Research '92

Reality and Vision...

Today and Tomorrow...

Research Branch
Division of Transportation Development
Colorado Department of Transportation

Research '92

Reality and Vision
Today and Tomorrow

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(Cover graphic: Rick Logsdon)

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Research, development, implementation, and technology transfer are an integrated effort among various units at CDOT, universities, and private consultants. The program is administered through the Research Coordination Branch of the Division of Transportation Planning. This is a program of transportation research which supports and coordinates national research efforts such as the Strategic Highway Research Program (SHRP), the National Cooperative Highway Research Progam (NCHRP), and the Transportation Research Board (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 the transportation practitioners.

"... (the Research Branch) ... 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 the transportation practitioners."

Research of national issues are supported by the department through contributions to the NCHRP and the TRB. Research of regional issuesare supported through pooling funds with other state transportation agencies.

This report should not be construed as documenting the accomplishments of just the Research Branch. The report addresses research achieved through the cooperation and strong support of headquarters and regional personnel. In many cases, as principal investigators, they worked extra hours over and above their assigned duties.

Regional construction, traffic, and maintenance, and materials engineers have been very proactive in the use of the highway system as our research laboratory.

Review, oversight, and feedback has also been provided by many forward thinking and concerned CDOT employees through various committees: the Research Council, the Implementation Committee, the Technical Research Oversight Teams, and the Research Study Panels.

· Organization

The Research Coordination Branch is generally organized by specialty areas. (see page 6) Each specialist manages all research in their specialty area through study panels and technical research oversight teams. As appropriate, research, development, or implementation can be conducted by the specialist, by others in the department, or contracted to a university or private consultant.

The primary customers of the program are the people responsible for the planning, design, construction, and maintenance of transportation systems in Colorado. Indirect customers are comprised of all users of Colorado's transportation system and those who are impacted by it.

Four types of groups provide the input from the primary customers of the program: the Research Council, the Implementation Committee, Technical Research Oversight Teams, and Study Panels. The Research Council provides overall priorities and direction of research, while the Implementation Committee sets direction for the activities of implementation. Technical Research Oversight Teams provide technical concerns and direction to the program, while the Study Panels keep individual studies on track.

The Research Council in session.

The Research Council prioritizes research problems and makes recommendations on the direction of the research program. The Research Implementation Committee reviews research findings developed in-house and those published by others for possible incorporation into the department's program. Recommendations are made for use of new procedures, materials, specifications, and other technological advances. The Technology Transfer Unit is the operating arm of this committee. Both groups have a membership designed to represent the full spectrum of activities in the department.

Research Council Members
Johan Bemelen - Staff Traffic
Richard Brasher - City of Denver
Warren Cramer - Region 2
Denis Donnelly - Staff Materials
L.G. Duncan - Region 4
David Fraser - Staff Maintenance
Kenneth Grambrill - Environmental
Ken Mauro - Staff Design
Maurice Mitchell - FHWA
William Pollard - Univ. of Colorado
Bill Reisbeck - Region 6
Dennis Roberts - Div. of Aviation
Al Shablo - Region 5
A. Joe Siccardi - Staff Bridge
Bill Stringfellow - DTD
Lewis Sturm - Region 3
John Unbewust - Region 1

Implementation Com. Members
Johan Bemelen - Staff Traffic
Denis Donnelly - Staff Materials
David Fraser - Staff Maintenance
Bill Gray - Staff Design
Steve Plasters - Staff Materials
Ken Mauro - Staff Design
Dan Mertz - Staff Personnel
Maurice Mitchell - FHWA
Sidney Motchan - Region 6
A. Joe Siccardi - Staff Bridge
John Unbewust - Region 1
Tony Ursini - Staff Construction

The mission of the Technical Research Oversight Teams (see graph on page 5) is to consider the technical issues of research and research findings in their specialty areas. Two specific functions are the review of the research problem statements and the consideration for implemen-

tation of any research development in their specialty area. A review of problem statements culminates in statements of urgency and cost-effectiveness, and a prioritization of the problem statements in each specific specialty area. The recommendations from the review will allow the Research Council to determine what part of the program should be focused in each specialty area. Another important mission of the teams is keeping abreast of research findings from all sources and recommending implementation. Each team has a Research Branch staff facilitator who will support their activities, possibly even carrying out some of the implementation recommendations.

Study panels are ad hoc and exist only for the life of the specific study. Each study panel is formed at the onset of the study with both experts and ultimate users of the research findings. Study panels develop and approve the study plan, they periodically review the activities of the principle investigator, and review and comment on the final research report to assure the quality and applicability of the research. Ultimate users on the study panel also facilitate implementation of the study findings.

"The purpose of the CTI is the conduct of research in all modes of transportation to provide the knowledge and technology base to improve the capacity to meet the present and future mobility needs of individuals, industry, and commerce of the State of Colorado."

· Colorado Transportation Institute (CTI)

One major focus of CDOT Research this last year has been the forming of the Colorado Transportation Institute (CTI). The Memorandum of Understanding, signed on September 10, 1992, established CTI as a joint public-private-university cooperative transportation research unit. Parties to this agreement are: the Colorado Department of Transportation, the Colorado School of Mines, the Colorado State University, the University of Colorado, the University of Colorado at Denver, and the University of Southern Colorado. As stated in this Memorandum of Understanding: "The purpose of the CTI is the conduct of research in all modes of transportation, to provide the knowledge and technology base to improve the capacity to meet the present and future mobility needs of individuals, industry, and commerce of the State of Colorado." The organizing committee, who was instrumental in making the institute a reality, was composed of:

N.Y. Chang - University of Colorado at Denver
Jerry Higgins - Colorado School of Mines
Ray Sisson - University of Southern Colorado
Bruce Suprenaunt - University of Colorado (Boulder)
Steve Abt - Colorado State Univerity
Bob Barrett - CDOT
John Kiljan - CDOT
Denis Donnelly - CDOT
Rich Griffin - CDOT

The first official meeting of the Executive Committee of the CTI convened on October 9, 1992 and selected an interim president. The Committee has choosen Ralph Trapani to serve, in a part-time capacity, as the Interim President. The Executive Committee also agreed that the CTI office will be at CDOT Headquarters. The Research Coordination Branch will provide extensive support for operation of CTI in its initial stages.

The CTI Research Committee . . . has broad-based composition with members that represent cities, counties, rural communities, consultants, private industry, universities, and CDOT.

The Research Committee has broad-based composition with members that represent cities, counties, rural communities, consultants, private industry, universities, and CDOT. This committee will provide input to the Executive Committee as it establishes general Colorado transportation research needs and will recommend priorities of research problems and proposals to the Executive Committee. Research committee members include:

Maureen Araujo - Pikes Peak Area Council of Governments
Nein-Yin Chang - University of Colorado at Denver
Robert Clevenger - CDOT
Joe Crocker - Mesa County Public Works
Joan Gosink - Colorado School of Mines
Rich Griffin - CDOT
Neil S. Grigg - Colorado State University
Micki Hackenberger - Colorado Counties, Inc.
Darrel V. Holmquist - CTL/Thompson, Inc.
Warren B. Peterson - Colorado Test Center/Pueblo
George Scheuernstuhl - DRCOG
Alfred R. Seebass, III - University of Colorado
John M. Unbewust - CDOT
Guillermo V. Vidal - CDOT
David S. Zelenok - City of Colorado Springs
Lawerence F. Cunningham (alternate) - University of Colorado/Denver
James P. Heaney (alternate) - University of Colorado
Evan C. Vlachos (alternate) - Colorado State University

It is expected that the Colorado Transportation Institute will significantly advance transportation technologies and methodologies in Colorado. The goal is not more research . . . but better "products" of the research that is done.

· Funding

The primary funding source for the Research program is the SP&R (State Planning and Research) program, previously known as the HP&R (Highway Planning and Research) program. A small amount of Federal Highway Administration money is available through the demonstration projects, FHWA Implementation funds, and the FHWA Special Experimental Features Program. These funds are limited in both the amount of money available and scope of the research activities. The monies are made available to meet certain objectives which have been determined to be priorities by FHWA. State money that is part of the M & O budget for the Division of Transportation Development and approved by the Highway Commission, is also available for research.

· Future

Future years will see a greater emphasis on implementation of new technologies and research findings resulting in even greater demands on the program. CTI is expected to address more and more of the long-term research needs of CDOT; while the Research Coordination Branch will focus more on implementation and experimental features and construction projects, including more "nuts and bolts" issues.

Technical Research Oversight Teams

1/93

Pavement Stucture/Concrete

ıvement maintenance: pothole patching, crackfilling, chip seals, pavement structure: soils, bases, concrete pavements

Sid Motchan - Region 6
Dave Gonser - Region 2
Gerry Peterson - Region 1
Dick Hines- Staff Materials
Bernie Piaz - Staff Materials
Ahmad Ardani - Research Facilitator

Geotechnical

rockfall, embankments, soils, foundations, and MSE type retaining walls

P.K. Padihar - Staff Bridge
Jim Bumanglag - Region 1
Paul Macklin - Staff Materials
Brandy Gilmore - Staff Materials
Bob Barrett - Research Facilitator

Management Research

)llection, processing, analysis and use of information related to managing the transportation system

Bob Sakaguchi - Transportation Development
Jeff Kullman - Information Systems
Brian Pinkerton - Staff Bridge
Shelley Ostrem - Information Systems
Doug Lang - Transportation Development
David Price - Research Facilitator

Transit/Multimodal

public transportation, bicycles, air, pedestrian

Brian Mezger - Information Systems
Janice Finch - Transportation Development
Tom Mauser - Transportation Development
Nancy Cifelli - Transportation Development
Greg Mugele - Region 6
Tom Hunt - Research Facilitator

to provide input in the selection of research studies and implementation of all research

Maintenance

snow and ice control, roadside maintenance, roadside appurtenances, work zone safety, pavement markings

Joe Herrera - Region 6
Charles Cunningham - Region 6
Harvey Lovato - Region 6
Tom Templeman - Region 4
Ray David - Region 3
Matt Flores - Staff Traffic
Gary Gonzales - Staff Traffic
David Woodham - Research Facilitator

Environmental

air/water quality, wetlands, noise, landscaping, hydraulics

Ed Demming - Region 4
Randy Flodine - Environmental Analysis
Ed Hocker - Transportation Development
Rick Moser - Staff Design
Becky Spaine - Environmental Analysis
Tom Hunt - Research Facilitor

Structures

inspection, fatigue, rehabilitation, corrosion protection bridge management systems

Myron Swisher - Staff Bridge
Christopher Beller - Region 3
Wolney Cunha - Region 2
David Woodham - Research Facilitator

Asphalt

asphalt mixes, additives, construction methodologies, Euro-lab spin-off research

Robert LaForce - Staff Materials
Tim Aschenbrener - Staff Materials
Ken Wood - Region 4
Joe Elsen - Region 3
Donna Harmelink - Research Facilitator

IVHS/Traffic

advanced traffic management systems, advanced traveller information systems, commercial vehicle operations, automatic vehicle identification systems, congestion management, traffic and safety systems

Johan Bemelen - Staff Traffic
Lou Lipp - Region 6
Matt Reay - Region 1
John Conger - Transportation Safety
Larry Corcoran - IVHS Operations
Joni Brooks - Region 6
John Muscatell - Region 6
Neil Lacey - Research Facilitator

Research Areas of Specialty (in alphabetical order)

Ahmad Ardani-
757-9978

- SHRP LTPP Coordination
- Concrete Pavements
- Subgrades
- Traffic Loadings and Analysis
- Snow fences

Terry Barela-
757-9454

- IVHS Support
- Enterprise Support

Bob Barrett-
757-9522

- Rockfall Mitigation Devices
- Retaining Walls
- Geotechnical
- Soils

Richard Griffin-
757-9506

- Research Branch Coordinator
- Administration
- CTI

Donna Harmelink-
757-9518

- Asphalt
- Euro-Lab

Tom Hunt-
757-9971

- Environmental
- Transit/Modal

John Kiljan-
757-9508

- Enterprise
- IVHS
- Traffic
- Incident Management
- Business Management
- Communications

Neil Lacey-
757-9823

- Enterprise
- IVHS
- Traffic
- Incident Management
- Communications

Beth Moore-
757-9220

- Research Implementation
- SRHP Products Implementation
- Local Rural Assistance Program (LTAP)

Skip Outcalt-
757-9984

- Maintenance Support
- Research Support

Audrey Perich-
757-9506

- Administration Support

Dave Price-
757-9976

- Concrete
- Shoulder Treatments
- Asphalt Support
- Information Management

David Woodham-
757-9975

- Safety
- Maintenance
- Stuctures

Perform research which is cost-effective by:

- Trying innovative and creating methods
- Fully utilizing staff and equipment
- Utilizing the Colorado Transportation Institute
- Working together (Teamwork)

Perform research that meets the priority needs of the customer by:

- Soliciting problem statement
- Using Research Council process to establish priorities
- Participation in working committees of CDOT and staying aware of needs
- Utilizing study panels to develop and guide research
- Maintaining flexibility in programs

Perform research that is accurate and valid by:

- Developing and maintaining expertise through training, self-study, problem solving, and participation in national committees
- Maintaining a staff of well trained professionals in specialty area, research methods, composition, and public speaking
- Utilizing expert staff at CDOT
- Refusing to do research which cannot result in valid results
- Utilizing Colorado Transportation Institute
- Utilizing peer review

Keep transportation workers informed of emerging technologies by:

- Preparing and distributing publications
- Maintaining a targeted and accessible technical library
- Providing technical information services
- Organizing seminars, symposiums, etc. focusing on research findings and emerging technologies
- Developing multimedia displays and present them, as appropriate
- Utilizing universities and consultants
- Utilizing the Colorado Transportation Information Program

Implement research findings by:

- Working closely with operations personnel before, during, and after research (technical research oversight teams and study panels)
- Maintaining awareness of new developments in research
- Disseminating research finding
- Developing of standard drawings
- Incorporating findings in training programs, guidelines, and specifications
- Making expertise available department wide and to other transportation agencies in Colorado
- Participating in specification writing and working committees (Lighting Committee, Materials Advisory Committee, Management Team, Incident Management task force)
- Disseminating information through appropriate and effective media.

There has been bad news and good news with asphalt pavements in Colorado. In the last several years, some asphalt pavements have experienced early deterioration and premature pavement failures, resulting in several pavements having to undergo extensive rehabilitation. Those pavement failures resulted in several studies - it was also the driving force behind Colorado's solicitation to secure the only U.S. European testing facility outside of FHWA Turner-Fairbanks in Virginia. The Euro-Lab is presently being built in the Staff Materials Lab building and is scheduled to be completed in 1993. Tim Aschenbrener, Staff Materials, has championed the Euro-lab since its conception. He, and some of the asphalt staff, have already put the new testing equipment to use, resulting in several reports. Asphalt research in Colorado will never be the same.

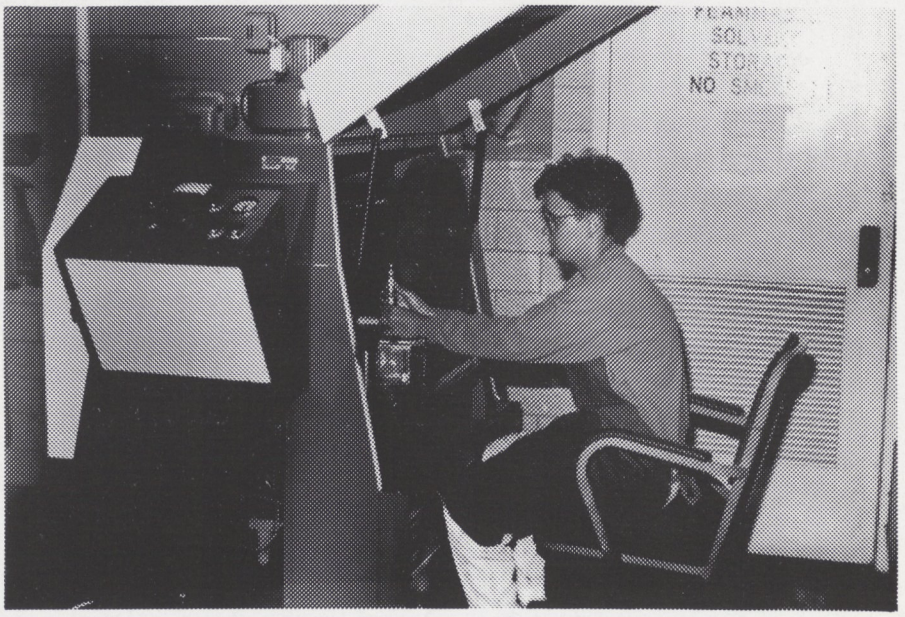
"... the FHWA purchased and set-up two facilities equipped with European testing equipment. One is located at the Turner-Fairbank Research Facility and the other is located at the Colorado Department of Transportation."

