



# Research Digest

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## *Item 1*

### **Stay-Cable Vibration Monitoring of The Fred Hartman Bridge (Houston, Texas) and The Veterans Memorial Bridge (Port Arthur, Texas)**

*CENTER FOR TRANSPORTATION RESEARCH*

*CTR 1401-2 • 2006*

This report summarizes the accomplishments of a field investigation project that was conducted in order to understand the mechanisms of wind- and rain-wind-induced stay cable vibrations and to assess the effectiveness of passive viscous dampers and crossties in mitigating such vibrations. The field investigation project was based on two full-scale measurement systems installed on the Fred Hartman Bridge in Houston, Texas and the Veterans Memorial Bridge in Port Arthur, Texas. The systems systematically monitored the vibrations of selected stay cables on these two bridges, as well as the vibrations of the bridge decks and the corresponding meteorological conditions at the bridge sites. The system on the Fred Hartman Bridge started collecting data in October 1997; the system on the Veterans Memorial Bridge became functioning in January 1999. Both systems have remained in operation through the present time.

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## *Item 2*

### **Bridges with Premature Concrete Deterioration: Damage Indices, Strand-Pullout Tests, and Field Observations**

*CENTER FOR TRANSPORTATION RESEARCH*

*CTR 1857-4 • 2006*

This report describes part of the work associated with TxDOT Study 1857 (Structural Assessment of In-Service Bridges with Premature Concrete Deterioration). The primary objective of this report is to determine the effects of premature concrete deterioration on the bond between prestressing strands and concrete, using damage indices and strand-pullout tests. Sixty-four strand-pullout tests were performed on sixty strands from four laboratory specimens taken from full-size precast concrete box girders. The field observation program, begun earlier in this study, of five large TxDOT structures in different parts of Texas was continued for two additional years. Recommendations are made for addressing deterioration in the FM 1929 structure over the Lake Ivie Reservoir in Concho, Texas. Results from the laboratory tests and the field observation program are used to relate external damage to reductions in structural capacity of in-service structures with premature concrete deterioration.

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## **Item 3**

### **Development of a new methodology for characterizing pavement structural condition for network-level applications**

*CENTER FOR TRANSPORTATION RESEARCH*

*CTR 4322-1 • 2006*

Huge quantities of bituminous mix in the form of seal coats and HMAC thin overlays are applied by the TxDOT every year to improve ride quality and seal existing cracks, but these measures do not correct possible underlying weaknesses that will cause roughness or distress to quickly reappear. As a result, the overall pavement condition keeps deteriorating due to the structural deformation of pavement layers and the subgrade, even though surface treatments are applied periodically. The developed methodology introduces the Structural Condition Index (SCI). The SCI is based on the estimated effective Structural Number (SN), and its main purpose is to discriminate pavements that need structural reinforcement from the ones that are in sound structural condition. In addition, a contingent sampling procedure was developed to determine the minimum number of FWD tests required for each management section of pavements. The comprehensive guidelines were developed for using the SCI in the selection of the best maintenance and rehabilitation alternatives at network level. Finally, a pilot application of the SCI was carried out with several pavement rehabilitation projects to verify the validity of the developed SCI, with the intention that modifications would be made to the developed procedure if such a need is determined from the pilot application.

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## **Item 4**

### **Diverting Containerized Freight from Key Texas Corridors**

*CENTER FOR TRANSPORTATION RESEARCH*

*CTR 4410-2 • 2006*

The Texas Department of Transportation (TxDOT) has supported several freight studies since 2000 to enhance the transportation of freight in the state. The report covers the results of a study to examine container flows in Texas, display available data using a GIS platform, and evaluate the potential for diverting containerized traffic from Texas highways to other modes, such as rail and barge. Chapter 2 gives background of the growth of rail-containerized flows and reports on the current flows of containers in the state. Chapter 3 provides current developments in containerized flows on rail and the potential for growth. If greater volumes are to move on rail, there needs to be a more structured relationship between TxDOT, the rail sector, and other private entities. This calls for an understanding of the nature and characterization of public-private partnerships, and Chapter 4 sheds light on that subject. Finally, Chapter 5 summarizes the findings and makes recommendations based on the conducted research, including some policy options to divert more containerized flows on rail.

