Improving the Foundation Layers for Concrete Pavements

Proposed Pooled Fund Project

Problem Statement
February 26, 2008

PROJECT TITLE

Improving the Foundation Layers for Concrete Pavements

PROBLEM STATEMENT

Quality pavement foundation layers are essential to achieving excellent pavement performance. In recent years as truck traffic has greatly increased, the foundation layers have become even more critical to successful pavement performance. Unfortunately, there are still many pavement failures in the U.S. related to inadequate subbase, natural subgrade, and embankment (commonly referred to as foundation layers or roadbed). Factors that contribute to pavement foundation problems are believed to be poor construction practices, ineffective QC/QA testing methods and sampling plans, material variability and unpredictable long-term material behavior, poor verification of material properties during construction, insufficient development of performance-related specifications, and low capital investment in the foundation layers.

The recent International Technology Scanning Program report *Long-Life Concrete Pavements in Europe and Canada* (2007) describes that countries with emphasis on long-life pavement performance (30+ years), commonly design foundation layers to incorporate thick drainable but stable base layers, interlayer geotextile, cement treated bases, rigorous compaction control specifications with in-situ load testing (e.g. static plate load tests and falling weight deflectometer) to verify performance, and other improvements. This emphasis does not always exist in the U.S., and when efforts have been made to improve drainage or stabilize layers, the results are not consistent. According to NCHRP 1-37A (2004), "the current state of the art is such that conclusive remarks regarding the effectiveness of pavement subsurface drainage or the need for subsurface drainage are not possible." It is further reported in NCHRP 583 (2007) "The best-performing pavements … were those with bases that were neither too weak (untreated aggregate) nor too stiff (lean concrete)." ACPA (2007) reports that "…low strength soils where construction methods provide reasonably uniform support perform better than stronger soils lacking uniformity." Subsurface drainage, stiffness, strength, uniformity are clearly engineering parameters that affect performance, yet only limited specifications and protocols have been developed for construction, testing, and evaluation to verify achievement of these parameters. Implementation of new construction, testing and characterization technologies (e.g. intelligent compaction, rapid non-destructive testing methods, etc.) have the potential to improve selection of foundation materials, characterization of performance-related engineering properties, and development of construction specifications with meaningful QC/QA testing. Fundamental to the problem is that the foundation layers properties must be verifiable with selected pavement design input parameters.

Specific examples of recently observed field performance problems with subbase layers include: cement treated subbase eroding causing pumping, faulting, and loss of support; asphalt treated base course stripping causing fine materials to pump and increase joint faulting and loss of support; and unbound

aggregate subbase course becoming saturated and loosing strength and eroding causing loss of support. All of these mechanisms lead to slab cracking, joint faulting and roughness. Many permeable subbase layers have been constructed with edge drains on high trafficked highways. Some of these have failed due to design, some to construction, some to material quality, and some to lack of maintenance. Although permeability is considered a critical design input parameter, no consensus exists concerning field QC/QA methods for verifying the as-built condition. The subgrade layer (either new or reconstructed) can be so wet and soft that it cannot be easily prepared for placement of the first subbase layer, or it can exhibit non-uniform settlement resulting in a rough pavement above. The subgrade (stabilized or non-stabilized) can also pump up into the subbase layer (dense or permeable) contaminating it and causing it to lose stiffness and strength. Another rarely considered, but important aspect of the subbase layer, is the contact friction between the slab and base. Some friction is necessary for joint formation and recent research has shown that long-term friction between these two layers can be beneficial to performance. In fact, the loss of friction has resulted in rapid increase in cracking in some jointed plain concrete pavement (JPCP) sections as documented in the Long-Term Pavement Performance (LTPP) database. Although known to be an important parameter to performance, no widely accepted methods exists for measuring the contact friction between the slab and base layer.

