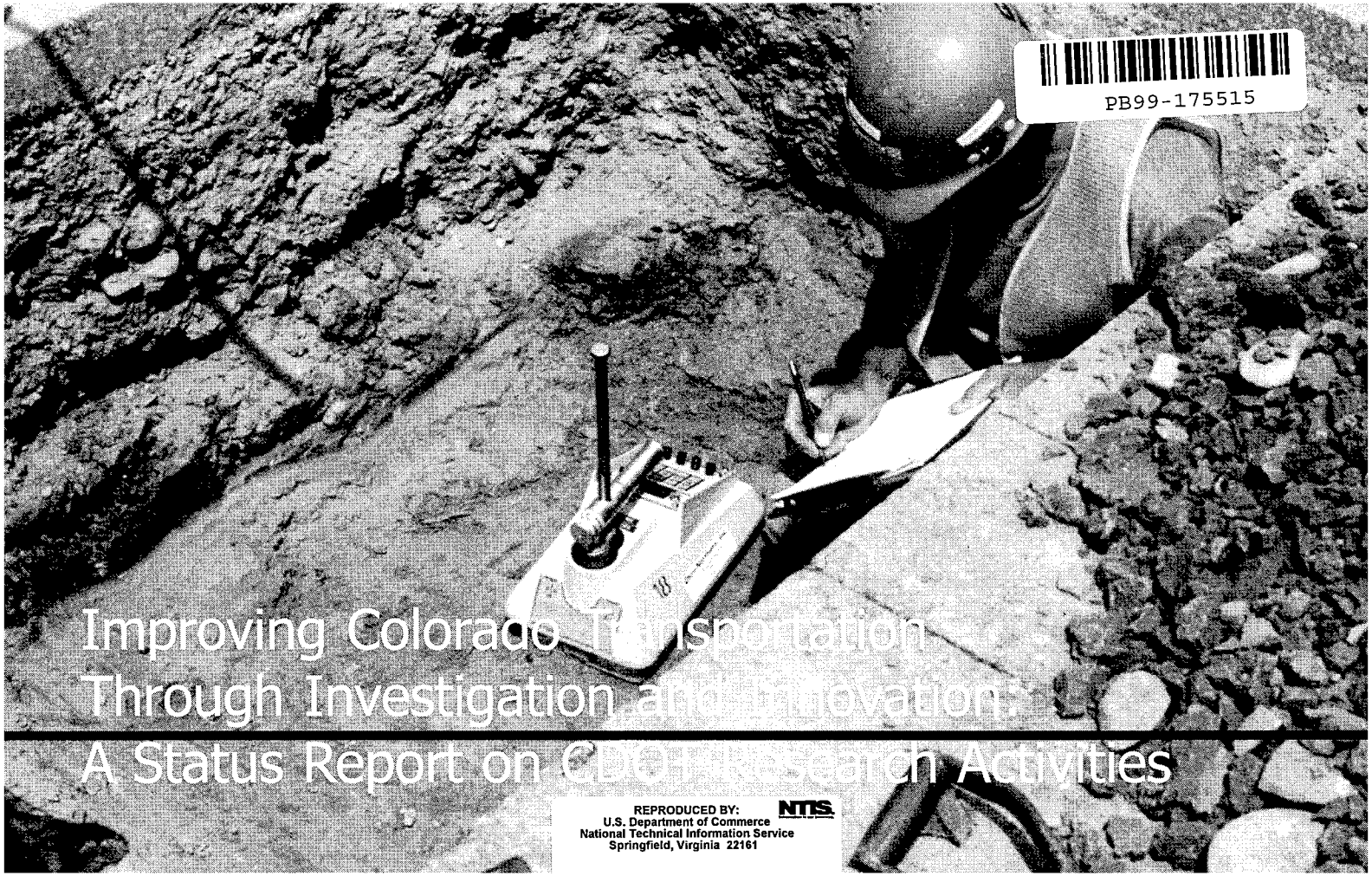


Improving Colorado Transportation Through Investigation and Innovation: A Status Report on CDOT Research Activities

Improving Colorado Transportation Through Investigation and Innovation: A Status Report on CDOT Research Activities

June 1999

Colorado Department of Transportation
CDOT-DTD-R-99-6

Contents

Introduction

This Colorado Department of Transportation Research Branch report "Improving Colorado Transportation Through Investigation and Innovation: A Status Report on CDOT Research Activities" highlights current and completed research studies from January 1996-present. The report focuses on seven subject areas: asphalt and concrete pavements, bridges and structures, environmental, safety, smart highways/intelligent transportation systems, multi-modal, and technology transfer services.

If you would like additional information on any of the studies presented within this report, a CDOT study manager is listed following each current study. You are invited to call them with any questions you may have.

Mission Statement

The mission of the Research, Development, and Technology Transfer (RD&T) Program is to save Colorado citizens money, time, and lives while preserving the environment and quality of life through the development and deployment of innovative products, materials, and methods in transportation.

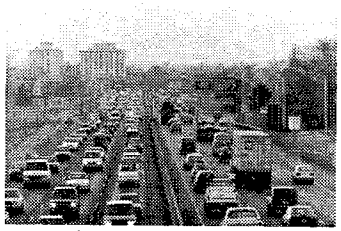
Strategic Direction

Due to the limited amount of funds available for research, the Research and Implementation Council (RIC) has been working toward focusing the program into areas of strategic importance to CDOT. The RIC is composed of several upper level managers at CDOT.

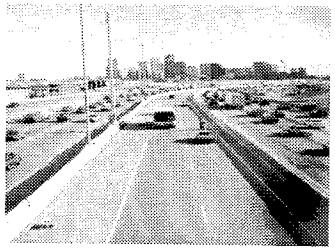
Every year in either late summer or early fall, the RIC meets to consider the strategic direction that CDOT research should take for the next budget year. Even though it is expected that the strategic direction would continue more than a single budget year, an annual review is necessary as strategic issues change and already-funded research is expected to address some of the current strategic issues.

During 1998, under the leadership of CDOT's Deputy Chief Engineer, and based on input from the technical research oversight teams, the RIC set the following focus areas for research contracts.

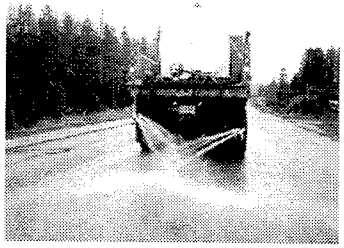
Highway Safety



Multi-modal



Environmental



The RIC also recommended setting aside contract funds to supplement staff resources for pilot studies and the evaluation of experimental features on construction projects. It was perceived that research in the more traditional areas of pavements and structures would continue as experimental feature evaluations.

How Does the Research Branch Decide Which Research Studies to Do?

Research needs, in the form of problem statements, are solicited every August from CDOT employees, FHWA Division office employees, Metropolitan Planning Organizations, and Colorado universities. A corresponding technical research oversight team composed of subject matter experts then evaluates the submitted problem statements. Combining literature searches from the national Transportation Research Information Service (TRIS) with their technical knowledge and experience in the field, the oversight team submits recommendations to the RIC. The RIC then prioritizes these problem statements for funding in the next fiscal year. The criteria for the prioritization of the problem statements includes the following questions.

√Can the research effectively address the problem with the time and budget proposed?

√Have others, including state DOTs, already conducted research to solve a similar problem?

√Is the problem an urgent or emerging issue to CDOT?

√Do the potential benefits justify the cost of the research?

√Does the research fit the strategic needs of CDOT? Is this the only way that CDOT can have a research need addressed?

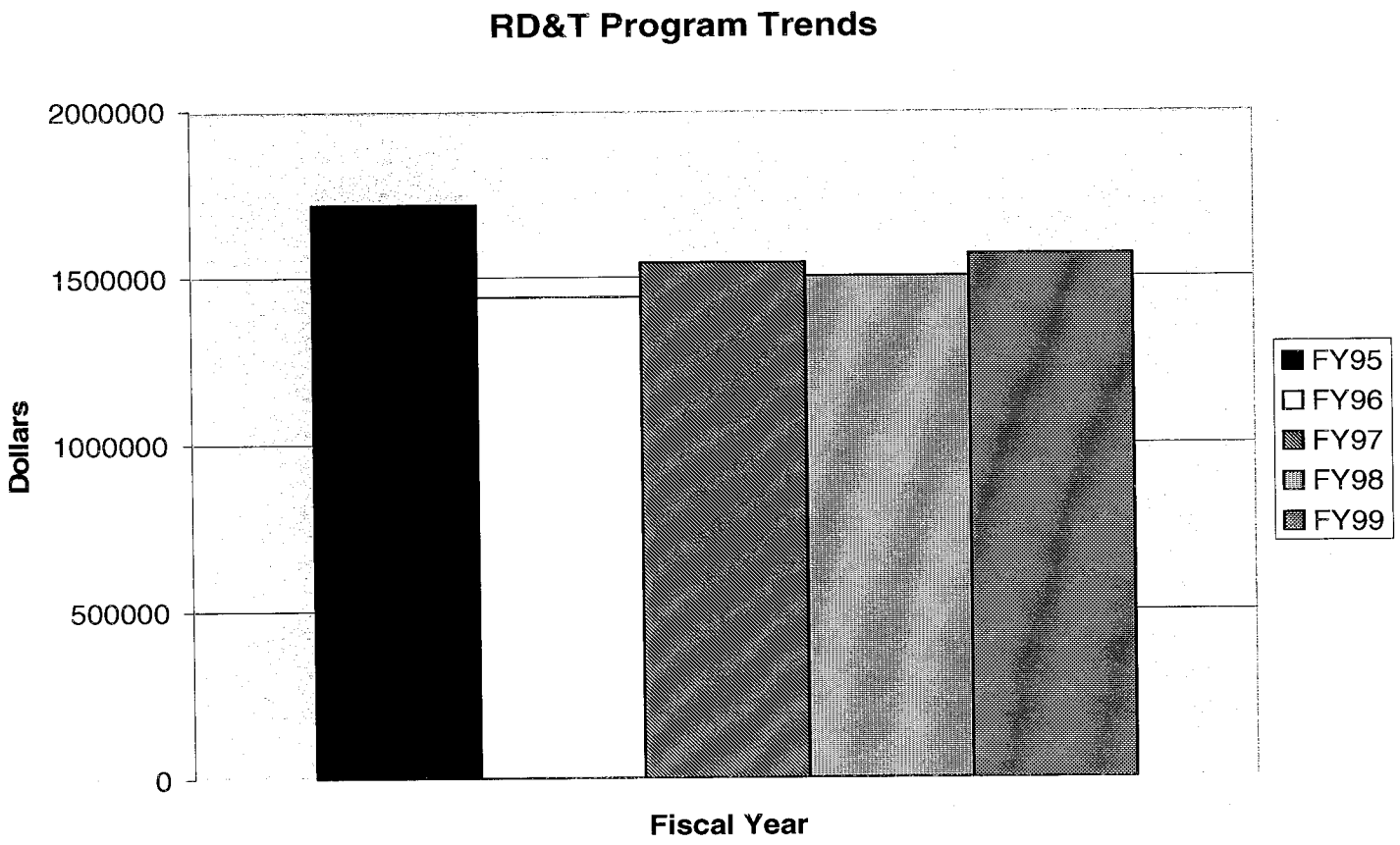
Is This the Only Way I Can Have My Research Needs Addressed?