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## *Item 5*

### **Diesel Emissions Testing, Performance Evaluation, And Operational Assessment; Project Extension To Examine An Ultra-Low Sulfur Diesel Fuel: TxLED**

*CENTER FOR TRANSPORTATION RESEARCH*

*CTR 4576-4 • 2006*

When TxDOT began using an ultra-low sulfur diesel fuel, Texas Low Emission Diesel (TxLED), they commissioned a simultaneous study of the effectiveness of the use of TxLED by both the TxDOT fleet and their contractors, the Associated General Contractors (AGC). Because TxLED is similar to conventional diesel fuel, there were no health or safety issues that had to be addressed in this study. The results from the full load torque curve tests and the operator assessments, together with the properties of TxLED compared to those for 2D on-road diesel fuel, indicate that there should be no performance penalties associated with use of TxLED. It was also found that, as expected, TxLED does not separate into lighter and heavier components over time and does not pose corrosion problems. For all engines tested, TxLED provided a statistically significant benefit in NOx emissions compared to 2D on-road diesel fuel. With the exception of only one engine, the NOx emissions benefits from using TxLED were higher than the benefits claimed in Texas State Implementation Plan. Additionally, statistically significant benefits in PM emissions were found for three of the six engines tested and small, but statistically significant, benefits in fuel consumption or fuel economy were found for three of the engines. Therefore, the cost-effectiveness of the NOx emissions reductions obtained with TxLED was the primary focus of this study. It is concluded that TxLED is a cost-effective strategy for reducing emissions from the TxDOT and AGC fleets.

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## *Item 6*

### **Pollutant Removal on Vegetated Highway Shoulders**

*CENTER FOR TRANSPORTATION RESEARCH*

*CTR 4605-1 • 2006*

Nonpoint source pollution is an environmental problem that is a concern among regulatory agencies and water quality professionals. A portion of this pollution is conveyed to receiving waters by stormwater drainage from highways, often via vegetated roadside shoulders, also called borrow ditches. The vegetated shoulders may act as filter strips, reducing the concentrations of pollutants in highway runoff. Vegetated filter strips are recognized by many regulatory agencies as a Best Management Practice for the control and treatment of stormwater; however the relationship between performance and design parameters such as length, width, and vegetative cover are not well understood. Therefore, it is important to evaluate and document the extent to which these vegetated areas may reduce pollutant loads in runoff and mitigate the effects of discharging untreated highway runoff directly into receiving bodies of water. The primary objective of this study is the documentation of the stormwater quality benefits of these vegetated sideslopes typical of common rural highway cross sections in Texas. The scope of this project included the selection of six sampling sites in the Austin and College Station areas that met a predetermined set of site criteria; the installation of 24 passive stormwater samplers and collection systems; monitoring of the sites and collection of runoff samples from storm events over a 14-month period; laboratory analyses of each of the runoff samples; compilation of the results into a database; statistical and graphical analyses of the results to determine differences between sites; and the evaluation of the performance of each of the vegetated filters and recommendations of site conditions conducive to maximum pollutant removal. Results from this study indicate that significant removal of some pollutants occur over the width of vegetated filter strips, often within the first four meters of the edge of pavement. The results also indicate that vegetation density has a direct effect on the performance of vegetated filter strips. Dense vegetative cover within close proximity to the edge of pavement and vegetative cover of at least 90% are recommended to allow for maximum pollutant removal. The effects of a permeable friction course on the quality of runoff leaving the road surface were also examined. These results indicate that the porous surface appears to have a substantial impact on the quality of runoff leaving a road surface. These improvements in water quality are as great, if not greater, than the improvements gained from the vegetated filter. Overall, the results from this study indicate that vegetated filter strips should be utilized by TxDOT as a best management practice for controlling and treating stormwater runoff from Texas highways. These filter strips demonstrate consistently high removal efficiencies for many of the pollutants of concern in stormwater runoff. In addition to providing water quality benefits, these vegetated areas are inexpensive and easy to implement, are easy to manage, and provide aesthetic benefits to the surrounding environment.

