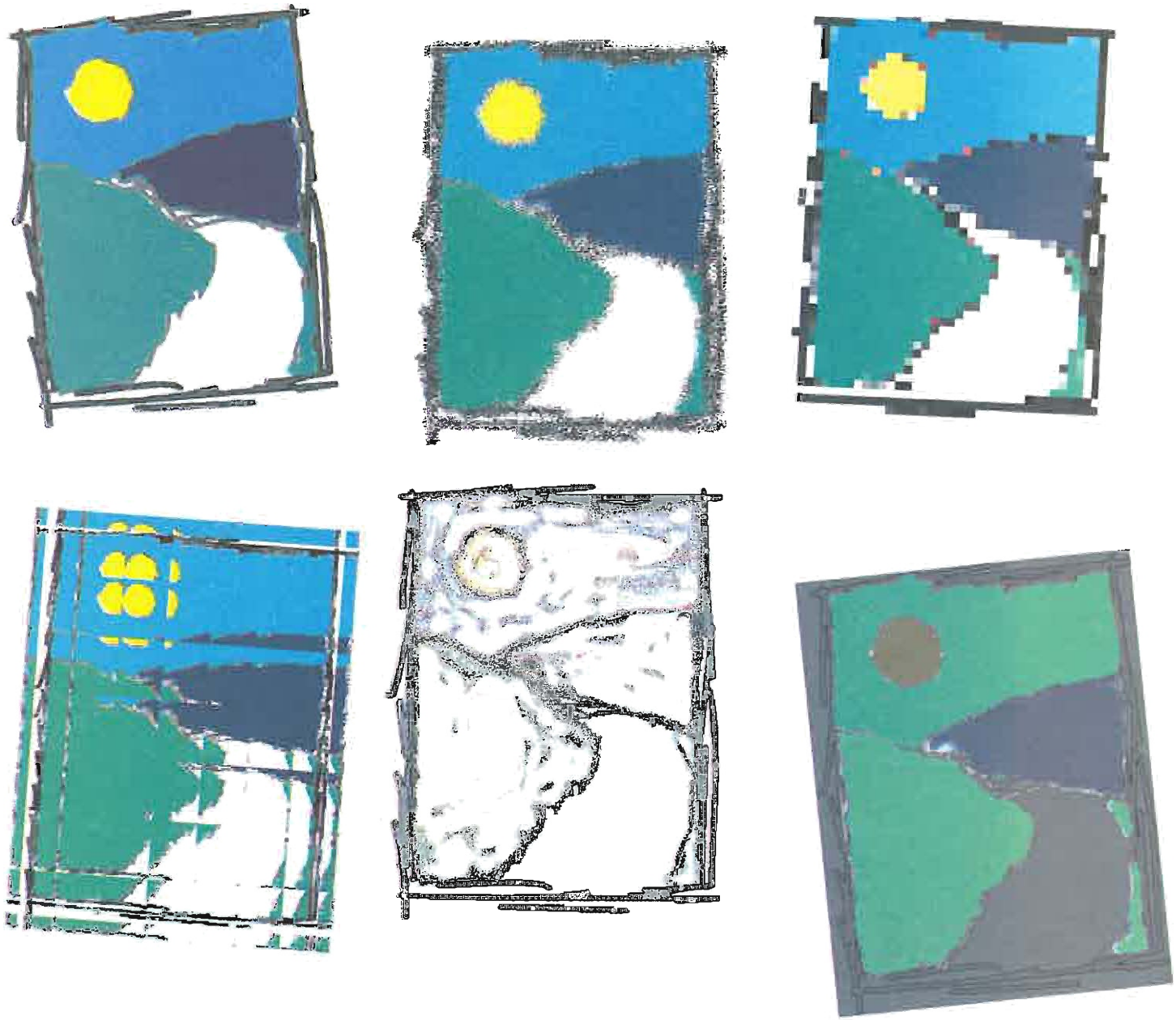

Research

An Investment in the Future

CDOT-DTD-R-95-13
COLORADO DEPARTMENT OF TRANSPORTATION

Research

An Investment For The Future

A biennial report of CDOT
research activities
1993-1994

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July 1995

Program Overview..... 1

Technology Transfer Program..... 5

Structures Research..... 8

Concrete Research..... 15

Maintenance Research..... 22

Asphalt Research..... 30

Construction Research..... 38

Safety and Design Research..... 40

Geotechnical Research..... 45

Intelligent Transportation Systems Research..... 51

CDOT Research Reports 1993 - present..... 62

The Research Branch of the Division of Transportation Development is responsible for research, development, and technology transfer of research findings for the Colorado Department of Transportation. This is a program of transportation research which supports and coordinates national research efforts (SHRP, NCHRP, and TRB), drives the implementation of research findings, demonstrates research findings, evaluates new materials and methods, performs research studies which address state needs, and disseminates the research information to transportation practitioners.

The primary customers of the program are the people responsible for the planning, design, construction, and maintenance of the transportation systems in Colorado.

Research of national issues is supported by the department through contributions to the National Cooperative Highway Research Program and the Transportation Research Board. Research of regional issues is supported through pooling funds with other state highway agencies. Research studies which primarily address Colorado issues are administered by the Research Coordination Engineer. The research is performed by Research Branch staff, other department staff, Colorado universities, and private consultants as appropriate.

Organization

The Research Branch is organized by specialty areas. (see next page) Each specialist manages all research in his or her specialty area through study panels and oversight teams. As appropriate, research is conducted by the research specialist, by others in the department, or contracted to a university or a private consultant.

Facilities

State-of-the-art technology and equipment is used whenever possible in the research program. Commercial suppliers are often selected when equipment is needed for research activities such as pavement monitoring, laboratory tests, other data collecting, and data analysis. However, equipment designed and fabricated as part of the research activity is a common practice in the Research Branch. Quite often, it isn't long before a standard computer or data analyzer is modified for use on a specialized research study.

The laboratory testing facilities of the Staff Materials Branch play an important part in the evaluation of research features. Various soils, asphalt, concrete, and steel testing equipment are routinely used in evaluating experimental materials. Laboratory personnel often play a significant role in developing and implementing these new technologies. When specialized equipment is not available within the department, local universities or private consultants participate in the program as described in this report.

Research Areas of Specialty
(in alphabetical order)

Ahmad Ardani-
(303) 757-9978

-Concrete Pavements
-SHRP LTPP Coordination
-Pavement Structures
-Subgrades
-Traffic Loads

Bob Barrett-
(303) 757-9522

-Geoservices
-Geological
-Geotechnical
-Rockfall Mitigation
-Mechanically Stabilized Backfill (MSB)
-Underdrain Design

Dave Black-
(303) 757-9054

-Videography
-Media

Richard Griffin-
(303) 757-9973

-Research Branch Coordination
-Administration
-Colorado Transportation Institute (CTI)

Donna Harmelink-
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-Asphalt Pavement
-Euro-Lab
-Crumb Rubber
-Polymers
-Stone Matrix Asphalt (SMA)

Beth Moore-
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-Research Implementation
-SHRP Products Implementation Coordination
-Local Transportation Assistance Program (LTAP)
-Special Projects

Skip Outcalt-
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-Maintenance Support
-Research Support

Joan Pinamont-
(303) 757-9972

-Staff Librarian
-Electronic Bulletin Board (BBS)

Dave Price-
(303) 757-9976

-Maintenance Support
-Research Support
-TEL8 Site Coordination

Dave Woodham-
(303) 757-9975

-Safety
-Maintenance
-Structures
-Pavement Markings
-Avalanche Control
-Road Weather Information Systems
-Deicing
-Air Quality

Reinventing Research

This was a fresh look at the traditional approach to research, development, and technology transfer for transportation in Colorado. This process began as an element of a broad strategic plan for CDOT. The development, evaluation, and utilization of new technology was identified as an important strategy to achieve the mission and goals established in this strategic planning process. A multi-disciplinary team was established to develop a business plan to address this strategy. Concurrent with this process was an activity titled "Reinventing Research." This process reviewed the way CDOT has supported Research and Development (R&D) in the past and presented dramatic changes in the way we make and evaluate changes to transportation programs. The reinventing process considered all aspects of the research procedure: how we identify and select priority projects, how we conduct the research, our contracting practices, our relationship to the Colorado Transportation Institute, and how we insure that findings are implemented in a timely manner.

"Reinventing research" was started in response to a changing external environment that has forced CDOT to conduct business in a new way. Some of these changes included: 1) pending changes in FHWA regulation for State Planning and Research (SP&R); 2) passage of a tax limitation referendum in Colorado that eliminated increases in gas tax without being voted on by Colorado citizens; 3) CDOT's refocusing on maintenance, more efficient use of existing highways, and alternative modes; 4) air quality conformity requirements that threaten the availability of federal funds; 5) the expectation of enabling legislation for public/private partnerships; and 6) the expectation that future transportation decisions will be based on the statewide transportation process and management systems.

"Reinventing research" is based on the premise that we ultimately need to deploy what is developed. Except for long-term basic research, the management of research projects must have some essential elements to ensure the ultimate deployment of positive findings. Some of these elements include:

- future-focused (innovation for future issues);
- stakeholder involvement from beginning to deployment;
- a high-level commitment from senior management to the research innovation;
- presence of a committed champion;
- commitment of resources to support the deployment of the innovation;
- tracking of innovation after deployment.

(cont'd on next page)

Reinvention involved:

1. reviewing and clarifying the purpose of CDOT research;
2. developing a shared vision of what research should be to achieve its purpose;
3. an honest look at the current reality;
4. and finally, developing a plan/strategy to get from the current reality to the vision.

The "reinventing process" will culminate in a new RD and TT procedures manual for CDOT, which will also meet the ISTEA requirements. The manual will be distributed in the summer of 1995.

Research contact: Richard Griffin, 757-9973

Technology Transfer is the process by which existing research and development findings, and other new technologies are transferred operationally into useful processes, products, or programs that fullfill existing or potential public or private needs. In the two years since the last status report, the role of the Technology Transfer Program has continued to expand and diversify.

The CDOT Technology Transfer Program compliments the work done by the Research Branch. The process of transfering new technology can take on many forms. It can be a report, a brochure, a video, a training course, or a demonstration. It can also be something as simple as one-to-one communication. The program is responsible for producing the CDOT Research Newsletter and the biennial status report.

Strategic Highway Research Program

The Technology Transfer Program has expanded its role to include implementation activities that have both state and national significance. One of those activities would be the coordination of the implementation of the Strategic Highway Research Program (SHRP) into CDOT now that the research phase has ended. Even partial implementation of the 130+ products produced by SHRP is expected to take several years. Right now the department is focusing on those products that have the most potential for a big payback to CDOT. About 15-20% of the products will not be pursued for implementaion because they have little value to the department or their value is less than or equal to something already in place. Still several other products may not get implemented due to their high costs. The department is currently seeking alternate means of financing for several high priority SHRP items.

The SHRP Implementation Committe is composed of seven subject matter experts in the department:

Bill Reisbeck- State Coordinator
Beth Moore- CDOT Implementation Coordinator

Tim Aschenbrener- Asphalt Mixes
Bob LaForce- Asphalt Binders
Dick Hines- Concrete
Steve Horton- Structures
Jerry Simpson- Work Zone Safety
Dave Fraser- Maintenance
Ahmad Ardani- LTPP

Local Transportation Assistance Program (LTAP)

LTAP is a joint project of the FHWA, CDOT, and Colorado State University. Their main goal is to provide affordable, high quality training on transportation issues to cities and counties throughout Colorado. The Local Transportation Assistance Program has made tremendous progress the past two years. The program has benefited greatly with the hiring of full-time director/manager Alex Ariniello in 1993. Between 1993 and 1994, over 3100 individuals attended an LTAP training course.

LTAP presents about 40+ training classes per year. The Road Scholar program, the mainstay of LTAP training, is a two-year program where a participant must attend 9 out of the 12 modules. Some classes in the Road Scholar program include - winter maintenance, signing, pavements, bridge maintenance, road maintenance, and a management/supervision class. Across Colorado there are 100+ graduates who can call themselves Road Scholars. At present, about 21% of those attending training are CDOT employees. In fact, CDOT employees are encouraged to take advantage of the low-cost transportation training opportunities afforded by LTAP.

LTAP also publishes the quarterly newsletter "The Wheel", a familar publication to many CDOT employees. They too have a library of transportation related reports and videos that can be accessed by CDOT employees.

Library

Without question, the most significant happening in the Technology Transfer Unit was the hiring of a part-time library professional, Joan Pinamont. Joan was hired in March of 1994 after years of temporary, part-time help. Joan has a Master's Degree in Library Science and the library has flourished since her arrival.

Research contact: Beth Moore, 757-9220

Library Services

The Technology Transfer Library has the most comprehensive collection of transportation materials in Colorado. Over 150 people use the library per month, which is open to the public. In fact, about 40 percent of all library users come from outside the department. Information is available in many formats: books, periodicals, audio and video cassettes, slides, CD-ROMs, and on-line via Internet and DIALOG. The collection, which has over 18,000 items, includes FHWA and FTA reports, ASTM and AASHTO Standard Specifications, Federal Regulations, TRB publications, SHRP publications, CDOT Research Reports, and standard specifications from other states.

Research Bulletin Board System (BBS)
The library maintains several data files on the Research Bulletin Board, which is part of the CDOT Bulletin Board System (BBS). CDOT employees can use the BBS to access the last five years of the library database catalog, new library acquisitions listings, newsletters, research progress reports, and current research report listings.

Career and Development Collection
A new and popular addition to the library is the Career/Personal Development Collection for CDOT employees. This collection of a 150+ books, audio cassettes, and video cassettes is the result of a group CDOT effort. A comprehensive listing of the collection can be found in the Research BBS. New selections are added monthly.

Journal Articles
The library has set up an account with UnCover, a local periodical index database and document delivery service. The UnCover database includes scientific journal collections from a number of academic and public libraries. The database can be accessed through the Colorado Alliance of Research Libraries (CARL) on-line catalog. For a nominal charge, the TT Library staff will order UnCover articles for CDOT employees.

Transportation Research Information Service (TRIS)
Customized searches of TRB's on-line database, TRIS, are another library service available to CDOT employees. TRIS contains worldwide information on all aspects of transportation and construction, including planning, design, finance, maintenance, equipment, traffic, management, and marketing. More than 315,000 abstracts of completed research and summaries of research-in-progress are indexed in the database.

Federal Register
The library has a two-year collection of Federal Registers, which are daily records of public regulations and legal notices issued by Federal Agencies. There is a weekly/monthly CIS Federal Register Index that provides specific subject access to the regulations.

Library contact: Joan Pinamont, 757-9972

Highway structures represent a large expenditure by the department. Research on the rehabilitation methods of existing structures and on the construction methods and materials of new bridges holds the potential for large dollar savings for CDOT.

