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Bridges; Other Structures; and Hydraulics and Hydrology

- Asphalt Plug Joints: Characterization and Specifications
- Automated Hydrologic Analyses in Maryland with GISHydro2000
- Bridge Monitoring in Connecticut
- Broken-Back Culverts
- Culvert Design Manual for Passage of Weak-Swimming Fish
- Detecting Corrosion of Steel Strand Using Time Domain Reflectometry
- Development & Evaluation of Passive Cathodic Protection Used on PCI-Beam Ends
- Instrumentation for Measuring Scour at Bridge Piers and Abutments
- Keeping Oregon's Bridges Strong and Handsome
- Polymer Overlays
- Seismic Column Reinforcement Study
- Seismic Retrofit of Flared Columns at the Airport Viaduct in Reno
- TxDOT Saves Money and Time with New Precast Bent Cap System
- Use of Carbon Fiber Wrap to Retrofit Bridges in Utah
- Validation of Bridge Engineering Computations (11/8/2001)
- Validation of Bridge Engineering Computations (4/8/2002)

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  - Fast Track Concrete - Keeps the Traveling Public Moving in New Jersey
  - Maine's Highways Sit on Rubber
  - Pavement Smoothness Research
  - Performance Evaluation of Polymer Modified Asphalts
  - Quantitative Studies of Chloride Permeability of Concrete (FHWA-RI-RTD-98-1)
  - Rapid, Modified National Aggregate Association Flow Test (ASTM C1252) to Determine Fine Aggregate Angularity
  - Road Lifecycle Innovative Financing Evaluation
  - Thermal Differentials and the Related Density Differentials in Asphalt Concrete Pavement Construction
  - Tire Chips in the Base Course of a Local Road
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  - Rockfall Catchment Area Design Guide
High Value State DOT Research
Asphalt Plug Joints: Characterization and Specifications

Sponsored By: Wyoming

Problem
Asphaltic plug joints (APJs) are a type of bridge expansion joint that has been promoted by manufacturers as simple general purpose expansion devices for bridges with less than 50 mm (2 in) total motion. These joints are simple to construct - a flexible asphalt segment that spans between the abutment and the bridge deck. While the joint is physically simple, it requires a complex engineering definition to describe, model, and prescribe for service applications. Unfortunately, APJs have been developed by trial and error and used when little engineering research exists outlining their complex behavior. Although the advantages include: ease of installation, ease of repair, are relatively inexpensive, are not as prone to snow plow damage, and may be cold milled, the disadvantages are major. APJs are soft and pliable when warm, rut with heavy traffic volumes, and heave with low traffic volumes. They become stiff when cold, become brittle, lose ductility and crack causing leaks and debonding at the joint-pavement interface. They may also track out, delaminate, and spall. Is there a happy medium?

Solution
This research report linearly flows from general topic on the subject to focused and detailed research into the joint behavior and material qualification tests. The research focus is on delivering a concise engineering-based design guideline and corresponding material qualification test. The report is structured to present this body of information through five stand-alone technical papers. The first paper addresses the state of the practice through a survey of state DOTs. In the second, the material characterization is presented from a battery of material tests using temperature-dependent elastic and elastic-plastic models. Within the third paper, the material characterization is used within the finite element analysis method to develop design guidelines based on elastic-plastic material models. The fourth presents the validation study used to verify the assumptions incorporated into the elastic-plastic material characterization and the finite element analysis. The fifth paper presents the design guidelines and a modified standard AASHTO test to qualify the APJ material.

The validation study highlighted the overwhelming importance of relaxation in the function of the APJs. This geometry of the joint presents problems from a classical elastic engineering perspective with its re-entrant corners, bonded substrates, and theoretically infinite stress concentrations. However, with the material relaxing by viscous flow at about the same rate as the bridge places motion demands on the joint, minimal loads and stresses are created. With these small loads almost no limit on the allowable motion exists from a structural perspective. However, functional limitations exist from a volumetric perspective and the need to maintain a smooth and serviceable transition from the pavement onto the bridge deck. This volumetric limit is the basis for the bridge-motion limits that are proposed.
Two material characteristics fully define the structural applicability of an APJ location/application. These are the material time constant, $t_{75}$, for the load to relax to 75% of its initial load and the material glass-transition temperature, $T_g$. Both of these qualifying characteristics may be obtained using a UW-modified AASHTO TSRST test. The UW modification determines the material time constant, which characterizes the relaxation. The material may be evaluated and qualified quickly with this test using readily available standard AASHTO TSRST equipment. This relatively simple test should allow suppliers to develop better joint material through careful qualification.

While the relaxation allows for the material to function from a structural perspective, it can be detrimental to roadway roughness. The design trade-off is that a soft viscous material allows bridge motion but also allows the material to flow out of the wheel paths creating rutting. Another problem is that the asphalt binder is highly modified and will lose ductility as it ages, resulting in structural failures. The last major concern is that while relaxation lowers the loads and stresses it does not remove them entirely. These problems can be mitigated. Maintenance and inspection of APJs will be required. In summary, APJs are good for some applications but should not be considered maintenance-free, long-term solutions. Periodical replacement will be required.

**Implementation**

Since the publication of this report, May '99, WYDOT is investigating the redesign of its APJs.

**Benefits**

This research provides engineering-based design guidelines and material specifications for APJs, which until now have been developed by trial and error and used when little engineering research exists outlining their complex behavior. Since the publication of this research, numerous requests have come from commercial manufacturers, as well as state DOTs, interested in improving their APJs. Australia requested a copy two months before the research was published. Such is the perceived need for better expansion joint performance.

**Product(s) Available**

"Asphalt Plug Joints: Characterization and Specifications" FHWA-WY99/03F, may be ordered by E-mail at <mpatri@state.wy.us>

**For more information:**

Contact Michael J. Patritch, Research Coordinator, Wyoming Department of Transportation (WYDOT), <mpatri@state.wy.us> or B. Patrick Collins, State Bridge Engineer, <pcolli@state.wy.us>
Sponsored By: Maryland

Problem
The application of standard hydrologic analysis programs to examine flood flows at a given design point (e.g. a highway bridge crossing) has historically been a tedious and laborious task. The engineer would first assemble topographic, land use, and soils data, then delineate the watershed, and finally use a tracing paper/light table approach to overlay these different types of information to derive the watershed parameters necessary to run standard hydrologic models. Small changes in the location of the proposed highway structure or unfortunate errors in the data gathering and assimilation steps could render weeks of work obsolete or useless, requiring a repeat of the same tedious and time-consuming analysis procedures to address these changes or errors.

Ideally, the engineer should have a complete archive of geographic data from which to develop a watershed analysis. In addition, a tool that takes care of performing most, if not all, of the necessary calculations to set up the execution of a hydrologic model would be very useful. The ready availability of the database and analysis tools would free the engineer to spend more time examining the robustness of model output to differing data or design input.

Solution
The program, GISHydro2000, developed at UMD takes advantage of GIS technology to reduce the amount of time required to perform hydrologic analyses while improving the integrity and reproducibility of these analyses. Analyses follow along three broad types of procedures: data assembly, estimation of peak flows, and analysis/critique of modeled results.

Data Assembly: Figure 1 shows the "Maryland View" used by the engineer for the initial step of selecting information from a database that spans the entire state of Maryland as well as those areas of Pennsylvania, Delaware, and West Virginia that drain into Maryland. This database continues to grow as new land and higher resolution elevation data become available. The existence of redundant geographic information allows the user to potentially examine the sensitivity of model output to changing interpretations of land use, topography, and soils.

Estimation of Peak Flows: The analysis proceeds through menu selections and GUI-based interactions in which the engineer progressively indicates the location of key elements such as the overall watershed outlet (design point) and identifies the location of specific internal features (such as reservoirs or other existing infrastructure). At present two fundamentally different hydrologic analysis
programs are supported: "TR-20," a rainfall-runoff model developed by the Natural Resources Conservation Service (NRCS) and required by the state for all significant hydrologic analysis, and the U. S. Geological Survey (USGS) peak flow regression equations. The support of two different approaches allows the user to critically compare results for consistency, in the absence of supporting stream gage data.

Analysis / Critique of Modeled Results: an important bonus of the developed software is that the time saved by using the software can instead be spent analyzing the model results. Multiple scenarios can be investigated in an effort to determine the most cost-effective or environmentally sound design. Also, multiple characterizations of the watershed in terms of differing land use, soils, and topographic data can be examined as well, indicating the sensitivity of modeled results to the integrity of the input data. These information give the engineer an appreciation of how certain the derived results are and suggest where greater care or effort must be taken in describing the system to the hydrologic models.

Implementation
GISHydro2000 and earlier versions of this software have been in operational use at MSHA since 1991. It is a standard component in the analysis of any watershed study at MSHA and is recognized by the Maryland Department of the Environment as a valuable tool for these analyses. Other state, local, and private agencies use GISHydro2000 in their analyses as well.

Benefits
Recently, MSHA has developed an estimate of the money saved in their analyses with GISHydro2000 and its earlier versions. Across 83 projects varying in size from 1 to over 50 square miles, an estimated $994,600 were saved based on a time savings of approximately 18,000 engineer-hours. These savings only account for efforts of MSHA engineers and neglect any additional savings that may have been realized by consultants or other government agencies that have used this program. Further, efficiency of this program has increased over time such that the MSHA estimates a 70% savings on hydrologic analyses studies using GISHydro2000 over the traditional paper methods used previously. Because of this increased efficiency, future savings are expected to be even greater than those documented here.

Savings have not only been realized in the analysis stage, but in the construction stage as well. Before GISHydro2000 and its earlier versions, calibration of model results was difficult to impossible owing to time constraints. Sensitivity analyses were simply not feasible. Today a standard 25% of the time in the analysis effort is spent on sensitivity studies that result in more reasonable discharge estimates and save an estimated 40%-70% on construction costs. It is difficult to place a number on these construction savings, but they likely total in the millions of dollars.

Another possibly just as valuable benefit of this program is the standardization it provides to all hydrologic analyses performed by and for the MSHA. The traditional, labor intensive approach used before the existence of this program involved considerable subjective decisions to be made by the engineer in delineating the watershed and deriving various watershed parameters. Using GISHydro2000, all decisions are well documented and results can be reproduced by different engineers, lending greater credibility to the output of the models. Further, because outside consultants and reviewers involved in the permitting process also have access to this program, they too can produce analyses that are consistent
with those generated by MSHA. Before the use of this program and its earlier versions, turn around time for review and approval of MSHA studies generally ranged from 12 to 24 months. With this software, this process now generally requires only 2-4 weeks.

**Product(s) Available**
Present and Future: GISHydro2000 Website

The current version of this program, including documentation and a user's manual can be downloaded from the UMD website: [http://www.gishydro.umd.edu/](http://www.gishydro.umd.edu/)

This site allows the developers of GISHydro2000 to continually maintain and update this program and allow for users to always have access to the most recent revision of this program. It also allows the authors to track interest and usage in this program. At present the GISHydro2000 software has been downloaded to many states across the country and has recently spawned interest from abroad, as well.

The Maryland State Highway Administration and the University of Maryland plan to develop a new version of this program that will work directly from the web site mentioned above. This web version is presently only in the planning stages, however, over the next year we plan to slowly post an increasing amount of the current GISHydro2000 functionality directly on the web site. The result will be that users can perform all their hydrologic analyses at the web site, with the only required hardware/software being a networked computer running web browsing software. This will relieve agencies of the need to purchase multiple, expensive software licenses while centralizing the location of the software and database where they can be readily maintained, updated, and supported. We hope for this program and website to become a model for other neighboring states to follow or to join with us in a still greater collaborative effort.

**For more information:**
For further information contact Glenn Moglen, University of Maryland, Department of Civil and Environmental Engineering, University of Maryland, College Park, MD 20742 (telephone 301-405-1964; fax 301-405-2585; e-mail moglen@eng.umd.edu) or Andrzej Kosicki, Office of Bridge Development, Maryland State Highway Administration, 707 North Calvert St., Baltimore, MD 21202 (telephone 410-545-8340; e-mail AKosicki@sha.state.md.us).
Sponsored By: Connecticut

Problem
Transportation authorities are continually faced with the challenge of providing an infrastructure by which persons, goods, and services can travel safely and efficiently. The largest component of this infrastructure is highways made up of pavement and structures that are continuously deteriorating, always in service, and difficult to inspect and maintain.

Bridges are an integral part of a highway network and represent a multi-billion dollar investment. It is imperative that they are always open to traffic, resistant to natural disaster, undaunted by millions of loading cycles per year, and are inexpensive to maintain. However, bridges are expensive to maintain and do occasionally fail. Both of these facts are exacerbated by the reactionary position of bridge owners. To effectively manage bridges today, more needs to be done to assess the day-to-day condition and behavior of bridges, and the deterioration rates of their components, so that efficient and proactive measures can be taken.

Solution
By using proven and state-of-the-art technologies, it is currently possible to utilize monitoring systems on in-service highway bridges to determine their behavior and condition, and promote a proactive response to maintenance and inspection needs. The goal of this research is to provide a reliable supplement to current inspection procedures and improve the understanding of the behavior of bridges as they carry traffic. The objectives of this study include the installation of continuous monitoring systems on specific bridges of various type, size, and vintage, to record long-term behavior and develop a global condition assessment, and the application of temporary instrumentation with portable equipment on an as needed basis to determine in-service behavior and justify rehabilitation and repair plans.

Implementation
The scope of the research includes the seven in-service bridges that have or will have continuous monitoring systems placed on them. Activities have also included monitoring of additional bridges with portable equipment on an as needed basis.

Tasks performed to date include the specification, purchase, and installation of three continuous monitoring systems, the earliest of which has been operational since June of 1999. They include a curved three-span continuous cast-in-place concrete multi-box-girder bridge, a ten-span continuous pre-cast concrete single-cell girder bridge, and a curved three-span continuous steel dual-box-girder bridge. Each monitoring system has unique features that are conducive to monitoring the aspects of each bridge. Sensors include tiltmeters, accelerometers, stain gauges and thermocouples, which measure tilt, vibration, strain and temperature at various locations throughout the structures. The maximum number of sensors on any one bridge is 52 and includes all the previously mentioned types. The minimum number of sensors on any one bridge is 14 thermocouples, which measure the temperature at various location of the bridge cross-section.

Other bridges scheduled to have continuous monitoring systems installed include typical rolled-beam concrete-deck bridges, one susceptible to scour, another regularly subjected to heavy loads, a typical pre-cast concrete girder bridge,
and a large deck truss with a suspended span. Sensor types used on these bridges are planned to include a linear variable distance transducer (LVDT) to measure the movement of an expansion bearing, a state-of-the-art scour detection system, and a non-destructive strain-monitoring sensor. The temporary monitoring has been performed on several large steel bridges that have had questions regarding fatigue cracking in diaphragm connections, cracked secondary connections, main girder cracking, counter weight support capacity, load rating, over-load influence, drive mechanism stresses, and movable bridge member stresses.

In general the findings have shown that the ability to monitor an in-service bridge on a temporary basis is invaluable for determining specific repair and rehabilitation plans. Continuous monitoring is anticipated to have as equally large an influence on the design and management of the entire bridge network.

**Benefits**
The application of the continuous monitoring results are still forthcoming however, an indirect result is the inclusion of a specification for a such a system in the design and construction of a major new bridge on the historic Merritt Parkway in southwestern Connecticut. This is the first bridge in the state, and one of the few in the country, to have a monitoring system included in the original construction documents. Strain, tilt, vibration, and expansion will all be monitored continuously after the bridge is put into service.

The applications of the portable monitoring are far more numerous and quantifiable. A typical use is for the determination of stress levels in steel members or bridge components to identify the cause of cracking or fatigue categories applicable to the structure. Rehabilitation options for several bridges in Connecticut have been decided using data collected with the portable monitoring systems. These are summarized in Table 1.
The monetary benefits of this research are a savings of over three million dollars since 1997 through revised rehabilitation plans and in-house data collection. An example of rehabilitation plans being decided by field data is the case of a steel girder bridge that had cracks in approximately 900 connection angles. Preliminary plans called for the total replacement of these angles. Research into the cause of the cracks, that included field measurement of strains, concluded that repairs would be sufficient. It is estimated that this saved $250,000 and shortened the length of the project by a year. Understanding the real-time behavior of bridges in a particular region is also anticipated to save money in that deterioration rates for these structures will be more accurate and provide more realistic support data for bridge management decisions.

Safety benefits include the strengthening of a suspect counter weight hanger on a movable bridge. Field measurements and analysis of the data concluded that the hanger was inadequate. Strengthening was done in time to maintain the functionality of the bridge and the safety of public.

Ultimately, the continuous monitoring of a bridge will serve as an indicator of the integrity of the bridge. This will save both human life and a tremendous amount of money.

It is anticipated that this study will also advance the use of permanent and portable computer-based bridge monitoring systems in Connecticut, and that publication and presentation of the results will assist others in the consideration, specification, and use of these systems.

### Product(s) Available


For more information:
For more information, contact Dr. Robert G. Lauzon at the Connecticut Department of Transportation, Division of Research, 280 West Street, Rocky Hill, CT 06067-3502 Tel. (860)258-0305, email: Robert.Lauzon@po.state.ct.us.
Problem

A culvert is a hydraulic structure designed to convey water under a roadway. When one or more changes of grade occur within the culvert profile, it is called a broken-back culvert. Broken-back culverts are usually placed in areas where laying a straight culvert would require large excavations or where other site conditions dictate a break should occur. Broken-back culverts may also be intended to reduce outlet velocities when normal outlet velocities are greater than desired.

A double broken-back culvert is characterized by three sections, an inlet section, a steeply sloped section, and the outlet section. A single broken-back culvert consists of only a steeply sloped section and an outlet section. As water flows through the steeply sloped section, it becomes supercritical or rapid. Supercritical flow occurs when inertial forces dominate the gravitational forces. If the supercritical flow continues through the outlet section, there will likely be problems with scour at the outlet and erosion in the downstream channel. Therefore, the goal of broken-back culvert design is to produce subcritical or tranquil flow within the outlet section. Subcritical flow occurs when the gravitational forces dominate the inertial forces. If a hydraulic jump occurs or is forced to occur inside the culvert barrel, then the flow at the outlet will be subcritical. It is important for the designer to know the water surface profile throughout the broken-back culvert and to be able to predict the occurrence of a hydraulic jump.

Solution

The researcher developed a computer analysis model called the Broken-Back Culvert Analysis Program (BCAP) for the Nebraska Department of Roads (NDOR) for use as a method for hydraulic analysis.

The hydraulic properties of a broken-back culvert are similar to a straight culvert in many ways. However, there are a few differences that are important and must be considered when evaluating culvert performance. The properties include the control section and the water surface profile calculations.

A control section is defined as a point that limits the culvert's ability to pass a flow and is used to calculate the headwater depth at the inlet. In a double broken-back culvert there are two possible control sections: the inlet and the upper break. If the inlet is the control section, the barrel has a greater conveyance capacity than the inlet. If the upper break is the control, the inlet can allow more water into the culvert than the barrel will convey. The inlet control headwater depth is affected by submergence, culvert size and shape, and inlet type. The break control headwater depth is affected by the barrel size and shape, material, and inlet type.

When calculating the flow profile through the culvert, there are two possible scenarios that may occur. If the culvert is operating in inlet control, the water surface profile is calculated by assigning critical depth to the inlet and moving down the culvert. If the culvert is operating with the control at the upper break, critical depth is assigned to the break and the water surface profile is calculated from this starting point.

If the culvert is a single broken-back, there is no inlet section; therefore, the culvert will operate in inlet control, and the water surface profile can be calculated by assigning critical depth to the inlet.

Implementation

The researcher gave a two-hour presentation on the hydraulic theory used in developing and writing the computer program BCAP and demonstrated how to use the program. The software was installed on the computers of those responsible for designing culverts.
Following are copies of two screens of the computer software program that show graphics and data.

**Concrete Box Culvert**
Span (per barrel) = 10 ft
Rise = 10 ft

**Inlet Type**
Wingwall, 1.5:1 Bevel (18-34 deg. Flare)
Rough. Coeff. = 0.013
Outlet Sec. Rough. Coeff. = 0.024

**Q = 800 cfs**

Source: C:\BCAPTMP\TEST1.BCP
Benefits
The BCAP fills the void in broken-back culvert design by enabling designers to: 1) analyze existing installation, 2) educate designers about broken-back culvert hydraulics; 3) optimize design of broken-back culverts; 4) help recognize improper design of existing facilities, and 5) predict erosion and reduce risk and liability.

Product(s) Available
The final report is available and to obtain a copy contact:
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High Value State DOT Research
Culvert Design Manual for Passage of Weak-Swimming Fish

Problem

In the past, fish passage problems were studied by either engineers or biologists. These disciplines rarely mingled. Thus, communication problems often arose and specific concerns were not met. Engineers concentrated on passing flood flows without subjecting the highway to unreasonable risks. Biologists wanted upstream migrating fish passed through the drainage structures during critical times in the fishes' lifecycle. These objectives conflicted when the resource agencies recommended installing bridges instead of cheaper culverts. The cost difference between installing culverts and bridges was substantial. Therefore, the FHWA and DOT&PF decided to commit funds and resources to study the problem. They tasked the research team to develop cost-effective design recommendations that were agreeable between DOT&PF and the resource agencies.

Solution

Properly designed culverts don't produce water velocities that exceed fish swimming abilities. Fish have two different musculature systems for swimming. A white muscle system generates power for short, vigorous swimming. A red muscle system furnishes power for long, sustained swimming. The culvert design must account for both swimming modes. Therefore, the engineer must know the hydraulic conditions where the fish swims. These conditions change throughout the culvert. The engineer determines the acceptable hydraulic conditions for fish by matching known fish swimming power and energy capacities.
Subcritical flow is necessary to pass weak-swimming, upstream-migrating fish. Therefore, this requirement precludes the use of inlet control. The engineer may use artificial roughness to create areas of slower water velocities within culverts. Examples of these are depressed inverts, weir baffles, and deep culvert corrugations.

This document presents the fundamental fluid mechanic and biological aspects of fish passage through culverts and relates them to the passage of weak-swimming, Class-I fish through culverts (Table I-1). Because the writers have made rather detailed studies of only Arctic grayling (Thymallus arcticus), their design recommendations should be used only for Class-I fish. These recommendations must not be considered for the cost-effective design of culverts for the passage of salmon or other strong swimming fish. However, this report's fundamental biological and fluid mechanics concepts of swimming fish apply to moderate- and high-performance swimming fishes, including salmon.

**TABLE I-1. Class-I fish. Low-performance swimmers.**

- Arctic Grayling
- Long Nose Sucker
- Northern Pike
- Stickleback
- Whitefish
- Burbot
- Sheefish
- Smelt
- Sculpin
- Dolly Varden/Arctic Char
- Upstream migrant salmon fry

Northern pike, *Esox lucius*
The successful passage of fish through highway culverts depends on hydraulic conditions at the culvert outlet, in the barrel, and at the inlet. Normally, culvert design consists of selecting a culvert that successfully passes a flood of given magnitude without producing undesirable consequences upstream, downstream, and to the roadway. This document attempts to acquaint the design engineer with the micro-hydraulic details of a culvert's inlet, outlet, and barrel relevant to fish passage. In addition to hydraulic conditions in the culvert itself, those of the outlet pool take on special significance for the passage of weak-swimming fish.

**Implementation**

The procedures developed for designing culverts to pass weak swimming fish are accepted throughout Alaska DOT&PF as the method of choice. A follow-up study has shown that where these procedures have been followed, fish were able to pass through the culvert.

**Benefits**

The study was completed with cooperation of Alaska Department of Fish and Game. Through this project, the relationship between the two departments has improved and the number of culverts replaced by bridges have been greatly reduced. The ability to maintain a single culvert in place of a bridge will save in excess of $1 million. While the reduction in the number of bridges is unknown, we believe that at least 10 bridges have been eliminated. Our ability to pass weak-swimming fish through culverts has now developed to the point that bridges are used only where hydraulic or terrain conditions warrant.
Product(s) Available
A research report, "Fundamentals of Culvert Design for Passage of Weak-Swimming Fish", Report No. FHWA-AK-RD-90-10 and the software "FISHPASS" can be downloaded from the State of Alaska, Department of Transportation and Public Facilities, Research and Technology Transfer Section website.

Download report (5531k)

Download "FISHPASS" software (90k)

For more information:
For further information, contact Billy G. Connor, Statewide Research Manager, Alaska Department of Transportation and Public Facilities, 2301 Peger Rd., Fairbanks, AK 99709-5399 or email billy_connor@dot.state.ak.us or call (907) 451-5320.
Problem
Establish the context for the problem and describe the transportation-related problem (150 words). Corrosion of metallic reinforcement is a major threat to the aging infrastructure. Prestressed structures, such as many of the bridges built in the early 1950's and 1960's, are showing signs of deterioration. The NCHRP has identified a concern regarding the structural integrity of prestressing steel used in concrete and cable stayed bridges. According to the NCHRP, no economical field method exists for determining the condition of prestressing steel (location and severity of corrosion).

Solution
Describe the research objectives, scope, tasks performed, and findings (450 words). A novel nondestructive evaluation technique for detecting damage in metallic reinforcement using time domain reflectometry (TDR) has been developed and demonstrated. The types of metallic reinforcement being considered include stay cables, prestressing strands, post-stressing strands and bars, and steel reinforcement. TDR is a well-established technique in the field of electrical engineering that has been used for many years to detect faults in transmission lines. Preliminary analytical and experimental development of the method has been conducted with the support of both the Delaware Department of Transportation and the National Science Foundation (NSF).

Implementation
Briefly describe a project where the research findings were implemented. Describe what development and technology transfer efforts were needed to turn the research results into something practical. (150 words). Through analytical models and small-scale laboratory tests, the following results have been shown:

- TDR can detect damage sites on a steel strand or reinforcing bar.
- TDR measurements do give indications of the severity of the damaged region.
- The system (steel strand/bar and sensor wire) can be modeled as a transmission line and evaluated analytically.

Benefits
Describe the actual or expected benefits from this research for the transportation agency or public in economic, social, or environmental terms, e.g., monetary savings, reduced fatalities and crashes, reduced...
pollutant emissions, as well as enhanced productivity or performance. Measured benefits are preferable (200 to 250 words). Based on the initial results, the TDR corrosion detection method has proven to be more robust than existing methods because it allows one to detect, locate, and identify the extent of corrosion damage.

**Product(s) Available**
List any research reports, specifications, training manuals, etc. that are available and describe how they can be obtained. Draft report submitted to Delaware DOT. Final report anticipated before 9/1/00.