OBJECTIVE

The objective of this research is to improve the construction methods, economic analysis and selection of materials, in-situ testing and evaluation, and development of performance-related specifications for the pavement foundation layers. The outcome of this study will be conclusive findings that make pavement foundations more durable, uniform, constructible, and economical. Although the focus of this research will be PCC concrete pavement foundations, the results will likely have applicability to ACC pavement foundations and, potentially, unpaved roads. All aspects of the foundation layers will be investigated including thickness, material properties, permeability, modulus/stiffness, strength, volumetric stability and durability. Forensic and in-situ testing plans will be conceived to incorporate measurements using existing and emerging technologies (e.g. intelligent compaction) to evaluate performance related parameters as opposed to just index or indirectly related parameter values. Field investigations will be conducted in each participating state. The results of the study will be compatible with each state's pavement design methodology and capable for use with the Mechanistic-Empirical Pavement Design Guide (MEPDG). Evaluating pavement foundation design input parameters at each site will provide a link between what is actually constructed and what is assumed during design. There are many inputs to the pavement design related to foundation layers and this project will provide improved guidelines for each of these. The study will benefit greatly from maximizing the wide range of field conditions possible within the framework of a pooled fund study.

Before initiating the forensic and in-situ investigations, information will be compiled from literature worldwide as it relates to pavement foundation construction, testing, evaluation, performance, and specifications. Detailed and comprehensive field studies will be carried out in each of the participating states for existing pavement sections that have good and poor performance and also new pavement foundation construction. A detailed experimental plan will be developed for each site. In-situ testing will be extensive and involve the current state of practice and emerging testing technologies including non-destructive methods and intelligent compaction. The Iowa State University Geotechnical Mobile Lab will be used at each field site. Equipment available in the mobile lab includes a cyclic triaxial system for resilient modulus testing, static and repetitive plate load testing (PLT), light weight deflectometers (LWDs), falling weight deflectometer (FWD), dynamic cone penetrometers (DCP), cone penetrometer

tests (CPT) with seismic and visual capability , in-situ permeameters, variety of soil compaction equipment including gyratory, vibratory, kneading, static , and impact compaction, global position system (GPS) with a base station, and others. Comprehensive project reports will be submitted to each state summarizing the findings from the field investigations. Further, an interactive open house will be conducted at each site to facilitate discussion and review of the field measurements.

The final product of this study will be the development of the *Manual of Professional Practice for Design, Construction, Testing, and Evaluation of Concrete Pavement Foundations*. It will include field testing recommendations, design aids, and suggested specifications. The manual will be modeled after FHWA Publication No. HIF-07-004 "Integrated Materials and Construction Practices for Concrete Pavement: A State-of the-Practice Manual" (commonly called the IMCP manual).

PROJECT ADMINISTRATION

The Iowa Department of Transportation, through the Center for Transportation Research and Education (CTRE) at Iowa State University, will serve as the lead state and handle administrative duties for the project. The research efforts will be coordinated through two research entities within CTRE, the Earthworks Engineering Research Center (EERC), and the National Concrete Pavement Technology Center (CP Tech Center) that have technical capabilities to conduct the study, in concert with appropriate partners. The CP Tech Center will contribute $1 million to the research effort through its cooperative agreement with the Federal Highway Administration. Each participating state may provide two individuals who will serve on a Technical Advisory Committee (TAC) that will provide direction to the project. Funding for one representative to attend all TAC meetings will be paid for with the pooled funding. It is anticipated that the TAC will meet twice per year during the life of the project. The TAC's mission is to organize the specifics of the cooperative work tasks and to oversee the accomplishment of these tasks. The research team, under the direction of the TAC, will manage the accomplishment of the research agenda. Iowa State University will be the lead research institution and will issue subcontracts with appropriate entities as necessary. Experts from other research institutions and experienced consultants will be brought into the research team to provide technical leadership as needed.

POOLED FUND STUDY TASKS

The proposed research is divided into four major phases. Below is a short synopsis of each phase, with additional detail provided in the Research Plan.

