identify a project manager and assign appropriate staff to each task. Develop a detailed delivery plan.
- Liaison with industry groups, e.g. AGC, EUCA/SCCA, RPC[3].

Develop QC/QA and IQA Policy and Practice

- Review current test methods and inspection practices. Update, replace with recognized national methods, or remove as appropriate.

[3] AGC – Associated General Contractors, EUCA/SCCA – Engineering & Utility Contractors Association/Southern California Contractors Association, RPC – Rock Products Committee

- Review lessons learned in *Standard Specifications* Section 40 QC/QA practice.
- Develop QC/QA/IQA for each test method or inspection practice.
- Retool inspection protocols for batch plants. Include protocol for inspection and certification of equipment related to the batching and delivery of concrete.

Specifications

- Review lessons learned from states that have implemented QC/QA specifications.
- Determine key quality characteristics to measure for acceptance.
- Modify specifications to include contractor's QC and the implementing agency's QA requirements for structural concrete.
- Reconcile QC/QA/IQA requirements for minor concrete and Portland Cement Concrete pavement.

Guidance and Training

- Develop QA sampling and testing guidance to be incorporated into the *Construction Manual*, *Bridge Construction Records & Procedures Manual*, and the *Office of Structure Materials Practices and Procedures Manual*.
- Update or remove CTMs as needed.
- Modify the Department's *Independent Assurance Manual* to accommodate outside certification and accreditation agencies.
- Develop IA tools that will enable the Department to implement consistent QC/QA concepts statewide.
- Train staff and industry on structural concrete QC/QA philosophy and its implementation.

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Appendix A

Code of Federal Regulations
TITLE 23—HIGHWAYS

PART 637—CONSTRUCTION INSPECTION AND APPROVAL

Subpart B—Quality Assurance Procedures for Construction

§ 637.201 Purpose.

To prescribe policies, procedures, and guidelines to assure the quality of materials and construction in all Federal-aid highway projects on the National Highway System.

§ 637.203 Definitions.

Acceptance program. All factors that comprise the State transportation department's (STD) determination of the quality of the product as specified in the contract requirements. These factors include verification sampling, testing, and inspection and may include results of quality control sampling and testing.

Independent assurance program. Activities that are an unbiased and independent evaluation of all the sampling and testing procedures used in the acceptance program. Test procedures used in the acceptance program which are performed in the STD's central laboratory would not be covered by an independent assurance program.

Proficiency samples. Homogeneous samples that are distributed and tested by two or more laboratories. The test results are compared to assure that the laboratories are obtaining the same results.

Qualified laboratories. Laboratories that are capable as defined by appropriate programs established by each STD. As a minimum, the qualification program shall include provisions for checking test equipment and the laboratory shall keep records of calibration checks.

Qualified sampling and testing personnel. Personnel who are capable as defined by appropriate programs established by each STD.

Quality assurance. All those planned and systematic actions necessary to provide confidence that a product or service will satisfy given requirements for quality.

Quality control. All contractor/vendor operational techniques and activities that are performed or conducted to fulfill the contract requirements.

Random sample. A sample drawn from a lot in which each increment in the lot has an equal probability of being chosen.

Vendor. A supplier of project-produced material that is not the contractor.

Verification sampling and testing. Sampling and testing performed to validate the quality of the product.

§ 637.205 Policy.

(a) *Quality assurance program.* Each STD shall develop a quality assurance program which will assure that the materials and workmanship incorporated into each Federal-aid highway construction project on the NHS are in conformity with the requirements of the approved plans and specifications, including approved changes. The program must meet the criteria in § 637.207 and be approved by the FHWA.

(b) *STD capabilities.* The STD shall maintain an adequate, qualified staff to administer its quality assurance program. The State shall also maintain a central laboratory. The State's central laboratory shall meet the requirements in § 637.209(a)(2).

(c) *Independent assurance program.* Independent assurance samples and tests or other procedures shall be performed by qualified sampling and testing personnel employed by the STD or its designated agent.

(d) *Verification sampling and testing.* The verification sampling and testing are to be performed by qualified testing personnel employed by the STD or its designated agent, excluding the contractor and vendor.

(e) *Random samples.* All samples used for quality control and verification sampling and testing shall be random samples.

§ 637.207 Quality assurance program.

(a) Each STD's quality assurance program shall provide for an acceptance program and an independent assurance (IA) program consisting of the following:

(1) Acceptance program.

(i) Each STD's acceptance program shall consist of the following:

(A) Frequency guide schedules for verification sampling and testing which will give general guidance to personnel responsible for the program and allow adaptation to specific project conditions and needs.

(B) Identification of the specific location in the construction or production operation at which verification sampling and testing is to be accomplished.