**For more information:**
Provide the name and a method of contacting an individual whom readers can contact for further information. If desired, provide a link to the DOT's website. Dr. Robert Hunsperger, University of Delaware. Telephone: 302-831-8031. E-mail: hunsperg@ee.uedl.edu
Sponsored By: Michigan

Problem
Develop and evaluate passive cathodic protection systems to be used on prestressed concrete I-beam (PCI-beam) ends that are not deteriorated to the point of needing the "overcasting" repair, but could use some protection from further deterioration.

Solution
The objective is to determine if passive cathodic protective systems will provide sufficient protection to corroding PCI-beam ends. This will be determined by half-cell potential mapping according to ASTM C876, as well as visually inspecting the protected beam ends for delaminations. Prior to the installation of the selected systems, the Structural Research Unit will take a series of half-cell potential reading to establish a base line condition. Once the selected system is installed, additional half-cell readings will be taken to ensure the material is performing as stated. Half-cell potential readings will continue the duration of the project.

Implementation
This project will evaluate existing passive cathodic protection systems to determine if they are practical and cost effective for use on corroding PCI-beam ends. A special provision and construction details will be developed. The Structural Research Unit will monitor one of the selected system's, 3M zinc-hydrogel on S03 of 56044 (M-30 over US-10), and measure its effectiveness over the seven-year period. The Structural Research Unit will also evaluate an Al-Zn-In system and compare its performance with the 3M Zinc-Hydrogel.

Benefits
If the passive cathodic protection systems prove useful, the Michigan Department of Transportation will save money by applying a cheaper alternative that the current "overcasting" repair on beam ends that require protection from further deterioration, but not necessarily the level of "overcasting."

Product(s) Available
Research project 99 G-326 currently underway. Estimate completion in 2006. Estimated project cost of $56,000.

For more information:
For more information, please contact Steve Kahl of the Michigan Department of Transportation, Testing and Research Section, at 517-322-5655. Or you can e-mail him at kahls@mdot.state.mi.us.
Instrumentation for Measuring Scour at Bridge Piers and Abutments

Sponsored By: NCHRP

Problem
Scour is the erosion of waterway soils and sediment that provide support for bridge foundations. More bridge failures are caused by scour than all other processes combined. The resulting disruptions of river crossings represent a safety hazard for travelers and can have devastating impacts on local economies. Thus it is important for bridge owners to know the scour susceptibility of their bridges.

An ongoing scour evaluation program being conducted by the Federal Highway Administration and all state highway agencies has led to the identification of more than 17,000 scour-critical bridges and nearly 100,000 bridges with unknown foundations. An additional 86,000 bridges screened as scour-susceptible have not been evaluated. Given the limited funding available, bridges that have been identified as scour-critical, cannot be immediately repaired or replaced. Because scour holes generally fill in as stream flows diminish, postflood inspections are not adequate for determining the full extent of scour damage. Methods for measuring the maximum scour depth are needed in the management of scour-susceptible bridges.

Solution
Technically and economically feasible instruments for monitoring scour depth were developed under the National Cooperative Highway Research Program (NCHRP) Project 21-3, "Instrumentation for Measuring Scour at Bridge Piers and Abutments". Two instrument systems--a low-cost sonic fathometer and a magnetic sliding collar device using a driven-rod support--were installed and tested in the field under a wide range of bridge substructure geometry, flow, and geomorphic conditions.

The low-cost sonar device (Figure 1) consists of a simple fish-finder-type sonar connected to a data logger. The logger tells the sonar when to turn on, how much data to collect, and when to turn off. The magnetic sliding collar device (Figure 2) consists of a stainless steel pipe driven into the channel bottom with a sliding collar that drops down the pipe as the scour progresses. The location of the collar is detected by the magnetic field created by magnets on the collar. Installations conducted in cooperation with state highway agencies demonstrated that these simple, low-cost instruments are adaptable to various field situations, and can be installed with the equipment and technical skills normally available at the district level of a state highway agency.
Figure 1: Above-water serviceable low-cost fathometer system
Implementation
In preparation for storm events driven by El Niño, several states installed a variety of instruments at bridges in the southwestern United States in late 1997 and early 1998. Five bridges were instrumented in California, five in Arizona, and four in Nevada. The equipment included the automated sliding collar...
and low-cost sonar devices. These installations also provided an opportunity to test a number of new concepts, including two- and four-channel sonar devices, early warning concepts (through definition of threshold scour levels and automated calls to pagers when that threshold is exceeded), and a float-out device.

During the testing, the SR 101 bridge over the Salinas River near Soledad, California, experienced several scour events that triggered threshold warnings. In one case the automated sliding collar dropped 1.5 m (5 ft), causing a pager call-out. Portable sonar measurements confirmed the scour recorded by the sliding collar. Since the critical scour depth was about 6 m (20 ft) below the streambed, no emergency action was needed to ensure public and bridge safety. Because pager call-out was ineffective in alerting maintenance personnel during nonoffice hours, a programmed voice synthesizer call-out to human-operated 24-hour communications centers was implemented at other bridges.

There have been additional applications. Virginia has instrumented the Woodrow Wilson Bridge with a sonic fathometer device, Rhode Island is installing a sliding collar device, and New Jersey is instrumenting two bridges, each with a sliding collar and sonic fathometer device. Some states have chosen to contract with instrument suppliers to install the instruments, while other states have opted to install the instruments themselves. It is estimated that 23 magnetic sliding collar devices, and 42 sonar devices are now in use by bridge owners in the United States.

Benefits
The instruments developed under this research and through additional commercial development have been tested extensively and are fully field-deployable. Use of these instruments for scour monitoring has provided state highway agencies with an essential element of their action plans for bridges that are scour-critical or scour-susceptible, or have an unknown foundation. Use of these devices has allowed monitoring of scour-critical bridges so that solutions could be developed before the problem becomes severe.

Product(s) Available
*NCHRP Report 396: Instrumentation for Measuring Scour at Bridge Piers and Abutments* documents all phases of the development work for the devices described in this article. Findings from laboratory and field testing are presented for each device, and a detailed discussion of the significance of these findings is presented. The companion manuals (*NCHRP Report 397A: Sonar Scour Monitor: Installation, Operation, and Fabrication Manual* and *NCHRP Report 397B: Magnetic Sliding Collar Scour Monitor: Installation, Operation, and Fabrication Manual*) provide guidance for selecting the device most suitable for a bridge and its location. Detailed instructions, including fabrication drawings and parts lists, are included to permit fabrication of the monitors in most machine shops. Instructions for operation and maintenance are also given.

For more information:
For further information contact Peter F. Lagasse, Ayres Associates, 3665 JFK Parkway, P.O. Box 270460, Building 2, Suite 300, Fort Collins, Colorado 80522 (telephone 970-223-5556).

Adapted from "Research Pays Off" article submitted by the California Department of Transportation for the July-August 1999 issue of *TR News*. 
Problem
The historic Horsetail Falls Bridge is a 60-foot reinforced concrete bridge that consists of three 20-foot spans. The structure, built in 1914, at a cost of $1,817, is located in the Columbia Gorge, 30 miles east of Portland, Oregon. This bridge, like many others in Oregon, was not designed to carry the traffic loads that are common today.

The bridge was rated and was found to have only 4% of the needed shear capacity and approximately 50% of the required flexure capacity. Visual evaluation revealed that the bottom of the deck, and beams had many hairline cracks, a few larger cracks, and some exposed, corroded reinforcing steel. However, the condition of the concrete and the reinforcing steel was very good, considering the age of the bridge.

The Horsetail Falls Bridge is an historic structure, located within the Columbia Gorge National Scenic Area. As such, any structural upgrade to the bridge could not significantly alter its appearance. Furthermore, imminent load restrictions on the structure would have disrupted heavy tour bus traffic on the Historic Columbia River Highway.

HORSETAIL FALLS BRIDGE
Solution

Oregon Department of Transportation (ODOT) Research Group, in collaboration with Oregon State University (OSU) studied fiber reinforced polymer (FRP) materials as a cost-effective, structurally sound methodology for upgrading bridges. The decision to use this approach was based on the early findings from this research effort. The approach consisted of three phases:

The first step was to design and install an FRP composite retrofit for the structure. Responsibility for this phase was shared by Oregon State University, the ODOT Research Group, the ODOT Bridge Section, the materials supplier and an installation contractor.
The second step was to instrument the bridge with fiber optic sensors embedded in the concrete and attached to the surface of the FRP composite material. Responsibility for this phase was shared by the ODOT Research Group and Blue Road Research, a consultant in Troutdale, Oregon specializing in fiber optic sensing technology.

The third step was to construct and load test four full-size beams patterned after the Bridge beams. One beam was used for control. Two beams were strengthened for shear and flexure respectively. The fourth beam was strengthened for both shear and flexure using the same materials and configuration as the Bridge beams. Responsibility for this phase was shared by the ODOT Research Group and Oregon State University.
Upon completion of the construction work, the bridge was loaded using a vehicle with known axle weights. Follow-up load testing has shown that the bridge has maintained a consistent response to loading over time. Laboratory results and a finite element computer model indicate that the bridge meets or exceeds HS20 load carrying capacity.

Implementation
As a result of the successful Horestat Falls Bridge experience, ODOT has used this same approach to strengthen several other bridges, including interstate highway bridges. External composite reinforcement has become one of the key strengthening techniques for Oregon bridges.

Benefits
- The historic Horsetail Falls Bridge now meets or exceeds HS20 load requirements.
- The appearance of the structure was not significantly altered, satisfying the requirements for an historic structure within a National Scenic Area.
- The OSU study provided validation of concept.
- The cost of the composite retrofit, at about $35,000, was approximately half the engineering estimate for a conventional repair.
Product(s) Available
The following three reports are available in PDF from the ODOT web page: http://www.odot.state.or.us/tddresearch/reports.htm

"Finite Element Modeling of Concrete Structures Strengthened with FRP Laminates"
"Testing of Full-size Reinforced Concrete Beams Strengthened with FRP Composites: Experimental Results and Design Methods Verification"
"Behavior of Concrete Specimens Reinforced with Composite Materials"

For more information:
If you have any questions or comments, please feel free to call, write or email Steven Soltesz with the ODOT Research Group.

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Salem OR 97301-5192
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Problem
Overlays are used to provide a skid resistant weaving and protective surface for bridge decks. The timely application of a low permeability concrete overlay can stop or retard the infiltration of chloride ions and therefore extend the life of a bridge by 20 to 40 years or more. Conventional hydraulic cement concrete overlays perform well but lane closures of a week or more are usually required for the installation of the overlay. The traffic on many bridges is too heavy to allow weeks or even 24 hours of continuous lane closure and therefore conventional overlays can not be installed without causing major delays to the traveling public.

Solution
Polymer concrete overlays are particularly suited for installations during off peak traffic periods such as at night and can be constructed in situations where it is necessary to minimize lane closures and traffic disruption. Polymer overlays are constructed with epoxy, unsaturated polyester styrene and methacrylate and graded aggregates. Overlays may be multiple-layer, slurry or premixed. Polymer overlays provide an economical skid resistant weaving and protective surface for bridge decks.

Implementation
Research and initial implementation efforts began in the late 1970s with FHWA funded Work Orders to cover part of the cost of construction and all of the cost of the evaluation of various polymer overlay systems. Other evaluations were done with FHWA State Planning and Research (SPR) funds. Promising systems were identified in the 80s. SHRP research evaluated the various overlay systems and focused on the development and refinement of generic specifications for the promising polymer overlay systems. AASHTO Task Force 34 published Guide Specifications for polymer overlays in 1995. The AASHTO SHRP Lead State Implementation Effort in the late 90s fueled the implementation effort and resulted in polymer overlays being accepted nationally as a cost effect overlay system. A recent nationwide survey of polymer overlay usage revealed there are 555 overlays in place in thirty-three states and Canada. Four hundred and sixteen of these were constructed since 1990.

Benefits
Cost data from 79 overlay projects in Virginia in 1995 showed that due to large savings in the cost of traffic control, polymer overlays can be installed at a third the cost of hydraulic cement concrete overlays based on a life cycle cost analysis. DOTs that spend $5 million per year on concrete overlays can save $3 million using polymer overlays.
**Product(s) Available**
See "AASHTO Task Force 34 Guide Specifications for Polymer Concrete Bridge Deck Overlays", October, 1995

**For more information:**
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Sponsored By: Pennsylvania

The interest for this study stemmed from the fact that recent editions of the American Association of State Highway Transportation Officials (AASHTO) code (1992 and after) incorporated significant changes in seismic provisions with respect to detailing of reinforced concrete column confinement reinforcement. The recent editions of AASHTO code require the spacing of the transverse reinforcement columns not to exceed 4 inches or 6 inches, depending on the Seismic Performance Category (SPC).

Problem
Because most of Pennsylvania bridges with a variety of column geometry and bent types have been built prior to 1990s, the transverse reinforcement details in most existing bridges do not satisfy the current AASHTO seismic provisions. PENNDOT was interested in this study because, like many other Dot's, it has to decide whether to seismic retrofit existing apparently deficient bridge columns or rely on reserved capacity of such bridges to resist future earthquakes.

Solution
The study determined that, for the level of earthquakes expected in Pennsylvania based on AASHTO provisions, the existing spacing of hoops (No. 4 at 12 inches) by itself is not the critical issue. Instead, according to the available test results, columns with short splice length at column-footing connection area provided a more critical situation as far as the ductility capacity during lateral cyclic loading is concerned. Based on calculated values for displacement ductility, R-factor values ranging from 1.75 to 3.0 were obtained for bridge piers studied.

Implementation
The study recommended that some testing be done on large-scale bents with insufficient column reinforcement detailing in order to obtain accurate values of available displacement ductility factors from which more reliable R-factor values can be determined.

Benefits

Product(s) Available
Technical Memorandum Seismic Column Reinforcement Study.

For more information:
PENNDOT Research
The Pennsylvania Department of Transportation
Problem
Many existing highway bridges were constructed prior to research and understanding of seismic actions. Hence, in nearly every recent major earthquake, bridge failures have occurred resulting in extensive bridge damage, collapse, and in some cases loss of life. In California and Nevada, the use of non-prismatic reinforced concrete highway bridge columns (one-way and two-way flared columns) has been extensive. The dramatic failure of the flared columns in the Mission Gothic Overpass in Southern California during the Northridge Earthquake of 1994 prompted the Nevada Department of Transportation (NDOT) to fund an evaluation of flared bridge columns in Northern Nevada. A multi-phase study involving an analytical and experimental assessment of seismic vulnerability of flared columns and the development of retrofit methods was undertaken at the University of Nevada, Reno.

Solution
Analytical studies revealed two types of flared columns are particularly vulnerable. Both have "structural flares" unlike those typically used in California which are architectural. The steel reinforcement in structural flares is the only source of flexural strength, while in architectural flares, the main steel is in the core and flare reinforcement is minimal. To retrofit architectural flares, the main steel is in the core and flare reinforcement is minimal. To retrofit architectural flares, the flares are cut around the column at the junction to the superstructure. This method cannot be used in structural flares because the column would lose its flexural capacity. Therefore, new retrofit methods had to be developed for Nevada bridges.
Cyclic tests of as-built column models showed that only columns with high vertical steel ratios are vulnerable. Tests also showed that the columns, despite their deficiency in shear and confinement, have an inherent advantage. Plastic hinges do not occur at the end of the column but are shifted to some distance away from the end. The shifted plastic hinges have the advantage of leaving the connections damage free and improve the overall stability of the structure. The retrofit methods that were investigated were developed so that the plastic-hinge location is maintained. The most common method to retrofit bridge columns for shear and/or confinement is the installation of steel jackets. However, no past studies had been conducted on the use of steel jackets on flared columns. A series of cyclic tests and shake-table simulations were conducted on column models that were retrofitted with a steel jacket. A gap was left in the jacket in the plastic hinge area to avoid connection damage. The 1994 Northridge-Sylmar earthquake was simulated on the shake table. The tests showed that the steel jacket improved the shear capacity substantially and the ductility capacity was increased by approximately 40 percent. It became clear that a gapped steel jacket would be an effective seismic retrofit measure for the columns from a technical point of view. However, due to space limitations adjacent to the columns on one major bridge, an alternate retrofit strategy had to be found.

Fiber reinforced plastic fabrics are an alternative material for seismic retrofit of reinforced concrete structures. They require only a limited clearance around the column for installation. These fabrics, however, were not initially considered because they have been used only on circular bridge columns, and there was no research data on their performance. The next phase of the research was to investigate the shake-table response of flared columns with carbon and glass fiber composite jackets. A new method of installation of composite fabrics had to be developed for flared columns. A continuous wrap normally placed on circular columns cannot be used on a flared column and leads to a change of fiber angle that could adversely affect the column performance. The effect of reducing the height of the jackets was also investigated to determine if there were any problems in stopping the jackets above the ground level. The shake-table data showed that the carbon and glass fiber composites both performed as well as a steel jacket, and it is not necessary to excavate to the top of footings to extend the jackets.
Implementation
A step-by-step design and installation procedure was prepared and used to implement the research results. The columns were retrofitted in spring 2000 using glass fiber composites. Glass was selected over carbon due to its lower cost.

Benefits
1) Many of the columns were found to have sufficient ductility and did not need retrofitting. This led to significant cost savings for the project. 2) Research showed that composite fabrics are effective retrofit measures. Because the fabrics are relatively easy to install in a tight working space, they were implemented in the actual retrofit plan. 3) Research results demonstrated that the parts of the columns that are embedded below grade did not need to be covered by jackets. As a result, excavation to the top of footings was not necessary. This also led to considerable cost savings, less disruption to traffic on adjacent streets and no disturbance to the Regional Transportation Commission buildings under the bridge.

Product(s) Available
Reports are available from the NDOT library by contacting Mr. Tie He at (775) 888-7220 or by e-mail at the@dot.state.nv.us.

For more information:
Please contact Mr. Bill Crawford, Chief Bridge Engineer at (775) 888-7542.
Sponsored By: Texas

Problem
Building bridges in congested urban settings is becoming more challenging for the Texas Department of Transportation (TxDOT). Concerns about traffic delays and public safety in such congested construction zones have intensified. Additionally, the costs associated with traffic control and with disrupted traffic flow have increased substantially. TxDOT already has a number of economical, standard superstructure elements, such as precast I-girders with precast concrete deck panels, that facilitate rapid and highly cost-effective construction. The next best opportunity for economy and speed of construction lies in the development of precast substructure elements.

The Pierce Elevated section of IH-45 in the Houston central business district needed to have 113 spans replaced. A conventional TxDOT bridge system, consisting of a precast superstructure and cast-in-place substructure, would have required more than a year and a half to complete construction. Since user delay costs were estimated at greater than $100,000 a day in urban Houston, TxDOT bridge designers decided to try using precast bent caps as a means to speed up construction.

Two problems were associated with using precast bent caps. One, no comprehensive design methodology existed for beam-to-column connections. Two, of the myriad of commercial products and published information available, nothing completely satisfied cost-effectiveness and constructability...
High Value State DOT Research - Texas

demands as a complete system. Also, in order to be competitive with cast-in-place construction, the proposed precast bent cap connections had to be compatible with conventional bent cap reinforcement details. Any deviation from conventional bent cap steel detailing would be detrimental to the cost-competitiveness of a precast system.

Solution
The Pierce Elevated project motivated TxDOT to let a research contract with the Center for Transportation Research at The University of Texas at Austin. It was decided to limit the scope of the research to conventional bridge systems that are predominant in Texas. The research study had three major objectives: 1) develop preliminary details for connecting precast bent caps to cast-in-place concrete columns and precast trestle piles; 2) evaluate candidate details with full-scale specimens in the laboratory; and 3) finalize standard connection details for precast bent caps through the construction and testing of full-scale bents in the field by a highway contractor. Standard cast-in-place bent cap reinforcement details were used in the cap itself so contractors could determine for themselves the optimum construction technique. Shipping weight limitations would be accounted for by constructing wide bents as a series of smaller independent bents.

Working closely with the TxDOT bridge designers and contractors, the researchers developed and validated a strength-design procedure for several connection systems and obtained predicted connection strength with the laboratory specimens. The researchers made use of state-of-the-art connection hardware and grouting technology in the development of the connections.

The final design and detailing standards, currently under final revision, benefited greatly from the experience gained with a leading highway contractor, Champagne Webber, Inc., who built and tested two full-scale bents using the details developed in the laboratory. Lessons learned include the importance of including a step-by-step grouting procedure in the plans and the importance of designing "forgiveness" into the connection.
Implementation

The implementation of the connection details for precast bent caps allowed the 113-span Pierce Elevated job to be completed in 95 days, rather than the 548 days that conventional construction would have taken. For this incredible time reduction the contractor, Traylor Brothers, Inc., received the largest incentive award ever paid in Texas -- $1.2 million.

One of the strengths of this research and development project is that the combined creativity and experience of industry, academia, and TxDOT were fully utilized. The resulting connection details are highly constructable and efficient. It is anticipated that this technology will be included in plan sets as an optional construction method by including a connection detail standard and specification in the construction contract documents. Maximum cap weight is expected to be limited to the maximum crane capacity on a given job, which is in turn determined by the weight of the beams placed on the project. The connection details developed are appropriate for typical highway bridges with multiple columns and a relatively low bending moment demand at the top of column. Using this technology, it is feasible to construct a single-span bridge using precast piles, bent caps, wing walls, and beams with a cast-in-place wearing surface in days instead of weeks or months.

This technology is most advantageous in long and highly repetitive bridges, bridges over water, and in many off-system bridges where detours are long and phasing is difficult and costly.

TxDOT is working on an implementation plan to use precast bent caps on a large project on IH-35 that will require 200 similar bents and a project in west Texas where delivery of concrete to the job site is a problem. The implementation plan includes monitoring of the project by the researchers, documentation of the work, and reporting of the results.

Benefits

The research cost $289,200 to perform: three days of saved user costs (approximately $100,000 a day) on the Pierce Elevated project would have paid for the research. Even conservatively figured, the rest of the savings to road users on this one project exceeded the total cost of TxDOT's $18 million Research Program in 1999.

The use of precast bent caps means faster construction, less risk associated with construction zone traffic control and traffic detours, and maintained or improved quality control. Using precast bent caps has been shown to speed up construction. Time and monetary benefits are project specific, but precast caps will always reduce project duration. Construction phasing can be rethought or eliminated in light of reduced construction time. Monetary benefits are more difficult to quantify because they are proportional to time savings at a project specific rate. One rule, without exception, is that reduced project time greatly increases public satisfaction.

Product(s) Available

The final design and detailing standards are currently under final revision. Draft copies could be made available to other DOTs. A research report, "Development of Precast Bent Cap Systems and Testing Program," is in the final stages of the review process.
For more information:
For further information, contact John Vogel, P.E., Bridge Design, Texas Department of Transportation, Houston District, 7721 Washington Ave., Houston, TX 77251-1386 or jvogel1@dot.state.tx.us or telephone (713) 802-5235.
Problem
Many bridges in the Nation were constructed 30 or 40 years ago, and are nearing their design life. Available funding in many states falls short of that needed to address this problem. New innovative methods are needed to extend the life of these structures, and to optimize the use of bridge replacement budgets.

Solution
The use of carbon fiber wrap on bridge columns and bents has been shown to extend the life of bridges with damage due to corrosion. The carbon wrap can also enhance the seismic capacity of many bridges. Research projects were conducted in Utah to demonstrate how carbon fibers can be applied, how they increase the strength and ductility of bridge components, and how this light weight material brings less momentum to a structure in a seismic event. Testing as part of the I-15 National Testbed has contributed significantly to the state-of-the-art related to bridge rehabilitation and restoration.

Implementation
The use of carbon fibers to rehabilitate bridges has been implemented into practice at UDOT. A series of bridges were treated using the technology on I-80 on the East side of Salt Lake City as part of an $8 million corridor improvement project. Other bridge restoration projects are planned using carbon wrapping.

Benefits
The carbon wrap strategy has been shown to be a very cost-effective treatment for structures with significant corrosion. Carbon fibers add very little weight to the structure, when compared with an in-fill wall, or an increase in column diameter. The wrapping process in many cases can be conducted during off-peak traffic times and lanes can be opened to traffic during rush hour. Other strategies require extensive forming and scaffolding, and significant curing time, requiring lanes to be closed for longer periods of time. The ability to increase the seismic capacity of a structure while repairing corrosion damage is a definite advantage of this technology.

Product(s) Available
A report describing the research project is available. Two videos have been produced that illustrate the construction methods required to place the material, and the destructive testing performed to measure the increases in strength and ductility. Specifications are available that were used during the bidding process.
of the I-80 retrofit project, as well as training materials utilized to prepare engineers and technicians for the construction.

**For more information:**
Contacts-Samuel Musser, 801-964-4568, smusser@dot.state.ut.us
Doug Anderson, 801-965-4377, danderso@dot.state.ut.us
Sponsored By: NCHRP

Bridge engineers rely on automated computations to increase productivity and therefore need procedures for assuring error-free software. The large number of bridge types, geometric configurations, materials, and loadings creates a challenge for software developers and end users to provide this assurance.

Whether a single spreadsheet or a complex three-dimensional finite element analysis and design tool, automation of bridge computations is an integral part of the design engineer's daily routine. Bridge designers are and will be using software to design bridges based on new specifications. Ideally, this software should be error-free--yet perfect software remains elusive.

Research conducted under NCHRP Project 12-50 provides a standardized process that is useful for a host of applications in bridge engineering, specification development, and software development and maintenance.

Problem
The effectiveness of testing of new bridge software and specifications is unknown, and this is a barrier to acceptance. Bridge owners lack the resources for lengthy validations of bridge software. Software developers and specification writers need a standardized process to validate and report results.

The great diversity of bridge types, geometric configurations, materials, and loadings creates a challenge for software developers and users. Only limited independent validation of software can be performed.

The AASHTO LRFD Bridge Design Specifications require verifying computer programs against the results of closed-form solutions, physical testing, or previously verified computer programs. This is difficult, because closed-form solutions are generally limited to the most trivial cases, physical testing is expensive, and few--if any--computer programs for bridges have completed a formal validation procedure.

Solution
The researchers have systematically identified the range of practical input values and possible outputs for bridge design and analysis. To make the solution manageable, the process was divided into smaller subdomains, such as dead-load distribution and live-load actions. Twenty subdomains were identified for bridge superstructures. A test-bed of bridge data with well-defined parametric inputs and outputs was developed. The data were created to rigorously test the limits of the associated subdomain. These bridges or portions of bridges are usable by developers, end users, and others. The researchers suggest that, at the completion of this project in the second quarter of 2002, the data sets should be made available through a website or compact disc.
A careful review of the design specifications catalogued the possible results of computations. For superstructures, nearly 900 possible outputs were identified, such as exterior girder slab weight and deflection of steel I-sections due to truckloads. Each output was assigned a unique report identifier, permitting efficient review and comparison of results.

