Standards and Testing, The Key to Quality[1]

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INTRODUCTION

Weidlein and Reck [1], in a paper titled "A Million Years of Standards" state, "Standards are as old as man. The spoken word, perhaps the oldest standard of all, grew up with him; others slowly developed over the millenia. Standards of behavior, which may antedate even the language, crystallized gradually as folkways and mores, and as practices of worship." Although we are not interested in those types of standards here, we are interested in a number of different types, and the first of these might be called measurement standards.

MEASUREMENT STANDARDS

The most basic of measurement standards are those for length, mass, and time. As man began to construct things he found it necessary to develop some unit or units of length. Such units as the span of the hand, length of the foot, distance between the tips of the fingers with arms outstretched, and others were useful for short distances. A day's journey served as a longer unit. There were no free yardsticks to be had for the asking at a local lumber yard or hardware store. Many ancient civilizations developed local standards of length which were used in their building and were carried by them into the lands they conquered. Some of these were well defined in terms of markings on durable pieces of stone, but as late as 1120 A.D. King Henry I of England ordered that the ell, the ancient yardstick, should be the exact length of his arm, and commanded that that distance henceforth be the standard unit of comparison of lengths throughout his kingdom.

Today, the civilized world measures distances and lengths, whether a fraction of a millionth of an inch or an interplanetary distance, in terms of the distance between two fine lines on a platinum-iridium standard meter bar kept at Sèvres, a suburb of Paris. Duplicate bars

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at the National Bureau of Standards in Washington, which are periodically compared with the bar in France, enable the bureau to calibrate the standard tapes and gage blocks used in surveying, precise mechanical engineering, and production. It appears certain that the standard meter will eventually be defined in terms of some specific wave length of radiant energy.

The development of trade and the collection of taxes made other measurements necessary. An Egyptian mural dating from about 3000 B.C. shows a series of 14 capacity measures for grain, wine, and oil, in which each succeeding measure holds twice as much as the next previous one.

The earliest man-made weights now known consist of cylindrical stones from Egypt and date from about 7000 B.C. In Egypt, the balance was substituted for volume measures for use in trade in the 15th or 14th century B.C., while a thousand years earlier King Dungi of Babylonia established a testing house where that country's primary standards were preserved and where copies were tested and certified.

Henry III of England established a commercial pound in terms of the English penny which was to weigh "32 grains of wheat taken from the middle of the ear." Today's pound is defined in terms of the mass of the standard kilogram located at Sèvres. Based on this standard, the National Bureau of Standards calibrates weights of all sizes from small weights used with analytical balances to those used by the states and railroads in checking large truck and railroad scales. In addition, the bureau maintains a set of standard dead weights totaling 110,000 pounds which are used to calibrate the proving rings that in turn make calibration of large testing machines possible. A one-million-pound dead-weight system will be one of the early features at the bureau's new laboratories to be built near Washington, in Gaithersburg, Maryland.

The unit of time, the second, is defined in terms of a specific period of the earth's rotation about the sun and could quite accurately have been determined from the precise astronomical observations and knowledge of the ancient Egyptians. Sometime soon, it probably will be re-defined in terms of some highly-reproducible atomic process and with greater precision than can be obtained from the rate of revolution of the earth.

From the standards of mass, length, and time it is possible to derive, by suitable definitions and precise measurements, a great many other standards, such as those for force, volume, density, voltage, and horsepower. With these measurement standards available it becomes possible to develop another class of standards which we might designate as dimensional standards.

DIMENSIONAL STANDARDS

Dimensional standards control screw sizes and threads, railroad gages and couplers, and interchangeable parts in general. These standards are made possible by the existence of measurement standards and measurement techniques. Some of the items first produced to close dimensional tolerances were type used in printing and the bore of firearms. In the 15th century A.D. the Venetians even built standard galleys, using something resembling an assembly line.

A great milestone in the development of dimensional standards was passed in 1811 when Eli Whitney took a box of unassembled rifle parts to Thomas Jefferson and demonstrated that no special matching of parts was necessary in assembling the complete rifles.