Simply put, no. When a research need is the evaluation and documentation of an experimental feature on a construction project, the above solicitation and prioritization process is not necessary. Research staff members are available to conduct these evaluations upon the request of a Region office to the Research Coordination Engineer.

An experimental feature is a method, material, or practice which is not a state or industry standard. In accordance with Procedural Directive 3.1, all experimental features incorporated into Federal-Aid projects must be formally evaluated. Funding for the first year is normally provided by the construction project account and subsequent years of evaluation are normally funded under the State Planning and Research (SP&R) RD&T program.

Research Funding

Research studies are funded through a federal set-aside called the SP&R program. Federal law mandates that two percent of the federal funds provided to the states for transportation must be set aside for planning and research activities. Federal law further mandates that a minimum of 25 percent of SP&R funds must be programmed for a RD&T program. The total CDOT Research Branch budget has been around $1.5 million dollars for several years. (see chart next page) After funds needed to support the National Cooperative Highway Research Program (NCHRP) per agreement with the American Association of State Highway and Transportation Officials (AASHTO), the Local Technical Assistance Program, staff salaries, and operating costs are taken out, there remains approximately $500,000 each year for contract research.


RD&T Program Trends
2000000
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FY95
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FY97
FY98
FY99
Fiscal Year

Research Study Panels

Once a study has been identified for funding through the RIC and budget process, a research study panel is formed. The study panel plays a key role in assuring that the study addresses the problem statement and produces a product that will have direct application in either the planning, design, construction, maintenance, or operation of Colorado's transportation system. Each study panel is made up of CDOT personnel, and sometimes interested others, who have expertise in the subject area or have a vested interest in implementing the product of the research. The study panel determines the scope of work that will address the problem statement and then selects the research entity to conduct the research. The entity can be a university, a consultant, another state or federal agency, or CDOT staff. The study panel tracks the research through progress reports and presentations and decides on the changes in the Scope of Work that may be needed. They review and approve the final research report and make recommendations regarding the implementation of the findings.

While it would be impossible to list all the study panel members at this point, the Research Branch would like to take this opportunity to thank the numerous study panel members for their role in, and dedication to, the research process.

The Peer Exchange

In 1998, the CDOT Research Branch underwent its first "peer exchange." The peer exchange, which is mandated by federal regulation, consists of a team of research managers from state DOTs, FHWA , and other research organizations. Colorado hosted members from the Washington State and Pennsylvania DOT, Region

8 FHWA, and the FHWA Colorado Division for its peer exchange. The purpose of the peer exchange is actually a formalized technology transfer activity where RD&T policies and procedures are reviewed with the intent of improving each participating state's overall RD&T management process. Peer exchange members travel to the host state, review policies and procedures, speak with customers, and then make final recommendations to management. Recommended improvements for Colorado included:

•Making adjustments in the membership of the Research and Implementation Council;

•Establishing a cooperative agreement with the University of Colorado at Denver to streamline the contracting process;

•Including an implementation action plan in each research study that also defines success/failure for the plan, and; and

•Establishing a standardized report format that includes an executive summary and implementation recommendation.

All recommended improvements have been accomplished.

University Participation In Research

The University of Colorado at Denver, the University of Colorado at Boulder, Colorado State University, and the Colorado School of Mines have all participated in the CDOT RD&T program over the years. Each has contributed research problem statements and Colorado universities have been selected to conduct the majority of research for CDOT. While the study panels may select whoever they wish to conduct the research for CDOT, the study panels are encouraged to select one of Colorado's universities. When appropriate expertise is available in the universities, their participation provides a good value to CDOT and a training ground for engineering students who may someday contribute to Colorado's transportation system.

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CDOT Library, Research Web Site Administration

Principal Investigator: Person with the primary responsibility for performing and documenting a research study.

Study Manager: A CDOT employee, responsible for keeping the research study moving and servicing the study panel. The Study Manager and Principal Investigator are normally the same person when the PI is an employee within the Research Branch.

Technology Transfer Program

It is the goal of the Technology Transfer Program to promote the utilization of new transportation technology and research findings developed by the CDOT Research Branch and to a lesser degree, research developments made by other state DOT's and national research organizations. Research dollars can be wasted if potential users of research are unaware of the research or are unable to determine its usefulness. Promotion of the new technologies and methods are accomplished with the use of visual aids such as reports, brochures, display boards, videos, training and the use of computer technology such as the CDOT intranet and internet sites.

Publications

The Technology Transfer program publishes the Research Newsletter on a quarterly basis. The Research Newsletter is sent to 750 transportation professionals both in and out-of-state. Technology Transfer also publishes the research status report.

Deployed Research

The Technology Transfer Program is currently tracking the deployment of research that has been completed and the use of this research within CDOT. To see some examples of how research results are being used in the department, see "1996-1998 Completed Research Studies" on page 59.

CDOT Transportation Library

The Technology Transfer Program also provides administration of the CDOT Transportation Library. The CDOT Transportation Library provides library service to approximately 150 customers per month. On average, 30% of the library users come from outside the department. (For more on the Transportation Library, see "Library Services" on pages 12-14.)

Colorado LTAP

The Technology Transfer Program also coordinates administration of the Colorado Local Technical Assistance Program (LTAP) which provides training for Colorado local governments both in current and new technologies and methods. LTAP also offers a "Road Scholar" training program consisting of twelve basic training modules presented over a two-year period. Subjects covered in the two-year program include drainage, safety on the job, road materials, pavements and others. LTAP also publishes a quarterly newsletter. To reach the Colorado LTAP program please call 1-888-848-5827.

Program Manager: Beth Moore

Library Services

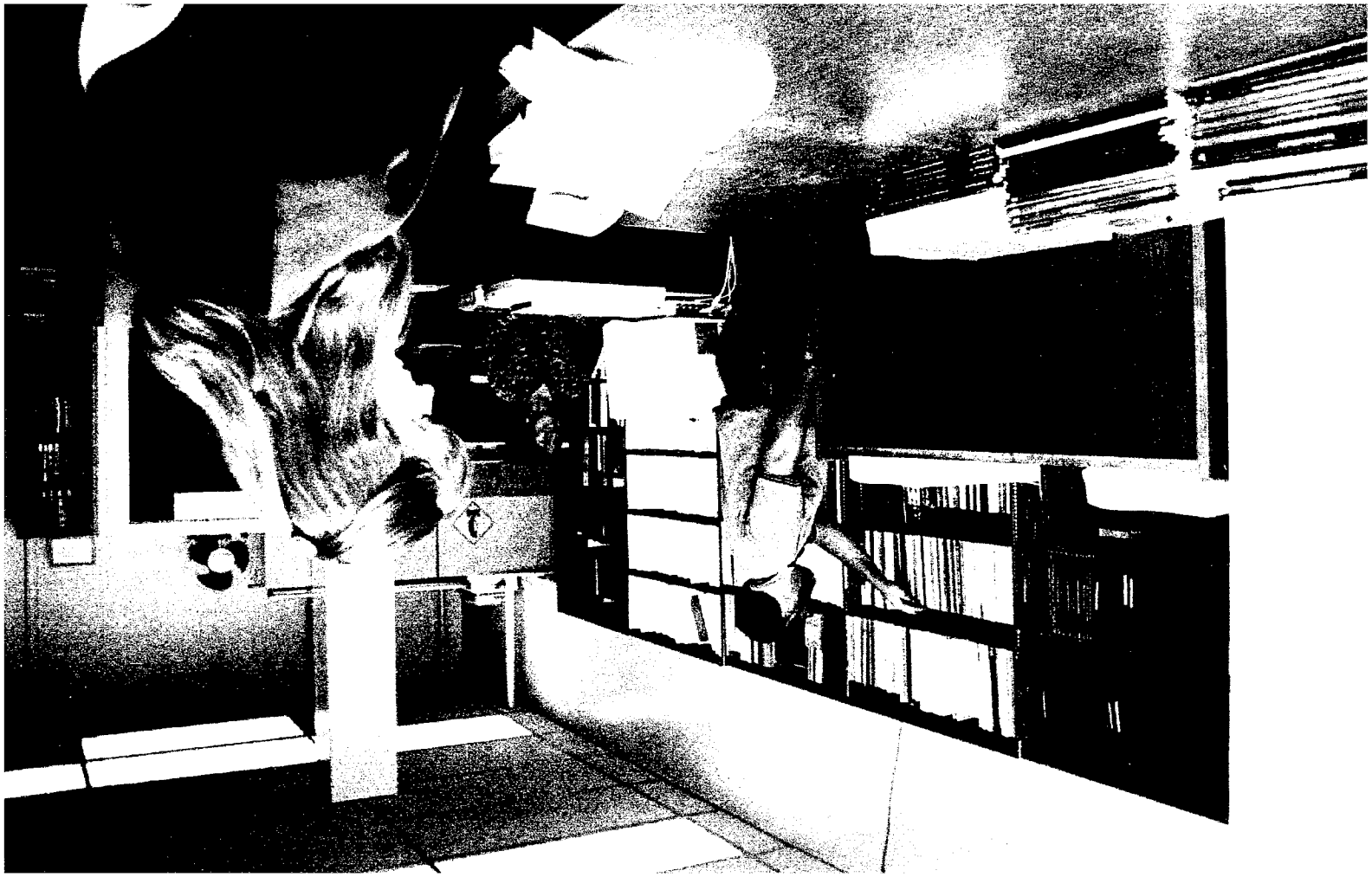
The CDOT Transportation Library has the largest, most comprehensive collection of transportation-related materials in the state. The library, which is open to the public, handles requests for information from all over the world. Circulation of library materials is limited to residents of the State of Colorado. The collection of more than 14,000 publications includes CD-ROMs, audio and video cassettes, periodicals, and slides, as well as books and reports. The in-house collection is supplemented with electronic resources from the Internet and DIALOG. City, county, state and federal employees, transportation consultants and contractors, students and faculty, historians, and attorneys all take advantage of the library's extensive resources.

Web Pages

Research Branch information, including the library, are now on the web. Reaction to the library pages has been very positive. It is expected that the current library pages will soon be enhanced by the addition of an online catalog of the library's collection. The current pages, meanwhile, contain the monthly CDOT Library acquisition lists, an index of video cassettes available for loan, online CDOT electronic documents, CDOT Research Newsletters, an index of CDOT Research Reports, and dozens of links to very useful web sites. The URL is: http://www.dot.state.co/us/business/library/index.htm

Collection Development

Collection development plays an important role in providing timely, accurate information to library customers. Every effort is made to keep up with transportation trends and anticipate requests for materials. The Staff Librarian is always on the lookout for new resources on such topics as partnering, benchmarking, innovative financing, design-build, intelligent-vehicle systems, geosynthetics, and anti-icing. In response to employee requests, a core collection of computer software "how-to" books has been established. CDOT employees can also take advantage of the popular career/personal development collection, which includes selections on



resumes, interviews, grammar, presentations, customer service, conflict resolution, management, and reengineering.

