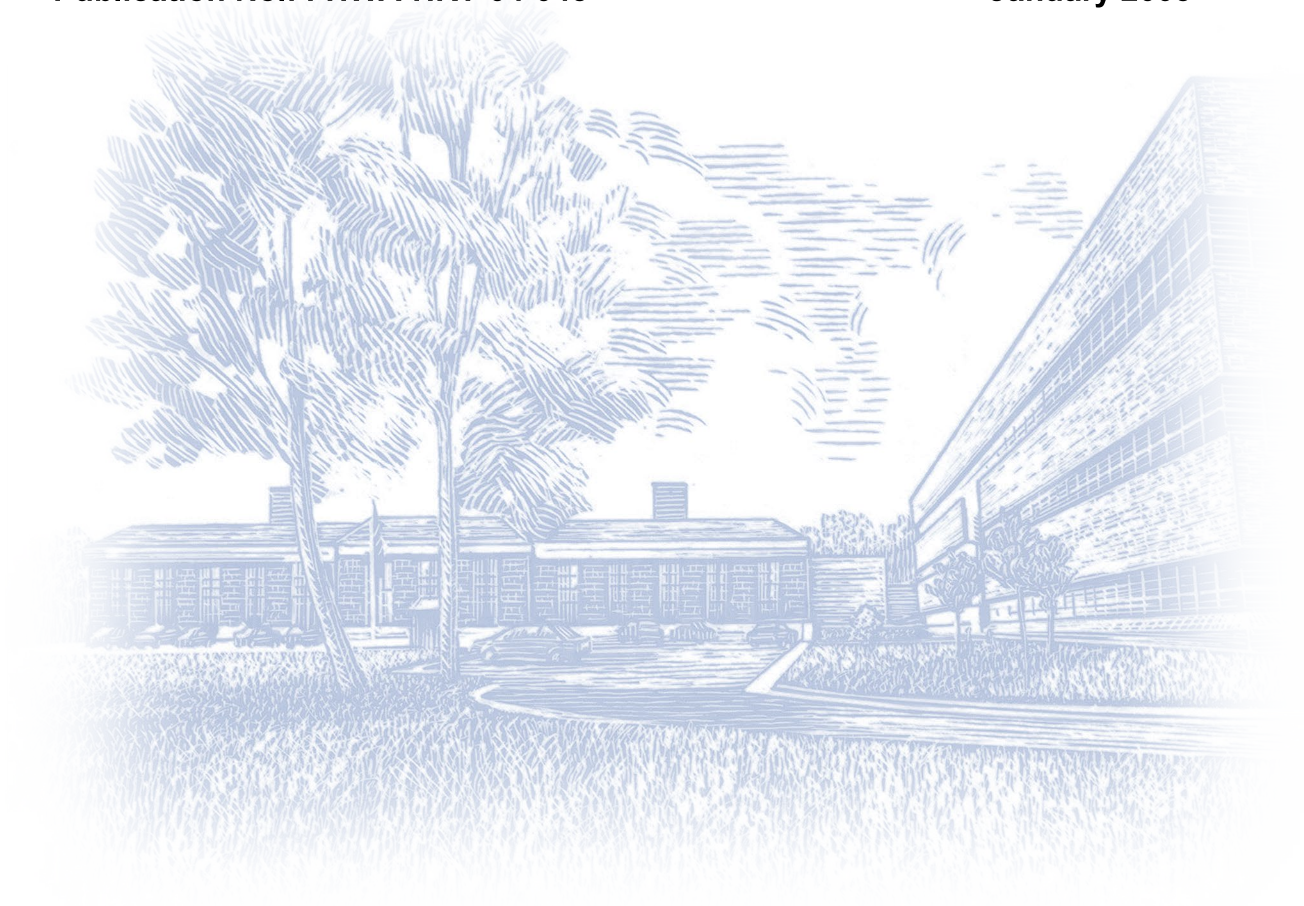
Incremental Costs and Performance Benefits of Concrete Pavement Design Features