· Demonstration of a European Asphalt-Aggregate Mixture Analysis -- The Euro-Lab

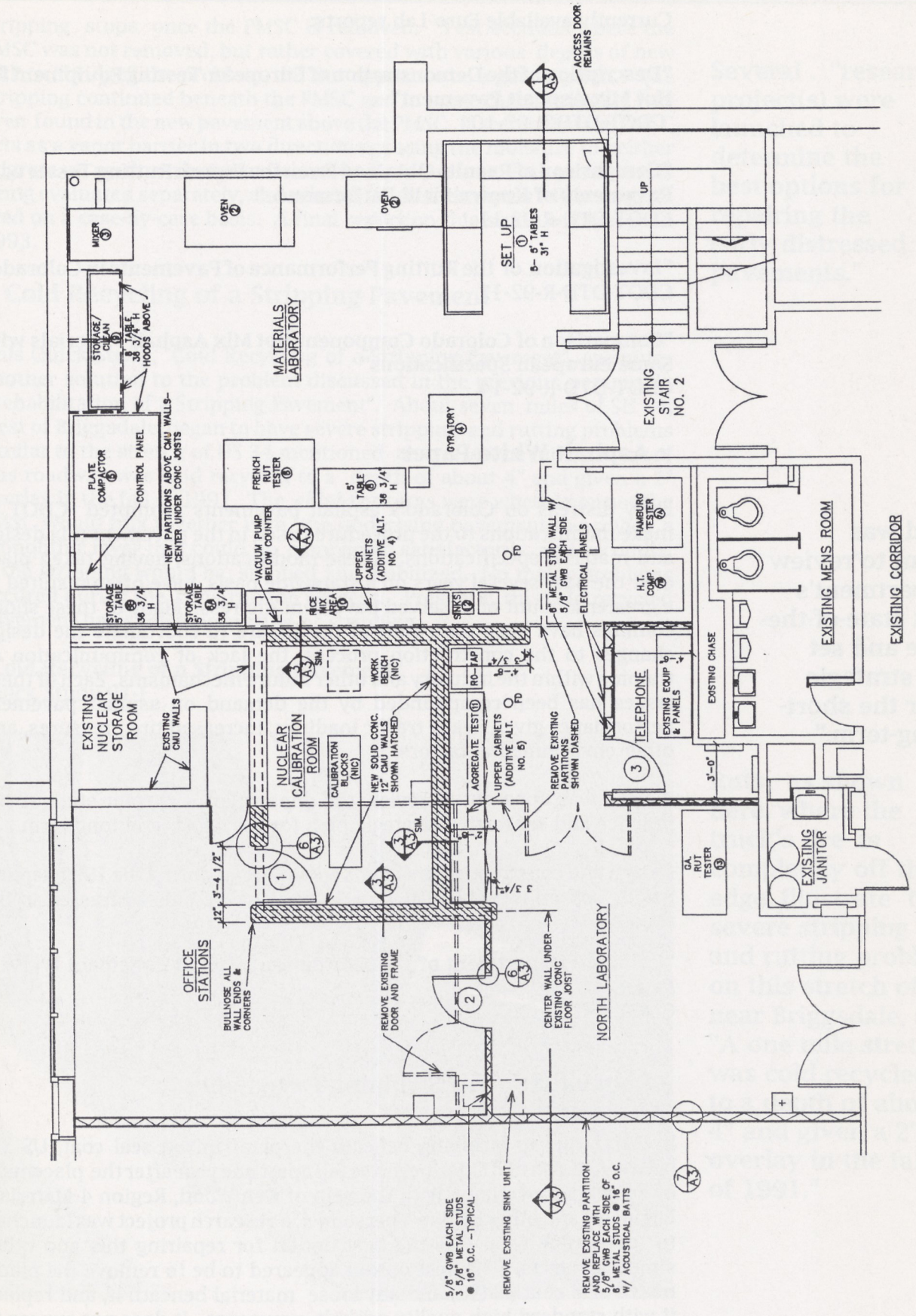
In September 1990, a team of pavement experts from the United States participated in a two-week tour of six European nations.The team viewed the latest European asphalt pavement technology.

Following this tour, FHWA purchased and set-up two facilities equipped with European testing equipment. One is located at the Turner-Fairbank Research Facility and the other is located at the Colorado Department of Transportation.

Turner-Fairbank Research Facility and the Colorado Department of Transportation are working together to evaluate and develop criteria performance-based specifications which will help identify poor or marginal mixes. This will improve the quality of the pavements placed and increase the overall performance life.



This French Rutter is one of the new pieces of equipment for the Euro-Lab, currently under construction in the Staff Materials Lab.



(blueprint provided by Oliver and Hellgren Architects, Denver)

Currently available Euro-Lab reports:

"Description of the Demonstration of European Testing Equipment for Hot Mix Asphalt Pavement"
CDOT-DTD-R-92-10

"Comparison of Results Obtained From the French Rutting Tester with Pavements of Known Field Performance"
CDOT-DTD-R-92-11

"Investigation of the Rutting Performance of Pavements in Colorado"
CDOT-DTD-R-92-12

"Comparison of Colorado Component Hot Mix Asphalt Materials with Some European Specifications"
CDOT-DTD-R-92-14

· Asphalt White Paper

"A need was apparent to review the department's current state-of-the-practice and set forth a strategic plan for the short- and long-term."

Early distress on Colorado's asphalt pavements prompted CDOT to make modifications to the procedures used in the pavement mix design and material specifications. These modifications, having taken place over the past several years on a statewide basis, have often resulted in a greater amount of observed pavement distress. Many of these shortcomings have been the result of the failure to coordinate the design changes to the construction process, the lack of communication or training within the industry and other failure mechanisms. Each of these issues has been compounded by the demand on asphalt pavement performance given heavy traffic loadings, increased tire pressures, and other environmental factors.

A need was apparent to review the department's current state of the practice and set forth a strategic plan for the short- and long-term.

Design and construction problems encountered during the 1991 asphalt paving season were identified and corrective actions addressed in the report.

"Colorado Department of Transportation Asphalt Pavement White Paper"
CDOT-DTD-R-92-1.

· Rehabilitation of Stripping Pavements

In 1990, due to stripping beneath the plant mixed seal coat, US 34, between Akron and Otis, began to fall apart one year after the placement of an asphalt overlay. With the help of Ken Wood, Region 4 Materials Engineer, and other Region 4 personnel, a research project was launched to determine what was the best option for repairing this and other similar projects. The best option appeared to be to remove the plant-mixed seal coat (PMSC) and any loose material beneath it, and replace it with standard high quality asphalt pavement. It does not appear to be necessary to remove much more than the loose material because the

stripping stops once the PMSC is removed. Test sections where the PMSC was not removed, but rather covered with various depths of new HBP to "bridge" the problem, did not appear to be a good option. The stripping continued beneath the PMSC and in some cases stripping was even found in the new pavement above the PMSC. It seems that the PMSC acts as a vapor barrier in two directions causing the moisture to neither migrate up or down but remain next to it. At present, each pavement is being evaluated separately, and rehabilitation techniques will be considered on a case-by-case basis. A final report on this study will be out in 1993.

Several . ."research project(s) were launched to determine the best options for repairing the early distressed pavements."

· Cold Recycling of a Stripping Pavement

This Quick Study, "Cold Recycling of a Stripping Pavement", examines another solution to the problem discussed in the previous paragraph, "Rehabilitation of a Stripping Pavement". About seven miles of SH 14, west of Briggsdale, began to have severe stripping and rutting problems similar to the stretch of US 34 mentioned above. A one mile stretch of this roadway was cold recycled to a depth of about 4" and given a 2" overlay in the fall of 1991. The chief concerns were whether or not the PMSC would mix together with the underlying pavement to provide a monolithic layer that could be compacted satisfactorily, and secondly, if the stripping would be stopped and stabilized. No major problems occured during the construction process. Presently, this cold recycled pavement has shown no rutting or stripping.

"Cold Recycling of a Stripping Pavement"
Quick Study 91-I

Ruts, as shown here, where the truck's tire is completely off the edge, illustrate the severe stripping and rutting problems on this stretch of road near Briggsdale, CO. "A one mile stretch . . . was cold recycled to a depth of about 4" and given a 2" overlay in the fall of 1991."

· Hot In-Place Recycling

"The cost of hot-recycling was about the same as the 2" overlay, but is performing better at this time in terms of cracking and rutting."

In the late summer of 1990, a hot in-place recycling (also known as remixing) project was completed on US 50, east of Penrose. Three evaluation sections were set up on this project. The first section was remixing covered by a 2" overlay. The second was a 2" overlay only. The third was remixed, and not overlayed. The remixing process consisted of heating the pavement surface, milling the pavement to a depth of about 1-1/2", mixing new hot mixed asphalt in at a ratio of about 2 parts recycled to 1 part virgin mix, then spreading the mixture and compacting it. The cost of hot-recycling was about the same as the 2" overlay, but is performing better at this time in terms of cracking and rutting. A final report will be published in 1993.

· Rehabilitation of Rutted Asphalt Pavement

This study examined the rehabilitation of rutting in the five-inch overlay. The rehabilitation involved removing two inches of the southbound driving lanes and replacing it with a higher stability mix. Both lanes were then overlaid with a plant-mixed seal coat (PMSC). A short section of the rehabilitation was only milled 1/2 inch.

Rut profiles were acquired annually for the last three years since the rehabilitation. An analysis of the rut profiles has revealed that:

· Rutting is returning to the rehabilitated southbound lanes.

· Rutting is re-occurring faster in the test section (with minimal milling) then where the pavement was milled two inches and replaced with high-stability mix.

· Rutting on the un-rehabilitated northbound lanes is continuing at a rate of .06 inches per year and now averages .5 inches with occasional ruts up to .75 inches in some locations.

· 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."

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

FHWA Technical Advisory T5040.29, dated February 2, 1990, deals with the recommended practices for the design of paved shoulders. The advisory states the following about textured shoulders: "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."

"Shoulder treatments that provide an audible/vibrational warning to errant drivers have proven effective in keeping traffic off the shoulder. . . ." Here a chip seal shoulder treatment is rolled into place by a maintenance crew.

Various treatments are being included in this study for evaluation:

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

The evaluation will include the effect on safety that various treatments produce, the overall costs of various treatments, maintenance problems associated with the treatments, and overall constructability of the treatments. The final construction project to be included in this study was completed in the fall of 1992. All sites will be evaluated as to safety, constructability, and durability during the spring of 1993. A report will be issued in late 1993.

These rumble strips are being rolled directly into the asphalt right after the pavement was laid.

· Microsurfacing

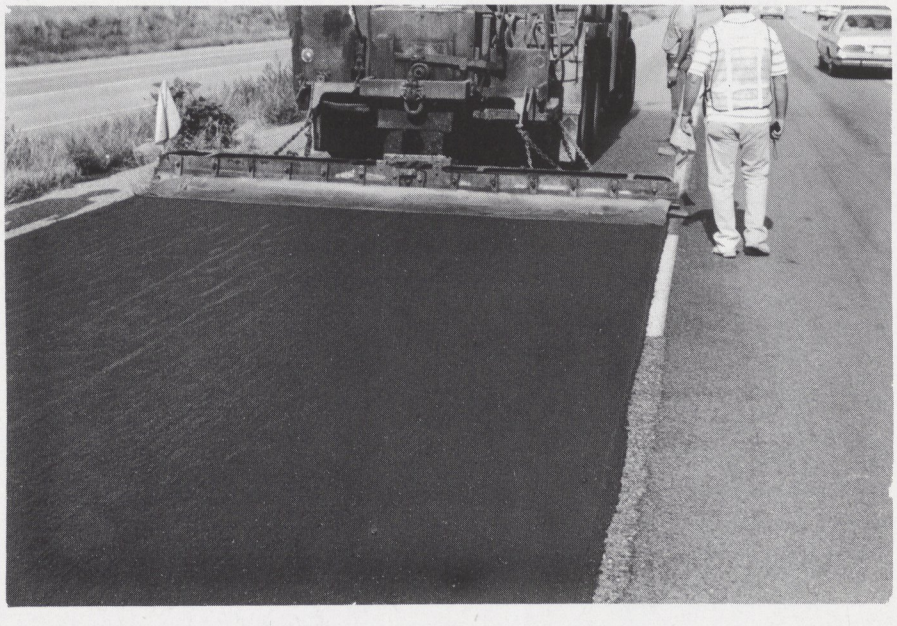
During the fall of 1992, Belleview Ave., from Broadway east to University Blvd., was surfaced with Microsurfacing. The cost effectiveness and performance of Microsurfacing, as it was used on this job, is being evaluated by the Research Branch. Microsurfacing is a thin coating that has no structural value itself. Emulsified asphalt makes the mix very fluid and allows it to fill ruts and other surface depressions, seal cracks, and provide a new textured driving surface. Two lifts were used; the first, a scratch coarse, filled ruts and small surface irregularities, then the final coarse provided the driving surface. The final lift is only slightly thicker than the diameter of the largest aggregate used, which, in this case, was 3/8 inch.

Conditions at the site where trees and high walls shade the roadway, made this project a good test for Microsurfacing. The shade allows water in warm weather and snow and ice in cold weather to remain on the pavement for long periods causing damage to the pavements.

There were ruts up to two inches deep at places. Some of them were removed by planing and some were filled with Microsurfacing before the final coarse was laid.

The Research Branch will compare rut measurements taken before construction, to ruts that develop over the next several months, to evaluate the effectiveness of using Microsurfacing for filling ruts. The general condition of the pavement will also be observed to monitor the overall performance of the Microsurfacing. Another Microsurfacing project has also been completed on I 25 in Pueblo. A report will be available in the fall of 1993.

"Microsurfacing is a thin coating that has no structural value itself."



"Microsurfacing on E. Bellview Ave."
Quick Study 93-A

· Stone Matrix Asphalt

CDOT's first stone matrix asphalt (SMA) pavement will be constructed in the spring of 1993 on US 85 north of Ault. This study will feature four SMA test sections, and a grading C control section. Ken Wood, with input from many sources, put together the specifications for the test sections. The SMA sections will contain three different additives; Vestoplast (a brand name for polyoleofin pellets), cellulose fibers, and a polymer as in our standard AC-20P (this will most likely be a block co-polymer like styrene-butadiene-styrene). These three sections will be in the top lift of pavement only. The fourth SMA section will be full depth with AC-20P. The grading C control section will also contain AC-20P. Before the mixes are placed, verification of their rutting and stripping characteristics will be performed with CDOT's European testing equipment.

Becoming ever more popular is the inclusion of additives into the hot-mix pavements. Some additives serve to strengthen the pavement, while others offer a way of recycling an abundant resource, such as tires.

· Fiber Pave

Asphalt pavement's ability to resist rutting has been a continuing concern for designers of paving mixes. In recent years these concerns have increased as asphalt pavements have been subjected to higher loadings and have shown a tendency to rut earlier in their lives. In 1986, at the request from the Region 4 Engineer, an evaluation of the product Fiber Pave was initiated.

Fiber Pave 3010, consists of short length polypropylene fibers designed for use as a reinforcement in bituminous concrete and asphalt pavements.

This study evaluated the effect the Fiber Pave additive had on the performance of the pavement when compared to the standard mix without fibers. Both the test section and control section performed equally well with deflection testing giving a slight edge to the Fiber Pave section. But due to the fact that that the fibers increased the cost of the mix by 40% no further implementation of these fibers are recommended.

"Fiber Pave, Polypropylene Fiber"
CDOT-DTD-R-92-9

· Special Polymer Modified Asphalt Cement

Laboratory testing has shown the addition of polymers in asphalt mixes improves the physical properties of the mix when compared to conventional asphalt. These tests indicate this polymer modified asphalt would be more flexible during cold temperatures and provide increased stability during warmer temperatures. These enhanced characteristics create a pavement which retards thermal cracking during cold periods, and shoving and rutting during summer months.

This study will evaluate and compare the effectiveness of the special polymer modified asphalt (modified from AASHTO Task Force 31, Type I-C) in improving the performance of the roadway in relation to rutting and cracking as compared to CDOT's standard mixes without modified binders, and the standard asphalt mix using rubberized asphalt, AC-20R (modified from AASHTO Task Force 31, Type II-B).

A report documenting the pre-construction, construction and the first evaluation following construction on four of the five locations is available.

"Special Polymer Modified Asphalt Cement" Interim Report
CDOT-DTD-R-92-5.

· Gilsonite, An Asphalt Modifier

Gilsonite is a naturally occurring solid hydrocarbon and is currently being marketed as an asphalt modifier. Gilsonite is a modifier which is intended to increase the stability of the pavement and help resist rutting often found on today's pavements.

Following the three-year evaluation, the data indicates the addition of Gilsonite, although appearing to reduce or retard rutting, does tend to harden the pavement, creating a pavement structure which is more susceptible to premature cracking. The cracks also appeared at a much faster rate, deteriorated more quickly and to a greater extent in the Gilsonite section.

"Gilsonite, An Asphalt Modifier"
CDOT-DTD-R-92-3

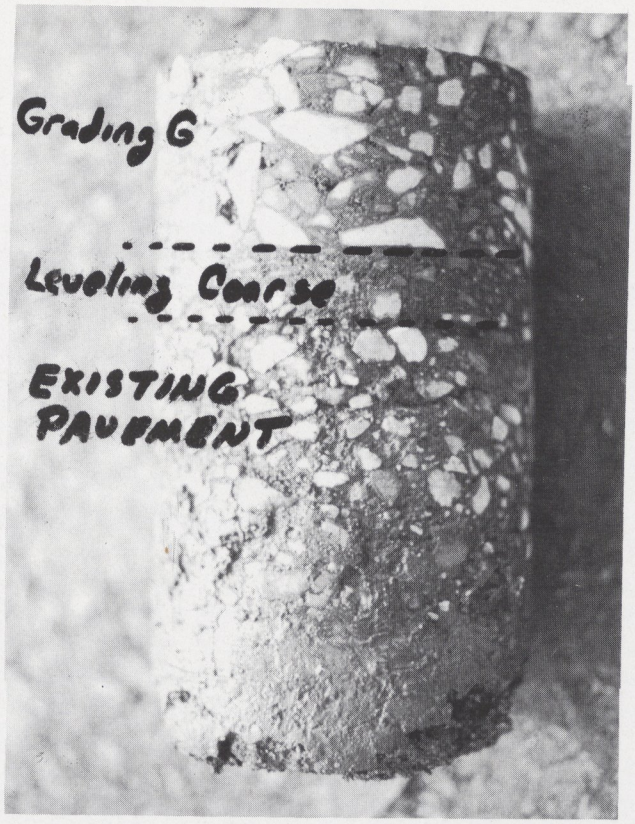
· Using Ground Tire Rubber in Hot Mix Asphalt Pavements

"In 1994, 5% of all hot mix asphalt placed using federal aid money shall use recycled tire rubber. The percentage will increase incrementally to 20% by 1997."