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## *Item 7*

### **Quantitative Description of Informational Dimensions of Urban Freeways**

*CENTER FOR TRANSPORTATION RESEARCH*

*CTR 4621-1 • 2006*

In an urban environment drivers typically have numerous information sources contributing to performance of driving tasks. An objective of this research is development of a practical tool to help traffic and safety professionals analyze driver information load and select countermeasures for information level corrections. The first task to accomplish the project objective was development of a methodology for quantitative description of informational dimensions of urban freeways, taking into account the complex impact of different information sources. Corresponding with a Positive Guidance concept, all sources of information were classified into three groups in relation to highway, traffic control, and traffic. The first group includes such roadway design features as horizontal and vertical alignments, number of traffic lanes, width of traffic lanes and shoulders, entrance and exit ramps. The traffic control group includes road signs, signals, and pavement markings. The third group, traffic, characterizes impacts of other vehicles on driver information load. In addition, the analysis considers that urban freeways are typically surrounded by numerous objects that are not related to traffic but can take driver attention or create inappropriate background for road signs and therefore interfere with perception of more vital information. These include commercial electronic billboards, commercial static billboards, buildings, and any other objects that consume driver attention but do not relate to traffic. With the purpose of determining typical combinations of the above-mentioned information sources, urban freeways in Texas were investigated. Based on joint analysis of the information load and principles of driver information processing, information quantification criteria were identified and the methodology for quantitative description of informational dimensions of urban freeways was developed. The structure of the utilized information load matrix isolates impacts of different information sources, and, therefore, with further investigations of their impact on driver behavior and reactions, will allow determination of each source contribution.

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## *Item 8*

### **2004 Annual Interim Report**

*CENTER FOR TRANSPORTATION RESEARCH*

*CTR 4661-1 • 2005*

This report includes a synthesis of the main findings from the investigations conducted during the first year of the research project.

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## *Item 9*

### **Trans-Texas Corridor Right-of-Way Royalty Payment Feasibility**

*CENTER FOR TRANSPORTATION RESEARCH*

*CTR 4808-1 • 2006*

The Trans-Texas Corridor is a proposed new tolled multimodal transportation system 4,000 miles long across Texas. The 1,200-foot-wide right-of-way (ROW) required is significantly more than that for previous transportation projects. Recent legislation (HB 3588) permits the Texas Department of Transportation (TxDOT) to offer landowners in the corridor ROW a corridor participation payment—a portion of the revenue to be derived from the corridor, for an interest in real property or a real property right. Such payments (termed “royalty payments” when this research project commenced) are a completely new approach to procurement of ROW for transportation corridors in the United States. This report presents the results of research conducted by the Center for Transportation (CTR) for TxDOT on the feasibility of paying for ROW for the Trans-Texas Corridor with toll revenues. It includes results presented in previous products of this research project, namely: P1— an assessment of Trans-Texas Corridor ROW acquisition issues, P2— an analysis of the financial feasibility of paying for ROW with toll revenues, P3— a study of landowner response to the ROW royalty concept and alternatives, P4— a financial analysis of alternative deferred payment options, and P5— royalty payments plans and financial outcomes.