Publication No.: FHWA-HRT-04-045 **January 2003**



U.S. Department of Transportation
Federal Highway Administration

Federal Highway Administration
Turner-Fairbank Highway Research Center
6300 Georgetown Pike, McLean, VA 22101

U.S. Department of Transportation
Federal Highway Administration

Foreword

The primary product developed under this project is a software analysis tool that can evaluate the relative performance benefits and costs associated with adding different design features to a PCC pavement design. The tool is for pavement designers who are interested in comparing costs versus performance associated with the selection of design features during the PCC pavement design process. This software is only a computational tool. It is not intended to provide absolute answers on the effect of different design features, but rather to offer insight into general performance and cost trends associated with the use of different design features.

Introduction

Designing portland cement concrete (PCC) pavements involves more than determining slab thickness. PCC pavement system components, such as transverse joint design, base type, drainage design, and shoulder type, significantly impact pavement performance and must be considered during the structural design process. As shown in figure 1, these features either help maintain a high level of pavement serviceability or extend pavement performance life.

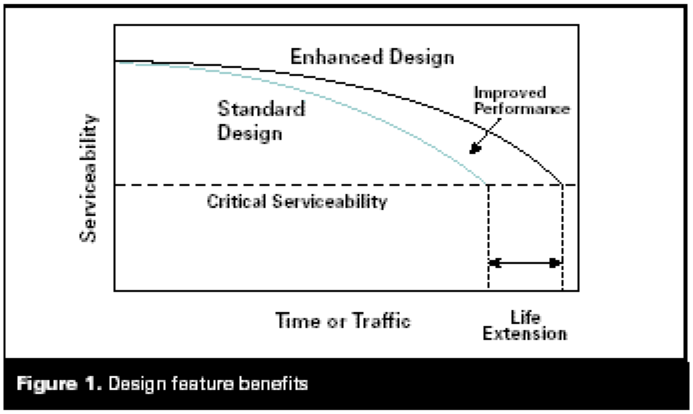


Figure 1. Design feature benefits. Diagram.

Although these system components improve pavement performance, adding them to a PCC pavement also increases costs. To determine whether these design features are cost effective, planners must consider both the performance benefits and design feature costs when designing PCC pavements. Because PCC pavement designers do not always consider these trade-offs, there is a strong need for a methodology and evaluation tool that will help these designers analyze project costs and benefits. Toward this end, the Federal Highway Administration (FHWA) has developed a simple methodology for comparing the impact of various PCC pavement design features on the cost and performance of PCC pavements.

To develop this methodology, FHWA:

- Documented the relative performance benefits of different PCC pavement design features on PCC pavement performance.
- Established relative construction costs associated with different PCC pavement design features.
- Developed a software analysis tool that compares and evaluates trade-offs to assess the relative performance benefits and costs of various design features.

Data Collection

Literature Review

Researchers first conducted a detailed literature review to identify pertinent reference documents regarding the cost and performance benefits of different PCC pavement design features. A previous literature review conducted for a National Highway Institute (NHI) training course was the basis for this literature search.(1) Researchers gathered additional information on pavement cross sections, PCC strength, PCC materials, and ride specifications to supplement existing review documents. Annotations were written for the new records, and a final annotated bibliography was prepared and grouped by topic. Key documents were reviewed, and these provided the foundation for determining which pavement design categories and design features would be evaluated in the study. These articles also provided insight into general costs and performance trends.

Survey Development

Data collection surveys were developed next. First, researchers identified 10 primary categories of PCC pavement design features, and within each category, determined possible design feature alternatives. One feature was selected as the standard feature for each category, because pavement designs can vary considerably within each category. The collection of standard features from all design categories represented the standard PCC pavement cross section. This standard cross section was used as the basis for comparison, helping researchers determine the incremental increase or decrease in cost and performance, relative to the standard design.