Phase I – Problem Identification and Economic Analysis (12 months)

A comprehensive review of current practices worldwide with regard to materials selection and characterization, in-situ testing, stabilization practices, design, construction methods, specifications, maintenance, cost and rehabilitation of pavement foundations will be made. Included will be a review of LTPP and NCHRP studies, applicable case histories, interviews with state and federal agency representatives', evaluation of current subgrade and unbound base design methodologies, and identification of the knowledge gaps in the current state-of-the-practice related to pavement foundations. International practices will be investigated by reviewing past scan tour reports and via selected interviews with international experts and with input from international technical organizations. On-going studies (e.g. SHRP R02, R06, R07, etc.) related to this project will be identified (with assistance from the TAC) to prevent duplication of efforts and share knowledge and site information.

Phase II – Design Parameter Selection and Sensitivity Analysis (18 months)

Several states have recently completed projects to evaluate the MEPDG and a review of those studies is warranted to learn from the findings and also to prevent duplication of previous or on-going work. Based on the Phase III (in-situ testing) results, an analysis of the MEPDG program will be conducted related to performance parameters for the pavement foundation layers. This will establish a link between pavement design and actual field conditions at each site. In addition, design parameter input values will be compared to information in the LTPP database for information and test sections that have a variety of subbases and subgrades to seek information about their effect on performance. Further analysis using the finite element method to analyze the effect of the foundation performance (e.g. non-uniform stiffness) will be conducted. All results will be summarized and provide an analytical approach to assist with the characterization of the foundation layers in Phase III. Phase II will be staged to evaluate results of the Phase III efforts in parallel to provide insights into experimental testing plans. The findings of Phase II will also be used for correlating the results on design parameters to the state's existing design approach.

Phase III – In-Situ Forensic Investigation and Parameter Characterization (42 months)

In this phase, which is the major effort of the project, extensive field studies in participating states of selected in–service concrete pavements, with condition surveys, and new pavement foundation construction projects will be conducted to measure parameters related to pavement foundation performance. The field studies will be interactive and include an open house to communicate results. The in-situ forensic studies will serve to investigate the effects of construction methods, site evaluation, materials selection, design, treatments and maintenance procedures on the performance of specific pavement sections. In-situ testing will include combinations of static/repetitive plate load tests (PLT), light weight deflectometer tests (LWDs), falling weight deflectometer tests (FWDs), seismic and visual cone penetration tests (CPTs), dynamic cone penetration tests (DCPs), moisture-density, rolling deflectometer (pavement foundation layers) and other tests. Intelligent compaction will be used at selected sites to map ground stiffness parameters and non-uniformity during and after construction. An extensive field testing program will provide sufficient detail to use geostatisitcal analysis to quantify the measurements. Three dimensional (3D) color coded maps of the various engineering parameter values will be a product of this phase of the research. For comparison purposes, both premature failures and successful long-term pavement sections will be investigated. The LTPP database will provide information to assist in project selection (locations along a project may show foundation problems that could be investigated). A key aspect of the studies will be to tie the foundation performance to the depth of influence and uniformity for key engineering properties. Materials characterization will focus on stiffness/modulus, strength, erodibility/pumping, permeability, friction with the slab, volumetric stability (i.e. mineralogy and in-situ stress conditions), and other performance related parameters. In-ground instrumentation will be used at some sites to evaluate variations in performance conditions (e.g. moisture contents, etc.) and in ground stress conditions due to traffic loading. In addition to the field measurements, construction data and maintenance/rehabilitation histories will be collected to provide an evaluation of time dependent factors on performance. Comprehensive project reports will be submitted to each state after the respective field work is completed.

Phase IV – Preparation of Manual of Professional Practice and Final Report (24 months)

In this phase, the *Manual of Professional Practice for Design, Construction, Testing and Evaluation of Concrete Pavement Foundations* will be prepared. The manual will be a

compilation of what we know now and all the new knowledge gained during the course of this study. It will include best construction practices to provide stable and uniform pavement foundations, QC/QA testing recommendations, design aids, and suggested specifications. In brief, the manual will address:

1) How do we characterize what we have?
2) How do we make the best use of the materials?
3) How can economic analysis be used in the decision making process and what are the correct parameters?
4) Are there constructability issues that will cause constraints?
5) How can we enhance the engineering properties of the materials to improve quality and performance characteristics?

