

TRANSPORTATION RESEARCH DIGEST

AUGUST 2008

ARIZONA TRANSPORTATION INSTITUTE

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AUGUST 2008

TO: TRANSPORTATION PROFESSIONALS, MANAGERS, & POLICY MAKERS

FROM: ARIZONA TRANSPORTATION INSTITUTE

The volume of information on transportation issues, policies, technologies, and related topics is huge. Not even the most well-read professional can keep up with everything that might be useful to know. The *Transportation Research Digest* series is designed to expedite the transmission of information by condensing and summarizing significant documents. Busy professionals or managers may quickly obtain the gist of new developments and determine whether they need to see the full document.

The *Transportation Research Digest* is not meant to present definitive resolutions of scientific or policy controversies, but contributions to the pursuit of knowledge and the debate of issues. The intent is to be comprehensive rather than conclusive on the multitude of issues and topics of concern to those working in the field of transportation. Readers are encouraged to obtain the original document summarized in the *Transportation Research Digest* and subject the content to their own judgment.

Transportation professionals who would like to recommend documents to be summarized or submit summaries to be considered for inclusion in this publication are invited to do so. To recommend a document please send a copy (or information indicating how a copy can be obtained) of the research report to be summarized. To be considered, the report must meet the following requirements: (1) it is transportation related, (2) it is no more than two years old, (3) there is enough information in the report to warrant a two page summary. To write a summary, insure that the document being summarized meets the above requirements. The summary should be submitted in an electronic format. This summary should be in the 500 to 800 word range and may include tables and/or simple graphics—all of which must fit within the *Transportation Research Digest's* two-page format. Submissions are subject to editing for clarity and length. We do not guarantee that all submissions will be published.

If you would like to obtain the full report upon which a *Transportation Research Digest* summary is based you have several options. Check your local university library. You may want to contact the publisher using the contact information appearing in the *Transportation Research Digest*. Some of the documents are free for the asking. Others can be purchased.

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Transportation Research Digests from December 1995 to November 2003 are available at <http://www.dot.state.az.us/ABOUT/atrc/Publications/DocRev/TRDtest.htm>

A “Topic” code in the Table of Contents will help readers more quickly identify items of interest. The topic codes are explained in the table below.

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ADM	Administration	PLAN	Planning
AIRP	Airports	PRIV	Privatization
AVIA	Aviation	RAIL	Railroads
BIKE	Bicycles	RDSO	Roadside
CON	Construction	ROW	Right-of-Way
ECON	Economics	SAFE	Safety
ENV	Environment	STR	Structures
FIN	Finance	TECH	Technology
INOV	Innovations	TOLL	Toll Roads
MAIN	Maintenance	TRAN	Transit
MISC	Miscellaneous	TRF	Traffic
MVD	Motor Vehicle Dept	TRK	Trucking
PAVE	Pavement	VEH	Vehicles

Requests or inquiries may be made via e-mail (jsemmens@cox.net).

Thank you.

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Emerging Technologies for Construction Delivery, NCHRP Synthesis 372 by John J. Hannon, University of Southern Mississippi Hattiesburg, Mississippi (Transportation Research Board, 500 Fifth Street, NW, Washington, DC 20001; (202) 334-3213; <http://gulliver.trb.org/bookstore>) (2007)

Highlights

- The five technologies addressed in this report are components that constitute what some are terming "smart jobsites."
- Early adopters of these technologies report an increase in quality, a decrease in rework and change orders, and improved safety.

This synthesis study provides information on the use of five emerging technologies by transportation agencies for construction projects. The technologies explored are:

1. Global positioning systems (GPS) for layout, machine guidance, and quantity tracking;
2. Handheld computers for construction records (e.g., inspection, materials testing, and quantity tracking);
3. Automated temperature tracking for concrete maturity monitoring to optimize concrete placement for bridge and road construction;
4. Four-dimensional (4D) computer-aided drafting (CAD) modeling for constructability analysis and for improved communications (public outreach and visualization of project staging); and
5. Remote project monitoring with web-based video cameras.

The TRB Committee on Application of Emerging Technologies (AFH30) described the need for exploiting current advancements in construction technology in the following terms:

As the new century approaches and the baby boomers age and begin to retire, labor shortages are anticipated. Therefore, new construction automation, equipment, and techniques will be needed so the equivalent work can be performed with fewer workers. The automation is likely to prove more reliable, efficient, and cost-effective as well.

Thus, using that belief as the backdrop, this study furnishes the necessary information for transportation officials to begin exploiting the five promising technologies, detailed herein. These technologies have reached a developmental maturity level to make them practical-if not imperative-tools in the delivery of construction projects. After conducting an extensive literature search, distributing and reviewing the transportation agency survey (41 state departments of transportation and 7 Canadian transportation agencies responded), and collecting additional information gathered from various subject-matter experts, it is clear that these technologies have proven their value in the field despite the industry's low adoption rate. The application of these technologies promises potential time and cost savings over time. A return on investment analysis is required to accurately justify incorporation of the technologies into the construction project life-cycle work-flow process of transportation agencies. Risks may lie in the fast development of new technologies and the relative lack of standardization and specification, rendering fiscal investments in technology systems that are quickly obsolete or that are unable to scale

as required by the size of transportation agencies.

Several of these technologies are disruptive in nature, that they require changes in how business is conducted. Although the private sector, which is typically less bureaucratic and driven by the profit motive, can justify such process changes more quickly, public agencies must take a different route to incorporate change. The public agency attitude toward risk-taking as well as the autonomous segmentation of transportation agencies (many regional offices with differing levels of technology application and work-flow processes) may require a concerted effort toward standardization and cost justification to realize the potential benefits of these technologies.

The five technologies addressed in this report are components that constitute what some are terming "smart jobsites." They can be used together, in conjunction with other supporting technologies, to create a more efficient system of construction project delivery. The motive for adopting these tools is not necessarily payroll reduction overheads, but the empowerment to compress construction schedules, spend payroll time in critical thinking activities (management) instead of administrative functions, and provide access to information more quickly so as to justify the investment. Faster project delivery, without decreases in quality, is a benefit to the traveling public. In addition, early adopters of these technologies report an increase in quality, a

decrease in rework and change orders, and improved safety for both project and non-project personnel.

The smart jobsite concept is realizable today. The five technologies explored in this synthesis, along with background support tools such as broadband network connections and databases, have proven to be workable and beneficial for some contract stakeholders. With regard to transportation agencies, the synthesis survey revealed common responses across the technology types as to the restriction of their adoption or use. The most prevalent responses regarding barriers to implementation of the technologies are:

- Budget restraints,
- Absence of specifications,
- Ignorance of the technology's potential benefits,
- Lack of end-user technical skills (personnel skills), and
- Agency procedural issues.