Although an unlimited number of design feature alternatives could have been selected for this project, the number of alternatives was limited to represent established design practices and streamline the survey. The selected design feature categories were:

- Subgrade.
- Base/Subbase.
- Drainage.
- Thickness/Slab Size.
- Shoulders.
- Pavement Cross Section.
- Joints/Load Transfer.
- Joint Sealing.
- Concrete Strength/Materials.
- Initial Smoothness.

Researchers then developed two surveys; one targeted State Highway Agencies (SHA) to solicit relative performance data, and the other targeted PCC paving contractors to collect relative cost data. Although these were separate surveys, the pavement design variables presented in each were identical, so the data could be paired directly for analysis. Both surveys were structured so that only one design feature from the standard design was altered at any given time; survey participants then were asked to assess the effect that change might have in terms of the relative performance (SHA survey) or cost (contractor survey).

Respondents provided the relative ratings for the alternative changes in the 10 design feature categories. Respondents were asked not to enter a rating if they had no experience with a particular design feature.

SHA Performance Survey

A project summary and request for participation was faxed to 43 SHAs, and 14 SHAs responded. Because of the considerable variability associated with many of the responses, experts identified perceived outlier data from the survey responses. Outlying data points were identified as those performance values that 1) grossly contradicted the expected performance trends or 2) differed greatly from the reasonable performance range determined from engineering judgment.

As an additional check, researchers used available PCC pavement performance models to predict the expected performance associated with various design feature changes. These included 1993 and 1998 American Association of State Highway and Transportation Officials (AASHTO) models and models from FHWA field performance studies.[2-5] The performance ratings received from SHAs were evaluated against these performance models to check validity and reasonableness.

SHAs also were asked to rank the relative importance of each design feature category to PCC pavement performance-of the 10 design feature categories in the survey, respondents were asked to rank each factor on an integer scale of 1-10 (1 represented the least important factor; 10 represented the most important factor). No two design features were allowed to share a ranking, resulting in a forced ranking of the importance of each design feature category. Results of these category rankings were used in the analytical approach to evaluate the effect of multiple design feature changes on PCC pavement performance.

PCC Paving Contractor Cost Survey
A project summary and request for participation was faxed to 216 contracting companies; the American Concrete Pavement Association provided this list. Sixteen contractors responded. An initial review of the data collected indicates that comprehensive drainage systems, PCC shoulders, and high earlystrength PCC mixtures increase pavement costs substantially. In contrast, survey results indicate that pavement cross sections (trapezoid or thickened edge), widened slabs, and joint sealing have very little effect on PCC pavement construction costs.

Data Collection Summary

Results from the performance and cost surveys established the basis of the default data sets that are used in the software analysis tool described below. Agencies are encouraged to develop their own data sets to reflect local conditions.

Software Analysis Tool

The software developed during this project is intended for pavement designers and contractors who are interested in analyzing cost and performance benefits related to different PCC pavement design features. It is not intended as a design tool-the software only provides a reasonableness check to justify or question the addition of different design features. This tool only provides estimates of the cost and performance associated with various design features, therefore, the data should be used with caution.

The software can perform two types of analyses:

- Direct Comparison - This method compares two pavement sections, each with different design features, to determine the relative differences in their expected cost and performance.
- Sensitivity Analysis - This method defines more complex analyses,such as comparing one pavement section to multiple pavement sections, or assessing the sensitivity of a chosen pavement section to changes in other analysis session inputs (such as different cost data sets, performance data sets, or category ranking sets).

Analysis Approach Components

Pavement Section Definition
A pavement section is defined as a unique combination of specific pavement features chosen from the 10 design feature categories. The analytical software tool allows users to define any number of pavement sections by choosing unique combinations of the design features from the 10 categories. The tool then compares this design against the standard section.

Cost and Performance Data
The methodology is based on estimating the total difference in cost and performance associated with changing one or more design features from the standard pavement section. To do this, the software analysis tool creates cost and performance data sets. Each data set is the summary of the relative percent changes in cost or performance associated with all available design feature values in each of the 10 design feature categories.