The United States Congress has passed legislation requiring the use of tire rubber in hot mix asphalt (HMA). In 1994, 5% of all HMA placed using federal aid money shall use recycled tire rubber. The percentage will increase incrementally to 20% by 1997.

Adding recycled tire rubber is a specialty process. Tires ground very fine can be blended with the asphalt cement. Tires ground coarsely can be added to the aggregate. The most effective ways of adding tire rubber to HMA needs to be investigated before the impending legislation goes into effect.

The experience gained with this research project will provide guidance to develop an effective specification and identify potential problems with construction on a test section that may prevent a failure on a full scale project.



"Large-aggregate allows for better aggregate interlock within the pavement, reducing the rutting that can occur in wheelpaths."

· Large-Aggregate Asphalt Mixes

Large-aggregate asphalt pavements have been promoted by various asphalt associations including the National Asphalt Pavement Association (NAPA) as an answer to rutting problems with existing pavement designs. The Colorado Department of Transportation had little or no experience with the problems associated with these types of pavements until the 1989 construction season.

Past problems with large-aggregate pavements have included segregation of the mix and the validity of mix 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 equipment 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-aggregate pavements have been designated as Grading G, with a maximum aggregate size of 1-1/2 inches. Before this, Grading C was the mix with 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. An added benefit to Grading G pavements is reduced cost due to reduced asphalt content of the mix. At present, the three projects that are being monitored are showing no excessive distress, and are in good condition. A final review will be performed in the spring of 1993.

· Glasgrid

"Glasgrid is a fiber grid which does not provide any waterproofing. . . .it has a higher tensile strength and modulus than most engineering fabrics."

Colorado is currently using low modulus engineering fabrics to reduce reflective cracking in asphalt overlays. In the fall of 1988, Glasgrid, a different type of reflective cracking treatment was placed in a project in Colorado. Unlike other paving fabrics, Glasgrid is a fiber grid which does not provide any waterproofing. However, it has a higher tensile strength and modulus than most engineering fabrics, which was felt to provide better reinforcement for reducing reflective cracking in new overlays.

The evaluation section, located on I 70, west of the Eisenhower Tunnel, was compared with another fabric, Trevira Spunbound, and an untreated section.

After three years of evaluation, the Glasgrid section had an increase in cracking in the right wheel path of the driving lane, as compared to the Trevira and the untreated sections.

Cores taken during the spring 1992 field evaluation indicated the transverse cracks appearing on the surface were reflecting through the old mat. These cores separated easily at the layer interface of the overlay and Glasgrid. The lack of bond between the Glasgrid and the new mat could help to explain the increase in cracking in the Glasgrid section.

The field work was completed in 1992 and a report will be published in the spring of 1993.

· Lottman Repeatability

The Lottman test has been used for several years to determine the potential for stripping in asphalt pavements. A study was undertaken to determine if the Lottman test has good repeatability -- is it a test that will give the same results with the same material each time you run it, or does it give more random results, as some have suggested?

TheStaff Materials Flexible Pavement Unit found excellent repeatability when one individual tester ran the same test over and over. Round robin testing, coordinated by Bob LaForce of Staff Materials and carried out between all of the CDOT region labs, the central lab, and private labs around the state, did not show the same repeatability. A second round of testing, taking place in the spring of 1993, will be undertaken to verify the results and/or determine what the cause was of the variability in the first round of testing. A report will be issued in late 1993.

· Voids in the Mineral Aggregate (VMA)

The Colorado Department of Transportation will be specifying minimum voids in the the mineral aggregate (VMA) for the 1993 construction season. This study, with Tim Aschenbrener, Staff Materials, was undertaken to provide guidance and information for obtaining VMA.

One hundred and one mix designs performed by CDOT during 1992 were analyzed to determine the most appropriate method for drawing the

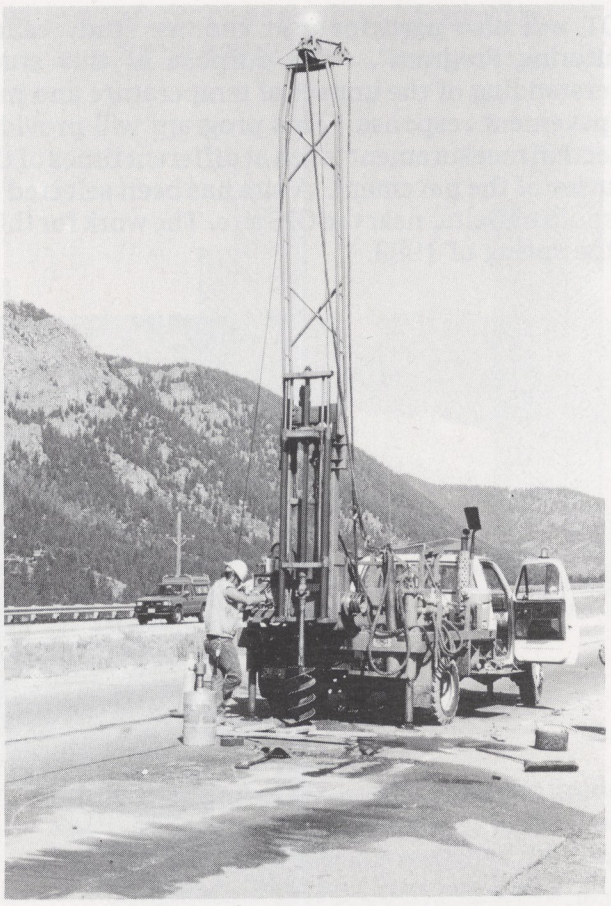
maximum density line. In addition, 24 laboratory mix designs were prepared to examine the effect of varying four factors considered important in obtaining VMA: gradation, quality of P200, size of P200, and fine aggregate angularity.

"Factors that Affect the Voids in the Mineral Aggregate in Hot Mix Asphalt"
CDOT-DTD-R-92-13

· Strategic Highway Research Program (SHRP)

SHRP is a five-year $150 million highway research program authorized by Congress under the 1987 Highway Act. This program is administered through the National Research Council (NRC), in cooperation with the FHWA and AASHTO. SHRP's Long-Term Pavement Performance (LTPP) will monitor the pavement performance of more than 1000 sites, of which 26 are located in Colorado, and cover two general programs: 16 General Pavement Studies (GPS), and 10 Special Pavement Studies (SPS). These test sites were selected to reflect a broad variety of materials, designs, climates, loadings, and ages.

GPS is a performance evaluation study, which examines the performance of various existing in-service pavement structures. The SPS studies are primarily designed to examine the effectiveness of various maintenance treatments, rehabilitation techniques, and construction practices. The main objectives of SHRP are: to evaluate existing design methods; to improve design equations for new and reconstructed pavement; and to improve design procedures and strategies for pavement rehabilitation.



Work crews take material samples at one of the General Pavement Study (GPS) sites here in Colorado.

CDOT is one step closer to initiate the construction of the SPS-2 experiment, "Strategic Study of Structural Factors For Rigid Pavement", and SPS-8, experiment, "Study of Environmental Effects In The Absence of Heavy Loads". SPS-2 is a very comprehensive study, which examines the effects of various strategic factors on the performance of rigid pavement. These factors include base type, lane width, pavement

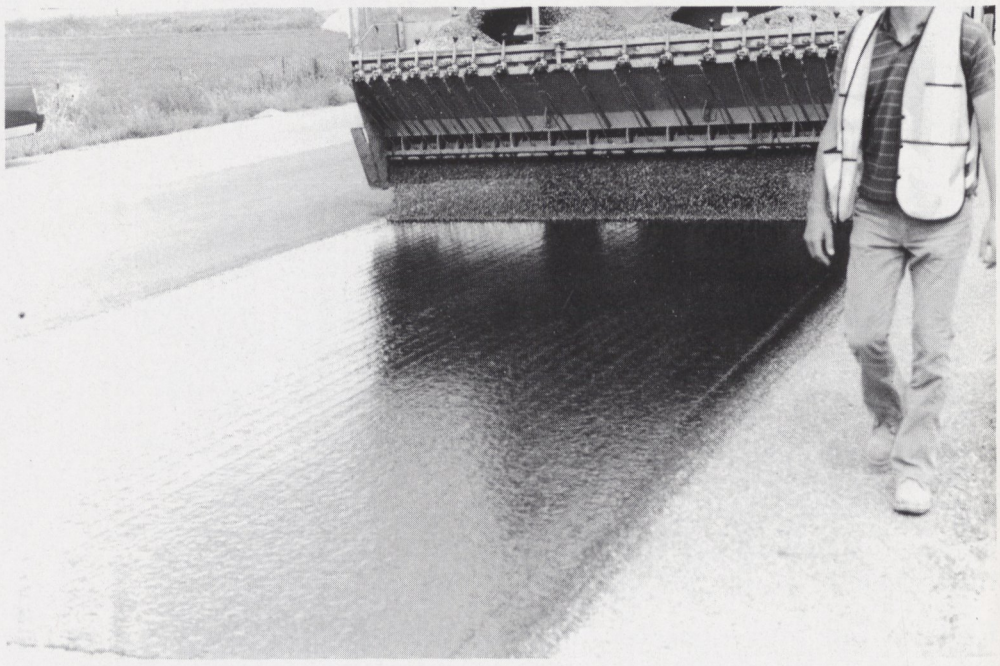
strength, drainage, and environmental factors. Thirteen different test sections will be constructed under the SPS-2 experiment. Some of the special features for this study include permeable asphalt treated base (PATB), edge drains, lean concrete base (LCB), and interceptor transverse drains.

The objective of SPS-8 is to isolate the load related factors and solely focus on the factors that are related to environment such as: moisture, temperature, and subgrade type.

In one of several meetings, it was decided to make the material sampling and field testing into a separate contract for the SPS-2 and SPS-8 experiments. After the selection process, CTLThompson was chosen to carry out the material sampling and field testing for both the SPS-2 and SPS-8 experiments.

The first phase of the weigh-in-motion (WIM) and automatic vehicle counting (AVC) installation is now complete, and the second phase is about to be completed. Of the 16 sites, only three remain to be equipped with traffic data instruments.

CDOT will also participate in another study called, "SHRP Seasonal Monitoring Program". The purpose of this study is to obtain an understanding of the impact of temperature and moisture variation on the pavement response. This program will provide a means to relate deflection measurement taken at different times of the year to the overall behavior of the pavement. A site has been selected for this study on SH 50, south of Delta, near the GPS site. The work for this study is scheduled for the spring of 1993.



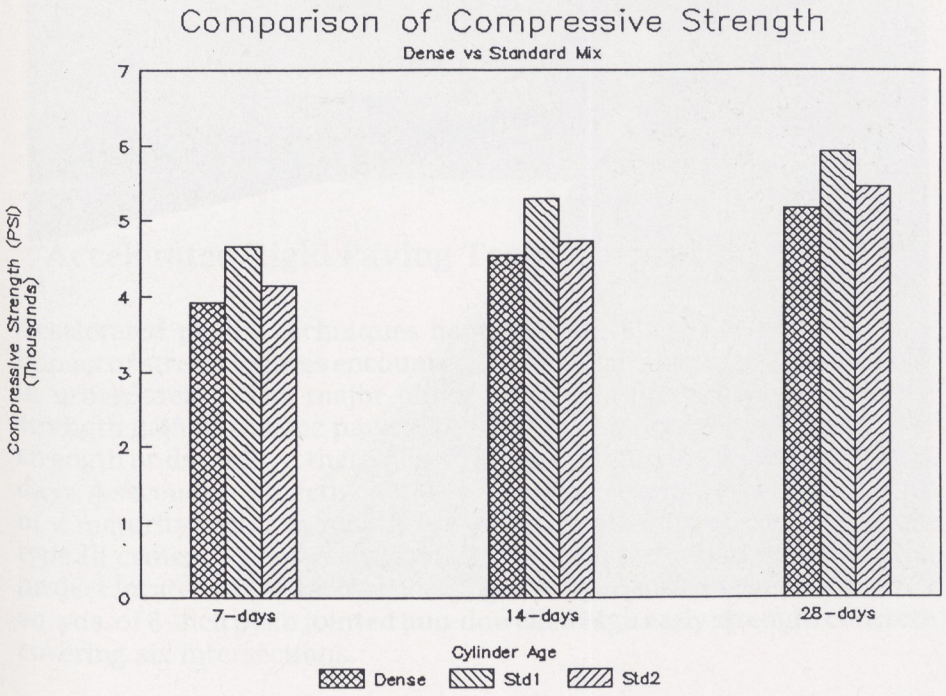
Work crews apply chip seal for the Strategic Highway Research Program (SHRP) SPS-3 experiment, "Preventive Maintenance for Asphaltic Pavements."

Concrete in Colorado . . . is making a comeback. In the last five years there has been a 10% increase, per year, in concrete usage, with 1992 being a banner year. The entire Mousetrap (I 70 and I 25) area and the I 76 interchange, north of the Mousetrap, are being done in concrete. Concrete in Colorado . . . is here to stay.

· Dense Graded Concrete Pavement

A dense graded concrete mix is one that contains intermediate aggregates. The intermediate aggregates (aggregate sizes between 3/8 of an inch and number 8 sieve) will increase the density of the concrete mix by filling the space normally occupied by less dense concrete paste and water. The general consensus is that intermediate sized aggregates have a significant effect on the plastic workability and long-term performance of concrete pavement.

This study will demonstrate and compare the economic and functional practicability of a dense-graded concrete mix against the traditional standard gap-graded mix on S.H. 83 (Parker Road, Hilltop south).



". . . the compressive strength of the two gap graded mixes are higher than the compressive strength of the dense graded mix."

Findings To Date:

The above figure compares a dense graded mix against two gap graded mixes (standard). As it can be seen the compressive strength of the two gap graded mixes are higher than the compressive strength of the dense graded mix. This contradicts the results obtained in the lab. Some of the reasons for this less than desired performance by the dense graded mix are that the W/C ratio of the dense mix was higher than the standard mix; and the air content of the dense mix was also higher than the standard mix (6.5% vs 4.0%).

· PCCP Overlay Evaluation

This report describes the testing, construction, and seven years of performance evaluations of an unbonded concrete overlay with and without tied shoulders. Unbonded concrete overlay was used successfully on a thirteen mile stretch of I 25 north of Denver in Colorado.

Visual investigation and distress surveys were performed. In general, the unbonded overlay has performed quite well, with little distress to date. It appears that tied shoulers are also doing what is expected -- increasing the load carrying capacity of the driving lane by transfering the load to the shoulder.

The results of this study demonstrated that unbonded overlays if properly constructed can be a viable method for resurfacing badly deteriorated rigid pavements. The use of unbonded overlays, where suitable, is recommended, with close attention being paid to design and construction details.

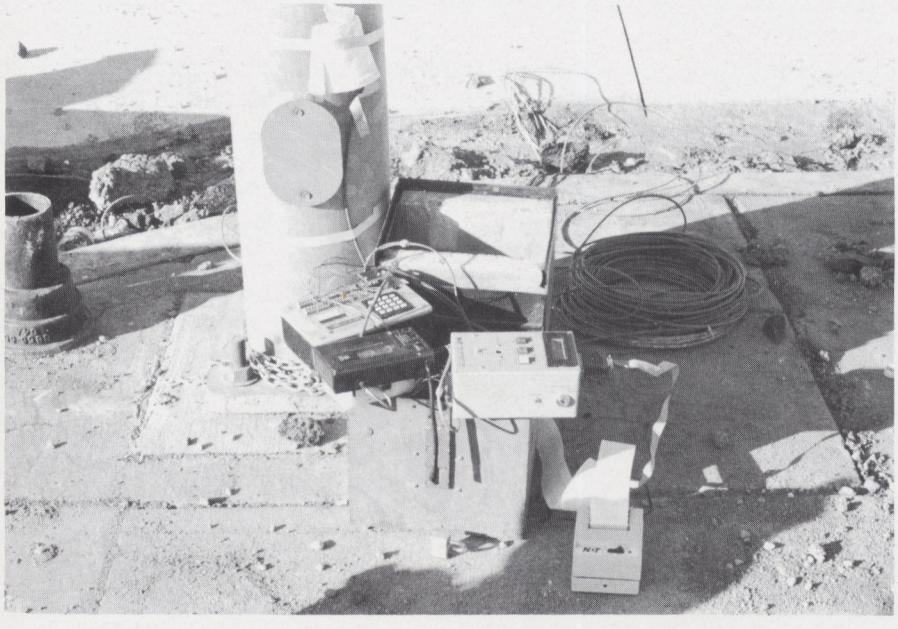
Here is a view of the PCCP overlay study site located on I 25, north of Denver.

"Evaluation of Unbonded Concrete Overlay"
CDOT-DTD-R-92-8

· PCCP Joints and Dowel Basket Evaluation

This study was initiated to examine the performance of various joint design with or without load transfer devices. It is the general consensus that transverse joints equipped with dowel baskets causes the load to be transferred from one slab to another. This in turn prevents the slab from faulting. The bi-annual evaluation of the project performed during the month of May and June revealed no faulting for the test (doweled) or the control (non-doweled) sections yet.

To inspect the rate of load transfer between adjacent slabs, Falling Weight Deflectometer (FWD) data was acquired before and after joint for both the dowel and non-doweled sections. The results indicated excellent load transfer rate for both sections (doweled and non-doweled). It is possible that more time is needed for the control section to show any faulting.



This maturity meter is used to monitor the strength gain of concrete during accelerated rigid paving. This technique is useful in areas of high traffic were road closures must be kept to a minimum.

· Accelerated Rigid Paving Techniques

Accelerated paving techniques have been developed to minimize the impact of street closures encountered with repairs or rehabilitation work in urban areas. The major objective of this project was to achieve strength gain in the pcc pavement without compromising the ultimate strength or durability, thereby permitting opening the facility in several days. A secondary objective of this study was to examine the applicability of a maturity meter in monitoring the strength gain of concrete using type III cement. The accelerated rigid paving technique was used in a project located in the town of Sterling. This project consisted of 13,400 sq. yds. of 8-inch plain jointed non-dowelled high early strength concrete covering six intersections.