Such standardization, greatly extended and refined, has made possible the mass production which has contributed so much to the high standard of living that we enjoy in the United States today. But the movement still has a long way to go. As late as 1948, the United States, Great Britain, and Canada signed a Declaration of Accord with respect to screw thread standards. With this shrinking world, further dimensional standards are in order. Strong impetus is now being given in the United States and other English-speaking countries for adoption of the metric system of measurement. Even the state of Indiana standard specification for sizes of coarse aggregates does not comply with the American Standards Association, American Association of State Highway Officials, and American Society for Testing Materials size requirements, all of which are identical.

QUALITY STANDARDS

Now I would like to discuss quality standards. These are the standards that are of the most direct concern to highway builders. They are the standards which most of us refer to as specifications.

The measurement standards—the standard kilogram, meter, etc.—make measurement possible and, indeed, they are useful only in conjunction with measurement and instrumentation. The need to make measurements must have been recognized prior to the establishment of any measurement standards. Beyond the ability to measure the quantities needed for trade, and the dimensions needed in building and manufacturing, measurement techniques and instruments make possible in many cases the effective characterization of materials. Tests may be designed to measure particular properties of a material. A group of tests may give information on all of the pertinent properties of a material.

Socrates is quoted as saying: "We are exposed to many delusions. But reason thus confused by false appearances is beautifully restored by measuring, numbering, and weighing. . . . By this is eliminated the rule of the senses over us. We disregard, now, sensual impressions of magnitude, of number, and weights of objects, but calculate, measure and weigh them."

Later the 19th-century English physicist Lord Kelvin stated: "I often say that when you can measure what you are speaking about and express it in numbers, you know something about it; but when you cannot express it in numbers, your knowledge is of a meager and unsatisfying kind. . . ."

The quality standard for the most part specifies the desired or undesired properties of materials by numbers—numbers obtained from some sort of test. The evaluation of the material may thus be made in a more objective manner than if it were to be judged merely by feel or appearance.

What are the advantages of using specifications to those who are building roads? These will depend upon the part of the organization concerned, but will include the following:

1. Specifications make it unnecessary for one to be an expert on the technology of each material he uses. We might take a brief look at how material specifications are written. My own particular experience happens to be mostly with cement and concrete, so I hope that you will not object if I use these materials as examples. Often, a specification is first set up by a producer or a group of producers to assist in controlling the manufacturing process. If such specifications are then used for the purchase of materials, the buyer soon wishes to have a hand in the determination of which properties should be tested and what the limits should be. In an organization like the American Society for Testing Materials, many of whose specifications are used by the American Association of State Highway Officials, the specifications are produced, assessed, and revised by committees composed of producers, consumers, and a few people with general interests, such as university professors, consulting engineers, or perhaps National Bureau of Standards' employees. All interests are thus represented, and, in addition, a numerical balance is maintained. By and large the committee members are competent technical people and are surprisingly objective in their approach. They are experts in their field. The specifications

which they produce are based on the best and latest knowledge available and therefore may be used with confidence by a man who does not have time himself to become an expert in that particular field.

But the specifications are not perfect—they never will be. The democratic process used in an ASTM committee may tend to slow up progress, and some users may become impatient. Then, too, there are important properties of materials which either are not completely defined in the specification or are ignored completely. Examples which might be mentioned are the frost resistance of concrete aggregates and the drying-shrinkage of portland cement. Completely reliable tests for aggregate durability are not available, and it is not fully known why one portland cement may cause more trouble than another with early cracking in concrete placed under hot, dry conditions. I am sure there are similar gaps in the knowledge of the materials used in flexible pavement and in foundations materials. And, of course, there may be particular properties and tests whose application to materials in specific locations or areas is particularly important.

Thus, the specification cannot be used blindly in all cases. In selecting frost-resistant aggregates, the long-time field performance of concrete made with the material may be of much more value than the test requirements in the aggregate specification, and only a well-qualified materials engineer is competent to select suitable materials. But for many other materials properties the specification furnishes adequate guidance for the user.