Category Ranking Factors
Category ranking factors are relative weighting factors that determine the assumed relative importance of each design feature category to overall pavement performance. The software analysis tool defines a ranking factor set by sorting all 10 design feature categories in order of decreasing importance. Next, integer values from 10-1 are assigned to the sorted category list (10 is most important, 1 is least important).

Simplistic Life-Cycle Cost (LCC) Analysis
Because design feature changes affect the expected performance (estimated service life) of a given PCC pavement section, the associated LCC stream also is affected. To investigate the impact of design feature changes on LCCs, the software analysis tool conducts a simplistic LCC analysis. In this context, simplistic means that the cost stream values (annual maintenance, rehabilitation, and salvage value costs) may be determined using simplified methods.

Analysis Example

Assume that relative performance values of +8.0 percent, -1.0 percent, and +15.0 percent are associated with changes in the Subgrade, Base/Subbase, and Drainage design feature categories, respectively. Next, assume individual ranking factors of 5, 8, and 7 are associated with these categories. Because the largest impact factor of these three is the "8" associated with the Base/Subbase category, all three impact factors are divided by 8 to compute normalized ranking multipliers. These are then multiplied by the associated expected relative performance values to provide a modified performance value for each design category. The overall section performance is determined as the sum of all modified performance values. In this example, the expected increase in performance is estimated to be 17.1 percent. These calculations are summarized in table 1.

Table 1. Example of using category ranking factors to determine an overall modified performance

Design Feature Category	Expected Relative Performance	Category Ranking	Normalized Ranking Multiplier	Modified Performance (%)
Subgrade	+8.0	5	(5/8)= 0.625	+5.0
Base/Subbase	-1.0	8	(8/8) = 1.00	-1.0
Drainage	+15.0	7	(7/8) = 0.875	+13.1
Total				+17.1

References

1. Smith, K.D. and K.T. Hall, *Concrete Pavement Design Details and Construction Practices*, reference manual for National Highway Institute Course 131060, National Highway Institute, Arlington, VA, 2001.
2. *AASHTO Guide for Design of Pavement Structures*, American Association of State Highway and Transportation Officials, Washington, DC, 1993.

3. *Supplement to the AASHTO Guide for Design of Pavement Structures, Part II-Rigid Pavement Design and Rigid Pavement Joint Design*, American Association of State Highway and Transportation Officials, Washington, DC, 1998.
4. Smith, K.D., A.L. Mueller, M.I. Darter, and D.G. Peshkin, *Performance of Jointed Concrete Pavements, Volume II-Evaluation and Modification of Concrete Pavement Design and Analysis Models*, FHWA-RD-89- 137, Federal Highway Administration, McLean, VA, 1990.
5. Yu, H.T., K.D. Smith, M.I. Darter, J. Jiang, and L. Khazanovich, *Performance of Concrete Pavements, Volume III-Improving Concrete Pavement Performance*, FHWA-RD-95-111, Federal Highway Administration, McLean, VA, 1998.

Research—This work was performed by Applied Pavement Technology, Inc., 3001 Research Road, Suite C, Champaign, IL, 61822 under contract number DTFH61-02-P-00412.

Distribution—This TechBrief is being distributed according to a standard distribution. Direct distribution is being made to the Resource Centers and Divisions.

Availability—The publication from which this TechBrief was developed-Incremental Costs and Performance Benefits of Concrete Pavement Design Features-is available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA, 22161 (www.ntis.gov). A limited number of copies are available from the Research and Technology Product Distribution Center, HRTS-03, FHWA, 9701 Philadelphia Court, Unit Q, Lanham, MD, 20706 (phone: 301-577-0818; fax: 301-577-1421).

Key Words—concrete pavement, rigid pavement, design features, pavement performance, costs, cost effectiveness.