Legislation

The Internet has proven to be extremely useful for tracking federal legislation. It is frequently used to supplement the library's legislative collection, which includes Federal Registers and transportation-related titles of the US Code Annotated and the Code of Federal Regulations. Internet searches of the Code of Federal Regulations, the US Code, the Federal Register, Office of Management and Budget Circulars, the text of various laws, and the status of pending legislation are performed on a regular basis. Impromptu internet training is provided for those who prefer to do their own searches.

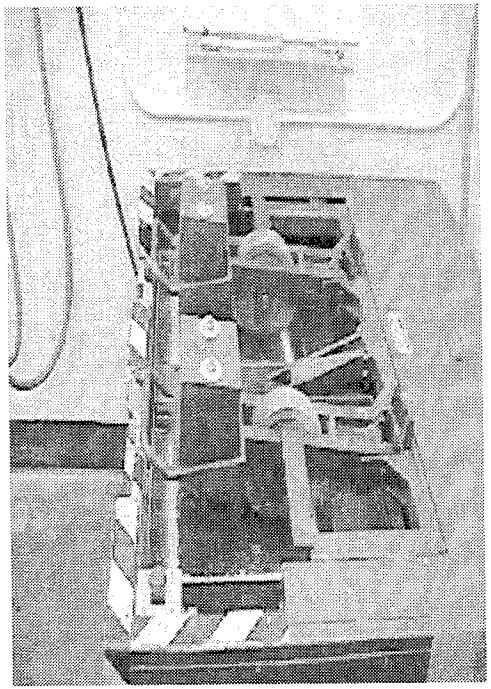
Transportation Research Information Services (TRIS) Searches

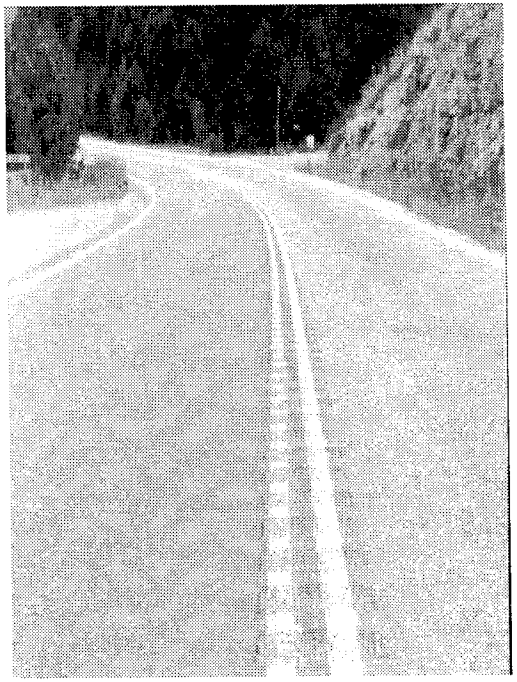
CDOT employees can ask the Staff Librarian to perform customized searches of the TRIS database on any transportation-related topic. TRIS is a bibliographic database maintained and operated by the Transportation Research Board (TRB). It provides international coverage of research-in-progress, journal articles, state and federal reports, conference proceedings, papers, and monographs on virtually all aspects of transportation. Database records contain document titles, publication information, document availability, abstracts, and subject headings. Search results are sent out on e-mail.

Interlibrary Loan/Document Delivery

If the library does not have an article or publication requested by a CDOT employee for use on a specific work-related project, the Staff Librarian will try to obtain the materials through interlibrary loan (courtesy of the Denver Public Library) or a document delivery service. CDOT Library materials are not available for interlibrary loan, but Colorado residents are welcome to borrow materials for two weeks.

Current Research Studies





In-Place Voids

The pavement design process assumes a pavement will consolidate to 4% air voids under traffic loading. The distress of rutting is typically found in pavements which consolidate to less than 3%. Stripping and cracking distresses are more likely to occur in pavements that consolidate to no less than 6% or 7%. Over the years, changes have been made to the pavement design process statewide. Because of the various traffic and environmental conditions in Colorado, these pavement design changes created new distresses in areas of the state which had not previously experienced these type of distress. High traffic in a high temperature area and low traffic in a cold temperature area need different mix designs.

To address the different environmental and traffic conditions when designing asphalt mixes in Colorado a research study was initiated in 1992. Traffic was divided into five categories and four environmental zones were identified. Mixes were designed using varying laboratory compactive efforts that corresponded to the various traffic and environmental conditions in Colorado.

Twenty three sites were identified for evaluation within the various traffic and climatic zones. Over the study period, cores will be taken each year to monitor in-place voids over time. Since pavement design and performance are tied together as they relate to air voids, monitoring the air voids in asphalt pavements over time will help identify mix design adjustments. This will make it possible to "customize" designs based on traffic and environmental conditions. Results from this study will be available in early 2000.

Principal Investigator: Donna Harmelink
Study Manager: Donna Harmelink

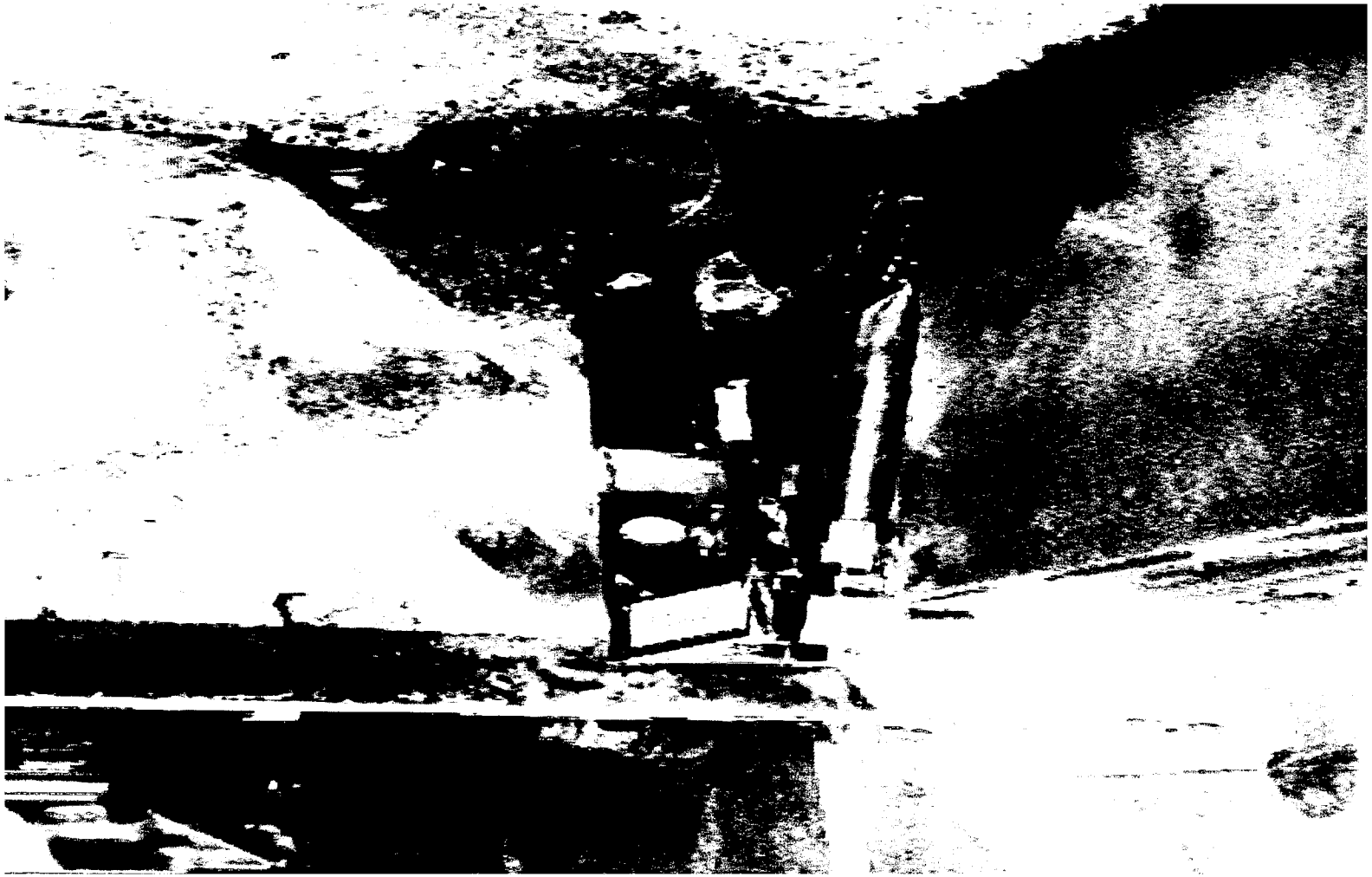
Stone Matrix Asphalt Pavements

In 1994, CDOT constructed its first project using Stone Matrix Asphalt (SMA). SMA pavements are gap-graded, hot bituminous mixes that have been used in Europe for over 20 years. These pavements provide a very durable wearing surface and can be placed in thin lifts (2 inches and under.)

Under this study there are three SMA projects being evaluated. The first, located on SH 119, contained nine evaluation sections. The nine evaluation sections were constructed using different additives and varied construction techniques. This project successfully demonstrated design, production and placement of the European SMA which led to the construction and evaluation of the two next projects. The second project, constructed in 1995, is located in downtown Denver on the Colfax viaduct between Federal Blvd and Osage Street. Asphalt overlays on bridge decks are common in Colorado, however, the typical replacement of the existing asphalt overlay is complicated by the fact that the maximum thickness of the asphalt wearing surface is limited to 4 inches. Since SMA pavements are durable, and can be placed in thin lifts, the decision to place an SMA on this bridge was considered to be the most cost-effective solution. The third project, constructed in 1996, is located on I-70 in Region 3. This project contained the mix design that had shown the best performance during evaluations on SH 119.

Preliminary results on the SH 119 project indicate that the severity of cracking and raveling found in each evaluation section is directly related to the amount of cracking found in the evaluation section. (The more cracking and raveling the section has the more severe the cracking and raveling is.) The section that has the least amount of cracking on SH119 contains the same additive that was used on the Colfax bridge and on I-70. Both of these projects are performing well. None of the projects have demonstrated any significant amount of rutting. The final evaluation on this study will be completed in Fall 1999.

Principal Investigator: Donna Harmelink
Study Manager: Donna Harmelink



Use of Pre-Compaction Technology for Better Pavement Performance

The longitudinal joint between asphalt mats has typically been a major area for pavement distress. Compaction of the unconfined edge at the joint is difficult to obtain, resulting in lower densities in the joint area than densities typically found in the remainder of the asphalt mat. Lower densities at the longitudinal joint increase the susceptibility to permeability which in turn increases the deterioration of the pavement through cracking and raveling.

In 1994, CDOT participated in a national study initiated to evaluate longitudinal joint construction. Under this national study seven longitudinal joint construction techniques were used in Colorado. In 1997, CDOT implemented a revised standard method for constructing longitudinal joints (1" vertical step at the top of joint with a 3:1 taper) based on the preliminary results from this study. This national study will conclude in 1999.

In 1997, a research study was initiated to evaluate the "Joint Maker System." This system is being marketed as a method that will pre-compact the longitudinal joint to within 2% of the densities found in the center of the mat. The intent of this study is to evaluate the pre-compaction technology and not to evaluate the "Joint Maker System" only. If this technology demonstrates that higher densities at the longitudinal joint can be achieved and improves the pavement performance, CDOT's current practices can be modified to incorporate provisions for obtaining higher densities in longitudinal joint areas. Results from this study will be available in December 2000.

