Tech Brief **January 2022**

ADDRESSING NONCOMPLIANCE WITH CONCRETE MATERIAL AND CONSTRUCTION SPECIFICATIONS

This document summarizes portions of the 2010 FHWA Technical Advisory "Development and Review of Specifications" *and discusses approaches for addressing noncompliance issues. Emphasis is placed on identifying ways that minimize risk of reduced pavement performance while avoiding wasteful rejection of processes or materials that fail to comply with specifications but can be left in place (often with a program of corrective action).*

INTRODUCTION

Background and Scope

Specifications for highway construction are written instructions that describe the materials that are to be used and the work that is to be undertaken. Specifications inform prospective bidders (including the eventual selected contractor) of the agency's requirements, including how items will be evaluated and paid for.

The specifications for any particular project may include standard language that is agency-approved for general and repetitive use on road construction projects (i.e., standard specifications and supplemental specifications) as well as project-specific instructions (i.e., special provisions and developmental or pilot specifications) that supplement or override the agency's standard specifications for a particular project. (FHWA 2010). The specifications are considered part of the contract documents.

This tech brief aims to address this need by helping agency and contractor personnel to better approach issues of noncompliance in ways that minimize the risk of reduced pavement performance while reducing wasteful rejection of processes or materials that fail to comply with specifications but can be left in place (often with a program of corrective action).

Highway construction specifications often present inspectors and contractors with hundreds of requirements concerning materials, equipment, construction processes and properties of the finished pavement structure. In some matters, the specifications may provide explicit instructions about handling noncompliance (e.g., requiring diamond grinding of any areas that fail to meet minimum texture depth requirements); in other matters, requirements are often stated without directions for handling noncompliance (e.g., directions to "Install dowel bars within 2 inches of the planned longitudinal location.") or may leave the matter to the judgment of the project engineer without providing any guidance (e.g., "Aggregate gradations that fall outside of specified limits can be accepted by the Engineer on a case-by-case basis."). When little or no guidance is provided concerning handling of noncompliance, decisions may be made that permit the inclusion of potentially detrimental noncompliant work (resulting in reduced pavement performance) or may lead to the rejection or removal of noncompliant materials or works that would have little or no negative impact on pavement performance (resulting in unnecessary waste, damage claims or litigation).

Well-written specifications (developed in accordance with the guidance provided in FHWA's Technical Advisory, *Development and Review of Specifications* [FHWA 2010]) reduce the potential for many of these types of problems, but there is a need for improved general guidance on handling issues of noncompliance in the field for highway construction projects. This tech brief aims to address this need by helping agency and contractor personnel to better approach issues of noncompliance in ways that minimize the risk of reduced pavement performance while reducing wasteful rejection of processes or materials that fail to comply with specifications but can be left in place (often with a program of corrective action).

While many of the concepts presented and discussed in this technical brief are applicable to specification compliance for various types of works, the intended focus of this document is pavement construction. Readers should apply the thinking presented herein to other types of construction only with caution and proper consideration.

Functions of Materials and Construction Specifications

Materials and construction specifications provide the owner/agency with a set of standards against which to evaluate the project materials and the contractor's work, often including allowable tolerances in evaluation measures. This information provides a basis for overseeing or managing the project (FHWA 2010). Well-developed specifications also serve to ensure that the constructed pavement system has properties and behavior that are consistent with the assumptions used in the design process, thereby minimizing the possibility of design-related premature failure.

The same specifications provide contractors with instructions on how the work is to be performed, how the quality and acceptability of the work will be determined, what the allowable tolerances (if any) are and how deviations from the tolerances will be handled, how payment for the work will be determined (i.e., incentives and disincentives or penalties), and how changed conditions will be handled (FHWA 2010).

Project specifications can also define limits or thresholds that define both acceptable practices or properties and rejectable ones. For purposes of handling noncompliance issues, it is important to note that these are often different thresholds.

This concept is illustrated in figure 1 (Snyder 2018), which presents a scale for dowel misalignment with two thresholds noted: one for acceptance that is based on a value considered to be consistent with good construction practices and for which no corrective actions are required, and a second threshold above which the dowel misalignment is believed to be detrimental to pavement performance. Values of misalignment that fall between the "acceptance" and "rejection" levels represent noncompliance with the specification for acceptance of the work and require that the construction process be corrected (possibly with a pay adjustment for the affected area) but may not require removal and replacement (or other corrections) of the affected work.

This dual-limit approach reflects the reality that modest noncompliance with acceptance criteria (especially those based simply on standard or accepted good practices) may represent undesirable quality of materials or construction (which require process corrections) without raising concerns about future performance or serviceability. However, some level of noncompliance exists (the rejection threshold) above which performance is believed to be compromised.

An illustrative example is a specification that requires concrete air content of 4.5 to 7.5 percent behind the paving machine. If one set of tests indicated 7.7 percent air, the material might be deemed noncompliant, and the process would need to be adjusted to reduce the air content of future concrete batches. However, it is unlikely that the concrete in that batch would have significantly reduced strength or would otherwise adversely impact potential long-term pavement performance; if the tests had indicated more than 10 percent air, removal and replacement might be appropriate (especially if supplemental strength testing indicated significantly lower concrete strength).

In some cases, even minor noncompliance may raise performance concerns. In such cases, the acceptance and rejection thresholds would be very close (or the same value). This might be true, for example, for initial pavement surface friction values.

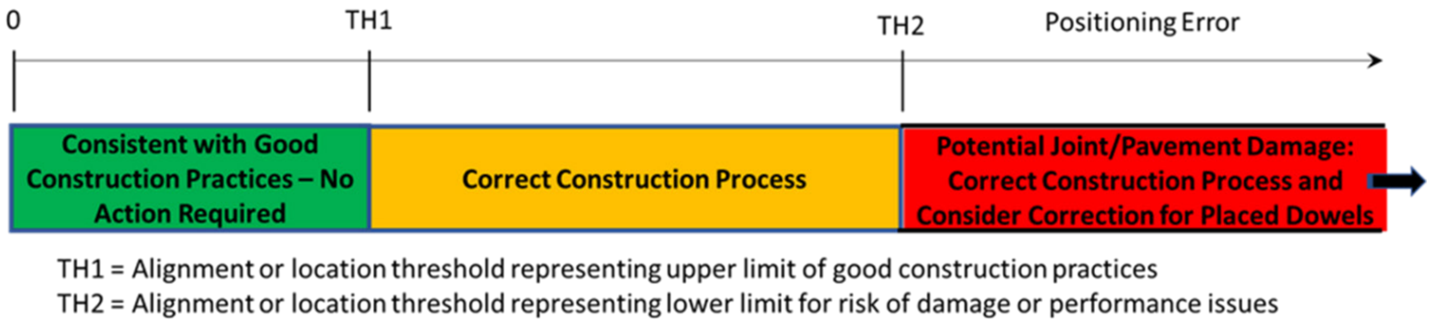

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Figure 1. Example of use of dual-limit specification for handling noncompliant work.