Finally, to implement the validation process, modifications were made to the LRFD computer program to produce a simple comma-delimited ASCII text file of outputs that can be imported into a relational database. The database values can be compared efficiently with the results from another program that has been modified to produce a similar comma-delimited file.

The figure below illustrates a comparison of results from two programs--Pennsylvania Department of Transportation (DOT) Prestressed LRFD and Wyoming BRASS Girder LRFD. In this case, the only difference between the programs appears to be the spacing of calculated values along the length of the girder. The process is particularly valuable in the development of software for the AASHTO LRFD Bridge Design Specifications and in the review of proposed amendments to the specification provisions.

**Implementation**

The validation of the concept and the research approach used design programs from Pennsylvania, Wyoming, Washington, and Alaska DOTs. The product, Bridge Software Validation Guidelines and Examples, NCHRP Project 12-50, is a standardized process for a host of applications in bridge engineering, specification development, and software development and maintenance. These applications include
• A systematic method for comparing and evaluating bridge design and analysis software,
• A standardized report format for presenting and comparing results for a specific bridge design, and
• A powerful method for formally reviewing specification changes.

Benefits
The research illustrated important benefits:

• Previously unknown errors were detected.
• Validation of the programs was achieved in significantly less time and with much more rigor—months of work can be completed in hours.
• Hundreds of test problems are now economically possible—when previously only tens were used. Moreover, the problems are more robust and address all parts of the specifications as well as the usual bridge configurations.
• The standardized results format is likely to evolve into an industry standard.

As a result of the demonstrated benefits, AASHTO has decided to implement the NCHRP 12-50 process in the AASHTOWare computer software bridge products now being developed for load rating and design (Virtis and Opis).

Design Comparisons
Using the NCHRP 12-50 methods, a designer easily can compare the results of alternative computational processes. The results can be imported into a common viewer for comparison, making the differences apparent. In the past, validation typically has consisted of producing a manual example that was computed and compared with results of the program. A typical manual example could take several days to several weeks to complete, producing a set of results representing a single bridge structure. The NCHRP 12-50 process has generated and compared dozens of examples in less time.

In addition to the time saved producing the examples, the NCHRP 12-50 process also realized savings in maintenance. Manual example problems are almost as costly to maintain as they are to produce. Changes in specifications or procedures often can lead to major revisions in the manual computations. The NCHRP 12-50 process simply reexecutes the automated processes.

Specification Review
Specification writing committees can use the software to compare different versions of the specifications on a large set of bridges to determine if the changes accomplish the desired objectives, and to prevent problems from developing. Similarly, bridge engineers can see the consequences of the changes on current engineering practices.

Software Validation
The cost of rigorous validation of software is 25 percent or more of the development cost. It is higher for engineering applications that involve manual computations. The cost associated with improperly
functioning software that is unserviceable or that crashes can be large. Software developers may use the NCHRP 12-50 process for verification and regression testing (version testing) of their software and to reduce verification times and costs.

Product(s) Available
The preliminary draft final report that was submitted as part of the first part of the project is available for short-term loan from the NCHRP.

For more information:
Additional information on the project is available at http://www4.trb.org/trb/crp.nsf/All+Projects/NCHRP+12-50
Bridge engineers are relying upon automated computations at an increasing rate. Whether it is a spreadsheet or a three-dimensional finite element analysis and design tool, automation of bridge computations is now an integral part of the design engineer's daily routine. Bridge designers are and will be using new software to design bridges that are based on new specifications. In theory, this software should be error-free. Yet the aim of perfect software remains elusive. The number of bridge types and geometric configurations, materials, and loadings creates a large solution domain that must be addressed.

**Problem**
The unknown quality and quantity of testing is often a barrier to acceptance of new software and specifications. Bridge owners lack the resources for a lengthy validation process. Software developers and specification writers need a standardized process to conduct their own validation and to report the results.

The large number of bridge types, geometric configurations, materials, and loadings creates a challenge for software developers and end users. Realistically, only quite limited independent validation of the software can be performed. The AASHTO LRFD Bridge Design Specifications require that computer programs be verified against the results of closed-form solutions, physical testing, or previously verified computer programs. This requirement is difficult to satisfy because closed-form solutions are generally limited to the most trivial cases, physical testing is expensive, and few, if any, computer programs in the bridge community have fulfilled any kind of formal validation procedure.

**Solution**
The researchers solved the problem by systematically identifying both the range of practical design input values and all possible outputs in bridge design and analysis. To make the solution manageable the bridge analysis and design process was divided into smaller 'subdomains' such as dead load distribution and live load actions. For bridge superstructures included in this research, 20 subdomains were identified. A test-bed of bridges with well-defined parametric inputs and outputs was developed. These bridges (or portions thereof) are readily usable by developers, end users, and others. It is planned to make these data sets available through a web site or by CD.

Next, through a careful review of the design specifications, possible computational results were cataloged. For superstructures nearly 900 possible outputs, such as exterior girder slab weight and deflection of steel I-sections due to truck loads, were identified. Each output was assigned a unique 'report identifier', permitting efficient review and comparison of results.
Finally, to implement the process, modifications are made to a computer program to produce a simple comma-delimited ASCII text file of outputs that can be easily imported into a relational database. Once in the database, the values can be quickly compared with the results from another program. The figure below illustrates a comparison of results from PennDOT Prestressed LRFD and Wyoming BRASS Girder LRFD. For this case, the only difference between the programs appears to be the spacing of calculated values along the length of the girder. The process is particularly valuable in the development of software for the AASHTO LRFD Bridge Design Specifications and in the review of proposed amendments to the specification provisions.

![Figure 1: Comparing Final Concrete Stresses from PennDOT LRFD and Wyoming BRASS Girder LRFD](image)

**Implementation**

Design programs from Pennsylvania, Wyoming, Washington, and Alaska DOTs were used in the validation of concept and research approach. The product of NCHRP Project 12-50, Bridge Software Validation Guidelines and Examples, provides a standardized process that is useful for a host of applications in bridge engineering, specification development, and software development and maintenance. These applications include:

- A systematic method of comparing and evaluating bridge design and analysis software,
- A standardized report format for presenting and comparing results for a specific bridge design, and
- A powerful method for formally reviewing specification changes.

**Benefits**

During the research phase, important benefits were illustrated, including:
• Previously unknown errors were detected.
• Validation of programs were achieved with significantly less time and much more rigor (months of work can now be completed in hours).
• Hundreds of test problems are now economically possible, where previously only tens were used. Moreover, the problems are more robust and address all specifications as well as usual bridge configurations.
• Standardized results format will likely evolve to an industry standard.

The benefits demonstrated during the research have led to a decision by AASHTO to implement the NCHRP 12-50 process in the AASHTOWare computer software bridge products for load rating and design (Virtis and Opis) now being developed.

Design Comparisons
Using the NCHRP 12-50 methods a designer can easily compare the results of alternative computational processes. The results from the processes can be imported into a common viewer for comparison so that differences will be apparent. In the past, validation has typically consisted of producing a hand example that was computed and compared to results of the program. A typical hand example could take anywhere from several days to several weeks to complete with the product being a set of results representing a single bridge structure. Using the NCHRP 12-50 process, dozens of examples have been generated and compared in the same period of time.

In addition to the time saved in producing the examples using the NCHRP 12-50 process, a maintenance savings of the examples is also realized. Manual example problems are almost as costly to maintain as they are to produce. Changes in specifications or procedures can often lead to major revisions in the hand computations. The NCHRP 12-50 process simply requires that the automated processes be re-executed.

Specification Review
Specification writing committees can benefit by comparing different versions on a large set of bridges, to determine whether or not changes accomplish the desired objectives and to prevent problems from arising because of the changes. Similarly, bridge engineers can see the consequences of the changes on current engineering practices.

Software Validation
The cost of rigorous validation of software often runs from 25 percent of development cost and upward. It is higher for engineering-type computations that involve hand-based computations. The cost associated with improperly functioning software leading to unserviceability or collapse can be large. The NCHRP 12-50 process may be used by software developers for verification and regression testing (version testing) of their software and to reduce verification times and costs.

Product(s) Available
The preliminary draft final report is available for short-term loan from the NCHRP by contacting Mr. David Beal (dbeal@nas.edu).
For more information:
NCHRP Project 12-50 was performed by Michael Baker Jr., Inc, in association with BridgeTech, Inc. and Modjeski and Masters, Inc. For further information contact Mark Mlynarski, Michael Baker Jr., Inc., 420 Rouser Road, Coraopolis, PA, 15108-2722 (telephone 412-269-7933, e-mail mmlynarski@mbakercorp.com).
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Problem
The South Carolina Department of Transportation (SCDOT) has been tasked by the Legislature to pursue the use of waste materials in highway construction and maintenance operations. One material identified by the Department for investigation was waste shingles. It has been estimated that asphalt shingles represent the third largest source of construction waste going into landfills after wood and wallboard (ARMA, 1992). In South Carolina, 900,000 tons of construction and demolition debris are generated each year. Of this, approximately 180,000 tons are roofing shingles (Amirkhanian, 2001).

Solution
A previous study conducted by Clemson University identified several waste materials with high potential for use in highway applications and explored how they could be incorporated into the Department's work. That study recommended the use of shingles in hot mix asphalt (HMA) since shingles contain many of the same materials as asphalt mixtures. Also, a literature search revealed several research projects had been conducted by others demonstrating that shingles could be successfully incorporated into HMA.

To pursue use of the waste material, a research project was entered into with Clemson University to develop an asphalt mix design incorporating shingles into the Department's Surface Type 1C mix and to place a test section in the field for evaluation. Waste shingles were obtained from Pickens County. The specification for the shingles required that the material be 100% passing the ½ inch sieve, free of asbestos, and contain only 0.3% (by weight) debris. The resulting mix design contained 8% shingles by weight of aggregate and had an optimum binder content of 6.60% (including asphalt from the shingles). The virgin binder content of the mix was 4.20%, which is approximately 0.9% to 1.0% lower than the optimum binder content for the standard Surface Type 1C mix.

A one (1) mile section of SC Route 135, a two-lane road with 2900 vehicles per day, in Pickens County was used as the test section. The mix was placed at a rate of 200 lbs/sy. There were no problems noted with placement of the mix with shingles or with obtaining the required density of 96% of the plant lab Bulk Specific Gravity. However, there was a small amount of oversize shingle material noted in the mix from time to time. The pieces, ranging in size from ¾ inch to a few inches, were found sporadically behind the paver. The oversized pieces were easily removed from the fresh mix by hand and the area repaired with material taken from the hopper and a lute. An equivalent length section of Type 1C mix without shingles adjacent to the test section was monitored for control purposes.
As part of the initial testing on the test and control sections, cores were taken and a variety of laboratory tests performed to determine Bulk Specific Gravity, percent air voids, Indirect Tensile Strength, Tensile Strength Ratio, asphalt content, gradation, etc. No significant problems were noted in the test results though some cores tested did not meet the required 6% to 8% air voids. Friction and ride measurements were also taken on the test and control sections. Friction numbers were very good on both sections. Also, ride results on the two sections met specification requirements though the roughness measurements on the mix containing shingles were somewhat higher than the control section.

Implementation
The detailed findings of the study, including recommendations for future work, are contained in the final report for the project. As a result of this study, a Supplemental Specification, "Utilization of Shingles in Asphalt Mixtures," is included in Department contracts permitting the use of shingles in Asphalt Aggregate Base Types 1 and 2, Binder Types 1 and 2, and Surface Types 1, 3, and 4.

Benefits
The primary benefit of the research is an alternative method of using scrap shingles that would otherwise be disposed of in a landfill. Use of shingles in the Surface Type 1C mix placed in this study allowed a reduction in the amount of virgin binder normally used in the mix. The Principal Investigator made the following statements in the "Conclusions and Recommendations" section of the report: "The addition of shingles to an HMA mixture may reduce the virgin binder requirement of that mix. This could reduce the cost of the mix if the cost of the shingles is not prohibitive."

Product(s) Available
A final report was prepared for the study, SPR 586, "Field Evaluation of Use of Waste Shingles in Asphalt Mixtures," and a specification developed for use of scrap shingles in selected HMA mixes. A copy of the final report or the specification can be obtained by contacting Mike Sanders as indicated below.

For more information:
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Problem
In an effort to reduce the amount of waste materials going to landfills in the state, the Legislature passed the "South Carolina Waste Policy Management Act" in 1991. The Act requires the SCDOT to pursue the use of waste materials in highway construction and maintenance operations. In response, the Department entered into a series of research projects with Clemson University beginning in 1992 dealing with the use of waste materials in highway applications. One study identified several waste materials with the highest potential for use. Rubber, in the form of discarded tires, was identified as the state's most abundant waste material. Applications were sought to utilize waste tires in the Department's work in a safe, cost effective manner.

Solution
An interesting application for utilizing waste tires was brought to the Department's attention in February 1996 by a company making landscaping products from shredded tires. Due to budget constraints within the Department at the time, a partnership was established with Three Rivers Solid Waste Authority to purchase and place the products at five (5) rest areas and welcome centers in the Three Rivers area. The Director of the Waste Authority obtained the funds through a grant with the South Carolina Department of Health and Environmental Control's Office of Solid Waste Reduction and Recycling.

Department maintenance forces prepared the sites by removing the existing mulch and leveling areas as needed. The landscaping products placed at the test sites were made from ninety-four (94) tons of tires collected from illegal dumps in the counties included in the Three Rivers Solid Waste Authority's area. The material, placed by the manufacturer, included loose mulch varying in size, from 3/8 inch to 2 1/2 inches, and color with different shades of brown resembling pine or hardwood bark and a yellow-green tint to approximate cypress mulch. A landscaping fabric was used beneath the loose mulch as a vegetation barrier. Mats ranging in diameter from twenty-four (24) inches to sixty (60) inches were used around trees, light supports, trash receptacles, and similar objects. Edging rolls, mat material formed into strips, were used around picnic shelters in some areas. Once in place, the rubber mulch, particularly in the smaller sizes, looked exactly like traditional bark mulch.
The products were evaluated for three (3) years. The material did not deteriorate and little difference in color was noted. Attendants maintaining the grounds at the facilities liked the rubber mulch and indicated that there was less upkeep than with wood mulch. Most reported that rubber mulch stayed in place after rains better than bark, especially over time as the wood deteriorated. Also, attendants at two (2) locations said there was a reduction in bug problems with the rubber mulch around buildings. The mats remained in good condition. However, those placed in isolated areas at the facilities generally received less maintenance and many were covered with soil and grass that grew on top of the mats. One problem noted with the material is the rubber smell, particularly strong on hot, humid days. Also, summer flowers did not survive in the rubber mulch in a couple of locations probably due to the heat. No problems were noted or reported with fall bedding plants or shrubbery at any locations.

The cost of the rubber mulch is substantially higher than traditional wood mulch. However, the Department replaces hardwood mulch yearly. Based on current costs, the rubber mulch would have to last four (4) to five (5) years to be cost effective. Though in place for only three (3) years, there is no indication that the rubber mulch will not last considerably longer.

**Implementation**
The findings of the study are included in the final report with descriptions of the products used, where they were placed, costs compared to traditional wood mulch, and specific recommendations on future
High Value State DOT Research - South Carolina

use. In addition, the Department's Landscape Architect was involved in the project from the beginning
and followed progress throughout its duration allowing him to become familiar with the rubber
landscaping materials. Therefore, though the study was only recently completed, it is anticipated that the
waste tire landscaping products will be used by the Department in the future at rest areas, welcome
centers, and similar locations that are well maintained and visible to the public.

In an effort to make others aware of the material, signs were placed at each test site informing the public
of the waste tire landscaping products at the facilities. Various offices in the Department responded to
numerous inquiries from visitors to the rest areas and welcome centers concerning the material and its
availability. Interest was expressed by individuals, representatives of golf courses, municipalities, and
other states' agencies.

Benefits
The primary benefit of the research is an alternative method of using scrap tires, this state's most
abundant waste material. Though the initial cost of the waste tire mulch is considerably higher than
traditional wood mulch products, the research indicated that the cost difference is negated if rubber
mulch lasts four (4) to five (5) years, assuming wood mulch is replaced yearly as is the Department's
standard procedure. After monitoring test sites for three (3) years, the waste tire mulch was in good
condition with no indications that it would not last several more years. Also, the cost comparison did not
give any credit for use of a waste material. In South Carolina, a $2.00 disposal fee is charged the
consumer for each tire purchased. This money is placed in a trust fund to use for clean up and/or
recycling of waste tires. If a portion of these funds can be utilized to purchase the material, the waste tire
mulch will be very cost effective.

Product(s) Available
The final report, SPR 580, "Investigation of Waste Tires in Landscaping Applications," can be obtained
by contacting Mike Sanders at (803) 737-6691 or e-mail sandersmr@dot.state.sc.us

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Problem
Like many states in the northern plains and the rocky mountain west, South Dakota lacks sound, consistently applied highway access policy and procedures. Although its Office of Roadway Design has recently begun to review the South Dakota Department of Transportation's access policies, the policies date from the 1970's and do not adequately meet today's challenges. Under pressure from business and development interests, decisions are often made case by case, rather than by consistently applying a comprehensive policy. Local policies, when they exist, sometimes fail to align with state policies. The problem is further compounded in that access is a property right in South Dakota law. With the natural tendency for highway access to proliferate, communities suffer.

When access proliferates excessively, highways lose their intended function and capacity. Arterial roads, designed to connect communities, instead become congested with local traffic, leading to delays and safety problems, not only for motorized traffic but also for pedestrians and other nonmotorized traffic. Until recently, degradation of service has typically occurred in about thirty to forty years, but the pace appears to be accelerating.

The loss of capacity comes at high cost, both financial and aesthetic. Users experience delays, inconvenience, and increased vehicle operating costs. To compensate for lost capacity, government agencies add lanes, often consuming adjacent property. Costs of construction and right-of-way acquisition can be substantial. When capacity deteriorates excessively, or when no room exists for additional lanes, parallel routes must be constructed, further dissecting community neighborhoods, and at even greater cost.

Ironically, lax access policy also harms the very interests that press for it to begin with. As an arterial highway loses its capacity, traffic volume declines, causing loss of business along the route. Faced with declining volume, businesses relocate along another route, where the cycle begins anew.

Several barriers stand in the way of a sound and coherent highway access policy. Stakeholders--such as local officials, developers and business owners--sometimes lack information about the long-term effects of lax access policy and, conversely, the benefits of sound policy. Those who understand the value of consistent policy lack ways to quantify and effectively communicate the costs and benefits to others. Finally, necessary partnerships, not only between state and local agencies, but also with business and political interests, may not be sufficiently cultivated.
Research was needed to develop a policy, procedures and design guidelines for controlling highway access in rural states of the upper great plains and the mountain west, and to evaluate and document the value of sound and coherent access policy. Furthermore, the research was to produce materials that could effectively communicate with groups affected by highway access decisions, and help foster partnerships between those groups.

Solution

The objectives of the research were to:

- Develop sound policies, design guidelines, and procedures for applying the policy and design guidelines, that state and local agencies can use to control access to rural and urban highways.
- Define measures, identify sources of supporting data, and validate their ability to assess the effectiveness of access policies that are actually applied.
- Using the recommended measures, evaluate the potential value of consistent application of sound access policy at corridors and locations in South Dakota where access is proliferating, placing capacity and safety at immediate or imminent risk.
- Equip state and local agencies to educate elected officials, business communities, and regulatory staff on the benefits of sound access policy and the impacts of access policy, process recommendations, procedures.

The following research tasks were successfully completed:

- Review the highway access regulations and policies of state and local agencies in South Dakota.
- Through interviews with state and local planning professionals and officials, develop background and identify key issues related to control of highway access in South Dakota.
- Through review of current and recent literature, and through contact with other states that are geographically and demographically similar, identify concepts and techniques for controlling highway access that are applicable to South Dakota's needs.
- Develop information, based on state and regional data, to support legislation, rule making, and application of rules, citing information on accidents, costs, capacity impacts, long- and short-term economic effects on businesses, impacts on freight movements, pedestrian and nonmotorized mobility, mitigation costs, community preservation, preserving public investment.
- Draft an improved highway access policy, identifying any legislation needed to allow its adoption.
- Draft design guidelines that address criteria, spacing, and limitations on highway access based on highway's functional classifications.
- Propose a process to incorporate the recommended procedures and designs into local platting, building permit, and land use planning decisions and into state DOT reviews and approvals.
- Draft a model ordinance, consistent with the state policy and design guidelines, that local agencies can adopt with minimal revision.
- Propose practical measures, and identify supporting information sources, for assessing the
effectiveness of access policies applied at the state and local level. Assess the measures' utility by applying them to a selected sample of existing locations in South Dakota where various access control policies have been applied. Estimate how much the degradation of the arterial function costs in lost travel time, vehicle operating cost, and expenditures on infrastructure improvements and capacity expansions.

- Prepare an implementation plan for equipping state and local officials to market the access policy, design guidelines, authorization process, and model ordinance to constituents throughout the state. (The marketing effort would be funded in part from the Transportation and Community and System Preservation Pilot Program.)
- Conduct a series of regional workshops with elected officials, business leaders, developers, motor carriers, and other interests affected by highway access policy to validate the draft highway policy, design guidelines, model ordinance, effectiveness measures, and implementation plan.
- Revise the draft highway policy, design guidelines, model ordinance, and effectiveness measures, based upon the comments and direction of the technical panel as well as feedback obtained from the regional workshops.
- Prepare materials that state and local agencies can use to educate state and local business community, elected officials, regulatory staff on the benefits and impacts of access policy, process recommendations, and authorization procedures, and provide to state and local officials training necessary for their use.

Implementation
The findings of this research led to passage of legislation giving the South Dakota Department of Transportation rule-making authority for highway access management. The research also produced guidelines for design of access on new and rehabilitated highways, as well as updated procedures for handling access permit requests. The research proposed a system for classifying state highways according to allowable access, as well as model ordinances for adoption by local jurisdictions. Further, it established performance measures by which the effectiveness of access management can be evaluated. The research directly led to the Department's establishing a highway access specialist and a highway access management team of state and local representatives. The team expects rule-making to be completed by early spring 2001. Intensive outreach to developers and local jurisdictions and training for Department staff are planned during and after the rule-making process.

Benefits
In the long term, this research will lead to improved access management practices by both state and local agencies. Resulting benefits include less congestion, preservation of highway function, protection of adjacent land use and value, and reduction in intersection-related accidents statewide. Currently, such accidents account for about $36 million in property and injury damage annually in South Dakota.

In the short term, this research fostered a strong partnership between the South Dakota Department of Transportation and county and municipal governments concerned with local access control. Because of involvement on the study's technical panel and participation in workshops that were part of the research, local jurisdictions led the effort to pass legislation granting SDDOT rule-making authority for access management. This partnership will be essential to all future efforts in highway access management.
**Product(s) Available**

**For more information:**
For further information, please contact David Huft, Research Engineer, SD Department of Transportation, by phone at 605.773.3358 or by e-mail at dave.huft@state.sd.us.
Problem
WisDOT has developed strategic plans for further deployment of ITS in Wisconsin along the Gary-Chicago-Milwaukee National Priority Corridor and the Interstate Highway 90/94 corridor. Plans affect passenger and commercial vehicles and public transit systems. Business plans have been developed for specific ITS deployments, such as traveler information systems and managing incidents on highways.

As the number and complexity of ITS alternatives grow, there is a need for WisDOT to apply better methods to estimate the cost vs. benefit of ITS deployments, to identify promising candidate projects and compare them with more conventional solutions such as highway construction and expansion.

Solution
1. The investigators reviewed recent literature on ITS evaluation frameworks and emphasized the need to complement a cost-benefit analysis with a thorough understanding of the interrelationships between benefits.

The investigators developed benefit trees to show how an ITS program has effects on agencies, travelers, non-travelers, freight and transit carriers, and the general population at different levels, as well as how these levels are related. This technique can eliminate double counting and help measure non-monetary benefits such as time saved, environmental protections, reduced pollution and goodwill. Benefit trees also help distinguish between internal benefits to the user and external (or system) benefits to non-users, the economy and the community.

The investigators developed benefit trees for the following three areas of ITS technology:

- Traveler information systems,
- Incident management systems and
- Commercial vehicle operation systems.

A detailed discussion of potential benefits in each area is complemented by a summary of actual benefits as reported by several different U.S. cities that have deployed the technologies.

2. The investigators discuss the merits and limitations of the following computer-based programs for estimating ITS benefits:
They then use an adaptation of the SCRITS spreadsheet model to perform a break-even analysis of ten ITS applications likely to be implemented in Wisconsin. The break-even analysis technique indicates the level of performance an ITS application needs for its benefits to equal its costs. This method can help to identify thresholds for ITS project screening and selection. The ITS systems examined include the following:

- Ramp Metering,
- Freeway Detection Systems,
- Closed Circuit TV,
- Highway Advisory Radio,
- Variable Message Signs,
- Traffic Information Kiosks,
- Internet Traffic Information,
- Commercial Vehicle Operators Kiosks, and
- Weigh-in-motion Systems.

3. This study shows that simple spreadsheet models such as SCRITS, when supplemented with break-even and sensitivity analysis, can be adapted for use as screening tools for ITS project assessment with limited data requirements. Based on such a screening of ten potential ITS applications, key findings are:

- ITS systems can be more logically selected and deployed when knowledge of their performance tradeoffs are known.
- ITS systems can have large benefits, which easily exceed their costs. These benefits are especially likely to occur if the existing level of performance of the highway is poor.
- Other effects such as increased peace of mind, crash reduction, greater reliability in arrival times, non-traveler benefits, agency benefits and environmental benefits cannot be easily quantified but would add to the benefits of an ITS.
- Ramp metering systems benefits depend on tradeoffs between increased freeway speeds with metering vs. ramp delays and arterial speed decreases. Ramp metering projects should be concentrated on places where the level of performance of a highway facility is poor and ramp volumes are moderate.
- Weigh-in-motion systems appear to have a positive net benefit even with small levels of usage.
- Incident Management Systems should be implemented in a way to minimize incident duration. This is an area of very high potential benefits. Incident detection and traveler information
systems should be concentrated on locations where there is significant incident-related delay and where alternative routes are available.

- Internet information systems and highway advisory radio appear to have a good likelihood of favorable benefit cost ratios with even low levels of utilization because of their low costs.
- Mechanisms to disseminate real time traffic data should be actively explored to provide the best use of traveler information systems.

Implementation
The methods developed through this study, including the SCRITSUWM (University of Wisconsin-Milwaukee) spreadsheet, will help WisDOT:

- Determine conditions where application of ITS technology is likely to have favorable benefit-cost ratios;
- Program and prioritize ITS projects for the six-year State and District Highway Improvement Programs;
- Determine what data should be collected for ITS project evaluation;
- Perform life cycle cost analysis of ITS projects.