Innovative Bridge Deck Design

CDOT, in conjunction with Allen Engineering and the University of Colorado at Boulder, is investigating a new bridge deck design method. A bridge incorporating this design feature in one span was built in early 1993 over the South Platte river in Adams County.

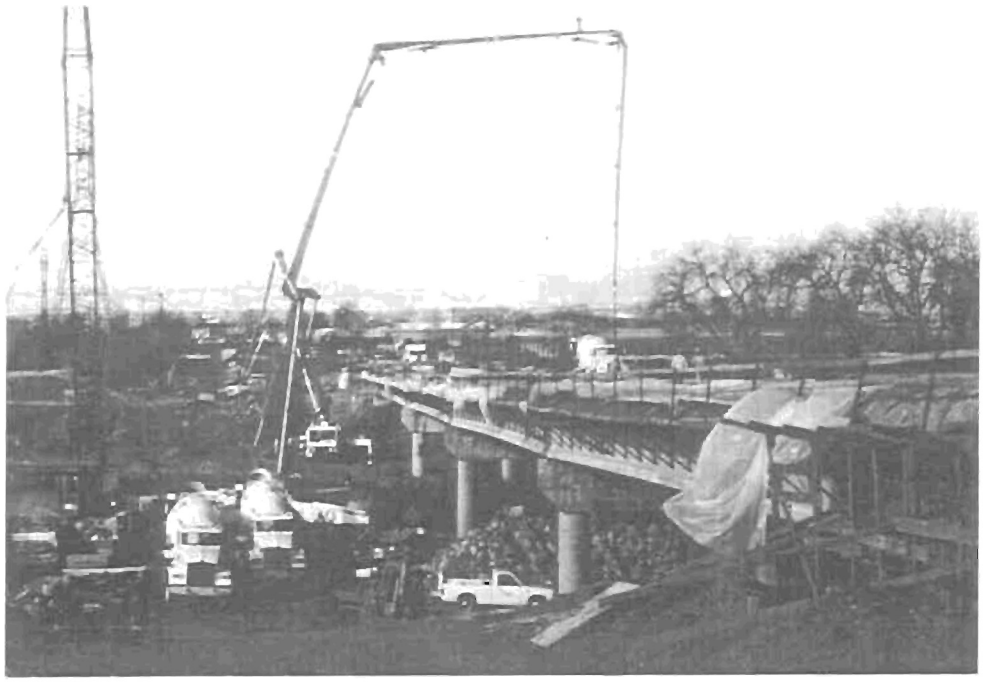
The AASHTO Standard Specifications for Highway Bridges require both bottom and top mats of steel reinforcement to carry positive and negative moments in the deck and to control shrinkage. This alternative design method eliminates the top layer of reinforcing steel and uses the limited tensile strength of concrete to accommodate the small transverse tensile stresses present in bridge decks. The transverse tensile stresses at the top of a bridge deck are much smaller than those designed for the bottom because the girders flex with the deck and reduce the negative moments over the girders.

Because these negative moments are smaller than those predicted, reinforcing steel is not required in the top of the bridge deck as it would be using the current AASHTO design method. Eliminating the top mat of reinforcing steel reduces the cost of steel for a deck, saves labor costs by not having to place the top mat, and reduces the amount of steel which is subjected to a corrosive environment.

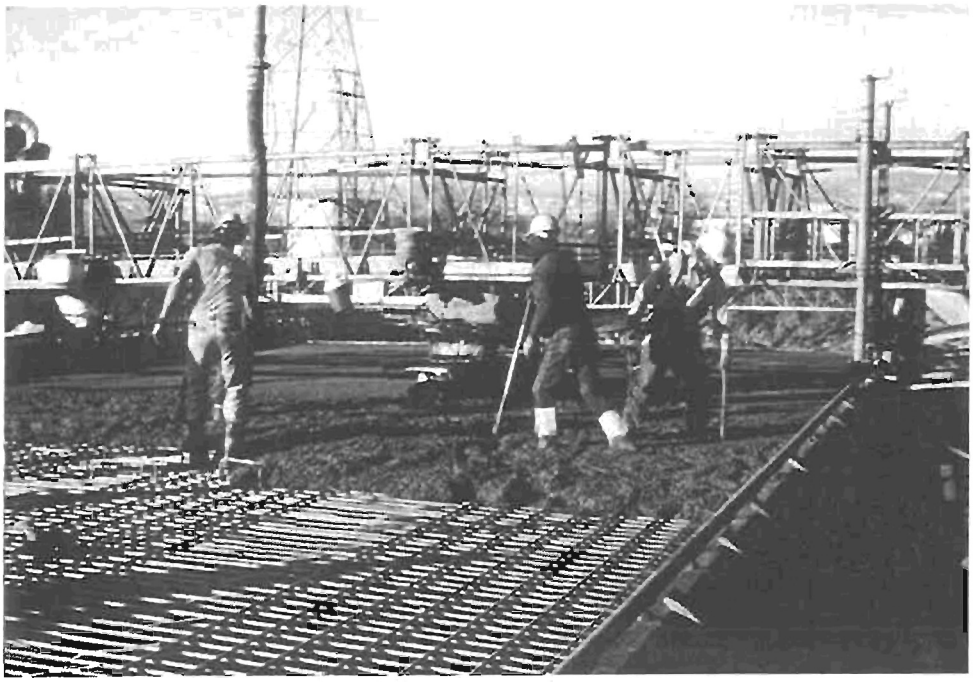
Static load testing performed on the experimental bridge deck shows good correlation between strain gages installed in the deck and nonlinear finite element analysis performed by CU Boulder. The structure has been monitored for the last two years and all measured strains have been smaller than expected.

Further tests of this reinforcement method will be required, however the potential for substantial cost savings has been successfully demonstrated in this project.

Research contact: Dave Woodham, 757-9975



(Top/bottom) This bridge, built with an alternative design method, eliminates the top layer of reinforcing steel and uses the limited tensile strength of concrete to accomodate the small transverse tensile stresses present in bridge decks.

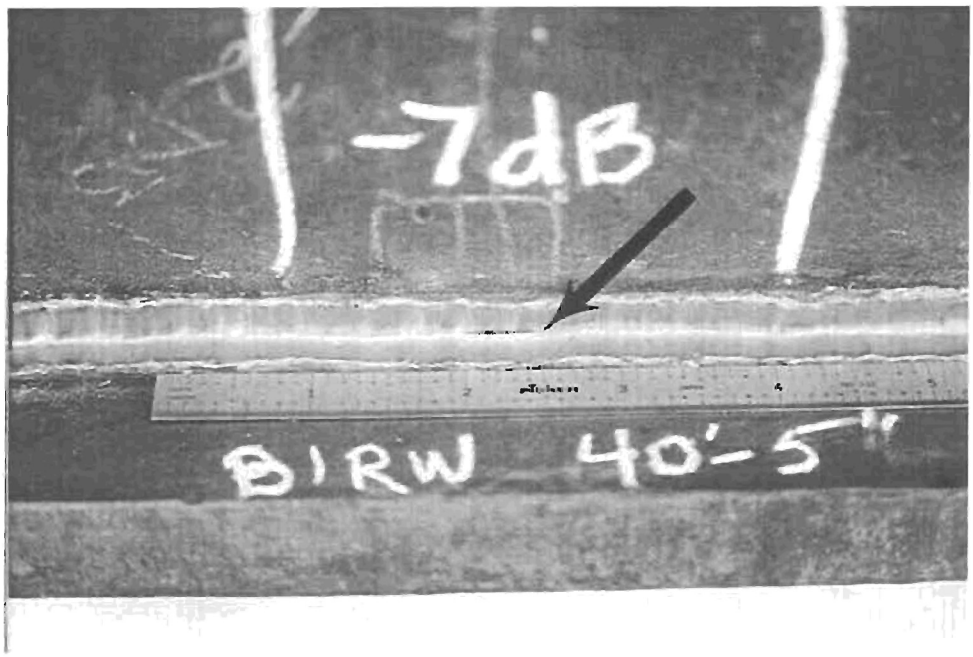


The Effect of Welding Materials on Cracking in Bridge Welds

Cracking in fillet welds has been identified in several recently built structures. The cause of these cracks is thought to be related to the types of structural steel as well as the materials used in welding. Residual stresses, as a result of the welding process, and thermal stresses are contributing factors to crack development and growth.

This research will determine the activity of internal cracks in fillet welds. Determining whether cracks are actively growing and if they propagate failure will provide data to assess whether or not CDOT should implement selective nondestructive evaluation during fabrication of steel bridge girders.

Research contact: Dave Woodham, 757-9975



This picture shows an example of one of the fillet cracks occuring in the bridge welds. The ruler indicates that the crack is about 1/2 inch long.

Scour Monitoring and Instrumentation - Timber Piles Length Test Equipment Evaluation

Knowledge of timber pile lengths is essential when evaluating the potential effects of scour. The depth of scour below the present flow line can be determined. However, the length of timber piles extending below the flow line is presently unknown for many bridges.

This study will evaluate a nondestructive technique developed by Engineering Data Management (EDM) to measure in-place pile lengths. The method uses a lag bolt inserted into the pile which is then struck with an instrumented hammer to induce stress waves into the pile. Two sensors located below the lag bolt are used to determine the velocity of the stress wave in the dry portion of the pile. A single sensor opposite the lag bolt is used to determine the resonant frequency of the pile. The pile length can be determined from the stress wave velocity and the resonant frequency.

Sixty timber piles on a timber bridge over the Platte River near Brush were evaluated for length in June of 1994. Since this bridge is scheduled for replacement, the piles will later be extracted and measured for length, biodegradation and mechanical damage (both of which affect the accuracy of the nondestructive test).

CDOT plans to use the non-destructive technique, after it has been verified, to evaluate six scour-critical bridges supported by timber piles.

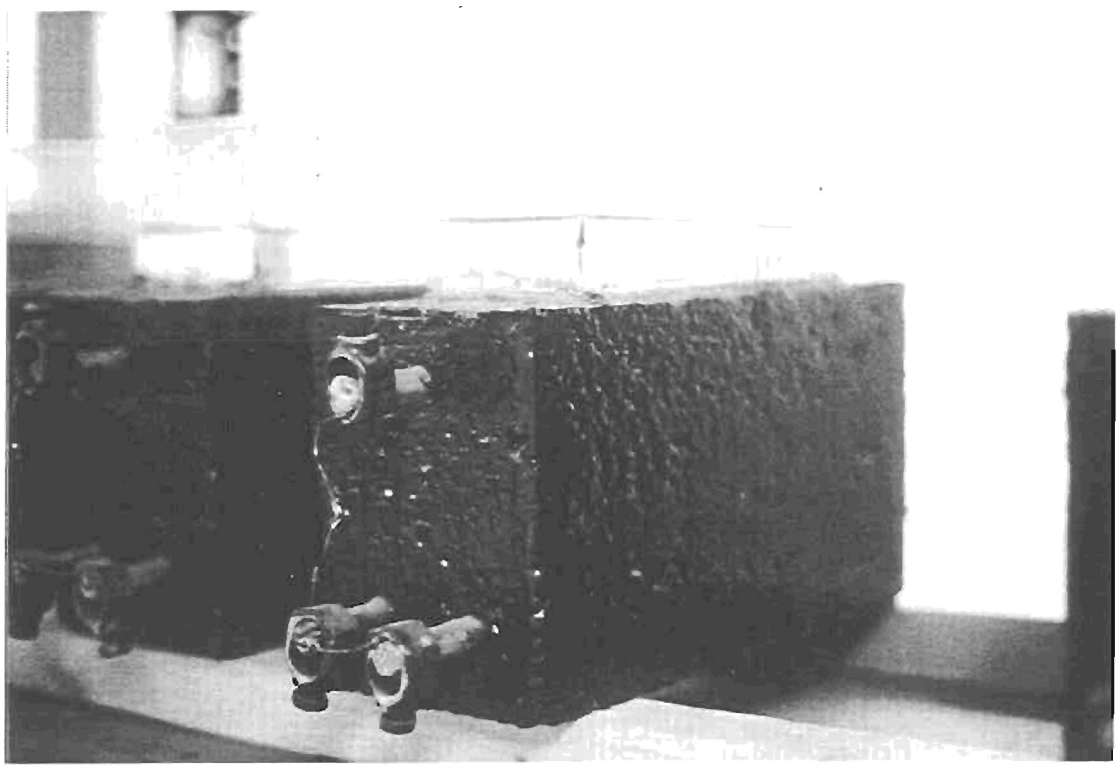
This study is being conducted under FHWA Demonstration Project DP 97, "Scour Monitoring and Instrumentation."

Research contact: Dave Woodham, 757-9975

Calcium Nitrite Corrosion Inhibitor

Calcium nitrite will be used as a corrosion protection system for a bridge in Region 2 to be constructed in 1995. Calcium nitrite has been in the concrete industry for over 20 years as a corrosion inhibitor and set accelerator. Test cells using calcium nitrite, constructed by the CDOT Materials Lab Concrete Unit and the Research Branch, have shown no electrochemical activity in over two years of ponding with 3% sodium chloride solution. It appears that calcium nitrite could be used as an alternative corrosion protection system to epoxy-coated steel in bridge decks. This would allow shorter steel development lengths and ease handling and storage constraints necessary with epoxy-coated steel. The Research Branch will instrument both the calcium nitrite test portion of the bridge deck and an epoxy-coated steel control section. Corrosion monitoring will be done at two-year intervals.

Research contact: Dave Woodham, 757-9975



This test cell, with calcium nitrate, showed no electrochemical activity in over two years of ponding.

Investigation of Cracking in Bridge Decks

Cracking in bridge decks has become a concern in recent years. Some of these cracks extend through the deck and allow moisture and de-icing chemicals to reach bridge components that were previously well protected by the deck. Extensive bridge deck cracking can pose a serious risk to the durability of the entire bridge.

Over thirty bridges have been selected for study under this project. The material records, construction records, and weather records at the time the deck was cast have been reviewed and incorporated into a data base. In addition, most bridges will be crack mapped and typical cracks will be cored to observe crack geometry. The resulting data base should be able to establish statistical links between materials, construction practices, environmental factors and the occurrence of cracks in bridge decks. This research could then lead to the development of changes in the material and construction specifications necessary to avoid transverse through deck cracking.

Research contact: Dave Woodham, 757-9975

Bridge Protection Systems

This study will review the work done nationally to determine if bridge deck protection methods used in Colorado can be made more cost effective. A potential exists for savings in bridge construction and bridge rehabilitation. The study will consist of literature reviews and contacts with researchers in other states. The end result of this study will be a document which describes the current practice in Colorado, the chronology of the decisions made to arrive at the current practice, and materials and procedures which have the potential for improving the cost/performance of bridge decks in the future.