SPECIFICATION TYPES AND CONTENT

Types of Specifications

FHWA (2010) identifies four different types of specifications that agencies can prepare and submit for FHWA approval: method specifications (sometimes also known as "prescriptive" specifications), performance specifications, proprietary specifications and reference standards. Brief descriptions of each of these, including their advantages and disadvantages, are presented below.

Method Specifications

Method (or "prescriptive") specifications describe the specific materials, equipment, and methods that the contractor is to use in completing the contract work. They are typically developed from agency experience with proven materials and techniques and are based on the assumption that good results will be obtained if the contractor complies with all specification requirements.

Advantages. The main advantage of method specifications is that there should be little risk of construction or performance problems (due, for example, to the use of newer materials, equipment or work techniques) because the spec is based on methods and materials that have historically provided good results. Many agencies also like the control provided to them by method specifications.

Disadvantages. Specifications that control materials and methods may prevent the use of more economical or innovative materials and methods. In addition, specification-compliant contractors are not generally responsible for deficiencies in the performance or quality of the final product. Further, payment is generally not based on work quality, so contractors typically receive full payment for work performed if it was done in compliance with the specifications, regardless of work quality. Agency inspectors must often be omnipresent—an added expense and use of resources—to ensure that correct methods and materials are used.

Best Uses. Prescriptive specifications are often preferred when end product performance cannot be easily defined or easily/economically measured and verified. They may also be preferred when agency requirements can be met in a limited number of ways, or when removing and replacing unacceptable work is impractical.

Performance Specifications

Performance specifications define work requirements in terms of indicators of longer-term pavement performance, such as selected functional characteristics (e.g., surface friction and ride quality), engineering properties (e.g., material strength) and measurable distresses (e.g., cracking) within some period of time after construction. Performance specifications typically do not dictate methods, equipment, techniques, or other prescriptive elements typically found in method specifications. Unlike method specifications, the structure and philosophy of performance specifications allow the inclusion of pay adjustments that reflect the value of the completed work.

AASHTO (2003) defines and describes several sub-types of performance specifications, including: end-result specifications, quality assurance (QA) specifications, performance-related specifications (PRS), performance-based specifications (PBS) and performance warranty provisions. More information on these specific performance specification sub-types can be found in FHWA (2010) or AASHTO (2003).

Advantages. Performance specifications enhance bidding competition by providing competing contractors (that often have different material, equipment and staffing resources) the ability to select materials, equipment and construction techniques that may allow them to: improve the quality of work (thereby earning positive pay adjustments or "incentives"); perform the work more economically (thereby making their bid more competitive); or both. Therefore, well-developed performance specifications can attract capable contractors and offer the potential for better-than-typical construction quality and long-term pavement performance. In addition, many agencies find that performance specifications reduce the need for (and cost of) inspection. Additional advantages of specific performance spec sub-types are described in FHWA (2010) and AASHTO (2003).

Disadvantages. The primary disadvantages of using performance specifications are that agency staff may be uncomfortable with relinquishing control of some aspects of project construction, and some contractors may be reluctant to assume the risk and penalties (or "disincentives") for failures of selected materials and techniques to achieve the anticipated or desired results. Other potential problems include specifications that fail to include effective performance measure requirements that achieve the agency's needs or goals, and performance models that do not accurately predict long-term pavement performance. Additional disadvantages of specific performance spec sub-types are described in FHWA (2010) and AASHTO (2003).

Best Uses. Performance specifications are most appropriate for situations where end product performance is measurable, testing can be performed quickly, economically and in real-time, and contractors are willing to assume performance risk because they are in a position to control that risk or because they balance that risk with the opportunity for increased profit through pay adjustments or incentives (FHWA 2010). Performance specifications are often used in design-build contracts to offer contractors the flexibility needed to achieve a good balance of quality and timely project delivery; they are also being used with increasing frequency in conventional bid-build construction.

Proprietary Specifications

Proprietary specifications (also called "Product-specific Specifications") typically identify desired products or processes by name, source, or another unique characteristic. A specification can be considered proprietary without identifying a specific product or process if only one manufacturer can provide the product or controls the process, or if the specifications or plans implicitly “steer” the contractor towards one product (FHWA 2010; NPCA 2019).

Advantages. Proprietary specifications offer the agency close control of product selection and implementation. They are usually developed or selected based on proven experience with that product or process within or outside of the agency (NPCA 2019). Such specifications may also be accompanied by a higher level of design based on more precise information from the manufacturer (FHWA 2010).

Disadvantages. The primary disadvantages of proprietary specifications are that they may unnecessarily narrow (or eliminate) competition, which can lead to higher bid prices or charges of impropriety. They may also force contractors to work with products or equipment with which they are not familiar or have had bad experience, potentially resulting in lower productivity, higher prices and lower quality.

Reference Standards

“[Reference standards] refer to specifications prepared by recognized trade associations, professional societies, standards-writing organizations, or agencies that provide national standards of performance or measurement” (FHWA 2013). They may be prescriptive specifications, but they are more typically end-result-type performance specifications that can be incorporated in either method or performance specifications. In any event, reference standards are simply special cases (by source) of method and performance specifications with similar advantages, disadvantages and uses to those described previously.

Examples of reference specifications used in highway construction include the AASHTO Standards for Materials and Methods of Sampling and Testing, various ASTM International standards for materials and testing, design standards from American Concrete Institute (ACI), military specifications (e.g., U.S. Department of Defense), and others.

Hybrid and Other Specifications

Few highway construction specifications are purely prescriptive or performance specifications; most include some elements of both prescriptive and performance specifications and are sometimes called hybrid specifications.

“Allowable systems specifications” result when proprietary or product-specific specifications are written around two or more products or systems that the owner/agency considers acceptable. This type of spec allows specifiers to identify proven products or systems for use while providing opportunity for competition. Allowable systems specifications are often used in precast concrete paving projects (NPCA 2019).

Key Components for Effective and Useful Specifications

FHWA (2010) provides detailed guidance concerning the development and review of highway construction specifications. The following is a synopsis of key specification components that help to ensure specification usefulness in handling noncompliance issues in the field.

Control of Factors that Impact Pavement Performance

Pavement materials and constructions specifications must include provisions for controlling factors that are known or strongly believed to impact pavement constructability, service life and performance. This requires that the specification writer first anticipate and recognize all the construction and in-service processes, mechanisms and conditions that can result in unsatisfactory pavement performance, including pavement distresses, material durability and built-in construction defects (e.g., inadequate surface friction, poor ride quality, etc.) The specification must be developed with a thorough understanding of the factors or mechanisms that underlie each potential distress type or performance parameter, and provisions must be incorporated to control or limit each impacting factor or mechanism that is within the contractor’s control. Accepted standard tests or procedures must be available to measure or otherwise verify each critical material, construction, or performance parameter.