The second phase of this study which deals with long-term evaluation of accelerated rigid paving was initiated during the September of 1991. The evaluation consisted of visual examination, deflection measurement, and photographic documentation. In general, the pavement surface appeared to be in good condition. Some minor distresses primarily in the forms of small corner breaks, moderate sealant deterioration, minor spalling, were detected. The long-term evaluation of this research study is continuing.

There are hundreds of structures in Colorado, vital links in the transportation system. Their health and well-being are crucial to the movement of people and goods across Colorado, yet they can also be the most vunerable -- facing the elements , both top and bottom. They can also be the costliest feature in any stretch of roadway.

· Innovative Bridge Deck Design

An innovative bridge deck design is being evaluated by researchers at the University of Colorado, Allen Consulting, and the Research Branch. The new design eliminates the top layer of reinforcing steel in a concrete bridge deck . The new design method accounts for girder deflection which reduces the stresses in the top of the deck. Potential benefits are the reduced initial cost and increased resistance to corrosion.

The bridge chosen for this project is on SH 224 in Adams County, and is a four-span continuous structure over the south Platte River. The deck will be instrumented with approximately 90 strain gages to monitor traffic-induced strains. The measured strains will be compared with those calculated using a finite-element program at CU-Boulder so that the behavior of the deck is better understood.

· Chloride Content in Reinforced Concrete Bridge Decks

"By being able to predict, based on chloride content, when a bridge deck will deteriorate and need rehabilitation, budgeting and rehabilitation timing can be optimized."

The University of Colorado at Boulder has completed a study of chloride contents in bridge decks and methods to reduce the diffusion of chlorides through concrete bridge decks. This study is important as a key element in a bridge management system. By being able to predict, based on chloride content, when a bridge deck will deteriorate and need rehabilitation, budgeting and rehabilitation timing can be optimized. The program is able to calculate a diffusion coefficient if a chloride profile is input, or conversely, a chloride profile if the diffusion coefficient is known from laboratory tests. From the diffusion coefficient and the yearly application of chlorides, the time to corrosion can be estimated. The effects of bridge deck membranes and sealers can also be modeled to investigate how protection methods will reduce chloride induced corrosion.

"Chloride Content Evaluation Program for Reinforced Concrete Bridge Decks"
CDOT-DTD-R-92-7

· Fillet Welds

An effort is currently under way to find funding for a national study of cracking in fillet welds. Cracking in fillet welds has been identified in several recently built CDOT 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 further refine an ultrasonic testing method for identifying subsurface flaws in fillet welds, identify the variables involved in solidification cracking, and identify the mechanism by which solidification cracks occur in bridge steel weldments.

· Koch Bridge Joint System

A Quick Study is underway which is documenting the short-term performance of the Koch Bridge Joint System (BJS). This type of expansion device is an asphaltic plug-type design which allows horizontal, lateral, and rotational expansion movements of up to 2 inches per joint. Two expansion joints of this type were installed in December of 1991 on eastbound I 70 over I 225. Both joints appear to be performing well although some shoving of the joint binder occurred during the warm summer months.

David Woodham, Research Branch Engineer, checks the level of a newly installed Koch Bridge Joint System.

· Fly Ash in Bridge Stuctures, A Follow-up

Since limited data was gathered on the performance of two bridge structures built in 1986 using fly ash concrete, this study was undertaken to look at their long-term performance. Fly ash was used as a replacement for 15% of the cement in the mix. The use of fly ash had caused several problems including: inconsistent setting, a rough and open surface texture, variable air and slump measurements, and shrinkage cracking.

Over time, most of these problems have been resolved due to increased knowledge of how fly ash works in concrete mixes and additional experience with the product. No changes to the current CDOT specifications, which allows contractors to substitute up to 20% fly ash (by weight), were proposed as the result of this research.

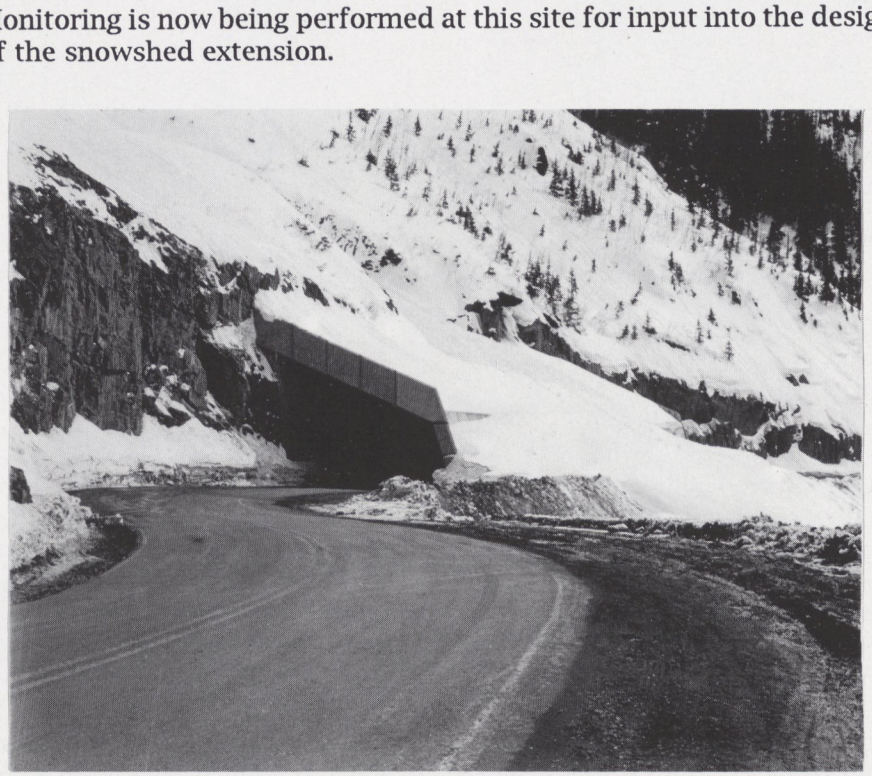
"Use of Fly Ash in Structural Concrete"
CDOT-DTD-91-8

· Avalanche Property Measurements for Snowshed Design

A snowshed at the Riverside Slide on SH 550, just south of Ouray, was constructed in the summer of 1985. Although the 180-foot snowshed will not protect the highway from all avalanches in this area, it is located where the most severe and frequent runs of the Riverside slide occur. Since this shed may be extended, or additional snowsheds may be built at some future time for more complete protection, this study reviewed: 1> design of the instrumentation system, 2>installation of the system, 3>monitoring of the instruments, and 4> analyzing the data. The goal of this monitoring program was to determine the load on the structural elements of this snowshed during major avalanche runs while measuring the velocity and extent of the moving snow.

Avalanche velocities were measured in two events and estimated in eight others by a simple empirical runup equation. Measured and computed velocities ranged from 69 to 124 mph (31 to 55 m/s); however, avalanches were relatively small, ranging from 10 to 30% of design size. More detailed avalanche-dynamic calculations applied a stochastic particle model to compute velocity and momentum distribution at the shed and compute shear stresses. The results of the runup equation and stochastic modeling were in general agreement with measurements.

Monitoring is now being performed at this site for input into the design of the snowshed extension.



This snowshed on SH 550, south of Ouray, was constructed in the summer 1985.

"Avalanche Characteristics and Structural Response"
CDOT-DTD-R-92-4

Building a road, or a bridge, is only the beginning. They take maintenance and lots of it. And maintenance takes money -- and there is never enough of that. Mother Nature can be as relentless as the motoring public. And the work never ends. . . because you usually never get to the bottom of a list, or even close to it, before a new priority makes you reschedule. Research, with the cooperation of maintenance staff, is dedicated to finding those products, or a method that can do the job quicker, easier, and with better results.

· Cold Hand Patching

The "Cold Hand Patching" study has been completed and the final report is being written. Four cold mixes were used to make repairs in five locations. One of the sites was overlaid and lost before an evaluation could be made.

All of the mixes performed well when they were placed using "by the book" methods. That is to say if the edges of the hole were squared, the hole was dry and carefully swept out, good tack coat was used, the cold mix was placed and thoroughly compacted, and the work was done in dry moderate weather -- any well prepared cold mix could do the job. If the cold mix is low quality, or the surface is wet, or the edges of the pothole aren't squared , or the weather is cold -- some of the mixes work better than others.

"If the cold mix is low quality, or the surface is wet, or the edges of the pothole aren't squared, or the weather is cold -- some of the mixes work better than others."

Under extreme conditions such as cold or standing water in the hole, the Sylvex mix stays in where the others don't. This mix, however, is about three times as costly as the others. It is also very difficult to work with in cold weather, and must be warmed before it can be used.

At two locations in Maintenance Section 8, patches were made where large areas were cut out and replaced using cold mix. Both patches were over one hundred square feet and the full depth of the existing pavement. Both worked well for several weeks but had to be replaced -- very large cold patches can be laid in an emergency, but they require replacement with hot mix at the earliest possible date.

The main conclusions of the study are that: 1> A good quality mix will work well if time and conditions permit thorough preparation and placement. 2> The higher priced mixes can be justified for use where the surface will be wet or conditions require a "throw and go" repair. 3> There are places where no cold patch will last very long, and sometimes hot mix is the only way to make the repair.

· Shoulder Erosion Control

Erosion immediate to the edge of pavement is a safety hazard that can be caused by rain water run-off directly from the paved way, ruts from vehicles leaving the traveled way, and even wind blowing top soil away from the edge of the pavement. Frequent blading of material back along the shoulder by maintenance crews has been the only cure once this problem occurs. In areas with severe erosion problems, the blading process can become very expensive and sometimes overlooked, causing a hazard.

Erosion problems, such as this, can become safety hazards when vehicles leave the roadway.

Erosion immediate to the edge of pavement can also result in the spalling of the shoulder edge, which can only be cured with expensive maintenance patching or during overlay construction. A large part of the erosion problems encountered are felt to be due to the time of year in which seeding of shoulders is performed. Types of shoulder erosion control are determined by the time of year in which they are to be placed. Many construction projects are held back from bidding and actual construction long after all design issues have been taken care of. If this happens, the type of seed used may be completely wrong for the time of year in which it is placed. This will hamper growth and increase the chances of future erosion. An ideal situation to investigate the effectiveness of different erosion control materials would be to construct an erosion control test deck on several construction projects. Currently, construction sites are being sought by Research personnel and Staff Design. Each project will contain several hundred feet of various materials that can be compared to each other as to their cost, constructability, and overall performance in soils that are identical.

· Truck Mounted Attenuators

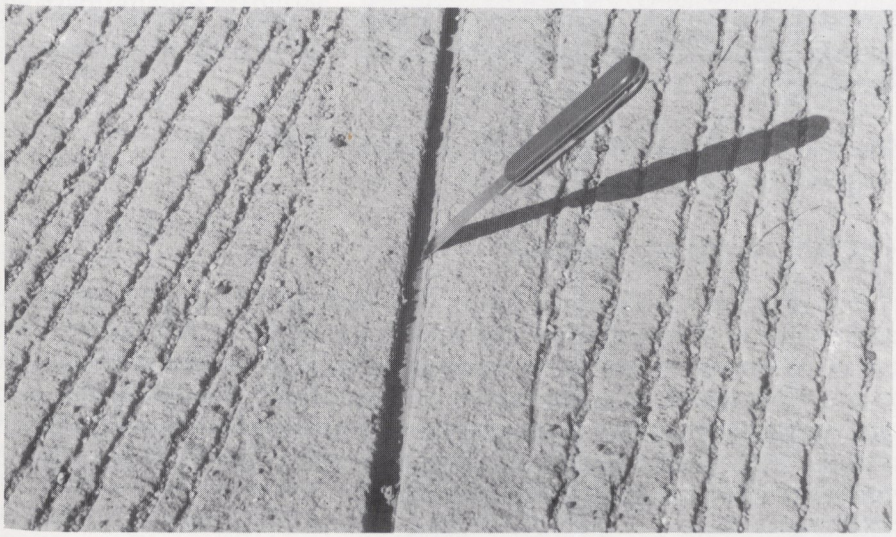
In late 1990, the CDOT Research Branch was asked for information regarding the approved uses and methods for use of Truck Mounted Attenuators and a Quick Study was initiated. At that time Colorado did not have any written guidelines. Investigation of the practices of other states showed that use of TMA's was widespread, use is increasing rapidly, and having good results.

A section regarding the use of TMA's was included in the 1991 Colorado MUTCD. Presently, TMA's are currently being used for painting and slow moving maintenance operations mostly in larger Colorado cities.

"Truck Mounted Attenuator"
Quick Study 91-D

· Joint Sealant Evaluation In Colorado

To review and evaluate the performance of various in-service sealant materials used by the Colorado Department of Transportation, a survey questionnaire was designed and sent to the Region Materials Engineers and Maintenance Superintendents in all the regions. In addition, a field evaluation was conducted to visually inspect the condition of various in-service sealant materials in Regions1, 4, and 6. A number of research studies performed by various states and by research organizations were also reviewed.



"Among all the existing in-service sealant materials inspected. . . the silicone sealants exhibited the best performance, as shown here. The members of the task force investigating the sealant materials recommended the use of silicone over all other sealants."

The following is the summary of all the findings:

· Among all the existing in-service sealant materials inspected in Regions 1, 4, and 6, the silicone sealants exhibited the best performance. The members of the task force investigating the sealant materials recommended the use of silicone over the other sealants.

· The hot poured sealant (ASTM D-3405, and ASTM D-3406) showed poor performance mainly in the form of adhesion and cohesion failures. Intrusion of incompressibles were also evident in many locations.

· The plastic parting strip showed fair performance with low levels of spalling failures.

· Cleanliness of the joint should be closely monitored to ensure compliance with the specifications.

· Utah DOT conducted a study on the joint geometry. Their findings concluded that sections overfilled with the hot poured sealant exhibited significantly higher levels of performance than those sections filled flush or below the pavement surface.

· The performance of compression seals needs to be evaluated. Their use is recommended by FHWA and other agencies.

"Joint Sealant Evaluation in Colorado"
Quick Study 91-B

· Swareflex Wildlife Warning Reflectors

Swareflex wildlife warning reflectors were installed on a four-mile section of road near Denver. Two half-mile test sections were alternately covered and uncovered for a three-month period to see if any significant change in deer-vehicle accidents could be detected. No accidents occurred in the test sections during the evaluation period. The cover/uncover evaluation method proved too costly for the limited budget of this study. Photometric measurements of the reflectors were made using vehicle headlights as the light source.

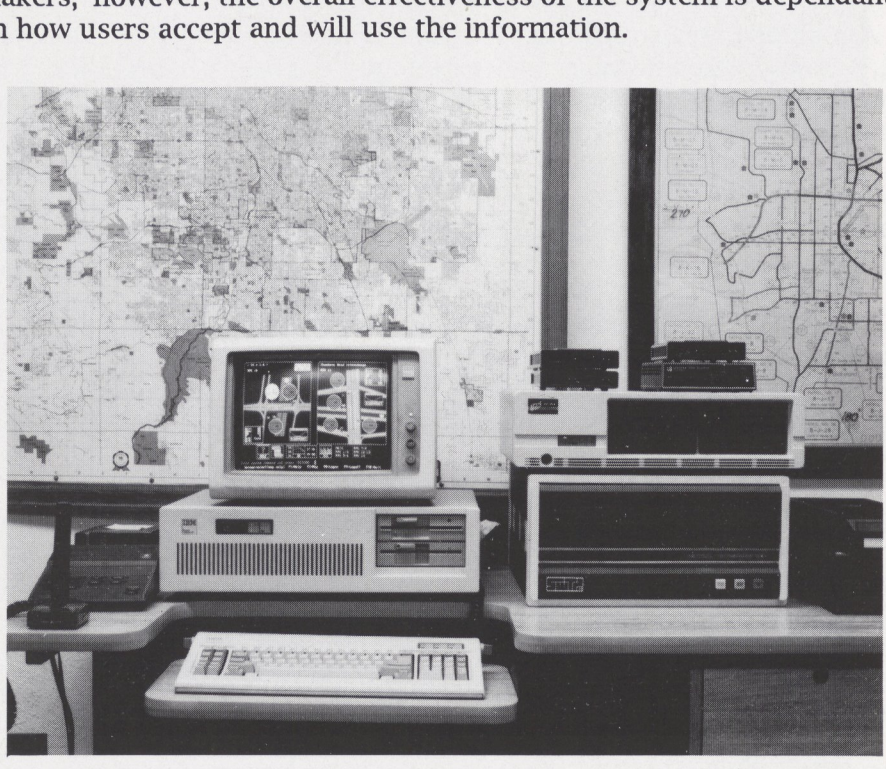
The study concluded that the use of wildlife warning reflectors should be discontinued until more evidence is available on their effectiveness -- especially on mule deer.

"Evaluation of Swareflex Wildlife Warning Reflectors"
CDOT-DTD-91-11

· SCAN Weather System

This evaluation consisted of interviews with SCAN system users and evaluations of the manpower and material savings associated with the use of the system as well as the possible influences the system may have on accidents which occur during winter conditions. It appears that salt/sand usage and overtime costs have been reduced by the use of the SCAN system. Anecdotal information suggests that there have been fewer winter accidents at one instrumented site.

The system provides relevant information to maintenance decision makers, however, the overall effectiveness of the system is dependant on how users accept and will use the information.