For transportation agency budgeting to include the cost of these technologies, the benefits of their use must be known for return on investment decisions. If the agency can procure the technology, it must have available personnel skilled in its use for implementation. Finally, like all organizations that adopt technology that effects work flow processes, it should be prepared to change procedures (specification) of organizational operation as needed.

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Greenhouse Gas Emissions of the U.S. Transportation Sector by John Davies, Michael Grant, John Venezia, and Joseph Aamidor in *Transportation Research Record 2017* (Transportation Research Board, 500 Fifth Street, NW, Washington, DC 20001; (202) 334-3213; <http://gulliver.trb.org/bookstore>) (2007)

Highlights

- GHGs from heavy-duty trucks have increased by 62%.
- GHGs from light-duty vehicles have increased by 23%.
- Commercial aircraft GHG emissions have increased by about 10%.

This paper was developed with the U.S. Environmental Protection Agency's (EPA's) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2004* as its primary foundation for data. The inventory is prepared annually by EPA and accounts for all national greenhouse gas (GHG) emissions within a framework specified by the United Nations Framework Convention on Climate Change (UNFCCC). Data are organized primarily around specific GHGs such as carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), and hydrofluorocarbons (HFCs). Many of these gases are further characterized by source categories specified by the UNFCCC, such as fossil fuel combustion or non-energy use of fuels. This method of presentation is most useful for climate specialists but is not easily understood by analysts focused on specific economic sectors such as transportation. To improve the usefulness of GHG data for these professionals, the EPA inventory includes GHG emissions by economic sector. EPA also disaggregates transportation GHG emissions in the inventory by mode, including passenger cars, light-duty trucks, heavy-duty vehicles, aircraft, boats and ships, and so forth.

EPA's Office of Transportation and Air Quality (OTAQ) has recognized that further detail is necessary to identify significant trends and factors affecting transportation-related GHG output. In March 2006, OTAQ released *Greenhouse Gas Emissions from the U.S. Transportation Sector 1990-2003*, which provides complementary detail to the Inventory transportation estimates. The report contains analysis of historical trends, estimates of life-cycle GHG emissions, and discussion of emerging issues. This paper highlights significant findings from the report, with updates to reflect data through 2004, including

1. Factors affecting GHGs from personal and freight transport,
2. Sources of uncertainty in the inventory estimates of transportation GHGs, and
3. Methodological improvements developed for the 2006 inventory (*Inventory of u.s. Greenhouse Gas Emissions and Sinks: 1990-2004*) and possible improvements for the 2007 Inventory (addressing years 1990-2005).

Transportation fuel consumption is broadly affected by travel activity and the amount of energy vehicles use to move people and goods. In the short term, changes in transportation GHG emissions primarily reflect variation in travel activity that accompanies year-to-year economic fluctuations. Additional factors are influential over longer timeframes, especially the cost of fuel and vehicle purchase

decisions, which in turn can influence travel patterns and vehicle energy efficiency.

From 1990 to 2004, there has been a significant increase in travel associated with three major categories of transportation: light-duty vehicles, heavy-duty trucks, and aircraft. Commercial aircraft passenger miles traveled (PMT) increased by 64%, heavy-duty truck vehicle miles traveled (VMT) increased by 53%, and light-duty VMT grew by 37%. However, the change in energy efficiency has

been substantially greater for aircraft than light-duty vehicles and heavy-duty trucks. These trends have resulted in significant differences in the GHG growth rate of major transportation sources. GHGs from heavy-duty trucks have increased by 62%, GHGs from light-duty vehicles have increased by 23%, and commercial aircraft GHG emissions have increased by only about 10%.

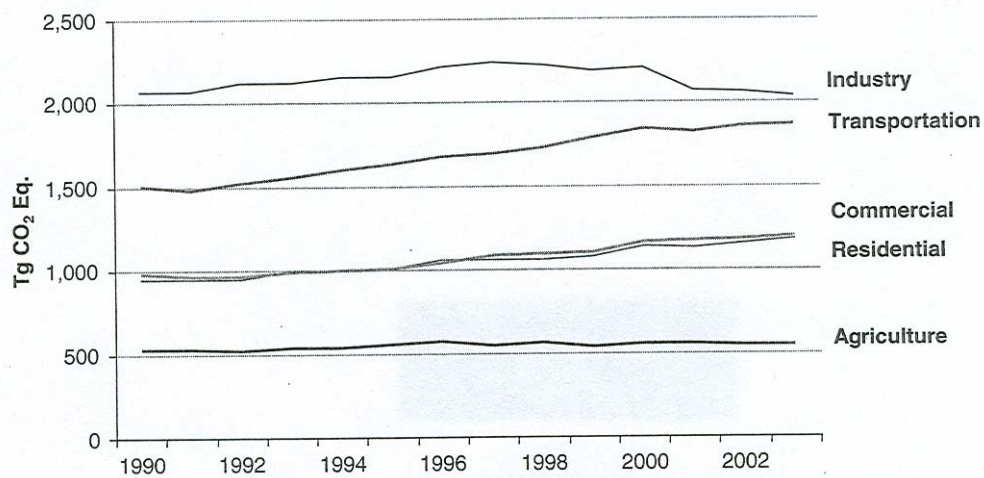


FIGURE 1 U.S. greenhouse gas emissions by end-use economic sector, 1990-2004.

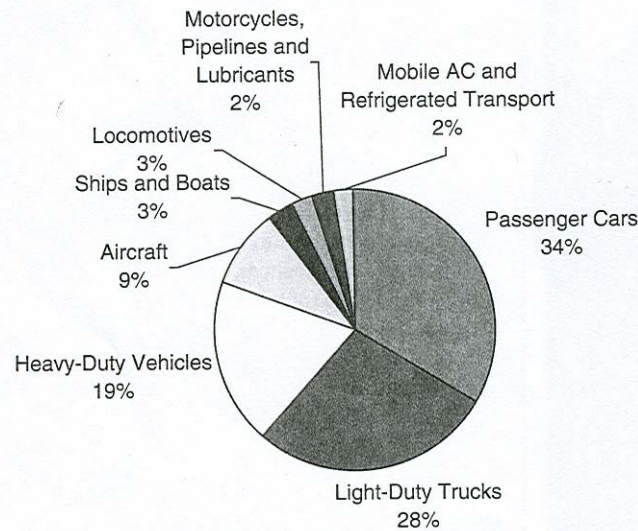


FIGURE 2 U.S. transportation GHG emissions, by source, 2004 (1).

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Evaluating the Retroreflectivity of Pavement Marking Materials Under Continuous Wetting Conditions by Adam M. Pike, H. Gene Hawkins, Jr., and Paul J. Carlson in *Transportation Research Record 2015* (Transportation Research Board, 500 Fifth Street, NW, Washington, DC 20001; (202) 334-3213; <http://gulliver.trb.org/bookstore>) (2007)

Highlights

- Wet weather performance is one of many factors that practitioners should consider when selecting pavement marking materials.
- Other factors to consider include dry weather performance, costs, application capabilities, availability, service life, maintenance requirements, and driver needs.