The manual will be modeled after FHWA Publication No. HIF-07-004 "Integrated Materials and Construction Practices for Concrete Pavement: A State-of the-practice Manual" (IMCP manual). Appropriate executive summaries, technology transfer summaries, TRB presentations and papers, and seminars will also be developed.

RESEARCH PLAN

A conceptual overview of each phase of the project is given below. The proposed research will have four phases:

1) Problem Identification and Cost Analysis
2) Design Parameter Selection and Sensitivity Analysis
3) In-situ Forensic Studies and Materials Characterization
4) Preparation of a Manual of Professional Practice and Final Report

There will be some overlap between phases (see schedule and budget).

Phase I – Problem Identification and Economic Analysis (12 months)

Despite much research into pavements in the recent past, problems with premature failure continue. In this study the focus will be on the foundation layers and seeking innovative and practical solutions to pavement foundation practices with regard to the construction, evaluation (investigation), design, specifications, and cost.

Task 1.1: Form a Technical Advisory Committee (TAC) that will provide overall direction and evaluation to the project. Each participating agency may provide two individuals who will serve on the committee. The first task for the TAC will be to review the workplan and provide additional guidance to the research team. As tasks and phases are completed, the TAC will provide continual review and updating of the research directions. TAC members will also provide local contacts for coordinating site investigations.

Task 1.2: A comprehensive review of the literature related to pavement foundations, including in-situ testing and site characterization, construction practices, evaluation, design criteria, QC/QA methods, costs, and specifications will be conducted. This will include a review of recent NCHRP and FHWA studies, the results of various studies of the LTPP database, State Highway Agency studies and current international practices. The focus of the review will be to identify the critical issues and capture and build upon current professional practices to achieve durable foundations. A strategy for economic analysis of pavement foundation materials will also be

developed based on case histories and cost data collected from DOT agencies. The review will also be used to later identify appropriate test methods and strategies for the analytical, laboratory, and field-testing portions of the research program.

Task 1.3: Participating State DOT representatives will be interviewed to document current and best practices for subgrade and subbase design, economic analysis construction specifications and field QC/QA testing. A part of this task will be to develop a database of historical problems encountered by State DOTs over the past 15 years, and to document the changes that states have made to address identified problems (and whether the problems were solved). A critical evaluation of these practices will be conducted, taking into account the level of expected/observed pavement performance. From the interviews with State DOT representatives, a list of potential projects that show poor to excellent pavement performance will be developed for forensic study in Phase III. A web-based survey will be used in this task.

Task 1.4: The applications and benefits of various techniques used to improve the engineering properties of pavement foundations will be documented. This will include recycled materials, geotextiles, treated/stabilized materials, and constructed methods.

Task 1.5: The research plan for the succeeding phases of the project will be reviewed, revised, and approved.

Task 1.6: The Phase I draft report will be submitted to the TAC summarizing the problems, known solutions, economic analysis based on literature review and synthesis, and research needs related to pavement foundations for achieving excellent pavement performance. Results will be updated in subsequent tasks to eventually become part of the final report.

Phase II – Design Parameter Selection and Sensitivity Analysis (18 months)

Task 2.1: Using the LTPP database, information from a variety of subbases and subgrade conditions will be selected to evaluate their effect on performance. Performance evaluation will be carried out using the MEPDG, finite element methods, and ICM (climate models). Submit a Phase II interim report to the TAC summarizing the sensitivity study using the analytical tools. The sensitivity analysis will be focused to provide input to the Phase III effort by identifying the key performance parameters of the pavement foundation that need to be measured. New modeling approaches that evaluate the impact of non-uniformity will be investigated and provide assistance in developing spatial sampling plans. Previous and on-going MEPDG sensitivity studies (e.g., IA, CA, TX, AR, MO, KY, MS, SD, KS, MN, and others) will be reviewed under this task, and not duplicated.