(C) Identification of the specific attributes to be inspected which reflect the quality of the finished product.

(ii) Quality control sampling and testing results may be used as part of the acceptance decision provided that:

(A) The sampling and testing has been performed by qualified laboratories and qualified sampling and testing personnel.

(B) The quality of the material has been validated by the verification sampling and testing. The verification testing shall be performed on samples that are taken independently of the quality control samples.

(C) The quality control sampling and testing is evaluated by an IA program.

(iii) If the results from the quality control sampling and testing are used in the acceptance program, the STD shall establish a dispute resolution system. The dispute resolution system shall address the resolution of discrepancies occurring between the verification sampling and testing and the quality control sampling and testing. The dispute resolution system may be administered entirely within the STD.

(iv) In the case of a design-build project on the National Highway System, warranties may be used where appropriate. See 23 CFR 635.413(e) for specific requirements.

(2) The IA program shall evaluate the qualified sampling and testing personnel and the testing equipment. The program shall cover sampling procedures, testing procedures, and testing equipment. Each IA program shall include a schedule of frequency for IA evaluation. The schedule may be established based on either a project basis or a system basis. The frequency can be based on either a unit of production or on a unit of time.

(i) The testing equipment shall be evaluated by using one or more of the following: Calibration checks, split samples, or proficiency samples.

(ii) Testing personnel shall be evaluated by observations and split samples or proficiency samples.

(iii) A prompt comparison and documentation shall be made of test results obtained by the tester being evaluated and the IA tester. The STD shall develop guidelines including tolerance limits for the comparison of test results.

(iv) If the STD uses the system approach to the IA program, the STD shall provide an annual report to the FHWA summarizing the results of the IA program.

(3) The preparation of a materials certification, conforming in substance to Appendix A of this subpart, shall be submitted to the FHWA division administrator for each construction project which is subject to FHWA construction oversight activities.

(b) In the case of a design-build project funded under title 23, U.S. Code, the STD's quality assurance program should consider the specific contractual needs of the design-build project. All provisions of paragraph (a) of this section are applicable to design-build projects. In addition, the quality assurance program may include the following:

(1) Reliance on a combination of contractual provisions and acceptance methods;

(2) Reliance on quality control sampling and testing as part of the acceptance decision, provided that adequate verification of the design-builder's quality control sampling and testing is performed to ensure that the design-builder is providing the quality of materials and construction required by the contract documents.

(3) Contractual provisions which require the operation of the completed facility for a specific time period.

[60 FR 33717, June 29, 1995, as amended at 67 FR 75934, Dec. 10, 2002]

§ 637.209 Laboratory and sampling and testing personnel qualifications.

(a) Laboratories.

(1) After June 29, 2000, all contractor, vendor, and STD testing used in the acceptance decision shall be performed by qualified laboratories.
(2) After June 30, 1997, each STD shall have its central laboratory accredited by the AASHTO Accreditation Program or a comparable laboratory accreditation program approved by the FHWA.
(3) After June 29, 2000, any non-STD designated laboratory which performs IA sampling and testing shall be accredited in the testing to be performed by the AASHTO Accreditation Program or a comparable laboratory accreditation program approved by the FHWA.
(4) After June 29, 2000, any non-STD laboratory that is used in dispute resolution sampling and testing shall be accredited in the testing to be performed by the AASHTO Accreditation Program or a comparable laboratory accreditation program approved by the FHWA.

(b) Sampling and testing personnel. After June 29, 2000, all sampling and testing data to be used in the acceptance decision or the IA program shall be executed by qualified sampling and testing personnel.

(c) Conflict of interest. In order to avoid an appearance of a conflict of interest, any qualified non-STD laboratory shall perform only one of the following types of testing on the same project: Verification testing, quality control testing, IA testing, or dispute resolution testing.

APPENDIX A TO SUBPART B OF PART 637—GUIDE LETTER OF CERTIFICATION BY STATE ENGINEER

Date
Project No.

This is to certify that:

The results of the tests used in the acceptance program indicate that the materials incorporated in the construction work, and the construction operations controlled by sampling and testing, were in conformity with the approved plans and specifications. (The following sentence should be added if the IA testing frequencies are based on project quantities. All independent assurance samples and tests are within tolerance limits of the samples and tests that are used in the acceptance program.)

Exceptions to the plans and specifications are explained on the back hereof (or on attached sheet).

Director of STD Laboratory or other appropriate STD Official.