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Establishing Acceptance Thresholds or Conditions

An acceptance threshold or condition must be established for each critical parameter. The acceptance threshold or condition for any process or property can be considered or established to be the minimum required action, condition, or property value that the agency is willing to accept without penalty or corrective action. They must be established at levels that preclude the development of distresses and conditions that lead to unsatisfactory pavement performance (or failure) but may be even more stringent if it is reasonable to expect better-than-critical values with typical construction practices.

For example, the ACPA guide specification for dowel alignment sets the acceptance limit for longitudinal translation (side shift) at ± 2 inches even though research indicates that dowel embedment of as little as 4 inches (i.e., 5 inches of side shift for an 18-inch dowel) will perform acceptably (ACPA 2019). The 2-inch limit was selected based on NCHRP research field studies reported by Khazanovich, Hoegh, and Snyder (2009) which showed that more than 90 percent of all dowels examined were located within 2 inches of the joint, so it is reasonable to expect that dowels should be placed to this tolerance with typical good construction practices.

A corollary of the recognition of inherent variability in material properties and test results is that it must be expected that the observation of a small percentage of noncompliant test results will be observed and should be accepted…

Establishing Rejection Criteria

A rejection threshold or condition must also be established for each critical parameter. The rejection threshold or condition for any process or property can be considered or established to be the action, condition or property that is likely to result in unsatisfactory pavement performance or failure. Materials and processes that fail to meet rejection thresholds generally will not be accepted even with penalties or reduced payment; corrective actions (including removal and replacement) are typically required.

For example, the ACPA guide specification for dowel alignment sets the rejection threshold for longitudinal translation (side shift) at ± 5 inches for an 18-inch dowel (ACPA 2019) based on NCHRP (Khazanovich, Hoegh, and Snyder 2009) and other laboratory studies that showed significant changes in joint behavior when dowel embedment length was reduced to 4 inches or less. Similarly, agency concrete paving specifications typically limit pavement thickness deficiencies to one inch (or less) because load-carrying capacity and expected pavement life decrease rapidly with even small decreases in slab thickness.

Recognition (and Acceptance) of Inherent Variability

There is point-to-point variability in almost all properties of paving materials and pavement structures, including strength, layer thickness, foundation support, ride quality, pavement texture, etc. Some degree of variability is also inherent in most measures or indicators of these same properties due to the use of different devices (even of the same model), differences in operators and operating conditions, and other factors.

Therefore, specifications must establish required average test values (e.g., average as-built strength of 4200 $\mathrm{lb/in^2}$) with consideration of the values assumed in design and project development (e.g., design strength of 3000 $\mathrm{lb/in^2}$) and expected variability of measures (e.g., a coefficient of variation of 15 percent for a normally distributed parameter) and the desired reliability of the construction (e.g., 95 percent, such that only 5 percent of randomly obtained samples will have values lower than the design value). A corollary of the recognition of inherent variability in material properties and test results is that it must be expected that the observation of a small percentage of noncompliant test results will be observed and should be accepted (provided they are not beyond the bounds of the rejection limit).

Pay Adjustments

Specifications (especially performance-type specifications) are increasingly being written with various forms of unit price increases (and decreases) to reward the use of superior materials and pavement construction practices (and, conversely, to discourage the use of inferior materials and construction practices). The amount of the pay adjustment should usually be based somewhat on the change in value of the performance or service life of the resulting pavement (e.g., pay increases for smoother initial ride quality being linked to the value to the agency of deferred pavement maintenance activities and extended service life).

ADDRESSING SPECIFICATION NONCOMPLIANCE IN THE FIELD

The Ramifications of Failing to Meet Specification Requirements

Specification noncompliance issues can impact the interests of owners/agencies, contractors and their suppliers, and pavement users. For example, owners and agencies are mainly concerned with controlling project costs while obtaining satisfactory performance throughout the pavement service life; spec compliance issues can result in project delays and pay adjustments for contractors and suppliers, along with performance issues and user costs for the traveling public.

The impact of specification noncompliance on pavement performance can vary broadly, depending upon:

- The subject of the requirement (e.g., concrete strength, edge slump or some aspect of the construction process).
- The specification limit and its relationship to a value that would seriously impact performance.
- The degree to which the specification is not met (i.e., by a little or by a lot).

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For example, concrete paving specifications often require that the base or subbase be moistened prior to placing the concrete pavement to avoid having a hot or dry surface that weaken the bottom of the slab by removing moisture from the mix before it cures. Failing to moisten the material may have little impact for conventional paving in cool weather on a nonabsorptive base but could cause a problem for a thin concrete overlay being placed on an asphalt concrete interlayer in hot, sunny weather.

An example of a specification component with potentially major impact on performance is slab thickness. Concrete pavement design theory states that the load carrying capacity of a slab varies directly with the stiffness of the slab, and the stiffness varies with the cube of the slab thickness (Huang 2004). This suggests that even relatively small deviations in slab thickness (say, 5 percent or 0.5 inches for a 10-inch designed slab thickness) can have a significant impact on slab stiffness and load carrying capacity ($1.05^3 = 1.158$, a nearly 16 percent change) and a similarly large effect on the development of distresses such as slab cracking.

Many additional examples can be cited to illustrate that the impact of failing to meet paving specification requirements varies widely and depends on many factors. It follows that, if the impact of specification noncompliance varies widely, there is also a broad range of approaches for appropriately addressing noncompliance with different specification requirements.

Examples of Common Specification Noncompliance

Some of the most commonly cited types of spec noncompliance are listed below, together with possible causes, concerns and considerations:

- **Low concrete strength, usually at early ages** (e.g., failure to meet 1-, 3- or 7-day strength requirements). Possible causes include errors in mixture proportioning (e.g., too much water, too little cement, etc.), cool mixture and air temperatures, overdose of set-retarder or air-entraining admixtures, and other factors.

  Depending upon the cause, low early strength may indicate lower long-term strength (with less resistance to loads and cracking) or may result in higher long-term strength (with more resistance to loads and cracking). Therefore, an understanding of why early strength is low can be useful in determining how best to address the issue of noncompliance. In either case, lower strength development likely means a delay in use by construction traffic and in opening to service traffic.

> *… low air content alone does not necessarily indicate a durability problem … high air content alone may not indicate a problem with concrete strength …*

- **Noncompliant concrete air content** (usually too low, but sometimes too high) measured either as the plastic concrete is delivered and placed or behind the paver (after consolidation). Possible causes of air content deviations include improper admixture dosage (including consideration of interactions with other admixtures, mixture temperature, etc.), too much or too little mixing, excessive vibration or mix consolidation, and other sources.

  The primary use of air content measures is as an indicator of future freeze-thaw durability of the hardened concrete, but air content also provides an indication of batch yield and consistency in mix proportioning between batches. Concrete freeze-thaw durability is better indicated by measurement of the hardened air void system than by total plastic air content (which can contain large, entrapped air voids that contribute little to freeze-thaw durability). Therefore, low air content alone does not necessarily indicate a durability problem. Similarly, high air content alone may not indicate a problem with concrete strength, and the measurement of concrete strength or hardened air content may help in determining appropriate ways for addressing noncompliance with specified air content requirements.

