Preface
An important function of the Transportation Research Board (TRB) is to stimulate research that addresses problems facing the transportation community. In support of this function, TRB technical committees identify problems, and develop and disseminate research problem statements for use by practitioners, researchers, and others. The problem statements listed below were developed by the TRB committee noted above. These problem statements should not be considered comprehensive; they may only represent a portion of overall research problems identified by committee members.

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I. Problem 1: Design of Subsurface Drainage for Multi-Layer Pavement Systems

II. Research Problem Statement

A fundamental and universally accepted precept of pavement engineering is that an effective subsurface drainage system improves the performance and extends the life of a pavement. There is, however no universally accepted methodology for the design of such systems. This is especially true relative to subsurface drainage for the multiple layered pavement systems being used today.
Today’s newly constructed pavements typically contain three or more layers including a lime or cement stabilized soil, a dense graded aggregate separator layer, an open graded drainage layer, and a surface layer of Portland Cement Concrete (PCC) or multiple layers of hot mixed asphalt concrete (HMAC). Rehabilitated pavements are even more complex consisting of their original layers and additional layers added during the rehabilitation. In some cases all or part of the original layers are removed and in many cases modified. For example, many rehabilitated pavements are PCC that has been rubblized then overlaid with HMAC.

A procedure is needed to analyze the drainability of multiple layered pavements that can be used to design an effective subsurface drainage system. The procedure needs to include methodologies for evaluating the drainability of individual material layers both in-situ and in the lab and for assessing the overall drainability of the combined system of layers.

III. Research Objective

The overall objective of this project is to develop a complete subsurface pavement drainage design manual. It is anticipated that the project will require two phases. Phase 1 will determine the current state of practice in the design of subsurface drainage systems for new and rehabilitated pavements and develop recommendations for the research needed to develop a complete pavement subsurface drainage design procedure. Phase 2 will involve carrying out the plan of study established in Phase 1.

- Phase 1 – Determine Current State of Practice, Survey the states to determine the methods currently being used to design subsurface pavement drainage, and Develop Research Study Plan for phase 2;
- Identify and evaluate methods used to determine permeability of pavement layers in the field and laboratory;
- Categorize typical existing new and rehabilitated pavement sections and compile and/or collect existing information available relative to the drainability of pavement layers and pavement systems;
- Identify and evaluate existing analytical models for analyzing and predicting flow paths and flow capacity of individual pavement layers and pavement systems;
- Formulate research study plan for the development of a complete subsurface pavement drainage design manual.
- Phase 2 – Conduct Study Plan Prepared in Phase 1.

IV. Estimate of Problem Funding and Research Period
Recommended Funding: Cost - $100,000 for Phase 1 and $250,000 for Phase 2.

Research Period: Duration of Phase 1 is 9 months; duration of Phase 2 is 27 months for a total of 36 months.

V. Urgency, Payoff Potential, and Implementation

Subsurface pavement drainage systems are being constructed on most major highways despite the fact that no universally accepted method of design and analysis exists. Not only, do these not exist but also in many cases little is known relative to the drainability of in place pavement materials. This lack of knowledge is further compounded by the complexity of multi-layered pavement systems including the many miles of older pavements that have been rehabilitated. Without effective analysis and design, it is quite probable that most drainage systems are far less than optimal and possibly not even cost effective. In some cases they may even be detrimental to the pavement. The findings of this research should be distributed to all state DOT agencies, AASHTO, and FHWA. The implementation of the findings from this research will result in better design of subsurface drainage systems, which will ultimately increase pavement life.

I Problem 2: Validation of the Drainage Component of the Integrated Climatic Model

II. Research Problem Statement

The Integrated Climatic Model (ICM) provides a framework to simulate the effect of climatic and subsurface conditions on pavement response, structural properties and ultimate performance.

The ICM consists of four separate models (routines); Precipitation Model, the Rainfall, Infiltration and Drainage (ID) Model, the Climatic/Materials/Structural Model, and the CRREL Frost Heave and Settlement Model. The ICM has been incorporated in a Windows-based software program and has been available to researchers.

The ICM model’s capability was of great interest to the NCHRP 1-37 Team charged with developing the 2002 Mechanistic Pavement Design Guide. As such, the Model was incorporated in the Mechanistic Design software. Currently, AASHTO has not endorsed the Mechanistic Pavement Design Software. The field verification of the models incorporated in the package would enhance its acceptance by the users. States, Universities and Individual researchers would greatly benefit from the results of the field-validation and calibration of such models.