Pavement markings serve an important role in delineating the road way and providing regulatory, warning, and guidance information to drivers. The *Manual on Uniform Traffic Control Devices* (MUTCD) requires pavement markings to be retroreflective, unless ambient illumination ensures that the markings are adequately visible. Markings provide this retroreflective capability through the use of beads embedded in the marking's binder. These beads help to reflect light from a vehicle's headlamps back toward the headlamps. Because drivers are close to the illumination source, they can see this retroreflected light.

Over the years, many advancements in pavement marking materials have improved both durability and visibility of markings. In particular, the last decade or so has witnessed an increased emphasis on the nighttime visibility of pavement markings. In a recent rule-making activity, FHWA indicated that it plans to initiate rule making in the near future to revise the MUTCD to establish minimum levels of pavement marking retroreflectivity. Virtually all of the research supporting minimum retroreflectivity recommendations for

pavement markings has focused on the performance of dry markings. More recently, however, researchers and industry have focused increased attention on the nighttime visibility of wet pavement markings. This includes developing standard methods for measuring pavement marking retroreflectivity in various conditions of wetness. The Texas Transportation Institute (TTI) recently conducted research that expands the knowledge base on wet pavement marking visibility. A portion of that research effort included evaluations of issues related to measuring marking retroreflectivity in dry conditions and various conditions of wetness. This is because there is no published research on the impacts of various continuous wetness conditions on retroreflectivity measurements. This paper describes that research and offers findings about the materials evaluated and the standard methods used to measure retroreflectivity.

Conclusions

The findings from this research clearly indicate that retroreflectivity of dry markings are almost always higher than the retroreflectivity of the same markings in various conditions of wetness. Furthermore, the retroreflectivity of wet markings generally decreases as the amount of water on the marking increases. However, the change in retroreflectivity as the wetness increases is not consistent across material types or rainfall intensities. This makes it difficult to use the ASTM wet marking standard procedures for

predicting wet marking retroreflectivity. On the basis of results and findings of this experiment, the following conclusions are offered:

Wet weather performance is one of many factors that practitioners should consider when selecting pavement marking materials. Other factors to consider include dry weather performance, costs, application capabilities, availability, service life, maintenance requirements, and driver needs.

While wet marking retroreflectivity provides a measure of performance for selected materials, by itself, ASTM E2176 should not be used to establish performance criteria or requirements associated with installation or maintenance for the following reasons:

- Markings are not viewed at night in rainy conditions very often.
- The rainfall intensity recommended by E2176 is much greater than what can be expected during virtually all rainfall events.
- The rainfall intensity range allowed by E2176 has a significant impact on retroreflectivity measurements, making it difficult to provide comparable and repeatable measurements between installations unless exactly identical setups and conditions are used.
- Variability in spray characteristics and marking longitudinal and lateral slope has a significant impact on wet retroreflectivity measurements.

More research is needed to evaluate the accuracy and application of wet marking

retroreflectivity measurement. Specific issues that should be addressed in future research include the following:

- Impact of rainfall intensity across a wider selection of material types;
- Impact of longitudinal and lateral slope on wet marking retroreflectivity values and development of correction factors, if possible, to provide the ability to compare wet retroreflectivity measurements for markings with different slope values;
- Impact of spray characteristics (droplet size, density, uniformity, etc.) on various pavement marking systems;
- Ability to develop a continuous wetting retroreflectivity measurement procedure that provides unbiased and repeatable results that relate to the actual field performance of pavement markings in a rainy condition;
- Determination of the precision and bias of the continuous wetting retroreflectivity measurements across a range of rainfall rates; and
- Cost-effectiveness of using markings with improved wet weather performance criteria. Such an analysis should include an assessment of the safety impacts of improved nighttime visibility in wet weather conditions, the amount of time when such benefits would be realized, and the costs and benefits associated with using wet weather marking materials.

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Managing Selected Transportation Assets: Signals, Lighting, Signs, Pavement Markings, Culverts, and Sidewalks, NCHRP Synthesis 371 by Michael J. Markow, Teaticket, Massachusetts (Transportation Research Board, 500 Fifth Street, NW, Washington, DC 20001; (202) 334-3213; <http://gulliver.trb.org/bookstore>) (2007)

Highlights

- This synthesis study examined several key aspects of asset management related to the selected infrastructure assets.

This synthesis study examined several key aspects of asset management related to the selected infrastructure assets, including primary sources of technical guidance for management; basic approaches to budgeting for and conducting preservation, operation, and maintenance; organizational responsibilities for ongoing maintenance; measurement of asset condition and performance, including methods and frequencies of data collection; estimates of service lives (or deterioration models) for key components of the selected assets, accounting for the different materials used; information technology capabilities available to help agencies manage these selected assets; perceptions of the transportation objectives that are served by maintaining selected assets in good condition; and major gaps in knowledge that impede better asset management, with recommendations for future research. These data were gathered through a review of U.S. and international literature, and a survey of state, provincial, county, and city transportation agencies in the United States and Canada.

The literature review indicated that management of these assets can be complicated in several ways.

- From an engineering and technical standpoint, selected assets comprise a number of components and materials,

serve in many different environments and are subject to many different types of deterioration. Developing models that adequately explain these deterioration mechanisms and that can predict service lives for the complete range of possible conditions is a major challenge.

- From a human factors perspective, the selected assets that affect mobility and safety can have complicated impacts.
- From an organizational, institutional, and procedural view, selected assets present challenges in management, coordination, and data compilation, given the typically diffused responsibility for their operation and maintenance.

The survey questionnaire was distributed to the contact individuals for asset management within each state department of transportation or state highway agency, as identified by AASHTO. A total of 35 agencies responded to this questionnaire.

Those agencies that responded to the survey were clearly interested in the management of these selected assets. Several have already developed management systems specifically directed at one or more of these classes of infrastructure. Others have incorporated these selected assets within agency-wide asset management systems or enhanced maintenance management systems. Others are now in the process of developing an

asset management approach for these assets, although they are not yet completed. At a minimum, agencies rely on existing maintenance management systems or other analytic and data gathering tools such as spreadsheet workbooks and paper log books to track and manage these selected assets.