In an effort to slow the entrance of chlorides, several bridge deck protective systems are generally used. Because there is insufficient information on the performance of each protective system (and their cumulative performance), it is not known which systems or combinations of systems are the most cost-effective. It is suspected that there is some redundancy in bridge deck protection.

This study will investigate the performance of individual treatments against chloride intrusion. The objective is to gather information on how each system performs (individually and together with other treatments) and what the "as-constructed" costs are in order to find what combinations of systems are the most cost-effective.

Research contact: Dave Woodham, 757-9975

PCCP Texturing Methods

Surface texture in rigid pavements plays an important role in providing safety (providing skid resistance surfaces) for the travelling public. The depth, spacing, and the orientation (transverse or longitudinal) of surface texture can significantly affect frictional characteristics, noise, and the quality of ride. Very little is known about the effectiveness of various texturing methods used by Colorado Department of Transportation and other transportation agencies. Questions have been raised regarding the constructability, costs, and the performance of various surface textures in rigid pavements.

In an attempt to answer some of these questions, CDOT's Research Branch, in cooperation with Region I Materials, initiated a study to examine the pros and cons of various texturing methods, and to develop guidelines and specifications for future construction. The objectives of this study are:

1-To document the constructability, costs, and the functional practicability of several PCC surface textures installed on I-70 for the project IR (CX)70 - 4 (153) in Colorado.

2-To assess the impacts of various surface textures on the frictional characteristics, noise, and the ride quality of concrete pavements.

3-To identify the best performing surface texture which is cost-effective, provides adequate frictional characteristics, and minimizes tire noise.

Nine test sections with varying textures were installed on I-70 east of Deer Trail. The following is the description of all the test sections:

Stations	Texturing Method Used	Length in ft.
1) 2715 - 2743	transverse tining 1"/ state standard	2800
2) 2743 - 2768	trans. astro-turf/ no tining	2500
3) 2768 - 2789	long. astro-turf/ trans. tining random	2100
4) 2789 - 2806	long. astro-turf/ trans. tining 1/2"	1700
5) 442 - 452	long. astro-turf/ trans. sawing random	1000
6) 452 - 480	long. astro-turf/ trans. tining 1"	2800
7) 480 - 490	long. astro-turf/ long. sawing 3/4"	1000
8) 490 - 500	long. astro-turf/ no tining	1000
9) 500 - 510	long. astro-turf/ long. tining 3/4"	1000

Data acquisition consisted of acquiring frictional data, noise, texture depth measurement, and smoothness. Frictional data were acquired using the ASTM E 274 procedure with ribbed-tire and smooth-tire at 40, 50, and 65 mph The pavement surface texture not only impacts the frictional characteristics, but also plays a major role on the loudness of the noise generated at the interface of the tire and pavement surface.

(cont'd on next page)

PCCP Texturing Methods (cont'd)

To examine the noise properties of various surface textures, noise data were acquired in the following three locations: inside of the test vehicle, 25 feet from the center line (three feet away from the right shoulder), and near the right rear tire of the test vehicle away from the exhaust pipe. Noise data acquisition was conducted as a joint effort between CDOT's Research Branch and a local noise consultant, David L. Adams Associates, Inc.

Numerous direct methods were utilized to quantitatively measure texture. Among the ones used for this study were: Texture Van, Texture Beam consisting of an LVTD (Linear Variable Differential Transducer), and a Commercial Laser Stylus, Outflow Meter, Tire Tread Depth Gauge, and the standard Sand Patch Method.

"PCCP Texturing Methods" CDOT-DTD-R-95-2

Research contact: Ahmad Ardani, 757-9978

This equipment is collecting noise data for the PCCP texturing study.

Effects of Widened Concrete Slabs on Performance

During July 1994, Region 1 Materials and the Research Branch, in cooperation with ERES Consultants, initiated the instrumentation of the widened concrete slabs. Widened concrete slabs (14 ft. slabs with the paint stripe creating a 12 ft. lane) may have the ability to increase the load carrying capacity of the PCC pavements by reducing the fatigue damage caused by heavy truck traffic.

This research study will evaluate and compare the effects of the following three pavement designs on the performance of rigid pavement:

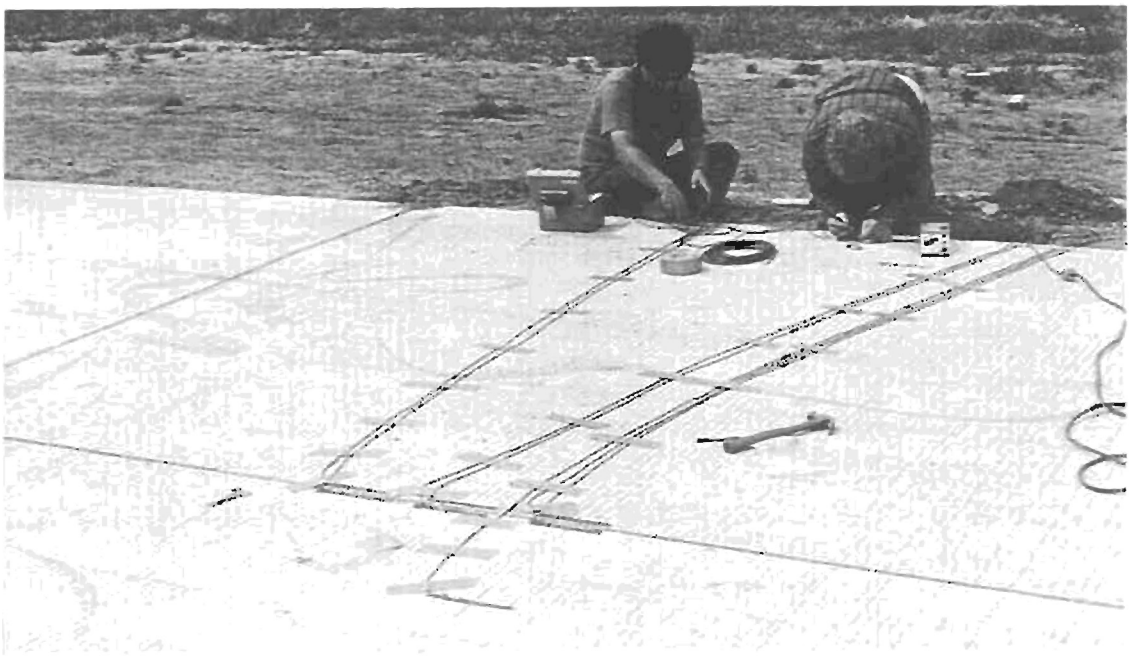
- 14 ft (4.3-m) slab with tied PCC shoulders
- 14 ft (4.3-m) slab with untied PCC shoulders (full saw cut)
- 12 ft (3.6-m) slab with tied shoulders (standard)

The project is located on level terrain on I-70 westbound near the Kansas state line, approximately 10 miles east of Burlington. The construction consisted of paving 11 miles of I-70 from the Kansas state line westbound to Burlington. The project plan called for a full depth (11 1/2 inches thick) overlay of concrete Class P over the badly deteriorated existing flexible pavement.

The goal of this study is to use the ILLI-SLAB finite element program and a fatigue model developed by ERES in conjunction with the acquired data in the field to predict pavement performance for each of the three test sections.

A final report will be released in the summer of 1995.

Research contact: Ahmad Ardani, 757-9978



These employees are instrumenting the widened concrete slabs.

White Topping

The first white topping project in Colorado was constructed on SH 68 (Harmony Road) north of Fort Collins in Region 4. The construction consisted of installing two 300-foot test sections with 3 1/2 and 5 inch thick concrete pavement over the existing asphalt pavement. After 4 years of being in service, both test sections are performing well with some isolated minor distresses. The 3 1/2 inch test section has already exceeded its design life, with an estimated 16,349,000 vehicles, which translates into an 18K ESLA of 775,000 in a 4-year period. The American Concrete Pavement Association recommends a minimum thickness of 5 inches for the secondary and 8 inches for the primary and interstate highway system.

Because of the success of the white topping project in Region 4, and reports of successful projects in other states, it is recommended that white topping technology be considered as an alternate method of designing overlay pavements. White topping can be used as a cost-effective method to reduce maintenance costs for the transportation agencies and to reduce delays and backups for the travelling public. Resurfacing the existing asphalt pavements with concrete is an effective method of eliminating rutting, shoving, and temperature cracking in asphalt pavements, at least for the time being.

Research contact: Ahmad Ardani, 757-9978

Evaluation of white topping project.

SHRP SPS-2 Experiment

One of CDOT's biggest accomplishments under the SHRP/LTPP program was the construction of our SPS-2 experiment, "Strategic Study of Structural Factors in Rigid Pavements." This experiment is by far is the most comprehensive of all of our LTPP studies and deals with various structural and environmental factors in rigid pavements. Altogether, 13 - 600 foot test sections were installed. They included:

- two concrete thickness levels, 8 and 11 inches.
- 14 days flexural strengths at three levels - 550, 650, and 900 PSI.
- three different bases: one which drains water, Permeable Asphalt Treated Base (PATB), and two without drainage, the Lean Concrete Base (LCB) and Dense Graded Aggregate Base (DGAB).
- lane widths of 12 & 14 feet.

None of the test sections has its shoulder "tied" to the paved lanes. This will allow SHRP researchers to compare these test sections with another state's test sections knowing that shoulders, whether they were concrete or asphalt, did not affect pavement performance.

One of the unique features incorporated into this experiment was drainable bases. This study used a PATB in conjunction with an edgedrain and transverse interceptor drains. A layer of dense-graded aggregate base was used as a filter-separator to separate the subgrade from the PATB. This layer prevents the migration of fines from the subgrade into the treated base layer. After all the edge drains were installed, the PATB layer was laid using a track-mounted paver with extended screed. The paving operation went smooth and the PATB mix appeared to be very homogeneous.

Research contact: Ahmad Ardani, 757-9978

Performing the plate bearing test.

SHRP Seasonal Monitoring Program

CDOT in cooperation with the LTPP Division of FHWA and the SHRP Western Region Coordination Office sponsored a workshop and a field demonstration of the SHRP Seasonal Monitoring program in Grand Junction and Delta. The purpose of the workshop and the field demonstration was to train and familiarize LTPP SHRP coordinators with the Seasonal Monitoring program concept, equipment installation, operation, and data collection.

The SHRP Seasonal Monitoring program evaluates and monitors the impact of seasonal variations in moisture and temperature on pavement response. This program will attempt to establish a relationship between pavement response and deflection measurements taken at different times of the year for a given climatic zone. The ultimate goal of this program is to rationally use the acquired deflection data for evaluation, analysis and design.

The instrumentation consisted of installing the following measurement sensors:

- TDR (Time Domain Reflectometry) sensors, for moisture;
- Resistivity sensors, to monitor frost penetration;
- Thermistors, to measure temperature of the subgrade;
- Observation well, to monitor depth of ground water;
- Tipping Bucket Rain Gage, to measure rainfall;
- Ambient Temperature probe, to monitor the air temperature.

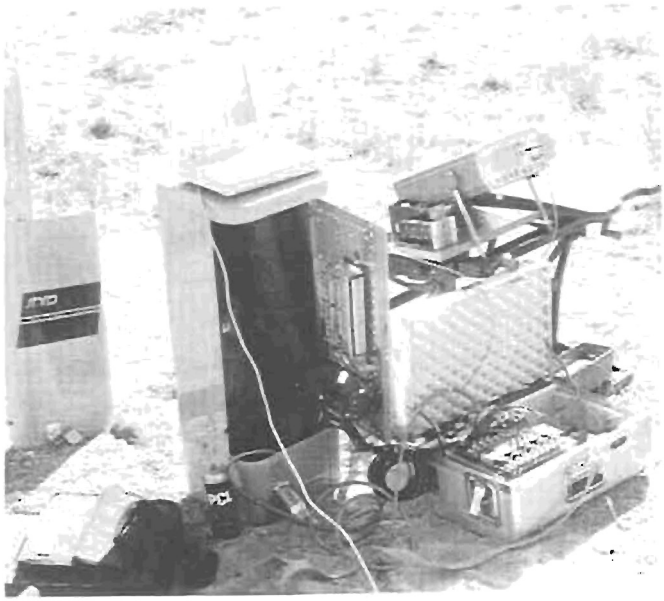
The SHRP seasonal monitoring site at the Delta site will be tested on a two year cycle; i.e, testing in years 1, 3, 5... etc. The data collected from this site will be entered into the National Information Management System (NIMS), along with data from 63 other sites across the United States and Canada.

Interim results can be expected in 3 years, and final results within the next 7 years.

"SHRP Seasonal Monitoring Program, Delta, Colorado." CDOT-DTD-R-93-15

Research contact: Ahmad Ardani, 757-9978

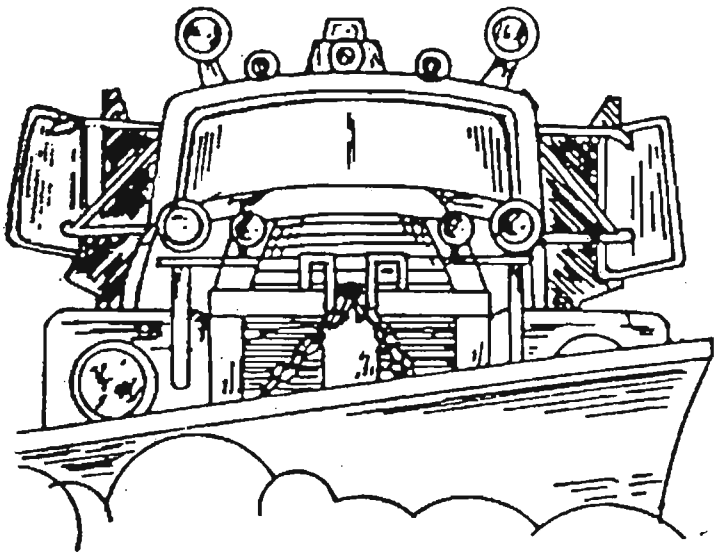
Top photo: Ambient temperature probe.
Middle photo: Augering the observation well.
Bottom photo: Data aquisition system



Maintenance operations present an area where research can have a big payback for CDOT. Colorado's maintenance forces are continually under pressure to do "more with less." The appropriate application of high technology tools and methods will allow them to accomplish their jobs in a safe and efficient manner. Many of the current studies are involved with winter maintenance and avalanche control.