The ICM model contains empirical relationships that may need further validation. For instance, the ID model uses an empirical relationship between the base/subgrade geometry, materials drainage properties, and drainage time. Some independent researchers noted a gap between the observed moisture profile in the base/subgrade, and that computed by the model. Recent revisions to the model produced the Enhanced Integrated Climatic Model (EICM). The EICM should also be included in the field validation study.
III. Research Objective

Possible useful outcomes of such validations include:

1. Evaluation of model accuracy and its standard error of estimate
2. Establishing confidence in the model
3. Performing sensitivity analysis of the input parameters relative to design outcome.
4. Enhancement of model to improve its accuracy, if needed
5. Modifying or rebuilding the models if needed.

IV. Estimate of Problem Funding and Research Period

Recommended Funding: Cost: $300,000  Research Period: Duration: 2 years

V. Urgency, Payoff, Potential and Implementation

Successful completion of this evaluation will put the transportation industry one step closer to the implementation of the mechanistic pavement design. It is expected that AASHTO will endorse the Mechanistic-Empirical Pavement Design Guide leading to a nationwide use. Addressing the concerns about model accuracy and validation would provide not only a realistic design, but an economical one.

I. Problem 3: Optimizing Drainability While Maintaining Stability of Aggregate Base Courses

II. Research Problem Statement

Although the benefits of well-drained pavements have been clearly shown, practitioners still hesitate to use base courses that have a limited amount of fines because of concerns regarding a lack of stability. While a tight, well-graded base may be the easiest to work with from a construction standpoint, the strength and the hydraulic conductivity of the layer are lower than a more free-draining aggregate, containing limited amounts of fines. In the pursuit of a more free-draining aggregate base, some of the stability problems have been overcome by the addition of asphalt or cement. However, these bound bases are expensive solutions (especially for low- to medium-volume roadways) to a problem that can be solved simply if the designer was aware of a properly graded unbound aggregate base that is highly drainable and stable during both construction and long-term use.

After years of apparently satisfactory service, distress has been observed in some pavements with free-draining bases. Initial indications suggest support problems stemming from the reported instability of the free-draining layer. Agencies are now focusing on the long-term stability of free-draining bases and their effect on pavement performance. Another problem observed is that drainage from these layers is slowing over time. While the use of a dedicated drainage layer allows the designer to assign “drained” strength parameters to pavement structural layers around the drainage layer, the third problem is that designers have not had good design strength numbers, or structural coefficients, to assign to the drain layer. For existing AASHTO pavement design methods and with the move towards the use of mechanistic-empirical pavement design procedures, there is a need to characterize the structural response of these layers using more fundamental materials inputs, such as layer moduli and Poisson’s ratio. There is a
related need to predict how these material properties change over time.

There is doubt as to how long the hydraulic conductivity of open-graded bases can be maintained because of upward migration of subgrade soil particles into the layer. NCHRP project 1-34 revealed that fines migration often occurs. Other projects that studied subsurface edge drain performance have questioned the ability of the open-graded layers to maintain their long-term hydraulic conductivity due to the reported contamination from an increase in the amount of fines in the drainage system. Therefore, another problem is the ability to construct and maintain the integrity of the drainable layer. Some agencies have reported success with separator layers that keep the fines out of the drainable base. The effectiveness of these separators, such as geotextiles, needs to be verified and, if effective, recommended specifications need to be available to agencies.

III. Research Objective

There are two primary objectives of this research:

1. Identify successful practices associated with the use of drainable bases and provide guidance for the practical implementation of such drainable bases and, if appropriate, associated separation materials.
2. Determine the appropriate design structural properties of drainable base aggregate gradations.

The following tasks will be performed:

1. Compare the long-term stability, drainage characteristics, and costs of various drainable base designs (gradations). Identify successful drainable base designs that have been functioning for years in pavements in frost and in non-frost influenced regions. A literature review and a survey of agencies with successful applications will facilitate this objective.
2. As a result of the information and test sections obtained from Task 1, develop and execute a laboratory experimental plan to develop relationships between the structural properties (resilient modulus and strength) and hydraulic conductivity properties of laboratory tested drainable bases. Develop the design parameters needed for mechanistic-empirical design procedures and construction specifications for controlling and accepting the placement of these layers.
3. Evaluate drainable bases that were constructed with a properly designed geotextile separator between the base and the subgrade. Evaluate studies of geotextiles to enhance the stability and long-term performance of drainable bases, including work done at the University of Washington and ongoing work at the Geosynthetic Institute.
4. As a result of the outcome of the first three tasks, develop practical drainable base design gradations and material selection criteria based on ease of construction, long-term stability, hydraulic conductivity, and construction costs for the most economical and long-lasting designs. Also, develop typical strength and stiffness values of these materials for use with mechanistic-empirical design procedures,
such as the 2002 Design Guide (NCHRP project 1-37A). If there is evidence that geotextile separators contribute to improved performance by minimizing fines contamination and/or by stabilizing the drainable base layer, make recommendations of practical separators consistent with current AASHTO M 288 specifications.