Agencies that responded to the survey agreed substantially on why these selected assets should be managed. Many provided exactly the same or very similar rankings of the transportation goals served by these assets. However, estimates of technical data such as asset service life varied across agencies. These agencies reported that additional work is needed in a number of areas:

- *State of knowledge* -current state of knowledge regarding the performance and service life of selected assets needs to be improved to reduce variability and increase consistency and completeness.
- *Inventory*-lack of a complete, accurate, and current inventory of these selected assets was viewed by many agencies as one of the key issues to address.
- *Management capabilities and information*-although research continues on understanding and modeling the service life of selected assets and implications for performance, participating agencies identified several additional capabilities and types of information that are needed to improve management. These included a need for greater standardization in how asset service life is measured and reported; the need to evaluate service life under field conditions; additional modeling tools and related information; and simple, practical, and streamlined analytic tools to aid decision making without the need for substantial data gathering.
- *Beyond physical condition*-these selected assets demonstrate performance impacts that go beyond physical condition and service life. Measures of performance and life expectancy need to be broadened to encompass concepts such as energy consumption and functional, rather than physical, obsolescence of electronic components.
- *Dynamic commercial environment*-new technology is continually evolving for these selected assets. Although these advances provide many benefits to transportation agencies and users, they complicate an agency's ability to remain current regarding the performance and compatibility of new versus existing products.
- *Institutional factors*-maintenance responsibilities for these selected assets tend to be shared among public- and private-sector entities. Although these arrangements may make efficient use of resources, they complicate information awareness and enforcement of maintenance standards.
- *New technology*-several ideas were proposed by participating agencies for new technology that could aid in the management and repair of selected assets.
- *Better communication of priority*-participating agencies identified the need for stronger communication of the priority of selected assets.

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Assessing the Ability of Fog Seals to Seal Pavements, to Rejuvenate in Situ Binder, and to Retard Binder Oxidation by Nikompon Prapaitrakul, Thomas J. Freeman, and Charles J. Glover, Texas Transportation Institute, Texas A&M University System, College Station, Texas 77843-3135 (Texas Department of Transportation, Research and Technology Implementation Office P.O. Box 5080, Austin, Texas 78763-5080; 979.845.1734; <http://tti.tamu.edu>) (Feb 2007)

Highlights

- Effects of fog seals on pavement durability appear to be minimal, with respect to binder rejuvenation or sealing.
- Engineers should reassess the cost-benefit balance of fog seal treatments.

With the Performance Grading of asphalts, the asphalt industry has a better understanding of the additives and agents available and the performance characteristics when used in the department's more traditional surfacing treatments, i.e., thin asphalt concrete overlays and one course surface treatment. Due to the increased use of fog seal as a tool to better maintain our roadways, it has become apparent that fog seal material can be improved. Limited field trials have been conducted on fog seal products that are designed as maltene rejuvenators. Because different materials affect the performance of a fog seal and the rejuvenating properties on the existing pavement, the purpose of this project was to determine which asphalts and additives are best suited to TxDOT's needs.

This work was conducted for the purpose of assessing the effectiveness of fog seal treatments as an aid to highway maintenance managers in making sound decisions for fog seal treatments. Specifically, the objectives of this project were:

- to evaluate the physical and durability properties of fog seal binders;

- to determine whether or not the fog seal treatments penetrate into the pavement and if so, whether they are performing any significant sealing of the pavement;
- to investigate the effects of the fog seal treatments on the in situ binder; possible rejuvenation of the binder and possible effects to retard the binder aging; and
- to review the data of this project to assess the effects of air voids or binder content on binder aging in pavements.

The fog seal materials studied in this project were of two basic kinds, based upon their size exclusion chromatography chromatograms: asphalt emulsions and coal-tar type materials (a light, primarily aromatic, hydrocarbon material). The asphalt materials were both polymer modified (PASS) and unmodified (MS-2, asphalt emulsion, CaS-50). These base materials typically were 1,000 to 3,000 poise (low shear rate limiting viscosity at 60°C), approximately AC-10 to AC-30 viscosity grade, but one was quite high, at 30,000 poise.

Based upon the detailed SEC chromatograms that were measured on binder extracted from quarter inch slices of the top inch of the pavement and based upon measured water permeabilities, the conclusion seems clear that if the fog seal is penetrating into the pavement, it is not doing so to a detectable level (it is either draining off the side of the

pavement or it is draining through the pavement and away from the top surface of the pavement) and that the permeability of the pavement is not significantly reduced. Furthermore, APA tests did not show any softening of the pavements by the treatments.

Several possible effects of the fog seal treatments on the pavement and its *in situ* binder were evaluated. The effects of the treatments that were primarily of interest were rejuvenation of the binder and retardation of binder aging. The latter effects, in principle, could occur because of changes to the binder chemistry or because of restricting the transport of oxygen to the binder.

Based on these investigations, the following conclusions were reached:

- Generally, no clear effect of the fog seal treatments on the DSR map plots of binder recovered from the several slices of the pavement was observed. By comparing the DSR map to SEC chromatograms, the differences between the untreated and treated slices seem more likely due to original binder variability with depth than to the fog seal treatments. The one exception seems to be for the coal-tar treatments, which appear to harden the top layer.
- Generally, over the year or so time frame over which cores were obtained for this project, only minimal differences in the recovered binder hardening were observed. Thus, accurate hardening rates could not be

obtained for the binders recovered from the pavements.

- An effect of the fog seal treatments on hardening susceptibility was not observed.
- A paired t-test statistical analysis of recovered binder stiffnesses shows that practically the only significant effect on the rheology of the *in situ* binder was by the EB44 coal-tar type material, that it stiffens the binder, and that this effect is primarily restricted to the top quarter inch or so of the pavement.

In addition to the above results, the effect of air voids, and accessible or interconnected air voids in particular, on binder oxidation were investigated. The results are only qualitative because of the nature of the experimental data. Nevertheless, they support previous work, that the aging rates of asphalt binders are decreased by very low accessible air voids.

Conclusions

Effects of fog seals on pavement durability appear to be minimal, with respect to binder rejuvenation or sealing. Cosmetic effects or possibly protecting against shelling or raveling remain as possible benefits, although they were not assessed by this project. In response to this work, engineers should reassess the cost-benefit balance of fog seal treatments.

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Experimental Assessment of Aggregate Surfacing Materials by Robert Mokwa, Nicholas Trimble, and Eli Cuelho, Montana State University, Civil Engineering Dept., Bozeman, Montana 59717 (Research Programs, Montana Department of Transportation, 2701 Prospect Avenue, Helena, Montana 59620-1001; phone: 406.444.7693; <http://mdt.mt.gov/research>) (Jun 2007)

Highlights

- The CBC-6A aggregates generally exhibited the highest strength and stiffness of the three material types.
- Based on the results from strength, stiffness, and drainage testing, the CBC-6A materials were generally the best performers in this study.

This report details a laboratory analysis of three different grades of Montana Department of Transportation (MDT) aggregates. Two of these grades were crushed base course (CBC) materials (CBC-6A and CBC-5A) and the other grade was a crushed top surfacing (CTS) material (CTS-2A). CTS materials have smaller maximum particle sizes than CBC materials because they are intended for different uses. CBC materials are used as full depth base course aggregate layers, while CTS materials are typically used in relatively thin lifts over the CBC aggregate layer to provide a smooth flat surface for the placement of asphalt concrete.