Snow and Ice Control

In recent years, the use of road sand to provide traction during storms has become an issue. Sand used in snow and ice control is a 10-15% contributor to the winter air pollution problem (brown cloud) and is a component in the geologic particulates under 10 microns (PM_{10}) which constitute approximately 35-45% of PM_{10} in the winter. Sand actually decreases traction once pavements are bare. It can break windshields and chip paint on motorist's cars when kicked up by vehicles. Sand also decreases the life of pavement marking, and clogs drainage structures along the roadway. In addition, the disposal of used road sand is becoming a problem in the Denver area with the distinct possibility that future legislation will make this issue more complex and more expensive.



Alternative Deicing Chemicals

This research was begun in 1990 at the request of Section 8 Maintenance, who are responsible for snow and ice control in the Denver-metropolitan area. Section 8 has responsibility for approximately 3130 lane miles in the Denver area and typically spends $1.9 to $2.2 million per year to perform snow and ice removal. In order to provide traction and melt snow and ice, Section 8 traditionally used a mixture of 18% salt (NaCl) and 82% hard aggregate less than 3/8 inch.

With the above mentioned problems in mind, personnel from the Research Branch and Section 8 Maintenance set out to test various combinations of chemicals and sand which might partially alleviate the problems associated with the use of sand. The idea that improved deicing chemicals can reduce the need for road sand is fundamental to this research.

In the laboratory, tests were done to establish corrosion rates for different deiciers and melt characteristics at three different temperatures. Limited field tests were done to gain experience with alternative deicing materials and practices.

"Alternative Deicing Chemicals Research" CDOT-DTD-R-94-4

Research contact: Dave Woodham, 757-9975

This laboratory test was established to determine different corrosion rates for several deicers.

Environmentally Sensitive Sanding and Deicing Practices

The study "Environmentally Sensitive Sanding and Deicing Practices" performed by the University of Colorado at Denver investigated literature and current practices from a wide variety of sources to arrive at a document which summarizes the current state of knowledge about deicing practices and their effect on human health and the environment. Topics include: properties of snow and ice, roadway traction, anti-skid materials, air quality impacts of anti-skid materials, water quality impacts of deicing chemicals, deicing chemicals, equipment to apply deicers, snow and ice management practices, and current practices obtained from interviews and site visits. Topics for further research were also discussed.

This report recommends that the use of sand be reduced, that sand be swept up as soon as practical, that the use of alternative deicers be considered, that winter maintenance activities be timed for optimal efficiency, and that CDOT conduct implementation seminars around the State to increase awareness of the environmental impacts.

"Environmentally Sensitive Sanding and Deicing Practices" CDOT-CTI-95-5

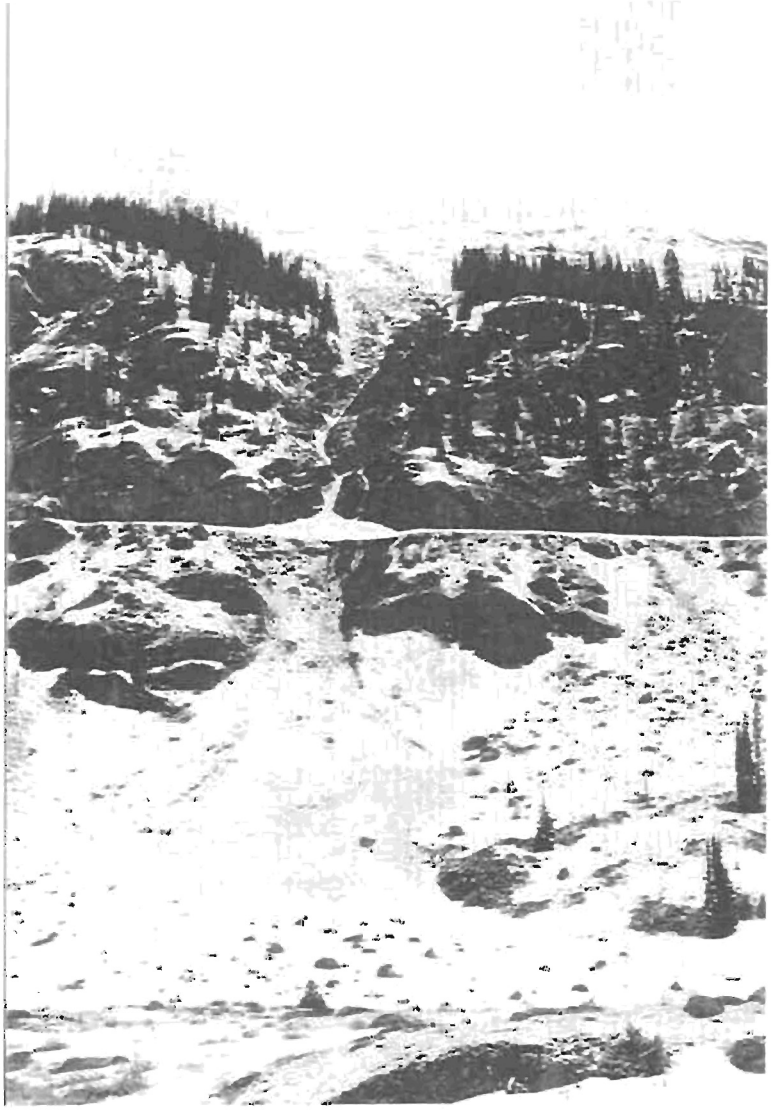
Research contact: Dave Woodham, 757-9976

Avalanches

Snow avalanches are a significant safety problem on Colorado mountain highways. On a statewide basis, approximately twenty transportation corridors are intersected by more than 500 avalanche paths. Avalanches are a major concern for CDOT as they endanger mountain travelers and maintenance personnel and can isolate mountain communities, cutting them off from essential services.

Since 1950, 12 people have been killed on Colorado highways by avalanches. On a national level, the average annual number of fatalities due to all avalanche activity is about 14 in the US, and 7 in Canada.

Colorado's most avalanche-affected highway is US 550 in the southwest corner of the state. In an average year, almost 90 avalanches will cross the road leaving significant debris. A single storm in 1993 covered over 22,000 lineal feet of US 550, and in some places the snow was as deep as 40 feet.



Beeler Grade, an avalanche path on Independence Pass in Western Colorado.

Avalanche Detection

In 1993, the Colorado Transportation Institute (CTI) began exploring less costly alternative measures to provide protection against the threat of avalanches. The approach focused on using advanced technologies to detect avalanches.

This CTI study is investigating the feasibility of detecting avalanches using acoustic sensors. In many avalanche paths, if the initiation of the avalanche can be detected, there is sufficient time, typically 40 - 60 seconds, to warn motorists before the avalanche actually reaches the road.

Two acoustically-based monitoring systems were tested during the winter of 1993-94 in an experiment conducted in Gothic, Colorado. The site at Gothic was chosen because of the high number of naturally-released avalanches documented on nearby Gothic Mountain, the presence of a trained avalanche observer living in Gothic, and the availability of phone lines, power and laboratory space offered by the nearby Rocky Mountain Biological Laboratory.

Both of the systems under evaluation used acoustic sensors to "listen" for signals which propagate through the air. Based upon the dated collected during 1993-94, both systems show promise for expanded future testing during the coming winter.

In the winter of 1994-95, one system was expanded to include observatories at Silverton and Ouray to allow monitoring of the area around Red Mountain Pass. This system was well suited to monitoring areas of 30 to 40 kilometers in diameter for avalanche activity. The capability to detect avalanches over widespread areas is useful for improving avalanche forecasting. Forecasters will have almost immediate feedback on the quality of their avalanche activity forecasts as well as up-to-date information on snow pack stability.

Another system was deployed on Loveland Pass to collect data under typical roadway conditions. This system shows the greatest promise for triggering a roadway warning system at locations with high avalanche hazards.

Research contact: Dave Woodham, 757-9975

Avalanche Hazard Forecasting Methods for US 550

A systematic collection and analysis of snowpack and weather data has been shown to be an effective methodology for determining avalanche-control and highway closures. This study will adapt this methodology for use on U.S. 550 in southwestern Colorado.

Avalanches result from a critical combination of terrain, snowpack, and weather parameters. Since terrain is a constant factor, locations where avalanches reach the highway have been mapped and photographed.

Snowpack parameters (e.g., depth, internal structure, surface characteristics) are being obtained at locations that represent the avalanche paths affecting the highway. Weather parameters are also being obtained at similar locations.

The data collected and studied in this project indicate a relationship between weather, snowpack strength, and avalanche activity and will result in improved avalanche-control and highway closure procedures.

Research contact: Dave Woodham, 757-9975

This sensor is one of two acoustically based avalanche monitoring systems tested in Gothic, CO.

Avalanche Hazard Index

Avalanche paths on the CDOT road network range from small bank slides on many of the mountain passes to very large avalanches such as the East Riverside on US 550. CDOT is developing a rational method for assessing the level of hazard that exists by calculating the encounter probability of an avalanche with a vehicle for a given slide. The Avalanche Hazard Index (AHI) will be used to determine how to best allocate CDOT resources to address mitigation efforts on a given avalanche path.

The concept of the AHI has been used in the past as a quantitative measure of the avalanche hazard to traffic. The AHI takes into account the probability of an avalanche encounter with a vehicle in a given time period while estimating the amount of damage this encounter is likely to produce. The AHI for all avalanche paths affecting state-maintained roads will be calculated during this study.

Research contact: Dave Woodham, 757-9975

I-76 Truck Study

Portions of the driving lane on I-76 in District IV are seriously distressed. To help prolong the life of the portland cement concrete pavement, District IV has placed signs advising truckers to use the passing lane in the area between Roggen and the state line. According to a survey conducted by CDOT 90% of the total truck traffic was concentrated in the outside lane. Although both lanes are subjected to the same environmental stresses, the outside lane became prematurely distressed due to unusually heavy loads caused by the trucks. The objective of this study was to investigate the practicality of diverting truck traffic from the driving lane to the passing lane. This was accomplished by evaluating traffic classification by lane before and after signing, pavement distress, and economic feasibility. A final evaluation and report will be completed in 1995.

Research contact: Dave Price, 757-9976

On this section of I-76 trucks are asked to use the left lane due to a badly distressed right lane.

Approximately 90% of all paving by CDOT on an annual basis is with a hot bituminous mixture - at a cost of millions of dollars each year. Heavier trucks, changes in asphalt cement, mandated changes, changes in additives, and past pavement failures point directly to the need for continued research.

Crumb Rubber

Approximately 285 million used tires are discarded each year in the United States. This averages out to one tire, per person, per year. In Colorado, about 3.5 million tires per year are discarded. A used tire weighs approximately 20 lbs. After the metal and fibers are removed, and the tire is ground up, each scrap tire produces only 12 lbs of reusable material.

In December 1991, the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) was signed into law. Section 1038(d) of this legislation requires states to use crumb rubber from recycled tires in minimum percentages of asphalt surfacing placed each year. The utilization requirement was to begin in 1994 with 5% utilization and increase in increments of 5% until the utilization requirement reached 20% in 1997. For Colorado's 5% utilization requirement, 1,000,000 lbs of crumb rubber would have to be used.

In October of 1993, the House and Senate agreed to impose a one-year moratorium on Section 1038. In effect, this moratorium deleted the state's obligation to the 5% requirement for 1994.

In September of 1994, the House and Senate passed the FY95 Department of Transportation Appropriations Bill (H.R. 4556). This bill extended the moratorium on crumb rubber usage until 1996.

Since incorporating crumb rubber into pavements is fairly new for CDOT, it has been decided not to risk future sanctions by waiting until the crumb rubber issue is resolved.

In 1994, CDOT constructed their first crumb rubber project. This project is located on Platte Canyon (SH 75) from Bowles to C470. Four evaluation sections were established on the project with varying amounts of crumb rubber.

This project used 20,000 lbs of crumb rubber - or approximately 1,700 tires. Because of the small quantities involved this project there was barely a dent made in the number of tires generated, per year, in Colorado.

CDOT is planning to construct several more projects containing crumb rubber. These projects will incorporate an even higher percentage of crumb rubber. These projects, in addition to the project constructed in 1994, will help CDOT develop guidelines and provide construction experience for when the crumb rubber utilization requirement becomes effective.

Research contact: Donna Harmelink, 757-9518

Stone Matrix Asphalt

Colorado completed its first Stone Matrix Asphalt (SMA) pavement in 1994. SMA pavements are gap-graded, hot bituminous mixes that have been used in Europe for over 20 years. These mixes were developed originally in Europe to provide a pavement surface that would be resistant to rutting and shoving under studded tire use. Even though the use of studded tires has been banned in most of Europe, SMA pavement continues to be used due to its increased resistance to rutting and shoving under heavy traffic.

The Colorado Department of Transportation initially intended to construct a trial section of SMA on US 85 north of Ault in 1992; however, because of advertising delays the SMA was incorporated into another project on SH 119, near Niwot. This project was advertised and awarded in the late summer of 1994.

The project contained five different mix designs:
1) standard dense graded HBP (Grading C);
2) Stone Matrix Asphalt (SMA) with Vestoplast;
3) SMA with polymer modified asphalt (AASHTO Task Force 31, Type I-D polymer);
4) SMA with cellulose fibers;
5) and a Grading C with rubber (AASHTO Task Force Type II-B).

A demonstration workshop was held on August 29, 1994 to view the production and placement of the SMA pavement located on this project. Included in the demonstration was a four hour seminar that included the FHWA, state and contractor/industry/supplier perspective.

On August 30, 1994 participants inspected the plant and construction sites. Project and construction personnel were on hand to answer questions during the tours. Approximately 50 people attended the workshop and on-site demonstration. The workshop participates represented FHWA, state, city, counties, and industry.

This project will be under evaluation for a three year period. At the conclusion of the study a final report will be prepared documenting, evaluating and making recommendations as to the future of SMA mixes in Colorado.

"Demonstration of the Placement of Stone Matrix Asphalt in Colorado" (Interim report) CDOT-DTD-R-95-1

Research contact: Donna Harmelink, 757-9518

In-Place Voids

Historically, only one laboratory compactive effort for asphalt mix design has been used in Colorado regardless of traffic or temperature environment. A recent change in CDOT's asphalt mix design procedure from the California kneading compactor to the Texas gyratory compactor has resulted in significantly lower optimum asphalt contents. To address the concern of lower asphalt contents, adjustments to CDOT's hot mix asphalt design procedure were made.

Using results from the California kneading compactor, samples from existing pavements, experimental field projects, and results obtained from the European equipment, customized designs for each traffic and environmental area in Colorado were developed.

The recommended laboratory compacting effort (variable end point stress) developed for the Texas gyratory for various traffic and environmental zones is shown below:

Traffic	High Temperature			
	Very Cool	Cool	Moderate	Hot
Low	25	25	25	50
Medium	25	25	50	75
High	25	50	75	100
Very High	50	75	100	125
Very Very High			125	

This study will evaluate one or two sites from each category. In-place voids will be monitored over a five year period. This study will evaluate the existing laboratory compactive efforts and help determine if additions to the design procedure will be needed.