Benefits
Use of these benefits evaluation tools is expected to result in more cost effective deployment of ITS to applications that have a high likelihood of resulting in:

- Fewer crashes and fatalities;
- Faster clearance of crash vehicles and other incidents;
- Less travel time, greater predictability of travel time;
- Increased traffic throughput.

Product(s) Available
The final report, "A Framework for the Evaluation of the Benefits of Intelligent Transportation Systems," is available as an Adobe Acrobat file. A PowerPoint presentation and a paper for TRB based on the study are also available.

To download the files, go to the website of the Center for Urban Transportation Studies at the University of Wisconsin-Milwaukee: [http://www.uwm.edu/Dept/CUTS//its/](http://www.uwm.edu/Dept/CUTS//its/).

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Problem
Incandescent bulbs, when used in traffic signal devices, are prone to short life expectancy, possible insufficient lumen output, and inability to handle voltage variations and heat fluctuations.

Solution
Light Emitting Diode (LED) indications could address some concerns that arise with incandescent bulbs. The objectives of this study were to develop an evaluation methodology that would provide data comparing LED signal heads to incandescent signal heads and accelerate the implementation of LED signal head technology within the State of Missouri.

Light emitting diodes are small semiconductor chips that emit light. Measuring just 1/100th of an inch long, they are encased in epoxy to protect them from shock, vibration and environmental contaminants. Vast amounts of research have been developed by the industry in LED applications in the area of signalized intersections. The LED signal indications utilize a combination of LEDs to provide the green, green arrow, red ball and amber indications. The Institute of Traffic Engineers (ITE) has approved green and red LEDs, but the yellow or amber LED has not yet been approved at the time of this study. For an LED to receive ITE approval, it has to meet lumen and color requirements. MoDOT put this existing research and technology into a "real world" location to evaluate it.

The data collected from the test intersection shows the LED signal heads are cost beneficial as compared to incandescent signal heads. The Life Cycle Cost Analysis (LCCA) for the test intersection gave an Incandescent Bulb/LED ratio of 1.36 (using 1999 costs). The factors used in calculating the benefit to cost ratio included the life cycle, power usage, installation, materials, maintenance and repair costs. This ratio would have been even higher if the intersection had been located farther from the signal shop. The greater the distance the maintenance crews have to travel for repairs and relamping, the more expensive incandescent bulb indications become compared to LED indications. Converting to red, green, and amber LED signals should provide for virtually maintenance free signals. In addition, the ratio will continue to increase as the price of LED signals is reduced.

Implementation
LED signal indications were installed in 41 out of the 51 indications at an intersection in the Jefferson City. The intersection was monitored for 22 months for electrical use, frequency of maintenance, motorist reactions, and dependability. Based on the results of this study, MoDOT recommends using
LED signal indications in lieu of incandescent bulb indications. Until this study was undertaken, no LED signals had been used on a statewide basis. Red LEDs have been implemented elsewhere in the state and are currently in the Missouri Standard Specifications. After this study, MoDOT will implement the use of green LEDs and will include green in Standard Specifications. The Department will consider the use of amber LEDs in some locations after ITE approval.

**Benefits**
The advantages of LED signal heads to incandescent bulbs include greater energy efficiency, longer signal life, less maintenance, increased signal intensity, improved motorist awareness, and decreased long term overall cost. The implementation of red ball, green ball and green arrow LED signals would save the department at least $1 million a year after all signals have been retrofitted. Decreasing costs of LED indications and increasing power costs over time will increase the savings to the department.

The greater energy efficiency was documented with a 75% reduction at the intersection test location. Longer signal life and less maintenance have already been seen in the last 2 years. The expected life of an LED signal is projected to be seven years or more compared to one year for an incandescent bulb. Maintenance costs have been reduced by more than 90% from less outages and yearly relampings. From comments received, motorist awareness and signal intensity have increased. In addition, if the incandescent bulbs burn out the entire indication is lost whereas with LED signal heads, the loss of individual LEDs will not lead to a total loss of the indication. The only disadvantage found was the initial cost of the LED signals. However, with the above mentioned savings, and the significant drop in price over the last two years, LED signal use has many advantages.

**Product(s) Available**
If you would like to receive a full copy of the final report "Light Emitting Diode (LED) Signals Installation" RDT 99-010, please contact the MoDOT RD&T Division, or contact Jim Radmacher, telephone 573-751-0852 or email: radmaj@mail.modot.state.mo.us.

**For more information:**
Anika Careaga  
Missouri Department of Transportation  
Phone: (573) 522-1947  
E-mail: careaa@mail.modot.state.mo.us
The concrete cover over the deck's upper reinforcing mat is one of the measured attributes in the specification. Adequate concrete cover is essential in protecting the reinforcing steel from the adverse effects of environment, de-icing chemicals and traffic. Excessive cover is wasteful and can create problems as well, such as increased dead load and problems with finished grades.

Originally, a limited-production device known as a rolling pachometer was utilized to measure the concrete cover. The Department began to experience problems with the reliability of this instrument, reducing its effectiveness to unacceptable levels for use under the specification. The rolling pachometer was no longer manufactured and parts were unavailable. To allow for continued implementation of its QC/QA program, a suitable replacement device was needed.

Solution
Ground penetrating radar (GPR) was identified as an innovative and potentially effective device for measuring concrete cover on new bridge decks. NHDOT's willingness to pursue GPR technology for this purpose was enhanced by its positive experiences with GPR for determining repair quantities on existing bridges and for measuring pavement thickness in the early 1990's. The Department partnered with Geophysical Survey Systems, Inc. (GSSI) of Salem, NH to develop a ground-coupled radar system for QC/QA use. Utilizing existing hardware and software shells, GSSI created a new data processing module and produced a portable GPR unit for the required application.

The figure below shows processed data obtained from a new bridge deck using the GPR device. In the top panel, circles overlay the reinforcing steel reflection picks. The picks are located automatically by the system software through an algorithm that searches for the peak of each hyperbolic reflection in the data. In the bottom panel, horizontal position and depth to top of rebar are displayed with the results output to ASCII database.
To determine the effectiveness of the radar system, NHDOT evaluated the device under actual field conditions. It was hoped that the study would validate the use of radar as a measuring tool for QC/QA. Because future measurements could be used to compute pay factors on associated projects, and because the overall effectiveness of the program requires confidence in test results on the part of the construction community, high levels of accuracy and precision (repeatability) were essential.

The NHDOT collected GPR data from 53 locations on 12 new bridge decks and compared it to actual measurements obtained by drilling into the decks. Multiple sites and various concrete mixes were used. All decks were constructed under the Department's QC/QA specification. Radar data were collected with assistance from the manufacturer to insure correct operational procedures.

The mean difference between predicted and measured values was 1.95 mm for the study. With increased technician experience, all GPR predictions were accurate to within 3 mm of the actual measured depths. The GPR data correlated with the actual measured depths with a correlation coefficient of 0.98 and a standard error of estimate of 2.2 mm. Multiple runs with the GPR device produced a maximum standard deviation of 2.15 mm. The repeatability of the GPR test results also improved with increased technician experience.
Commercially available magnetic rebar locators (pachometers) were also evaluated. These devices are portable and relatively inexpensive. Convenience and practical features vary significantly between models. The importance of these features is influenced by the desired use. Evaluated devices lacked the necessary accuracy, precision, and reliability for use with the Department's QC/QA specification.

**Implementation**

The Department believes that the study supports the use of GPR for measuring concrete cover, and has fully implemented the technology through its QC/QA specification for concrete bridge decks. A second unit was purchased in 1999. The radar system is easy to use and was quickly mastered by NHDOT technicians. Data acquisition time is considered reasonable for the intended use. The Department's QC/QA specification was easily adapted to the use of GPR as a concrete cover-measuring device.

Contractor confidence in test results was enhanced during the study. At one site, the GPR survey revealed that the concrete cover was significantly below the limits of the specification. The contractor disputed the output, which indicated that cover depths were as low as 11 mm (7/16 inch). An NHDOT technician, with a single blow from a hammer and chisel, exposed the reinforcing steel at precisely the depth predicted by the GPR. The repeatability of these predictions was also tested under actual construction conditions when a contractor challenged the results of a survey at another site. By specification, an overall mean and standard deviation for bar depth is calculated for each subplot, which is
then input into an equation to calculate the price adjustment. A second set of measurements yielded nearly identical results, which ended the dispute.

**Benefits**

Adequate concrete cover is essential in protecting the reinforcing steel from the adverse effects of environment, de-icing chemicals and traffic. Excessive cover is wasteful and can create problems as well, such as increased dead load and problems with finished grades.

Successful implementation of this technology provides benefits to the transportation community by promoting quality, reducing variability of test results, and minimizing field data acquisition time. Variability in actual cover values observed during the study justifies the continued verification of concrete cover per the specification. An available software module for performing condition surveys on existing (older) bridge decks enhances the overall value of the GPR device to the Department.

**Product(s) Available**


**For more information:**

For more information, contact Glenn E. Roberts, P.E., Research Engineer, NHDOT, PO Box 483, Concord, NH 03302-0483, Tel: (603) 271-1660, mailto:groberts@dot.state.nh.us
Sponsored By: Pennsylvania

As society continues to generate waste and the cost of disposal continues to rise, government legislation has placed economic incentives and pressure on industry to recover and recycle these materials for use in secondary applications. Since highway construction requires large volumes of materials, the Pennsylvania Department of Transportation (PENNDOT) is interested in participating in the recycling effort.

Problem
Americans throw away approximately 280 million tires each year, which is approximately one tire per person in the United States. Around 11 percent of these tires are reused, leaving roughly 250 million scrap tires to be managed annually. Automobile tires make up 85 percent of the scrap tires to be managed each year. As many as 2 billion to 3 billion tires have accumulated over the years in numerous stockpiles. Scrap tires are managed as whole tires, slit tires, shredded or chipped tires, ground rubber, or crumb rubber products. In Pennsylvania, scrap tires are an abundant recyclable resource. At many local transportation projects in Pennsylvania, utilizing industrial co-product materials to substitute conventional soils as fill material may reduce the cost of construction.

Solution
The purpose of this research was to develop a product and material use approval process for state and local projects to utilize scrap tires as alternative to conventional aggregates and soils in embankments. As a result of this work, state and local projects will be able to take advantage of the Liquid Fuel Monies. The purpose of this document is to provide guidance on the utilization of scrap tires in embankments.

Implementation
The research recommends the following design guidelines to avoid exothermic reactions:

- Tire shreds should be utilized in construction of embankment fills.
- The gradation of scrap tires should have a maximum of 1 percent by weight passing the No. 4 sieve.
- The scrap tires should be free of oils, gasoline, diesel fuel, hydraulic fluid, grease, wood, fibrous organic matter, ice, and snow.
- Tire shreds should have less than 1 percent by weight of metal fragments, which are at least partially encased in the rubber. Tire shreds should also have metal fragments encased in rubber that does not protrude more than 25.4-mm (1 inch) from the cut edge of tire shreds on 75 percent of the pieces and no more than 50.8-mm (2 inches) on 100 percent of the pieces.
● It is recommended that tire shred embankments be built above the water table. If a tire shred embankment is to be built below the water table, precaution in the design and construction of the embankment must be taken to assure that water does not pond up in the embankment.
● To increase the stability of the slope, it is recommended that a layered system be utilized where tire shreds and conventional soils are placed in alternating layers. Moreover, to be on the conservative side, it is recommended that the tire layer should not be greater than 1 meter in thickness. This will also aid in reducing the potential for exothermic reactions.

Benefits
As a result of this work, state and local projects will be able to take advantage of the Liquid Fuel Monies. Furthermore, the use of this material will reduce the large tire stockpiles throughout the state and will eliminate between 100,000 and 500,000 tons of material in the stockpiles.

Product(s) Available
Technical Memorandum Development Of Product/Materials Use Approval For Scrap Tires For State And Local Projects.

For more information:
PENNDOT Research
The Pennsylvania Department of Transportation
P.O. Box 3789
Harrisburg, PA 17105-3789
Tel.: (717) 787-5593 Fax: (717) 783-9152
Internet: http://www.dot.state.pa.us
Sponsored By: Florida

Problem
To avoid the contamination of concrete when pouring into a drilled shaft and to improve shaft capacity, Florida Department of Transportation (FDOT) Specification 455-15.11.4 mandates that cleaning operations be adjusted "so that a minimum of 50% of the base of each shaft will have less than ½ inch (13 mm) of sediment at the time of placement of the concrete." Sedimentary deposits or any other debris at any place on the base of the shaft excavation may not exceed 1 ½ inches (40 mm). If slurry is used, it must meet the requirements of Specification 455-15.8; and the sedimentary deposits or any other debris may not exceed 1 inch (25 mm).

For the last twenty years, FDOT has employed the Shaft Inspection Device (SID) to meet these requirements (Figure 1). FDOT currently owns two SIDs, each of which carries a replacement value of approximately $485,000. Additional annual expenses are incurred for the crane and crane operator, which are necessary to deploy the SIDs.

The FDOT annually inspects approximately 200 shafts with a shaft inspection device. Each inspection takes approximately four hours. The time and cost currently involved in shaft inspection is not optimal.
In 1997, FDOT entered into a research contract with the Florida Agricultural and Mechanical University-Florida State University College of Engineering (Contract #BB-279) to investigate more cost and time effective means of conducting shaft inspections. The result was the Digital Video Boroscope (DVB), an optical device that can inspect the adequacy of the bottoms and the sides of drilled shafts. The DVB operates to a maximum depth of 300 feet.

Unlike the SIDs FDOT currently uses, the DVB is small and may be operated by one person. It is portable (Figure 2), takes only about ten minutes to set up, and may be lowered either manually with a cable winch or with a compact motorized winch. The camera may be powered by a compact internal 12-volt rechargeable battery or by an external AC power source.

A one-gallon clear water observation chamber gives unlimited inspection time over a large area at the bottom and sides of a borehole. The observation chamber is interchangeable (e.g., 6? or 8? diameter) to facilitate different viewing abilities. It also has a built-in metric scale for size proportion measurements of loose debris (Figure 3). Attached to the observation chamber is one or more calibrated, miniature, spring penetrometer(s) that can measure the thickness and the unconfined compressive strength of the bottom of a borehole.
In its first of two design modifications, a LCD display unit replaced a larger, less portable monitor. Also, two different lowering devices are available. The first is a tripod, which may be used to lower the DVB into drilled shafts that have no steel casings. The second was built specifically to clamp onto steel casings, and it utilizes a rotating rod design (Figure 4) to facilitate ease of scanning.

**Implementation**

In March 1999, boroscopes were implemented in three districts. Reports detailing functionality of the device were submitted and led to design modifications to better facilitate use. The third model incorporated these changes and is currently being tested in the field.

**Benefits**

The DVB produced the desired results: greater ease of use, and time and cost reductions. Not only is the DVB significantly less expensive, approximately $5,000 for the current model, but a single person may operate it. Utilizing the DVB, a drilled shaft inspection may be completed in approximately one hour, which may significantly expedite and increase contractor productivity.
The alternate lowering options allow for site-specific equipment use, and both tripod and rotating rod are portable. The capability to interchange observation chambers (increasing or decreasing diameter) offers the ability to tailor the DVB to the job. Also, both steel (for bottom inspection) and clear (for side inspection) cylinders are available.

In addition to reducing costs, the DVB produced a benefit that lay beyond the scope of the problem as originally defined: specifically, the ability to view the sides of drilled shafts. The DVB met the goal to decrease cost and labor to inspect shaft bottoms, and enhanced its functionality with side-view capability. The capacity for lateral views allows inspectors to detect defects in the side walls, such as bulging or off plumb placement. Side inspection will also allow inspectors to check hollow pipe piles for defects resulting from driving or splicing.

**Product(s) Available**
Research reports available upon request.

**For more information:**
For more information, contact Dr. Sastry Putcha at the Florida Department of Transportation, Construction Office, 605 Suwannee Street, Tallahassee, FL 32399. Tel. (850) 414-4148, e-mail: sastry.putcha@dot.state.fl.us
Problem
The once proud Interstate Highway System, built in the 60's and 70's, is showing signs of severe aging. The bridge decks and substructures are cracked and deteriorated and the pavements, both asphalt and concrete are failing at an ever-increasing rate due to increases in traffic volumes and loads. The State's capital program has shifted from one of new construction to rehabilitation and reconstruction. And therein lies the problem. The traveling public and the state's commerce rely on the existing network of road to travel to work and to move the goods that we all depend on for our daily lives. The rehabilitation and reconstruction programs require lane closures that disrupt normal traffic flows and cause hardships for our taxpayers.

New Jersey has some of the highest traffic volumes in the country. Taking a lane out of service for more than 10-12 hours is simply not an option. Because of this time restriction, the Department has in the past, used bituminous stabilized base course material to replace deteriorated concrete pavement joints or slabs prior to resurfacing. The practice was used as an expedient measure due to the more extensive cure time required for standard concrete materials--even high early mixtures. The resulting nine to ten inch patch was too dissimilar to the adjacent concrete and was subject to excessive rutting and shoving, requiring frequent maintenance and accelerating the deterioration of the new pavement overlay.
Solution
This study funded by FHWA and NJDOT resulted in the development of a fast track concrete material for pavement slab or joint removal and replacement. The fast track concrete material developed can achieve the required strength for opening to traffic in as little as 6.5 hours thereby mitigating the traffic delays from lane closures and greatly improving the longevity and the quality of the repair.
The Bureau of Research worked as part of a partnership with the Bureaus of Materials, Geotechnical Engineering, and Construction, and Rutgers and NJIT Universities and the Sika Corporation to develop a Portland cement concrete material using Type I cement and a hardener accelerator that can rapidly develop the necessary flexural strength. In addition, the Department utilized concrete maturity as a mechanism to estimate the in-situ concrete strength instead of the traditional cylinders or beams for early opening to traffic.

Members of the team monitored the construction operation and coordinated the laboratory and field testing of the concrete mixes. Based on the results of the field testing, the team published a construction operations procedure, a material specification, and a set of construction details, now used extensively throughout the state for the repair of deteriorated concrete slabs and joints. This research earned the team an ASCE Nova Award for innovation.

**Implementation**
The research that was started on Interstate Route 295 in south Jersey is now used throughout the state and on several county routes as well.
Benefits
The cost of the fast track concrete material is approximately 20% more than traditional concrete materials due to the amount of cement used and the cost of the accelerator, but it is a small price to pay for the mitigation of traffic delays. The fast development of strength allows the repairs to be done at night during off peak hours (9:00 p.m. to 7:00 am).

The study produced a generic Portland cement concrete material and procedure that is now routinely used for rapid repair or rehabilitation of concrete pavement joints and slabs while minimizing the lane closure time. This was a high value project for the Department that brought together the DOT, universities and industry in a strong partnership that successfully addressed a critical problem and minimized disruption for the traveling public.

Product(s) Available
The final report for the project is being prepared.

For more information:
For further information, contact Nicholas Vitillo, Manager, Bureau of Research, New Jersey Department of Transportation, PO Box 600, Trenton, New Jersey 08625-0600 [telephone: (609) 530-5966, e-mail: Nvitillo@cpm.dot.state.nj.us]
Sponsored By: Maine

Problem
As of a few years ago Maine had the most scrap tires per capita of all the states. However researchers from the University of Maine in partnership with the Maine Department of Transportation, the Maine Turnpike Authority, and Federal Highway Administration have found that the use of tire shreds in highway applications is both effective and economical. After nearly ten years of laboratory and field experimentation the engineering properties of tire shreds and the environmental impacts of using tire shreds in highways are understood. Applications in Maine now include lightweight fill, insulating and drainage layers, and as backfill for structures.

Too many scrap tires:Nationwide there are 850 million scrap tires in open piles with an additional 253 million scrap tires generated each year. The State of Maine as well as other states has millions of tires stockpiled creating a potentially serious health and fire hazard.

Inexpensive specialized engineering materials needed: Meanwhile our roads and bridges are often constructed on soft soils which challenges highway and bridge engineers. Often the solutions recommended are costly and ineffective. Traditional lightweight fill can easily cost five times that of normal weight fill. Rigid frame structures and integral abutment bridges can have lateral earth pressures that exceed normal design thresholds. Therefore these structures must be designed for increased loads which greatly increases costs. When these increased loads are not considered, long term maintenance problems arise. Fortunately scrap tires have many of the properties needed to solve these challenging problems.

Solution
After conducting laboratory studies to better define engineering properties the University of Maine in cooperation with the Maine Department of Transportation successfully incorporated tire shreds into several highway and bridge projects. Tire shreds are waste tires typically cut up into 2 inch to12 inch pieces. One cubic yard of tire shreds contains about 75 tires.

Tire shreds are used in highway applications because of their special properties. Most importantly, they have an in-place unit weight of about 50 pounds per cubic foot, this is less than half the typical unit weight for soils. Thus, tire shreds can be used to great advantage when constructing embankments on weak compressible foundations. When used as backfill behind walls and bridge abutments, tire shreds produce lower lateral earth pressures than conventional backfill. This allows for construction of thinner, less costly walls. The permeability of tire shreds is greater than 2800 feet per day, making them more permeable than most aggregate used for highway drainage applications. Moreover, tire shreds are an eight times better insulator than gravel so they have important benefits for reducing frost penetration beneath roads in cold climates.

Implementation
Highway construction projects that have used tire shreds include:

- Town Road in Richmond, Maine - 20,000 tires were used in 600 feet of road to provide insulation to limit frost penetration and to improve removal of excess water from the roadway section. This was a town project in partnership with the Army Corp of Engineers and the University of Maine.
- Two lane secondary highway in North Yarmouth, Maine - 100,000 tires were used in 400 feet of road to investigate the effect of tire shreds on pavement performance and the effects on water quality.
- Two lane primary highway in T31MD, Maine - 200,000 tires were used in 400 feet of road to investigate the effect of tire shreds on pavement performance.
- Highway embankment in Portland, Maine - 1.2 million tires were used in two bridge approach fills constructed on weak clay to improve slope stability. Use of tire shreds on this project saved over $300,000 over the next lightweight fill option.
- Backfill for a concrete rigid frame in Topsham, Maine - 100,000 tires were used to reduce lateral earth pressures on the rigid frame structure.
- Backfill behind abutment in Topsham, Maine - 400,000 tires were used to improve slope stability and reduce earth pressures on the bridge abutment.
- Highway embankment in Wesley, Maine - 300,000 tires were used as common borrow.
Over the next two years the Department of Transportation (DOT) plans to use an additional 1.2 million tires in projects. The Maine Turnpike Authority has plans for 1.3 million tires. Another project scheduled for construction this year will use tire shreds in as a longitudinal drain below a shallow ditch. This detail will save an estimated $150,000 in materials and right of way costs.

Field instrumentation and monitoring to evaluate the performance of these applications has proven invaluable. These have established the thickness of soil cover needed between the top of the shreds and the bottom of the pavement, lateral earth pressures, compressibility, and confirmed that temperatures in the tire shred fill remained at normal background levels. Proper design details and construction procedures were developed, tested, and refined on these tire shred projects.

Benefits
The benefits of the research simply stated is the recycling of waste tires in a beneficial, cost effective manner. The benefits of tire shreds as a highway construction material are its lightweight, high permeable, and ease of placement properties. On early projects, tire shreds were purchased on the open market as a normal bid item and proved to be very cost effective as lightweight fill. Recent projects have been greatly facilitated by a Memorandum of Understanding between DOT and the Maine Department of Environmental Protection (DEP). For approved highway applications, the DEP manages shredding and delivery of tires to projects. The DOT pays the contractor for installation and provides a reimbursement to the DEP for what the alternative construction material would have cost. Therefore there are no added costs to the project. This makes using tire shreds whenever practical a very cost effective solution. The DEP is able to rid the state of hazardous stockpiles of tires while the DOT is able to take advantage of a recycled material for use in construction.
Product(s) Available
Research reports, specifications, and a training manual can be obtained by contacting Dale Peabody at the address below.

For more information:
For further information contact Dale Peabody, Transportation Research Engineer, Maine Department of Transportation, State House Station #16, Augusta, Maine 04333-0016, telephone 207-287-5662, fax 207-287-3292, e-mail dale.peabody@state.me.us

Special thanks to Dana Humphrey, Professor, Department of Civil & Environmental Engineering at the University of Maine; Philip Dunn, Assistant Geotechnical Engineer, and Bruce Carter, Geotechnical Engineer, Maine Department of Transportation, for contributions to this article.
Problem
The most important roadway attribute to the traveling public in Arizona is pavement smoothness. This was recently established in a statewide survey and was previously found in the nationally conducted NQI survey of several years ago. This is not a new finding since the genesis of the AASHTO pavement design guide is the change in serviceability of a pavement surface with loading. Approximately 95% of this change in serviceability is attributable to the change in smoothness (i.e. roughness).

Ever since the AASHO road test of 1958-60, engineers have designed pavements based upon an assumed level of smoothness at the time of construction and a specified end of life roughness (i.e. smoothness). The relationships established by the AASHO road test and used in the AASHTO design procedures between road roughness and serviceability, indicate that the smoother the roadway is constructed the longer the roadway will last, all other things remaining constant. This has been the basis of structural pavement design for the last 40 years. Therefore, the most significant impact on increasing pavement life should result from constructing smoother roads initially.

In addition to providing longer lasting pavements, smoother roads have a secondary economic benefit in that user costs are reduced. In the recently completed WESTRACK research project sponsored by the FHWA, it was found that a 4.5% change in truck fuel consumption occurred as a result of the change in roughness (i.e. increase) experienced during trafficking. This vividly shows the economic impact that smooth roads can have.

Solution
In the late 1980's the Arizona Department of Transportation began an extensive research project into to developing an incentive/disincentive pavement smoothness specification for implementation into ADOT’s construction practices. The research also investigated the best methods and procedures for measuring pavement smoothness.

State-of-the-Art Pavement Profile equipment was purchased and implemented into ADOT's data collection efforts. This equipment was used to establish the current industry standards for initial pavement smoothness and to assess what smoothness levels might be possible to attain. Data collection procedures were developed to support the testing.

An incentive/disincentive pavement smoothness specification was developed for inclusion in ADOT’s construction contracts.
Implementation
Once the research had been completed and a draft specification developed, a team of agency and industry people was formed to implement the research into practice. Once the final procedures and specifications were agreed to, pilot projects were used to implement the new specifications and procedures and to refine them. These new specifications were implemented in the early 1990's.

Several times since the initial implementation the agency/industry team has met to modify and improve the specifications and procedures. Today's procedures and specifications are a result of approximately ten years of effort by the agency and industry.

Benefits
As a result of this research and the continuing efforts of the agency/industry team, the roadways in Arizona have become smoother and smoother over the last half of the past decade. Arizona now produces the smoothest newly constructed pavements in the United States. Contractors are now averaging smoothness levels for entire construction projects that were not even possible to attain at the time the research began.