The primary goal of this laboratory analysis was to quantify differences in engineering properties of these three material types. This information could be used to alleviate confusion among designers and District personnel regarding differences in customary practices, and to provide valuable information to construction personnel when faced with requests by contractors to change or substitute aggregate types.

The engineering properties examined in this study were: compaction, durability, strength, stiffness, and drainage. These properties were quantified by synthesizing and analyzing results from the following laboratory tests:

- geotechnical index tests,
- direct shear,
- R-value,
- permeability, and
- Los Angeles abrasion/degradation.

Statistical analyses of average values based on material type were conducted using the two sample t-test to determine if apparent trends in measured laboratory test results represented true differences between aggregate types.

Direct shear tests were performed to quantify the strength and stiffness of the materials. Several parameters were quantified during this testing including the initial stiffness (k_i), the secant stiffness (k_u), and the effective friction angle (ϕ). Another test that is used to quantify the strength and stiffness of a material is the R-value test. The R-value test is used by MDT to evaluate the stiffness, strength, and stability of sub grade and base materials. All R-value tests were completed by MDT at their Helena materials testing lab. Trends in comparing average values of these various strength/stiffness parameters based on material type are summarized in Table 15.

In summary, the CBC-6A aggregates generally exhibited the highest strength and stiffness of the three material types. The CBC-

6A aggregates exhibited higher k_i and k_u values than both the CBC-5A and CTS-2A material types. On average, the CBC-6A aggregates exhibited higher ϕ values and higher R-values than the CTS-2A materials. In terms of strength parameters measured from direct shear tests, there was no statistically significant difference between CBC5A and CTS-2A materials. The CBC-6A and 5A materials exhibited similar average R-values, which were both slightly greater than the CTS-2A materials. Overall, the CTS-2A materials generally exhibited the lowest average strength and stiffness. Although this material was the poorest performer when compared to the two CBC materials, it still exhibited relatively high strength and stiffness.

Drainage capacity was quantified using saturated constant head permeability tests. There was some scatter in the measured permeability (k) results; however, trends based on material type averages could still be statistically discerned, as summarized in the last column of Table 15. The CBC-6A and CTS-2A materials exhibited the highest average k values, while the CBC-5A materials exhibited the lowest. Permeability was shown to depend more on the fine fraction void ratio (e_f) than on aggregate type or maximum particle size. A method of predicting k based on e_f was developed, which will allow MDT

designers to estimate k based on gradation and state of compaction. This equation could be useful for comparing the hydraulic properties of base course aggregates, for estimating the hydraulic properties of materials that are out of specification, or to determine the maximum amount of material passing the No. 10 sieve to achieve a particular minimum k .

LA abrasion testing was performed to quantify the durability of the aggregates. CBC-5A Missoula and CTS-2A-Havre did not meet MDT durability specifications based on LA Abrasion testing. Results from the LA abrasion tests did not show any trends with regard to material type. It is hypothesized that the durability measurement in this test depends heavily on the mineralogy of the aggregate.

Based on the results from strength, stiffness, and drainage testing, the CBC-6A materials were generally the best performers in this study. The CBC-5A aggregates generally exhibited the second highest strength and stiffness, but also had the lowest drainage capacity. The CTS2A aggregates generally exhibited the lowest strength and stiffness, but had relatively good drainage capacity. The ability to substitute CTS-2A material for CBC aggregates depends on the relative importance that is assigned to strength, stiffness, and drainage in the pavement design model.

Table 15. Summary of Key Test Results

k_i	k_u	ϕ	R-value	Permeability
6A>5A	6A>5A	6A=5A	6A=5A	6A>5A
6A>2A	6A>2A	6A>2A	6A>2A	6A=2A
5A=2A	5A=2A	5A=2A	5A>2A	5A<2A

TRANSPORTATION RESEARCH DIGEST

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Factors Affecting Bicycling Demand by Jennifer Dill and Kim Voros in *Transportation Research Record 2031* (Transportation Research Board, 500 Fifth Street, NW, Washington, DC 20001; (202) 334-3213; <http://gulliver.trb.org/bookstore>) (2007)

Highlights

- ❑ Street networks that provide shorter distances to destinations may increase cycling.
- ❑ The most common environmental barrier keeping people from cycling more was "too much traffic."

With the rates of obesity, heart disease, and related health problems increasing in the United States, health professionals, urban planners, and policy makers are looking for ways to increase physical activity by changing the urban form. Much of the focus is on walking. Although walking is an attractive option for many reasons, bicycling offers many benefits and warrants further research. According to the *Nationwide Household Travel Survey*, more than 60% of all personal trips are 5 miles or less in length—a reasonable distance to ride a bike—and nearly 40% are 2 miles or less. However, only about 14% are within a reasonable walking distance, ½ mi or less. Despite the potential, only about 1% of the trips that people make in the United States are on bicycles, and less than 5% of trips under ½ mile are made on bicycles. A 2002 nationwide survey of people age 16 years and older found that 27% had bicycled in the past 30 days, with recreation being the most common purpose.

Given the potential for bicycling for both utilitarian travel and recreational purposes, why are more people not cycling? The research on bicycling in the United States provides some general indications, but it is limited in scope and sometimes uses unreliable methods. This

research project aims to help fill some of the gaps by examining the relationship between community environmental factors (e.g., bicycle infrastructure, land use, and network connectivity) and people's decision to bicycle, along with other intervening factors, such as weather, topography, attitudes and perceptions, and sociodemographics.

Conclusions

Demographic characteristics vary between types of adult cyclists and the desire to cycle more. Men and younger adults (those younger than 55) cycled more and were more likely to want to cycle more. The relationship between income and vehicle ownership and cycling was less clear. Although cycling to school as a child was not associated with higher levels of cycling as an adult, cycling for fun or to other destinations as a child was. If planners and advocates hope that increasing cycling among children will lead to more cycling among adults as they age, this finding indicates that efforts need to focus on cycling for all purposes for children, and not just to school. However, people's recollections of their childhood behavior may be influenced by other factors and may not be accurate. People who lived in households with other adults who cycled regularly, who had coworkers who cycled to work, or who saw adults cycling on their street frequently were more likely to be regular cyclists themselves. These findings could be interpreted in different ways. On the one hand, having the social support and cues about cycling may promote more cycling.

However, cyclists may just be more aware of the cycling behavior of those around them. In addition, the level of cycling at work may be a function of the work site location, facilities at work (e.g., lockers and showers), the type of employer, or a combination of these.