Research contact: Donna Harmelink, 757-9518

Rumble Strip Treatments on Asphalt Shoulders

Single car run-off-the-road accidents are one of the most common and severe types of accidents experienced on rural highways. Although much has been written about the effectiveness of shoulder rumble strips to prevent these types of accidents, the Colorado Department of Transportation has no standard details or specifications to implement this safety item on our highways.

FHWA Technical Advisory T5040.29 indicates that "Shoulder treatments that provide an audible/vibrational warning to errant drivers have proven effective in keeping traffic off the shoulder and reducing accidents on long tangent or monotonous highway sections with a history of run-off-the-road accidents."

Various treatments are being included in this study for evaluation:

- Rumble strips rolled in the asphalt shoulder at various distances and lengths;
- Rumble strips cut into the shoulder at various distances and lengths; and
- Chip seal placed on the shoulder for rumble effect.

An evaluation in the spring of 1995 will review the safety, the overall cost, maintenance problems, and overall constructability of the treatments.

A final report will be completed in the summer of 1995.

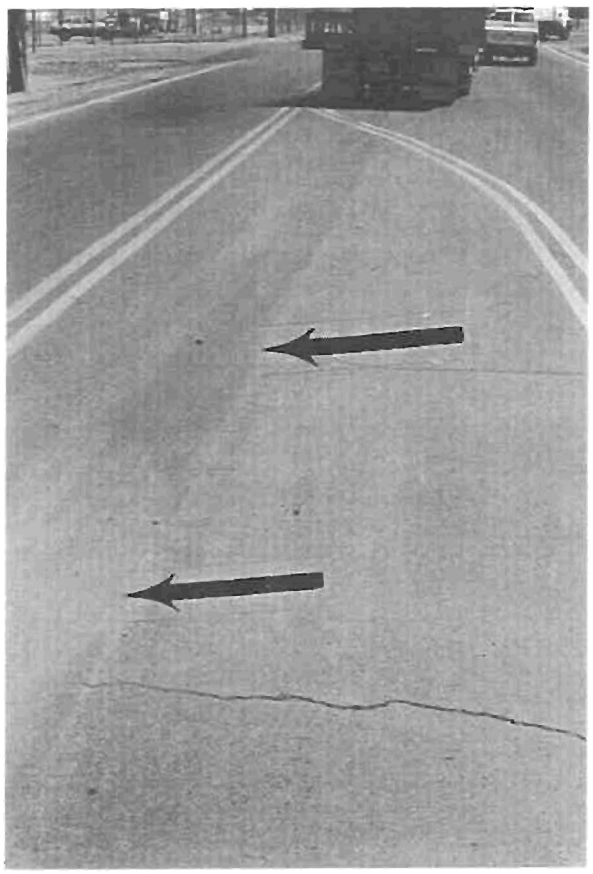
Research contact: Dave Price, 757-9976

Rumble strips being rolled into the asphalt shoulder.

Special Polymer Modified Asphalt Cement

In 1995, the last field evaluation for this study will be completed. A report will available for distribution by the end of 1995. The data collected to date does not show a significant difference in the performance with, or without, the polymer. However, as the department begins to incorporate the new SHRP binder specifications into the mix design phase, the responsibility for determining the need for polymers will be on the contractor. The binder will need to meet the SHRP specification and the contractor will need to do whatever it takes to provide the binder that meets the specification.

Research contact: Donna Harmelink, 757-9518



This picture shows two different polymer modified pavements placed on Brighton Blvd., one eastbound and one westbound. The pavement on the left is performing well.

Large-Stone Hot Mix Asphalt Pavements

Large-stone asphalt pavements have been promoted by various asphalt associations including the National Asphalt Pavement Association as an answer to rutting problems with existing pavement designs. Past problems with large-stone pavements have included segregation of the mix and the validity of mlx designs produced with standard test equipment. Thin overlays can also be difficult to place as the mat thickness approaches that of the maximum sized aggregate -they are generally unsuitable for the top (finished) mats, and they may cause excessive plant wear - negating some of the cost benefits. These problems have been looked at for the past two years on three separate construction projects.

In Colorado, large-stone pavements have been designated as Grading G with a maximum aggregate size of 1-1/2 inches. Before this, Grading C was the largest aggregate size at a maximum 3/4 inches. The larger aggregate allows for better aggregate interlock within the pavement, reducing the rutting that occurs in wheelpaths. Three projects were monitored durring construction and and for a three year period following for distress. The final report was written in the spring of 1994. Following are the conclusions and recommended implementation for the use of large stone mix determined by construction monitoring and following evaluations of the three sites.

Study Conclusions

1. The large-stone mixtures were very difficult to place. Segregation was always a problem. By using better construction techniques, segregation was reduced, but was still present.

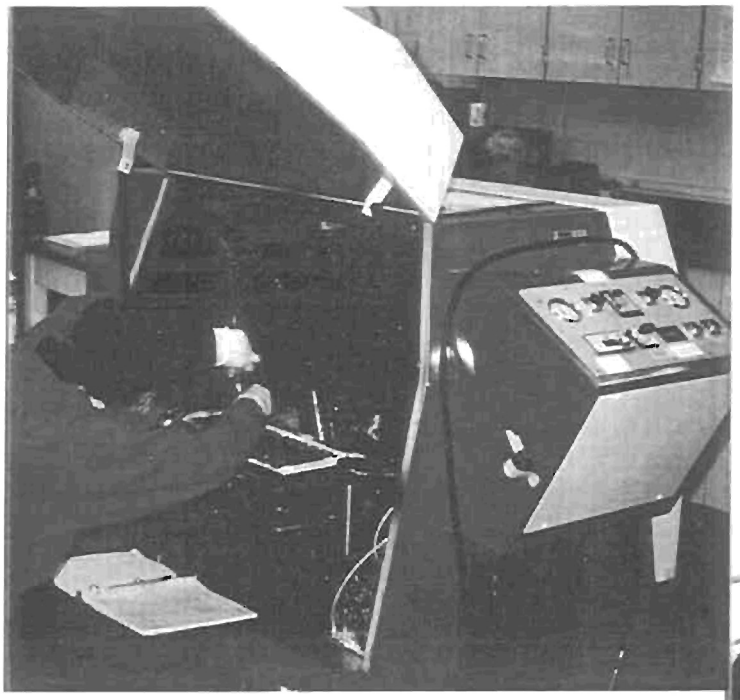
2. Rut depth measurements showed that the control sections built with the smaller-aggregate HMAs and the test sections built with the large-stone HMAs had the same rutting potential.

3. The control sections were consistently smoother than the test sections. All of the large-stone mixtures would have required corrective action with the 1994 Smoothness Specification; two of the three smaller aggregate HMAs would have received incentives.

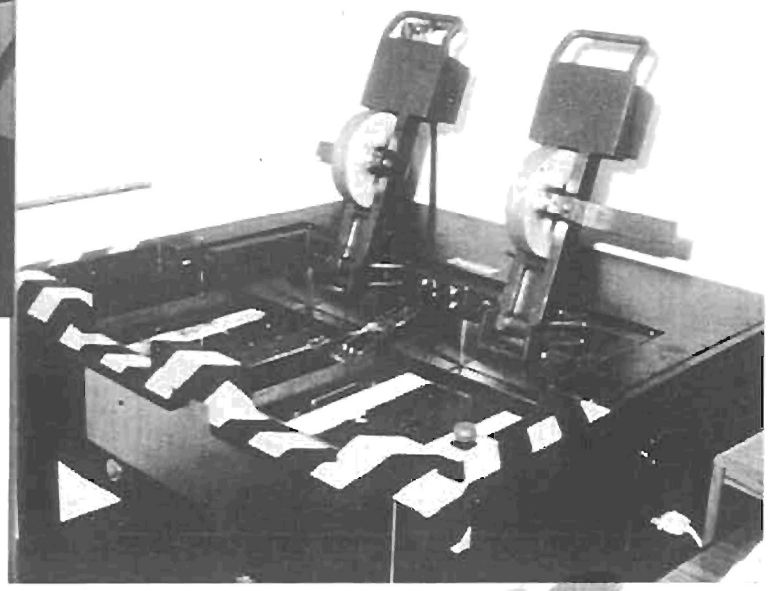
4. The cost of the smaller aggregate HMAs are very similar to the large-stone HMAs. It was thought the large-stone HMAs would have lower costs due to less crushing of the aggregate and less asphalt content, but as a whole the large-stone HMA was not less expensive. These costs may lower if large-stone HMAs are used more frequently bringing up the overall tonnage.

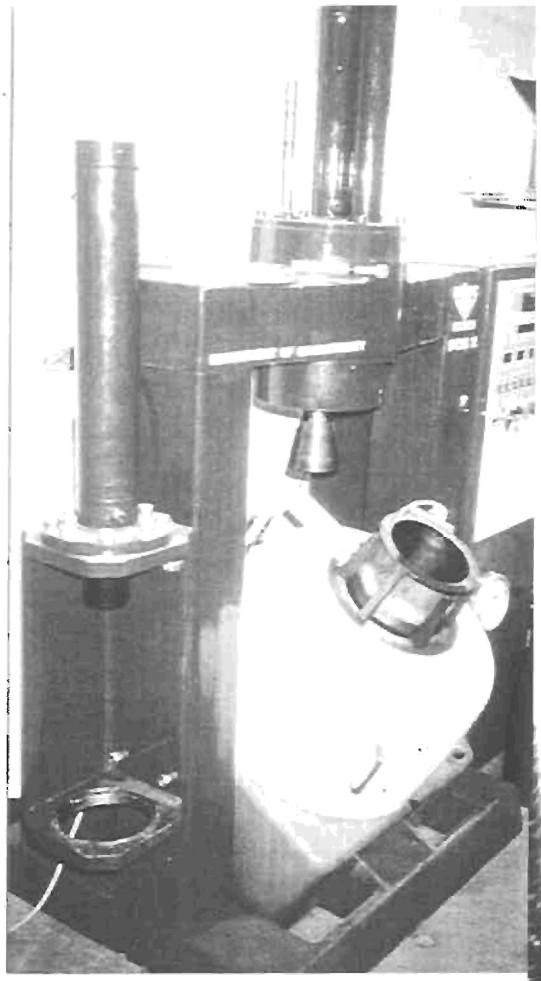
"Large-Stone Hot Mix Asphalt Pavements" CDOT-DTD-R-94-5

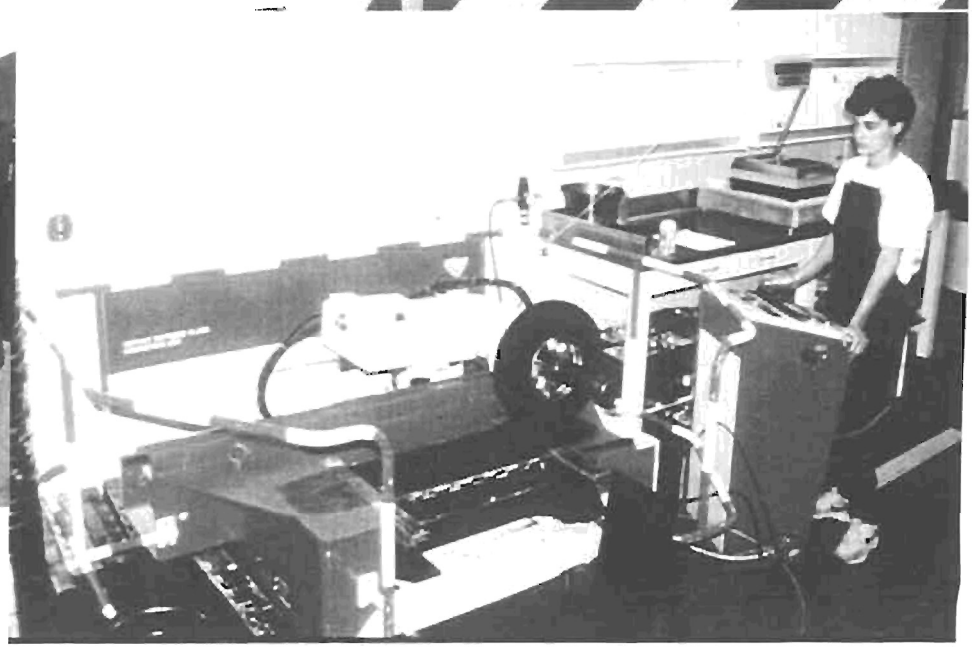
Research contact: Dave Price, 757-9976



Just a few pieces of equipment from the European Testing Laboratory located in Staff Materials. Clockwise: French Rut Tester, Hamburg Wheel Tracking Device, Wheel Plate Compactor, and the French Gyratory Compactor.







European Laboratory Equipment

CDOT's European laboratory began operating in June 1992. In the 3 years that CDOT has had the European equipment, many new developments have occurred.

The European equipment has helped discover which conventional tests are most able to predict future rutting of roads.

The European equipment has helped develop a modified mix design method customized to individual roads.

The European equipment has helped detect and correct mix problems which are not identifiable using current CDOT mix testing procedures.

The European equipment has helped enable pavement lifespan research to be conducted in a reasonable amount of time.

The European equipment has helped enable a final check on designs of high profile projects to give an extra margin of comfort to project personnel.

But this is only the beginning - CDOT also has future plans for the European equipment. The European equipment will be used to develop new CDOT Standard Specifications to increase the quality of material supplied to state projects. It will also be used to developed new asphalt paving mixes for increased durability and rideability of pavements. In addition, the equipment will be used to validate current tests that identify which tests best predict future performance of pavements. And lastly, the European equipment will be used to evaluate current state-of-the-art materials tests to determine their ability to identify Colorado's unique materials problems.

Numerous reports have been published documenting study findings. (see Research Publications at the end of this report.)

Research contact: Donna Harmelink, 757-9518

Key Way Curb

Key Way Curb is a continuous concrete curb that is poured using a slip form which travels over a groove (the keyway) that has been cut into asphalt pavement. Eliminating concrete curb and gutter at the edge of asphalt roadways and paving full width with asphalt, then adding a key way curb on top of the asphalt can save time and money.

A small milling machine travels along the edge of the pavement cutting a groove about one inch deep by two inches wide. When the curb is poured and shaped by a traveling slip form, the groove forms a key shape that is a part of the curb and holds it in place. There are no bars to install to tie the curb to the pavement. There are no forms to set and strip for curbs and gutter.