The two attached plots indicate the dramatic impact on initial pavement smoothness that has resulted from this research. Figure 1. Figure 2 indicates this same occurrence, but also indicates that this has occurred even though the existing roadway conditions (i.e. before construction) have become worse due to the aging infrastructure.
Interstate Final Averages Over Time

Figure 1
Product(s) Available
Smother roads in Arizona. An improved infrastructure and reduced vehicle operating costs for the tax payers of Arizona.

For more information:
For additional information contact Larry Scofield of the Arizona Transportation Research Center @602-712-3131.
High Value State DOT Research
Performance Evaluation of Polymer Modified Asphalts

Sponsored By: Mississippi

Problem
Due to the viscoelastic properties of the material, a problem which plagues asphalt pavements is rutting, which develops because of high summer temperatures combined with heavy loading. A rut, as defined by Webster, is the formation of a recessed track, channel or furrow, worn by the habitual passage of a wheel on the surface of pavement. This channeling effect is detrimental to drainage, ride quality and ultimately the safety of the travelling public. The typical rehabilitation method for rutted asphalt pavement in Mississippi is to remove the rutted surface course by milling and replace with a new lift of asphalt.

Manufacturers of polymer modifiers claim that the incorporation of polymers with the asphalt cement binder can significantly reduce the pavements propensity to rut, thus extending the service life of the pavement and providing a safer transportation system. If additional service life can be achieved by the incorporation of polymers, then life cycle costs can be lowered, thereby allowing an overall savings in the cost of maintaining pavements.

Solution
The primary objective of this research was to evaluate the engineering properties and performance, particularly rut resistance, of dense graded hot mix asphalt containing different polymers as well as a control section containing no polymer modification. This project was constructed in July of 1996 on Interstate 55 northbound near Grenada, Mississippi in an area that had experienced unacceptably high rutting in recent years.

The experimental design called for the utilization of nine different polymer modifiers, each to be used in sections approximately 0.5 miles in length in the 1.5 inch top binder and 1.5 inch surface courses. All ten test sections (9 different modifiers & 1 control without polymer modification) are located in the northbound lanes of I-55 and have essentially the same traffic loading. Asphalt cement grade AC-20 was the base asphalt for all the modified asphalt cement binders and the control section utilized an AC-30 asphalt cement. (Note that this study began prior to the adoption of SuperPave performance grading (PG) for asphalt cement in Mississippi)

A concerted effort was made to include modifiers from each of the different chemical groups that are in widespread use for modifying asphalt binders. Polymer loading for each different polymer was determined on the basis of its manufacturer’s recommendation.
The following is a list of modifiers used in this research:

<table>
<thead>
<tr>
<th>Tradename</th>
<th>Manufacturer</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kraton</td>
<td>Shell Chemical Company</td>
<td>Styrene-Butadiene-Styrene Block Copolymer</td>
</tr>
<tr>
<td>Ultrapave</td>
<td>Textile Rubber &amp; Chemical</td>
<td>Styrene-Butadiene Random Copolymer</td>
</tr>
<tr>
<td>Novophalt</td>
<td>Advanced Asphalt Tech.</td>
<td>Low Density Polyethylene</td>
</tr>
<tr>
<td>Styrelf</td>
<td>Koch Materials</td>
<td>Styrene-Butadiene Block Copolymer</td>
</tr>
<tr>
<td>GF-80 Rubber</td>
<td>Rouse Rubber Industries</td>
<td>-80 Mesh Crumb Rubber (wet blend)</td>
</tr>
<tr>
<td>Seal-O-Flex</td>
<td>Ergon</td>
<td>Styrene-Butadiene-Styrene Block Copolymer</td>
</tr>
<tr>
<td>Vestoplast-S</td>
<td>VP-S Company</td>
<td>Ethylene Butylene Terpolymer</td>
</tr>
<tr>
<td>Multi-Grade</td>
<td>Asphalt Materials</td>
<td>Gelled Asphalt</td>
</tr>
<tr>
<td>Cryo-80 Mesh</td>
<td>Cryopolymer</td>
<td>Cryogenic Ground Rubber</td>
</tr>
</tbody>
</table>

After four years, it is obvious that all of the modified binders are providing superior rutting resistance as compared to the control binder. This validates the wisdom of using modified binders for areas of high equivalent single axle loading (ESAL).

**Implementation**

The findings of this research led to MDOT adopting Special Provision No. 907-702-6 "Petroleum Asphalt Cement and Polymer Modified Petroleum Asphalt Cement". As related to polymers, the requirements of this special provision were the following:

- Unless otherwise specified, polymer modified asphalt cement for use in plant mix bituminous base and pavements shall conform to AASHTO Designation: MP-1, Grade PG 76-22.
- Asphalt cement Grade PG 76-22 shall be the product resulting from the addition of a polymer modifier to a PG 64-22 or lower grade asphalt cement and not by some other refining technique.
- The polymer shall be a Styrene Butadiene Styrene, a Styrene Butadiene Rubber or an equal approved by the Engineer. The polymer shall be thoroughly blended with the asphalt cement at the refinery or terminal prior to shipment to the hot mix plant.
- Crumb rubber shall be produced by ambient grinding methods.

**Benefits**

Mississippi is certainly realizing substantial benefit from the utilization of polymer modification of asphalt binders. It will however take time to implement polymer modification throughout our road network. With each polymer modified asphalt pavement that is constructed in Mississippi, the service
life of the network is being extended, thus providing a more economical road network. More importantly, by reducing a pavements propensity to rut, Mississippi is creating a safer system of highways, thereby protecting her most precious resource....her people.

Product(s) Available
The Research Division of the Mississippi DOT established the following three state studies to evaluate the polymer modified field trial installation:

- State Study No. 111 "Polymer Modified Hot Mix Asphalt Field Trial" FHWA/MS-DOT-RD-99-111, December 1999. This report was authored by MDOT Research Division and details the construction and field performance of the project.
- State Study No. 123 "Evaluation of Polymer Modified Asphalts for Potential Application on Mississippi State Highways" FHWA/MS-DOT-RD-99-123, July 1999. This report was authored by The Mississippi Polymer Institute and the School of Engineering Technology at The University of Southern Mississippi and details the lab analysis of the different asphalt binders.
- State Study No. 141 "Performance of Polymer Modified Hot Mix Asphalt Pavements - An Extended Evaluation" This study is currently underway by the MDOT Research Division with cooperation from Paragon Technical Development and will document the long-term performance of the test sections.

Both State Study No. 111 & 123 are complete and have research reports available for distribution. State Study No. 141 is ongoing and a final report should be available in the spring of 2003.

For more information:
To request copies of any of the available documentation on this project, please contact:

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Problem
The AASHTO T-277 test covers the determination of the electrical conductivity of concrete to provide a rapid indication of its resistance to chloride intrusion. This is not solely due to the presence of chloride ions in the concrete matrix. Other elements, such as calcium nitrite corrosion inhibitors or aggregate with traces of ferrous compounds, can contribute to the total charge passed. This could cause results that misrepresent the actual permeability of the concrete. The question then becomes how to correct for these effects.

Solution
Studies were undertaken to develop a quantitative determination of chloride ion permeability in concrete based upon measuring the chloride ion migration in the concrete. The intent was to modify AASHTO standard method T-277 by measuring the amount of chloride ion which completely passed through a concrete specimen instead of measuring total charge as described in the method. Studies showed that more than 99% of the chloride ion does not pass completely through the concrete disk specimen, but instead, remains within the concrete disk. Evaluation of permeability by measurement of complete passage of chloride ion was therefore not feasible. However, measurement of the test cell chloride ion transferred into the concrete disk was found to be a means to evaluate chloride permeability of the concrete specimen. This enables the measurement of chloride ion permeability in grams of chloride rather than in coulombs of total charge.

The studies also showed that total charge as measured in the T-277 method is not due solely to chloride ion, but that the total charge is an accumulation of charges also contributed to by a water electrolysis background charge, and charges due to presence of other ions in the test cell solutions.

It was shown that based upon the amount of chloride ion transferred into the concrete disk, the total charge measured was always much greater than that possibly due to chloride ion alone. Based upon these findings, total charge is not a specific measure of chloride ion permeability. Measurement of chloride ion transferred into the concrete specimen appears to be a direct evaluation of chloride ion permeability of the concrete. It is actually a measure of the absorbance of chloride ion by concrete, and specifically defines the amount (by weight) of chloride ion taken-up by, or permeating into a concrete specimen.
Implementation
It is thought that the measurement of the chloride transported into the concrete specimen during the test can be used as a refinement of AASHTO T-277, where more certainty of the properties of the concrete is required. Since the determination of the chloride content of concrete is a standard test and automatic titrators are readily available to simplify the method, this could readily be put into use.

Benefits
The rapid chloride permeability test, while useful, is potentially imprecise because of the variation in factors that affect the conduction of current through the concrete. This adds another item to the tools available to characterize the resistance of concrete to chloride intrusion, without adding significantly to the time required to obtain results. It may not be necessary to have this degree of precision in all cases, but as it does not call for modifications to the method, it can be used as needed on a case-by-case basis.

Product(s) Available
The report is available, as is the manual for the automated permeability apparatus.

For more information:
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or Mike Sock @ (401) 222-3030 x4114 [email: mdsock@dot.state.ri.us]
Problem
The Kansas Department of Transportation (KDOT) requires a minimum percentage of crushed aggregate for Marshall mix designs. Minimum coarse aggregate angularity and Uncompacted Void Content (U-Value) of fine aggregate are required for Superpave mix in high-stability hot-mix asphalt mixtures. The eastern one-third of Kansas has an abundance of stone that can be crushed for coarse aggregates and manufactured sands. However, the western two-thirds of Kansas relies mainly on sand and gravel deposits or aggregates imported from other states.

Previously, the percentage of crushed material in the sand-gravel after crushing was determined by test methods relying on visual and microscopic examination of aggregate samples. Fine aggregates were tested using a microscope, which was time consuming, subjective and operator dependent. It was desirable to find a simple test method adaptable to field use, preferably related to mixture performance, to determine the acceptability of aggregate. This study had three objectives: to develop a new test method replacing the microscopic test for fine aggregate in the field; to distinguish the difference between samples of crushed material with slight contamination and blends of crushed/uncrushed samples; and to develop justifiable specification limits related to performance.

Solution
This study modified the National Aggregate Association (NAA) flow test (ASTM C1252) to determine the percentage of crushed materials. The goal was to use the modified NAA flow test, called Kansas Test Method KT-50, to replace the microscopic test for field use and determine the U-value for Superpave mixes. To begin, the percentage of crushed material of 54 samples, all typical of western Kansas aggregates, was determined by microscopic examination. The U-value was determined from NAA flow test Methods A, B and C and the proposed modification to the test. Kansas Test Method KT-6 measured bulk and apparent specific gravity. The relationship between U-value and percentage of crushed material was studied. As expected, there is no correlation in the results. This indicates, from the samples evaluated, the NAA flow test cannot detect slight changes in the percentage of crushed material. This was expected because the NAA flow test measures surface texture and angularity of the aggregate, not the percentage of crushed material.

The NAA flow test requires bulk specific gravity of samples, requiring a 24-hour soak of the aggregate, making this test unfavorable for field use. Western Kansas aggregates tend to have low absorptions and similar specific gravities; therefore, the hypothesis is as follows: apparent specific gravity, instead of bulk specific gravity, could be determined without affecting the results. This would save time and make the test adaptable to field use. In the modified test, aggregate in the calibrated cylinder was transferred to a volumetric flask and weighed. Volume of voids was determined by adding water and re-weighing. The original calculations were modified due to the substitution of apparent specific gravity for bulk specific gravity. The new formula is found in Figure 1. Figure 2 shows the original formula for determining uncompacted voids as found in ASTM C1252.
Percent void content = \( U_{1,2} = \frac{100(W_w - (V_f - V_c))}{V_c} \)

Where: \( W_w \) = Mass of water = \( B - A \), g

\( B \) = mass of flask, water and aggregate, g

\( A \) = mass of flask and aggregate, g

\( V_f \) = volume of flask (normally 200 mL)

\( V_c \) = calibrated volume of cylinder, mL

Figure 1: Current formula for determining Uncompacted Voids
Using KT-50, each sample was tested. The results indicated KT-50 and the NAA Method A flow test have similar means. To determine the significance of the similarity, the uncompacted voids were put through a one-way analysis of variance (ANOVA). Results from the experiment revealed NAA Method A and KT-50 tests give statistically similar results for the samples utilized, a confidence limit of 95 percent was established. NAA Methods B and C were found significantly different. It was determined KT-50 could be used instead of the NAA Method A flow test with less testing time.

The next step was to determine if there was a relationship between the KDOT flow test U-Value and the percent angular and rounded material in the mixtures. This was tested by mixing very angular material with differing amounts of very rounded material and finding the U-Value. The relationship was linear; however, the slopes of the regression lines appear to be dependent upon the material.

It was also investigated whether the KDOT flow test could detect contamination of natural sands, silts or clays in the samples. To test this, crushed gravel was mixed to Method A gradation; contamination materials were substituted into the mix in a series of percentages. The results indicated if 100% crushed material was used, indicated by the void content being set at an appropriately high level, the test could differentiate between crushed material and crushed material with varying amounts of contamination.

Could the KDOT flow test be associated with Gyratory Elastic Plastic Index (GEPI), a measure of mixture performance? To determine this, five percent asphalt cement by weight of the aggregate was mixed with samples with known KT-50 values.
Samples with various void contents were tested for GEPI in accordance with ASTM D3387. The results indicated mixtures with a U-Value of 46 percent or more would have a GEPI, or index of internal friction, as low as a sample of 100% crushed gravel. For the aggregates used in this study, a void content of 46 percent or higher indicated a fine aggregate with a rough angular surface texture, which performs the same as a mixture using 100 percent crushed gravel.

The last phase of this project verified the proposed specification limit of 46 percent for KT-50 for crushed gravel used in Marshall mix design projects was satisfactory. However, if NAA Method C was used, the limit would need to be lowered approximately 5.5 to 6.0 percent. An ANOVA performed on the data indicated the means of treatment and each flow test were significantly different. The study revealed the flow test could differentiate sources at a confidence limit of 95 percent.

Implementation
A special provision to the standard specification for crushed gravel was developed based on the results of this study and the test method added to the KDOT Construction Manual. Microscopic evaluation to determine the percentage of crushed material in the specifications was changed to require a minimum U-Value of 46 percent as measured by KT-50. Initially, the test method was used to evaluate crushed gravels primarily being supplied from Texas and New Mexico sources. Materials suppliers could be assured that materials delivered would meet specifications prior to shipping. KDOT field labs could confirm that stockpiles met specifications without shipping samples to the Central Lab in Topeka for microscopic evaluation by Geologists. Subsequent evaluation of fine aggregates of mixed origins (limestones and sand-gravels) being used in typical Superpave mixes confirmed that the absorption of the limestone fractions did not significantly affect the results. As a result this test method is now also being used to determine the uncompacted loose voids for Superpave mixes.

Benefits
The adoption of KT-50 and the ability to test fine aggregate in field construction labs has lead to significant time savings for KDOT and the construction industry. The KT-50 test takes about 30 minutes to complete start to finish and requires only a volumetric flask in addition to the standard flow test apparatus to perform thus is much quicker than ASTM C1252 to perform with equivalent accuracy. The KT-50 test is much less subjective and operator dependent than the previous microscopic method to determine percent crushed faces. Superpave criteria currently mandates an uncompacted void value based on depth of pavement and traffic loads. KT-50 has proven adaptable and is being used to meet Superpave design requirements.

Product(s) Available

Certification School Training Materials.

For more information:
For more information contact: Barbara J. Smith, Research Geologist, Kansas Department of Transportation, 2300 Van Buren St. Topeka, KS 66611-1195. (phone: 785-291-3848, fax: 785-296-2526, e-mail: barbara@ksdot.org).
Problem
How can success of the innovative design, construction management and financing be measured? Does a 20-year warranty really provide a benefit and savings to the Highway Department and the traveling public? Is economic growth and development related to a four-lane highway system? What are the impacts to the traveling public and communities along the route when 120 miles of highway are under construction? How will four lanes change the safety issues of the route?

These were the questions that arose when the idea of four lanes on NM44 was first proposed. To resolve these questions, monitor and evaluate the innovations being used on NM 44 the Road LIFE project was initiated.

Solution
Objective: This research project is concerned with evaluating the innovative ideas in the NM 44 highway project. Road Lifecycle Innovative Financing Evaluation (Road LIFE) will establish the model for and will assess the benefit and cost of the NM 44 innovations. Based on this assessment, the research will recommend whether or not all or some of the NM 44 innovations should be used on other projects in New Mexico and nationally. This research project is also related to smooth roads; safe transportation system; access to divided highways; adequate funding and prudent management of resources; cost-effective, quality transportation; and timely completion of construction/maintenance projects.

Scope: Road LIFE research will monitor and evaluate the innovations implemented on NM44 for the life of the warranty. Monitoring and evaluation will require acquisition of data and a procedure to manage that data. The integrity of the data must be maintained for the period of the warranty.

The Research Team will develop models to be used in the benefit/cost analysis. These models must be developed in manor that can be followed from beginning to end of the warranty, possibly 20 years.

Tasks Performed

The research team has been formed for the three primary areas of research economic, pavement and structures. The economic model work is conducted by Volpe National Transportation Systems Laboratory, Cambridge, Massachusetts. Doug Lee is the lead economist. Pavement work is conducted by the Pavement Materials Research Center, ATR Institute, the University of New Mexico, Albuquerque, New Mexico. Gordon McKeen is the lead pavement engineer. Structures work is conducted by the Bridge Evaluation Center, New Mexico State University, Las Cruces, New Mexico. Ken White is the lead bridge engineer.
Each member of the research team will develop a model for the lifecycle analysis of innovative highway investments. Data will be collected from a transportation system perspective and retained with integrity for a minimum of twenty years. Based on the model and initial data collection and analysis, there will be an annual report on the benefit/cost of NM 44.

Two advisory committees were established for the research:

- The New Mexico Research Advisory Committee (RAC). Consisting of representatives of public and private entities with a vested interest, positive or negative, in NM 44. Chaired by Max Valerio, the Engineer in Responsible Charge of the NM 44 project.
- The second advisory committee is the Road LIFE National Expert Panel. Consisting of nationally recognized leaders in various technical areas associated with NM 44. Their interest is to ensure best practice is followed in the research so the results are beneficial. The National Expert Panel chaired by Madeleine Bloom, Federal Highway Administration, Washington, DC.

The first annual report has been drafted and is in the review stage.

**Implementation**
This project will be on going for many years. However, that does not mean the findings will not be implemented for twenty years. As models progress there will be valuable information for the State of New Mexico and other states.

**Benefits**
The expected benefit through this research is the use of innovative financing to design, construct, and maintain a corridor. Economic development resulting from widening a highway and providing a safe transportation facility will be a benefit for the Highway Department and the public.

**Product(s) Available**
The first annual Road LIFE Report will be available January 2001. Contact the New Mexico State Highway and Transportation Department Research Bureau at 505-246-6446 or [http://nm44.unm.edu/RoadLife](http://nm44.unm.edu/RoadLife).

**For more information:**
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Problem
Numerous asphalt concrete paving projects on the Washington state highway system suffer from a phenomenon called density differentials, also known as cyclic segregation. The end result of density differentials is a regularly spaced, open-appearing pavement texture that can fail prematurely because of fatigue cracking, raveling, or both. Some Washington State Department of Transportation (WSDOT) pavements with this problem have lasted only half their intended life before needing repair. Fortunately, research into the causes and prevention of density differentials may improve pavement performance, and in doing so, save the state money.

To better understand the causes of density differentials, and to determine what the state could do about them, researchers at the University of Washington and WSDOT, with support from the Federal Highway Administration and The Asphalt Paving Association of Washington, analyzed 60 WSDOT hot mix asphalt (HMA) paving projects and assessed traditional quality control tests from 1998 through 2000.

Solution
Analysis showed that pavement quality is being compromised by the inclusion of cool areas of asphalt mix when the pavement is laid. The cooler mix typically does not compact to the same density as the surrounding pavement, producing pavement areas with higher air voids that make the pavement more susceptible to deterioration by traffic and the environment.

The cause of these differences in pavement density was traced to the trucks that carry the asphalt mix from the plant to the job site. A crust of cooler mix, like the skin on a pudding, forms on the outside layer of the asphalt as it is transported from the plant to the paving machine. When the truck dumps the asphalt, this crust breaks off the hotter mix and enters the paver as one mass of material. If not thoroughly remixed, this mass then passes through the paver and appears in the final pavement mat as cooler, and potentially lower density, areas. Typically, each patch of low density corresponds to one truckload of mix, thus the cyclic nature of the problem.

The researchers found density differentials on many WSDOT projects. Paving operations are complex, so no single piece of equipment or type of operation can be guaranteed to reduce differences in temperature or density. However, some things can help.
The easiest way to prevent temperature differentials is to remix the HMA before it enters the paving machine; unfortunately, not all remixing machines consistently prevent the cooler spots.

Paving during warmer temperatures can help, and using insulated or tarped trucks to maintain the asphalts heat during transport has the potential to reduce temperature differentials. Typically, the less time the mix is in the haul vehicle and allowed to cool, the lower the potential for temperature differentials.

If temperatures are still lower than desirable once the mix has been placed, good rolling and paver operation practices can help minimize compaction deficiencies.

The researchers also found that WSDOT's Quality Assurance program does not reliably reveal the full extent of the problem. Because low-density pockets typically occur in a systematic pattern, the program's random sampling cannot find them all. In a worst-case scenario, pockets of low density may be located every 75-100 ft, and lower density areas can cover up to 50 percent of the pavement.

**Implementation**

To address this problem, the researchers devised a procedure that can locate potential areas of lower density to determine the extent of the problem on any job. First, infrared imaging or an infrared temperature gun can be used to locate cooler areas. These cooler areas may be related to either aggregate segregation or temperature differentials. The ultimate concern is the density of the pavement, so these areas are then tested for density differentials with a nuclear asphalt content gauge. The result is a workable quality control procedure for paving operations.

**Benefits**

The cost savings that would result from eliminating density differentials are difficult to estimate. WSDOT paves roughly 1.5 million tons of HMA per construction season at an average cost of $30 per ton. If eliminating differences in density produced a 10 percent increase in pavement life, the improvement would amount to about $4.5 million in savings per year.

**Product(s) Available**

A technical summary of the project is found at [http://www.wsdot.wa.gov/PPSC/Research/NewsClip/Thermdiff.pdf](http://www.wsdot.wa.gov/PPSC/Research/NewsClip/Thermdiff.pdf)

A research report should be available on the following website by June 2001. [http://www.wsdot.wa.gov/fossc/mats/pavement/pave_research.html](http://www.wsdot.wa.gov/fossc/mats/pavement/pave_research.html)

An infrared image base that holds all of Washington's infrared images and project details from the 1999 and 2000 studies and Minnesota's infrared images from 2000 can be found at [http://www.wsdot.wa.gov/fossc/mats/pavement/sptc.htm](http://www.wsdot.wa.gov/fossc/mats/pavement/sptc.htm)

For a copy of the density profile procedure, please use the contact below.
For more information:
For more information, please contact Kim A. Willoughby, Pavement Structures Engineer, Materials Laboratory, Washington State Department of Transportation, Tumwater, WA. Telephone (360) 709-5474 or e-mail at willouk@wsdot.wa.gov
Problem
In the past few years, post consumer recycling of materials has gone from being desirable to mandatory in most states. Some of these materials, such as glass and various forms of plastic can be recycled back into the form which they were previously used. Materials such as rubber tire chips cannot be recycled in this fashion and other applications must be found for them. A few possibilities exist in the transportation industry and include such applications as embankment and underdrain fill as well use as a roadway subbase layer.

Currently in Vermont there are 13,862 miles of town and state highways. Only 19.4% (2,692 miles) are under state jurisdiction. The remaining 80.6% (11,170 miles) fall under the responsibility of the various towns and cities for maintenance and rehabilitation. Many of these roads are unpaved and are being subjected to greater traffic loads each year. This can render them impassable at most anytime, but especially in the late winter and early spring. Some towns can do little more than fill and grade these roads given the financial constraints of current budgets. Because of these factors, a joint decision was made by the town of Georgia and the Vermont Agency of Transportation to use waste rubber tire chips as a way to assist in creating a drainage and frost barrier in an unpaved town highway, therefore prolonging the life of the roadway.

Solution
In 1990, the town of Georgia, Vermont faced the problem of what to do with an unpaved section of Oakland Station Road. The original roadway composition consisted of approximately two feet of gravel on a silty sand subgrade. Traffic was mostly occurring during the early morning and late afternoon commute. A high water table commonly resulted in the area becoming impassable for two-wheel drive vehicles during the spring mud season. Clearly a solution was needed to help alleviate this situation.

By partnering with the Vermont Agency of Transportation, the possibility of using tire chips (nominally less than 1" in size) as a base course layer on this road began to take shape. The tire chips were designed to serve as both a drainage layer and a barrier, preventing contamination between a wet silty sand subgrade and the gravel base.

Construction of a 300 foot segment began on July 31, 1990. It included removing the existing gravel with a backhoe, removing and disposing of approximately six inches of silty sand subgrade material, and backfilling with tire chips. The chips were placed and leveled in a 9 to 12 inch course with the backhoe.
Replacement of most of the original gravel and the addition of several inches of new gravel completed the process.

An inspection of the initial test section on August 30, 1990 revealed the existence of some fine longitudinal cracks totaling approximately 63 linear feet on the surface of the gravel roadway. There was no detectable rutting in the wheel path areas. On April 3, 1991, the roadway was again inspected, with the water table elevation also being measured, using monitoring wells. The roadway surface within the test section was visibly dry and free of any rutting. In comparison, the untreated roadway north and south of the tire chip section was in poor condition. In general, the tire chip section was in better overall shape than prior to treatment.
Implementation
Another segment, 400 feet long, was constructed immediately south of the first section in July 1991. A backhoe was utilized to install two additional monitoring wells and to dig a 2 foot by 6 foot test pit in the existing tire chip section. The pit revealed 21 inches of gravel over eight to nine inches of tightly compacted tire chips. A trace of moisture was noted on the top side of the chips while the bottom side was dry. The silty sand beneath the chips contained enough moisture to form a ball when squeezed together.

A 3/4 inch macadam surface treatment was placed on the entire section of roadway in the fall of 1992. Falling weight deflectometer tests were taken on the two month old surface treatment in November 1992. The test values indicated significant deflection in the test areas. This would suggest that the tire chip layer will deflect too much under heavy loads for any future bituminous pavement to survive without additional subbase cover thickness.