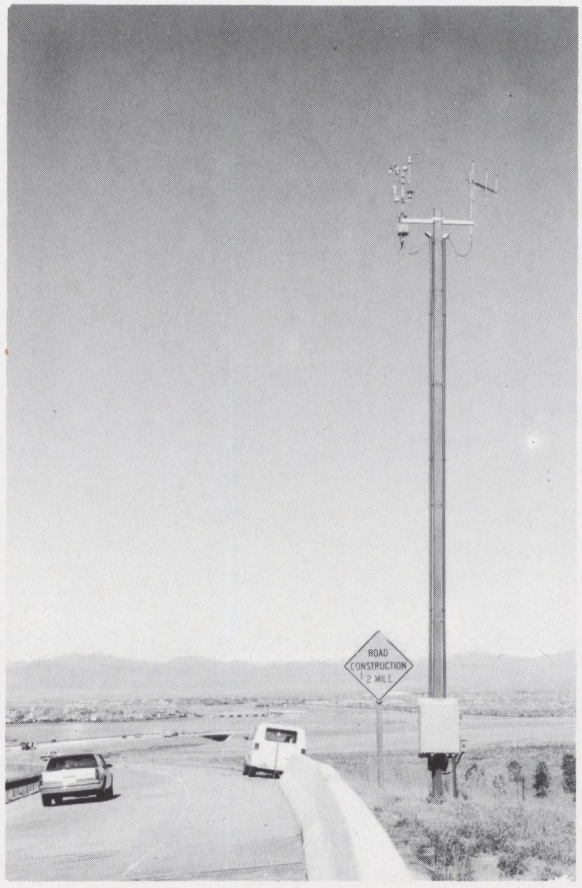
The screen on this computer displays the data compiled by the SCAN equipment. "It appears the salt/sand usage and overtime costs have been reduced by the use of the SCAN system."

• Cost Analysis and Safety Aspects of Ice Detection Equipment - Experimental Project No. 13

This study is being done under Experimental Project No. 13 and will address the cost-effectiveness and safety aspects of ice detection equipment. The study consists of documenting the maintenance activities during several storms and determining how the ice detection system impacts winter maintenance costs and safety.

The metro-area SCAN system consists of eight instrumented locations owned by CDOT. In addition, there are three other sites on the system which are owned by local governments. The information is transmitted via radio and microwave to the central location at Denver maintenance headquarters. Current instrumented locations include:

Santa Fe and Evans
C470 and I25
I25 and I70
I70 and Chambers Rd.
I25 and Walnut St.
I70 at Washington
I25 at SH 7
C470 and S. Wadsworth Blvd.



This SCAN ice detector is one of several in Colorado. The SCAN information is transmitted via radio and microwave to Denver maintenance headquarters.

"Ice Detection System Evaluation"
CDOT-DTD-R-91-10

· Weather Prediction Model for Highway Operations

"The weather prediction model uses data gathered by the U.S. Weather Service as input into a numerical model which is capable of producing forecasts reflecting the effects of local terrain."

Wels Research Corporation has developed a computerized weather prediction model for use in highway operations. The weather prediction model uses data gathered by the U.S. Weather Service as input into a numerical model which is capable of producing forecasts reflecting the effects of local terrain. The forecast can incorporate user-supplied observations which will correct the forecast if discrepancies develop. The data is displayed in graphic form with emphasis on a "point and click" user interface. The program was used during the Winter of 1991/92 by Greeley Maintenance with favorable results. Currently Aurora, Denver, Greeley, and Durango maintenace sections, and the Avalanche Control Center are subscribing to the program. Evaluations of their experience with program will continue for two years.

· Glenwood Canyon Ice Detection Equipment

A study has been initiated to monitor the use of the Surface Systems Inc, (SSI) ice-detection equipment to be installed in Glenwood Canyon. The system is expected to be installed, and be operational, for the 92/93 winter. This study will look at the effectiveness of the system in reducing chemical application due to increased awareness of pavement temperatures. In addition, the system should help maintenance forces to identify critical conditions which could be extrapolated to similar locations throughout the canyon.

· Alternative Deicing Chemical Use

"Emphasis is on determining which deicing chemicals are the most cost-effective and then deciding if current methods of snow and ice control can be improved."

Section 8 Maintenance and the Research Branch are investigating the use of alternative deicing chemicals for use in urban areas. Emphasis is on determining which deicing chemicals are the most cost-effective and then deciding if current methods of snow and ice control can be improved. Several tests have been run on a section of SH 121 which show that improvements are possible over the standard salt/sand mixtures. A series of laboratory tests are also being conducted to characterize the melting capacities as well as the relative corrosive properties of various deicers. Further field tests are planned for the Winter of 1992/93.

· Reflective Sheeting Field Weathering Test Deck

Historically the Colorado Department of Transportation approved roadside sign material based on data obtained using the weatherometer. The weatherometer is a piece of equipment used for performing accelerated weather testing. While the weatherometer gives some comparative performance data related to UV stability and exposure to moisture, the true performance is best measured under actual field conditions.

An outdoor exposure deck was constructed to test sign materials for their field performance and expected longevity. Sample materials were split into three pieces, one for the weatherometer testing, one for the

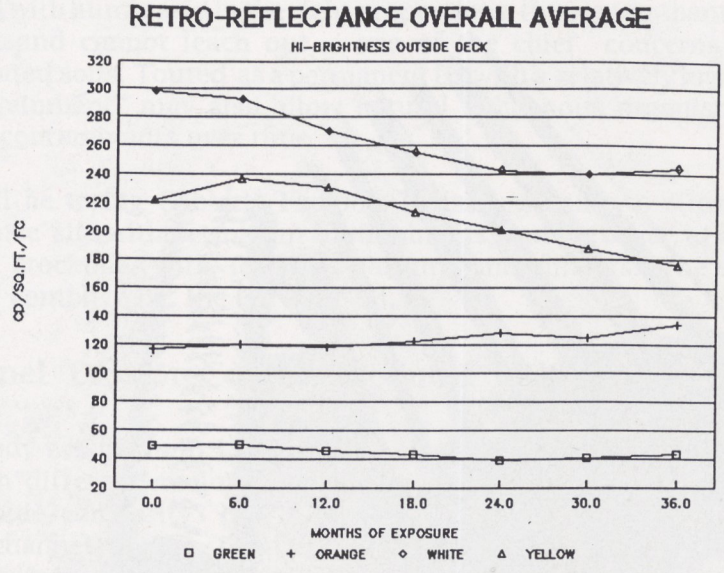
outdoor exposure deck, and one to remain in original condition for later comparison.

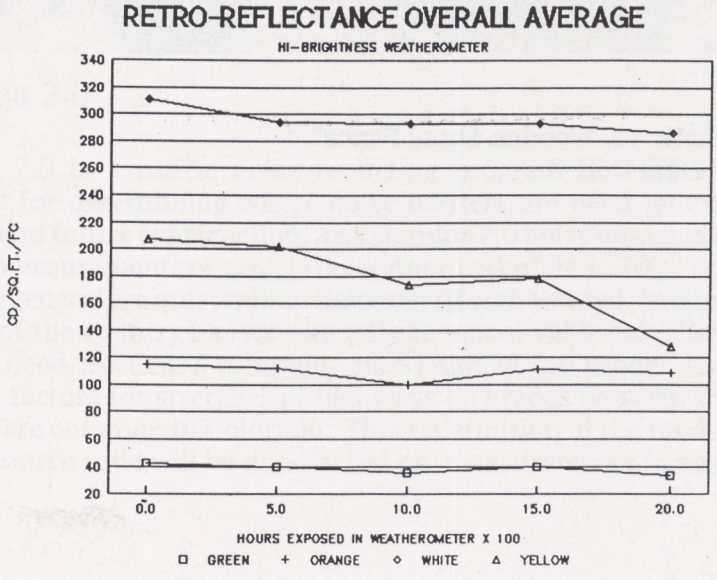
The completed report describes the construction of the deck, and the sheeting results after three years of exposure to Colorado weather. Sheeting installed on the deck was tested bimonthly for retroreflectance, color retention, and visual defects and compared to the test results of 2,000 hours exposure in the weatherometer.

The study concluded that the outdoor exposure deck is impractical for acceptance testing of sheeting materials due to the extreme amount of time the panels must be exposed to sustain sufficient deterioration. Testing with the weatherometer should be continued with the assumption that this test only yields comparative exposure data, and is not truly correlated, whereas, time in weatherometer equals a specific time of actual weather.

"Field Weathering Test Deck for Reflective Sheeting"
CDOH-DTD-R-91-5

"Sample materials were split into three pieces, one for the weatherometer testing, one for the outdoor exposure deck, and one to remain in original condition for later comparison."





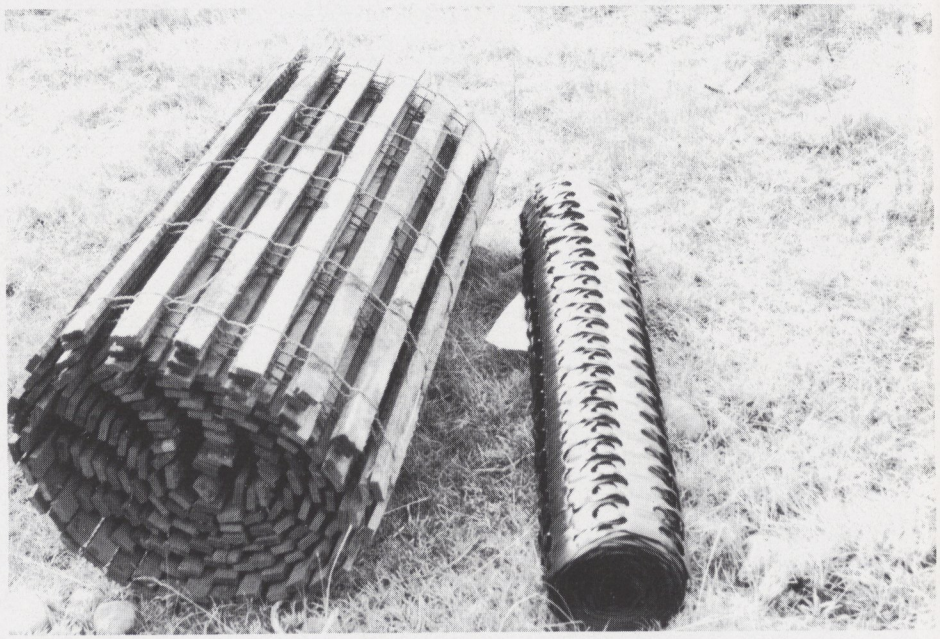
These graphs illustrate the difference between the two evaluations, the outside test deck evaluation took three years, while the weatherometer equipment took only twenty hours. It was concluded that the weatherometer yeilds only comparitive data but in a much more timely fashion.

· Synthetic vs. Wooden Snow Fence

This study sought to compare and demonstrate the economic and functional practicability of several types of synthetic snow fences against the traditional wooden fences. The synthetic snow fences are made of high-density polyethylene with a laminar setting which possesses a very high tensile strength (7000-8000 lbs. per four foot roll width). The synthetic snow fences were much easier to install than the wooden fences, because they were lighter (approximately one-forth of the weight of the wooden fences), and because they stretched easier. They require substantially less room to store or to haul. They will not rust or corrode, and they are ultraviolet and heat resistant.

The synthetic snow fences were quite effective in controlling snow during the winter, however, they are susceptible to damage by cattle in the summer. Their installation close to a ranch with grazing bulls is not recommended due to the bull's tendency to chew on them and rub up against them.

This photo compares one 50 ft. roll of wooden fence with 100 ft. of synthetic.



"Synthetic vs. Wooden Snow Fence"
CDOT-DTD-R-91-3

With increasing understanding of environmental issues, and increasing public awareness of environmental issues, the transportation coummunity has become more focused on how their activities can affect the environment. Nationwide there is a huge need for environmental research in the transportation industry. New Federal regulations such as the National Pollutant Discharge Elimination System, the Resource Conservation and Recovery Act, the Clean Air Act, the Clean Water Act, and the Leaking Underground Storage Tank regulations have also forced us to look at issues we have never looked at before.

· Micro-Containment

A new study, "Micro-Containment of Contaminated Soils", will begin in the spring of 1993. This study will look at a new technology called the "Gabbitta Fixation Technology" and will receive the input from Staff Materials, Region 6 Maintenance, Region 1 Maintenance, and the Office of Environmental Review.

"Gabbitta Fixation Technology. . . may allow natural indigeous organisms to "eat" the contaminants over time."

When contaminated soils, particularly petroleum contaminated soils, are mixed with humic acid in the right proportions, the contaminants are contained and cannot leach out -- one of the chief concerns with contaminated soils. Touted as a permanent fix with a relatively low cost, this "containment" may also allow natural indigenous organisms to "eat" the contaminants over time.

CDOT will be trying Gabbitta Fixation Technology on two sites; one maintenance site with petroleum contaminants, and the other at street sweeping stockpiles with lead and barium contaminants. The study should be complete by the fall of 1993.

· Channel Erosion Control Products (SH83)

A new study will begin in 1993 on SH 83 near Parker. On this project at least ten different erosion control fabrics will be placed side by side to determine comparity how effective they each are at preventing roadside channel erosion. This study is being conducted by an independent consultant.

· Stamina 2.0

STAMINA 2.0 is a traffic noise modeling program developed by a consultant for determining where noise barriers are need on existing highways and future construction. The Stamina 2.0 noise model is based on actual measurements of vehicle noise done in the late 1970's. Today's vehicles in general are quieter than those used for the model. In addition, each part of the country has its own unique mix of vehicles. Therefore there is a need for CDOT to update its STAMINA 2.0 model and add correction factors for stretches of highways on grades between 2% and 8%, which are common in Colorado. This redefinition of the model and program source code will be done based on measurements to be taken this year.

Assuring that the roadways are safe for the travelling public is a very big priority in every transportation agency, and CDOT is no exception. It is not often that you settle for something that is "good enough" -- with all the new products coming to market you keep on looking for something better. In some way, all of the research that takes place in the Research Branch, provides a safer transportation system.

· Demonstration Project of Highway Safety Devices

The ET2000 guard rail end treatment, is a system designed to stop a vehicle, in a head-on hit of the end of a guard rail, in a controlled manner. This system is new to Colorado but has been used in other states for several years. The first two guardrails were installed on US 40 on Rabbit Ears Pass in July 1992. The vehicle hits the extruder terminal on the end of the rail. As the terminal is driven down the guard rail, shearing the wood support posts, the rail is forced through a narrow throat on the terminal, flattened and bent to the rear away from the roadway thus absorbing the energy of the vehicle, much like dominos. The terminal prevents the rail from spearing the vehicle, prevents the vehicle from vaulting, and reduces the chance of a rollover. A vehicle striking the system at an angle from the side is redirected on to the roadway just as it would be by a W-beam guard rail.

The ET2000 is designed to stop a vehicle, making a head-on hit, in a controlled manner. This ET2000 guard rail end treatment is located on US 40.

One of the benefits of this system is that it is quicker and easier to repair after a hit than some of the other end treatments used. The rail is normal W-beam guard rail, and the wood posts are held in square tubes driven into the ground. Since the posts are bolted into steel tubes instead of being set in concrete, the only tools needed to repair the system are wrenches and a way to pull the broken end from the tube.

Original cost for an ET 2000 should be under $2000 installed. Since it does not require digging holes and pouring concrete, this system can be installed by an experienced crew in about two hours.

"ET2000 Guardrail"
Quick Study 91-F

"Cost effectiveness, ease of maintenance and repair, and the effectiveness of the . . . (10 gauge guardrail, Breakmaster, and the CAT guard rail) in controlling accidents are to be assessed." Pictured is a newly installed CAT guard rail on SH 8 and US 285.

· In-Service Evaluation of Highway Safety Devices

"In-Service Evaluation of Highway Safety Devices," was a study to evaluate the use of 10 gauge guardrail, Brakemaster, and CAT guard rail end treatments. Cost effectiveness, ease of maintenance and repair, and effectiveness of the devices in controlling accidents are to be assessed.

The CAT, and the Brakemaster, are systems designed to protect narrow hazards such as double- sided guard rail ends in highway medians. Both systems are designed to stop a vehicle in a controlled manner. This can reduce the damage to the vehicle and its occupants, and reduce the chances of the vehicle becoming violently out of control, such as being launched into the air, or rolling over.

Twelve gauge guard rail, which is .105 inch thick, is normally used by CDOT. Ten gauge guard rail, .135 inch thick, was installed on US 24 between Battle Mountain and Camp Hale to see if it would prove more cost effective than 12 gauge rail by lasting longer and being damaged less in minor incidents, thus reducing replacement and maintenance.

Snow plow operations can do some damage to the end treatments and make them look somewhat battered, but due to its heavier construction, 10 gauge rail should take more minor beating and scraping and still retain its appearance. To date, several incidents of damage to the devices have been recorded and are being evaluated. A final report will be issued in late 1993.

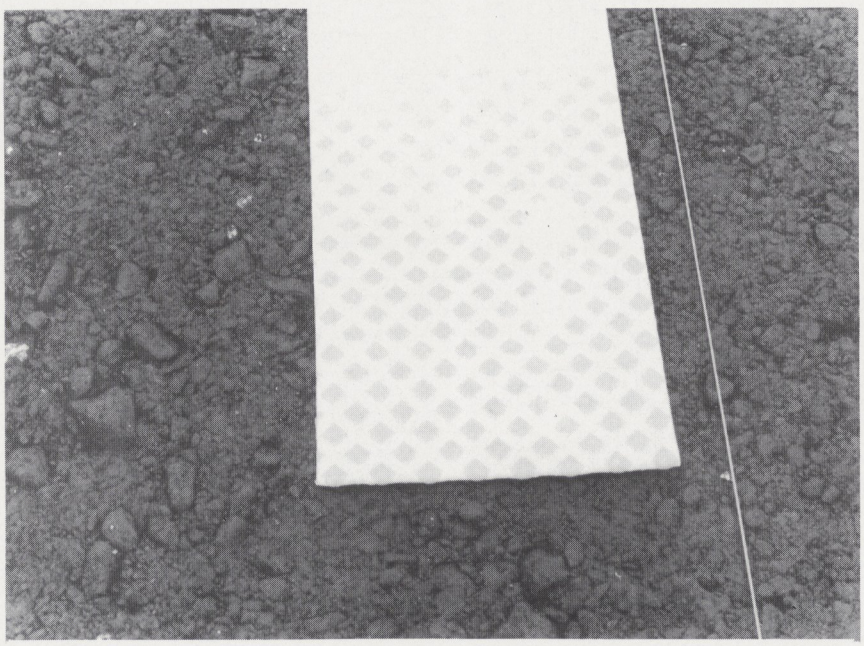
"In-Service Evaluation of Highway Safety Devices - Experimental Project No. 7 - Construction Report"
CDOH-DTD-R-90-13

· Stamark 350 Pavement Marking Evaluation

This was our first study to evaluate the Stamark 350 pavement marking tape. While our research does not generally focus on a single product for evaluation, this product, with its waffle pattern had the potential to maintain retroreflectivity longer and provide more retroreflectivity on wet roads than standard marking tape.