Principal Investigator: Donna Harmelink
Study Manager: Donna Harmelink

This "Joint Maker" is installed on the edge of the paving machine.

PCCP Texturing Methods

What are the impacts of various surface textures on the frictional characteristics, noise properties and overall ride quality of concrete pavements? What is the most cost-effective surface texture that provides adequate friction and at the same time is quiet? Is it the tinned or the sawed textures? How about longitudinal vs. transverse, randomly spaced vs. uniformly spaced and more importantly micro vs. macro textures?

In an attempt to answer these questions, CDOT Research initiated a study to investigate the pros and cons of various surface textures and to develop guidelines and specifications for future construction. Altogether, nine test sections with varying textural characteristics were established on I-70, eastbound approximately 60 miles east of Denver, between mileposts 335-338. Data acquisition included frictional data using both the ribbed and the smooth tire at three different speeds of 40, 50 and 65 miles per hour. Noise data were acquired at three locations: inside the test vehicle, behind right rear tire and next to the right shoulder.

The interim results of this study revealed the following:

·The smooth-tire is more sensitive to changes in the surface texture than the ribbed- tire and its use over the ribbed tire is recommended;

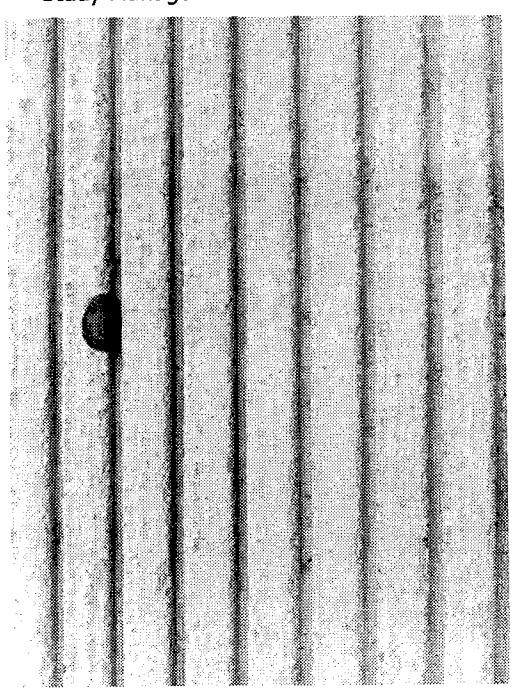
·Longitudinal macro and micro-texture were the most quiet surfaces based on the sound pressure levels taken at the shoulder, inside the test vehicle, and at rear tire; and

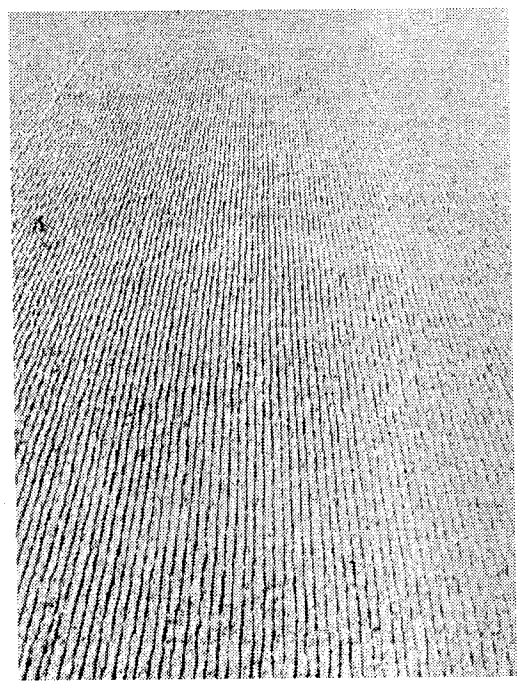
·The use of the sand patch test as a texture-depth-measuring device is highly recommended. Excellent correlation was achieved between the sand patch test and the smooth-tire skid numbers.

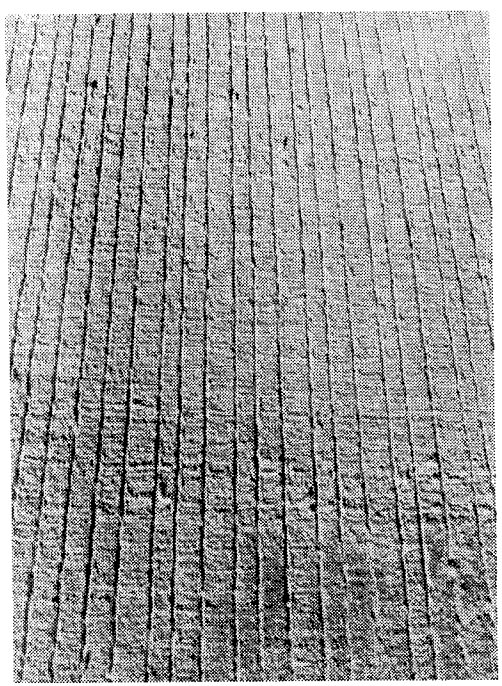
Pictured from left to right are three texturing techniques: sawed, 1/2" uniform spaced tining, and random spaced tining

CDOT has already adopted the longitudinal tinning as a preferred method of texturing concrete pavements. The longitudinal tinning is less expensive to install and produces much less noise. A final report for this study will be out by the end of 1999.

Principal Investigator: Ahmad Ardani
Study Manager: Ahmad Ardani







SHRP - Seasonal Monitoring Program Update

Colorado's SHRP monitoring site is one of 64 sites across the country that is being monitored on a monthly basis by the SHRP Regional Contractor. This experiment will evaluate and monitor the impact of seasonal variations in moisture and temperature on pavement response. The SHRP seasonal monitoring program will attempt to establish a relationship between pavement response and deflection measurements taken at different times of the year for a given climatic zone. A variety of data is being acquired at this site on a monthly basis, it includes the following:

·Moisture and temperature of the subgrade at 12-inch intervals;
·Ambient temperature;
·Frost penetration depth at 2-inch intervals;
·Rainfall and ground water table depth;
·Falling weight deflectometer data (FWD); and
·Pavement surface elevation.

Work is currently under way to establish a correlation between the back-calculated resilient modulus using the FWD and the laboratory-measured resilient modulus. The expected goal is to use the back-calculated values for characterization of subgrade, base and the pavement surface. The ultimate goal of this program is to rationally use the acquired deflection data for evaluation, analysis and design. This project is ongoing.

Principal Investigator: Ahmad Ardani
Study Manager: Ahmad Ardani

Taking samples from one of Colorado's SHRP seasonal monitoring sites

SHRP - AASHTO Task Force on SHRP Implementation Lead State Program

The AASHTO Task Force on SHRP Implementation developed the concept of "lead state" in order to facilitate the implementation of high-payoff SHRP technologies among states. A lead state is a transportation agency that has gained expertise by working closely with a particular SHRP technology. An AASHTO designated lead state will transfer its knowledge of a technology and share its proficiency with others in order to advise new users of potential benefits and ultimately to shorten their learning period.

Altogether, seven key high payoff products have been designated by AASHTO for lead state implementation. They are as follows:

·Innovative Pavement Maintenance Materials: Colorado, Idaho, Iowa, and Pennsylvania;
·High Performance Concrete: Missouri, Nebraska, New Hampshire, Texas, Virginia, and Washington;
·Superpave: Indiana, Maryland, New York, Texas, and Utah;
·Anti-Icing/Roadway Weather Information Station: Colorado, Iowa, Minnesota, Nevada;
·Concrete Assessment and Rehabilitation: Missouri, Virginia;
·Preventive Maintenance: Georgia, Michigan, Minnesota and Texas; and
·Alkali Silica Reactivity: Pennsylvania, North Carolina.

Contact: Ahmad Ardani, Innovative Pavement Maintenance Materials
(Research Branch)
Wayne Lupton, Anti-Icing/Roadway Weather Information Station
(Region III Maintenance)

SHRP - SPS-4 Experiment, Joint Geometry Evaluation, SH 287 South of Lamar

The SPS-4 experiment was originally designed to examine the effects of sealed vs. non-sealed joints on the performance of rigid pavements. The study panel modified this experiment in order to examine the effectiveness of various joint geometry as well as sealed and non-sealed joints. CDOT installed twenty test sections on SH 287 near the Oklahoma/Colorado state line. The width of the joints installed for this study were either 1/8, 1/4, and 3/8 inches, both with and without sealant materials.

The results of this study revealed that the single cut 1/8" joints were as effective as CDOT's standard double cut 3/8" joints. The only difference was that the narrower joints were less labor-intensive and required much less sealant materials. Arizona has already adopted this new joint design, saving 57 cents per linear foot of joint. This equates to an approximately 2 million dollar savings for every 100 miles of 2-lane concrete pavement. CDOT has also adopted this new joint design and is well positioned to realize a substantial savings for years to come.

Principal Investigator: Ahmad Ardani
Study Manager: Ahmad Ardani

SHRP - Joint Resealing Experiment, I-25 (MP 260 -261), Contract H-106

In order to address the deficiencies of current joint resealing materials, designs, and practices, the Strategic Highway Research Program (SHRP) initiated contract H-106. In this experiment, researchers will conduct a field performance evaluation of various joint sealant materials, designs, and installation procedures. A total of 32 test sections were installed, using a variety of joint sealant materials, of which 16 were replicates.

Three different sealant configurations were used for this study, the conventional recessed configuration used for every sealant material, and the flushed and overband configuration which were used only for the hot-poured sealants. The evaluation consisted of visual inspection on a foot-by-foot basis. The primary distresses looked for and recorded were adhesion loss, cohesion loss, spalling, and stone intrusion.

One product, Dow 888, out-performed all the other sealants. For the hot-poured sealant, Koch 9005 using the recessed and overband configuration was among the best performing. The final results of this study will be available in 1999.

Principal Investigator: Ahmad Ardani
Study Manager: Ahmad Ardani

CDOT Maintenance staff cut existing joints for the joint resealing experiment

SHRP - SPS-2 Experiment, Study of Structural Factors in Rigid Pavements

The SPS-2 experiment was developed as a coordinated national experiment to address the effects of various environmental and structural factors on the performance of rigid pavements. The factors studied under this experiment include concrete thickness, concrete strength, base type, lane width, drainage and environmental factors such as temperature, moisture and soil type. CDOT participated in this national study by constructing 13 different test sections on I-76, approximately 18 miles east of Denver. These test sections which are being evaluated under the SHRP program until year 2007 include the following combination of factors:

·Concrete thickness at two levels of 8 and 11 inches;
·14-day flexural strength of 550, 650 (state standard) and 900 PSI;
·Non-draining bases: lean concrete base (LCB) and dense graded aggregate base;
·Draining bases: permeable asphalt treated base with edge drain and transverse interceptor drain; and
·Lane width at two levels of 12 and 14 inches with untied shoulders.

Virtually no distress is evident in any of these sections at this time. Profile data indicates virtually no change in the ride quality for the sections. However, analysis of the deflection data reveals variations in load carrying capacity. Both widened lane sections and the state standard section with tied concrete shoulder exhibited lower deflections than those with untied shoulders. At present, no difference can be identified between the deflection magnitude of the widened lane and the state standard sections. Deflections are higher for the 8-inch sections, reflecting the relatively lower structural capacity of these sections. LCB sections, particularly in conjunction with higher strength mixes (14-day 900 psi) show higher deflection, indicating the presence of greater slab warping under these conditions.

