Joint Transportation Research Program

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Pavement Acceptance Testing: Risk-Controlled Sampling Strategy

Introduction

Acceptance testing is a critical aspect of the quality control and quality assurance (QC/QA) program to ensure the reliable long-term performance of pavement. A typical acceptance testing specification includes acceptable quality characteristics (AQCs), testing methods, number of samples, sample locations, and acceptance criteria. In the current practice, the Indiana Department of Transportation (INDOT) accepts pavement by sampling and testing materials with a predetermined very low frequency at random locations. This leads to a significant problem: testing results are not truly "representative" of the project because sampling is not based on a statistical foundation nor on the reliability concept. Therefore, there is a critical need for INDOT to develop a guideline for the testing protocol from a system perspective to minimize risk and ensure the reliability of material acceptance testing.

This study developed a systematic guideline that addresses the aforementioned problem with material acceptance testing in four aspects: (1) identifying key material properties for testing, (2) selecting sample locations, (3) designing acceptance criteria, and (4) determining optimal sample size. Key material properties that are critical to pavement long-term performance are identified by comparing them with sensitive material properties in the Mechanistic-Empirical Pavement Design Guide (MEPDG). A random sampling mechanism was devised based on two spatial indices to control the spatial pattern of samples in order to minimize the influence from spatial autocorrelation. Acceptance criteria were proposed to control the agency's risk at a desired level given a specific sampling and testing strategy, based on which optimal sample size is determined from a risk perspective. Cost analysis approaches were developed to estimate the total cost of acceptance testing by integrating the risk of making incorrect decisions and to enable the determination of optimal sample size from a cost perspective. Additionally, a quality control chart was exploited as a complementary tool to ensure the consistency of pavement quality. The results of this study were validated using real data from INDOT projects, and a web tool that incorporates the newly created methods in this study was developed to assist the field pavement QA practice.

Findings

The main findings and recommendations to control the risk and improve the reliability of pavement and soil acceptance testing are summarized into four aspects, detailed as follows.

1. Findings and recommendations related to key material properties.
   - Ten hot mix asphalt (HMA) properties, 10 Portland cement concrete pavement (PCCP) properties, and 9 soil properties have been identified to be very important to the pavement performance, among which 5 in HMA, 4 in PCCP, and 6 in soil are not tested in the current INDOT practice. Most of the missing items in PCCP and HMA do not have certified testing standards or are difficult and not warranted in laboratory testing. They can be substituted by default design value.
   - It is recommended that (1) HMA thickness be tested and measured directly rather than being estimated, considering its effect on pavement performance, and (2) a sampling and testing protocol be established for key material properties of soil that are currently not tested.
2. Findings and recommendations related to random sampling.
   - ITM 802-based sampling leads to "gaps"—areas that will never be tested due to the limited random numbers in the published table. For earthwork, gap areas can receive insufficient compaction without being caught. For pavement, although gap areas are not large enough to accommodate a whole truckload, they lead to lower probabilities for certain trucks to be tested, compared with the true random sampling process. Such discrepancy results in a lower risk for contractors to manipulate these trucks, and a higher risk for INDOT to accept inferior materials. Therefore, the ITM 802-based sampling is less reliable than the true random sampling process that generates random numbers in real time.
   - Material properties are spatially auto-correlated. Therefore, the sample spatial pattern must be controlled to avoid spatial clustering and ensure the effectiveness of random sampling. Two spatial pattern indices, i.e., nearest neighbor index (NNI) and coefficient of variance

(CV), are proposed for this purpose. NNI assesses the degree of spatial dispersion and is recommended to serve as the primary metrics. CV measures the variability of sample locations and is recommended to serve as the secondary metrics.
    - It is recommended to (1) use a real-time random number generator to determine sample locations, and (2) control the spatial pattern indices sample locations to ensure that the sample locations are spatially distributed and truly representative of the project.
3. Findings and recommendations related to acceptance criteria.
    - The current acceptance methods based on either percent within limit (PWL) or sample mean at INDOT do not achieve the desired level of risk control.
    - For pavement acceptance, the newly proposed numerical M-method and Spk-method incorporate sample variance and treat statistical measures of samples as random variables. They are capable of controlling the risk at a desired level and achieving higher testing power compared to the current practice at INDOT.
    - The numerical M-method is suitable for all scenarios and is recommended to replace the current practice, while Spk-method can be applied when the sample size is relatively large to simplify the computation.
    - For the soil compaction acceptance, a simulation approach is proposed to assess INDOT's risk. It is recommended to conduct the simulation to examine the risk once a sampling strategy is determined, and then make a corresponding adjustment to the sampling strategy according to the desired risk.
    - Plotting QA data on a QC chart helps identify out-of-control process at both project and lot levels. It is recommended that a QC chart be used as an additional quality assurance tool to supplement the numerical M-method.
    - Findings and recommendations related to optimal sample size.
    - The optimal sample size for pavement acceptance testing can be determined to satisfy the risk expectation of both agency and contractor using the proposed numerical M-method and Spk-method. The optimal sample size for soil acceptance can be determined as the smallest value that satisfies the agency's desired risk level using the proposed simulation approach.
    - Two cost analysis methods have been devised to determine the optimal sample size by minimizing the total cost of acceptance testing, one for accept/reject decision only and the other for pay factor decisions.

Implementation

The newly developed methods and corresponding results in this study have been validated using real data from INDOT projects. For practical implementation, a web tool that incorporates the newly created methods in this study has been developed based on R Shiny. It is an effective tool to facilitate the pavement and soil QA practice for the INDOT engineers and has the ability to select random samples, control the agency's risk, and determine optimal sample sizes for both pavement and soil acceptance testing. The web tool consists of seven separate tabs that correspond to different tasks in this study. Tabs 1 and 2 generate random locations and control their spatial pattern for the random sampling in both pavement and soil. Tabs 3 and 4 control the agency's risk of making incorrect acceptance/rejection decisions and calculate the confidence interval of PWL given a specific strategy for pavement acceptance testing. Tab 5 estimates the agency's risk of not identifying defective material and determines the optimal sample size for soil acceptance testing. Tabs 6 and 7 determine the optimal sample size for pavement acceptance testing from both a risk and a cost perspective.

A phased implementation is suggested as follows:

1. Set up R Shiny website to implement the web tool.
2. Tool rollout and pilot testing by phases.
    - Phase I: field crew adopt the random number generator tool to locate sample location.
    - Phase II: field crew and material engineers use the risk assessment tool to determine the probability of accepting inferior products given the testing results.
    - Phase III: engineers use the web tool to determine the optimal sample size.

A clear understanding of the technical principles and a set of skills are necessary to use the web tool and interpret the results. As such, training for INDOT staff is recommended.

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