Two installations were evaluated under this study: I 70 west of Georgetown and I 25 Colorado Blvd. to University Blvd. in Denver. The installation on I 70 rapidly became victim to the aggressive sanding and plowing in that area and lost most of its retroreflectivity after the first winter. The tape itself did remain intact, and in place, for many years later. The Stamark 350 on I 25, however, retained an adequate level of retroreflectivity (Mirolux readings over 100) after five years of very heavy traffic. Flat tape in that area had significantly lower retroreflectivity. (Mirolux readings of 60 to 70). Two other studies are currently underway evaluating a this material and an even more durable Stamark 380 material.

"The . . . waffle pattern . . . (of these tapes) had the potential to maintain retroreflectivity longer and provide more retroreflectivity on wet roads than standard marking tape."



· Stamark 380 Pavement Marking Evaluation

The 3M Company has recently introduced a new product called Stamark 380. It 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 new product to compare its performance against the Stamark 350 tape.

The evaluations have monitored the tape for its reflectivity and durability as well as to its ability to stick to the new pavement surface it was placed on. So far, after one and a half years, the tape shows good reflectance and has not pulled away from the pavement surface.

· High Performance Delineation Devices

The newer sections of C470 use "high performance" delineation devices. High performance pavement markings include 3M's 350 and 380 series tapes. All the signs have been upgraded to high-intensity sheeting. Flexible delineators, using 3M Diamond Grade reflective sheeting, are also being used on this section of C470. It is expected that these products will reduce nighttime accidents on the newer sections of C470. This study

"It is expected that . . . (high performance delineation devices) will reduce nighttime accidents on the newer sections of C 470."

will document any changes in accident rates between the newer section of C470 and adjacent control section (also on C470) which uses standard delineation materials. Measurements of the reflective properties of the signs, pavement markings and other delineation have been made at six-month intervals. At the conclusion of this study, a comparison of the accident rates will be made as well as a comparison of the retained reflective properties of the test and control sections.

Even if the best, most expensive materials are used to construct a roadway, it will rapidly become damaged if proper drainage is not provided. Water can come from above and below to attack the pavement, sub-base, and side slopes.

· Underdrains

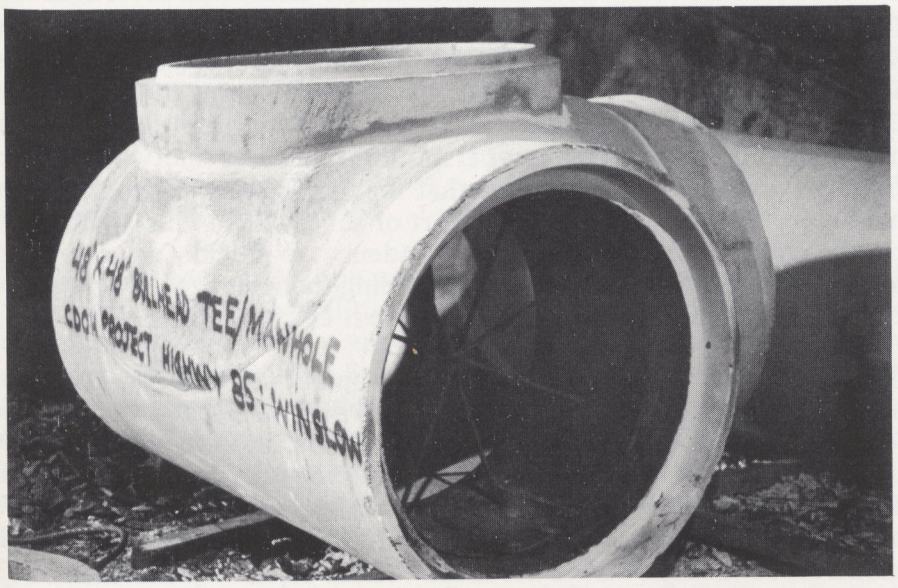
For many years, CDOT has used underdrains with geo-fabric wrap to drain water from under roadways. Some of these geo-fabrics have been reported to have clogging problems. Groundwater close to the pavement, due to a nearby irrigation canal, has been a problem on a section of the US 34 bypass on the south side of Greeley. When this stretch of highway was reconstructed during the 1992 construction season, underdrains were installed to mitigate the groundwater problem. Steve Smith, Hydraulics, initiated a research project to determine how quickly underdrains become clogged or develop other problems.

Data collected so far has indicated that this underdrain, shown under construction here, has been very effective at draining the ground water. Flows from the system have been about four times what was expected.

Depth readings from groundwater monitoring wells on both sides of the underdrain will be compared to flow measurements from the underdrain. Periodic depth readings will be taken, more frequently when the canal is opened or closed. To measure flow rates, a V-notch Weir was placed at the exit of the underdrain. The flow rate can be calculated based on the depth of water behind the Weir. The depth is being measured by a pressure transducer and recorded by a micro-logger attached to it. One reading is recorded each hour.

The data collected so far has shown that this underdrain is very effective at draining ground water. Flows from the system have been about four times what was expected. These measurements will be taken for the next three years to see if the effectiveness of the underdrain is reduced over time.

• Type T Manholes - Experimental Feature



". . .manholes are used for inspection of the drainage lines and periodic maintenance." The design shown here is called a type "T" manhole.

At present, the Colorado Department of Transportation calls 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 design can be expensive and difficult to build.

A new design for mainline manholes has recently been considered that should ease installation and reduce installation costs. This design is called a type "T" manhole. Type "T" manholes are fabricated by the 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 that it is a much more efficient hydraulic design than that of the Colorado Standard Design.

However, even with the believed ease of construction, improved hydraulic efficiency, and reduced cost, the actual performance of the finished construction must be evaluated for future use. This project was constructed in 1990. After two years of evaluations the manhole appears to be in good condition with no apparent distress. A final report will be available in the spring of 1993.

• Hydrain

Gary Johnson, Hydraulic Design Engineer, and staff have recommended that all hydraulic engineers use this PC-based program for design. They found it accurate, but not entirely user friendly. Some problems with graphics printing also need to be worked out. They recommend that it become an AASHTO shareware product to keep the software current.

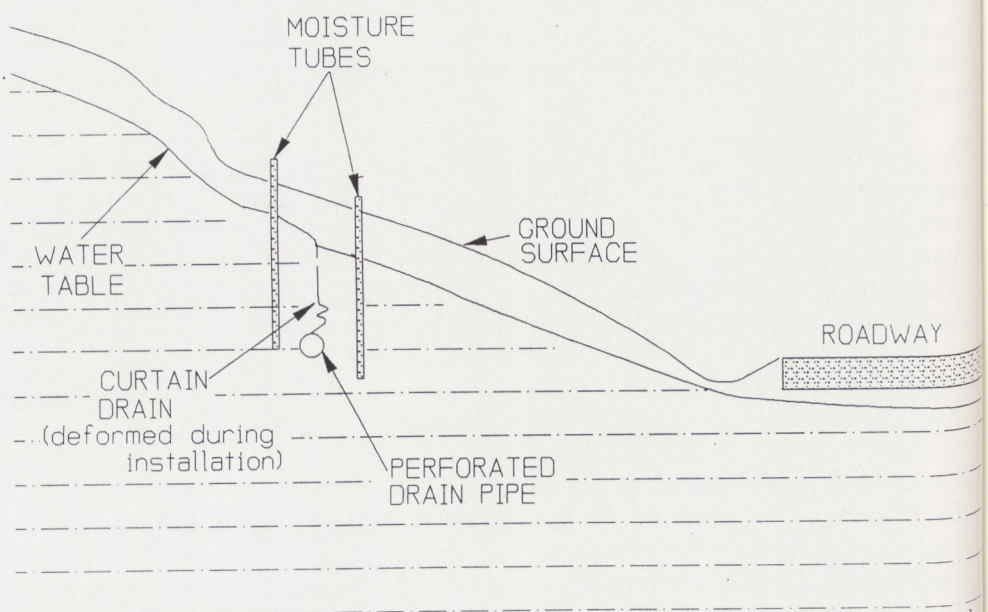
"A User Experience With Hydrain"
CDOH-DTD-R-92-6

· Curtain Drains

Curtain drains are panels of polyethylene "egg shell" core covered by geo-fabric filter cloth placed vertically in the soil to intercept and drain water. Ten foot deep curtain drains were installed on a slope by US 550 near Electra Lake, north of Durango in 1987. The flow from the drains was never more than about 5 gallons per minute, much less than was expected from the system. This indicates that the drains were not removing as much groundwater as intended. Part of the problem was difficulty in construction. The panels had a tendency to buckle as they were backfilled. Workers had a hard time holding them vertical. The wet soil conditions during installation also made it extremely difficult.

In 1990, a section was excavated and the top of the drain was found to be six feet under the surface as opposed to the two feet it was supposed to be. With this buckling, the drains were effectively six feet high rather than ten feet. This system was 1400 feet long, which should have still produced a significant amount of flow. Groundwater level measurements on both sides of the curtain drain showed that there was only moderate reductions across the drain. A final report will be out in 1993.

This drawing shows how the drain system partially collapsed during construction. Groundwater level measurements on both sides of the curtain drain showed that there was only moderate reductions across the drain.



· Polyethylene Pipes for Highway Culverts

This report details some of the design and construction considerations with polyethylene and similar pipes. Included are descriptions of polyethylene pipe failures and ways to prevent those failures.

"Polyethylene Pipes for Highway Culverts"
CDOH-DTD-R-91-9

Traffic -- the figures only go up. Colorado's population growth is one of the highest in the nation. Roads designed to carry several thousand cars a day may now be carrying two or three times as many. Pavements designed to last twenty years are deteriorating at a much faster rate as more trucks with heavier loads, and more vehicles, stretch the pavement's capacity.

· Vehicle Classification

This study grew out of the need to automatically count and classify vehicles on multi-lane facilities. Induction loop vehicle detectors, rubber hoses, and pieziocable are currently available for automatically counting and classifying vehicles, but require multiple lane closures for both installation and maintenance making this operation both disruptive and hazardous. Detection devices that could be installed on the side of the road or on existing overhead structures could greatly improve our vehicle classification ability while eliminating the hazards of lane closures on busy urban freeways.

"Research staff will be working to coordinate and promote a national pooled-fund study to develop such a (vehicle classification) device."

Based on a team approach between Region 1, Region 6, Program Support, and Research; the study has evolved into a two pronged approach to solving the problem. First, because developing an effective device is beyond the current CDOT Research budget, Research staff will be working to coordinate and promote a national pooled-fund study to develop such a device. Secondly, CDOT has joined other states in another national pooled-fund study that is looking at vehicle detector systems for incident management and IVHS systems.

· Lightning Protection of Automatic Traffic Recorders

The department now maintains over 60 automated traffic recorders. The automatic traffic recorder (ATR) system throughout the state operates 24 hours per day, 365 days per year. These stations represent the core of the traffic counting program. It is from these stations that seasonal adjustment factors are drawn toward adjusting the other 2000 short term counts. These counters are also critical in development of design hour factors, 20 year traffic factors, and directional distribution factors.

Each year a significant number of the ATR's are made inoperable for a variety of reasons including lightning strikes, power surges within electrical lines, traffic detection loop failure and assorted other reasons. The damage ranges anywhere from the replacement of the modem to replacement of the modem and traffic counter. Although the cost of materials is substantial, a significant cost is the cost of the staff required to repair and replace the units. Even more significant is the loss of traffic count data. In many cases, a full week's worth of traffic count data on the ATRs is lost.

Lightning and surge protection for the ATR's may significantly reduce their down time. A data base search has been conducted and other possible solutions for this problem are being pursued through contacts with the phone company, electrical company, state agencies outside of Colorado, and FHWA.

· Pavement Deterioration vs Truck Weights

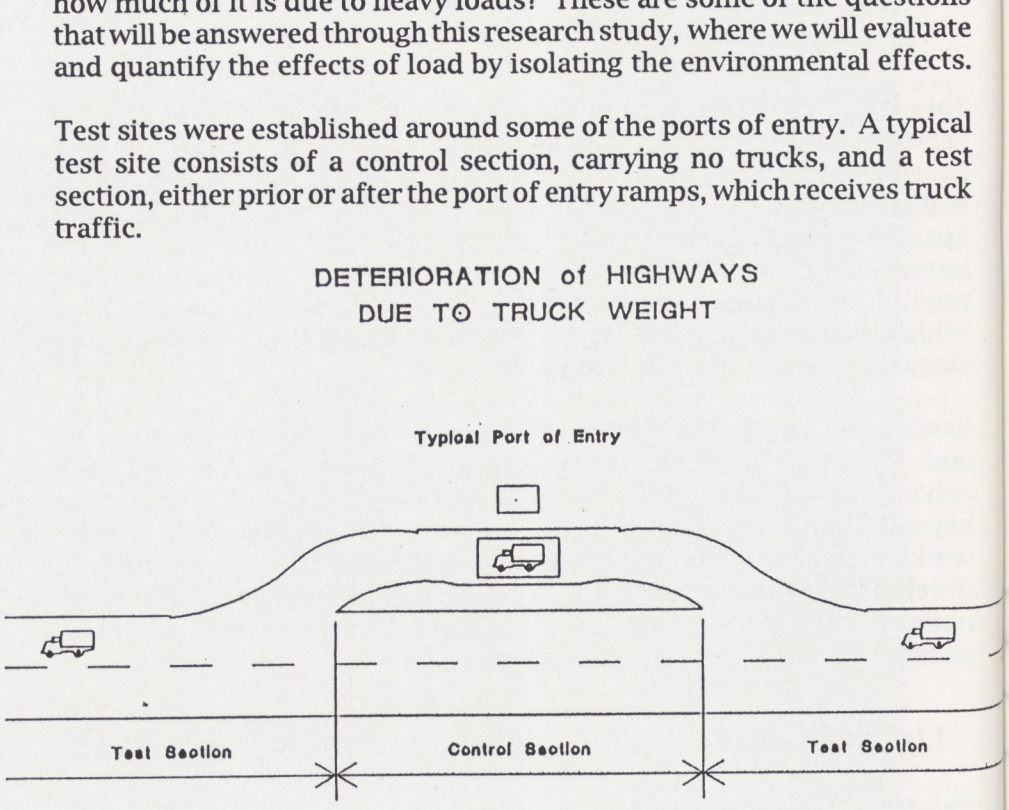
What causes the pavement to fail? Load? Environment? Or a combination of them both?

How much of the deteriorative causes are environmentally related and how much of it is due to heavy loads? These are some of the questions that will be answered through this research study, where we will evaluate and quantify the effects of load by isolating the environmental effects.

Test sites were established around some of the ports of entry. A typical test site consists of a control section, carrying no trucks, and a test section, either prior or after the port of entry ramps, which receives truck traffic.

"Test sites were established around some of the ports of entry. A typical test site consists of a control section, carrying no trucks, and a test section, either prior or after the port of entry, which has no truck traffic."

DETERIORATION of HIGHWAYS
DUE TO TRUCK WEIGHT

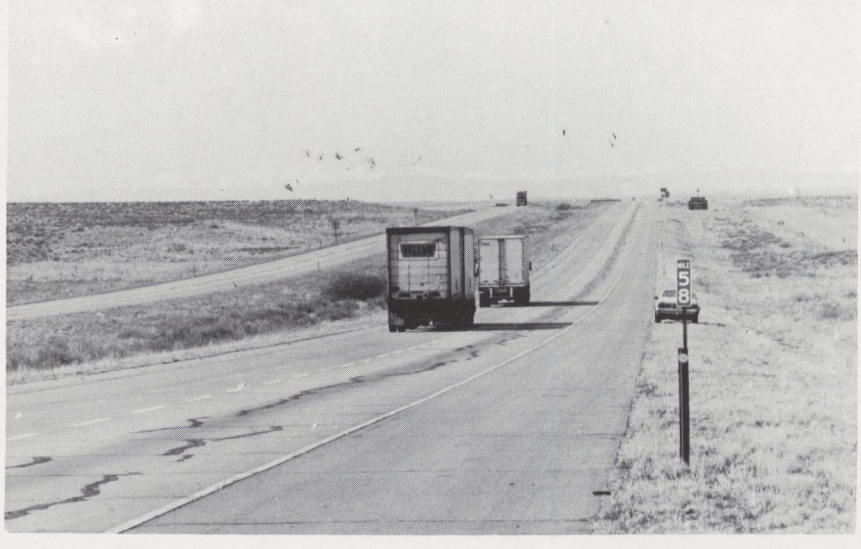


Among the data acquired for this project were: rutting depth, crack mapping, deflection, and roughness data. Rutting may be the best criteria for assessing the effects of heavy load on pavements. Rut depth acquired for the test sections were consistently higher than those acquired for the control section. Cracking and deflection data also showed good correlation, however, the results of the roughness data were inconclusive. Despite the higher rutting in two of the test sections, a review of the roughness data showed a smoother pavement surface for the test sections than for the control section, suggesting that roughness is not be a good tool to predict pavement performance.