- **Unacceptable ride quality.** There are many possible causes of unacceptable ride quality, including improper set-up and operation of paving equipment, concrete delivery and placement issues, improper setting of forms, over-working concrete behind the paver, concrete mixture problems (i.e., too stiff, too fluid, or inconsistent), string line sag, soft track lines during paving, postconstruction settlement, poor curing (resulting in built-in slab cur/warp) and more.

  The primary use of ride quality measures is to provide an indication of smoothness and satisfaction to the traveling public when overall materials and construction qualities are good. In addition, initial (new construction) ride quality is also generally correlated with pavement service life (i.e., smoother roads tend to stay smooth for longer periods). When ride quality is unacceptable (noncompliant with specifications), the cause of the noncompliance should be considered in determining how best to address the problem. Minor surface irregularities in an otherwise well-constructed pavements may be effectively corrected with spot-grinding or accepted with minor pay adjustments. Significant ride problems in otherwise well-constructed pavements may require extensive diamond grinding (or thin surface overlays if the required grinding would remove too much structure). When ride problems are related to foundation settlement or similar problems, the source of the problem cannot be addressed with diamond grinding or overlays; removal and replacement, foundation injection and slab jacking, or other approaches may be necessary.

- **Dowel misalignment or mislocation.** Dowel bars (often provided in transverse joints for load transfer) can be incorrectly positioned in one or more of five ways: vertical tilt, horizontal skew, vertical translation, lateral translation (across the pavement) and longitudinal translation (along the pavement), as described in FHWA (2007). There are many potential sources of incorrect dowel positioning relative to the joint, including: damaged dowel basket assemblies, inadequately anchored dowel basket assemblies, damaged or improperly functioning dowel bar insertion equipment, joints sawed at incorrect locations, variations in pavement thickness over fixed-height dowel baskets or fixed depth dowel insertion, and more.

Each type of mispositioning has a potential impact on joint restraint (and possible spalling), joint load transfer, or both, depending upon the type(s) of positioning error, the degree of positioning error, the number of affected dowels, the location of the affected dowels, and other factors. Dowels with only minor positioning errors have little impact on joint function. The impact of a single significantly mispositioned dowel can range from negligible (e.g., a longitudinally translated dowel between the wheel paths) to damaging (e.g., a horizontally skewed dowel close to a longitudinal joint or a badly tilted dowel that approaches the pavement surface at any location).

…it is important to understand the nature and extent of dowel positioning noncompliance, as well as the possible negative impacts of potential corrective actions (e.g., full-depth joint replacements, cutting dowel bars, dowel bar retrofits, doing nothing) before determining the best course of action …

The impact of groups of mispositioned dowels on pavement performance can also vary greatly. For example, a single joint with many rotated dowels may restrain the joint from opening and closing, but experience has shown that pavement cracking and deterioration will not take place if leading and trailing joints are functioning properly (ACPA 2019). Similarly, if a single joint saw cut is misplaced, resulting in greatly reduced dowel embedment on one side of the joint, that joint may not have good load transfer characteristics and may develop faulting more rapidly than other pavement joints, but it will not greatly affect the overall pavement performance. However, if several consecutive joints have rotational misalignment or longitudinal translation of dowels, overall pavement serviceability and performance may be impacted.

Therefore, it is important to understand the nature and extent of dowel positioning noncompliance, as well as the possible negative impacts of potential corrective actions (e.g., full-depth joint replacements, cutting dowel bars, dowel bar retrofits, doing nothing) before determining the best course of action for each case.

- **Pavement cracking.** Concrete pavements can develop many types of cracks soon after construction, including transverse, longitudinal, diagonal, corner, drying shrinkage, and plastic shrinkage cracks. Cracking can also develop (generally over longer periods of time) due to fatigue, alkali-aggregate reactions, freeze-thaw damage, chemical attack, and other mechanisms. These causes of construction-related cracks generally vary with the type of crack, and can include early load damage, late joint sawing, late or poor curing, mixture proportion issues (e.g., excessive water, paste, fly ash or set-retarding admixtures), nonuniform pavement support, and excessive panel dimensions. Detailed discussions of the many causes of different types of cracking are presented in Harrington et al. (2018).

  Pavement construction specifications often include limits on the number or percentage of cracked panels. When these limits are exceeded, the causes and potential impacts of observed cracking must be understood to determine the best approach for addressing the noncompliance. For example, a few random panels with isolated transverse cracks near mid-panel may be better addressed by retrofitting dowel load transfer devices and routing/sealing the crack than by removing and replacing the panel. However, if the transverse cracks develop within a few feet of transverse joints, it is likely that the area between the crack and the joint will eventually deteriorate, so a joint or panel replacement is likely required.

- **Inherent variability and low sample rates producing noncompliant test results.** There is point-to-point variability in almost all properties of paving materials, including strength, layer thickness, foundation support, ride quality, and pavement texture. Some degree of variability is also inherent in most measures or indicators of these same properties due to the use of different devices (even of the same model), differences in operators and operating conditions, and other factors. The effects of this variability are often reflected in precision and bias statements that serve to temper expectations of test accuracy and repeatability, which can differ significantly between tests.

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  For example, the precision and bias statements in ASTM C39 indicate that properly conducted compressive strength tests of two 6- by 12-inch concrete cylinders from a single concrete batch may have results that differ by up to 8 percent when tested by a single operator. This indicates comparatively low inherent variability in test results when compared with other standard tests, such as ASTM C1202 (Rapid Chloride Permeability), for which precision and bias statements indicate that a single operator performing this test on two samples from a single concrete batch may see test results that differ by up to 34 percent.

  The impacts of inherent material variability and testing variability are often considered in specifications by using principles of statistics, including:

  - Requiring more replicate tests for material properties and test procedures that are more variable.
  - Establishing test requirements that provide a desired level of confidence or reliability to ensure

that few tests fall below the requirement and that average results are greater than the design or critical value for the test.

These principles are illustrated in the following example. Suppose that an engineer designs a pavement assuming the concrete will have a minimum compressive strength of 2500 lb/in^2. Concrete compressive strength test results, like many pavement material properties and test results, are typically assumed to be “normally” distributed, which implies a bell-shaped distribution of test results equally distributed about some average or mean value, as shown in figure 2 (NHI 1987). To reliably achieve the design strength of 2500 lb/in^2, the specifications must be developed to require an average compressive strength from limited test results that is higher than the 2500 lb/in^2 minimum. This will ensure that the minimum strength requirement is met with a high degree of reliability (i.e., so that there is only a small probability—often 5 percent or less—that any test results are less than 2500 lb/in^2). This is illustrated in figure 2, which shows that for an average test strength of 3531 lb/in^2, only a small percentage of tests (indicated by the shaded area) will have results less than 2500 lb/in^2.