One interesting observation, friction data collected in June of 1998 by CDOT indicates a significant difference between the 550 and the 900 psi test sections. The average friction numbers for the 550 psi sections is 51, while the 900 psi section's average is 34. The pavement surface of the 550 psi sections shows noticeable wear in the wheel paths exposing the aggregate, while the 900 psi sections exhibit very little surface wear. Future evaluation will determine if the 550 psi mix (lower cement content) in fact results in a shorter performance life, or improved friction quality.

Principal Investigator: Ahmad Ardani
Study Manager: Ahmad Ardani

Cracking in Bridge Decks: Cause and Mitigation

Cracking in bridge decks has become a serious concern in recent years. These cracks extend though the deck and allow moisture and deicing chemicals to reach bridge components that were previously well-protected by the deck. Extensive bridge deck cracking poses a serious risk to the durability of the entire bridge, increasing the maintenance costs and shortening service life.

This research project will be completed in two phases. The first phase, already completed, looked at the identification of materials, construction, and design factors that influence deck cracking. The study also sought to propose ways to improve existing concrete mixes to reduce the severity of deck cracking. Recommendations of the first phase support the use of Type II cement, reducing the cement content in concrete and the use of larger amounts of Type F fly ash in silica fume concrete. It recommended that CDOT use these modified concrete mix designs and evaluate their resistance performance in the laboratory first and then eventually in the field on a trial basis.

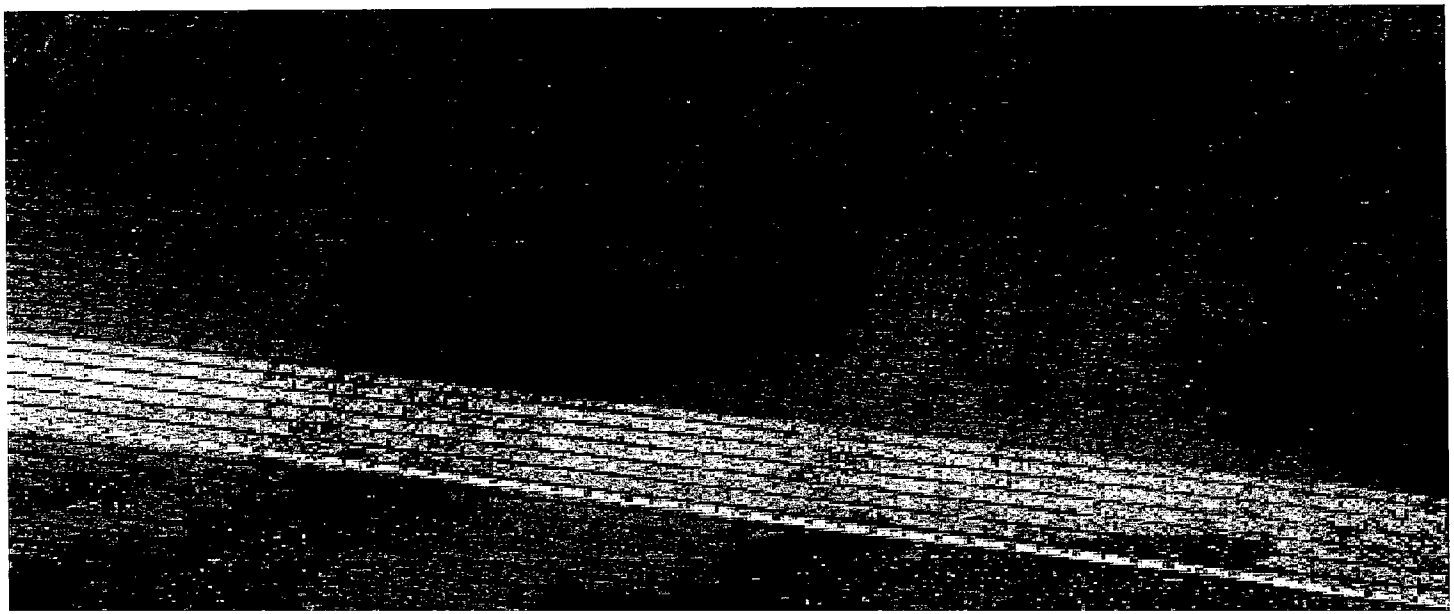
In phase two of the project, currently underway, the researchers have found that the deck concrete curing procedure currently in use by CDOT is a step forward and effective for the control of deck cracking. However, the current database is limited and additional information on the performance of newly constructed bridge decks needs to be gathered.

As a result of this need, seven newly-constructed bridge decks in the metro Denver area have been selected and will be crack mapped by CDOT-Research to assess the severity of the deck cracking problem with the concrete mixes currently being used by CDOT. The material, construction, and weather records at the time the deck was cast will also be reviewed and incorporated into the database. It is expected that the results of this

Bridge deck cracking, as shown here, can shorten a structure's life span

study will assess the performance of current CDOT bridge deck concrete mixes and determine what outstanding bridge deck issues need further study.

Principal Investigators: Benson Shing, University of Colorado at Boulder and Naser Abu-Hejleh
Study Manager: Naser Abu-Hejleh



Evaluating Performance and Design Assumptions of a Mechanically Stabilized Earth (MSE) Wall

For this particular project at 38th and Fox in metro Denver, a new, innovative retaining wall system was constructed. This MSE wall, developed by CDOT and the now defunct Colorado Transportation Institute, was built to support the traffic leaving I-25 north and connecting to I-70. The funding from this study will be used to evaluate the performance and the design assumptions of this MSE wall.

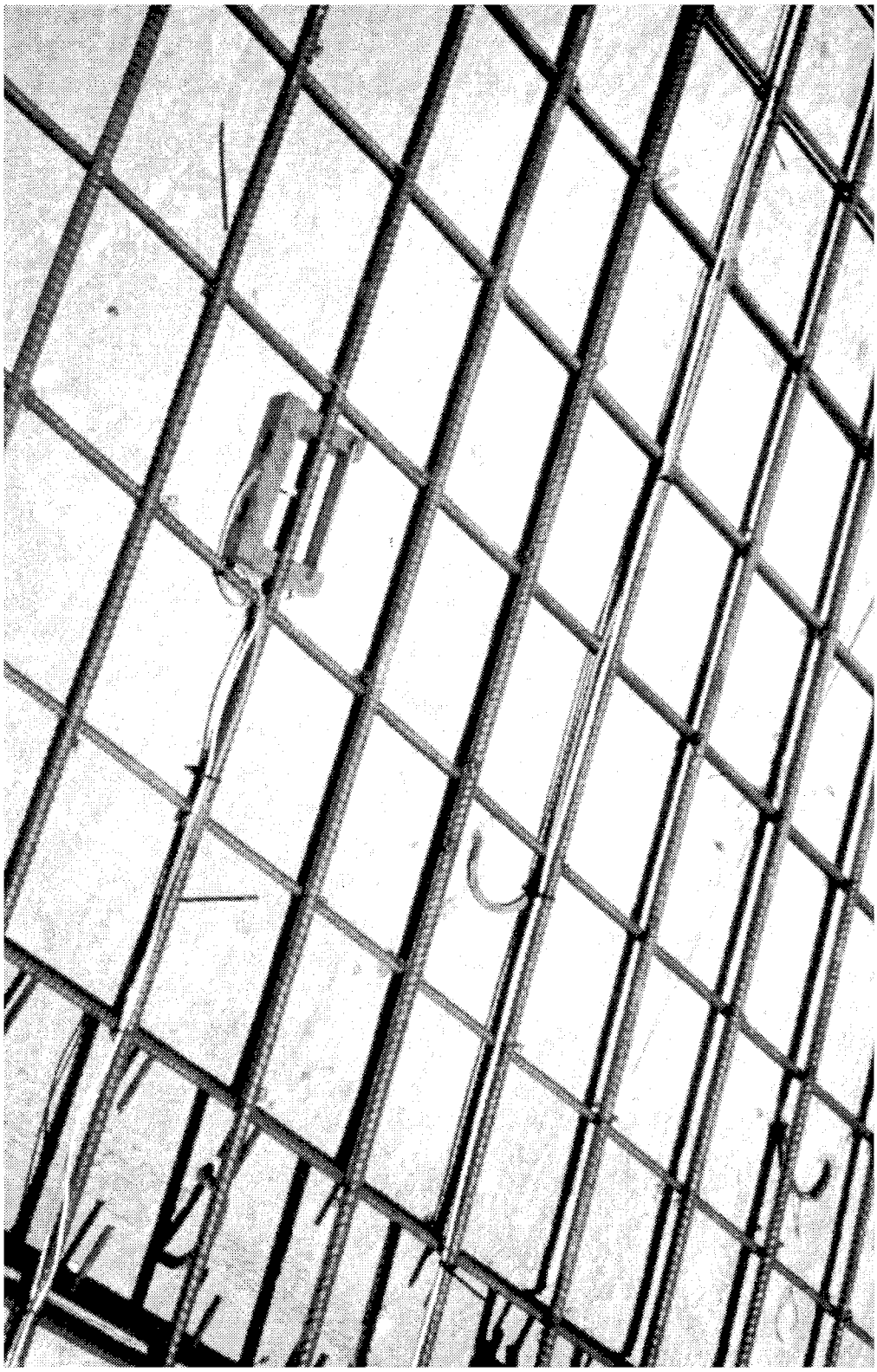
For this MSE wall, full-length panels were placed at specified amount of back batter and mounted in place with a couple feet of flow fill on the front and back. These panels are backfilled behind them with rebar tiebacks and welded wire fabric inserted in the backfill. The loosening of the flexible rebar bolts limits the earth pressure on panels, and allows wire fabric reinforced backfill to take the load.

The MSE wall was instrumented at two locations with inclinometers and strain gages. Additional monitoring of the wall included survey measurements to observe vertical and horizontal movements. Wall movements and strains were monitored throughout the construction and continued until the entire project was completed.

Currently analyses are being performed on the collected measured data and are being compared to the measured stresses and movements with predictions from the current design assumption. This comparison will provide important conclusions regarding the future design, construction, and use of this type of wall. If shown to be successful, the MSE wall can save money, resources and time in the construction of future projects. It is estimated that this design saved the project up to $500,000.

Principal Investigator: Jonathan Wu, University of Colorado at Denver
Study Manager: Naser Abu-Hejleh

This innovative MSE wall, one of the first of its kind to be



Calcium Nitrite Corrosion Inhibitor

As current practice, epoxy-coated steel is being used by CDOT as the primary corrosion protection system for Colorado bridges. In some cases where severe steel corrosion conditions are expected, calcium nitrate, a chemical added to the concrete mixture, may provide supplemental corrosion protection. Calcium nitrite has been studied as a corrosion inhibitor and set accelerator for over twenty years. Test cells, constructed by CDOT Research staff, with a 3% sodium chloride solution have shown no electrochemical activity in two years of ponding. Preliminary findings indicate that calcium nitrite could be used as a possible alternative to epoxy-coated steel in bridge decks. Benefits would include a shorter development length, ease of handling, less storage constraints than are necessary with epoxy coated steel and a reduced cost.