Construction in Colorado, with our great weather, sees very little down time, which is good for Research. Many of our projects rely on the cooperation of regional field engineers who let us use various roadways as our "research laboratory".

· I 76 Truck Study

Portions of the driving lane on I 76 in Region 4 are seriously distressed. To help prolong the life of the Portland cement concrete pavement, Region 4 has placed signs advising truckers to use the passing lane in the area between Roggen and the state line, approximately 140+ miles. According to a survey conducted by the Colorado Department of Transportation, 90% of the total truck traffic is concentrated in the outside lane. Both lanes are subjected to the same environmental stresses but it is because of the load related damages that the outside lane becomes prematurely distressed. This study will investigate the practicality of diverting truck traffic from the driving lane to the passing lane. This will be accomplished by evaluating traffic classification, by lane, before and after signing, pavement distress, and economic feasibility. The study is expected to last through the fall of 1993.



This truck is using the left lane on I 76, as instucted by signs along the highway, to help prolong the life of the current pavement until rehabilitation can take place.

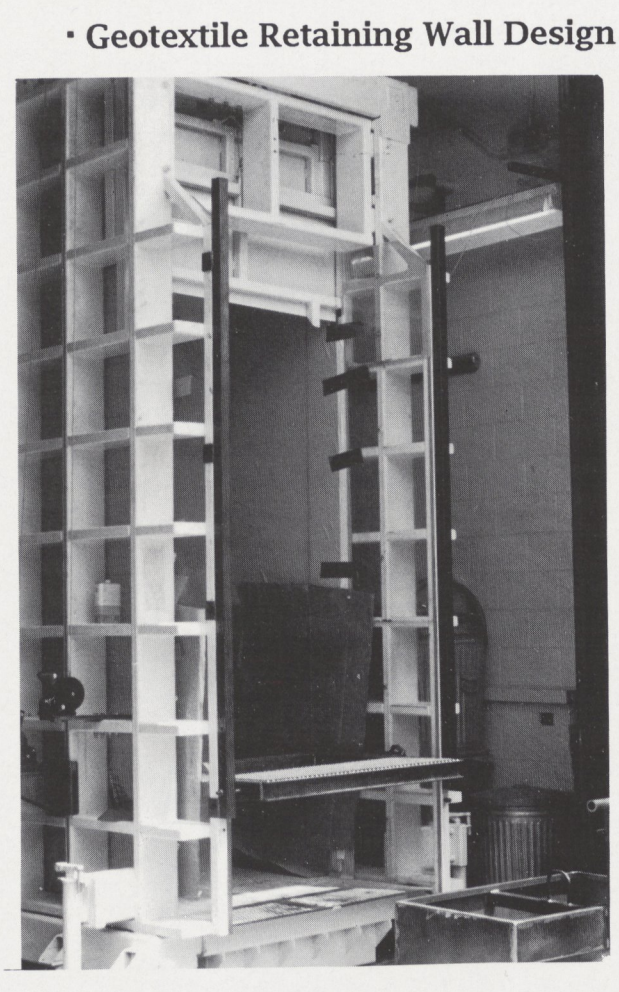
· Experimental Evaluation of a Keyway Curb

A new type of curb has been developed that should offer a strength and durability advantage over curbs anchored by dowel bars. The curb is called a keyway curb. The curb is slip formed over a notch cut in the pavement and eliminates the concrete pan normally used on curb and gutter. This keyway should reduce the possibility of the curb being knocked out of alignment by traffic as can be seen with curbs anchored by dowel bars.

Project FCU(CX)024-3(32) located in Colorado Springs has been identified as a location to place 812 linear feet of the keyway curb as a traffic separator. The keyway curb will be set above an HBP pavement with the key being cut prior to curb plåcement. Within the project their will also be a large area of standard curbing that can be used for comparison with the keyway curb. The keyway curb section of this project is planned for construction during the spring of 1993.

It's earth shaking, it's ground breaking, and it's research too. CDOT's commitment to geotechnical research has paid large dividends. Our transportation department is recognized as an international leader in rockfall management and in resolution of space constraint construction. The geotextile wall research program alone is expected to generate a savings of over ten million dollars annually.

· Geotextile Retaining Wall Design



Known as "King Kong's cage" this massive structure can hold a full-scale model of a geosynthetically earth reinforced wall.

CDOT has developed an innovative and low cost design and construction procedure for a timber-faced geosynthetically earth reinforced wall. This project involved construction of a full-scale model of this CDOT Geosystem and testing it to failure to verify design assumptions. Dr. Nelson Chou collaborated with Dr. Jonathan Wu at the University of Colorado/Denver to complete the testing and to earn his PH. D.

Dr. Chou has since resigned from CDOT and Dr. Trever Wang and Paul Macklin will complete the project that includes the development of an M" Standard design. This project should be completed by March, 1993.

· Keystone Wall

The Keystone Wall Quick Study involved the monitoring of the building of an earth wall with a wide sidewalk on top and the use of Keystone blocks for the face. This particular wall faces a shopping center to the east of Sheridan just south of 92nd Ave.

The poles, placed three feet from the wall, were used as reference points to determine the amount of horizontal displacement that was experienced at the face of the wall during and after construction. There was no movement in the face of the wall in relation to the reference poles during or immediately after construction. Observation after construction, however, indicated that the entire wall and the bank in front of the wall (which was where the reference poles were placed) settled and

moved away from the roadway (Sheridan Blvd.). This was made evident by the development of a large crack between the gutter on Sheridan and the wide concrete walkway that is on top of the wall. The movement that was apparent at this site did not occur in the MSER wall. These walls systems can accomodate relatively large settlements.

The Keystone facing, which has been used at several locations in Colorado, is an attractive and relatively easily constructed facing for a Mechanically Stabilized Earth Retaining (MSER) wall.

Keystone Wall
Quick Study 91-E

A completed Keystone wall.

• Expert System for Retaining Wall Design

Retaining walls are more often required on transportation projects due to right-of-way constraints, environmental considerations, and for other reasons due to space limitations. Retaining walls are expensive, and CDOT has sustained research programs for many years to find more cost effective wall systems. Rich Perske of Region 3 suggested that designers could benefit from a formal, rational retaining wall selection procedure. CDOT Bridge responded -- and Dr. Trever Wang under the direction of A. J. Siccardi, Staff Bridge Engineer, and P. K. Padhiar developed a milestone procedure that has since been implemented by CDOT.

Dr. Wang's retaining wall selection procedure was in flow-chart form, and was time-consuming to complete. Mr. Siccardi proposed a research project to investigate the feasibility of developing software to expedite completion of this procedure. Dr. Teresa Adams of the University of Wisconsin/Madison was selected to perform the evaluation.

Dr. Adams investigated the available shells for this type of program, and decided that a public-domain NASA-developed shell called CLIPS could be utilized to set up a user-friendly and time-saving selection procedure

for PCs. This work received national attention, and the software is being developed through a joint venture funded by Information Systems/ CDOT, the National Science Foundation, and the Federal Highway Administration. Chuck Conley played a key role in establishing CDOT's participation. Dr. Adams presented her first draft in February 1993.

This leading edge research will have far reaching impacts on the kinds of walls that are used on transportation facilities, and will accelerate the development and refinement of retaining wall designs, particularly earth-reinforced systems. Cost savings for Colorado and the nation, resulting from this and related work, will reach over 400 million dollars per year through better choices for walls and through the development of new and improved systems.

· Centrifuge Model Testing of Geosynthetic Reinforced Walls

This study was undertaken at the University of Colorado/Boulder by Dr. Hon Yim Ko, and several graduate students. The purpose is to compare the performance of scaled models of CDOT Geosystem walls in the CU centrifuge to their performance in the full-scale testing facility at UC/D. Centrifuge testing is a new field, and this study hopes to show that the expense of full-scale testing can be reduced or eliminated. The other benefit that we may show is that many more tests can be performed for the cost of one full-scale test. This research is nearly complete with a final report expected in 1993.

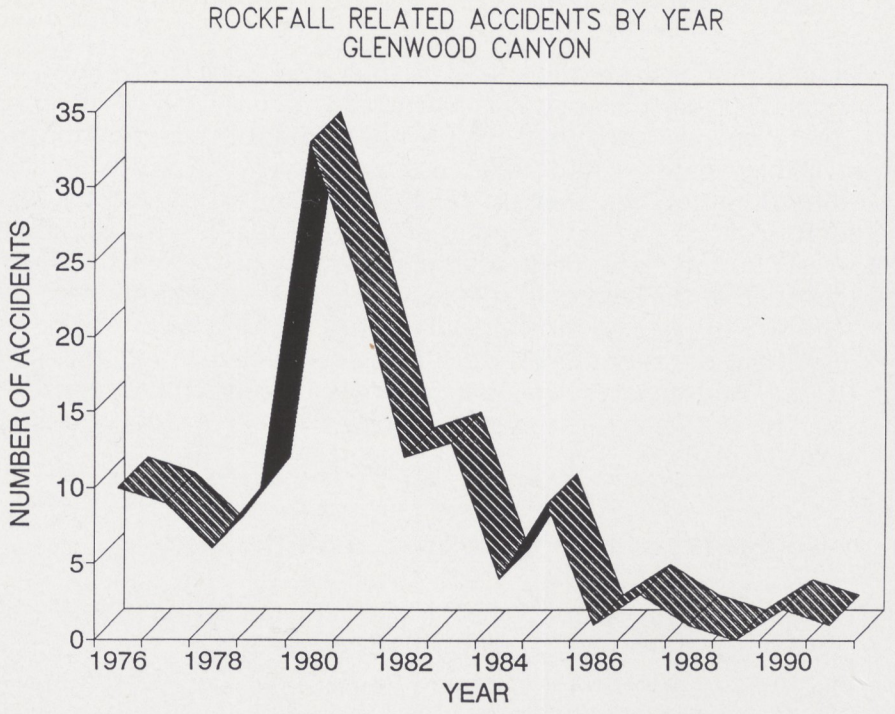
· Analytical Simulation of Rock Fall Prevention Fence Structure

"This study resulted in the development and field testing of the Colorado Flex-Post Rockfall fence." Bob Barrett, received the Governor's Creativity Award in 1991 for his participation in the fence's development.

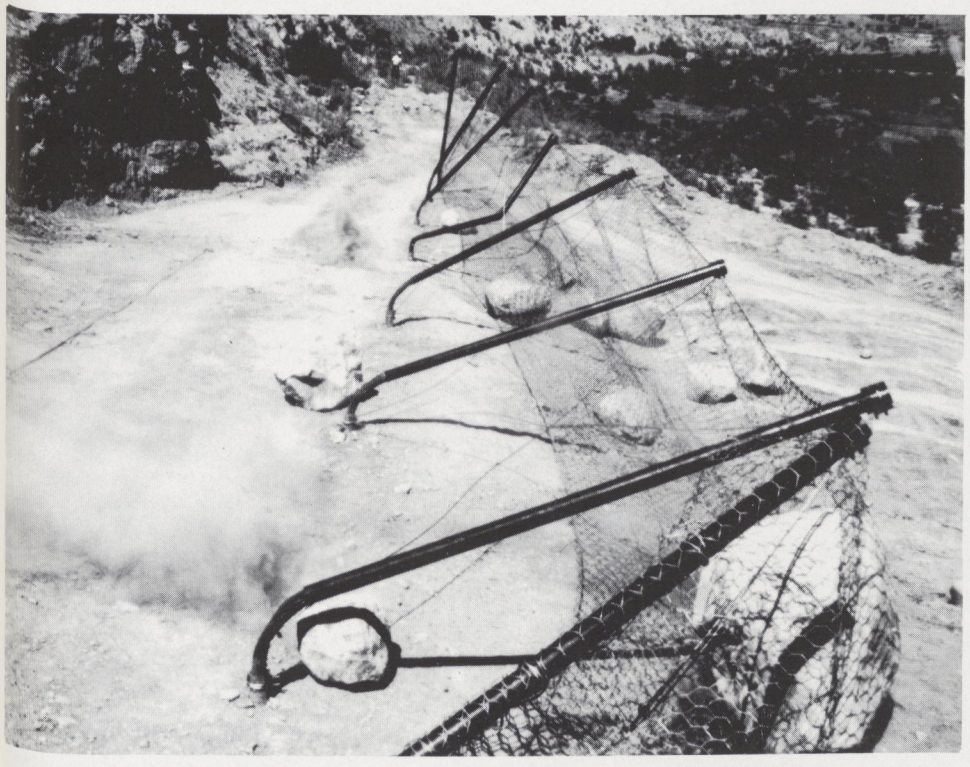
This study resulted in the development and field testing of the Colorado Flex-Post Rockfall Fence. This protection device was subsequently patented by CDOT. In the summer of 1992, 26 of these fences were installed along the Glenwood Canyon I 70 Project at a total cost of one million dollars.

The Colorado Flex-Post Rockfall Fence utilizes spring-based posts and wire mesh to catch rocks, redirect them to a collision with the ground, and then tosses the rocks upslope as the spring-based posts reposition back to a vertical position.

Dr. George Hearn at the University of Colorado/Boulder was the Principal Investigator on this project. The patent was awarded to Dr. Hearn, Mike McMullen, and Bob Barrett of CDOT. Bob Barrett received the Governor's Creativity Award in 1991 for his participation in development of this fence.



The removal of potentially harmful rocks and the placement of rockfall mitigation devices have significantly reduced rockfall related accidents in the canyon.



"The Colorado Flex-Post Rockfall fence utilizes spring-based posts and wire mesh to catch rocks, redirect them to a collision with the ground, and then tosses the rocks upslope as the spring-based posts reposition back to a vertical position."

"CDOT Flex-Post Rockfall Fence"
CDOH-R-UCB-91-6

• CDOT Flex-Post Fence: A Study to Double Capacity

Dr. George Hearn continued his original work with this project. The original Flex-Post Fence was constructed with one layer of mesh and it could stop rocks with up to 40,000 foot pounds of energy. This project investigated the feasibility of adding more layers of mesh to increase the strength of the fence. Mathematically, according to this work in progress, additional layers can be supported by the spring-based posts and these layers can increase the rock-stopping ability of the fence. There is a concern that the increased stiffneness resulting from multiple layers of mesh will decrease the ability of the mesh to form an adequate pocket to contain the rocks as they are being redirected to collide with the ground. Additional field testing will be performed at the Clough Rockfall Test Site at Rifle in the winter and spring of 1993 to observe this aspect of the stronger fence.

• Geogrids for Bridge Approach Settlement

". . . CDOT will continue to develop design methodologies for founding bridges on reinforced approach fills."

This project examined the use of geosynthetics, grids in this case, to prevent or minimize the "bump at the bridge" problem. It was concluded that these tensile inclusions were of little value. The reason -- is that the settlements are vertical, and therefore, the tensile strength of the geogrid is not mobilized. If there were an horizontal component, as in spreading or rotational failure, the outcome would have been more positive. Had the bridge been founded on the reinforced abutment fill, and not on deep foundations, the bump would not develop. Due to the urgent need, CDOT will continue to develop design methodologies for founding bridges on reinforced approach fills.

"Geotextiles in Bridge Abutments"
CDOH-DTD-R-91-2

• EPS for Bridge Abutment Backfill

It is assumed that the "bump at the bridge" is caused in part by the weight of the earth used for the approach fill to a bridge founded on deep foundations. This additional loading on the foundation soils causes these underlying soils to become more dense, and therefore, lose volume. This densification (compaction or consolidation) is time dependent. Thus, the bump may develop over several months or years, and may require repeated leveling. This ongoing maintenance is expensive, the bumps can reduce safety, and they certainly harm CDOT's image.

In this study, Principal Investigator Shan-Tai Yeh of CDOT is examining the use of light-weight backfill to mininimize the bump problem. The first project incorporates expanded poly styrene (EPS) as fill. The EPS weighs only one or two pounds per cubic foot and has a compressive strength of two or three psi. The approach fill was recently completed and Shan-Tai Yeh, C. K. Su and the Geotech group are monitoring the extensive instrumentation array at that project on I 76 and Broadway.

We expect that this will largely prevent the bump, however, the cost is very high. A more cost effective solution, where applicable, is to found the bridge on a reinforced soil abutment, therefore allowing the bridge to settle with the fill.

"EPS weighs only one or two pounds per cubic foot and has a compressive strength of two or three psi."

· Ground Penetrating Radar Investigation of Subsurface Properties

This is an ongoing project under the direction of Brandy Gilmore of Staff Materials. The study consists of performing GPR surveys of several sites selected to represent subsurface conditions related to highway design, construction and maintenance. The data obtained will be analyzed to evaluate the applicability of the method to each situation.

GPR has been used by archeologists to define ancient Indian villages, and by law enforcement agencies to find graves. GPR can also be used to find pipelines and other subsurface features that cause disturbances in uniform soil or rock layers. Florida has used GPR to find limestone caverns.

Uses tested in the department include: location of rock formations under roadways, analyzing base and subbase problems under roadways, location of archeology sites, location of abandoned mines under roadways, measuring clearance under bridges, and measurement of bridge scour.

Success of this equipment has been mixed and depends significantly on depth, features, and the type of soil, specifically clay. Clay tends to block the signal and obliterate information on features below it. In order to be useful to the department, equipment would have to have a broad range of antennas and transmitter frequencies to meet the various needs. Training and experience is also needed, along with test boring, for the equipment to provide accurate information.

· Expansive Soil Treatment Methods In Colorado

This reports reviews and summarizes the effectiveness of past expansive soils treatment methods used by Colorado DOT and other transportation agencies. Among the treatment methods evaluated were the following:

- Sub-excavation and removal of expansive soils and replacement with non-expansive soil.
- Application of heavy applied load to balance the swelling pressure
- Preventing access of water to the soil by encapsulation
- Stabilization by means of chemical admixtures
- Mechanical stabilization
- Explosive treatment to correct swelling shales
- Pre-wetting the soil
- Avoiding the expansive soil

A survey questionnaire was designed , and sent to the District Materials Engineers, to obtain their consensus on the treatment techniques used in Colorado. The results of this survey is presented in part VIII of the report.