The specified strength requirement increases with the variability of the test results (i.e., a higher “factor of safety” is required when test results are more variable). The specified value decreases as a greater number of test results are obtained and averaged to estimate the property of interest. However, there is always a small chance—that same 5 percent or less—that a random test will produce a result that is lower than the required minimum, even if the actual properties of the overall batch have not changed. If too few samples are tested, the presence of a single noncompliant result may incorrectly indicate a noncompliant material property or construction process. It is important to test enough replicate samples to avoid this situation.

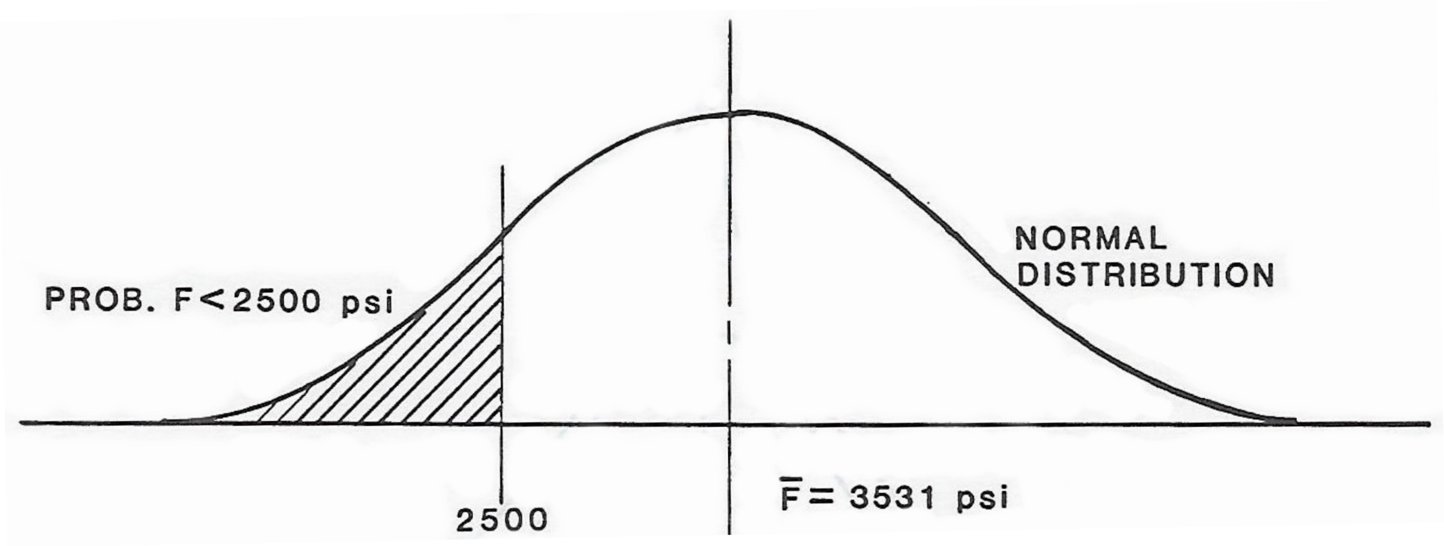

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Figure 2. Illustration of normal distribution of a set of concrete compressive strength tests (mean = 3531 lb/in^2) relative to design strength (2500 lb/in^2).

Approaches for Addressing Noncompliance

When noncompliance is detected or measured during ongoing construction, the first step that must be taken is to identify and correct the source(s) of noncompliance to avoid the construction of additional noncompliant work. In addition, if the issue is critical and threatens potential pavement performance or service life, it is imperative that the contractor stop construction until the source of the problem has been identified and corrected.

Whether noncompliance is identified during or after construction, it is necessary to determine how to treat the noncompliant work that has been constructed. Options for handling noncompliant work include: 1) removal and replacement; 2) do nothing; 3) acceptable correction of the work; 4) leaving the work in place without correction but with a pay adjustment; and 5) some combination of these options. Brief descriptions and discussions of these options follow.

Removal and Replacement

Removal and replacement of a portion (e.g., a joint or panel) or all the pavement is sometimes the default approach for addressing pavement that incorporates noncompliant work. This approach is sometimes necessary for grossly noncompliant work and deficiencies that cannot be adequately addressed in any other way that will provide expected levels of performance and service life. Additional testing may be useful for justifying the necessity (or not) of removal and replacement (e.g., the use of cores to determine the depth of damage from early-age rain events or to determine hardened air parameters when volumetric air test results are lower than specified).

The removal and replacement of individual joints and panels can introduce some of the same problems that often accompany patching and repair projects – the introduction of additional joints, immediate increases in roughness due to profile mismatches between the repairs and surrounding pavement, and longer-term increases in roughness if the repair settles due to foundation disturbance or poor dowel anchoring. There are often other, less-expensive alternatives that can provide good performance and restore expected service life. Therefore, removal and replacement should be required only after careful consideration of the costs and potential performance of all options.

Do Nothing

A pure “do nothing” approach is rarely appropriate because, as a minimum, the condition that created the noncompliance must be corrected. However, if a noncompliant test result or condition is verified (often considering the results of additional testing or measurements), it is sometimes an option to accept some or all the work with a pay adjustment (reduction).

Accepting Noncompliant Work for Reduced Payment

Sometimes it can be determined that a given aspect of the construction fails to meet the specifications but is adequate to serve the general design purpose without requiring costly and time-consuming removal and replacement. This approach is often used for common construction items that are subject to some variability when the deviation from specifications is relatively small. Pay adjustments should reasonably reflect the reduced present value of the work relative to the intended pavement function and service life.

One of the most common examples of this approach in concrete pavement construction is the use of pay adjustments for thickness deficiencies. Variations in measured concrete pavement thickness are expected due to artifacts of the paving process (e.g., varying concrete head in front of the paver, string line sag, etc.), variations in the subbase surface profile, inaccuracies in measurement techniques, and other factors. These sources of thickness variability can lead to the occasional measurement of slightly noncompliant thickness values that will have little impact on pavement function or service life. However, concrete pavement load carrying capacity and fatigue resistance are very sensitive to slab thickness, so larger deviations from the design thickness can significantly reduce load carrying capacity and service life. Thus, pay reductions for thickness deficiencies are often structured nonlinearly, with small adjustments for small deficiencies and much larger deductions for greater deficiencies.

An example pay adjustment structure for pavement thickness deficiency is presented in table 1.

Another example of this approach is when concrete volumetric air content is deficient. If the degree of noncompliance was small, the owner’s representative may: 1) elect to leave the noncompliant batch(es) in place without further testing or consideration; 2) may elect to perform hardened air tests on cores or beams cut from the affected section of pavement to determine whether to leave it in place; or 3) may apply a predetermined (specified) pay adjustment, based on the degree of noncompliance, to that batch of material.