There was no relationship between the number of miles of bike lanes within $\frac{1}{4}$ mile of the respondent's home and levels of cycling. This could indicate either that bike lanes do not increase levels of cycling or that the relationship is just not revealed by use of the variables as they were defined here. Further analysis should be conducted with different measures of bike lane infrastructure; perhaps a measure of the connectivity of the bike lane network should be used. In addition, different dependent variables may reveal different relationships. A dependent variable that better distinguishes between people who take their bike in their vehicle to cycle on trails elsewhere and people who cycle in their neighborhood, for example, would be worth exploring. Respondents who lived in neighborhoods closer to downtown and with higher levels of street connectivity were more likely to have made a utilitarian bike trip in the past summer. This may indicate that street networks that provide shorter distances to destinations may increase cycling for nonrecreational purposes.

There is a relationship between regular cycling and positive perceptions of a neighborhood for cycling. Respondents who agreed that there were bike lanes in their neighborhood that were easy to get to and that connected to places that they needed to go and who agreed that there were quiet streets that connected to places were more likely to be regular or utilitarian cyclists. It is difficult to know the direction of the relationship between positive neighborhood perceptions and cycling,

however. Do cyclists think that their neighborhood is better for cycling because they cycle and are more aware, or do their perceptions reflect the characteristics of the neighborhood and encourage them to cycle more? In addition, the lack of consistency between the findings with respect to the objective versus the subjective measures of bike lane infrastructure should be explored further. How well do people's perceptions of their environment match the objective measures? If they do not match well, what might cause the difference? The findings so far indicate that current cycling behavior may influence perceptions. However, if an objective is to increase cycling among irregular cyclists and noncyclists, it will be useful to understand what influences their perceptions. This could lead to policy responses, such as improved signage.

Attitudes toward bicycling, driving, and the environment relate to levels of cycling. The question as to the relative role of attitudes compared with the roles of the other factors, including the built environment, remains. This question must be explored by multivariate analysis.

Finally, a majority of the respondents indicated that they wanted to cycle more. The most common environmental barrier keeping them from cycling more was "too much traffic," cited by 56% of those who wanted to cycle more. Not having bike lanes or trails was a barrier for 37% of the respondents who wanted to cycle more. Further analysis of the data revealed that the people who cited this as a barrier did have significantly fewer bike lanes within a mile of their homes. Further analysis of these data may help identify appropriate responses to increase cycling rates.

TRANSPORTATION RESEARCH DIGEST

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Preserving Freight and Passenger Rail Corridors and Service, NCHRP Synthesis 374 by David P. Simpson, TranSystems Corporation, Minneapolis, Minnesota (Transportation Research Board, 500 Fifth Street, NW, Washington, DC 20001; (202) 334-3213; <http://gulliver.trb.org/bookstore>) (2007)

Highlights

- This synthesis was undertaken to document current practices with respect to rail corridor preservation.

Efforts to preserve rail corridors or restore rail service to dormant rail alignments across the United States are very uneven. A handful of states have aggressive, well-funded programs to support the preservation or reuse of rail alignments; more states have modest programs to support short line operations on a case-by-case basis, but attach no value to corridor retention *per se*. In 2005, California completed what is perhaps the nation's most comprehensive physical plant inventory of active and abandoned rail corridors; a review driven by interest in passenger rail and non-motorized corridor interests. A foundation has been set to more fully lever these valuable alignments in this country's most populous state.

This synthesis was undertaken to document current practices with respect to rail corridor preservation. State departments of transportation (DOTs), selected metropolitan planning organizations, commuter rail agencies, short line holding companies, and Class I rail carriers were all surveyed for information. Response rates to the survey were moderate, averaging 24%, and overall supporting the notion that preservation of rail alignments is not a high-priority issue in many jurisdictions. A handful of state respondents, however, had a great deal of experience and valuable observations on rail preservation

policies and could be said to have become experts on this subject through their dealings with several dozen rail corridors over the past two decades. North Carolina, Ohio, and Pennsylvania DOTs each have serious, well-established rail sections and a history of successful preservation efforts.

The success of active state programs appears to flow from a clear policy foundation that positions stakeholder agencies to act in advance of specific abandonment "crisis" situations. These programs include a mixture of loan and grant assistance programs and appear to have benefited from long-term partnership relationships with experienced short line operators. In states with well-funded programs, the success rates for retaining corridors are very high: 103 of 114 attempted preservation initiatives were deemed to be successful in those jurisdictions. The structure of public rail assistance for a given line often includes a combination of DOT and local (usually county-based) agencies in a joint-powers relationship designed to preserve or rejuvenate a specific rail property.

Preservation of lines for transit use more naturally falls into the purview of metropolitan planning organizations, with or without planning assistance from state-level agencies. Some cities have made excellent use of preserved alignments: St. Louis Metro service is perhaps the poster child for these opportunities in that grade-separated service to the downtown core for the region's first new light rail service was provided through 19th century rail tunnels.

Recreational interests may prove to be valuable allies in preserving rail corridors, but may also require accommodation if and when efforts are made to restore active rail service along a given line. New tools are provided by 1983 amendments to the Federal Trails Act for such groups to prevent dismemberment of a corridor with or without the support of local landholders or public agencies. Approximately 20% of the nation's rail trails have been created through application of the federal rules.

The "capacity crisis" that confronts all surface transportation users has yet to have a major effect on public agency perspectives toward dormant or lightly used intercity alignments. Class I freight providers are content to build ever-higher densities on consolidated, fully subscribed main track routes. Advocates of improved intercity passenger rail continue to favor development of higher speed services on those same high-density freight routes despite the challenges of integrating passenger and freight rail operations. Existing state-run rail assistance programs focus understandably on the short- to medium-term economic effects of public rail

assistance, which generally translates into support for lines with significant on-line rail industries and employment.

Rail service restorations, although relatively uncommon, fall generally into one of three categories:

- Startup light rail, commuter rail, or bus rapid transit services. Actions to preserve the alignments in question were generally led by local planning agencies or transit authorities.
- Opening or reopening of a single major rail-dependent facility such as a coal or mineral extraction facility or a large-scale chemical plant.
- Reinstitution of general freight service through a collaborative state, county, carrier, or shipper initiative. State grant and loan funds with a requirement for local matches are typical of such restorations.

Strategies for extracting better long-term use of the nation's rail resources may be helped through further targeted assessment of rail corridor issues.

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The Role of Safety Culture in Preventing Commercial Motor Vehicle Crashes, CTBS Synthesis 14 by Jeffrey Short, Linda Boyle, Sandra Shackeliord, Robert E. Inderbitzen, & Gene Bergoffen (Transportation Research Board, 500 Fifth Street, NW, Washington, DC 20001; (202) 334-3213; <http://gulliver.trb.org/bookstore>) (2007)

Highlights

- ❑ Recognition and certain rewards systems for safe behavior are an effective component of safety culture.
- ❑ A culture of fear is not positive or effective, nor are generic, indirect safety program methods.
- ❑ The safety culture requires a multilevel, comprehensive series of safety program steps and procedures that act as a baseline for safety management efforts.