This study is evaluating a bridge deck constructed at Kettle Creek near Colorado Springs with half black steel with calcium nitrite added to the concrete and half epoxy-coated steel. Corrosion monitoring devices were installed in the deck and will be monitored at two-to-three year intervals. At present, two corrosion activity measurements have been collected and no corrosion activity is occurring. Interestingly, preliminary results that have not been verified by CDOT, show the corrosion protection abilities of the concrete mixed with calcium nitrite have increased since construction.

Research has prepared a technical note on corrosion protection of embedded steel in Colorado on existing and new concrete bridges. This technical note was prepared to provide information and guidance to CDOT bridge designers.

Principal Investigators: Naser Abu-Hejleh and W.R. Grace
Study Manager: Naser Abu-Hejleh

This instrument was installed to measure

Reinforced Soil Abutment and Piers Demonstration

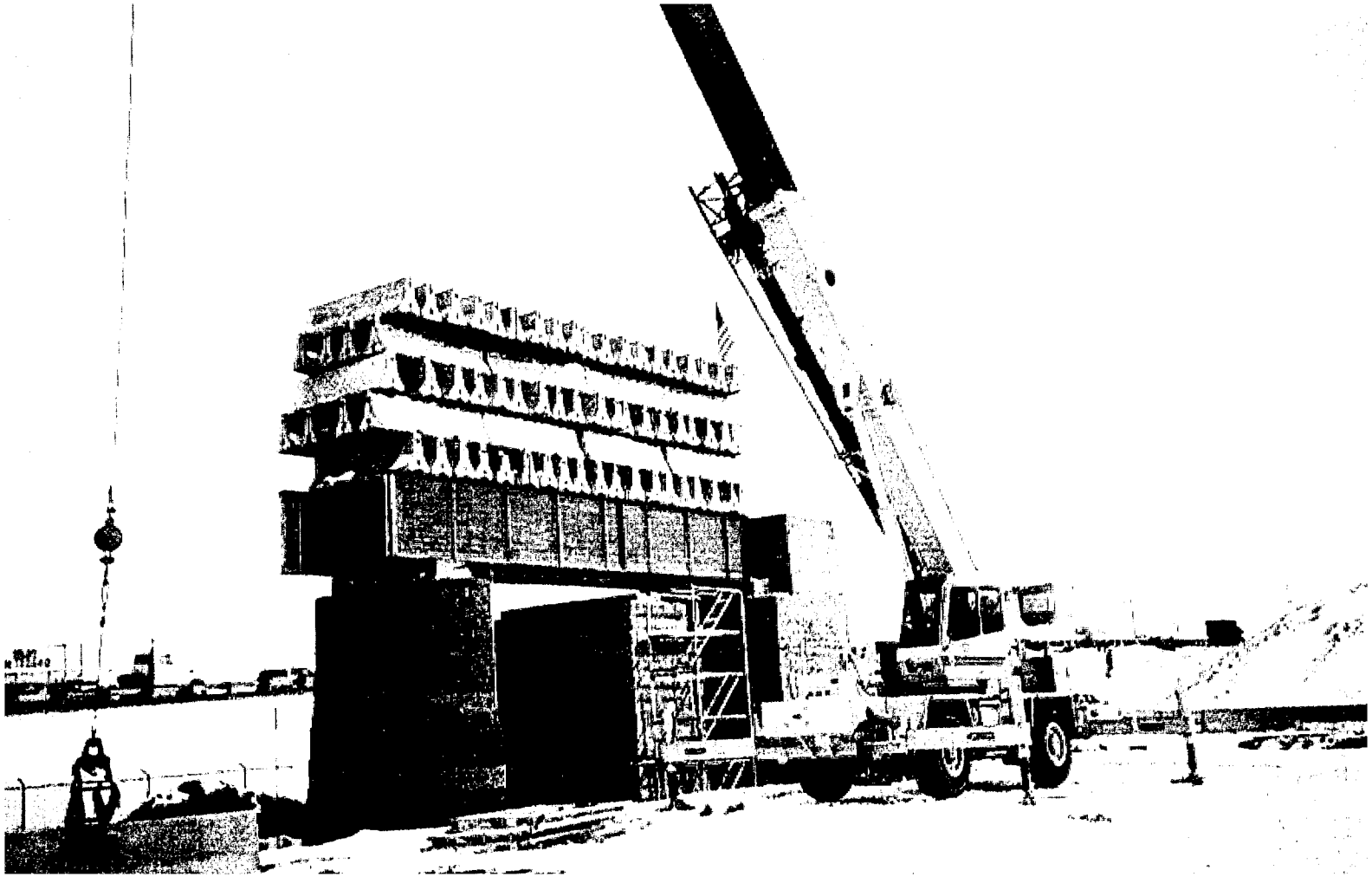
In this study, two geosynthetic-reinforced soil bridge piers and one bridge abutment were constructed, seeking to demonstrate the cost and functionality of geosynthetic reinforced backfill technologies as bridge supports. The structures were constructed with a "roadbase" backfill and internally reinforced with layers of a woven geotextile. Reinforced, dry-stacked hollow-cored concrete blocks were used as facing.

The west pier and the abutment structures were load tested and the movements of the facing and reinforcements were monitored. The satisfactory performance of the bridge abutment cleared the way for the design and prediction of the movements of geogrid reinforced abutment in the new Founders/Meadows bridge over I-25. This bridge is the first of its kind in the United States, and one of the many advantages of this structure is that it allows for more traffic space along I-25.

The top four feet of the west pier has moved outward. This behavior alerted our engineers to the importance of the concentrated surface loading near the edge of mechanically stablized earth walls. In addition, it supported the need for grouting the top four blocks, currently in CDOT specifications. A CDOT Research team conducted a field investigation and geotechnical analyses and identified the possible causes of this excessive movement.

Finally, the structures will be dismantled and removed, during which a forensic analysis of the internal conditions of the blocks, fabric, and backfill soil will be conducted. Additional field and lab testing will be performed. The durability of geotextile fabric buried in the structures for around thirty months will be evaluated. The measured structures movements, internal conditions, and material properties will be used as a reference by CDOT engineers when designing similar structures.

Principle investigators: Phase I – Jonathan Wu, University of Colorado at Denver, Phase II and III - Naser Abu-Hejleh
Study Manager: Naser Abu-Hejleh



The Performance of the Reinforced Soil Abutments of Meadows/Founders Bridge Over I-25 at Working Loads

The construction of a shallow strip spread foundation supporting the bridge abutment and placed directly on a geogrid reinforced earth wall is the subject of this evaluation. The geogrid-reinforced foundation is expected to not only provide bridge support, but reduce bridge approach settlement. The design of this bridge is overly conservative due to the fact that it is the first of its kind in standard highway practices and the critical importance of this structure to support six lanes over I-25.

Bridge abutments directly supported on the reinforced soil mass are more economical and were used in this project because the projected settlements of the foundations and the reinforced soil mass are small. This reinforced soil structure allowed for more space along I-25 and less differential vertical movement between the bridge structure and roadway approach.

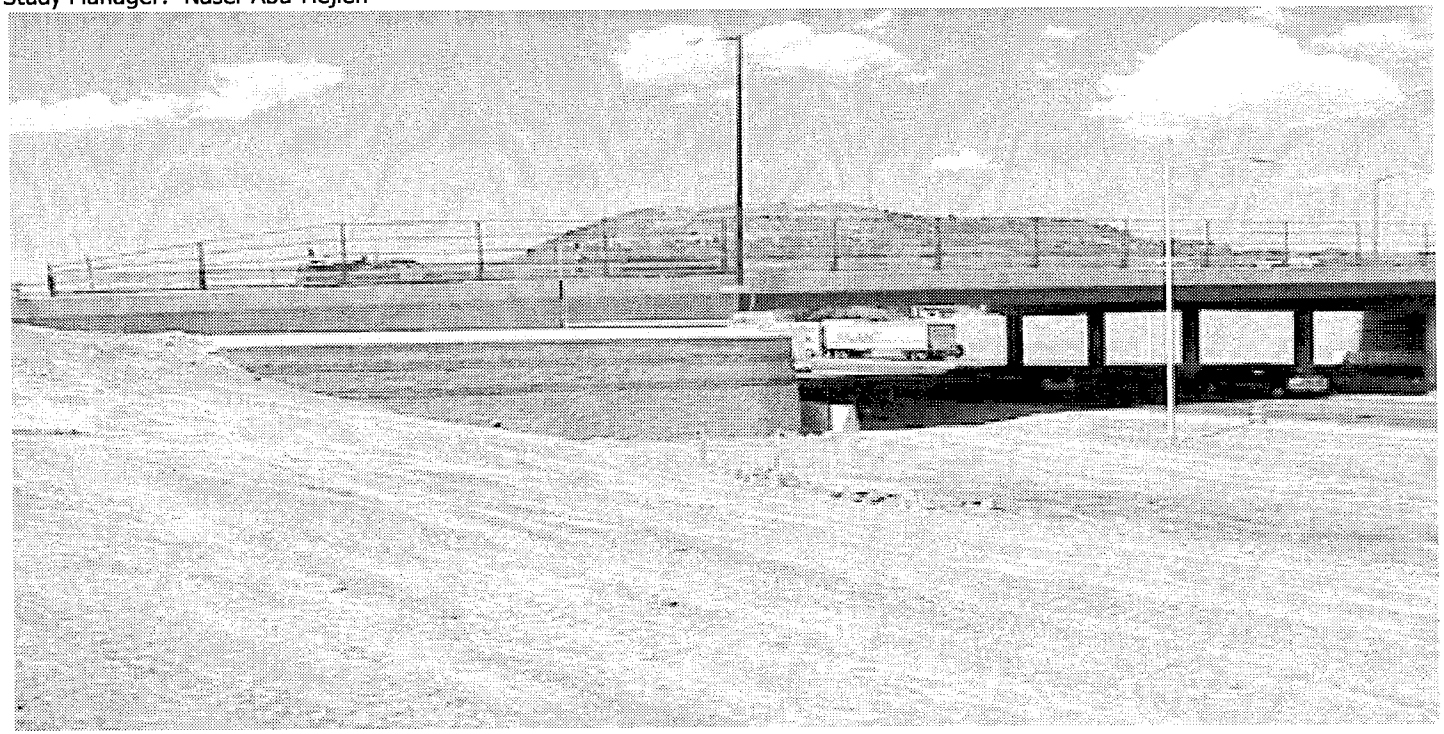
The movements and stresses experienced by this structure under working loads at various stages will be monitored at critical locations until the structure's long-term movements cease. Monitoring instruments include pressure cells, strain gages, settlement transducers, and an inclinometer with magnetic plates to measure vertical movement. The collected performance data will then be analyzed to achieve three objectives.

The first objective will be to compare the measured stresses and movements experienced by the structure under typical service loading conditions with prediction from current design procedure. The next objective will be to monitor the effectiveness of the reinforced backfill behind the abutment and the sleeper foundation in reducing bridge approach settlement. The third and final objective will be to assist the development of a verified and calibrated computer model that can be used to later analyze and design critical mechanically

This reinforced soil abutment was constucted for the Founders/Meadows bridge over I-25.

reinforced earth retaining walls under service load conditions. When complete, this study will provide conclusions regarding the future design, construction and use of reinforced soil abutments in Colorado.