Table 1. Example pay adjustment table for concrete thickness deficiency (MnDOT 2018).

Thickness Deficiency Exceeding Permissible Deviations, in	Adjusted contract unit price per sq. yd of Pavement
0.00 - ≤ 0.10	None (tolerance)
0.11 - ≤ 0.20	$0.20
0.21 - ≤ 0.30	$0.40
0.31 - ≤ 0.40	$0.70
0.41 - ≤ 0.50	$1.00
0.51 - ≤ 1.00	$20.00

Monetary deductions for final average core thickness (each plan thickness).

An illustrative case in point is the Minnesota DOT's 2018 Construction Specification Section 2301, which requires a target air content of 7.0 percent (plus or minus 1.5 percent). If the air content before consolidation is between 5 and 5.5 percent, a monetary reduction of \$25/yd^3 or 25 percent of the contractor-provided invoice is applied. If the air content is between 4 and 5 percent, the suitability of the concrete is determined by means that may include hardened concrete testing. If the air content is 4 percent or less, the concrete is either removed and replaced or may (at the Engineer's discretion and after additional testing) be left in place with no payment to the contractor and possibly with the addition of an epoxy penetrating surface sealer.

It should be noted that "stepped" or tabulated pay adjustments of the type described in the two examples above can result in significant pay adjustments for minor changes in material properties or test results. To illustrate, consider that the MnDOT 2018 air content requirement described above provides full pay at 5.5 percent air, but applies a \$25/yd^3 pay reduction at 5.4 percent air.

The use of pay factor equations (rather than tables or stepped pay functions) provides continuous pay adjustments and avoid the potential for large changes in pay for small changes in measured properties. For example, Section 740 of the Wisconsin DOT standard specifications provides the following ride quality pay adjustments for each 500-ft road segment (WisDOT 2019):

For IRI <35: \$250

For IRI > 35 and < 45: \$1125 – (\$25*IRI)

For IRI > 45: \$0

Accepting Noncompliant Work with Suitable Repair

Noncompliant work can often be acceptably corrected using appropriate repair and rehabilitation techniques. The most common example is the use of diamond grinding to improve unacceptable pavement ride quality and surface texture. Other examples include (but are not limited to):

- The use of retrofit load transfer devices across mid-panel transverse cracks in lieu of panel removal and replacement.
- The use of low-viscosity penetrating methacrylate sealer in plastic shrinkage cracking in lieu of panel removal and replacement.
- Cutting misaligned dowels in noncritical locations in lieu of joint replacement.
- Cross-stitching longitudinal joints with missing or excessively offset tie bars in lieu of removal and replacement.
- Use of thin bonded overlay materials to correct ride quality and surface texture deficiencies.

In most cases, corrective repairs are far less expensive and more quickly accomplished (less disruptive to users) than pavement removal and replacement. In many cases, less intrusive repairs also result in a better-quality product than removal and replacement of joints and panels, which can increase the total number of joints and decrease overall pavement ride quality if they are performed without diamond grinding.

Other Options

The best approach for addressing noncompliance on some projects may be a combination of the approaches described previously. For example, suppose that a surveying or string line setting error results in a gradual change in the placement of concrete where thickness varies gradually from the target value to being slightly more than an inch too thin over a distance of several hundred feet or meters. It is likely that some portion of the work would need to be removed and replaced for excessive thickness deficiency, but other deficient segments might remain in place with only minor pay adjustments.

Similar examples of combined approaches to noncompliance can be developed for variations in concrete properties (e.g., air content, strength, etc.), construction defects (e.g., edge slump, smoothness, etc.), early-age performance and behavior (e.g., cracking) and other issues. A discussion of some of the factors that should be considered in determining the most appropriate approach (or combination of approaches) to specification noncompliance follows.

Considerations for Approaching Specification Noncompliance

There are many factors that should be considered in selecting the best approach to specification noncompliance in any given case, including:

- The extent and severity of the noncompliance.
- The cause of the problem.
- The potential impact of noncompliance on pavement function and service life.
- The potential impact of each noncompliance remedy on the stakeholders (i.e., the agency, the contractor, and the users), including consideration of the "doctrine of economic waste."

Extent and Severity of Noncompliance

Isolated issues are typically addressed with localized repairs (e.g., for occasional mid-panel cracks) or may be ignored, depending upon the nature and severity of the problem (e.g., for shallow drying shrinkage cracks). More widespread problems may suggest systematic issues with materials or construction processes. Consideration of the causes and potential impacts of the noncompliance will help to determine whether the pavement can be effectively repaired (e.g., for shallow drying shrinkage cracking), must be removed and replaced (e.g., for widespread and grossly deficient concrete air systems, strength or thickness, or other pavement structural issues), or can remain in place, with or without a pay adjustment (e.g., for systematic dowel alignment issues that are beyond the limits of acceptance but not beyond rejection levels).

The development and use of Percent Within Limits (PWL) specifications can provide relief from disputes over the treatment of occasional but widespread noncompliant test results and measurements by recognizing and accepting limited numbers of noncompliant values. For example, the ACPA *Guide Specification for Dowel Alignment* (ACPA 2019) recommends full payment for load transfer devices when 90 percent or more of all dowels comply with acceptance criteria for rotational misalignment, side shift and depth (after corrections have been applied to all dowels that exceed rejection criteria). This approach recognizes the inherent variability in dowel positioning and positioning measurement that is likely to result in a small number of noncompliant positioning values on typical concrete paving projects; it also recognizes that occasional mispositioned dowels rarely impact pavement performance or service life. Guidance concerning the development of PWL specifications for pavements is provided in Burati et al. (2004).

Cause of Problem

The source of apparent noncompliance is an important consideration in determining how best to address the issue:

- Noncompliance that results from contractor negligence or poor quality control must be approached in a manner that addresses both the process that created the issue (to prevent or discourage the construction of additional noncompliant work) and the work already in place (to ensure or restore expected pavement function and service life. Work must be stopped until process corrections are made.

Additional testing should be considered to validate noncompliant test results when they are obtained from small or potentially unrepresentative samples.

- Noncompliance that may result from normal variance in test results or process measures (e.g., the occasional low strength or air content measurement) should not be ignored but must be considered in the context of adequacy of the sample size. A single volumetric air content test conducted typically uses a 0.25 ft^3 sample of concrete from a truck that may contain 10 yd^3 or more; the test is a measure of less than 1/1000 the volume of the batch. Further, it is not usual to observe slight variations in air content and other mix characteristics in different portions of the delivered material, so the small sample used for estimating volumetric air content may not be representative of the general batch properties, even when specified sampling and testing procedures are followed precisely. Additional testing should be considered to validate noncompliant test results when they are obtained from small or potentially unrepresentative samples.
- Some tests provide only indicators of actual pavement properties because they are performed on companion specimens to avoid damaging the actual pavement (e.g., the use of field-cast cylinders to estimate the strength of in situ concrete). Other tests are performed because they are relatively quick or inexpensive when compared to tests of the actual characteristic of interest (e.g., the use of surface resistivity test results to infer concrete resistance to chemical attack). Depending upon the number of tests performed and the degree of correlation between the surrogate test and the actual property of interest, a noncompliant result may not be sufficient to indicate an actual problem. Additional testing should be considered (including additional surrogate testing as well as possible testing of the parameter of interest, such as strength or freeze-thaw testing of cores or beams cut from the concrete) to validate the noncompliant test results.