The research team synthesized the current available research and literature pertaining to safety culture, finding specific ties between the available body of knowledge and the motor carrier industries. The effort also included a data collection component, consisting of convenience sample surveys and interviews of motor carrier safety managers and commercial motor vehicle (CMV) drivers, as well as case study data collect onsite, directly from motor carriers. This report contains an outline of suggested steps for increasing safety culture through a series of best practices.

The literature review identified the following key concepts:

- Culture and safety have a clear connection.
- Safety culture is best defined and indexed by an organization's norms, attitudes, values, and (beliefs regarding safety.

- Effective top to bottom safety communication and interactions enhance safety culture.
- Terms such as "accident" and "mishap" are often replaced with the terms "crash," "wreck," and other more appropriate, straightforward terms in many safe cultures.
- In many instances, organizations, organizational subgroups, and professions may each have identifiable safety culture.
- Recognition and certain rewards systems for safe behavior are an effective component of safety culture.
- Driver experience enhances a safety culture, especially if that experience is with one carrier. Driver retention problems, however, have the potential for degrading a safety culture.
- Many levels of communicating safety culture are necessary in "remote workforce" industries such as truck and bus operations.
- Policies, procedures, employee safety responsibilities, and safety messages must be clear and simple.
- Hiring practices, safety training and education, company orientation, and safety management are all key components of a safety culture.
- Measuring safety performance of drivers and the organization as a whole are key components of a safety culture.

Through the safety manager survey and interview process, it was found that safety managers look positively on top to bottom communications, as well as internal cooperation within an organization, effective and simple communications, safety training and education, full organizational participation in safety programs (not just safety departments and drivers), and a good balance between positive and negative motivations. Safety managers indicated that a culture of fear is not positive or effective, nor are generic, indirect safety program methods.

Drivers indicated that the independence found in the profession is a positive aspect, which in many ways contradicts the basic foundations of an organizational culture and a safety culture, even if a personal "safety ethic" exists. All drivers indicated that safety was a priority professionally and was also a priority for their employer. All drivers realized that the heaviest level of safety responsibility rested with them. Eighty percent of those interviewed indicated that their company had a rewards/recognition program for safe behavior, and there was an indication that drivers tend to communicate with peers within their own organization more often than those outside of their organization.

Three trucking companies participated in onsite safety culture discussions that acted as comprehensive case studies, detailing the company safety culture examples, and methods for producing and maintaining a safety culture.

The safety culture relationship framework section suggests a list of practices that will aid in the development of a positive culture of safety within a motor carrier:

- Develop or redevelop internal definitions of culture and safety.

- Conduct "Swiss cheese" analyses.
- Identify and dispel myths.
- Conduct institutional safety knowledge development.
- Define or redefine employee safety roles from top to bottom.
- Assess the effectiveness of safety communication and reengineer systems of safety communication.
- Create or enhance a system of safety record data collection and analysis.
- Develop motivational tools.
- Improve driver retention.

The safety culture itself, as has been shown through the literature and data collection, requires a multilevel, comprehensive series of safety program steps and procedures that act as a baseline for safety management efforts. When such programs are implemented, there is a tendency to seek to mitigate bad behavior by isolating such behavior and their relationships to future crashes. This leads to greater levels of safety, thus linking safety culture and safety performance.

The best practices guidelines chapter takes key findings from the literature review, data collection efforts, and discussion of the safety culture to develop practical questions and actions for motor carrier safety managers to use when developing their organization's safety culture. It is organized in four stages:

1. Assess Safety Culture
2. Identify Safety Culture Improvement Areas
3. Develop Solutions to Improve Safety Culture
4. Implement Safety Culture Improvement Plan and Reassess

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AUGUST 2008

Investigation of Materials for Thin Bonded Overlays on Bridge Decks by David Meggers & Cliff Hobson (Kansas Department of Transportation, Bureau of Materials and Research, 700 SW Harrison Street, Topeka, Kansas 66603-3754; <http://www.ksdot.org:9080/burmatres/kdotlib2.asp>) (Jun 2007)

Highlights

- The permeability tests showed the overlays containing the Type IP cement were the least permeable.
- Steel and polypropylene fiber overlays were the most permeable.

The objective of this study was to develop a durable thin bonded overlay with chloride resistance to protect the reinforcing steel of the bridge deck. Overlays were developed and monitored after their initial placement on the bridge.

Four different overlay materials were selected based upon KDOT's laboratory results and were tested on four separate bridge decks. All four bridges are new construction; the three in Greenwood County are pre-stressed concrete girder design and the Sedgwick County Bridge is a steel girder design.

The materials chosen for the overlays were: Type IP cement concrete, Type IP cement with 3% silica fume concrete, Type I/II cement with 5% silica fume and polypropylene fibers concrete, and Type II cement with 5% silica fume and steel fibers concrete. Construction samples and bridge deck cores were tested for compressive strength, permeability, chloride concentration, overlay adhesion, and cracking resistance.

Conclusions

The overlays all had compressive strengths greater than 5,900 psi, and all meet the design specification of at least 5,000 psi.

The permeability tests showed the overlays containing the Type IP cement were the least permeable while the steel and polypropylene fiber overlays were the most permeable. The Type IP cement overlays meet the design specification of passing less than 1,000 coulombs (1.5 inch thickness); however, the overlays with the fibers do not.

The ability of each overlay to resist chloride ion migration will only truly be known as "in service" time accrues. Based upon the chloride ion contamination after five years, all overlays would appear to be functioning equally unless there is cracking in the overlay.

Grouting between the sub-deck and the overlay had negative effects on bond strength in this study. The one overlay that did not use a bonding grout, had a significantly higher bond strength than the other three that did use a grout (241 psi vs. 163 psi (average value)).

Greenwood County Bridge #62 with the steel fibers had virtually no cracks, but the surface was almost entirely exposed aggregate. Sedgwick County Bridge #445 with the polypropylene fibers had minimal cracking and surface damage followed by Greenwood County Bridge #61 and Bridge #60.

Greenwood County Bridge #62 was the most costly overlay at \$3.72 per ft² and Sedgwick County Bridge #445 the least costly at \$2.93 when comparing actual dollars spent. With the adjusted apples to apples basis, Greenwood County Bridges #60 and #61 were the least costly at \$3.48 since the adjusted cost of Sedgwick County Bridge #445 is \$3.61. The

cost for a typical KDOT Type I/II cement with 5% silica fume concrete overlay is generally \$3.48 per ft². Therefore, to install an overlay using the fiber materials in this study, would increase the overlay cost up to 7%.