A 1500 foot long trial section was installed in the median on US 24, just east of I 25 in Colorado Springs, during the fall of 1993. Since it is free standing, (not filled behind the curb), it will be a good evaluation of the durability of this type of curb. Durability of a keyway curb when it is hit by traffic and snow plows, and whether water getting under it and freezing will lift the curb out of the keyway are among the questions that will be answered during the evaluation. In the first winter there appeared to be no damage to the curb beyond some gouging by snow plows. CDOT is investigating having a specification for keyway curb that can be included in future projects.

Research contact: Skip Outcalt, 757-9984

Finishing touches are applied to this Key Way Curb trial section in Colorado Springs.

Type T Manholes Experimental Feature

An experimental feature was introduced to familiarize CDOT with the use of a Type T manhole. Earlier designs called for a concrete box base at the location of each manhole in the Colorado Standard Plans (CDOH Standard M-604-20). These manholes are used for inspection of the drainage lines and periodic maintenance. This cast-in-place manhole is expensive and hard to build.

Type T manholes are fabricated by concrete pipe manufacturers and are constructed to be part of the pipe. This type of manhole is a pre-cast design that is delivered to the site and set in place rather than cast-in-place like the standard. An advantage of the Type T manhole is a much more efficient hydraulic design than that of the Colorado Standard Design with which the Type T manhole was compared.

The Type T manhole was placed on Hampden Ave. with little difficulty in construction and minimal disruption to traffic flow. There are two main advantages to a Type T manhole. One of the advantages is the ease of placement allowing quicker installation and thereby causing less traffic congestion and increasing overall safety on heavily traveled roadways. The other advantage is the fact that the manhole is basically part of the pipe, allowing good hydraulic flow with minimal restrictions caused by the manhole. A box base manhole has an area at its base that can collect trash and must be cleaned out to reduce the restrictions to hydraulic flow.

The Type T manhole on this project had a 62% higher cost, possibly due to the fact that it was a new design and thereby causing a lot of work to be accomplished in the design and prefabricated construction. This cost should drop somewhat as this design sees more use. However, even with higher costs, the fact that construction can be completed in such a reasonably short time, thereby reducing traffic congestion, justifies the use of this manhole in high traffic areas.

(The Type T manhole design was added to the CDOT Standard Plans in 1992.)

"Type T Manholes (Experimental Features)" CDOT-DTD-R-93-13

Research contact: Dave Price, 757-9976

The Research Branch is involved in several studies in the area of highway safety and the evaluation of new products and methods. Currently the major focus is on durable pavement markings and pavement markings which will help meet the new requirements for Volatile Organic Compound (VOC) emissions.

Pavement Marking Research

New regulations will penalize the release of volatile organic compounds (VOC) in non-attainment areas such as the metro-Denver area. This study will compare various water-borne paints on a test deck established on C470. The test sections include both concrete and asphalt substrates. Waterborne paint stripes from various manufacturers were installed in June of 1994. Retroreflectivity readings using the Mirolux 12 were taken at 1, 3, 6, and 12 months.

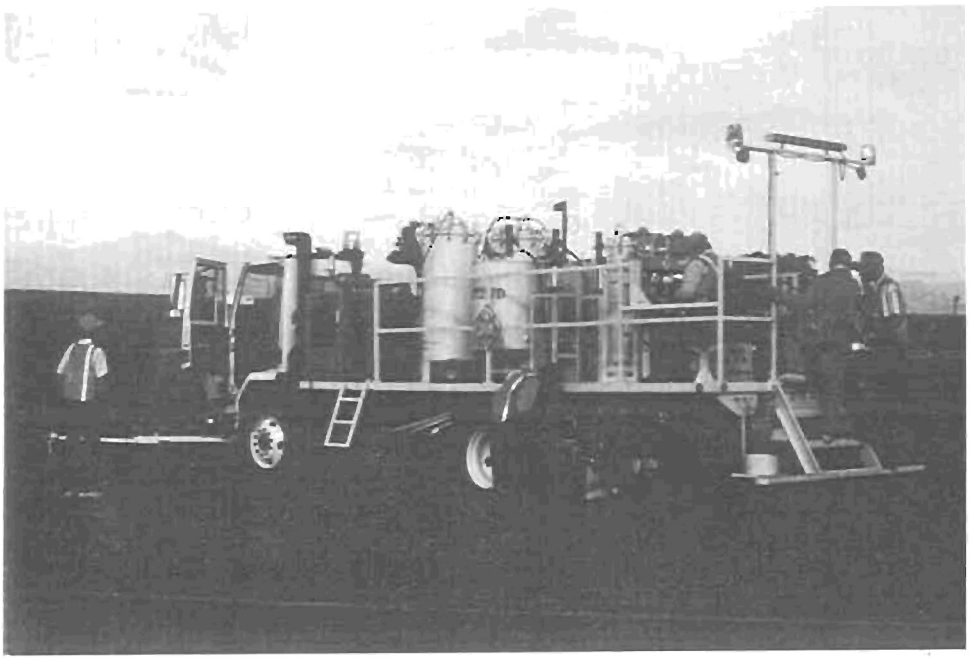
Research contact: Dave Woodham, 757-9975

Pavement marking research test section.

All Weather Pavement Markings

Section 6005(a) of the ISTEA bill provided $2 million for evaluation of all-weather pavement markings. FHWA has developed a test program to evaluate pavement markings in as many climatic conditions as possible. Colorado has agreed to participate in this study and test sections were established on I-25 north of Denver. This study will evaluate epoxy paints, thermoplastic pavement markings, preformed pavement marking tape, and methyl methacrylate paint on both concrete and asphalt pavements. The study will continue for 5 years to determine life-cycle costs for these durable pavement marking systems. All systems were installed in the summer of 1994 and initial readings were obtained for each test section.

Research contact: Dave Woodham, 757-9975



This truck is applying an experimental pavement marking on I-25.

High-Performance Safety Devices

High-performance highway safety devices are those which provide service which far exceeds that of the normally specified products. Although the high-performance devices cost more than more conventional products, their use is often justifiable if a measurable increase in highway safety can be linked to the product's use.

Phase III projects on C-470 incorporated high-performance sign sheeting, pavement markings, flexible delineators, guardrail delineation tabs, and sign post breakaway devices.

The objective of this study is to determine if the use of high-performance highway safety devices has a measurable effect on accident rates.

Research contact: Dave Woodham, 757-9975

Brakemaster and CAT Guardrail End Treatments

"In-Service Evaluation of Highway Safety Devices" evaluated the use of 10 gauge guard rail and the effectiveness of Brakemaster and CAT guardrail end treatments. This evaluation included the cost effectiveness , ease of maintenance and repair, and effectiveness of the devices in controlling accidents.

The CAT and Brakemaster terminals are designed to protect narrow hazards such as the ends of double sided guard rail and traffic barriers in medians and on shoulders. Both systems are designed to control a vehicle as they collapse and bring the vehicle to a relatively gentle stop (gentle when compared to the stop provided by a concrete bridge abutment at least). The chance of the vehicle being launched into the air, rolling over, or being impaled on the end of the guard rail is greatly reduced by the design of these terminal systems.

CDOT uses 12 gauge guard rail along highways statewide. During winter storms in the mountains, snow plows often hit the rail and damage it. Along US 24 south of Minturn, CDOT replaced some old cable guard rail with new W-Beam guard rail and, as part of this project, installed some 10 gauge guard rail to see if it would last longer and show less damage from winter plowing operations. 12 gauge rails are .105 inch thick, about the same as 27 pages of this book. 10 gauge rail is .135 inch, or about 34 pages thick. Those extra six pages equal extra strength which means that the guard rail can take more abuse before it needs to be replaced.

"In-Service Evaluation of Highway Safety Device" CDOT-DTD-R-93-17

Research contact: Skip Outcalt, 757-9984

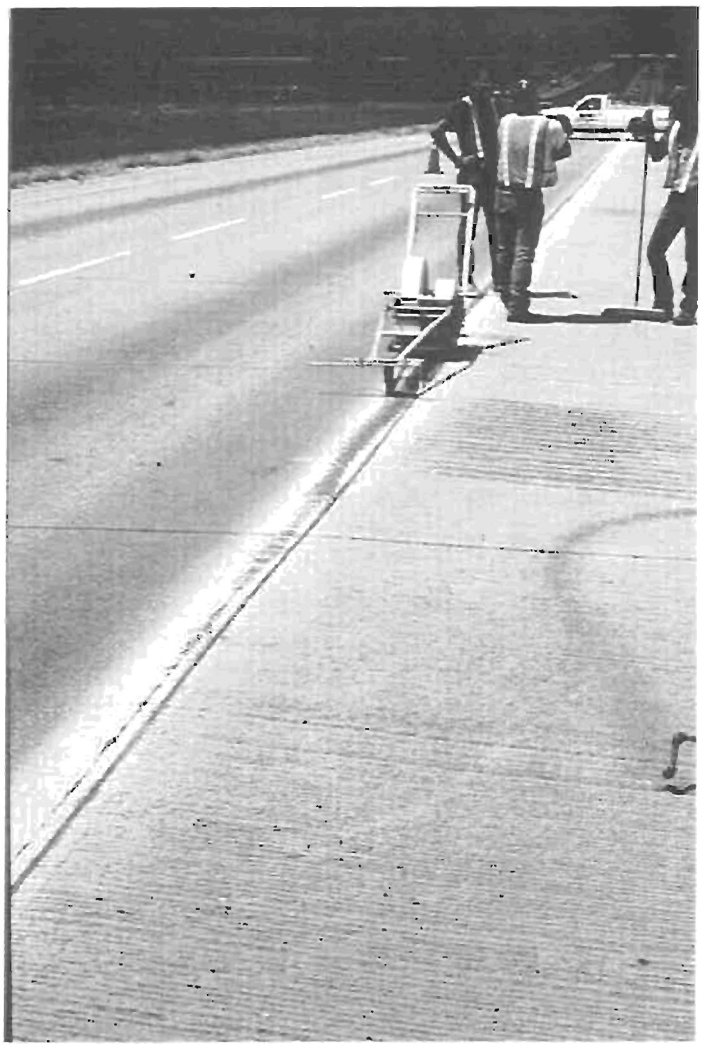
This guardrail is designed to control an errant vehicle and will collapse upon impact.

Stamark 380 Pavement Marking Evaluation

Stamark 380 is a preformed pavement marking tape that uses ceramic beads instead of the glass beads that are used in Stamark 350. This enhancement may add to the long-term life of the pavement marking while retaining its retroreflectivity. The Research Branch has been conducting an evaluation on this product to compare its performance against the Stamark 350 tape.

Two sites have been monitored for the reflectivity and durability of the Stamark 380 to stick to the new pavement surface. After approximately three years the tape shows good reflectance and has not pulled away from the pavements surface. One more evaluataion will be performed during the spring of 1995. The results will soon be published in a final report.

Research contact: Dave Woodham, 757-9975



Application of the Stamark 380 preformed pavement marking tape.

Geotechnical research continued to be strong during the past two years, especially with the creation of the Colorado Transportation Institute who has made this type of research a top priority. Much of this research is a partnership effort involving experts from CDOT, various universities, and the private industry.

Geosynthetic Wall Standard Design Charts

Geofabric retaining wall research has been conducted extensively by CDOT/UCD in recent years. The two full-scale test walls (with sand and clay backfills) performed in August 1991 show that geofabric walls have very high safety factors. Results of recents bids on CDOT projects show that geofabric walls can save over 50% in some situations. Statewide implementation of this new technology will save millions each year.

"Design and Construction of Simple, Easy and Low Cost Retaining Walls"
CTI-UCD-94-1

Contact: Paul Macklin, 757-9750

Geofabric Wall with Clayey Backfills

The design of a conventional fabric wall requires granular soil as the backfill material. This, in some cases, can be difficult or expensive to achieve due to the lack of such material. Therefore, this research was initiated to study cohesive soils as the backfill in construction of fabric walls. This study concluded that clay, kept dry, is a suitable backfill.

The study was then amended to include the development of a finite-element-based, user-friendly computer program for standard wall shapes.

The FEM model and its documentation are complete and being used by the MSB design experts of CDOT on an experimental basis.

CDOT does not plan to make general distribution of this computer program until there is sufficient validation with actual field performance. Further, the program has the potential to be inappropriately applied. A user must have some experience with FEM models to appreciate the limitations and pitfalls of the program.

Research contact: Bob Barrett, 757-9522
Principal investigator: Jonathan T. Wu, UCD, 556-8585

EPS for Bridge Abutment Backfill

This study was originally established to investigate the possibility of using recycled polystryrene in some highway construction applications. Polystyrene has been used as fill material in the past, but its application has been limited due to the high cost of polystyrene. It is hoped that the use of the recycled material will reduce the total costs to a point that it will make it economical to apply polystyrene as a lightweight fill material in some selected highway construction projects.

Project ID(A) 076-1(122) was selected to test the EPS in a bridge approach. This study will also test "flowfill" in two approaches as a way to mitigate approach settlement problems. All abutments are performing very well, however the draft report concludes that the approaches backfilled with flow fill show the least post construction embankment compression and provide a better ride than approaches backfilled with either EPS or class 1 structural backfill.

Research contact: Bob Barrett, 757-9522
Principal investigator: Shan-Tai Yeh, Staff Materials, 757-9274

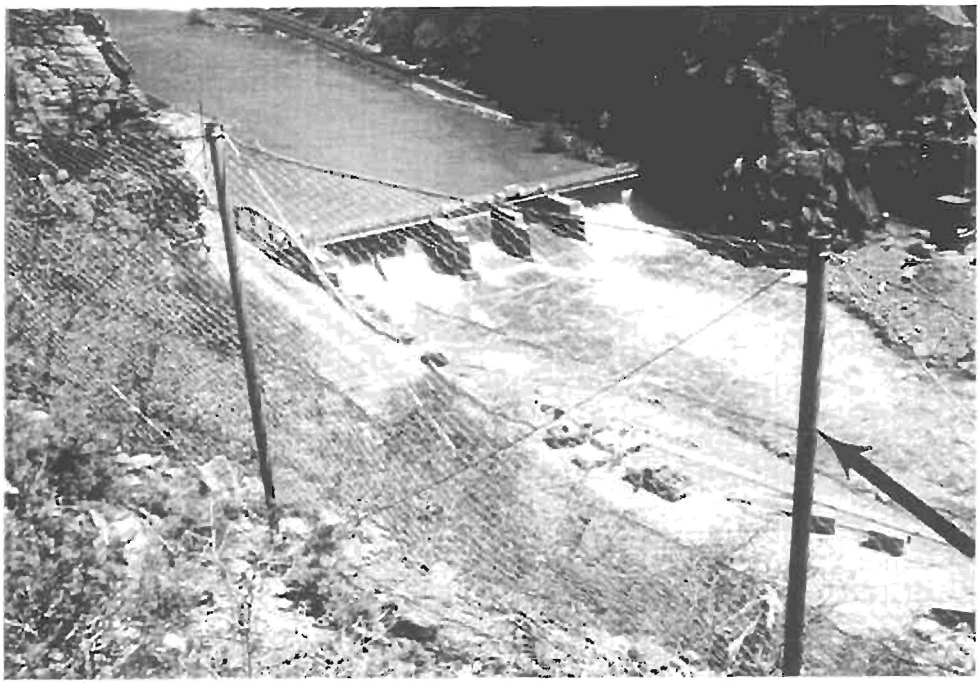
Here, recycled polystyrene is being used as a fill material on a bridge approach.