This study showed that the performance of some the swelling soil treatment methods used in Colorado has been poor. As a result, initiation of the second phase of this study is recommended. The ultimate goal of the second phase will be to establish up-to-date design guidelines that offers specific strategies for highway construction on swelling soils and swelling shales in Colorado.

"Expansive Soils Treatments In Colorado"
CDOT-DTD-R-92-2

· Resilent Modulus of Granular Soils of Different Gradation

"Increasingly, pavement engineers use the theory of elastic layers in estimating the performance of pavement structures and calculating the design pavement thickness."

Conventionally, the mechanical properties of soils are assessed using stabilimeter R value. Increasingly, pavement engineers use the theory of elastic layers in estimating the performance of pavement structures and calculating the design pavement thickness. Under repetitive traffic load the effort requires the resilient modulus of elasticity of all the materials involved in the pavement structure.

This study will formulate a functional relationship for the resilient modulus as a function of R-value, and the parameters which define the gradation characteristics of soils.

Technology Transfer (TT) is a collection of programs and activities aimed at bringing new technology into the hands of potential users. Because technology is continuously evolving, so it goes that our emphasis also continues to change with the times. There is also talk that technology transfer may be a misnomer and that technology exchange may be a better description. Why? Because when communication flows -- it's usually in more than one direction.

· Implementation

Technology Transfer is also synonymous for implementation. And implementation of research does not stop with the publication of a report, nor is it easy. That is why implementation activities will be the new focus of TT. But to be successful it has to take on many forms - reports, brochures, videos, training, demonstrations, changing a current method or specification, or developing a computer program. Or in other words -- whatever it takes to get the message through.

". . . to be successful (implementation) has to take on many forms - reports, brochures, videos, training, demonstrations, changing a current method or specification, or developing a computer program."

And implementation doesn't just stop at those studies completed by our in-house staff. In 1992, Research began the concept of Oversight Teams to review and investigate research performed by other states to determine the feasibility of its use here. Implementing already documented and proven concepts, or methods, can increase the impact of available research dollars.

· SHRP Products Implementation

Begun in 1992, TT, has taken the lead in SHRP products implementation. Currently we are coordinating a database of all SHRP products currently in use in the department. Next, with team members Denis Donnelly, Staff Materials, Rich Griffin, Research, and Dave Fraser, Maintenance, TT will seek to further implement available SHRP products throughout the department. We will be seeking, and working with, a product champion for every implementable SHRP product.

· Reference Materials

One of our best known activities involves making our entire collection of reference materials available to the department. Also open the public, over 150 customers seek research assistance in our office each month. The Technology Transfer Unit has one of the premier collections of transportation reports in Colorado. Over 10,000 reports are indexed online, and this accessibility will soon be available to all employees statewide as the database is added to the VAX system in the spring of 1993.

And when what we have isn't enough, TT can also perform a national database file search for its CDOT customers. These searches, completed for us by the Transportation Research Board offices in Washington, D.C., can be done on any transportation subject. The results will include all transportation research being completed with federal and/or state money.

TT also has a collection of video tapes on various transportation subjects including maintenance, safety, and drainage, to name a few. An index of those tapes will be available in the summer of 1993.

· Publications

TT also produces the quarterly "Research Newsletter." This newsletter is aimed at keeping CDOT employees, and state research staffs across the country, informed of completed and ongoing research studies. It has a current circulation of around 900.

The staff is also responsible for publication of a bi-annual report on research activities, this years edition is what you are reading now "Research '92 Reality and Vision -- Today and Tomorrow."

· ReACH

" . . . the ReACH program was a week long, and filled with training and demonstration activities."

ReACH is an audio and visual display of research activities held every other February. In 1991, starting a semi-annual schedule, the ReACH program was a week long, and filled with training and demonstration activities. After wards, the ReACH display portion, is made available, by request, to interested groups.

· Colorado Transportation Information Program (COTIP)

The TT Unit manager provides contract administration for the COTIP program and serves as an advisory board member.

The COTIP program is part of the nation Local Transportation Assistance Program (LTAP). Located in Fort Collins, CO., COTIP is located on the campus of Colorado State University. It is a joint venture between the Federal Highway Administration, the Colorado Department of Transportation, and Colorado State University.

The objective of both the Colorado and national program is to provide coordinated information dissemination, technical assistance, and training activities to local transportation agencies. At present, CDOT employees make up around 20% of those involved in training.

Traffic congestion is becoming a national problem which is beginning to affect our quality of life. State highway agencies are faced with the dilemma that they can no longer build their way out of the congestion problem by continuing to widen freeways as they have done in the past due to financial as well as environmental reasons.

Highway safety is also an issue of prime concern. Thousands of motorists continue to die and become injured each year as a result of traffic accidents. Continued emphasis on driver education programs as well as vehicle safety innovations are needed in order to substantially decrease highway accidents in the future.

One of the programs initiated in the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) to help focus on these as well as other transportation issues is the Intelligent Vehicle Highway Systems (IVHS) program. The IVHS program established in ISTEA will authorize approximately $660 million of funds for IVHS activities over the next 6 years.

Intelligent vehicle and highway systems, or IVHS is the merging of electronic technology with motorized vehicles and the surface transportation system on which they operate. With the recent developments in advanced computer, telecommunications, and control systems technologies IVHS can improve communication between drivers and traffic control centers creating an integrated highway transportation system. IVHS has the potential for improving safety, reducing congestion, enhancing mobility, reducing environmental problems, conserving energy and promoting economic productivity in our transportation system.

"(incident management) . . . can reduce the number of accidents, clear them more quickly when they do occur, and divert traffic around them . . ."

IVHS is not a distant vision. Already, real systems, products, and services are being tested throughout the United States, Europe, and Japan. Some examples of these first generation systems are:

>Collect and transmit dynamic information on traffic conditions and transit schedules for travelers, whether they are at home, in the office, or en route. Alerted to hazards and delays, they are able to change their plans to minimize inconvenience.

> Expand the existing capacity of our highways by reducing the number of traffic incidents, clearing them more quickly when they occur, diverting traffic around them, and automatically collecting tolls.

>Improve the productivity of commercial, transit, and public safety fleets by using automated tracking and dispatch systems that dynamically reroute vehicles to accommodate changes in customer needs.

>Assist drivers in reaching a desired destination with navigation systems enhanced with pathfinding, or route guidance. Stored directories that are part of such in-vehicle systems will provide information on nearby businesses or tourist attractions.

· IVHS Program

Putting together a write-up on the IVHS program would take an entire report of its own...and it has. The two key individuals within CDOT responsible for launching an IVHS program in Colorado are Harvey Atchison, Director of Transportation Development and John Kiljan, IVHS Research Engineer. It is because of their initial efforts that the IVHS program has continued to blossom. Some of the IVHS activities planned and underway are listed below.

"ENTERPRISE is a multi-state pool funded research program established to perform research and implementation of IVHS technologies."

· The ENTERPRISE Program

Colorado was one of the founding members of the ENTERPRISE organization. ENTERPRISE (Evaluating New TEchnologies for Road PRogram Initiatives in Safety and Efficiency) is a multi-state pool funded research program established to perform research and implementation of IVHS technologies. The goal of ENTERPRISE is to perform cooperative research and implementation programs involving the private sector on an interstate basis. Other member states include: Arizona, Iowa, Michigan, Minnesota, North Carolina, Washington, Ministry of Transport Ontario, and Transport Canada. John Kiljan, CDOT is the ENTERPRISE Chairman and Neil Lacey, CDOT Research Branch is the Program Administrator.

Some of the current activities currently taking place include the sponsorship of a National Rural IVHS conference to be held in Keystone, CO in February 1993. This conference will help draw attention to the need for development of rural IVHS technologies as well as urban needs. ENTERPRISE is also involved in the development of a digitally based traffic message information technology which uses location coding.

· Colorado Incident Management Coalition

In September 1991, Colorado became the second state to hold an Incident Management conference sponsored by the National Incident Management Coalition. The planning and support for this conference came from John Kiljan and the CDOT Research Branch staff. The result of this conference was the formation of a coalition headed by a Task Force to recommend and pursue the implementation of incident management strategies for the Denver, CO metropolitan area. Thus the Colorado Incident Management Coalition (CIMC) was created.

The CIMC is a multi-agency, multi-disciplinary group representing a wide variety of agencies and corporations that have a specific task to carry out in responding to incidents on the roadway system. John Kiljan serves as the co-chair of the CIMC Task Force along with a representative of the Denver Metropolitan Planning Organization.

The initial recommendations of the CIMC are contained in the September 1992 CIMC Recommendations report. One recommendation that was implemented was a pilot program, "The Mile High Courtesy Patrol." The pilot program began in late August 1992 and will continue for six months until the end of February 1993. The purpose of the program is to assist motorists whose vehicles are disabled in the lanes of traffic or on the shoulder. The services provided by the patrol include providing gasoline, changing flat tires, jump starting batteries, providing water for overheated vehicles and if all else fails relocating the vehicles from the freeway by either a tow truck or vehicle equipped with a push bumper.

The Mile High Courtesy Patrol ". . . (will) assist motorists whose vehicles are disabled in the lanes of traffic or on the shoulder."

The program is unique in that two different types of patrol vehicles that perform similar services are being evaluated. The first type of patrol vehicle are four (4) tow trucks owned and operated by AAA Colorado. The second type are two (2) Colorado State Patrol Chevrolet Suburbans equipped with push bumpers. Each of the patrol vehicles collects information about the types of services it performs for each vehicle it

assists. This information is recorded on a pre-printed collection sheet. One other aspect of the program is that an outside consultant was hired to perform an independent evaluation of the effectiveness of the program. The consultant will prepare a written report at the end of the pilot program.

The pilot program is a cooperative effort between several branches of CDOT including the Research Branch, Division of Transportation Safety and Region 6 which has responsibility for design, construction, and maintenance of state highways in the Denver metropolitan area. Since the early indications of the program indicate that it has been a huge success, a permanent program will be pursued for operation by Region 6.

Other CIMC recommendations being implemented in the near future include: an 800 Mhz communications system which will allow multi-agencies to be able to communicate with one another in the event of an incident; legislation requiring motorists to move their vehicles out of the lanes of traffic in the event of a breakdown or property damage only accident; and establishment of freeway corridor management teams.

· The HELP Program

" . . . HELP is developing an advanced truck monitoring and management system with both government and motor carrier applications."

The Heavy Electronic License Plate (HELP) program is a multi-state IVHS effort in which Colorado participates along with 13 other states, FHWA and the motor carrier industry. HELP is exclusively focusing on fleet management control systems. Specifically, HELP is developing an advanced truck monitoring and management system with both government and motor carrier applications.

The HELP system combines the technologies of automatic vehicle identification (AVI) and weigh-in-motion (WIM) with the networked communications and data processing. This supports efficient data collection for state agencies and motor carrier users. The system also allows legally-laden vehicles equipped with electronic tags to bypass weigh stations and ports of entry.

· COmmercial VEhicle (COVE)

The COmmercial VEhicle (COVE) program is a consortium of neighboring states that are looking into and trying to develop solutions to the institutional barriers involved in commercial vehicle operations. The states are interested in the development and implementation of policies that would create transparent borders between the states where the interstate commerce would be regulated and allowed to flow freely when possible. These types of efforts would support the trucking industry. The states currently involved in this effort include: Arizona, Arkansas, Colorado, Louisiana, New Mexico, and Texas. The Colorado COVE Coordinator is Greg Fulton, Division of Transportation Development.

· The C-Star Program

The C-Star Program is the Statewide IVHS Strategic Plan for Colorado. The plan originated with the legislation that created the Colorado Department of Transportation from the Colorado Department of Highways. The enacting legislation required an investigation into the feasibility of intelligent vehicle highway systems and traffic management systems. John Kiljan, IVHS Research Engineer coordinated the writing of the strategic plan.

A traffic operations center, like the one shown here, will soon become a reality for Colorado. Sites for construction are under review at the present time.

The strategic plan is a vision of what is possible to improve the capacity, efficiency, and the safety of the Colorado state highway system using advances in electronics and information processing. Because it covers the use of existing and potential IVHS technologies which are constantly changing, the plan is intended to be a dynamic and evolving document. It is only intended to be an overall framework for all of CDOT's future IVHS activities. The plan will be supplemented by regionally developed metropolitan, corridor, and area-wide plans. Here are some of the highlights of the report:

· Current Activities

Several activities are underway or planned in Colorado that relate to the C-Star program. These can be divided into three areas as follows:

1) IVHS Studies and Demonstrations - CDOT is actively pursuing a number of IVHS projects. These include the Denver Metro Area IVHS study, Interstate 70 Rural IVHS Corridor Planning and Feasibility Analysis, environmental sensor technology research, and the formation of a university-based research organization - The Colorado Transportation Institute (CTI).

2) IVHS Related Projects - A number of systems and activities in Colorado have potential to support the C-Star program. These include design and construction of a traffic operations center in Denver, the state microwave communications network, cellular phone coverage, construction of an electronic port of entry in Trinidad, CO using state of the art technology, design and construction of an intermodal bus-transfer facility, and innovations with the existing traffic information services.

3) IVHS Enhancement Opportunities - Several additional areas have potential for enhancement through IVHS application. These include transit services and rideshare programs, rest areas and welcome centers, and the Canada-to-Mexico free trade corridor.

IVHS technologies provide exciting opportunities to address the needs of highway transportation. CDOT Executive Director, Dr. Ray Chamberlain foresees that half of CTI's activities will be in the field of IVHS. Through the C-Star Program, Colorado is in a position to take a major step forward in highway system improvements. C-Star will bring together a variety of organizations, integrating current activities and facilities, and developing new technologies that meet the state's unique needs. Overall, C-Star, has the potential to introduce a new era in transportation, providing Colorado with a truly optimized highway system to meet the challenges of the next century.

· 1991

***DYNAMIC MEASUREMENTS ON PENETROMETERS FOR DETERMINATION OF FOUNDATION DESIGN PARAMETERS**
CDOH-DTD-R-91-1

***GEOTEXTILES IN BRIDGE ABUTMENTS**
CDOH-DTD-R-91-2

SYNTHETIC VS. WOODEN SNOW FENCE
CDOH-DTD-R-91-3
Ahmad Ardani

RUT RESISTANT COMPOSITE PAVEMENT DESIGN
CDOT-DTD-R-91-4
Donna S. Harmelink

FIELD WEATHERING TEST DECK FOR REFLECTIVE SHEETING
CDOH-DTD-R-91-5
David A. Price

CDOT FLEX-POST ROCKFALL FENCE
CDOH-R-UCB-91-6
George Hearn

GEOTEXTILE WALLS FOR ROCKFALL CONTROL (CANCELED)
CDOH-R-91-7

USE OF FLY ASH IN STRUCTURAL CONCRETE
CDOT-DTD-91-8
David Woodham

POLYETHYLENE PIPES FOR USE AS HIGHWAY CULVERTS
CDOT-DTD-R-91-9
Thomas R. Hunt

ICE-DETECTION SYSTEM EVALUATION
CDOT-DTD-R-91-10
David Woodham

EVALUATION OF SWAREFLEX WILDLIFE WARNING REFLECTORS
CDOT-DTD-91-11
David Woodham

ANALYSIS AND DESIGN OF GEOTEXTILE-REINFORCED EARTH WALLS
CDOT-UCD-R-91-12
Jonathan T.H. Wu and J.C. Lin

• 1992

COLORADO DEPARTMENT OF TRANSPORTATION ASPHALT PAVEMENT WHITE PAPER
CDOT-DTD-R-92-1
CDOT Advisory Team

EXPANSIVE SOIL TREATMENT METHODS IN COLORADO
CDOT-DTD-R-92-2
Ahmad Ardani

GILSONITE, AN ASPHALT MODIFIER
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AVALANCHE CHARACTERISTICS AND STRUCTURE RESPONSE
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SPECIAL POLYMER MODIFIED ASPHALT CEMENT
CDOT-DTD-R-92-5
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A USER EXPERIENCE WITH HYDRAIN
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Gary Johnson & Hydraulic Staff Designers

COLORADO DEPARTMENT OF HIGHWAYS CHLORIDE CONTENT EVALUATION PROGRAM FOR REINFORCED CONCRETE BRIDGE DECKS
CDOT-DTD-R-92-7
Arne B. Riple & Bruce A. Suprenant

*EVALUATION OF UNBONDED CONCRETE OVERLAY
CDOT-DTD-R-92-8

FIBER PAVE, POLYPROPYLENE FIBER
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DESCRIPTION OF THE DEMONSTRATION OF EUROPEAN TESTING EQUIPMENT FOR HOT MIX ASPHALT PAVEMENT
CDOT-DTD-R-92-10
Timothy Aschenbrener & Kevin Stuart

COMPARISON OF RESULTS OBTAINED FROM THE FRENCH RUTTING TESTER WITH PAVEMENTS OF KNOWN FIELD PERFORMANCE
CDOT-DTD-R-92-11
Timothy Aschenbrener

FACTORS THAT AFFECT THE VOIDS IN THE MINERAL AGGREGATE IN HOT MIX ASPHALT
CDOT-DTD-R-92-13
Timothy Aschenbrener & Charles MacKean

COMPARISON OF COLORADO COMPONENT HOT MIX ASPHALT MATERIALS WITH SOME EUROPEAN SPECIFICATIONS
CDOT-DTD-R-92-14
Timothy Aschenbrener

INVESTIGATION OF PREMATURE DISTRESS IN ASPHALT OVERLAYS ON IH-70 IN COLORADO
CDOT-SM-AI-92-15
Robert B. McGennis, Robert T. Rask, Timothy B. Aschenbrener

*Indicates that a report is not yet available

Copies of these and all other CDOT Research reports are available from:

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