KDOT commonly uses 7% silica fume overlays on many of the state bridges requiring overlays. None of the four overlay mixes tested in this project, are performing any better than the standard KDOT silica fume overlay.

The Type IP cement with silica fume concrete overlay on Greenwood County Bridge #60 is tending to crack and scale more than one would like to see; however, the chloride concentrations in the sub-deck were not excessive at the 5 year inspection.

The Type IP cement concrete overlay on Greenwood County Bridge #61 had very few cracks, but had scaling over most of the surface. A concern would be that between years three and five the length of cracking almost doubled.

The silica fume and steel fibers concrete overlay on Greenwood County Bridge #62 was not performing at an acceptable level after five years due to erosion of the paste, tining and fibers; however, there are no cracks.

The silica fume and polypropylene fiber concrete overlay on Sedgwick County Bridge #445 was performing the best of the four overlay mixes. There were very few cracks and minimal scaling only on the west one-third of the deck. However, the higher chloride concentration throughout the overlay and into the sub-deck was of concern.

A visual surface survey of the Greenwood county bridges on US-400 was made in March of 2007; this is 10 years after the overlays were placed. The overall appearance was generally the same as they appeared in September 2002.

The Type IP cement concrete with 3% silica fume Bridge #60 still has the most cracks. 70% of the bridge's surface showed scaling or

loss of surface paste (same as 2002), with the westbound lane still worse. The majority of the cracks appear to be shrinkage cracks and show up more in the traffic lanes than the shoulder. The eastbound lane is map cracked, approximately 8 inches center to center, nearly the entire length (not just the east end as in 2002). It appears that there are a few new cracks and some lengthening of the existing cracks.

The type IP cement concrete overlay on Greenwood county Bridge #61 still has very little cracking and the cracks are generally still on the north side or westbound lane. In 2007 it appeared that there are a few new cracks. The cracks are typically longitudinal cracks in or near the outer wheel path. The traffic lanes have shrinkage map cracking in both lanes that is barely visible and this cracking has increased to around 80% of the surface in 2007 (50-60% in 2002). There are still longitudinal cracks at each end of the bridge. Most of the surface still has roughly the same amount of scaling with the westbound lane the worse.

The silica fume and steel fibers concrete overlay on Greenwood County Bridge #62 continues to have no visible cracks in 2007. The surface appears to be generally the same as in 2002. The surface continues to look ugly due to the exposed steel fibers and the rough look of eroded paste exposing the aggregate. The original tining is nearly gone; however, the grooved surface from the original tining is still in place over the majority of the bridge. The 2007 review of this bridge showed very few loose steel fibers in the overlay and along the edges of the bridge (in 2002 there were many in both the overlay and along the edge of the bridge). The scaling continues to be worse in the westbound shoulder. Overall, the overlay surface looks bad; however, it appears to have stabilized without cracks and may continue to function for many years.

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Post-Tensioning the Inverted-T Bridge System for Improved Durability and Increased Span-to-Depth Ratio by Rim M. Nouredin Nayal, Robert J. Peterman, and Asad Esmaeily, Department of Civil Engineering, Kansas State University, 2136 Fiedler Hall, Manhattan, Kansas 66506 (Kansas Department of Transportation, Bureau of Materials and Research, 700 SW Harrison Street, Topeka, Kansas 66603-3754) (Sep 2007)

Highlights

- Construction sequence was found to be one of the most effective and critical parameters in design.
- It is recommended that post-tensioning be applied as soon as possible after casting the deck.

As considerable numbers of bridges need to be replaced or repaired in Kansas and other states, it is important to implement a standard method for replacement in which the capacity of the bridge is maximized and cost is minimized, while durability and safety are not compromised. Existing replacement methods do not satisfy one or more of these conditions.

A post-tensioned, inverted-T bridge system (PT-IT) was implemented in this study, where pretensioned inverted-T beams are post-tensioned to improve the capacity and durability of the system, increase span-to-depth ratio of the beam, and eliminate cracks in the deck over the piers.

A computer program (PT-IT) was developed to be used as a tool for the analysis of the PT-IT system. A comparison between analysis results from the PT-IT program and Consplice was conducted; the comparison proved the capability of the PT-IT program to analyze the system.

An extensive parametric study was conducted to provide guidelines for designing and constructing a PT-IT system. Construction sequence was found to be one of the most

effective and critical parameters in design. Different construction scenarios were investigated, including two main options of applying one or two stages of post-tensioning.

Results of parametric study showed that both scenarios of one-stage post-tensioning (Dia-Deck-PT) and two-stage PT have the highest span-to-depth ratio and satisfy the crack-free deck criteria. Since the option of Dia-Deck-PT incorporates less labor, it is recommended to be used for construction of PT-IT systems.

Different methods for estimation of time-dependent restraining moment, and modifications for both CTL and P methods were suggested in this study. Comparison for CTL, P, and PCA methods with experimental results showed that the P method better estimates time-dependent restraining moment for shallow girders, while the CTL method better estimates it for deeper girders.

While PCA, CTL, P, and creep-transformed section properties methods are considered in the course of the parametric study to estimate the range in which time-dependent restraining moment will fall, it is recommended that experimental investigations be conducted in order to determine the method that is capable of providing a better estimation of the effect of time-dependent forces on restraining moments in the piers.

Girder concrete strength plays a major role in increasing span-to-depth ratio. Increasing girder concrete strength from 6 to 8

ksi helps increase the span by 15% of 6 ksi girders, while increasing strength from 8 to 10 ksi increases the span by 11% of the 8-ksi girders.

On the other hand, deck concrete strength doesn't affect time-dependent restraint moment under creep and shrinkage, nor losses in stresses of pre-stressing strands and post-tensioned tendons.

Different creep-and-shrinkage models were investigated including AASHTO LRFD, ACI-209, CEB-FIP-90, SCC, and NCHRP 496. It was found that while estimation of losses in pretensioned strands and post-tensioned tendons is not significantly affected using different models, variation of time-dependent restraining moment is significant for different models.

The effect of timing on different construction stages was also discussed and addressed in the parametric study. Establishing continuity was found to be an effective parameter in the design. For early ages of

establishing continuity, positive time-dependent restraining moments tend to develop in the pier, while for late age of establishing continuity, negative time-dependent restraining moments tend to form. It is recommended that continuity be established between 56 and 112 days of girder age. Time between establishing continuity and casting the deck was not found to play a major role in the time-dependent restraining moment.

It is recommended that post-tensioning be applied as soon as possible after casting the deck to close the crack in the top of the diaphragm. This could be done as soon as two days after casting the deck. The time of post-tensioning doesn't affect the value of time-dependent restraining moment, but for durability issues related to control crack initiation and development in the diaphragm, it is recommended that post-tensioning be applied to the structure as soon as possible after casting the deck.