Progress Report on the Establishment Of Tolerances in Highway Construction Specifications

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Highway engineers and contractors are being criticized for deviations from specifications, even though in many instances there are sound engineering justifications for permitting the deviations. This problem underscores the need for tolerance on specifications. This is a progress report on the establishment of these tolerances.

•WHEN THE American Road Builders' Association held its 60th Annual Convention in San Francisco in March 1962, Louis W. Prentiss devoted a major part of his annual report to a discussion of administrative changes he felt would benefit the highway program. In regard to highway specifications, he proposed not only that there be wider acceptance of deviations from specifications where justified by engineering judgment, but that the allowable tolerances based on this engineering judgment be written into the specifications to insure that the exercise of sound engineering judgment would not be interpreted by non-engineers as a "failure".

The ARBA Committee of contractors, organized to implement this proposal, first met with a group of officials in the U. S. Bureau of Public Roads headed by Robert F. Baker, Director, and H. A. Radzikowski, Deputy Director for Development, Office of Research and Development. We found that our problem was one of major concern to this office of the Bureau. The officials were convinced that there was much merit in using what they termed a statistical approach in analyzing the data gathered in the acceptance tests performed on completed highway and bridge construction projects.

The statistical approach begins with the taking of samples at random. The test results are then plotted on a curve. Typically, most of the test results fall on or near a line representing the thickness or density which has been specified, and a small number of tests either fall short of or exceed the specification. Thus, the typical curve is bell-shaped.

Analyses of this kind point the way to precise, scientific answers to the question of what deviation from the specified norm can be tolerated within the limitations of sound engineering. When this question is answered for various materials and conditions of use, the specifications can be adapted accordingly.

Because the objectives of the Office of Research and Development paralleled those of our Committee, we were able to assure the Bureau officials of our full support at that first meeting.

An action program for the Committee was then drafted to support the Bureau's work effectively. This four-part program is as follows:

1. To recommend an order of priority for application of this concept to highway construction specifications;
2. To assist the Bureau in gaining acceptance of this concept by industry and state highway officials;

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3. To support and cooperate in research and development projects at the state level; and
4. To present the contractor's point of view on practical applications of the concept.

It may be well now to take a closer look at how this statistical concept can be applied in the construction of highways and bridges. In this country, almost 3.5 million miles of roads and streets and hundreds of thousands of highway bridges, practically all constructed by contract, have withstood the test of long years of good service to highway users, which is the acid test of quality.

This high degree of quality must be maintained in new highways and bridges. The achievement of this objective in recent years has placed a greater burden on the highway engineer-contractor team. The increased burden has been generated by the rapid expansion of the highway program, new concepts in highway design, and other factors, such as the non-engineering highway investigation.

Some aspects of the current program affect quality control in the construction of highway bridges. To expand the highway program, the rate of construction had to be greatly accelerated. This means that constantly more bridge construction than ever before is being initiated all over the nation. The total productive capacity of highway bridge contractors has had to be increased to meet the accelerated demand.

This has been done. At the bridge sites, new, more efficient machines are moving material and compacting it into place to form the approaches at a faster rate than ever before. Larger mixers have increased the number of yards of concrete produced and placed in highway structures each hour. Increased use of offsite prefabrication of steel and concrete structural members has speeded up onsite construction operations. New contractors have entered the field.

Access control is a concept that has meant more bridges per mile in the current highway program. Separate structures to carry opposing traffic are not being built because of the medians required under new design criteria. This means more bridge construction, not only because the lanes are wider but also because more miles of multilane highways are being built to meet the needs of present and future traffic. Major structural members today frequently incorporate a variety of types of steel to take advantage of the greater quality and economy possible with these new materials. In short, the bridge construction business has increased both in quantity and in complexity, and the task of quality control has increased proportionately.

At the same time, new questions have been raised as to the adequacy of standard quality control procedures, particularly by investigators with backgrounds in law or accounting rather than engineering. The lawyer or accountant, reading a specification for an eight-inch thickness of some material, wants every measurement of that material to be precisely eight inches. If he finds a measurement a fraction of an inch over, he is concerned that the state may have wasted money by purchasing more of the material than was absolutely necessary. If he finds a measurement a fraction of an inch under, he worries about quality. This type of investigator is usually unimpressed with the contention that reasonable variations are normally permitted by the supervising engineer whenever, in his judgment, no material extra cost and no notable loss of quality are involved. The investigator insists the specifications mean or should mean exactly what they say.