CDOT Flexpost Fence: A Study to Double Rockfall Capacity

Rockfall is a hazard along highways in all regions of Colorado. Concentration of population and tourist traffic along major transportation routes brings many people near rockfall hazard sites. Among the new barriers is CDOT Flexpost Rockfall Fence. The flexpost has evolved into an innovative, cost effective and proven rockfall mitigation structure. The rockfall capacity is somewhat greater than half that of commercially developed fence systems. The rockfall capacity of flexpost fence is limited by the tensile strength of its fabric of stell mesh and cables. Using a stronger fabric could equal or exceed strength of commercial fences and be stiffer and more massive. Fabric tensile improved fabric will not merely be stronger, it will be stiffer as well. The dynamic response of the fence will be altered. Modifications intended to reanalysis of dynamic forces during impact. Previous research on Flexpost fence included testing three prototypes and development of specialized impact analysis software for flexible post systems. The software computes member forces needed for design checking and generates a graphical depiction of fence response. This work is described in two reports.

"High-Capacity Flexpost Rockfall Fences" CDOT-CU-94-13
(This is a revision of a report published February 1992.)

Research contact: Bob Barrett, 757-9522
Principal investigator: George Hearn, 492-6381



A CDOT Flexpost Fence in place in the Glenwood Canyon.

Geofabric-Wrapped Underdrains

Interceptor drains, also called under-drains or French drains, have been used for many years to prevent ground water intrusion below the pavement. In recent years, these interceptor drains have been wrapped with geofabric to prevent sediment intrusion. There is some question about whether or not these geofabrics become clogged with sediment and how rapidly this occurs. Six groundwater monitoring wells have been installed. A flow meter was installed at the effluence of the interceptor drain. Measurements were taken from each of the wells and the flow meter periodically, especially before and after the nearby irrigation canal was opened or closed. The drains are performing as designed.

Research contact: Bob Barrett, 757-9522

Geofabric-wrapped underdrains under construction.

Shredded Tire Embankment

The use of shredded tires can provide lightweight fill material for embankment construction. It also can lower the burden of filling up sanitary landfills with an ever increasing numbers of wasted tires.

This research study was developed to monitor the performance of an 8-foot high composite embankment filled with 20,000 cubic yards of shredded tires. The embankment is in service on I-76 and is performing well. Shredded tire embankments appear to be a cost-effective way to limit settlement in soft soils.

Research contact: Bob Barrett, 757-9522
Principal investigator: Brandy Gilmore, Staff Materials, 757-9275

This 8-foot high composite embankment is filled with 20,000 cubic yards of shredded tires.

The CDOT ITS program originated within the Research Branch several years ago. The program has continued to blossom over the years integrating with other branches within the department. The program has also undergone a name change from "C-Star" to "Smartpath". The Smartpath program involves the six CDOT regional offices and the newly formed ITS Program Office. The Smartpath program continues to place strong emphasis on the development of public-private partnerships. CDOT is pursuing legislation allowing for the formation of public-private partnerships in the area of transportation.

The Smartpath program, under the guidance of the CDOT statewide ITS team, has developed a long range vision for the development and implementation of ITS in Colorado. CDOT Research Branch staff with ITS experience participate as a member of this team. CDOT is seriously evaluating the implementation of ITS strategies as solutions to current and future transportation mobility problems. Significant efforts have been placed on incorporating ITS into the Colorado Department of Transportation 20-year transportation plan. One of those stratgegies calls for the construction and operation of a statewide Traffic Operations Center which would serve as an central real-time transportation information hub for the state. Other ITS activities involving CDOT Research Branch staff include the following:

(Editor's note: Research staff involved with ITS were, in 1995, reassigned to the the ITS Program Office. This report represents their activities from January 1993 - December 1994.)

Dynamic Traffic Modeling of the I-25 Corridor of Southeast Denver (DYMOD)

A study by the University of Colorado at Denver was performed to model the potential for predicting time varying traffic conditions in a moderate size urban network during peak traffic conditions. The results from the study indicated that alternate routes for bypassing accidents were underutilized. Also, delays due to incidents could have been significantly reduced had an travel advisory systems been operating to guide drivers around incident locations. This study has become a building block for future implementation of traveler information systems and their integration into a Traffic Operations Center.

Contact: Neil Lacey, 757-9971

ENTERPRISE

ENTERPRISE is a pooled fund consortium of transportation agencies dedicated to cooperative research, development and deployment of ITS solutions. Colorado serves as the lead state for the organization responsible for adminstration of the program. Other members include Arizonia DOT, Iowa DOT, Michigan DOT, Minnesota DOT, North Carolina DOT, Washington DOT, Maricopa County DOT, Ontario Ministry of Transport, Dutch DOT, and Transport Canada. ENTERPRISE was established in 1991. In addition to the two ITS Operational Test Projects - Herald (an AM subcarrier) and Mayday (an emergency notification system), ENTERPRISE is working on the following activities: Vehicle-to Roadside communications, Video Imaging for Travel Times, Vehicles as Traffic Probes, and non-proprietary communication protocals for dissemination of traveler information. Rural ITS is an area of particular importance to the organization. The members continue to be active participants and sponsors of the National Rural ITS Conference. ENTERPRISE embodies the positive aspects of a successful ITS program including intergovernmental cooperation, public-private partnership opportunities, and the exchange of information on national and international ITS projects.

Contact: Neil Lacey, 757-9971

ENTERPRISE

Interstate 70 Rural ITS Corridor Planning Feasibility Analysis

CDOT has identified the I-70 corridor from Denver to Glenwood Springs as an opportunity to implement ITS strategies through an exemplary vision for improving safety and mobility for the travelling public. The study to date has identified a corridor master plan along with recommendations for implemention of early action items. These recommendations are being incorporated into the Colorado Statewide Transportation Plan and ITS program for implementation.

Contact: Joni Brookes, 757-5159

ITS Operational Test Projects

Operational tests bridge the gap between R & D activities and full-scale deployment of proven technologies. Results of the operational test program will be key factors in evaluating potential ITS applications. Colorado DOT is currently managing/participating in 5 ITS Operational Test projects.

1)Dynamic Truck Speed Warning For Long Downgrades

The project provided for the installation of a weigh-in-motion station with loop detectors to determine vehicle speed and a variable message sign to determine the weight of each truck passing the site. The system ignores vehicles under 30,000 pounds GVW. The vehicles are advised of the safe speed using the varible message sign. The partners in the project include: Colorado DOT, Colorado Motor Carriers Association, and International Road Dynamics.

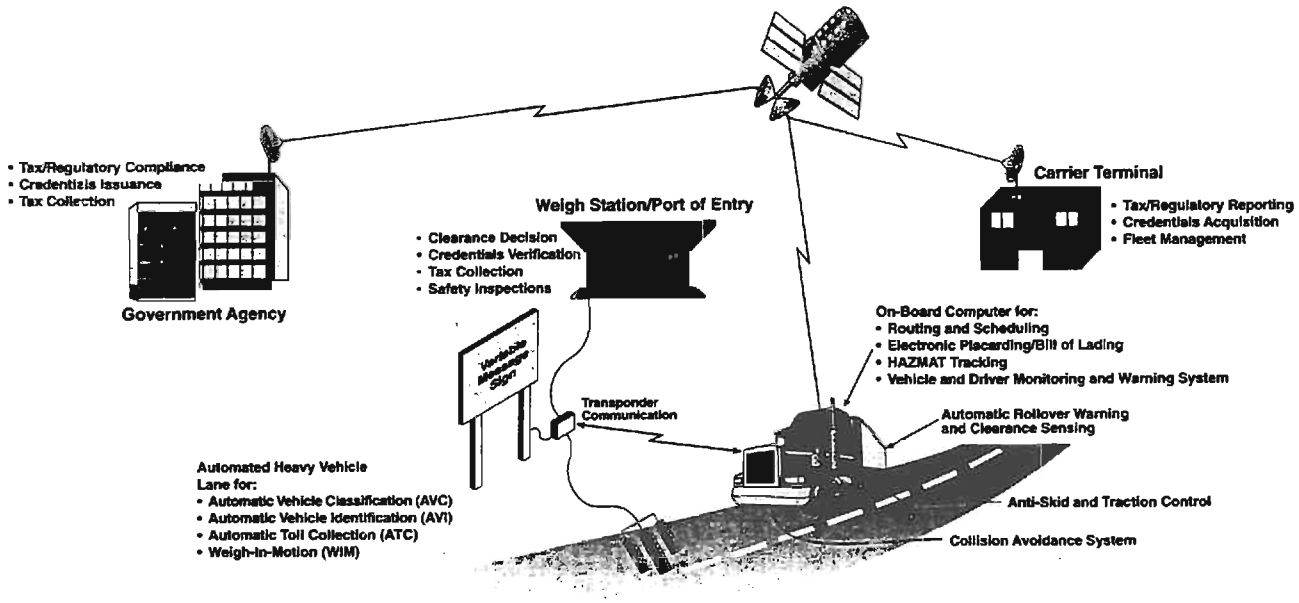
Contact: Dick Mango, 757-9801

This truck on I 70 west of Denver, is receiving a warning from a variable message sign.

2) Southwest States Electronic One-Stop Shopping

This project will demonstrate a microcomputer-based system to improve the issuance of commercial vehicle credentials and permits. Past research indicates that it costs the trucking industry approximately $12,000 a year per tractor-trailer simply to process the paper (not including fees) to comply with the myriad of state and federal adminstrative rules and regulations. Through automated sharing of credentialing expertise and other information, costs of the credentialing process can be substantially reduced. Three geographic separate states - Arkansas, Colorado, and New Mexico have partnered with Arkansas State University, Western Highway Institue, American Trucking Association, AAMVAnet, Neuron Data, and Ballofet and Associates, Inc. for this project.

Contact: Greg Fulton, 757-9813

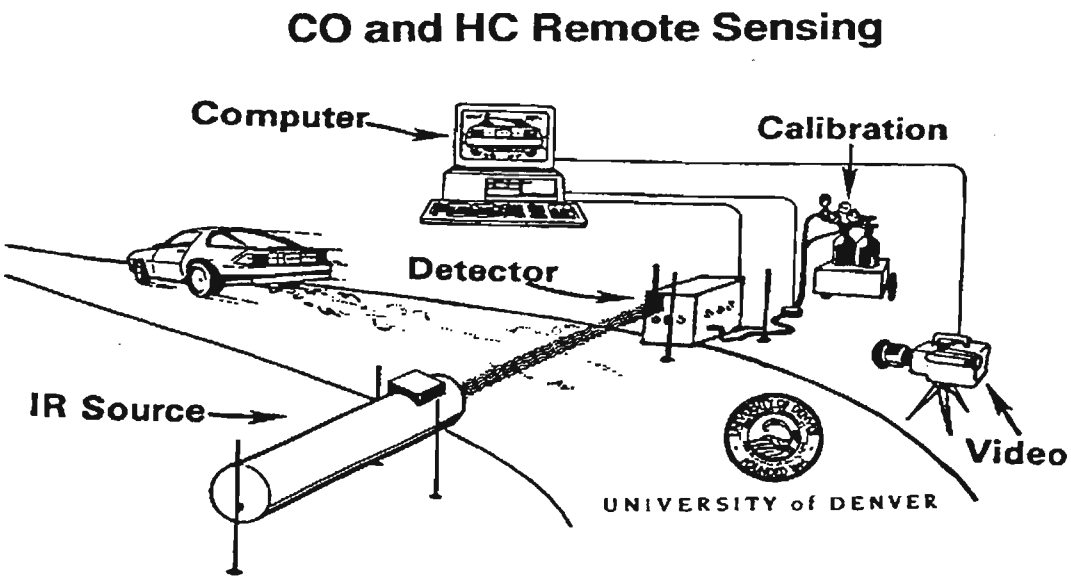


This graphic illustrates how "one-stop shopping" could improve the issuance of commercial vehicle credentials and permits.

3) IVHS For Voluntary Emissions Reduction

An active infrared emission sensor and a variable message sign at a freeway off-ramp will give real time vehicle emission readings to passing motorists. The primary objective of this test is to evaluate the usefulness and public acceptance of providing real-time vehicle emission information to the drivers and education material about the fuel savings and air quality benefits of well tuned vehicles. Project partners include: Colorado DOT, University of Denver, Remote Sensing Technologies, Conoco Inc., Skyline Products Inc., and Colorado State University.

Contact: Neil Lacey, 757-9971

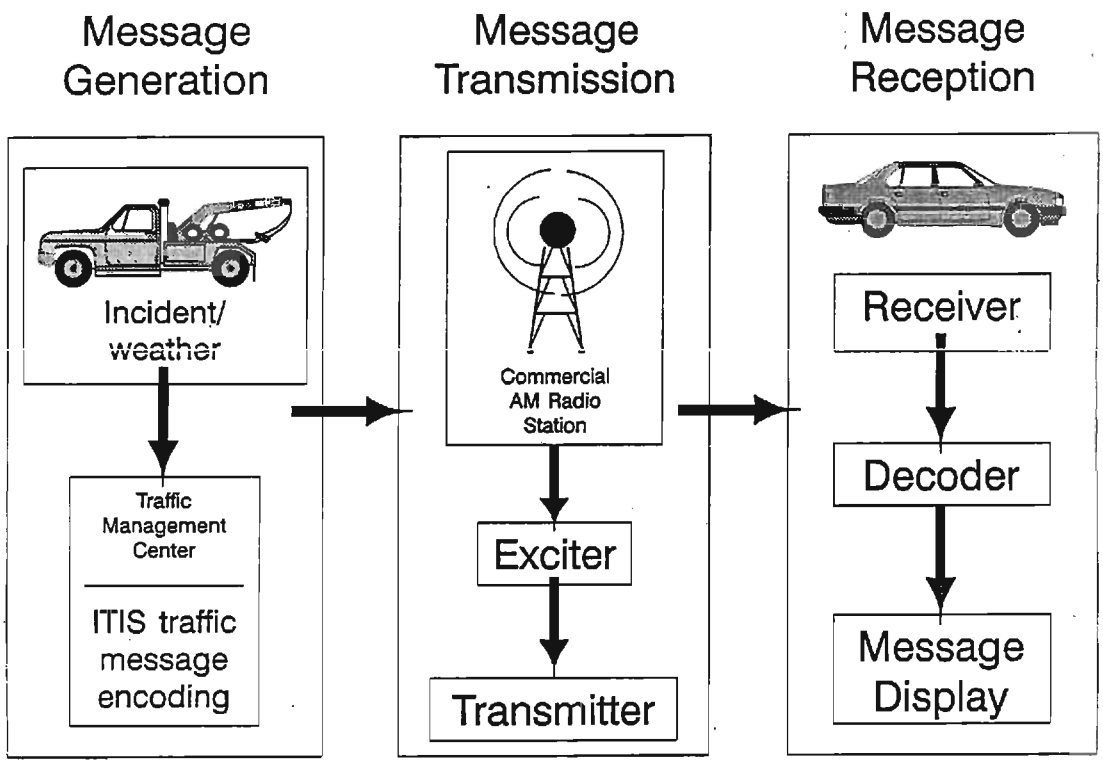


A schematic diagram of the University of Denver on-road emissions monitor.