Potential Impact of Noncompliance on Pavement Function and Service Life

The impact of unaddressed noncompliance on expected performance (e.g., ride quality, required future maintenance and associated traffic control and user costs, etc.) and service life should be considered when considering accepting noncompliant work (with or without pay adjustments).

Many method-type specifications contain instructions that represent accepted or “best” construction practices for which noncompliance will have little or no impact on performance and service life in many cases. For example, failure to dampen the subbase prior to placing the concrete (a common requirement in many method specifications for concrete paving) is most likely to impact performance or service when the subbase material is very warm (i.e., sunny summer conditions), dry and highly absorptive, or when the concrete layer is relatively thin (for example, thin concrete overlays placed on hot, dry asphalt pavement).

In other cases, the impact of noncompliance on performance and service life can be highly significant. Obvious examples include concrete strength, thickness, quality of the air void system (in freezing climate), initial ride quality, etc. Most measures of performance typically used in performance-based specifications are used specifically because they are important indicators of pavement performance or service life.

In some cases, the link between a specified parameter and pavement performance and service life is generally understood, but not easily quantified. Dowel misalignment (horizontal skew or vertical tilt), for example, is understood to restrain joint function, but recent studies suggest that misalignment (along with horizontal, longitudinal, and vertical translation) also contributes to reductions in joint load transfer that can be expressed as reductions in effective dowel diameter (Khazanovich, Hoegh, and Snyder 2009). The effect of decreased effective dowel diameter on predicted joint faulting and IRI (measures of pavement performance) can be evaluated using the AASHTOWare PavementME Design software, and the reduction in time required to reach critical thresholds of faulting and IRI are indicators of service life reduction.

Potential Impact of Noncompliance Remedies

While accepting noncompliant work (with or without pay adjustments) can impact pavement performance and service life, each candidate remedy for noncompliance has associated costs and may also impact pavement function and service life in ways that should be considered.

Economic costs and benefits to the agency, the contractor and the users will vary with the selected remedy. For example, consider the possibility of addressing early-age mid-panel transverse cracking using either dowel bar retrofit (DBR) with crack routing and sealing ("Option 1") versus removal and replacement (R&R) of affected panels ("Option 2"). Option 1 is likely to be a quicker repair process with lower reduced traffic control and user delay costs, reduced construction and inspection costs, etc.) than for removal and replacement. Option 1 may also have a smaller impact on current ride quality since the original pavement profile remains the same, while panel replacements often present different surface elevations than the original pavement, resulting in some immediate loss of ride quality or serviceability.

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In addition, the resulting pavement service life and quality of service provided may be different for these options. The work in DBR installations is confined to small areas in the top portion of the concrete layer, while full-depth removal and replacement involves several potentially impactful operations (e.g., foundation repair and compaction, drilling and anchoring dowels, placement and finishing of large areas of concrete, etc.), each of which can adversely influence the performance of the repair area, drive the need for future maintenance work, and impact pavement service life.

In the example above, the more cost-effective and least impactful repair strategy may be the use of retrofit dowel bars (assuming a good performance history of DBR installations on other agency projects). However, some owner-agencies would likely require removal and replacement of the cracked panels because they believe that they believe that they are entitled to full and complete compliance with the specifications, regardless of cost, even if the added benefit gained is marginal (or, as in this case, is a reduction in benefits). Arguments against this approach often invoke the "doctrine of economic waste," which is described below.

Doctrine of Economic Waste (Perloff 1993)

An important aspect of litigation concerning breach of contract (including cases of non-conforming construction work) is the computation of damages. In cases related to non-conforming construction work, courts often compute damages based on the cost of repairing the defect to satisfy the "owner's expectation interests." However, an important exception to the cost-of-repair approach is the "doctrine of economic waste," which holds that "if granting repair costs to the owner would result in 'unreasonable economic waste,' then the proper measure of the owner's damage should be the difference between the value of the project as promised in the contract and its value as delivered."

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The economic-waste doctrine applies in two types of situations: 1) "when the cost of repairing a defect is substantially greater than the increase in value an owner would realize with the repair" and 2) "when repairing a defect would require substantial destruction and reconstruction of usable property." In such situations, courts have often acted to avoid "imprudent use of resources."

The economic-waste doctrine has been widely applied under State law but has been applied inconsistently in construction contract litigation involving the U.S. Government because it is at odds with the U.S. Government contract principle of strict compliance, which provides that "the Government may require a contractor to repair all defects in performance at the contractor's cost irrespective of burden."

Perloff (1993) presents a comprehensive discussion of the economic-waste doctrine and the evolution of its consideration in Government contract litigation, which is not repeated or even summarized here. However, the concepts that underlie the doctrine of economic waste are worthy of consideration in determining equitable and appropriate approaches to addressing noncompliance in pavement construction.

SPECIFICATION NONCOMPLIANCE CASE STUDIES

The following examples are based on actual projects where the pavement construction was deemed "noncompliant" and describes approaches considered for addressing the noncompliance.

Rain-Damaged Pavement Case

A two-lane concrete county highway project was exposed to a brief heavy rain shower during construction, resulting in severe loss of mortar and exposed coarse aggregate at the pavement surface over several hundred yards. The owner's representative initially demanded removal and replacement of the pavement (including several hundred additional yards of pavement that had set and been sawed prior to the rain event).

Cores were drilled to determine the thickness of the as-built pavement and for use in petrographic examinations to determine the depth of water penetration (which would result in locally higher water-cementitious ratio and lower strength and durability). The average slab thickness was within 0.125 inches of the planned thickness in the obviously rain-damaged area and was greater than the planned thickness in the area that was set and sawed before the rain. Petrographic examination of vertically sawed and polished core specimens indicated up to a 0.25-inch of low-density (water-damaged) paste at the surface of the obviously rain-damaged area and no significant amount of low-density paste in the area that was set and sawed prior to the rain event. The contractor agreed to diamond grind the rain-damaged area to a depth of ¼ inch and take a modest reduction in the bid price for the concrete material and paving operations for the affected area. No repairs or pay adjustments were applied to the area that was set and sawed before the rain event.

Dowel Misalignment Case

An Interstate highway project was constructed with dowel positioning issues in many joints, resulting in longitudinal translations of up to 4 inches (i.e., as little as 5 inches of dowel embedment on one side of the joint). The owner identified several joints with the most significant embedment deficiencies and demanded that these joints be removed and replaced at the contractor's cost, and also that the contractor be assessed a large monetary penalty equal to the current cost of diamond grinding the entire project.