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## **Item 10**

### **Preliminary Experimental Plans for the Texas Accelerated Pavement Test Center (TxAPT)** *CENTER FOR TRANSPORTATION RESEARCH* *CTR 5-1924-01-P5 • 2006*

This document defines a test plan for a Shakedown test of the newly refurbished Texas Mobile Load Simulator (TxMLS). The test will be performed at the Texas Accelerated Pavement Testing (TxAPT) Center, which is currently under construction at the J.J. Pickle Research Campus in Austin, Texas, with an expected completion date in August 2003. Originally the Shakedown test was to be carried out by TxAPT staff in conjunction with the first research study, Project 0-4574. TxDOT decided to separate these two activities; therefore the Shakedown test will be the responsibility TxAPT Center staff, and the first research study, hereinafter referred to as the Pilot Study, will be performed under Project #0-4574 titled "Determination of the Impact of HB2060 Permits on Texas Load Zone Roads" at the University of Texas at Austin, Center for Transportation Research (CTR). The purpose of the Shakedown test is to: 1. Evaluate and characterize operational characteristics of the refurbished mobile load simulator (MLS). 2. Evaluate existing instrumentation and software used to collect research data 3. Install and evaluate selected instrumentation that has not yet been field test for either primary or secondary data collection. 4. Establish and formalize the data handling, cleansing, processing, storage, backup, and distribution protocols. 5. Collect pavement performance data for the Pilot Study. On June 15, 2003, construction began on the TxAPT test pavement at the J. J. Pickle Research Campus (PRC) in Austin, Texas. Ranger Excavating, Inc. is the prime contractor performing the site construction which includes, excavation, embankment construction, flexible base, asphalt installation, and utilities that include water/wastewater service; 110V - 100 amp and 480V - (3 phase) 400 amp electrical service, telephone and fiber optic Ethernet service. Expected completion date of construction is August 29, 2003. The MLS device is currently located on a temporary site at PRC where it is undergoing the final stages of renovation. This site was prepared by TxAPT to accommodate the TxDOT Pavement group renovations. Shakedown testing will commence shortly after the TxAPT test pavement construction is completed and the TxMLS renovations are complete and declared ready for testing (Figure 2.1). For the Shakedown, the MLS will be moved from it temporary site at PRC to the assigned test pad at the TxAPT Center (Figure 2.2).

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## **Item 11**

### **Application of Ultrasonic Impact Treatment to In-Service Signal Mast Arms** *CENTER FOR TRANSPORTATION RESEARCH* *CTR 5-4178-01-2 • 2006*

The application of Ultrasonic Impact Treatment (UIT) to signal mast arms in the field is described. UIT has been demonstrated in the laboratory to provide a simple means to improve the fatigue performance of the fillet weld of connection of the mast arm tube to the end plate. The procedures used in the field are detailed and the time required for a repair documented. A fatigue test of a mast arm treated in the field is presented. The fatigue test indicated that the UIT treatment improved the performance of the connection to the level of a connection with a thicker end plate. UIT provides a cost effective means of increasing the service life of the mast arms at intersections where galloping oscillations of the mast arms have been observed.

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## *Item 12*

### **Literature Review of Curing in Portland Cement Concrete Pavement**

*CENTER FOR TRANSPORTATION RESEARCH*

*CTR 5106-1 • 2006*

Curing of concrete has an effect on hardened concrete properties and overall long-term performance of portland cement concrete (PCC) pavement. A significant amount of research has been conducted to evaluate curing effectiveness and its effect on concrete properties. This report synthesizes the findings from the literature review, including the relative humidity measuring techniques. The most frequently measured concrete properties are strength and permeability. They are important properties; however, in portland cement concrete pavement, volume change potential affected by curing effectiveness is as important for its performance. Not much information has been found in this regard. It appears that the curing effect is confined to the surface of the pavement, which is called curing-affected zone (CAZ). The extent of this zone varies, depending on the concrete properties and curing effectiveness; with average values varying from 1/4in. to 1/2in. CAZ has a significant effect on the performance of PCC pavement. Further evaluation is needed to investigate the effect of curing on CAZ and overall pavement performance. Other state departments of transportation (DOTs) specifications for curing concrete pavement were investigated and all are nearly identical. They are prescriptive and method-type specifications and no compliance testing is required.