The ARBA Committee on Tolerance firmly believes the engineer should be free to apply his engineering judgment to accepting materials and contractor performance on highway and bridge construction projects. A major portion of the Committee's effort is directed in support of the free exercise of engineering judgment. The development of standard deviation curves and their application to highway specifications will help to shore up the authority of the engineer.

Of course, the statistical approach to quality control is not a new concept. Many industries have developed the tolerance ranges for their products through the use of statistical analyses. In fact, this approach was used in the development of the precise quality control procedures used successfully during the construction of the AASHO Road Test bridges and highway sections. We see no real problem, therefore, in establishing the validity of this concept to improve quality control on highway and bridge construction jobs. The problem is to secure acceptance and use. The joint effort of the ARBA Committee and the U. S. Bureau of Public Roads is producing results in this direction.

The ARBA Committee, through ARBA affiliated state contractor organizations, has contacted member contractors, material suppliers, and state highway officials. The need for realistic specifications has been discussed. The use of the statistical approach to improve both quality and economy has been pointed out. The response has been excellent and cooperation was assured by most of those contacted.

These discussions produced information as to the specifications requirements where the statistical concept would be applied most expeditiously and the areas in which improvements were needed most. This information has been made available to the U. S. Bureau of Public Roads which also has been informing its field personnel and state highway departments of the advantages of the new approach to improved quality control and economy in highway and bridge construction.

A list of critical areas for study in the BPR research and development program has been made and is included as the Appendix. It should be read with the understanding that it is a tentative list, subject to future revision and expansion.

Each study item on the list is accompanied by a summation of the characteristics of the study item which are defined by highway specifications. For example, the specification characteristics of asphaltic base are density and thickness. As a further step, each of the specification characteristics is classified as major or minor, depending on the importance of meeting close tolerances. To use the same example, the density of asphaltic base is in the major class, meaning that only a relatively small degree of deviation from the specifications can be accepted. On the other hand, the thickness of asphaltic base is placed in the minor class because a relatively large deviation in thickness will have no appreciable effect on the safety, performance and durability of the highway.

The computations of acceptable tolerances also will take into consideration the variations inherent in highway and bridge materials, construction processes, tests and measurements. These variations must be established by record sampling of completed highway and bridge construction projects and from new data obtained from projects now under way. This data will be the basis for establishing the standard deviations of materials, performances, tests and measurements that are involved in controlling quality on highway and bridge construction projects. They will be used to develop standard deviation curves or charts for the major quality control phases and to compute acceptable tolerances. Such standard deviations were computed for various materials and performance results on the AASHO Road Test (1).

The use of standard deviations developed in this manner to compute acceptable tolerances can put new realism into highway and bridge construction specifications. They are realistic to the extent that they take into account all of the known variations in materials, processes, methods of sampling and testing procedures and to the extent that these variations are properly evaluated. Conformance to specifications based on this concept will give assurance to the engineer that quality goals will be met and to the contractor that rejections of acceptable materials and performance are kept to a minimum.

The ARBA Committee has informed contractors of the need to expedite the development of this approach to more workable highway specifications. Their response has been gratifying. Mounting numbers are expressing their willingness to support this essential activity. Highway officials have been informed of the willingness of the American Road Builders' Association and its contractor members to assist in expediting this program.

The U. S. Bureau of Public Roads has been very active in this area. During November and December 1963, a team of Bureau engineers was in the field continuously. They held special meetings with state highway officials and BPR field personnel in each of the nine regions. The objective was to encourage the states to submit proposals for developing standard deviation curves in areas given first priority for study. These meetings have generated enthusiasm and action. Already project proposals are being received in the Washington office. The Alabama State Highway Department wants to undertake a project with its 1½ percent funds to develop standard deviations and acceptance tolerances in various areas, such as in the amount of degradation that may occur during the processing of a highway material. For example, after a subbase material has been accepted at a quarry, pit or producer's plant, it is transported to the project where it is spread and compacted into place. Thereafter, the subbase frequently is subjected to vehicle and equipment traffic which may change the physical characteristics of the materials. Rain and other climatic changes may introduce still other changes. As a result, the initial tests of the material may differ from those made after the subbase has been completed. This is a serious problem to materials producers as well as contractors.