IV. Estimate of Problem Funding and Research Period

Recommended Funding: Cost: $300,000. Research Period: Duration: 18 months

V. Urgency, Payoff, Potential and Implementation

The increased emphasis on the use of free-draining base courses makes assurance of their long-term performance characteristics very important. Premature failure of the pavement system due to contamination of drainable bases is exceedingly costly. However, if the hydraulic conductivity and stability of drainable bases can be maintained, pavement design life will be realized and very large cost savings in maintenance and rehabilitation of pavements are likely. The high cost of treated or bound open-graded base layers and the high maintenance costs associated with freeze-thaw and structural pavement damage due to poor drainage are significant, and their mitigation will be enhanced by this study. The lack of design guidance concerning the structural strength and hydraulic conductivity of base layers is the cause of many poor pavement designs. These design parameters will be increasingly important as designers move toward mechanistic/empirical pavement design.

The results of this study will provide practical guidance to designers and maintainers of pavement structures and should allow rapid implementation, leading to more durable, long-lasting pavements. The research conducted as part of this study will have potential pay-off to several State DOTs, AASHTO, and FHWA. Representatives of Virginia DOT, Mississippi DOT, and Wisconsin DOT recognize the importance of this study and have expressed preliminary interest in supporting this research effort.

I. Problem 4: Improved Installation Practices for Pavement Edgedrains

II. Research Problem Statement

Installation of all types of pavement edge drains and, in particular, prefabricated longitudinal round pipe and panel edge drains in new construction and rehabilitated pavements have become common as the detrimental effects of trapped subsurface water upon the life of pavement systems has become more widely recognized. Installation practice generally requires excavation of a trench adjacent to the pavement. No specifications of construction procedures are available to ensure adequate trench backfill compaction or proper drainage component placement. Field experience indicates that often backfill compaction is minimal or ineffective, while edge drains were damaged due to the poor placement of subsequent layers. Other damaging factors include; trench
settlement, construction traffic, and/or other project contractors prior to completion of the project.

The use of closed circuit television (CCTV) pipeline inspection cameras and fiber optic probes used for quality control/quality assurance (QC/QA) and the installation of loop or dual outlet pipe systems (allowing for 100% inspection or the system) has vastly helped in the evaluation of the these systems during construction. In addition, several states have realized that settlement will ultimately happen and have gone to a 30 to 45 day waiting period prior to the placement of final surface over the edge drain trench (This has been found to be critical when thin overlays are placed over the trench). Of particular concern is the outlet of all types of edge drain systems, which is a problem of the highest magnitude. As a result of the video inspections several state agencies have gone to heavy gage outlet pipes and flowable fill to reduce construction damage, wider radius 90’s to increase flow and assist in camera inspection and maintenance. Collection pipes are also being used in shallow ditch lines where it is difficult to place and maintain headwalls. Headwalls designs are also changing to reduce rearward settlement and reduce maintenance needs. Past work has been performed on large utility trenches. Work is being performed by the Kentucky Transportation Center to determine the effects of compaction forces on the edge drain structure. Edge drain performance reports by the Georgia DOT, Indiana DOT, Iowa DOT, Ohio DOT, West Virginia DOT, Penn DOT, Illinois DOT, Ontario Ministry of Transport, and NCHRP Report 367, discuss geocomposite edge drain performance and installation. Additionally, ASTM Procedure D6088 “Installation of Geocomposite Pavement Drains” was adopted in 1997.


III. Research Objective

The objectives of this research are:

• Evaluate current construction practices of pavement edge drains;

• Determine construction practices including construction staging to minimize construction damage or deformation of the drainage system products;

• Propose and evaluate appropriate construction procedures and backfill material to achieve high levels of trench backfill compaction and good soil-to-filter (usually geotextile) contact without destroying or damaging the edge drain.