2. A specification can aid the engineer and designer in the selection of suitable materials. A good specification, with its numerical limits on the various properties of the material, together with a statement concerning the applicability of the specified material or materials may be of great value to the designer. As an example, consider the specification for portland cement. Five basic types are included in the specification; each may be air-entraining or not air-entraining, and of low alkali or unspecified alkali content. By selection of one of five types, together with choice of low alkali, the designer may, very simply, go a long way toward insuring resistance of the concrete to frost action, to the deleterious action of sulphates in adjacent ground or ground waters, and to adverse chemical reaction between the cement and potentially-reactive concrete aggregates.

3. The use of specifications promotes uniformity of products furnished by the various producers. The demand that materials purchased for the construction work meet certain specification requirements forces the producer to tool up to meet them or to develop needed

manufacturing techniques and sources of raw materials. If the various agencies purchasing such materials use the same, or essentially similar specifications, the producers' efforts can be geared to a definite product, and uniformity in the material furnished is improved as a consequence. Not only is the uniformity from a particular producer improved, but the difference between similar products from different producers will tend to become less. This process leads to more choice in procurement. It benefits the producer in the long run because he has less need to change manufacturing procedures for specific orders, and he needs less inventory.

The objection has been raised that such uniformity may reduce competition and lead to mediocrity. In fact, the anti-trust aspects of standardization have received considerable attention. However, specifications usually only place a floor under the quality of a material—they do not impose a ceiling. As improved products become available, the floor is generally raised.

The lack of a ceiling may in some cases be a disadvantage, however. Often, the uniformity of a material from batch to batch is just as important as its average test performance. Likewise, the uniformity between one source and another is of considerable importance if the materials are to be used alternately on the same job. There has thus been some demand for ceilings as well as floors in specification requirements. When a material from a single source is being used, it is possible to specify a maximum rate of change in a specific property without establishing a ceiling. An example of such a requirement is that contained in ASTM Designation C-350 for fly ash which states: "In tests on individual samples, the specific surface shall not vary more than 15 per cent, nor shall the specific gravity vary more than five per cent, from the average established from the tests on the ten preceding samples. . . ."

4. From the standpoint of those who are directly involved with the purchase and acceptance of materials, a specification is of inestimable value. It tells the vendor exactly what you want, it enables you to tell whether you are getting what you ordered, and it furnishes a basis for rejection of substandard material.

So far, I have said very little about tests. I would like to emphasize their importance at this point. We have seen that the development of measurement standards together with instruments and techniques has enabled the description of the various properties of a material in terms of numbers. This description is the specification. One cannot usually tell whether the delivered material meets the specification requirements until tests have been performed which will give the numbers that are required by the specification. You cannot tell whether the portland cement you have purchased has adequate strength-producing qualities unless you make some specimens by the carefully prescribed method and then measure the strength by crushing. And I need hardly point out that one can't reject cement without those numbers on which to base the rejection.

The testing costs money. Recently, I read an article on standardization by an official of one of our largest cities in which he stated that often the city was not able to use a particular national specification because it couldn't afford to do the amount of testing that it called for. I think it is more likely that it really could not afford not to use it.

Testing is particularly needed when materials and commodities are purchased on the basis of the lowest bid. Such purchasing encourages the reduction of quality to the lowest point that can get by. Without an adequate testing program, that lowest point may be mighty low.

Testing and inspection are sometimes considered a nuisance and a burden by the manufacturer and are viewed with a critical eye by others. Businessmen may consider them as just another example of creeping government control over their business. But inspection and testing actually protect the quality manufacturers from marginal and unqualified competitors. John Riordan [2] has said: "I hardly need say that if government quality requirements were not enforced, vendors of inferior products would proliferate like rabbits and drive the 'good' vendors out of business." Testing is the only way to insure that the taxpayer gets his money's worth out of the materials being purchased.