Task 2.2: Based on field data collected during the Phase III studies, a performance evaluation using the MEPDG, finite element methods, and ICM (climate models) will be conducted. Phase II interim reports to the TAC summarizing analysis using the in-situ measured parameters values will be submitted. Results of this task will provide a link between the assumed design parameters, as-built conditions, and long-term performance parameter values. The findings of Phase II will also be used for correlating the results on design parameters to the state's existing design approach.

Phase III – In-Situ Forensic Investigation and Parameter Characterization (42 months)

Through developing an understanding of the distress and failure mechanisms, knowledge to improve construction, design, and performance can be gained. The field forensic studies will focus on defining and investigating the key mechanisms and parameters that affect long-life performance.

Task 3.1: Field forensic studies will be conducted to ascertain detailed information regarding the pavement foundation characteristics of selected pavements having poor to excellent performance ratings. Existing pavement sites with good and poor performance and new pavement construction field sites will be targeted for forensic analysis and in-situ testing in addition to several new pavement foundation construction sites. A key aspect of the forensic study is to define the limits of the depth of influence (i.e., depth over which the foundation layers impact pavement performance) and uniformity necessary to provide long-life pavement foundation design. Each participating state will be asked to identify known projects with both poor and good pavement performance and pavement foundations. To account for seasonal variations, select sites may be visited more than once. The field studies will include comparing the intended design life with the performance history of the pavement sections, related to the foundation layers. Geo-statistical analysis of the field measurements, including two and three dimensional color coded maps of the various engineering parameter values, will be a product of this phase of the research. Although the focus in this study will be on failure mechanisms due to pavement foundations, failures due to the structural section performance will also be documented. The TAC will help to identify the additional information to be collected by the agencies for those projects that are identified. Key measurements will include uniformity of the subgrade and base materials, the depth of influence related to traffic and environmental conditions, climatic conditions, and resilient and permanent deformation characteristics of the foundation layers. In-situ testing and in-ground instrumentation will be geared towards performance related parameters (e.g., stiffness/modulus). Use of technologies such as the FWD, PLT, CPT, DCP, intelligent compaction, rolling deflectometer (pavement foundation layers), and others will be investigated. The Iowa State University Mobile Geotechnical Laboratory will be used for rapid and efficient data collection/analyses and on-site interactive meetings.

Task 3.2: Develop failure/performance mechanisms for each project site. The field monitoring results will be summarized in a manner that:

- Identifies the critical material and property issues that lead to the failure condition. These studies are critical in that they represent the gaps in knowledge.
- Provides a comprehensive summary of the failure mechanisms of existing pavement foundations. This summary will allow assessment of the optimal method(s) of remediation to be considered and discerned.

In addition to the field measurements, construction data and maintenance/rehabilitation histories will be collected to provide an evaluation of time dependent factors on performance.

Task 3.3: Submit a Phase III draft report to TAC summarizing the results and conclusions from the forensic studies. Project reports will be submitted to each participating state to document field studies in their respective states.

Phase IV — Preparation of a Manual of Professional Practice and Final Report and Technology Transfer (24 months)

For this phase, guidelines and recommendations will be developed for subbases and subgrade treatments including constructability, characterization and use of pavement foundation materials (including recycled materials). Results will be applicable to new and reconstruction conditions. The detailed evaluation of existing pavement foundation layers will be included. Recommendations will be compatible with the MEPDG inputs. Although the focus of this research is PCC pavement foundations, the results will have applicability to ACC and unsurfaced pavement foundation layers as well.

Task 4.1: In this phase, the *Manual of Professional Practice for Design, Construction, Testing and Evaluation of Concrete Pavement Foundations* will be prepared. The manual will be a compilation of what we know now and all the new knowledge gained during the course of this study. It will include best construction practices to provide stable and uniform pavement foundations, QC/QA testing recommendations, design aids, and suggested performance-related specifications. Included will be technology transfer materials, including field tests for forensic investigation of pavement foundation layers.