The contractor did replace the owner-identified joints with the worst dowel positioning issues. The contractor's consultant examined the dowel positioning data and found that most dowels were offset far less than the 4-inch maximum (and that the worst joints had been removed and replaced, such that no embedment problems were now present at those locations). A worst-case assessment of the impact of the remaining translated dowels was begun by using the equations presented in Khazanovich, Hoegh, and Snyder (2009) to determine the effective equivalent diameter of the translated dowels and assuming that all dowels in every joint were translated by 4 inches.

AASHTOWare Pavement ME Design software was used to develop pavement performance predictions (cracking, joint faulting and IRI) for both the actual dowel diameter and for the reduced dowel diameter that represented the impact of all dowels being translated 4 inches. These analyses indicated that, for the design traffic levels and the very conservative reduced effective dowel diameter (which represented 4 inches of side shift for every dowel in the project), the pavement would not reach the joint faulting, slab cracking or IRI thresholds within the 30-year analysis period. Therefore, the imposition of a penalty equal to the cost of performing an additional diamond grind seemed excessive. These analyses led to the assessment of a greatly reduced penalty for the dowel positioning problems that remained after replacing the worst joints.

USE OF NONCOMPLIANCE CASES TO IMPROVE SPECIFICATIONS

Cases of specification noncompliance should be used to evaluate whether existing specifications should be updated or revised to avoiding future problems. Changes can include:

- Relaxation of acceptance criteria that are unnecessarily strict or in excess of what is actually required for acceptable performance.
- Changing a single-threshold requirement for acceptance or rejection to a dual-threshold specification of the type described earlier in this document.
- Clarifying ambiguous language that can be interpreted in different ways.

Making these types of specification improvements is a critical step, especially when certain noncompliance issues become chronic.

SUMMARY

Materials and construction specifications provide the owner/agency with a set of standards against which to evaluate the project materials and the contractor's work, often including allowable tolerances in evaluation measures. These specifications often present inspectors and contractors with hundreds of requirements concerning materials, equipment, construction processes and properties of the finished pavement structure.

Project specifications can also define limits or thresholds that define both acceptable practices or properties and rejectable ones; these are often different thresholds. The specifications may provide explicit instructions about handling noncompliance (e.g., requiring diamond grinding of any areas that fail to meet minimum texture depth requirements) but, when little or no guidance is provided concerning handling of noncompliance, decisions may be made that permit the inclusion of potentially detrimental noncompliant work or may lead to the wasteful rejection or removal of noncompliant works that would have little or no negative impact on pavement performance. It is important that specifying agencies explicitly consider potential noncompliance situations as they develop project specifications and attempt to provide guidance in handling these situations within each specification. While it is impossible to foresee and address every possible scenario of noncompliance, providing guidance for foreseeable situations will smooth and expedite the construction and inspection processes.

When noncompliance is detected or measured during ongoing construction, the source(s) of noncompliance must be identified and corrected to avoid the construction of additional noncompliant work. It is also necessary to determine how to treat the noncompliant work that has been constructed. Options for handling noncompliant work include: 1) removal and replacement; 2) do nothing; 3) acceptable correction of the work; 4) leaving the work in place without correction but with a pay adjustment; and 5) some combination of these options.

Factors that should be considered in selecting the best approach to specification noncompliance include the extent and severity of the noncompliance, the cause of the noncompliance, the potential impact of noncompliance on pavement function and service life, and the potential impact of each noncompliance remedy on the stakeholders (i.e., the agency, the contractor, and the users). The economic-waste doctrine may apply when the cost of repairing a defect is substantially greater than the increase in value that would be realized with the repair, and when repairing a defect would require substantial destruction and reconstruction of usable property. From this perspective, the owner, engineer, and contractor should work together to evaluate every situation and apply appropriate action in lieu of blindly enforcing the specifications to the detriment of the project. In all cases, the potential consequences of any noncompliance solutions must be fully considered before the solution is implemented.

REFERENCES

American Association of State Highway and Transportation Officials (AASHTO). 2003. *Major Types of Transportation Construction Specifications–A Guideline to Understand in Their Evolution and Application*. A Report of the AASHTO Highway Subcommittee on Construction Quality, Construction Task Force. American Association of State Highway and Transportation Officials, Washington, DC.

American Concrete Pavement Association (ACPA). 2019. *Guide Specification for Dowel Bar Alignment and Location*. American Concrete Pavement Association, Rosemont, IL.

Burati, J. L., R. M. Weed, C. S. Hughes, and H. S. Hill. 2004. *Evaluation of Procedures for Quality Assurance Specifications*. FHWA-HRT-04-046. Federal Highway Administration, Washington, DC.

Federal Highway Administration (FHWA). 2007. *Best Practices for Dowel Placement Tolerances*. FHWA-HIF-07-021. Federal Highway Administration, Washington, DC.

Federal Highway Administration (FHWA). 2010. *Development and Review of Specifications. Technical Advisory*. Federal Highway Administration, Washington, DC.

Federal Highway Administration (FHWA). 2013. *Questions and Answers Regarding Title 23 CFR 635.411*. Federal Highway Administration, Washington, DC.

Harrington, D., M. Ayers, T. Cackler, G. Fick, D. Schwartz, K. Smith, M. B. Snyder, and T. Van Dam. 2018. *Guide for Concrete Pavement Distress Assessments and Solutions: Identification, Causes, Prevention, and Repair*. National Concrete Pavement Technology Center, Iowa State University, Ames, IA.

Huang, Y. H. 2004. *Pavement Analysis and Design, 2nd Edition*. Pearson Prentice Hall, Upper Saddle River, NJ.

Khazanovich, L., K. Hoegh and M. Snyder. 2009. *Guidelines for Dowel Alignment in Concrete Pavements*. NCHRP Report 637. Transportation Research Board, Washington, DC.

Minnesota Department of Transportation (MnDOT). 2018. *Standard Specifications for Construction*. Minnesota Department of Transportation, St. Paul, MN.

National Highway Institute (NHI). 1987. *Pavement Design Principles and Practices – A Training Course, Participant Notebook*. National Highway Institute, Washington, DC.

National Precast Concrete Association (NPCA). 2019. *Manual for Jointed Precast Concrete Pavement, 3rd Edition*. National Precast Concrete Association, Carmel, IN.

Perloff, H. J. 1993. "The Economic-Waste Doctrine in Government Contract Litigation." *DePaul Law Review*. Volume 43, Issue 1. University Libraries, DePaul University, Chicago, IL.

Snyder, M. B. 2018. "Dowel Bar Alignment: What Do We Need? What Should We Expect?" *ACPA NC Concrete Pavement Conference*. Presentation. American Concrete Pavement Association, Rosemont, IL.

Wisconsin Department of Transportation (WisDOT). 2019. *2019 Standard Specifications. Section 740 – QMP Ride*. Wisconsin Department of Transportation, Madison, WI.

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