The Bureau will review these state research proposals as they are received to reduce undesirable duplication. In addition, it has assigned qualified personnel to monitor progress on such projects and to disseminate useful information as results are obtained. Here again, the ARBA Committee will assist.

The Bureau has let several pertinent contracts to private engineering firms as a part of its research and development program. This was done to expedite the development of guidelines and criteria that would be useful in applying statistically based acceptance tolerances in highway and bridge construction specifications. The results of these studies will be helpful in directing the 1½ percent fund projects toward the production of complete, uniform and widely useful data. One major contract has now been completed.

Probably the most significant development in this field is the tolerance provision in the AASHO Guide Specifications adopted in 1963. Section 105.03 in the general provisions recognizes the problem and establishes a broad base for tolerances. The ARBA Tolerance Committee reviewed and endorsed this provision, but it will mean little unless the tolerances are provided in the specifications.

Both the Bureau and the ARBA Committee have given high priority to efforts to gain widespread acceptance of the statistical concept in the development of highway and bridge construction specifications. Considerable progress as outlined here has already been made. Other applications, particularly as to the specifications for highway bridges and other structures, will be brought out.

Unrealistic specifications for highway and bridge construction add to the cost without a commensurate increase in quality. The adoption of the statistical concept and the incorporation in specifications of sound tolerances developed by utilizing the statistical concept will enable alleviation of many problems.

REFERENCE

1. The AASHO Road Test, Report 2: Materials and Construction. Highway Research Board Spec. Rept. 61B, pp. 111-150, 1962.

Appendix

AREAS TO BE STUDIED FOR STATISTICAL QUALITY CONTROL AND TENTATIVE ASSIGNED CLASSIFICATIONS TO VARIOUS CHARACTERISTICS OF MATERIALS AND PROCESSES[a]

Item	Characteristics	Class[b]
	(a) Portland Cement Concrete Pavement	
Pavement slab	Thickness	Major
	Air content of surface	Major
Plastic concrete	Slump	Major
	Air content	Major
	Cement content	Major
	Cylinder strength	Major

Item	Characteristics	Class[b]
Coarse aggregate	Grading	Major
	Durability	Major
	Passing No. 200	Major
	Deleterious materials	Minor
	Los Angeles loss	Minor
Fine aggregates	Grading	Major
	Fineness modulus	Major
	Passing No. 200	Major
	Sand equivalent	Minor
Cement	Alkali content	Major
	Strength	Major
	Air content	Minor
	(b) Hot Mix Asphaltic Concrete	
Asphaltic pavement	Density	Major
	Temperature at compaction	Major
	Thickness	Minor
	Surface tolerance	Minor
	Roughness	Minor
Asphaltic base	Density	Major
	Thickness	Minor
Asphaltic mix	Gradation of aggregate	Major
	Dust ratio	Major
	Asphalt content	Major
	Mixing temperature	Major
	Stability and flow	Minor
Asphalt cement	Penetration or viscosity	Major
	Retained penetration of thin residue	Major
	Thin film test loss	Minor
Aggregate	Los Angeles loss	Major
	Gradation	Major
	Liquid limit and plastic index	Major
	Durability	Minor
	Deleterious material	Minor
	Flat and elongated particles	Minor
	(c) Base Course	
Soil aggregate	Stability	Major
	Plasticity	Major
	Thickness	Minor
	Gradation	Minor
	Density	Minor
	Line and grade	Minor
Stabilized base	Stability	Major
	Additive quantity	Major
	Thickness	Minor
	Plasticity	Minor
	Gradation	Minor

(d) Soils		
Subgrade	Density	Major
	Stability	Minor
	Moisture content	Major
Embankment	Density	Minor
	Moisture	Minor

[a] Prepared by the Task Force Group on Statistical Quality Control, Office of Research and Development, U. S. Bureau of Public Roads; these tables subject to additions and changes as the project develops.

[b] Major—a relatively small degree of deviation acceptable; Minor—a relatively larger degree of deviation acceptable.