The entire roadway was reexamined on August 12, 1993. Full width transverse cracks and a few random longitudinal cracks were visible in the northbound lane. A continuous longitudinal crack extended for one-half the length of the treatment in the southbound lane. All of the cracks were very fine, and stone loss was minimal.

The road was most currently examined in April, 2000. The macadam surface had been rehabilitated in 1997, and after three years, has begun to show rutting. This distress has become more pronounced in the outer wheel paths, and appears both inside and outside the experimental section. Some stone loss was evident, but overall the road itself is free draining and travelable.
Benefits
In summary, the tire chips have provided a tightly compacted subbase layer, cut off the capillary rise of subsurface water and reduced the moisture content of the gravel through proper drainage. The bituminous surface treatment placed on the initial test section revealed only minor distress through its first year of service. Rutting was evident inside and outside of the experimental test area and did not appear to be caused by the tire chips. However, falling weight deflectometer test values suggest the tire chip layer will deflect too much under heavy wheel loads for a bituminous overlay to resist cracking.

Product(s) Available

- Frascoia, R.I. Report 94-2, Tire Chips as the Base Course of a Local Road, March 1994.

For more information:
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Problem
Governmental agencies and Departments of Transportation (DOTs), in particular, as large volume users of natural and man-made materials, are also feeling the pressure to use recycled waste materials. Nationally, in 1991, the U.S. Congress passed the Intermodal Surface Transportation Efficiency Act (ISTEA) which directed the U.S. DOT and EPA to conduct studies on the reuse of recycled materials in highway construction. In a subsequent transportation bill, Congress established the Recycled Materials Resource Center (RMRC), as part of the 1998 Transportation Equity Act for the 21st Century (TEA-21) to use research and outreach to reduce barriers to recycling in the highway environment as well as to research recycled materials to improve the durability of the surface transportation infrastructure.

Similar legislative initiatives have been underway in Indiana. In 1991, the Indiana General Assembly asked the Indiana Department of Transportation (INDOT) and Purdue University to perform a feasibility study on the use six waste streams in road construction projects, including coal combustion byproducts, waste tires, ebonite materials (found in waste batteries), waste foundry sand, recycled asphalt pavement and building demolition materials. In 1997, as part of Indiana House Bill 1541, a new section was added to be Indiana Code to allow for use of Type III (~10X DWS) waste foundry sand without the need for a permit for numerous applications including embankments for airports, bridges and overpasses, various structural fills, and as a raw material in flowable fill, concrete, asphalt, brick, block, and Portland cement.

Solution
Performance of the coal combustion byproduct demonstration projects, thusfar, have indicated the bottom and commingled ashes (up to 50% flyash) performed well from a geotechnical standpoint, were well drained and easily compacted. Environmental characterizations have indicated the CCBP do not pose a significant risk, however, some restrictions relative to pH, arsenic and boron were included, as well as siting criteria near sensitive areas, are included in the special provisions. Geotechnical results of the waste foundry sand indicate WFS can perform well as a structural fill with strength and deformation characteristics comparable to natural sand, but cannot be considered as freely draining. Environmental test results indicate that the WFS have not resulted in toxicity higher than those expected from natural sands. Ion migration was found from the WFS, but at concentrations below regulatory reuse criteria. Metal concentrations were generally below Indiana regulatory reuse Type III criteria and Drinking Water Standards. Where metal concentrations in the wells exceeded regulatory criteria, exceedences appeared in both up- and down-gradient wells suggesting background metal concentrations as opposed to significant leaching from the WFS. The WFS did not result in a negative environmental impact on the site.

Implementation
INDOT, as well, has been proactively involved in evaluating various waste materials for use in transportation infrastructure. As part of this effort, five demonstration projects have been constructed using waste foundry sand and coal combustion byproducts (e.g. bottom ash and commingled fly/bottom ash) as embankment fill. Thus far, 52,000 cubic yards of waste foundry sand, 26,000 cubic yards of bottom ash and 84,000 cubic yards of commingled fly/bottom ash have been used. Demonstration projects using tire shreds as a lightweight fill, high fly ash content (e.g. 60% or greater) fill material, and cement kiln dust in soil modification/stabilization are also underway.
Demonstration projects using coal combustion byproducts (CCBP) include:
- U.S. 12 bridge project (B20590), 12,000 cubic yards NIPSCO bottom ash used as fill
- Indiana Toll Road (112 street), 14,000 cubic yards NIPSCO bottom ash used as fill
- U.S. 50, Knox Co. (R-22454), 70,000 cubic yards PSI commingled ash as fill material
- Indianapolis I465 & 56th. street bridge project (B-21496), 14,000 cubic yards IPL commingled ash as fill material

A waste foundry sand (WFS) demonstration project (R-22343) utilizing 52,000 cubic yards of fill material was constructed on County Road 206 in Dekalb County. The Auburn Foundry, a ferrous foundry, in Auburn Indiana, generated the WFS.

**Benefits**
For the demonstration projects, thusfar, waste generators have supplied their wastes at no cost to INDOT either for the waste itself or for trucking costs to the jobsite. Besides proving the feasibility of use the respective waste, the generators received benefits including avoiding landfill tipping fees and preserving public or industry owned landfill space. In the interim, it is anticipated waste materials will be allowed as an alternate material (vs. virgin materials). As such generators will have to market their waste materials, address quality control issues to make their wastes attractive for use, and be cost competitive.

Cost savings from the use of the coal combustion byproducts ranged from $4.50/cu. yd. to $14/cu. yd. The total estimated savings to INDOT, resulting from the use of CCBP versus available fill material (e.g. B-borrow), was $765,000. For the waste foundry sand INDOT's savings from using WFS in lieu of conventional clay fill was $283,436. The value of landfill space that was freed up through the reuse of the WFS was estimated by the industry at $189,656 if current landfill space was considered, and at $956,852 if new landfill space had to be obtained.
Product(s) Available
Sampling and testing protocols and Special Provisions have been developed for the use of coal combustion byproducts and waste foundry sands in transportation construction. Though primarily developed for structural fill applications (which use large quantities of the waste material), protocols and special provisions are
adaptable for other uses. In fact, INDOT, has just finished a draft specification which will enable waste foundry sands, meeting specifications, to be considered as an "approved material." INDOT specifications for use of flyash, boiler slag, steel slag, recycled asphalt and concrete, asphalt shingles, reclaimed metals, as well as recycling of other waste products have been in place by the department for some time.

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Problem
Modern transportation structures rely on weldments for structural integrity. Knowing the notch toughness of weld joints before final construction can substantially increase their quality and safety. Notch toughness is directly related to fracture toughness, which determines the tolerable size of flaws and cracks in key structural elements under load. Weld joint toughness should be at least equal to the toughness required of the structural steel. The principal quality test used to measure notch toughness is the ASTM E23 Charpy V-notch impact test.

The current AWS Bridge Welding Code plate qualification test for weldments is time-consuming, uses thick plates with backing bars, and only measures weld metal toughness. The AWS test configuration is a full-penetration weld which does not measure actual toughness of the weld joint, and is not representative of most weldments. A rapid, portable test was needed for shop and field work to measure notch toughness of partial penetration welds.

Solution
The welded notch toughness test was originally developed [1] to measure the actual impact toughness of steel weldments under typical welding conditions. Further refinements have expanded it to study other welding parameters [2]. In this new test configuration, two plates with 30° bevels; bevels are butted together in a portable, rigid test fixture. The bevels have a root face of 4-6 mm, with the two plates separated by a gap of 0.005". The root face dimension depends on welding amperage. Plate thicknesses can range up to 1.5", but 5/8"-thick plates are most commonly used to minimize machining. An alternate configuration, called the heat-affected zone (HAZ) notch test, consists of a plate with a 45° bevel butt ed up to a square-cut plate. See Figures 1 and 2 for dimensions of the fixture and test plates. Combined weight is about 10 to 15 lbs, depending on size and thickness of the plates, which can be welded in the field, shop or laboratory, using any construction welding processes. After welding, a sharp notch about 2-3 mm deep develops. Toughness specimens are then cut from the welded plates, and machined into ASTM E23 Charpy-style impact bars, using either the sharp as-welded notch or standard broached or machined V-notch.

The welded notch test specimen measures the actual impact toughness of a weldment. When a natural weld root notch is impacted, a crack front propagates and finds the zone(s) of least toughness in the weld joint. In contrast, the AWS qualification plate test only measures toughness of the weld metal, which typically has a greater toughness than the fusion zone, heat-affected zone, or the steel itself. The AWS
test gives the illusion of high toughness, because it does not always measure the integral toughness of the zones of true vulnerability.

The welded notch toughness test has many advantages, including speed of testing, portability, high levels of restraint, and minimal machining. The welded notch test permits fabricators to evaluate or qualify the effects of different welding variables on weld joint toughness at various temperatures. Typical variables are type of electrode, voltage, amperage, travel speed, stress-relief treatment or preheat. An example of the marked difference in toughness of as-welded vs. stress-relieved submerged arc welds is shown in Figure 3.

The welded notch toughness test also provides information about the weld joint and the weldability of different steels, including (a) weld penetration and fusion; (b) presence of inclusions and voids; (c) the heat-affected zone; (d) strength and ductility of the joint; and (e) measurement of the actual toughness of two dissimilar steels welded together. Examples are ASTM A36 structural steel joined to AISI 304 stainless steel or AISI 8620 or 4130 alloy steels. (unable to post figures at this time - please contact Chris Hahin as noted below if interested.)

Implementation
The welded notch toughness test has been used in many construction projects and by several large fabricators, government agencies and research organizations who appreciated its simplicity and low cost. Users include Vincennes Steel of Vincennes, IN and Stupp Bros. of St. Louis, MO, for submerged arc welds; by X-Tek of Cincinnati, OH for evaluation of flux-core arc welding of dissimilar steels used in gears for movable bridges; by the US Army Corps of Engineers for evaluation of gas-metal arc welds; by Northwestern University for welding qualification of a new as-rolled, high performance structural steel produced by Oregon Steel; and by Youngberg Industries of Belvidere, IL in the fabrication of new 12-ft. diameter sheaves for the Shippingsport Vertical Lift Bridge over the Illinois River.

Benefits
The welded notch toughness test finds the zone(s) of lowest toughness in an ASTM E23 impact bar, using actual sharp notches formed in weld joints cut from 5/8" or thicker test plates.

The test has been used with manual arc, submerged arc, flux-core and gas-metal arc welding. The test fixture is portable and has been used in shop, field and lab environments, and is far less costly and time-consuming when compared to the standard AWS plate qualification test.

The welded notch toughness test can provide valuable insights on how various electrodes, welding parameters, and job-site conditions affect the weld joint quality and integrity of structural steels.

Product(s) Available
Two product reports are available, and a technical manual for users is in preparation.

For more information:
For further information, please contact Christopher Hahin, PE, the principal investigator, at the Illinois Department of Transportation, Bureau of Materials and Physical Research, 126 East Ash St., Springfield, IL 62704. Telephone: 217-782-0574; FAX: 217-782-2572; e-mail: hahinc@nt.dot.state.il.us.
Problem
Urban pavements are subject to points of high stress concentration due to the presence of numerous utility and drainage structures. Figure 1 shows a typical joint detail for a PCC pavement containing a catch basin with isolation joint and a telescoping manhole. The joint systems for the catch basin provide isolation from the surrounding pavement, but not load transfer, while differential slab-support may exist at the manhole. Unless addressed, these conditions will inevitably cause premature cracking of pavement slabs. To eliminate the potential for pavement cracking, a research study was conducted to develop new design details for urban PCC pavements.

Solution
Finite-element analyses (FEA) were conducted on a typical joint detail to calculate critical stresses for the combined effects of environmental and traffic loading and to evaluate effects of utilities structures and differential support on rigid pavement performance. Typically, a 2.2 by 2.2 m square concrete structure rests about 500 mm below the pavement surface. A manhole is placed at the center of this structure. This structure presents several different marginal support conditions for pavement slabs. The portion outside the manhole is a rigid area that is practically incompressible. Because of changes in support conditions, base material near the perimeter of the structure is susceptible to settlement,
resulting in some loss of support under concrete slabs. Support conditions for pavement slabs over such structures thus could vary from very weak to normal to extremely rigid. Depending on placement of the structure and load locations, very high stresses may develop because of the discontinuous support conditions. Results from the FEAs show critical stresses in the range of the concrete modulus of rupture, explaining failures at many typical utility layouts.

Based on the FEA results of typical design, several factors were identified as contributing to high critical stresses: 1) notches in the pavement slab for catch basins; 2) transverse isolation joints at the catch basins, providing no load-transfer capacity and increasing top tensile stresses under negative gradient; 3) the longitudinal isolation joints that increase bottom tensile stresses under positive gradient; 4) locations of manholes with respect to catch basins; and 5) length, aspect ratios (width/length), and thickness of slabs containing manholes and catch basins relative to adjacent slabs. All these factors contribute to cracks developing in urban PCC pavements.

To avoid these high stresses, new slab details were proposed and analyzed. These include isolating catch basins without pavement panel notches, and using longitudinal shear keys and expansion joints with dowels at the catch-basin transverse joints. Also, a varying offset distance "D" between a catch basin and a manhole centerline required detailed modification to accommodate proper transverse joint and utilities alignment. For structural design purposes, support was considered non-uniform with hard and soft spots. Note that a telescoping manhole is best located at the center of the pavement slab where movement is minimal. Figure 2 shows a slab 3.5 m long with a catch basin and telescoping manhole, and an offset "D" less than 300 mm. Also developed were details when the "D" distance is larger than 300 mm and less than 3.5 m, and details when offset "D" distance is 3.5 m or larger, but less than 7 m. A transverse expansion joint is provided at each end of the catch basin, while an untied longitudinal joint with a shear key serves as the front face of the isolated area. This joint system provides isolation from the surrounding pavement as well as load transfer.

**Figure 2. Catch Basin and Telescoping Manhole with and offset distance “D”**

![Figure 2](image)

**Implementation**
Several cases investigating the effects of isolating catch basins on critical stresses of both the slab
containing the manhole and the adjacent slab were conducted using finite-element analyses. Results showed a slab length of 3.5 m with an aspect ratio 1.37 should work for slabs containing the manhole. The slab length containing the manhole was fixed at 3.5 m and cases were analyzed under positive and negative gradients with varying offset distances "D." Results show that slab length between 3.5 and 5.5 m should work for the adjacent slab with varying thickness between 250 to 325 mm depending of the traffic loading. Figure 3 shows a conventional catch basin resulting in high stresses and catch basin details that were developed providing isolation and load transfer. Details were developed for various combinations of catch basins and telescoping manholes, and catch basins without manholes. Details vary depending on the offset distance "D" between the catch basin and manhole center lines. They are now being incorporated into NYSDOT's standard detail sheets for urban concrete pavements. This will result in a smooth, long-lasting pavement for the traveling public--a high potential payoff for the research effort. This technique is being used in a reconstruction project, covering 8 km of Route 9A along the Hudson River in New York City from Battery Place to West 59th Street.

**Figure 3. Conventional Catch Basin Isolation and New Catch Basin Details**

**Benefits**

New York State Department of Transportation believes these new pavement design techniques for urban paving will produce higher-quality, longer-lasting pavement structures. These techniques should also reduce future maintenance and traffic disruptions, and provide long-term economic benefits, particularly for high-volume roads. Depending on the number of utilities and the complexity of the joint layout, this technique has the potential to extend the service life of pavements by 15-30 years, resulting in a significant savings for the Department and the traveling public.
Product(s) Available
NYSDOT Standard Detail Sheets are available by contacting the New York State Department of Transportation at:

NYSDOT Plan Sales
Building 5, Room 109
1220 Washington Avenue
Albany, NY 12232-0244
(518) 457-2124

For more information:
For more information about this research contact Julian Bendana at (518) 457-5826.
Problem
The Georgia Loaded Wheel Tester (LWT) is an economical and effective tool that has been used by the Georgia Department of Transportation (GDOT) and others to assess the rutting potential of asphaltic concrete mixes. By subjecting asphaltic concrete to a wheel load under repetitive loading conditions and measuring the permanent deformation induced under the wheel path, the rutting susceptibility of the asphaltic concrete may be determined. This approach closely simulates actual field conditions. The use of loaded wheel type testing can provide a fast and accurate means of predicting rutting at both the design and production stages of the mix.

In order to perform loaded wheel tester research, there was a need to develop an apparatus that could accomplish the testing. In 1985, when the GDOT began considering this approach, Georgia Tech was contacted to assist in the development of a machine that would meet GDOT's needs. During the preparation for this development work, it was decided that the Benedict Slurry Seal Tester, already in use by GDOT, could be modified for this purpose.

Asphalt mix design procedures are concerned only with the volumetric properties of the mix. These mix design procedures do not make use of proof testers to predict the performance of the mix in the field. There was a need for a device to predict rutting which is a common type of asphalt pavement distress in Georgia.

Solution
GDOT initiated Research Project No. 8503, "Development of a Simplified Test Method to Predict Rutting Characteristics of Asphalt Mixes" intended to accomplish the initial development of the Georgia LWT. One of the primary aims of this research was to evaluate a modified LWT's capability in predicting rutting tendencies of asphalt mixes. Initial testing concentrated on the three variables thought to be significant in potential rut development, tire pressure, testing temperature, and load.

Modifications were made to the Benedict Slurry Seal Tester converting it to a wheel-tracking device. Its original hard rubber wheel was replaced with a 3-inch diameter aluminum wheel attached to the reciprocating arm of the machine. A linear tube made of high-pressure rubber capable of maintaining pressures up to 120 psi was used to simulate tire contact. This tube was placed on the surface of an asphaltic concrete specimen and inflated to the desired pressure with static weights added to apply a load.
The modified loaded wheel tester developed under this research project demonstrated it could be successfully used in evaluating the rutting potential of asphaltic concrete samples. This study also showed that the modified loaded wheel test is relatively simple to perform in a laboratory environment.

GDOT Research Project No. 8717, "Development of a Laboratory Rutting Resistance Testing Method for Asphalt Mixes," was begun to make the loaded wheel tester a portable, self-contained unit. The objective of this study was to modify and improve the apparatus, fine tune sample preparation, and develop a standard testing procedure. Improvements and modifications made to the LWT included the development of an environmental chamber to house the machine and maintain a constant elevated temperature testing environment, a preheating box for pre-conditioning test samples to prescribed temperatures, and minor modifications to the controls and operation of the testing apparatus. Sample specimens were prepared using static compaction via compression test machine.

The Modified Georgia Loaded Wheel Tester is a triple track tester built by Georgia Tech. It is more automated, with the capability of testing three samples simultaneously, and allows better control of testing temperature. A commercial version of the Modified Georgia LWT is now being produced by a local manufacturer. Sample size was increased to a 5-inch width for testing large stone base materials. A mold that could be used with SUPERPAVE Gyratory Compacted samples was later developed as shown below.

**Implementation**
In 1989, GDOT implemented LWT testing on a routine basis for interstate projects and other state routes. Experience with the LWT helped in developing GDT-115, "Method of Test for Determining Rutting Susceptibility Using the Loaded Wheel Tester." The GDOT Standard Test method defines the beam preparation procedure, beam testing procedure, and specifies a maximum rut depth allowable.

**Benefits**
The LWT can give an indication of the rut susceptibility of a mix for a relatively low cost and can be used in conjunction with the SUPERPAVE mix design specification criteria. The SUPERPAVE design system uses complex performance prediction models based on various combinations of asphalt binder and mineral aggregate to predict pavement performance. The system evaluates three primary pavement distresses: permanent deformation (rutting), fatigue cracking, and low temperature cracking.
Rutting and fatigue cracking are the two primary pavement distresses found in Georgia. Using the SUPERPAVE system (Levels 2 and 3) it is possible to individually analyze the magnitude of each distress type relative to the proposed ESAL loading for a planned pavement. SUPERPAVE generated data also allows a comparison between low temperature cracking and proposed pavement life (in years). This information can enable the asphaltic concrete designer to make more accurate design decisions. This method, however, requires complex testing and is both labor and equipment intensive. The LWT, on the other hand, is a practical, easy to use, and relatively inexpensive "proof tester" which can be used in conjunction with the SUPERPAVE system at all levels of design.

GDOT worked with the Georgia Tech to develop a test method with the LWT utilizing asphalt specimens prepared with a SUPERPAVE Gyratory Compactor (SGC). SGC samples can be tested with the Georgia LWT in essentially the same manner as the typical 3"x5"x12" beam but using a modified sample holder.

A commercial version of the Georgia Loaded Wheel Tester called an Asphalt Pavement Analyzer (shown below) is being produced by a local manufacturer and has been sold in most every state and many foreign countries.
Product(s) Available
Final Reports from Research Project No. 8503, "Development of a Simplified Test Method to Predict Rutting Characteristics of Asphalt Mixes" and Research Project No. 8717, "Development of a Laboratory Rutting Resistance Testing Method for Asphalt Mixes" are available as well as GDT-115 Test Method for LWT.

For more information:
Please contact Rick Deaver at 404-363-7584 or e-mail rick.deaver@dot.state.ga.us
Sponsored By: Minnesota

Problem
In regions of the United States where pavements are constructed in freeze-thaw environments, spring load restrictions (SLR) are typically used as a preservation strategy. During the spring, pavement layers are generally in a saturated, weakened state due to partial thaw conditions and trapped water. The critical time for SLR is when the pavement first thaws and the stiffness of the base layer is low. Thus, proper measurement and prediction of freeze-thaw events is crucial to a successful load restriction strategy.

A Task Force developed the past SLR procedure practiced by the Minnesota Department of Transportation (Mn/DOT) in 1986 [1]. The procedure for load restriction placement involved monitoring:

- conditions that indicate the potential for spring load-related damage, such as movement and seeping water near cracks,
- thaw depth measurement using frost tubes or probe rods in shoulder, and
- weather conditions and forecasts.

The guidelines for lifting the load restrictions were to be based in part on deflection measurements. However, it has been found that basing the end of SLR on deflection measurements was not practical due to the large amount of roads that needed to be tested on a weekly interval.

The state of Minnesota places SLR by zones (Figure 1). Once the District Engineers agreed that SLR should be placed in a certain zone, the public was given a 7-day notice. Unfortunately, in some cases, SLR were placed 7 to 10 days too late. The damage results in additional direct costs to the State of Minnesota and to local units of government due to premature maintenance and reconstruction. In addition, there are user costs associated with vehicle damage, increased travel time due to pavement condition, and lost time due to construction detours.
In the past, the duration of the SLR would vary each year depending on roadway conditions. Table 1 shows the average placement and removal dates and duration of SLR in Minnesota. The typical duration of the SLR was 7 to 9 weeks.

<table>
<thead>
<tr>
<th>ZONE</th>
<th>ON</th>
<th>OFF</th>
<th>DURATION, weeks</th>
</tr>
</thead>
<tbody>
<tr>
<td>South</td>
<td>9-Mar</td>
<td>8-May</td>
<td>9</td>
</tr>
<tr>
<td>Southeast</td>
<td>10-Mar</td>
<td>10-May</td>
<td>9</td>
</tr>
<tr>
<td>Metro</td>
<td>12-Mar</td>
<td>29-Apr</td>
<td>7</td>
</tr>
<tr>
<td>Central</td>
<td>14-Mar</td>
<td>9-May</td>
<td>8</td>
</tr>
<tr>
<td>North</td>
<td>18-Mar</td>
<td>17-May</td>
<td>9</td>
</tr>
</tbody>
</table>

**Solution**

The study evaluated the past SLR policy and recommended changes for improvement. This included developing improved predictive equations for estimating when to place SLR.

The first step involved review of previous research concerning the placement and removal of SLR. The Washington State Department of Transportation (WSDOT) developed a thawing index equation based on air temperatures [2, 3, 4]. In this procedure, it is recommended that restrictions are placed once the cumulative thawing index (TI) reaches 15 to 30°C-days (25 to 50°F-days). The equation used to compute TI is:

\[
TI = \text{Summation of (Average Daily Temperature} - \text{Reference Temperature})
\]
It was found that adjusting the reference temperature improved the spring-thaw prediction. The revised Mn/DOT equation uses a reference temperature that changes 0.56°C (1°F) per week during February and March. This relationship is the result of increased solar radiation as the sun moves higher in the sky.

Researchers then compared the posting dates predicted using the new technique to historical posting dates from 1986 through 1998. As mentioned, there was typically a week or more delay from the time that SLR should have been placed until restrictions were actually posted. This delay caused damage that could have been prevented.

The predicted and actual SLR placement dates were compared to falling weight deflectometer and in situ instrumentation readings at the Minnesota Road Research Facility (Mn/ROAD). The FWD results from the low volume road at Mn/ROAD show that the deflections increase dramatically as the thawing index reaches 15 to 30°C-days (25 to 50°F-days). The deflections also show that, for roads with plastic subgrade soils, the recovery is long and continues to improve slowly throughout the entire summer.

Implementation
As a result of the research, Mn/DOT adopted a new method to improve the procedure for placing SLR. In February 1999, Mn/DOT issued a technical memorandum, which provides a uniform statewide procedure for determining the dates that SLR will be placed and removed on the Minnesota Trunk Highway System.

As part of that procedure, districts submitted their restricted roadway segments and Mn/DOT mailed the road restriction map in January or early February, along with an explanation of the new procedure for notification of postings. In addition, Mn/DOT established a toll-free telephone number and used the Mn/ROAD web site to provide information on postings in each frost zone as quickly as possible.

The current Mn/DOT policy uses actual and forecasted average daily temperature to determine when SLR should be placed. The duration of the SLR is fixed at eight weeks, which allows the transporters to plan for the end of SLR.

Mn/DOT fully implemented the new procedures in spring 1999. The change also impacts county, township, and municipal roads, which also follow the Trunk Highway system SLR.

Benefits
Mn/DOT estimates that a typical low volume asphalt road's life will be increased by about 10 percent due to implementation of the improved SLR procedures. The potential cost savings resulting from improved load restriction placement are expected to be substantial, impacting about 39,000 miles of paved roads that do not meet the 10-ton spring load design standard. The vast majority of these roads are paved with asphalt concrete, which has an annual construction and overlay cost of about $12,000 per mile per year, resulting in an approximate annual savings of more than $10,000,000.

In Minnesota, SLR impacts many more miles of the county, township and municipal systems than the state trunk highway system. The percentage of trunk highways subject to SLR is approximately 13 percent of the 11,900 miles of the state network. On the other hand, out of 30,300 miles of the total County State Aid Highway (CSAH) system, only 3 percent are 10-ton or greater, and thus, 97 percent are subject to SLR. County, township and municipalities are required to follow state recommendations on load restriction posting and removal dates.
Through research, we are better able to predict when the spring-thaw weakening will occur using air temperatures currently recorded and forecasted for most areas of Minnesota. Besides benefiting the local road network, the research results also are applicable to Minnesota's Trunk Highway system for at least two reasons. First, Mn/DOT currently allows a 10 percent load increase during the winter when the ground is frozen. This 10 percent load increase should be removed before any anticipated weakening. Second, Mn/DOT is asked to grant special overload permits for some unique loads. The correct application of these two policies requires knowledge of the strength of the roadway during the winter and spring to prevent excessive damage.