4) Herald En Route Driver Advisory System Via Am Subcarrier

This project was developed under the ENTERPRISE program. The main concept is to disseminate traveler information in remote, rural areas using a subcarrier on an AM radio broadcast station. The system will be tested in challenging terrain in Colorado and potentially interfering environmental conditions in Iowa. Project partners: ENTERPRISE consortium, Mobile Data Systems, Modulation Sciences, Inc., Institute of Telecommunication Sciences.

Contact: Neil Lacey, 757-9971

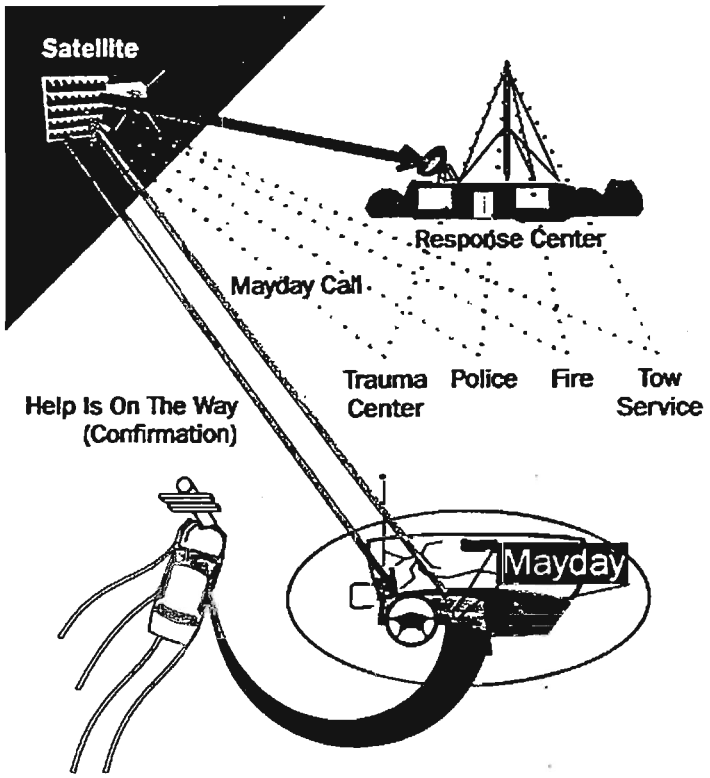


Herald system architecture.

5) Colorado Mayday System

This project will evaluate the use of GPS, for vehicle location, and a cellular phone, for two-way communications, in order to provide emergency and non-emergency assistance to travelers operating in an area of over 12,000 square miles in north-central Colorado. The primary objective of this test will be to evaluate the impact of an infrastructure-based GPS system and response network on emergency response activities, time and public safety. Additionally, this test will identify the necessary structure, responsibilities and service levels of a traveler assistance center necessary to commercially operate such a system.

Contact: Neil Lacey, 757-9971



Satellite Mayday system.

ITS Activities On-going Within CDOT

ITS activities that have moved on to different branches within CDOT outside of the Research Branch include:

Commercial Vehicle Operations and Institutional Barriers (COVE)

This project is a multistate government and industry group working to improve the productivity, safety, and efficiency of commercial vehicle operations. The COVE study member states have developed a regional action plan with recommendations for implementation. Several follow up activities are currently being pursued. COVE members include: Arizonia, Arkansas, Colorado, Louisiana, New Mexico, Oklahoma, Texas, FHWA, and the American Trucking Association.

Contact: Greg Fulton, 757-9813

Colorado Port of Entry (Trinidad)

The model port of entry is designed to permit trucks with legal weights and operating credentials to proceed non-stop at highway speeds past truck weigh stations. Trucks which are overweight, non-registered, lacking proper operating credentials, or selected for safety inspections are directed into the port for static weighing, inspection, and/or verification of compliance with operating regulations. The determination of eligibility for a truck to bypass the port would be made as the truck travels in the highway lane and at the normal highway speed. Construction of future additional sites for electronic ports of entry have been planned.

Contact: Dick Mango, 757-9801

Colorado Incident Management Coalition (CIMC)

The Colorado Incident Management Coalition has been working on the implementation of the 26 task force recommendations outlined in the September 1992, CIMC Recommendations report. The CIMC was established in 1991 with original support from the CDOT Research Branch staff. The program has since beem moved over to the the CDOT Maintenance and Operations Branch. Several of the recommendations that have been implemented to date include: a Denver area courtesy patrol program (Mile High Courtesy Patrol); passage of two pieces of legislation that have become laws to (1) require motorists to move their vehicles out of the travel lanes in the event the vehicle is disabled (if they are able to do so) and (2) allow CDOT personnel to move vehicles, motor vehicles, cargo and debris that are

(cont'd on next page)

obstructing traffic from the roadway without fear of liability; formation of corridor management teams; and designation of funds to design and construct a traffic operations center.

Contact: Joni Brookes, 757-5159

HELP

The Heavy Electronic License Plate (HELP) program is a multi-state ITS public-private partnership effort in which Colorado continues to participate along with 13 other states, FHWA and the motor carrier industry. HELP is now HELP, Inc. and continues to focus on fleet management control systems. Colorado DOT serves as the Secretary Treasurer for the organization.

Contact: Greg Fulton, 757-9813

Appendix

Colorado Department of Transportation
Research Reports 1993-Present

93-1 **DENSE GRADED CONCRETE**
Ahmad Ardani 2/93

93-2 **RESEARCH 92 - REALITY AND VISION, TODAY AND TOMORROW**
Beth Moore 1/93

93-3 **INVESTIGATION OF THE MODIFIED LOTTMAN TEST TO PREDICT THE STRIPPING PERFORMANCE OF PAVEMENTS IN COLORADO**
Timothy Aschenbrener 4/93

93-4 **LOTTMAN REPEATABILITY**
Charles MacKean 4/94

93-5 **EXPERT SYSTEM FOR RETAINING WALL SELECTION - PHASE I**
Teresa Adams 3/93

93-6 **CRACK REDUCTION, PAVEMENT REINFORCEMENT, GLASGRID**
Donna Harmelink 4/93

93-7 **A CASE STUDY OF ELASTIC CONCRETE DECK BEHAVIOR IN A FOUR-SPAN PRE-STRESSED GIRDER BRIDGE: FINITE ELEMENT ANALYSIS**
Li Cao, John Allen, P. Benson Shing 1/93

93-8 **REHABILITATION OF RUTTED ASPHALT PAVEMENTS**
Ahmad Ardani 5/93

93-9 **COLD HAND PATCHING MATERIAL EVALUATION**
William (Skip) Outcalt 8/93

93-10 **ICE DETECTION AND HIGHWAY WEATHER INFORMATION SYSTEMS, FHWA EXPERIMENTAL PROJECT NO. 13**
David Woodham 5/93

93-11 **COMPARISON OF 1992 COLORADO HOT MIX ASPHALT WITH SOME EUROPEAN SPECIFICATIONS**
Timothy Aschenbrener 6/93

93-12 **CURTAIN DRAINS**
Thomas Hunt 12/93

93-13 **TYPE T MANHOLES (EXPERIMENTAL FEATURE)**
David Price 7/93

93-14 **INTERIM REPORT FOR THE HOT BITUMINOUS PAVEMENT QA/QC PILOT PROJECTS CONSTRUCTED IN 1992**
Bud Brakey 6/93

93-15 **SHRP SEASONAL MONITORING PROGRAM IN DELTA, CO**
Ahmad Ardani 7/93

93-16 **DOT RESEARCH MANAGEMENT QUESTIONNAIRE RESPONSE SUM MARY**
James Mccambridge 8/93

93-17 **IN-SERVICE EVALUATION OF HIGHWAY SAFETY DEVICES**
William (Skip) Outcalt 12/94

93-18 **COURTESY PATROL PILOT PROGRAM**
Peggy Cuciti, Bruce Janson 8/93

93-19 **I-70 SILVERTHORNE TO COPPER MOUNTAIN: A HISTORY OF THE USE OF EUROPEAN TESTING EQUIPMENT**
Timothy Aschenbrener 9/93

93-20 **ANALYTICAL SIMULATION OF ROCKFALL PREVENTION FENCE STRUCTURES**
G.G.W. Mustoe, H.P. Huttelmaier 3/93

93-21 **INVESTIGATING PERFORMANCE OF GEOSYNTHETIC-REINFORCED SOIL WALLS**
Nelson Chou, Jonathon Wu 10/93

93-22 **INFLUENCE OF TESTING VARIABLES ON THE RESULTS FROM THE HAMBURG WHEEL-TRACKING DEVICE**
Timothy Aschenbrener, Gray Currier 12/93

93-23 **DETERMINING OPTIMUM ASPHALT CONTENT WITH THE TEXAS GYRATORY COMPACTOR**
Timothy Aschenbrener 12/93

94-1 **COMPARISON OF THE HAMBURG WHEEL-TRACKING DEVICE AND THE ENVIRONMENTAL CONDITIONING SYSTEM TO PAVEMENT OF KNOWN STRIPPING PERFORMANCE**
Timothy Aschenbrener 1/94

94-2 **DEMONSTRATION OF A VOLUMETRIC ACCEPTANCE PROGRAM FOR HOT MIX ASPHALT IN COLORADO - FHWA DEMO. PROJ. 74**
Timothy Aschenbrener 1/94

94-3 **COMPARISON OF TEST RESULTS FROM LABORATORY AND FIELD COMPACTED SAMPLES**
J.D. Stevenson 2/94

94-4 **ALTERNATIVE DEICING CHEMICALS RESEARCH**
David Woodham 4/94

94-5 **LARGE-STONE HOT MIX ASPHALT PAVEMENTS**
David Price 4/94

94-6 **IMPLEMENTATION OF A FINE AGGREGATE ANGULARITY TEST**
Timothy Aschenbrener 4/94

94-7 **INFLUENCE OF REFINING PROCESSES AND CRUDE OIL SOURCES USED IN COLORADO ON RESULTS FROM THE HAMBURG WHEEL-TRACKING DEVICE**
Timothy Aschenbrener 4/94

94-8 **A CASE STUDY OF CONCRETE DECK BEHAVIOR IN A FOUR-SPAN PRESTRESSED GIRDER BRIDGE: CORRELATION OF FIELD TESTS AND NUMERICAL RESULTS**
Li Cao, Jonathon Allen, P. Benson Shing 4/94

94-9 **INFLUENCE OF COMPACTION TEMPERATURE AND ANTI-STRIPPING TREATMENT ON THE RESULTS FROM THE HAMBURG WHEEL-TRACKING DEVICE**
Timothy Aschenbrener, Nava Far 7/94

94-10 **DENVER METROPOLITAN AREA ASPHALT MIX DESIGN RECOMMENDATIONS**
Denis Donnelly 10/94

94-11 **SHORT-TERM AGING OF HOT MIX ASPHALT**
Timothy Aschenbrener, Nava Far 12/94

94-12 **DYNAMIC MEASUREMENTS ON PENETROMETERS FOR DETERMINA TION OF FOUNDATION DESIGN PARAMETERS**
G.G. Goble 11/94

94-13 **HIGH-CAPACITY FLEXPOST ROCKFALL FENCES**
George Hearn 5/94

94-14 **PRELIMINARY PROCEDURE TO PREDICT BRIDGE SCOUR IN BEDROCK**
Steven Smith 12/94

95-1 **DEMONSTRATION OF THE PLACEMENT OF STONE MATRIX ASPHALT IN COLORADO**
Donna Harmelink, Timothy Aschenbrener, Ken Wood 3/95

95-2 **PCCP TEXTURING METHODS**
Ahmad Ardani, William Outcalt 3/95

95-3 **KEYWAY CURBS**
William (Skip) Outcalt 2/95

95-4 **EPS, FLOW FILL AND STRUCTURE FILL FOR BRIDGE ABUTMENT BACKFILL**
Shan-Tai Yeh, C.K. Su

95-5 **ENVIRONMENTALLY SENSITIVE SANDING AND DEICING PRACTICES**
Nien-Yin Chang, Walt Pearson, et. al. 3/95

95-6 **REFERENCE ENERGY MEAN EMISSION LEVELS USED IN STAMINA 2.0 FOR HIGHWAY NOISE PREDICTION IN THE STATE OF COLORADO**
Louis Cohn 2/95

95-7 **INVESTIGATION OF LOW TEMPERATURE THERMAL CRACKING IN HOT MIX ASPHALT**
Timothy Aschenbrener 2/95

95-8 **FACTORS WHICH AFFECT THE INTER-LABORATORY REPEATABILITY OF THE BULK SPECIFIC GRAVITY OF SAMPLES COMPACTED USING THE TEXAS GYRATORY COMPACTOR**
Charles MacKean 6/95

95-9 **RESILIENT MODULUS OF GRANULAR SOILS WITH FINES CONTENT**
Nien-Yin Chang

95-10 **HIGH PERFORMANCE HOT MIX ASPHALT PAVEMENTS FOR INTERSECTIONS**
Timothy Aschenbrener, Scott Schuler 4/95

95-11 **DYNAMIC TRAFFIC MODELLING OF THE I-25/HOV CORRIDOR SOUTHEAST OF DENVER**
Bruce Janson

95-12 **USING GROUND TIRE RUBBER IN HOT MIX ASPHALT PAVEMENTS**
Donna Harmelink, Robert LaForce 6/95

95-13 **RESEARCH: AN INVESTMENT FOR THE FUTURE (A BIENNIAL REPORT OF CDOT RESEARCH ACTIVITIES 1993-1994)**
Beth Moore 7/95

95-14 **A DOCUMENTATION OF HOT MIX ASPHALT OVERLAYS ON I-25 IN 1994**
Timothy Aschenbrener 6/95