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## **Item 13**

### **Amber Alert, Disaster Response and Evacuation, Planned Special Events, Adverse Weather and Environmental Conditions, and Other Messages for Display on Dynamic Message Signs**

TEXAS TRANSPORTATION INSTITUTE

TTI 4023-4 • 2006

This report provides the results of focus group studies and human factors laboratory studies to investigate issues related to America's Missing: Broadcast Emergency Response (AMBER) alerts, disaster response and evacuation (flooding, hurricane evacuation, and terrorist attacks), planned special events, and adverse weather and environmental conditions in order to design effective messages for display on dynamic message signs (DMSs). Focus group studies were conducted in six cities in Texas to obtain driver views of the above issues and to discuss driver information needs. The results of the focus group studies were used as the basis for more extensive human factors laboratory studies that were then conducted in six cities in Texas. The laboratory studies were administered using several different methods of participant interface including laptop computer programs, maps, card selection process, and a driving environment simulator. This report contains specific findings and recommendations concerning message design issues for DMSs for each of the topic areas identified.

Full-text PDF of this report is available for free download at <http://tti.tamu.edu/documents/0-4023-4.pdf>

## **Item 14**

### **Dynamic Message Sign Message Design and Display Manual**

TEXAS TRANSPORTATION INSTITUTE

TTI 4023-P1 • 2006

Stopped traffic on freeways poses safety and operational concerns to drivers, transportation agencies, construction and maintenance contractors, and enforcement and emergency service personnel. Safety issues relate to driver ability to make gradual transitions from freeway speeds to stopped conditions without erratic maneuvers or crashes. Operational concerns relate to the reliability and predictability of the freeway network. The primary type of multi-vehicle crash on a freeway facility is the rear-end collision, comprising over 50 percent of freeway crashes by some research findings, caused generally due to normal speed traffic encountering stopped traffic on the main lanes or ramps. Drivers frequently have minimal or no warning about downstream queuing, and information given on static signs is difficult to keep current with rapidly fluctuating queues in congested areas. Stopped traffic on the freeway may be due to a multitude of causes. This research project evaluated issues relating to stopped or very slow traffic due to three major causes: recurrent traffic congestion due to over-capacity conditions during peak periods, congestion due to construction and maintenance work zones, and congestion due to incidents such as crashes. In the first phase of this project, the research team conducted a literature review to determine current practices for advance warning for stopped traffic, observed field locations with traffic stopped due to various conditions, and determined advance warning techniques applicable to Texas. Report 4413-1 presents this information. In the second phase of this project, researchers tested two advance warning techniques using static warning signs on Dallas area freeways. The research team synthesized the field test results and developed recommendations for further research and ways to improve the signing. This information is presented in this report. Many factors remain to be addressed in future research; however, observations conducted in this project can provide guidance to those testing and implementing operating systems for advance warning of slow/stopped traffic on freeways.



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## **Item 15**

### **Recommendations for Stabilization of High-Sulfate Soils in Texas**

TEXAS TRANSPORTATION INSTITUTE

TTI 4240-3 • 2006

Over the last 15 years, the Texas Department of Transportation (TxDOT) has seen an increase in pavement failures during and immediately after construction on roads designed to last 20 years or more. The cause of many of these failures is sulfate-induced heave where an expansive mineral called ettringite is formed from a calcium-based stabilizer (lime or cement) reacting with clay and sulfate minerals (usually gypsum) in the soil. Traditionally, TxDOT has removed and replaced soils with more than 2000 ppm sulfates. Earlier in this research project, lime was identified as a plausible stabilizer in soils bearing sulfate concentrations up to 7000 ppm. This portion of the research investigates if anything can be used to stabilize soils (reduce swell and increase strength) with sulfate concentrations above 7000 ppm. Three-dimensional swell was measured on laboratory prepared specimens with sulfate concentrations of 0, 10,000, and 20,000 ppm. Twelve stabilizers were selected for the 3-D swell testing based upon positive results obtained by other researchers. Stabilizers that significantly reduced swell in the high-sulfate soils were then subjected to unconfined compressive strength testing. Three stabilizers (Clays tar 7, ground granulated blast furnace slag + lime, and class F fly ash + lime) provided significant swell reduction (10 to 12 percent) over the untreated soil; two of the stabilizers were selected for strength testing. The fly ash swell test results were obtained too late to include in strength testing. The Claystar7 showed an improvement of 41 Ib/in<sup>2</sup> over the untreated sample for retained strength in the unconfined compressive strength after 10 days capillary rise. The ground granulated blast furnace slag showed a 79 Ib/in<sup>2</sup> retained strength. This project showed that soils with sulfate concentrations up to 20,000 ppm can be treated in a timely manner without having to remove the high-sulfate soil and replace it with a select material.