Cooperative research between the Minnesota Department of Transportation, other state DOTs and several Canadian provinces continues to be important to further quantify the benefits and costs of SLR to the infrastructure and the economic transport of materials.

**Product(s) Available**
Mn/ROAD has written three papers about SLR, and a final report is also being drafted:


These can be obtained by contacting the Minnesota Department of Transportation, Office of Materials and Road Research, 1400 Gervais Avenue, Mail Stop 645, Maplewood, Minnesota 55109 (651) 779-5500 or by contacting any of the individuals listed below.

**For more information:**
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High Value State DOT Research  
PCCP Texturing Methods  

Sponsored By: Colorado  

Problem  
Surface texture in rigid pavements plays an important role in providing safety (providing skid resistant surfaces) for the travelling public. The depth, spacing, and orientation (transverse or longitudinal) of the surface texture can significantly affect the quality of ride. Questions have been raised regarding constructability, cost, and the performance of various surface textures in rigid pavements:  

What are the impacts of various texturing methods on the frictional characteristics, noise properties, and on the overall ride quality of rigid pavements?  

What is the most cost-effective texture that provides adequate friction without excessive noise, ride quality, or durability problems?  

How does performance compare for: longitudinal vs. transverse, randomly spaced vs. uniformly spaced and macro vs. microtexture on concrete pavement friction and noise?
Solution
In an attempt to answer these questions, CDOT engineers in cooperation with FHWA devised an experimental design to evaluate various surface textures and to identify the best performing surface texture that is cost-effective, minimizes tire noise, and provides adequate frictional characteristics.

To meet the objectives of this study, and base on the recommendations of the study panel, nine test sections with various textural characteristics were selected for evaluation:

1. 1-inch uniformly spaced transverse tining (state standard)
2. Transverse astro-turf
3. Random transverse tinning with
4. ½-inch uniformly spaced transverse tinning.
5. Random grooving (sawing)
6. 1-inch uniformly spaced preceded with longitudinal astro-turf
7. ¾-inch uniformly spaced longitudinal grooving
8. Longitudinal astro-turf
9. ¾-inch uniformly spaced longitudinal tining

Frictional characteristics of the individual test sections were evaluated using the ASTM E 274 skid testing procedure. Both ribbed-tire and smooth-tire friction tests were conducted at three different speeds of 40, 50, and 65 mph. To examine the noise properties of the test sections, noise measurements, based on the A-weighting scale and 1/3 octave bands, were taken:

- Inside the test vehicle
- 25 feet from the center line (3 feet from the edge of the shoulder)
- Near the right rear tire of the test vehicle

Cost and easy of construction, rideability, and durability were also monitored.

Implementation
Based on the results of this study, CDOT has adopted the longitudinal tining as a preferred method of texturing concrete pavements since 1997. The lower noise of the longitudinal tining was so much appreciated by the public that, based on public outcry, CDOT is planning on filling in the transverse tining in a sensitive area and installing longitudinal grooves.

Benefits
The results of this study indicated that longitudinal tining, in addition to possessing adequate frictional properties, provides the following advantages over the traditional CDOT’s standard transverse tining:
- Lower noise level
- Ease of installation
- Lower costs

Product(s) Available
PCCP Texturing Methods
Report No. CDOT-DTD-R-00-01

For more information:
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Em: ahmad.ardani@dot.state.co.us
Sponsored By: Pennsylvania

The purpose of 2000 Summer Transportation Institutes is to decrease the knowledge gap about transportation opportunities by lifting students to a higher level of awareness, understanding, and knowledge of the industry.

**Problem**
The knowledge gap about job opportunities in transportation, as in other sectors, is generally wider for minorities. The transportation sector needs to increase the size, quality, and diversity of the pool of potential transportation professionals and technicians. Exposing students to the latest developments in transportation-related technology can encourage them to consider the transportation sector as a career choice.

**Solution**
The Cheyney University of Pennsylvania hosted the 2000 Summer Transportation Institute (STI) from June 25 through July 21. This is the second year that Cheyney hosted the STI. The program was residential through the weekdays for high school students. Twenty-two students, 12 males and 10 females, from and around the Philadelphia area completed the program. The staff consisted of seven university faculty from four departments and three students, who served as resident counselors for the program.

The curriculum was centered on different modes of transportation and the career opportunities in the transportation industry. It consisted of classroom lecture, video, computer activities, hands-on activities, individual project and group project, field trips, and speakers. All the activities focused to broaden the concept of transportation, introduce some basic scientific concepts in interactive ways, its history, its importance in modern life, careers in transportation, skills and educational preparation required to pursue such a career.

**Implementation**
Increased outreach to potential students should be made. Personal connection with people proved to be the most effective method of recruiting students. Cheyney students will be asked to identify prospective STI students for the 2001 STI. Personal involvement with schools and personal acquaintances of some of the faculty was the most successful effort in recruitment. A limited success was achieved in the method to involve all Cheyney faculty and staff by the STI. The Cheyney STI and Lincoln STI, with PENNDOT's assistance, are also planning on joint recruitment effort for their institutes.
Benefits
To broaden the concept of the transportation industry to minorities, introduce some basic scientific concepts in interactive ways, its history, its importance in modern life, careers in transportation, skills and educational preparation required to pursue such career.

Product(s) Available

For more information:
PENNDOT Research
The Pennsylvania Department of Transportation
P.O. Box 3789
Harrisburg, PA 17105-3789
Tel.: (717) 787-5593 Fax: (717) 783-9152
Internet: http://www.dot.state.pa.us
Sponsored By: Pennsylvania

Lincoln University served as a host site for the Summer Transportation Institute (STI) for the second year in a row. The goal of the STI was to increase knowledge about career and job opportunities in transportation.

Problem
The 1999 STI created awareness among participants and their families about traditional and non-traditional occupations and careers in transportation. The 2000 STI strengthened that awareness. However, educating secondary students, especially minority students, so that they will rationally seek and choose careers in transportation is a process that may take several years of sustained STI effort.

Solution
The objective of the STI is to offer secondary school students early exposure to career types in transportation and to engage them, during the summer, in activities that are both educational and recreational.

Twenty students participated in the four-week residential program at Lincoln University. The program activities consisted of 10 field trips to interesting transportation sites mostly in Pennsylvania, 13 guest speakers from the transportation industry and agencies, projects that promoted hand-on learning and teamwork, and educational and recreational activities on campus.

Implementation
Basically, the objectives of the STI program are fourfold: to (a) offer students early exposure to both the traditional and emerging career types and training requirements in transportation; (b) engage students in rewarding educational activities during the program; (c) provide enjoyable recreational activities during four weeks in summer; and (d) have students consider careers and professions in transportation at all stages of the educational process.

Benefits
To broaden the concept of the transportation industry to minorities, introduce some basic scientific concepts in interactive ways, its history, its importance in modern life, careers in transportation, skills and educational preparation required to pursue such career.

Product(s) Available
For more information:
PENNDOT Research
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P.O. Box 3789
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High Value State DOT Research

Intermodal Management Coordinator Train-the-Trainer Course

Sponsored By: Pennsylvania

The Pennsylvania Department of Transportation's (PENNDOT) established policy direction is to advance intermodal and multimodal transportation throughout PENNDOT's central and district offices. Designating intermodal coordinators in each of PENNDOT's 11 engineering districts has organizationally advanced this direction. Because PENNDOT works so closely with the state's regional planning agencies (MPOs and LDDs), a similar position/responsibility has been defined for these agencies. Job descriptions for both the PENNDOT and the MPO/LDD intermodal coordinators have been developed.

Problem
The purpose of this program is for PENNDOT and its regional partners to recognize a need for capacity building with the intermodal coordinators and other personnel in their organizations. With this training and hands-on resources to more effectively execute their responsibilities, the coordinators will be better positioned to carry out their defined responsibilities.

Solution
This project is a training and development priority for PENNDOT. The core methodological challenge was to ensure that training materials were developed in sync with job performance requirements. This was accomplished through the development of a Requirements Analysis report (December 2000). PENNDOT desired to develop a curriculum for appropriate training and associated resources. The course development occurred through a series of logical tasks, including the requirements analysis that defined the core competencies required to effectively carry out the intermodal coordinator duties. The requirements analysis was the springboard for developing the course content: lesson plans and a resource or job book that provides a user-friendly day-to-day working reference for those who participate in the training. Moreover, the lesson plans and the job book have been designed to be modular to meet a variety of needs, formal and informal, as well as to be easily updated.

Implementation
The nature of this project did not result in any recommendations. Future considerations were identified as part of the project closeout project and are described in this section. They do not represent in any way PENNDOT decisions or adopted actions.
PENNDOT, in partnership with its regional planning partners, may want to consider the following post-pilot considerations:

- Develop a specific strategy for dovetailing continuous improvements and refinements to the existing pilot product (i.e., job book, CD, exercises, presentation/lesson plan, field view, etc.) over that same 12 months.
- Develop a customized version of the product for each PENNDOT district-or along some other "boundaries" that make sense vis-a-vis the regional planning partners' involvement too.
- Determine which process items in the book are most worthy of PENNDOT-wide implementation through district four-year business plans or other processes.
- Retain Intermodal training/implementation of the course concepts as a standing item with Regional Planning Partners for the next year or two.
- Begin to identify a longer-term curriculum strategy and topics with the Transportation University to build on this "101" type course.
- Present a status report on this initiative to senior management forums and DE meeting in particular.
- Develop an abbreviated version for use in PENNDOT new employee orientation.
- Present this course to a combined group of modal customers.
- Consider the opportunity for incorporating some of the concepts and applications in the course with annual organizational and individual goal setting.
- Establish a PENNDOT intermodal recognition program to reinforce some of the exciting things that are taking place and to promote organization-wide emulation.
- Determine what opportunite changes can be made to the project development process to constructively address some of the opportunities covered in the course.

PENNDOT should consider forming an intermodal work group with a representative from each mode, a district, a county maintenance operation, and the Bureau of Design. The purpose of the work group would be to guide the implementation of any initiatives such as those listed above. The work group could report to a higher-level policy type group that would not only consist of more senior management, but potentially regional planning representatives and modal customers.

**Benefits**
A better defined and more effective system.

**Product(s) Available**
Technical Memorandum Intermodal Management Coordinator Train-the-Trainer Course

**For more information:**
PENNDOT Research
PO Box 3789
Harrisburg, PA 17105-3789
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Problem
In recent years many states have been overwhelmed by a sharp increase in demand for these permits. For example, the State of Tennessee has seen average annual increases of almost 9% in the number of permits issued between 1991 and 1997. Unfortunately, the staff resources needed to accommodate this demand have not grown at a comparable rate. Several factors have worked in combination to cause a marked growth in permit vehicle traffic in recent years including the development of just-in-time inventory systems, access to the modern interstate highway system, and competitive operating costs for heavy trucks. This growth in permit requests for the State of Tennessee is continuing with the number of permits for fiscal year 1998-99 approaching 140,000.

Solution
To meet this challenge, the Tennessee Department of Transportation undertook a three-step process. First Terry Leatherwood, P.E. a TDOT engineer developed a screening method, the allowable weight ratio approach, intended to increase the efficiency of the permit analysis process. Second, researchers at the University of Tennessee performed an extensive evaluation of Mr. Leatherwood's algorithm. Finally, with the assistance of Cambridge Systematics, Inc., a new computerized permit routing/issuance process was designed and developed.

Methodology
One of the most challenging aspects to permit vehicle routing is bridge analysis. In an ideal world, every bridge crossed by a permit vehicle could be thoroughly analyzed. It was recognized early in the system development process that a complete analysis of every bridge on each requested route was unrealistic.

The permit issuance process is a regulatory process designed to exclude unacceptable vehicles from using the highway system. Therefore, rather than treating permit vehicle analysis as an engineering problem that requires an advanced computer analysis it was approached as a Quality Control issue which could be solved using the mathematics of Acceptance Sampling. In structure, this problem is no different than conducting acceptance sampling on parts that are shipped to a factory for use in production. The quality control engineer solves his problem by applying statistics, deciding on an acceptable quality level, and developing a sampling plan. The TDOT system applies a similar approach to permit vehicle analysis utilizing a combination of gross weight, axle load and axle spacing. The mathematical techniques required for such an analysis are well developed and can be found in a number of texts and reference volumes.
Proof of Concept
However, these techniques have not typically been applied to the problem of truck permitting. Which is why the University of Tennessee researchers got involved. TDOT felt that before this analysis technique was utilized in its permitting process it should be thoroughly evaluated. Drs. Hal Deatherage and Karen Chou of the Department of Civil and Environmental Engineering conducted a formal evaluation of this proposed screening methodology.

The UTK research team performed detailed structural analysis for over 2460 overload truck-bridge configuration combinations for interstate bridges and 220 combinations for bridges on state routes. The researchers concluded that for interstate bridges the odds that the method would make a wrong recommendation (approving an overload truck's permit which would cause overstress) is 1 in 26 trillion. For state route bridges the odds were calculated to be 1 in 1.3 billion of a wrong conclusion. Based on these dramatic findings the UT researchers concluded that the allowable weight ratio approach is a superior evaluation method. However, some modifications to the algorithm used for state routes were recommended.

The following is a simplified example of applying the methodology to a real scenario in Tennessee. Take the case of the hypothetical permit request to travel from North Carolina to Arkansas along Interstate 40 given above. Suppose we accept 5% as the significance level of our test, a common assumption in statistical analysis, and do only 100 of the possible 4,146 superstructure checks for the route. Also suppose that all engineering checks passed without a single failure. If we approve this permit to travel, what is our risk of making a Type II error (the probability that bridges will be unacceptably overstressed)? The risk can be computed to be 0.04 or only 4%. This risk can be reduced even further by not selecting bridges at random to test. In Tennessee, we have compiled a database of these sensitive structures and use them to test permit vehicle traffic.

Implementation
Once the methodology was validated the next step was to design a system in which it could be utilized. Development of the new computer system began in 1995 with testing and implementation being completed in 1998. The system is now utilized daily within TDOT. The productivity gains made possible by the new system have allowed TDOT to both keep up with the increasing workload and provide better service to the trucking industry.

Our system is designed to first subject overweight permit vehicles to a level 1 screening based upon the technique described above. Naturally, it is somewhat conservative but it does act to approve permit requests that clearly pose no danger to Tennessee bridges.

If the permit request fails the level 1 screen, it is transmitted to the Bridge Office for a more detailed (level 2) analysis. Here it is tested using the known sensitive bridges along the requested route. Because we bias the test by using sensitive bridges, rather than bridges selected at random, our risk of making a Type II error is reduced.
If the permit request fails the level 2 analysis, it is automatically rejected by our system. This is one disadvantage (or advantage depending upon one's point of view) of using an acceptance sampling method for permit vehicle approval. One cannot try to "work around" bridges that fail the test. To do so would invalidate the acceptance sampling method. Only if one were willing to test each and every structure would this be permissible.

Benefits
TDOT has studied the needs specific to Tennessee and developed a system that varies markedly from what "conventional wisdom" says that an overweight/over-dimensional permit issuance system should resemble. Our system rejects a GIS map interface in favor of a simpler and faster text based approach. It also rejects the requirement to analyze every bridge in favor of screening and acceptance-sampling methods of evaluating permit requests.

However, the improvement in operating efficiency has led to increased productivity and allows the Tennessee Department of Transportation to perform adequate regulation of permit vehicles with the limited staff resources available. Clearly, the circumstances of the State of Tennessee may not apply to other highway agencies. Each agency needs to evaluate the typical permit traffic patterns peculiar to their jurisdiction.

Product(s) Available
The following reports are available from Mike Presley at (615)532-9838:


For more information:
Mike Presley at (615)532-9838
Sponsored By: Connecticut

For thirty years the Connecticut Department of Transportation has been acquiring and distributing ground-based images collected with state-of-the-art photolog vehicles. The program is one element of the agency's program to maintain an inventory of its transportation infrastructure assets. The Photolog program has been successful due to the emphasis it has placed on distributing images and data to as many "clients" as will derive benefit from the information. Over the years Department-wide photolog retrieval tools had evolved from three film viewing stations used through the 1970s and early 1980s, to thirty-four PC-controlled Photolog Laser Videodisc (PLV) workstations accessed from the mid 1980s through the 1990s.

Beginning in 1985 and ending in 1998, DSS distributed sets of laserdiscs containing ten-meter interval images of all Connecticut roadways. Thirty-four standalone laserdisc workstations located throughout the Department were updated annually with a set of fifteen laserdiscs containing approximately 3,880 centerline roadway miles at each user station. Custom software called SuperHIWAY controlled both laserdisc player communication and the Department's linear reference database, allowing the user rapid access to an image at any given location.

Problem
In 1997 the Photolog Unit upgraded its two photolog vehicles with progressive scan (full frame), digital video image capture capability. While digital video and digital cameras were nothing new, digital imaging presented DSS with an opportunity to improve and greatly expand client use through the new personal computer storage media, Digital Versatile Disc (DVD).

DSS monitored industry development of DVD-ROM production technology throughout 1997 and 1998. With the new cameras and advances in dual-layered DVD production capabilities, it was clear that television standard (NTSC) laserdiscs were outdated for DSS' and the Department's needs. Drawbacks to the then fourteen-year-old laser videodisc distribution system included the reliance on external laserdisc players and internal PC imaging boards. In contrast, DVD-ROM drives would reside within the PC case and eliminate television-based internal and external hardware which, it was anticipated, would immediately reduce costs and make distribution more efficient.

Initial inquiries to DVD production houses were made to determine if DVD master and replicate production costs were comparable to those of laserdisc. Initial quotes led an optimistic DSS to initiate a research project entitled "Development and Implementation of Digital Versatile Disc for Photolog" in January of 1999.
Solution
Two primary work tasks were critical to the success of the project: First, a digital file format had to be chosen to replace the video images derived from laserdisc. Second, the SuperHIWAY software had to be completely overhauled to handle digital images viewable from DVDs. While these seemed straightforward enough, all work had to be done in a manner that would not adversely impact annual production and distribution goals of the 1999 photolog season (April through September of that year).

Investigating Digital Image File Formats

The first phase of the project involved choosing a digital image file format to replace still frame video images.

DSS investigated individual JPEG images, various digital video formats along with their compression and decompression (CODEC) strategies as well as MPEG1 and MPEG2. Table 1 summarizes the investigation parameters and results. Numerous tests at DSS and various production facilities were conducted in 1998. The primary goal of the project was to establish a working product that could be fully implemented for the 1999 image and data distribution. Therefore, testing, though vigorously pursued, had to be completed in a two-month period at the outset of the project. Image quality, basic navigation capabilities (i.e. the ability to navigate through the images frame by frame in both forward and reverse direction), and the ability to distribute with a minimum of required hardware were paramount concerns.

<table>
<thead>
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<th>Format</th>
<th>Image Quality</th>
<th>Frame Accurate Image Navigation (Forward and Reverse)</th>
<th>No Additional Hardware Required</th>
<th>Practical For ConnDOT Distribution</th>
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</thead>
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<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
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<tr>
<td>MPEG2</td>
<td>X</td>
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</tr>
</tbody>
</table>

Table 1

DSS determined that standard JPEG images organized by route and direction in an indexed image library file called a Compressed JPEG Library (CJL), stored on a dual-layered, single-sided DVD format (DVD-9) would provide one and a half times the storage capacity of a double-sided constant angular velocity laserdisc, immediately lowering production costs. Image compression tests were done at various ratios until it was decided that seventy percent compression was the maximum allowed before loss was markedly noticeable. The average raw image size out of the van was one megabyte. After JPEG
compression was performed the average image size was approximately sixty-five kilobytes. At this ratio there is little noticeable loss in quality and all pertinent roadway features are clearly visible.

**New Digital Image Retrieval Software**

Software products were developed for ConnDOT by consultants who created the original SuperHIWAY and the roughness, geometric and GPS database structure. A new three-tier software structure first creates the Compressed JPEG Library files and processes engineering data collected by the photolog vans for desktop retrieval. Second, Waypoint-Based Linear Referencing (WBLR) software matches traditional and custom linear referenced locations to van-collected GPS coordinates. Lastly, a new software package called DigitalHIWAY replaced SuperHIWAY, which enables users to view forward and side facing roadway images with interactive links to engineering data and traditional linear reference locations. Additional mapping, horizontal curve analysis, and virtual measurement software are now available also. Like its analog television predecessor, DigitalHIWAY is geared towards the traditional user-base that includes the majority of offices in ConnDOT including chief engineer, traffic, planning, maintenance, construction, research and materials, rights of way, public transportation and incident management.

DigitalHIWAY is also installed on desktop and notebook computers at the Federal Highway Administration's Connecticut Division office. FHWA staff have recently used photolog images for projects that require lane identification and traffic signal location. This method of verifying field conditions allows for the examination of many sites in a short period of time with very little cost.

**Implementation**

DigitalHIWAY software is now installed on over 400 desktop and notebook computers at the Connecticut DOT, Federal Highway Administration's Connecticut Division office, Connecticut Transportation Institute at University of Connecticut, several private organizations, one Connecticut Judicial Library, and Connecticut State Library.

**Benefits**

Fiscal and operational benefits from this research project for ConnDOT's asset management were realized immediately.

In 1999 over two million images were acquired. Eighty percent of Connecticut's roads were photologged with a dual-camera vehicle. The remaining roads were photologged with a single-camera van. This represented over 140 gigabytes of data and required production of seventeen single sided, dual layered DVD-ROMs. Equivalent data stored to laserdisc would have required the mastering and replication (fifty of each title) of twenty-one laserdiscs at a production cost of approximately $78,000. DVD-ROM mastering and 150 title replicates cost $43,000. In short, mastering and replication costs are almost half of the older media production costs associated with videodisc.

Unlike SuperHIWAY, DigitalHIWAY requires only a DVD-ROM drive and the software installation kit, which are quick and easy to install on any Department PC. In its first year of implementation (1999) DSS experienced a user-increase of 300%. Since that time more desktop usage has continued to reduce
man-hours in the field, save fleet vehicle costs, and increase personnel safety. Without the burden of additional hardware and the costs and space requirements that go with it, Photolog has seen an increase in users from thirty-four at the start of the project to over 400 at this writing.

Our 400+ users save the state an estimated $2+ million per year in costs associated with avoided field trips. This delivers an impressive 3:1 benefit/cost ratio, based on the annual operating budget for this Department function.

**Product(s) Available**

**For more information:**
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Problem
Shoulder rumble strips have proven to be an effective measure in reducing run-off-the-road (ROR) crashes on urban and rural freeways. ROR crashes may be reduced by as much as 20 to 50 percent when rumble strips are installed. As the use of shoulder rumble strips is extended to non-freeway facilities, bicyclists will encounter rumble strips more frequently in the future. Bicyclists are concerned about maneuverability problems while traversing rumble strips because they can be very uncomfortable to ride over and may cause loss of control of the bicycle.

Solution
This research was initiated to develop new rumble strip configurations that could alert inattentive or drowsy motorists and be safely and comfortably traversed by bicyclists. Thus, the objective of this project was to develop new rumble strip configurations that decrease the level of vibration experienced by bicyclists when traversing rumble strips, while at the same time provide an adequate amount of stimuli to alert inattentive/drowsy motorists.

To achieve this objective, two different perspectives needed to be considered throughout the research, that of the bicyclist and that of the motorist. From the bicyclist's perspective, rumble strips should not generate too much vibration or shake the bicycle as the bicyclist traverses the rumble strip, causing discomfort and possibly loss of control. From the motorist's perspective, rumble strips should transmit a sufficient amount of auditory and vibrational stimuli to warn an inattentive or drowsy motorist who drifts from the travel lane.

Four primary steps were involved in the development of the new rumble strip configurations. The first step was to evaluate and assess the Pennsylvania Department of Transportation's (PennDOT's) existing rumble strip configuration. The second step was to develop, evaluate, and rank different configurations for their potential to be "bicycle-friendly" without degrading the alerting properties for drivers in motor vehicles. A simulation model was developed and validated to evaluate various new designs. The third step was to install several of the recommended configurations with the greatest potential to be "bicycle-friendly" and conduct field experiments to further evaluate their effectiveness. The final step of the project was to analyze the data and rank the configurations that were installed, based on their ability to alert inattentive or drowsy motorists and provide a comfortable and controllable ride for bicyclists.
Effects of the different configurations on bicyclists, volunteer participants rode different types of bicycles over the rumble strip configurations at different speeds and different angles. Objective data, such as vertical and pitch angular accelerations, were collected to evaluate the comfort and control levels of bicyclists traversing the different configurations. In addition, bicyclists' perceptions were recorded through a subjective questionnaire rating the comfort and controllability of the configurations. To assess the effectiveness of various rumble strip configurations on alerting inattentive or drowsy motorists, measurements were taken of the auditory and vibrational stimuli generated by the rumble strip configurations.

From the bicyclist's perspective, test pattern 6 was the most "bicycle-friendly." However, from the motor vehicle standpoint, test pattern 6 generated the least amount of noise in the passenger compartment, in both the high-speed testing conducted at 55 mph (88 km/h) and the low-speed testing conducted at 45 mph (72 km/h). Because test pattern 6 was ranked the worst test pattern from the motor vehicle standpoint, it is not recommended for installation.

Test pattern 3 was ranked the second most "bicycle-friendly" configuration from the bicyclist's perspective. From the motor vehicle standpoint, test pattern 3 performed well during the high-speed testing and ranked second overall at 55 mph (88 km/h) with an average maximum sound level of 81.3 dB (A) versus 88.9 dB(A) for the existing configuration. Therefore, test pattern 3 is recommended for implementation along non-freeway facilities with higher operating speeds.

During the low-speed testing at 45 mph (72 km/h), however, test pattern 3 generated 74.7 dB(A) of noise, less than 7 dB(A) above the ambient noise. As a result, test pattern 3 ranked only fifth overall at this speed. Previous research by Watts (1977) indicated that rumble strips that produce 4 dB(A) or above can be readily detected by motorists who are awake, but there are no data indicating the sound level difference above the ambient noise necessary to alert a drowsy motorist. Given Watts' study, 7 dB(A) was not considered an adequate difference, so test pattern 3 is not recommended for implementation on non-freeway facilities with lower operating speeds.