Many people make the mistake of assuming that the percentage of failures of a particular product observed in a routine testing operation is a measure of how much substandard material would be encountered if there were no testing. In many cases such a conclusion is justified, but too often the quality delivered will depend upon whether the product is to be tested or not. Producers usually know more about their material than the purchaser does, and if they know the material is to be tested, a better product will probably be submitted.

The discussion of specifications so far has dealt largely with the materials that are furnished and delivered to the construction job. Getting the right materials for the job is of great importance, but it is largely a wasted effort if the materials are not properly used. If we think now of concrete as a material rather than of the ingredients which are used to make it—the cement, aggregates, water, and perhaps admixtures—a specification is required which will spell out the proportioning procedure, the mixing, the transporting, the placing and consolidation, and the curing required. Here again testing plays a vital role. Most of the characteristics of the final product may be assessed by tests. These tests, together with insistence on standard procedures in placing and curing the mixture, will go far toward insuring a good job.

TESTING

I have discussed the need for testing, but nothing has been said directly about test methods or procedures. Generally, a specification is of no value if adequate test methods are not available; in fact the test method must be developed before requirements for the property which it measures can be included in the specification. The science of measurement and the measurement standards have made the development of test methods possible. However, most of the test methods used to assess the properties of materials are more or less empirical in nature. That is, the results of the test will depend upon how it is made. If the numbers obtained by making the test are to mean the same thing to the vendor as they do to the purchaser—and they must, if the specification is to be part of a contract—those making the test must meticulously follow the exact procedures outlined in the specification or test method. Usually the person making the test must have considerable practice before uniform results can be obtained. In addition, the equipment used in the test must comply with all the details given in the test method. In many cases, environmental factors such as laboratory temperature and humidity must be controlled. There is a constant temptation to deviate from the standard methods because of convenience or because a different procedure may appear to be an improvement over that prescribed. Also unconscious deviations may often develop. Likewise, suitable apparatus may not be available or may be out of adjustment. It is surprising how many instrument companies apparently have no conception of the necessity of building test equipment in strict and literal accordance with the specification. Here is one case where imagination and inventiveness are not wanted. The imagination and inventiveness should be left for those who are developing, evaluating, or revising the test method.

SAMPLING

One of the more difficult and often the most difficult part of applying a specification is the procuring of representative samples. The conditions under which materials are stored vary so widely that comprehensive sampling specifications applicable to every situation are hardly possible to prepare. The instructions given, however, may serve as a most useful guide and should be followed as closely as possible.

The value of any test, no matter how carefully and competently performed, depends strictly upon how representative the test sample is. The purchaser, or his representative, should either take the samples or witness the sampling. Otherwise, the value of the test results may be questionable.

The specifications normally stipulate the sampling interval and the number of tests to be performed on each sample or group of samples.

Much work is being expended on the development of new sampling and testing plans, using statistical procedures, and when these plans become more widely used and are included in more specifications, substantial savings in testing costs will result. These new techniques may take into account the degree of quality control exercised by the manufacturers in determining how much testing is required. The current Federal Specification for Portland Cement [3] incorporates such a feature. The new techniques may also recognize the inherent error associated with testing and take it into account in deciding whether the specification requirements are met or not. American Concrete Institute "Recommended Practice for Evaluation of Compression Test Results of Field Concrete" (ACI 214-57) [4] is an example of the use of such an approach.

CONCLUSION

Quality standards and test methods make possible the intelligent selection of materials and the procurement of materials of specified quality. Their use, together with construction standards, testing of materials, and testing of the final product, furnishes the key to quality.

REFERENCES

1. Edward R. Weidlein and Vera Reck, "A Million Years of Standards," *National Standards in a Modern Economy,* (Harper 1956).

2. John T. Riordan, "Quality Control and Standardization," *Proc. Sixth National Conference on Standards,* American Standards Association Publication PM 151 (1955).

3. *Federal Test Method Standard,* No. 158 (May 1, 1957).

4. *Journal American Concrete Institute,* V. 29 (July 1957), p. 1.