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Appendix B

Examples of Contractor's QC Tests

Table 1. An Example of Materials Testing

TEST	METHOD	FREQUENCY (min.) for QC tests
Cleanness value	CTM 227	2 per day
Sand equivalent	CTM 217	2 per day
Mortar strength	CTM 515	2 per each of source of sand
Aggregate gradation	CTM 202	2 per day
Soundness of aggregates	CTM 214 / ASTM C 666	2 per day
Calibration of moisture meter	CTM 223 or CTM 226	1 per day
Curing compound	ASTM C309	Certificate of compliance

Table 2. An Example of Field Control Sampling and Tests

TEST	METHOD	FREQUENCY (min.) for QC tests
Sampling compressive strength test specimens	CTM 540 / ASTM C172	1 set per 300cy or 1 set per each day of production. Test results will be needed prior to applying stresses or loads to concrete elements with minimum strength requirements
Compressive strength	CTM 521 / ASTM C39	1 set per 300cy or 1 set per each day of production. Test results will be needed prior to applying stresses or loads to concrete elements with minimum strength requirements and also 28-day compressive strength
Air content	CTM 504 / ASTM C231 (CTM 543 for lightweight concrete)	Every 4 hours when entrained air is not specified. Once every hour when entrained air is specified.
Yield	CTM 518 / ASTM C138	2 per each mix design
Ball penetration (or Slump)	CTM 533 or ASTM C143	When test specimen is fabricated & when consistency is questionable (min 2/day).
Coarse aggregate proportion	CTM 529	As required to assume uniformity of concrete (min2/day)
Temperature	ASTM C1064	When test specimen is fabricated

General comments from stakeholders that will be considered by the implementation team:

1. The proposed changes should apply to all concrete, either roadway or structural.
Response: The concept is the same for all concrete. Specific tests and performance (quality characteristics) may be different. DES and Pavement will work jointly on this endeavor.

2. A QA plan should be developed with this decision document.
Response: Detailed QC process and QA plan requirements will be part of the specification.

3. Elaborate on the dispute resolution process.
Response: Dispute resolution process will be outlined sufficiently in the specification so disputes can be resolved swiftly. The asphalt concrete QC/QA specification will be used as a model.

4. There should be industry input (e.g. RPC) in developing the actual specification.
Response: Definitely. Workshops, webinars, outreaches with industry groups will be held.

5. Will there be more outside qualified laboratories?
Response: Yes, per the CFRs, certified labs are required in order to use QC test results as part of the acceptance process.

6. There have been reports in the past of implementing agencies not following QA.
Response: The Department needs to provide guidance and ensure implementing agencies' compliance with DD-90. This decision document and its subsequent specification will assist in this effort.

7. Examples of asphalt experience should be cited.
Response: Lessons learned in applying asphalt QC/QA Specification will be used in developing the concrete specification.

8. Are there schedules for action items under Proposed Implementation?
Response: Not at this time as DES is going through some reorganization. The schedule will be tight.

9. Frequencies for some of the tests in Appendix B may not be realistic.
Response: Yes, all the tests will be subject to a thorough review and update if necessary.

10. QA verification testing should be based on a statistical based risk analysis as described in FHWA-RD-02-095 Optimal Procedures for Quality Assurance Specification.
Response: The FHWA document was written primarily with asphalt concrete in mind where the quantity and performance characteristics are drastically different from those of structural concrete. However, the concept is sound and valuable. Therefore this document along with others will be used as references in developing the actual specification.

11. Will the proposed changes allow for increased inspection as well?
Response: Yes, Department resources will move from the actual sampling & testing to QA. Iinspection is part of the QA program.

Appendix 2: *Caltrans Sampling and Testing of Structural Concrete Survey 08/29/08*

The California Department of Transportation (Caltrans) currently performs most of its structural concrete sampling and testing using State forces. We are studying the potential to shift much of this work to the construction contractor through the implementation of quality control (QC) requirements in our construction specifications. It is envisioned that State forces would carry out quality assurance (QA) activities, including testing of benchmark samples and confirmation of QC activities performed by the contractor.

The survey below was sent to State DOTs, District of Columbia, Puerto Rico, and Canadian Provinces in August 2008.

1. Who has responsibility for design of the concrete mix?
   State Forces/Private Sector/Contractor

2. Who has responsibility for sampling concrete and making cylinders?
   State Forces/Private Sector/Contractor

3. Who has responsibility for testing concrete consistency (slump)?
   State Forces/Private Sector/Contractor

4. Who has responsibility for testing concrete cylinders for compressive strength?
   State Forces/Private Sector/Contractor

5. Are accredited laboratories used for testing?
   If so, who provides the accreditation?

6. Are the qualifications of personnel performing sampling and testing certified?
   If so, who provides the certification?

7. What is your State's experience on the effectiveness of instituting specific QC requirements for contractor sampling and testing for structural concrete?

8. Additional comments.

9. Name.

10. E-mail.

11. Phone number.

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