Principal Investigator: Naser Abu-Hejleh
Study Manager: Naser Abu-Hejleh



Backfill of Earth Retaining Walls: Design Parameters and Construction Specifications

The prevailing specifications for the construction of reinforced soil retaining walls require that the backfill be a Class 1 material. However, field experience has indicated that many reinforced soil retaining walls constructed with a backfill not meeting Class 1 criteria have shown satisfactory performance characteristics. Class 1 materials encompass a fairly wide range of different high-quality soils. While most Class 1 soils are suited for construction of reinforced soil retaining walls, it is conceivable that some Class 1 soils may not be suitable backfill material.

This study has three objectives. The first is to perform basic cost optimization between construction specifications and the design parameters of earth retaining walls, where construction acceptance is based on existing standard soil tests, and design is based on existing models. The second objective is to develop backfill selection guidelines and construction specifications for earth retaining walls in general and for reinforced soil retaining walls in particular. Various backfill selection criteria will also be developed for retaining walls with different performance tolerances. The construction specifications should allow the design parameters to be efficiently verified in construction. The final objective is a preliminary feasibility study of employing reclaimed asphalt pavement (RAP) as a backfill for retaining walls. The possibility of using RAP for the construction of retaining walls is highly desirable since Colorado has an abundant supply of this material.

When concluded, this study will provide the necessary backfill soil information needed for the safe and economical construction of earth retaining structures. Many internally reinforced soil projects constructed in Colorado have resulted in significant savings. Since the backfill is the most expensive component of mechanically stabilized earth structures, even more savings are expected from this study. It is also expected that there will be better utilization of a wide range of Colorado soils and aggregates instead of the current limit of using only high quality granular soils meeting the backfill Class 1 specifications.

Principal Investigator: Jonathan Wu, University of Colorado at Denver
Study Manager: Naser Abu-Hejleh

Evaluating Bedrock Bridge Scour Potential

Bridge foundations on sedimentary bedrock are currently designed by either treating the bedrock material as if it were noncohesive, as in the current FHWA guidelines, or using some other qualitative method to reduce the foundation depth to a more reasonable figure. A rational method is needed to quantify the scourability* of various bedrock materials, and thus have a more quantitative method of determining required foundation depths.

This study will establish procedures to quantify the scourability of sedimentary bedrock and other cohesive and consolidated materials. The procedures will then be verified though laboratory testing.

*Scour is the removal of soils and rocks from streambeds and streambanks by the erosive action of flowing water that can result in bridge failure.

Principle Investigator: Steve Smith, Woodward Clyde
Study Manager: Naser Abu-Hejleh

Effect of Magnesium Chloride on Asphalt Pavements - A Quick Study

Anti-icing and deicing for snow and ice control using magnesium chloride have been used in Colorado for the last five years. And while successful for their intended purpose, these chemicals have been suspected to affect the bonding of overlays, crack filling, and permanent pavement marking. This quick study was authorized to investigate any potential problems associated with magnesium chloride.

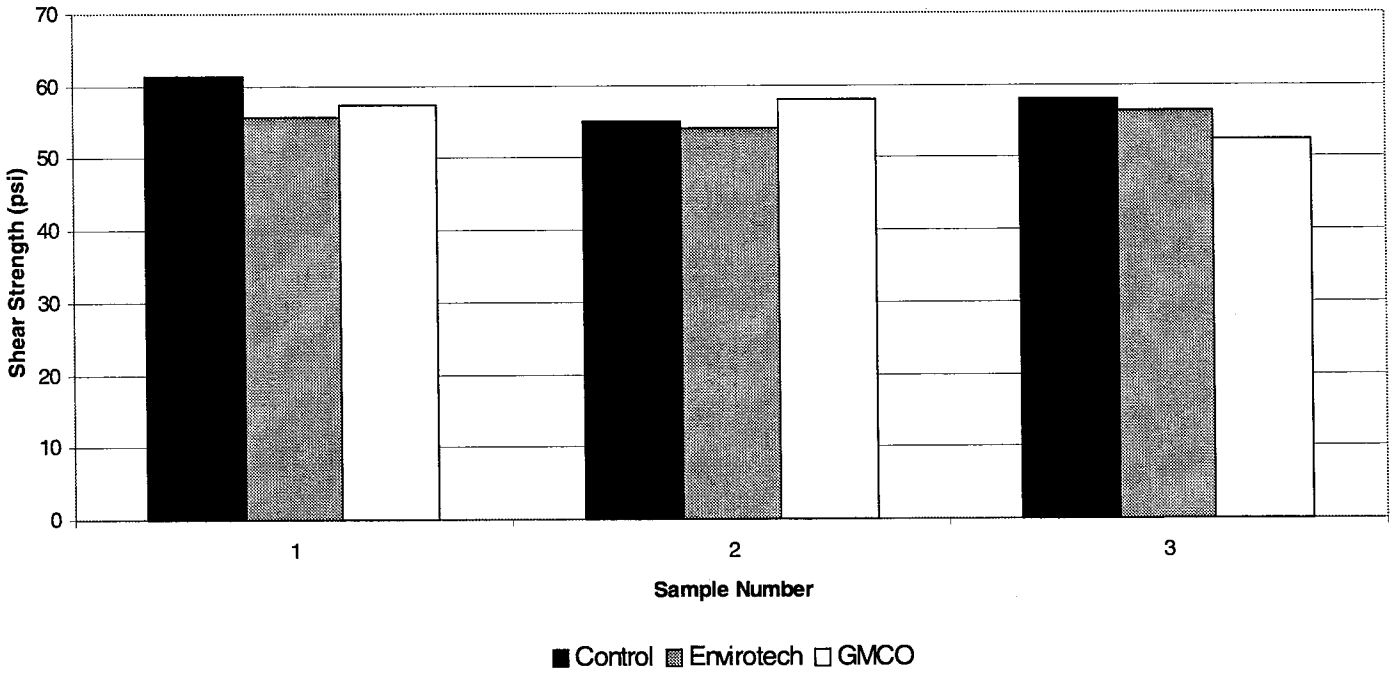
A survey of other states revealed that these problems either do not exist, or the problems have not been attributed to the use of chemical deicing/anti-icing. Although most respondents had little or no experience with magnesium chloride, it is reasonable to assume that other chemical deicing substances, such as calcium chloride or sodium chloride, would have similar effects because they are similar in chemical characteristics. A laboratory experiment was conducted to measure the shear strength of two-layer laboratory compacted samples. One layer of these samples was immersed in representative solutions of magnesium chloride for three days, and subsequently "overlaid" with the second layer. Control samples were not treated. The tests were conducted for two asphalt mix designs and the two magnesium chloride suppliers (Envirotech and GMCO) that are used in Colorado. In all, a total of 18 samples were tested for shear strength. As can be seen in the graph, there are only minimal differences in shear strength. The study will be continued to investigate bond properties of field cores from highway segments where magnesium chloride had been used prior to overlays.

In addition, there is currently no indication that magnesium chloride has had a negative effect on pavement markings. CDOT is, however, going to do additional evaluations and will establish a test site for pavement markings and the effect that magnesium chloride may have on them.

Principal Investigator: Werner Hutter
Study Manager: Werner Hutter

This graph indicates that there is very little difference in the shear strength of the pavement cores after exposure to magnesium chloride

Shear Test for Mix No 2 (326)



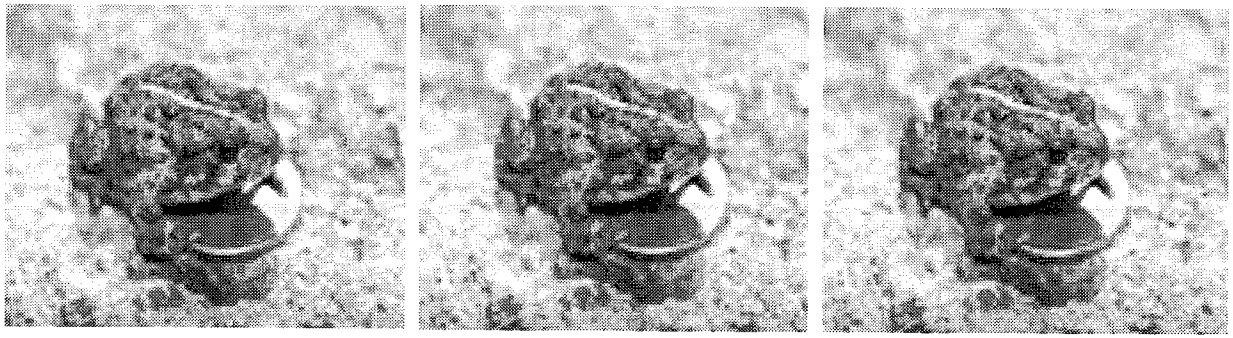
High Altitude Snow and Ice Control: Effects on Water Quality

Snow and ice control at high elevations in Colorado is a unique problem, requiring a balance of safety, environmental concerns, and commercial interests. This three-year study is being conducted to investigate the effects of magnesium chloride deicing material on plant life and water quality.

Of particular concern is the survivability of the Boreal Toad (see below), a species that is normally indigenous to northern regions. The research is 75% complete, with a final report to be published in the summer of 1999. All data to date indicate that the amount of deicing chemicals at concentrations used at this time have no deleterious effects on either plant or aquatic life.

Some concern had been voiced after the first year of the study in regard to heavy metal constituents in the deicing material, but at the expected dilution rates, there appear to be no further contamination problems.

Principal Investigator: William Lewis, Western Environment Analyst
Study Manger: Werner Hutter



Boreal Toad.

Effects of Cattails on Wetlands

Wetland mitigation is a federally-mandated program for highway projects. CDOT uses considerable funds to design, build, acquire water rights, and to purchase nursery grown plants for wetland mitigation. Unwanted cattail invasion compromises this effort and puts an additional financial burden on CDOT when the nursery grown plants are overrun by cattails.

This study investigates the conditions under which a balanced growth can be established, by assessing the various water depths that are enhancing cattail expansion in addition to the evaluation of other variables, which could affect growth patterns. Data analysis from field experiments will result in the development of a statistical model, which will facilitate the design of wetlands.

Principal Investigator: David Cooper, Colorado State University
Study Manager: Werner Hutter

Cost of Sanding

The traditional method for snow and ice control using a sand and salt mixture has been the mainstay of providing safe passage for Colorado motorists. Recent use of chemical deicing has been limited due to the much higher cost of these materials even though they are very effective under most conditions.

This research work will examine the complete cost of sanding. Many aspects of the sanding operations are currently not included in the cost figures but impact the maintenance budget. They include, but are not limited to, issues concerning accelerated pavement wear, paint stripe deterioration, increased labor time associated with sand removal in guardrail locations and drainage maintenance. A cost/benefit analysis could potentially prove the chemical deicing materials to be competitive.

The insurance industry has expressed a desire to participate in this study. Their concerns relate to windshield breakage, and paint damage to vehicles. They estimate that annual claims for windshield breakage are about $30 million dollars in Colorado.

Although the use of sand and salt will probably continue, the increased use of alternate deicing materials will surely impact the quantities applied to our roads.