The third-ranked test pattern from the bicyclist's perspective (test pattern 2) was considered for low-speed facilities. A close examination of the average normalized values for test pattern 2 and test pattern 5 showed very little difference between the two. Essentially, test patterns 2 and 5 performed equivalently from the bicyclist's perspective. From the motor vehicle standpoint, however, test pattern 5 generated slightly more sound in the passenger compartment at lower operating speeds than test pattern 2. Therefore, test pattern 5 is recommended for implementation along non-freeway facilities with lower operating speeds near 45 mph (72 km/h).

**Implementation**

Based on the results of the motor vehicle testing and the bicycle testing, two new "bicycle-friendly" rumble patterns are recommended for implementation along non-freeway facilities. Test pattern 3 is recommended along non-freeway facilities with higher operating speeds, near 55 mph (88 km/h). Test pattern 5 is recommended along non-freeway facilities with lower operating speeds, near 45 mph (72 km/h).
Output from the simulation model developed during this research indicated that 4" (102 mm) wide grooves would provide the smoothest ride for bicyclists. However, the cutting head on milling machines is a standard diameter, limiting the ability to vary the width of cut and depth of cut concurrently. Until a cutting head is developed that can cut a 4" (102 mm) wide groove, the effects on bicyclists and motor vehicles will never be fully known. By design a cutting head with a variable diameter, different rumble strip designs could be developed to better accommodate both bicyclists and motorists.

Benefits
The results of this research project will assist PennDOT in its effort to reduce crashes and fatalities by 10%. The benefits of this research include developing new rumble strip configurations that will alert inattentive or drowsy motorists and be safely and comfortably traversed by bicyclists. Thus, the objective of this research project was to develop new rumble strip configurations that decrease the level of vibration experienced by bicyclists when traversing rumble strips, while at the same time provide an adequate amount of stimuli to alert inattentive or drowsy drivers.

Product(s) Available
Final report: "Bicycle Friendly Shoulder Rumble Strips"

For more information:
For More Information Contact:

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Sponsored By: Pennsylvania

On September 30, 2000, Pennsylvania's ignition interlock program, intended to ground drunken drivers, became mandatory. The Pennsylvania Department of Transportation (PENNDOT) planned to adopt the National Highway Traffic Safety Administration's (NHTSA) testing criteria for ignition interlock devices and also consider additional requirements, which other states have implemented in conjunction with interlock programs.

Problem
The purpose of this research project was to review the draft specifications developed by PENNDOT, provide comments and recommendations for specification and programmatic requirements, and assist in the implementation of the interlock program.

Solution
The initial draft specifications, based primarily upon NHTSA standards promulgated in 1992, were found to be out-of-date. These standards provided only minimum criteria for the testing of interlock devices, which had already been addressed by the vast majority of interlock manufacturers. Key issues were identified such as the type and amount of information needed from certifying testing labs and the type of sensor technology allowable. Other important findings included a variety of programmatic issues surrounding administrative oversight for the interlock program, including the ongoing review and oversight of service providers and the need for central administration of the program.

Implementation
It is recommended that PENNDOT establish standards and requirements for the ignition interlock program using two separate sets of regulations. The first, dealing with device specifications, are set forth in sections I through IV of the draft specifications provided to PENNDOT on April 6, 2001. The second, dealing with the functional operation of the program and including issues such as quality assurance, offender monitoring, data reporting, device installation and removal, and sanctions for non-compliance should be set forth in a separate document developed by the agency that will have central administrative oversight for the ignition interlock program.

Benefits
On September 30, 2000, Pennsylvania's ignition interlock program intended to ground drunken drivers became mandatory. Persons with more than one drunken driving conviction would have an auto-ignition device connected to their cars requiring them to take a breath test before turning the key. The breath alcohol ignition interlock device is designed to prevent a driver from starting a car when the driver's breath alcohol content is at or above a set alcohol level.
Product(s) Available
Technical Memorandum Pennsylvania's Ignition Interlock Program. Submitted on April 6th, 2001, by, Jeffery H. Coben, MD

For more information:
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Sponsored By: Pennsylvania

The Pennsylvania Department of Transportation (PennDOT) guidelines for placement of median barrier take into account such factors as median width and five-year projected traffic volumes. According to PennDOT's current median barrier guidelines, barrier is not warranted if the median width exceeds ten meters or the average daily traffic is less than 20,000 vehicles, unless there is a significant history of cross median crashes.

Problem
From 1994 through 1998, there were 301 crossover crashes (80 deaths) on Pennsylvania's interstates and expressways. Research was needed to evaluate the overall median safety in Pennsylvania, including the relationship between median crossover crashes and median widths on interstates and expressways.

Solution
The project work plan addressed literature reviews of PennDOT's median barrier criteria and practices, national literature on the issue, and other state department of transportation policies and procedures related to median safety. In addition, an analysis of Pennsylvania's median safety characteristics was performed using both the PennDOT Roadway Management System (RMS) and Crash Reporting System (CRS) databases. Lastly, expert input and opinions regarding median safety and cross median crashes were used in combination with analytical data results for a more comprehensive research approach.

Implementation
PennDOT should continue to determine median barrier warrants based on their current policy until a more extensive evaluation of crashes involving cross-median non-collisions and collisions with median barriers can be completed.

Given the likelihood of CMC crashes in the portion of the roadway within 800 feet downstream of an entrance ramp, PennDOT should consider installing median barrier at such locations, even in medians wider than those for which their warrants show that the need for a barrier should be studied. Sufficient data to make a formal revision of current PennDOT median barrier warrant criteria for locations near entrance ramps is not available at this time.

Given the substantial number of CMC crashes at median widths where barriers are considered optional (31 percent) or not normally considered necessary (57 percent), PennDOT should evaluate the need to install median barriers in wider medians.
PennDOT should establish a monitoring program to identify where median-related crashes occur and evaluate the need for median barrier on these particular segments or routes. A specific code should be incorporated into PennDOT's CRS database to identify a CMC crash. PennDOT should consider revisions to its RMS database to make it easier to use in evaluating median-related crashes and in applying median barrier warrants. The following fields should be added to the data for each RMS segment to:

- Distinguish whether that segment is an undivided highway or part of a divided highway.
- Identify whether the segment has full, partial, or no control of access.
- Specify the median width for that segment.
- Identify the location of entrance and exit ramps on Interstate highways and expressways or provide a separate file.

**Benefits**
Improving median safety in Pennsylvania.

**Product(s) Available**
Technical Memorandum Median Safety Study (Interstates and Expressways).

**For more information:**
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Internet: [http://www.dot.state.pa.us](http://www.dot.state.pa.us)
Sponsored By: Pennsylvania

The purpose of this project was to provide assistance to the Pennsylvania Department of Transportation (PENNDOT) Pavement Markings Benchmarking Team in its effort to develop an improvement plan for pavement markings in Pennsylvania.

Problem
PENNDOT currently uses waterborne paint for 94 percent of its lines miles and is able to apply these markings at a very low unit cost. While PENNDOT's pavement marking program is highly cost efficient, it may not be cost-effective. An effective pavement marking program produces pavement markings that are sufficiently bright to provide drivers with adequate guidance at all times. Unfortunately Pennsylvania does not have a database of retroreflectivity readings that can be used to evaluate the quality of its pavement markings.

Solution
A literature search was conducted on pavement marking research related to process, materials, cost-effectiveness, and reflectivity under wet conditions and at night. Pavement marking benchmarking candidates were identified in eight US DOT and two foreign highway agencies. The benchmarking candidates were interviewed to identify the aspects of their pavement marking programs that are superior, how "superior" they are (quantitative measures), how they are able to achieve their superior performance, and how applicable their methods are to PENNDOT.

Implementation
A first step in the project is to establish where PennDOT's current PM program falls as far as cost (life cycle) and effectiveness (retroreflectivity levels and durability). This "benchmark" needs to be defined before comparisons with other programs can be made. It is not desirable to develop a single state-wide benchmark because of the major differences in PM environments (e.g., NW snowbelt vs. SE urban areas, rural 2-lane roads vs. urban interstate highways, etc.) that exist within the Commonwealth. It is important to insure that comparisons between PennDOT's practices and those of other agencies are done on an "apple-to-apple" basis.

Agencies suggested as possible contacts include MN, NY, MI, WI, VA, CO, MD, CA, southern Canada, Sweden, Germany, Austria, and the UK. Others may be identified through the literature search and conversations with people during the survey.
Benefits
A cost effective program that will insure better reflectivity and provide drives with adequate guidance especially under wet conditions and at night.

Product(s) Available

For more information:
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Internet: http://www.dot.state.pa.us
Problem
Presently, California Department of Transportation (Caltrans) sign maintenance crews must install/replace small wooden roadside signposts at locations which expose them to the hazards of passing traffic. For a typical signpost replacement, it takes a two-person crew approximately 30 to 40 minutes or more if a lane closure is required. This procedure involves removing the broken stub, auguring a new hole, bolting on the sign panel, placing the post in the hole, and compacting the fill. During this time, Caltrans crews are subjected to the hazards posed by passing traffic. The longer it takes to complete the job, the greater the exposure.

Solution
Researchers at Caltrans have developed a method to reduce the time needed to change a damaged sign to just ten minutes. The key to the quick change strategy is installing a permanent, reusable concrete footing designed to accommodate wooden signposts. Once the cylindrical, 540 kg (1200 lb.), concrete footing is properly installed, signposts can be placed quickly by inserting them into a deep hole in the footing and securing them with two specially designed plastic wedges. If a motorist hits the signpost, the footing and wedges hold the broken stub in place while the rest of the signpost breaks free.

Replacing a broken post becomes a simple matter of prying out the wedges (using tools like pickaxes and crowbars that highway crews already carry), removing the broken post, placing a new one, and replacing the wedges. Where proper installation is carried out to begin with, it takes an average of ten minutes to exchange the signs.

The concrete footing specifically designed for this project is heavy enough to withstand the wind force on the face of the sign, and the hole for the signpost is deep enough to hold it upright and steady. This hole is slightly offset, which makes the footing somewhat thicker on two sides, which resists the force of impact. To ensure that it is installed correctly, the footing is marked with an arrow indicating traffic flow. It's also reinforced with rebar to reduce breakage, and has threaded inserts for hoisting it into place. Proper compaction of the soil when first installing the footing is crucial, so that rain and erosion do not cause it to lean. The wedges are made of a tough plastic (recycled carpet fibers formed into blocks by an extrusion process) that can be cut and shaped with ordinary hand and power tools, doesn't readily absorb water, and is environmentally benign. The wedges can become difficult to remove if they are hammered into place: practice has shown that all is needed is foot pressure for
them to do their job. Because of the shape of the footing and the placement of the wedges, this system isn't recommended where signs are subject to being hit by wrong-way traffic.

Implementation
There are currently numerous ongoing field evaluations in several field offices to evaluate the Quick Change Signpost (QCSP) under actual field conditions. Initially, various sign maintenance crewmembers were skeptical of the new procedure. Following proper training and hands-on experience, the majority of crewmembers felt the QCSP is a worthwhile improvement that will save time and reduce exposure to the hazardous posed by passing traffic.

Benefits
Initially, the footings cost $100 to manufacture and $90 to install; however, subsequent signpost replacements are $30 cheaper than current methods. This makes the QCSP cost effective for "high-hit" locations, where signs are knocked down five to six times a year. More importantly, the safety benefits to the workers and the traveling public makes the system extremely attractive.

Product(s) Available
Plans and specifications to be available soon.

For more information:
If you have any questions or comments, please feel free to email Jarvis Mahe at jarvis_mahe@dot.ca.gov or visit the Quick Change Signpost web site at http://www.dot.ca.gov/hq/newtech/research/qcsp/qcsp.htm.
High Value State DOT Research
Rumble Strips for Lower Volume Roads With Narrow or Non-Existent Shoulders

Sponsored By: Pennsylvania

To address run-off-the-road crashes on Pennsylvania highways, the Pennsylvania Department of Transportation (PENNDOT) is currently using milled shoulder rumble strips (MSRS) to alert inattentive or drowsy drivers. MSRS have been installed primarily along limited access highways. To extend the use of MSRS to roads with narrow or non-existent shoulders, several issues need to be addressed. These issues revolve around the design of the rumble strips and their placement along the highway.

Problem
The goal of this project is to develop conceptual designs for rumble strips to be placed on roads with narrow or non-existent shoulders, so that (a) their installation does not compromise the integrity of the pavement, (b) their location and/or type are acceptable for bicyclists, and (c) they can alert inattentive drivers.

Solution
A new methodology was developed for determining (a) the preferred lateral width of the rumble strips and (b) the optimum placement of rumble strips within the roadway cross-section. The preferred lateral width of a rumble strip is a function of the desired exposure time of the stimuli generated by the rumble strips. The exposure time of the stimuli is a function of vehicle speed, departure angle, the lateral width of the rumble strips, and the contact area of the tire. The placement of rumble strips within the roadway cross-section is a function of the clear zone and the steering adjustment area. Given the difficulty in obtaining or estimating these, the placement of the rumble strips can be determined based on the roadside hazard rating of the site.

Implementation
It is recommended that the methodology developed in this project be followed to assist in the decisions regarding installation and lateral width of rumble strips. It is also recommended that any new rumble strip configurations be tested and evaluated as follows: (1) A before-after crash analysis should be conducted to estimate the safety effectiveness of the rumble strip installations. (2) Field tests of motor vehicles should be conducted to measure the auditory and vibration stimuli generated by the rumble strips. (3) Bicycle tests should be conducted to measure the accelerations experienced by the bicyclists while traversing the rumble strip configurations, and a survey should be filled-out by bicyclists local to the area to determine bicyclists’ perception of ride quality along the route prior to installation of the rumble strips and afterwards. (4) The impacts on pavement performance should be assessed through real-time and accelerated field testing.
**Benefits**
Using milled shoulder rumble strips (MSRS) to alert drivers who are drifting to the right and/or to the left, out of the travel lane. The rumble strip is a continuous pattern ground into asphalt or concrete, which transmits auditory and vibrational warnings to the drifting motorist.

**Product(s) Available**
Technical Memorandum Rumble Strips for Lower Volume Roads With Narrow or Non-Existent Shoulders. Submitted on August 1, 2001, by L. Elefteriadou

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Problem
Transportation structures in Louisiana require deep foundations to safely carry the superstructure loads. Over ninety percent of these foundations utilize driven piles with the overwhelming majority consisting of precast prestressed concrete piles. Pile projects are always costly; for example, the Louisiana Department of Transportation & Development (DOTD) spent about $19 million in construction costs for driven piles in 1995. There is also a large expense associated with the design of these piles. The current DOTD practice of pile design is based on the static analysis method (alpha method). Soil properties are needed as input parameters for the static analysis. Therefore, it is necessary to conduct field and laboratory tests, which include soil borings, standard penetration test, unconfined compression test, soil classification, etc. Running field and laboratory tests is expensive and time consuming.

Solution
Cone penetration test (CPT) can be utilized for a wide range of geotechnical engineering applications. The CPT technology is fast, reliable, and cost-effective, especially when compared to the traditional site characterization method (borings and laboratory/field tests). The predominate soil type in Louisiana is a saturated silty clay subject to remolding and set up properties. However, with a few exceptions, past implementation of CPT technology by DOTD has been limited to identification of dense sand layers required to support end-bearing piles. Moreover, DOTD uses the CPT to provide supplemental subsurface information between a full complement of soil borings. Unfortunately, this is a very limited application compared to the wide range of CPT capabilities. The DOTD materials section CPT system can perform an average of six to eight tests per day. In subsurface exploration, the CPT can be effectively used to identify and classify soils and to evaluate the undrained shear strength. Implementation of the CPT can drastically decrease the number of soil borings and reduce the cost and time required for subsurface characterization.

A research effort to identify the most appropriate CPT methods for predicting the axial load carrying capacity of piles driven into Louisiana silty clay soils has been completed by the Louisiana Transportation Research Center. The research considered only square precast prestressed concrete (PPC) piles predominate in Louisiana bridge structures. To achieve this goal, state projects that have both pile load tests and CPT soundings were identified and collected from DOTD files. Pile load test reports were selected based on selection criteria, compiled onto sheets, and analyzed. The ultimate axial load carrying capacity for each pile was determined using the Butler-Hoy method, which is the primary load test interpretation method used by DOTD. The CPT soundings close to the test pile location were identified and used to predict the ultimate pile capacity. Eight methods for predicting the ultimate pile capacity by CPT were selected. These methods included Schmertmann, de Ruiter and Beringen, Bustamante and Gianeselli (LCPC/LCP), Tumay and Fakhroo, Aoki and De Alencar, Price and Wardle, Philipponnat, and the penpile method.
An evaluation evaluation scheme was executed to compare the CPT methods based on their ability to predict the measured ultimate pile capacity. Four different criteria were selected to evaluate the ratio of the predicted to measured pile capacities. These criteria include the best-fit line, the arithmetic mean and standard deviation, the cumulative probability, and the Log Normal distribution. Figure 1 shows the Log Normal distribution for the different methods considered in this study. Each criterion was used to rank the prediction methods based on its performance. The final rank of each method was obtained by averaging the ranks of the method from the four criteria. Based on this evaluation, two methods, the de Ruiter/Beringen and Bustamante/Gianeselli, showed the best performance in predicting the load carrying capacity of square PPC piles driven into Louisiana soils. The worst prediction method was the penpilie, which proved to be very conservative.

Figure 1: Probability distribution of predicted versus measured ultimate pile capacity for all methods.
In order to foster the confidence of DOTD design engineers, the CPT pile capacity prediction capabilities have been demonstrated on additional pile load tests on bridge projects under construction. To date, the CPT prediction methods have been used on four bridge projects located in Jefferson, Lafourche, St. Mary, and Ouachita parishes.

Cost-benefit analysis showed that the implementation would result in cost reduction in pile projects and time savings without compromising the safety and performance of the pile supported structures. In fact, implementation of the CPT technology in pile design will reduce the level of uncertainties associated with traditional design methods.

**Benefits**

DOTD performs a traditional static analysis for pile design using the -method. Properties of cohesive soils are obtained from laboratory tests on undisturbed samples from boreholes and strength characteristics of cohesionless soils are evaluated from the Standard Penetration Test (SPT). Conducting field and laboratory tests are expensive and time consuming. DOTD Materials Section records indicate the average costs of a traditional boring, including lab and field tests, is $50/ft with DOTD forces and $60/ft by consultants. The average costs of CPT soundings is $14/ft with DOTD forces and $28/ft by
consultants for a cost reduction between 2 and 3.5 to 1. These costs do not include the tremendous time savings in expediting projects when using the CPT technology.

Due to uncertainties associated with pile design, load tests are often conducted to evaluate the actual response of the pile to load capacity. The cost of driving and loading a test pile in Louisiana ranges from $13,000 to $25,000. On small bridge projects, it is often cost effective to increase the safety factor (i.e. increased pile length) compared to conducting a pile load test. The CPT methods are proven herein to be more accurate in predicting the pile load carrying capacity of PPC driven piles in Louisiana soils compared to currently used static methods. On small projects, an accurate design leads to less uncertainty, less factor of safety (i.e. length), and, therefore, less costs. On large bridge projects, more accurate foundation evaluations will produce cost-saving by allowing a reduction in the required number of test piles.

Product(s) Available

Louisiana Pile Design by CPT (LPD-CPT), a Visual Basic MS-Windows program. The program performs the analyses on the CPT soundings using the selected CPT method and provides the design engineers with pile ultimate capacity profile with depth.

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Problem
Drilled shafts have been used frequently for the support of bridges, retaining walls, overhead signs, noise barrier walls, and in stabilizing both man-made embankments and natural slopes. In all cases, the drilled shafts are generally subjected to both lateral and axial loads. At the present time, the analysis of the response of the drilled shafts under lateral loads is done by using the theory of beam-column on Winkler foundation, in which nonlinear p-y curves are used to represent the Winkler springs. The key to the success of this analysis technique lies in the use of pertinent p-y curves.

The traditional approach for generating p-y curves relies on the use of semi-empirical equations in connection with certain key soil parameters, such as friction angle for sand and undrained shear strength for clay. In situ testing methods including the pressuremeter test and the dilatometer test have been developed for obtaining the p-y curves as well. Despite these advancements, there is a need for a comprehensive evaluation of these techniques in generating p-y curves, based on comparisons with full scale load tests results on fully instrumented drilled shafts. There is also a need to investigate the effect of the presence of a nearby slope on the lateral response of drilled shafts, particularly the initial portion of the p-y curve.

Solution
This research project was carried out to achieve three major objectives: (1) Development of a methodology for constructing the p-y curves used in analyzing the laterally loaded drilled shafts, (2) Evaluation and updating the existing design chart for the drilled shafts foundation of the noise barrier walls, and (3) Development of an analysis method for the drilled shafts used in stabilizing the embankments and slopes. A total of nine (9) lateral load tests were conducted on 18 fully instrumented drilled shafts. In addition, at each test site, soil boring, pressuremeter tests, and Standard Penetration Test (SPT) were conducted to obtain pertinent soil information. The size of the tested drilled shafts ranged from 30 inch to 48 inch diameter and 8 ft to 40 ft in length. The soils encountered included sandy silt, and soft to medium stiff clays. These test results, together with a compilation of test data from other projects, formed the basis of developing and validating the analysis methods.

There were six major research results: (1) It was found that the use of the pressuremeter test results usually led to over-design of the drilled shaft, (2) It was observed that the slope adjacent to the drilled shaft would exert effect on the behavior of the laterally loaded drilled shafts, (3) A new design chart was developed for determining the required length of the drilled shafts to support the noise barrier walls, (4)
A computer program was developed to allow engineers to design the drilled shafts in stabilizing an embankment or slope, (5) A new correlation chart was developed for relating the STP blow count \( (N) \) value to the relevant parameters in establishing the p-y curves, and (6) A methodology was developed for back analysis of the p-y curves based only on the shaft deflection measurements and the minimization techniques.

**Implementation**
There has been multiple Ohio Department of Transportation projects that have benefited from the results of this research. One project involved the noise barrier wall construction along I-270 near Columbus. The foundation length was reduced based on the results of the load test conducted as a part of this research project. The cost savings were estimated to be more than $300,000. On another project, the original design of 5000 drilled shafts for a noise barrier wall were modified to incorporate the findings of this research, which resulted in a savings of more than $3 million. On two bridges projects in the Cincinnati area, the drilled shaft reduced length requirements were validated with lateral load tests, which resulted in a cost savings of $1.5 million.

**Benefits**
The ODOT Office of Structural Engineering has implemented the new design chart for the drilled shafts of noise barrier walls. The new design chart has reduced previous foundation length requirements by about 20 percent. If one estimates that 10 million dollars would be spent every year for the noise barrier wall foundations, the cost savings due to this revised drilled shaft length requirement would be about 2 million dollars annually. The Office has also adopted the developed lateral load testing procedure together with the back-calculation techniques for the bridge or retaining walls supported by the drilled shafts. This procedure will validate the reduced design lengths of drilled shafts.

**Product(s) Available**

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High Value State DOT Research
Rockfall Catchment Area Design Guide

Sponsored By: Oregon

Through a joint effort funded by Eight states and the Federal Highway Administration, [SPR-3(032)] the Oregon Department of Transportation (ODOT) has completed an extensive research project to develop charts for designing rockfall catchment areas. Partners included Alaska, Arizona, California, New York, Oregon, Tennessee, Washington and Wyoming DOTs as well as the New York State Thruway Authority and the FHWA Western and Central Federal Lands Highway Divisions.
Problem
Hundreds of millions of dollars are spent annually in the U.S. to reduce rockfall hazards along highways. Rockfall occurs on slopes where rocks may free fall, bounce, roll or slide. Many factors cause rockfall, including discontinuities in the rock, groundwater conditions, climatic change, poor construction practices, trees and weathering. Legal claims due to rockfall reach millions of dollars each year.

One of the ways that transportation agencies manage rockfall hazards is to provide "catchment areas" (ditches) along the side of the road. The design of catchment areas is critical to their success in reducing rockfall hazards. The current practice is not consistent throughout the United States, because only limited research has been conducted to provide designers with the data they need to make informed design decisions.

Solution
Researchers rolled about 11,250 rocks off five different rock cut slopes of three different heights (40, 60 and 80 feet) into three different catchment areas. For each rock, location of both impact and rollout was observed and recorded. The results were used to develop empirically derived design charts contained in the "Rockfall Catchment Area Design Guide."

The design guide contains a set of "practitioner-friendly" design charts which can be used to design rockfall catchment areas to meet specific rockfall retention requirements. Based on three factors: rock cut slope ratio, vertical rock slope height and catchment area slope, the design charts provide an estimate of the required catchment area widths needed to retain up to 99% of rockfall.

The sample chart shows the cumulative percentage-retained curves for the 80-foot high, 0.25H:1V slope. The catchment area widths are plotted against the rockfall "cumulative percentages retained." In this example, the horizontal line denotes 90% rockfall retention. The line intersects the impact curve at a catchment area width of 14 feet, which means that 90% of the rocks initially hit the ground within a 14-foot wide zone adjacent to the toe of the cut slope. The 90th percentile line intersects with the 4H:1V catchment area curve at 22 feet; with the 6H:1V catchment area curve at 31 feet; and with the flat bottom catchment area curve at 51 feet, meaning 90% of all falling rocks had roll out distances less than or equal to these values.
Cumulative percent retained for the 80 ft, 0.25H:1V Slope

For sites with different height and width configurations, the designer could use other charts to determine the optimum slope and ditch. The same charts can also be used to evaluate the effectiveness of existing catchment areas. The Design Guide provides guidelines and a step-by-step design procedure using three example problems.

With tens of thousands of highway rock slopes in the U.S., some of them decades old, 100% control of rockfall is neither possible nor economically practical. Nonetheless, agencies can have greater confidence in making rockfall control design decisions using the results of this research project.

**Implementation**

The report includes seven highway project case study examples prepared by geotechnical professionals, that demonstrate the practical application of the design procedure and design charts and the use of site-specific rock rolling to aid in the rockfall mitigation design. The case studies also illustrate other
important design considerations, including constructibility and performing benefit-cost comparisons of design alternatives.

**Benefits**
The principle value of this research is to provide the ability to select from a range of solutions in the construction of rockfall areas, and to design rockfall areas with predictable performance. Also, as a result of it's comprehensiveness and flexibility, the Design Guide will support a number of other uses. The design charts can be used to conduct a risk assessment of an existing rock slope. They can also be used to prepare benefit-cost comparisons of design alternatives.

**Product(s) Available**
As of December 10, 2001, an 'English units' version of "Rockfall Catchment Areas Design Guide" can be obtained by calling (503) 986-2700. Within a few days a report will be available in PDF on the ODOT Research Web Site at [http://www.odot.state.or.us/tddresearch/reports.htm](http://www.odot.state.or.us/tddresearch/reports.htm). By January 31, 2002 a compact disk should be available that includes both English and metric versions of the report.

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