• Develop and implement more straightforward outlet designs with a focus on maintenance free performance.

• Evaluate the effects of QA/QC specifications in reducing construction damage.
IV. Estimate of Problem Funding and Research Period

Recommended Funding: Cost: $250,000  Research Period: Duration: 3 years

V. Urgency, Payoff Potential, and Implementation

All types of drainage systems including prefabricated pavement edge drains are being used to a greater extent now than in the past. Due to installation problems, some agencies have eliminated certain systems from their specifications (Indiana, Illinois), while others have restricted their use (New York, Ontario). The engineering profession needs to make sure that the installation of these drains to remove unwanted subsurface water does not result in magnified pavement strains which will, in turn, lead to shortened service life of the pavement system. Properly installed and specified, these products have proven to be a very cost effective means of increasing pavement service life. State DOT agencies, FHWA, FAA, and universities currently involved in subsurface drainage research. The findings of this research should be distributed to all state DOT agencies; FHWA, FAA, and geocomposite edge drain manufacturers and installers for development of improved specifications and installation procedures. The implementation of new construction procedures will offer a better and cost effective alternative to the current construction practices. It is expected that the new construction procedures will increase the life expectancy of the pavements.

I. Problem 5: Relationship of Pore Size Distribution of Geotextiles to Subsurface Drainage Design

II. Research Problem Statement

Geotextiles are routinely used as filters in Prefabricated Geocomposite Edge Drains, Geotextile Wrapped Underdrains and Geotextile Socked Perforated Pipes for subsurface drainage. To ensure the adequate performance of these subsurface drainage systems, it is critical that the geotextiles should meet the permeability and retention criterion throughout the life of the structure. The ability of a geotextile to meet these requirements is primarily a function of the pore-size distribution of the geotextile. Despite the importance of the pore-size distribution of a geotextile, no method has been universally accepted. Available standard test methods (dry, wet, and hydrodynamic sieving) can only measure larger pore openings. The dry sieving method, which is currently the standard test method in the United States, is limited to testing thin, nonwoven geotextiles. In addition, the available test methods are time consuming and expensive. It has been found that the clogging potential of a geotextile is related to the finer pore openings of a geotextile. Therefore, a method is needed which can be used to measure both the larger and smaller pore openings accurately. Recently, it has been shown that the bubble point method can be used to measure the complete pore-size distribution of a geotextile. In addition, this method can also be used to measure gas and liquid permeability and porosity of geotextiles. Preliminary results indicate that this technique is suitable for both
woven and nonwoven geotextiles. The bubble point method is simple, rapid, accurate, and precise. The bubble point method has the potential to be accepted as a worldwide standard test method.

The only related work in this area has been the evaluation of the performance of geotextiles in transportation-related drainage applications, such as in highway edge drains, selected retaining wall drains and erosion control systems. This study was performed at the Geosynthetic Research Institute (GRI) at Drexel University. The investigation noted completely clogged prefabricated geocomposite edge drains at several sites due to soil piping through the geotextiles. In this study no attempt was made to measure pore openings or porosity of the geotextiles.

III. Research Objective

The overall objective of this proposed research is to evaluate the feasibility of replicating existing methods (pore opening and permeability) by a rapid and accurate method. The specific objectives of this research are as follows:

Measure the larger pore openings of a variety of nonwoven and woven geotextiles using the bubble point method, compare the results with both dry and wet sieving results, and provide correlation factors between bubble point and sieving results;

Measure the smaller pore openings and porosity of the geotextiles using the bubble point method and compare the results with image analysis results;

Measure the liquid and gas permeability of the geotextiles using the bubble point method and compare the results with liquid permeability test results performed in accordance with ASTM D4491; and

Develop a user manual describing the procedures to evaluate the larger pore openings, pore-size distribution, permeability and porosity of geotextiles with the bubble point method. The manual should also include typical results.

IV. Estimate of Problem Funding and Research Period

Recommended Funding: $70,000 per year, for 2 years for a total of $140,000. Research Period: Duration: 2 years

V. Urgency, Payoff Potential and Implementation

Geotextiles are consistently being approved and rejected solely on the basis of large pore openings provided by manufacturers. Manufacturers' data are based on results provided by the dry sieving method. Since this method has limitations, the data becomes questionable for some types of geotextiles. Since the smaller pore openings of the geotextiles are not provided, it is impossible to evaluate the clogging potential of geotextiles without performance testing. A simpler method is needed for the evaluation of
the larger and smaller pore openings of geotextiles. This research will benefit designers, state DOT agencies, FHWA, researchers, and manufacturers. The results of this research should be distributed to all state DOT agencies, FHWA, and geotextile manufacturers. It should be available to all researchers. The implementation of the findings of this research will provide for better, more effective, and long-term performance of geotextile filters, thus providing more effective subsurface drainage of pavement sections.