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## **Item 16**

### **Incident Evaluation Procedures and Implementation Requirements**

TEXAS TRANSPORTATION INSTITUTE

TTI 4745-2 • 2006

Project 0-4745 developed a geographic information system (GIS)-based approach for the determination of patterns in the spatial and temporal distribution of incidents along freeway corridors. The research documented incident detection and data archival at several transportation management centers (TMCs) in Texas, a process to develop a data model and geodatabase of intelligent transportation system (ITS) equipment and archived ITS data, and a process to determine patterns in the spatial and temporal distribution of freeway incidents. This report contains products 0-4745-P3 (which includes detailed incident evaluation procedures) and 0-4745-P4 (which addresses process definitions and implementation recommendations) that were developed during the second phase of research project 0-4745.

Full-text PDF of this report is available for free download at <http://tti.tamu.edu/documents/0-4745-2.pdf>



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## **Item 17**

### **Incident Detection Optimization and Data Quality Control**

TEXAS TRANSPORTATION INSTITUTE

TTI 4745-3 • 2006

Project 0-4745 developed a geographic information system (GIS)-based approach for the determination of patterns in the spatial and temporal distribution of incidents along freeway corridors. The research documented incident detection and data archival at several transportation management centers (TMCs) in Texas, a process to develop a data model and geodatabase of intelligent transportation system (ITS) equipment and archived ITS data, and a process to determine patterns in the spatial and temporal distribution of freeway incidents. This report describes the procedures and activities completed during the second phase of the project. The analysis included an evaluation of incident detection procedures at a sample TMC (TransGuide) and an assessment of the feasibility to modify/calibrate alarm threshold values to help optimize incident detection practices at that TMC. The research involved the use of two performance measures (detection rate and false alarm rate) and the development of a prototype offline tool to evaluate automatic incident detection algorithm performance. The analysis also included an evaluation of archived loop detector data completeness and quality control.

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## **Item 18**

### **Evaluation of Cost-Effective Technologies for Advance Detection**

TEXAS TRANSPORTATION INSTITUTE

TTI 5002-1 • 2006

This project developed and evaluated various advance detection systems. The objective was to use off-the-shelf technology to develop these detection systems and evaluate their performance as well as their cost-effectiveness with respect to traditional advance inductive loop using lead-in wire. These systems were deployed on the northbound approach of the intersection of SH 6 and FM 185. The baseline system was the A WEGS detectors on this approach. This project developed the installation guidelines for various detection systems. TTI researchers found that inductive loops with contact closure radio were very accurate in counts, classification, and speeds. Traficon video detection system was very accurate in counts and measuring vehicle lengths during daytime and measuring speeds during both daytime and nighttime. The counts and classification can improve by providing some ambient light near the detector station. SAS-1 acoustic detector can be very cost-effective as it contains detection as well as a communication system. However, the performance needs to be checked by requesting the vendor to provide individual vehicle speeds and classification, which the unit is already measuring. TTI researchers recommend that the user not only look at installation cost, but also at life cycle cost of the system. Some systems such as inductive loops can have a higher life cycle cost.