Task 4.2: A final report documenting the results of each of the phases and tasks will be prepared and include final recommendations for the site characterization and evaluation criteria, design criteria, and construction methods and performance-related specifications.

Task 4.3: Technology Transfer materials will be produced. This will include presentations on various aspects of the project and in particular QC/QA testing methods and data analysis and guidelines for selecting inputs for the MEPDG for foundation materials and layers. A project web site will be established whereby the research team members will contribute and store documents, as well as TAC member states can log in and contribute. A three month review/comment period will be used to gather feedback from the TWG and make updates to the final products.

DELIVERABLE PRODUCTS

As indicated in the descriptions of tasks, an interim report will be submitted to the TAC at the end of each phase of the project. In addition to the interim reports, project reports will be submitted to participating agencies describing the respective forensic investigation and in-situ testing results. An integrated set of guidelines and associated educational modules designed to improve the quality and performance of pavement foundations will also be developed. The final product of this study will be development of the *Manual of Professional Practice for Design, Construction, Testing and Evaluation for Concrete Pavement Foundations*. It will include field testing recommendations, design aids, and suggested specifications. The manual will be modeled after FHWA Publication No. HIF-07-004 "Integrated Materials and Construction Practices for Concrete Pavement: A State-of the-practice Manual."

In general, the guidelines will specify the process of producing durable and constructible foundation layers. The guidelines will identify the key knowledge needed by practitioners and field personnel to successfully produce, verify, and construct pavement foundations. Key areas that will be addressed will include:

- Trouble shooting of field construction problems
- Use of field measurements to determine performance related parameters and for QC/QA acceptance
- Improve understanding of the behavior and potential failure mechanisms of various materials (including recycled materials) used in pavement foundations
- Calibrate analytical design tools (MEPDG) to actual field conditions
- Aids on how to treat foundation materials for regional environmental and loading conditions
- Best practice techniques for pavement foundations for long-term performance

The educational/technology transfer modules will consist of PowerPoint presentations and associated handouts and a seminar in each participating state.

PROJECT DURATION AND BUDGET

Proposed Project Schedule and Budget:

The total length of time for the project is 5 years. The tasks would overlap; the schedule for each task is shown below.

Phases	Schedule (months)	Estimated Cost*
Phase I: Problem Identification, Solutions, and Research Needs	12	$200k
Phase II: Design Parameter Selection and Sensitivity Analysis	18	$300k
Phase III: In-Situ Forensic Investigation and Parameter Characterization	42	$2,600k
Phase IV: Project Reports, Final Report and Technology Transfer	24	$400k
* Funding for TAC meetings/travel, reports websites, T2, and seminars included for each phase	TOTAL	$3,500k

Phases	Time (months)									
	6	12	18	24	30	36	42	48	54	60
1										
2										
3										
4										
Reports		Phase I (Final)		Phase II (Interim)		Phase II (Interim)	Phase II (Final)	Phase III (Final)		
		Phase III (Field investigation report for each site)								
							Phase IV –Final Report/Manual/T2			

Budget:

The total funding needed to complete this work is estimated at $3,500,000. The goal is to secure funding from 15 to 18 states (35k/yr for five years = $175k total). In addition, the National CP Tech Center, through its cooperative agreement with the Federal Highway Administration, will support the project with up to one million dollars of funding. Phase 1 of the project will begin as soon as five states have made commitments.

Summary of Requirements for Project Sponsors

- Financial support (35k/yr for five years = $175k total)
- Technical Advisory Committee participation – designate two individuals for representation. TAC members will be asked to participate in periodic conference calls and group meetings (one to two per year). Travel costs will be covered by the pooled fund for one TAC participant. TAC members would also act as a contact person for researchers when scheduling field studies.
- Support field data collection – traffic control, site access, coordination with contractors, provide access for geotechnical mobile lab, and assist with coordination of open house/interactive field visit.
- Championing, within their state, the deliverables from the pooled fund, such as technical material to key staff, and facilitate implementation of new technologies and practices.

SPONSOR CONTACTS

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