I. Problem 6: “Drainage Design of MSE Walls with “High Fines” Reinforced Fill

II. Research Problem Statement

MSE walls on transportation projects are generally conservatively designed, using soils of “low fines” in the reinforced zone. Private MSE walls are less conservatively designed, using a variety of soils in the reinforced zone (NCMA allows for 35% < 0.075mm), and have reported a number of successes. However, it is also clear from the literature (on not so successful private sector walls) that reinforced fill consisting of fine-grained soils (either “high” fines or “high” plasticity) and pore pressure resulting from lack of drainage in the reinforced zone are the principle reasons for serviceability problems (excessive deformation) or failure (collapse) of MSE walls.

Material properties of “high fines” reinforced fill that have an important effect on the design and performance of MSE walls are known. Therefore, a higher quantity of fines could be safely allowed in the reinforced fill, provided the properties of the materials are well defined and controls are established to address the design issues. The potential savings from replacing AASHTO backfill materials with marginal backfill materials could be in the range of 20 to 30% of current MSE wall costs.

NCHRP Project 24-22, “Selecting Backfill Materials for MSE Retaining Walls”, is focusing on developing selection guidelines, soil parameters, testing methods, and construction specifications that will allow the use of a wider range of backfill materials within the reinforced zone of mechanically stabilized earth (MSE) retaining walls. A full-scale, instrumented field test will be constructed in Spring 2005, and will include provisions to demonstrate the role of pore water pressure in the backfill and the importance of including a positive drainage system to obtaining good wall performance. Results from the field test will allow guidelines and specifications to be developed for suitable reinforced fills for MSE retaining walls.

However, a rational design methodology is needed for either including seepage forces, from both ground water and infiltration seepage water, in MSE wall design or designing drainage for walls incorporating “high fines” reinforced fill. The methodology should address the use of base drains, back drains and surface drains, as well as the use of composite reinforcement materials that both reinforce and drain the reinforced fill of MSE walls. The methodology should be validated with field measurements on full-scale structures, such as those planned for NCHRP project 24-22. The cost/benefit of various drainage systems should be established.

III. Research Objective
The objective of this research is to develop a design methodology for MSE walls, when using “high fines” (low permeability) soil as reinforced fill, that either: a) includes pore pressures in the analysis and design or b) incorporates drainage measures to mitigate, or entirely eliminate, seepage pressures.

The goals of the research are:

- Develop a numerical analysis method that estimates the seepage pressures generated from a wide variety of “high fines” soil types, and properly incorporates these pressures into the design of MSE wall reinforcement and facing systems. Evaluate the method using field measurements from full-scale field tests of various drainage conditions.
- Develop a methodology to improve the reliability of drainage design for MSE walls constructed with “high fines” reinforced fill. The methodology should include soil and geosynthetic materials used for base drains, back drains, ground surface barriers, and composite reinforcement materials. Establish the cost/benefit of the various drainage systems.
- Calibrate the methodology with respect to resistance factors that would be included in LRFD analyses.

IV. Estimate of Problem Funding and Research Period

Recommended Funding: Cost: $200,000. Research Period: Duration: 18 months.

V. Urgency, Payoff Potential, and Implementation

This topic is becoming one of significant importance, due to the increased use of MSE structures in transportation facilities and the economic incentive to use onsite soils as reinforced fill to lower costs. Without a proper design procedure for dealing with the positive pore water pressures that can develop in the “high fines” reinforced fill, the failure rate of MSE structures can be expected to increase. Research costs will be fully recovered, if the research results prevent just one significant failure of a MSE structure caused by both ground water and infiltration seepage water.

The potential savings from replacing AASHTO A-1-a backfill materials with “high fines” reinforced fill could be in the range of 20 to 30% of current MSE wall costs. However, to avoid problems in the form of excessive wall deformations and/or actual collapse, the walls must either be designed for seepage pressures or proper drainage precautions must be taken to mitigate seepage pressures.

The results of this study will provide practical guidance to designers to use “high fines” reinforced fill for MSE structures, without introducing uncertainty and higher risk associated with positive pore pressures that can develop in “high fines” soils.