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## **Item 19**

### **Evaluation of Wet-Weather Pavement Markings: First Year Report**

TEXAS TRANSPORTATION INSTITUTE

TTI 5008-1 • 2006

This report details the first year of a two-year project. During the first year the emphasis was on determining the wet-night visibility of various pavement marking systems under a variety of realistic rainfall levels. The researchers performed a literature review. They analyzed 20 years of Texas rainfall data to determine the most appropriate rainfall levels to use as design criteria for a rain tunnel. Using a low, medium, and high rainfall rate (0.28, 0.52, and 0.87 inches per hour, respectively), a 1600 ft long rain tunnel was designed and built at Texas A&M University's Riverside Campus. Experimental subjects drove through the rain tunnel and looked for pavement markings simulating skip lines. The researchers rotated pavement marking samples at different locations before each trial. The detection distance was recorded when the subject located the pavement marking sample. The data were analyzed in four main sections: waterborne paints, thermoplastics, tapes, and exotic materials. The analysis also included investigations into the wet-night visibility of rumble stripes, as well as wider lines. The measured dry and wet retroreflectivity measurements were analyzed, and the predictive capabilities of the wet retroreflectivity measurements were evaluated with respect to the wet-night detection distance of the markings. During year two the researchers will supplement the detection distance data with additional data from a second round of wet-night visibility experiments. The researchers will also consider durability and cost information before finalizing the research. The researchers will also develop and implement research activities that can be used to develop application recommendations for contrast pavement marking materials based on visibility performance, durability, and cost.

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## **Item 20**

### **Crack Width Prediction for Interior Portion of Inverted 'T' Bent Caps**

UNIVERSITY OF HOUSTON

UH 1854-3 • 2006

Inverted "T" bent caps are used extensively in highway bridges to support elevated roadways on beams. Such bent caps have appeal because they are esthetically pleasing as well as economically sound. The cross-section of an inverted "T" bent cap consists of a "web" (or "stem") with short cantilever "ledges" at the bottom to support the beams, thus minimizing the structural depth of bridges. At service load unacceptable diagonal cracking frequently occurs between the cantilever ledges and the web. An important factor contributing to the observed cracking is the lack of a rational behavioral theory that supports serviceability design of such bent caps. Current design guidelines are based on the ultimate load stage and do not address cracking at service load (AASHTO, 1996; ACI, 95; Mirza and Furlong, 1985). Thus, it is necessary to develop a serviceability design method that takes into account the deformation compatibility condition because any method that attempts to determine crack width must consider strains in both the concrete and the steel. To this end, we have taken the following approach: First, develop a compatibility-aided struts-and-ties model that leads to a simple design method capable of controlling crack widths at service load; and second, conduct experimental tests on full-sized specimen and use the test results to calibrate the theoretical model.

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### March Issue 06-03

Please check the box for the item(s) you want to borrow.

- |                             |                  |                             |                 |
|-----------------------------|------------------|-----------------------------|-----------------|
| <input type="checkbox"/> 1  | CTR 1401-2       | <input type="checkbox"/> 11 | CTR 5-4178-01-2 |
| <input type="checkbox"/> 2  | CTR 1857-4       | <input type="checkbox"/> 12 | CTR 5106-1      |
| <input type="checkbox"/> 3  | CTR 4322-1       | <input type="checkbox"/> 13 | TTI 4023-4      |
| <input type="checkbox"/> 4  | CTR 4410-2       | <input type="checkbox"/> 14 | TTI 4023-P1     |
| <input type="checkbox"/> 5  | CTR 4576-4       | <input type="checkbox"/> 15 | TTI 4240-3      |
| <input type="checkbox"/> 6  | CTR 4605-1       | <input type="checkbox"/> 16 | TTI 4745-2      |
| <input type="checkbox"/> 7  | CTR 4621-1       | <input type="checkbox"/> 17 | TTI 4745-3      |
| <input type="checkbox"/> 8  | CTR 4661-1       | <input type="checkbox"/> 18 | TTI 5002-1      |
| <input type="checkbox"/> 9  | CTR 4808-1       | <input type="checkbox"/> 19 | TTI 5008-1      |
| <input type="checkbox"/> 10 | CTR 5-1924-01-P5 | <input type="checkbox"/> 20 | UH 1854-3       |

These items are available on a **two-week** loan basis.

Please fill out form completely and use other side of this page to mail in order. Thank you.

NAME \_\_\_\_\_

D/D/O \_\_\_\_\_

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