Principal Investigator: N.Y. Chang, University of Colorado at Denver
Study Manager: Werner Hutter

Hamburg Rut Tester Implementation

In 1991, Colorado was selected to demonstrate the European asphalt testing equipment. Since that time Colorado has become a pacesetter in asphalt testing across the country. The European equipment is considered the state-of-the-art and is used for validating Superpave.

During the 1994 and 1995 construction season, Hamburg tests were performed on project-produced mix on most interstate projects in Colorado. In 1996, Hamburg testing was performed on 100 and 125 End Point Stress (EPS) mixes as well as all of the Superpave mixes. The Hamburg rut tester is a device that allows true performance testing of the various project mixes in an accelerated fashion.

Since 1994, the Hamburg testing equipment has only been used for project bonuses. No correlation between the values obtained from the Hamburg testing equipment and field performance has been made.

In the fall of 1998, in-place cores were obtained from existing pavements to evaluate long-term field performance. The pavements selected were from projects that had had Hamburg testing on project-produced material during construction. Information from the project produced mix and the cores will help develop a correlation between Hamburg tests on project mix and actual field performance.

The information obtained through this research will also be used to determine the proper test temperature for performance prediction. This performance prediction allows the European equipment to be implemented into the Colorado asphalt mix program, and will supplement the SHRP mix design and evaluation methods which were also implemented at the same time.

Principal Investigator: Skip Outcalt
Study Manager: Skip Outcault

Evaluation of Slope Stabilization Methods

State highway 40, west of Berthoud Pass, as we see it now was built in the early 60's. Standard practices for erosion control (in effect during the 60's) were applied to the cut and fill slopes created during construction. These slopes consist of highly erodible and unstable sandy soils mixed with a large quantity of rocks, which vary in size to over two meters in diameter. The snowmelt runoff, combined with the severe rain storms of spring and summer, wash away the top layer of soil and prevent vegetation from establishing itself.

Enhancement funds became available for the 1995 construction season to rehabilitate some of the eroded slopes. This project is testing various cost-effective erosion control materials and installation techniques to provide data for the application on future projects in this and similar areas.

Seventeen materials, from erosion mats and mulches to different tackifiers are being used within three work zones. These three zones will be evaluated for constructability and overall performance on the better than 1 to 1 slopes that are normal for Berthoud Pass. A construction report, "Evaluation of Slope Stabilization Methods: US-40 Berthoud Pass" CDOT-DTD-R-96-6 was published in March 1996. A final report documenting overall performance will be written during the fall of 2000. This report and the data collected during the study should give designers more information on product usage for future projects that incorporate erosion control products in steep and rugged environments.

Principal Investigator: Skip Outcalt
Study Manager: Skip Outcalt

Sites with Promise

Over the last 50 years of modern road building, highway safety has been measured in terms of accident rates. The use of accident rate is based on the assumption that the number of accidents on a segment of road is directly proportional to the amount of traffic. Recent research findings, independently confirmed by the analysis performed by the CDOT Accident Records and Analysis Group, show that this assumption is invalid and often leads to poor investments into safety improvements.

To replace the accident rate based approach, the CDOT Accident Records and Analysis Group is presently in the process of developing Safety Performance Functions (SPF) for all road classes on the Colorado State highway system. SPF accurately reflects the complex relationship between the amount of traffic measured in ADT and accident count for a unit of road section over a unit of time.

The first stage of this study will involve the examination and evaluation of Simple Safety Performance Functions (SSPF) that have been developed to date by CDOT. After the first stage is completed, members involved in the study will provide technical assistance in the development of the new Colorado-specific SSPF for selected roadway classes and junctions. Following the development of the SSPF, a procedure for selecting and ranking candidate sites for safety improvement, known as Sites with Promise (SWIP) will be recommended for implementation.

The use of SPF in deciding what constitutes a genuine safety problem in need of remedial action will elevate CDOT to a new level in its ability to identify and address locations with potential for safety improvement.

Principal Investigator: Jake Kononov, Safety and Traffic Engineering Branch and Dave Hattan, Felsburg, Holt, and Ullevig
Study Manager: Skip Outcalt

Integration of Ramp Metering with Ramp Traffic Signals

This research project will develop traffic control strategies to coordinate ramp metering and the adjacent traffic signals to reduce delay and queue lengths on the ramp and nearby signalized streets. The effort will focus on a core set of strategies, based on current ramp metering algorithms. The research is focusing on calibrating an existing simulation model on a limited basis to develop the potential control strategies based on current hardware and software technologies in place, and will also consider several scenarios of improvements to the hardware and/or software. The benefits associated with each scenario will be investigated. The second half of the project will focus on testing a given set of strategies for two or three interchanges such as Belleview and I-25, Orchard and I-25, or any on south I-225.

Principal Investigator: Sarosh Khan, University of Colorado at Denver
Study Manager: Rich Griffin

Parametric Cost Estimation Research

CDOT currently lacks a consistent source for estimating project costs at the sketch planning level. The lack covers both the accessibility of historic data and a method to analyze the data. During the development of the last long-range statewide plan, a number of different methods were used to estimate project costs. This inconsistency was cited as an area of concern in a legislative audit report.

To address this problem, a company has been hired to establish methodologies to generate consistent and reliable long-range multi-modal parametric cost estimates when little is known about the project.

Principal Investigator: Kathy Yelle and Roy Johnson, Info Tech
Study Manager: Richard Griffin

I-70 West Link Travel Time Study

This study will demonstrate a prototype system for estimating link travel times (the time that it takes a vehicle to travel from one section to the next) on the I-70 west corridor, Denver to Vail, based on vehicles used as probes. The Research program is funding phase two: instrumentation. In phase two, selected vehicles will be instrumented with radio modem devices with built in GPS units to report locations at pre-specified intervals. The field instrumentation demonstration will test the algorithm prototype developed in phase one and evaluate its performance for computing estimation of link travel times.

Institutional issues and public acceptance will also be examined. For example, can public sector data collection of this nature be offered to the private sector to market a value-added service to the general public?

What will be the value for the private shuttle operators to participate in this program? Will the public use the information, pay for it, and believe it?

Principal Investigator: Sarosh Khan, University of Colorado at Denver
Study Manager: Rich Griffin

Interaction Between Pedestrians and Vehicles Using Smart Signing

The Roaring Fork Transit Authority (RFTA) serves the communities along SH 82 from Glenwood Springs to Aspen. There are currently over 15 bus stops and a RFTA policy that does not allow for buses to cross the centerline for passenger pickup or drop-off. In other words, the buses will only drop-off the passengers on the side in which the bus is travelling. As a result, a number of informal pedestrian crossing areas have been created; a potential hazard on this high-speed highway.

A possible solution to this problem is to provide real-time information to drivers regarding upcoming pedestrian activity. This research study will test the effectiveness of a pedestrian activiated warning sign. The effectiveness of the warning sign was established through speed and break-time studies with pedestrians present and various messages displayed. The research will determine the most effective message, the best method to activate the sign, and the driver and pedestrian response.

Driver surveys were also conducted to determine the most memorable, effective warning message. Results of this research may be used to implement the system thoughout this corridor and other appropriate locations in the state. Part of the funding for this project was provided by Region 3.

Principal Investigator: CK Centennial
Study Manager: Rich Griffin

Cross Modal Performance Measures

This research is expected to establish a framework and the tools to provide a consistent means of making comparisons between different modes of transportation. This framework and tools would be developed primarily for application at the rural and smaller-urban transportation planning region levels for utilization in long-range planning processes.

CDOT's first effort at developing a multi-modal statewide plan was completed in 1996. However, CDOT has had little experience in the performance trade-off and comparable costs of alternative modes of transportation. Questions about how to make modal trade-offs and which measures to consider when comparing disparate projects, such as a transit project to a highway one, remain.

This research will define a performance measures framework which allows comparisons across varied transportation modes with an initial focus on the passenger component. The research intends to offer recommendations for comparing different transportation modes that are sufficiently comprehensive and conceptually consistent, yet practical in application. Since the focus of the research will be to develop a practical method accepted and understood by Colorado transportation planners and decision-makers, only components that contribute significantly to the comparison will be included. The research has currently identified five core categories of performance measures; agency cost, safety, user cost, mobility and environment.

Computer spreadsheets and a manual have already been developed. The next step will be to do a case study in which the best practice approach and methodology are applied to Colorado situations.

Principal Investigators: Sarosh Khan, University of Colorado at Denver and Larry Eubanks, the University of Colorado at Colorado Springs
Study Manager: Rich Griffin

New research will review the performance trade-offs and comparable costs of alternative modes of transportation

Effects of Geometric Characteristics of Interchanges on Truck Safety

National accident statistics show that up to 20 percent of truck accidents occur at interchanges, even though interchange areas comprise a much smaller percentage of total highway lane area (Firestine, et al. 1993). In many cases, these accidents may relate to the inadequate geometric design elements of interchanges from the perspective of large truck operations. In addition, there may be insufficient safety information alerting commercial drivers of potential interchange problems.

This project will determine potential improvement to interchange design specifications that could possibly reduce the frequency and severity of truck accidents. Overall benefits could include lessening the risk to all motorists, a greater level of service will reduce congestion and a reduction in accident related vehicle impacts.

To evaluate the effectiveness of the countermeasures applied at a problem sight in Colorado, an observational before-and-after study was set up at the US 34 and I-25 interchange. This sight was selected because it had significantly more truck rollovers, on average, per unit of exposure at an interchange. Following the identification of this interchange, additional signing was installed to warn truck drivers of potential interchange hazards. The "before" period included the three years prior to installation of this signing in September of 1995. The "after" period included the three years from September of 1995 to September of 1998. The findings of this observational study are included in a 1999 report, now available.

Principal Investigator: Jake Kononov, Staff Traffic and Bruce Jansen, University of Colorado at Denver
Study Manager: Skip Outcalt

Geofabric Interceptor Drains

Interceptor drains, also called underdrains or French drains, have been used for many years to prevent groundwater intrusion below the pavement. In recent years, these interceptor drains have been wrapped with geofabric to prevent sediment intrusion. There is some question about whether or not these geofabrics become clogged with sediment and how rapidly this occurs. Six groundwater-monitoring wells and a flow meter were installed at the effluence of the interceptor drain, along the SH 34 bypass, immediately following construction.

Two periods of flow in the canal were recorded the summer of 1992. Each time the canal was shut off, flows in the underdrain immediately began to taper off. After the second time, flows gradually tapered off for a month. A small amount of water continued to flow from the underdrain after the taper-off period. Whenever the canal is full, flows have been running around thirty gallons per minute, which is twice what was expected. This study is expected to be completed in the summer of 1999.

Principal Investigator: Tom Hunt, Region 6
Study Manager: Rich Griffin

Centerline Rumble Strips

SH-119 west of Boulder (Boulder Canyon) is a narrow winding road running approximately 20 miles from Boulder to the town of Netherland. This stretch of state highway has a history of vehicles crossing the centerline and causing head-on accidents. During the spring of 1996, Region 4 hired a company that uses a new type of equipment for grinding rumble strips into the center of the roadway hoping to reduce traffic accidents caused by vehicles crossing over the centerline. This equipment grinds a 12-inch wide strip, 7 inches long, with 5 inches between grindings by utilizing a compact diamond grinding tool attached to the front of the vehicle.

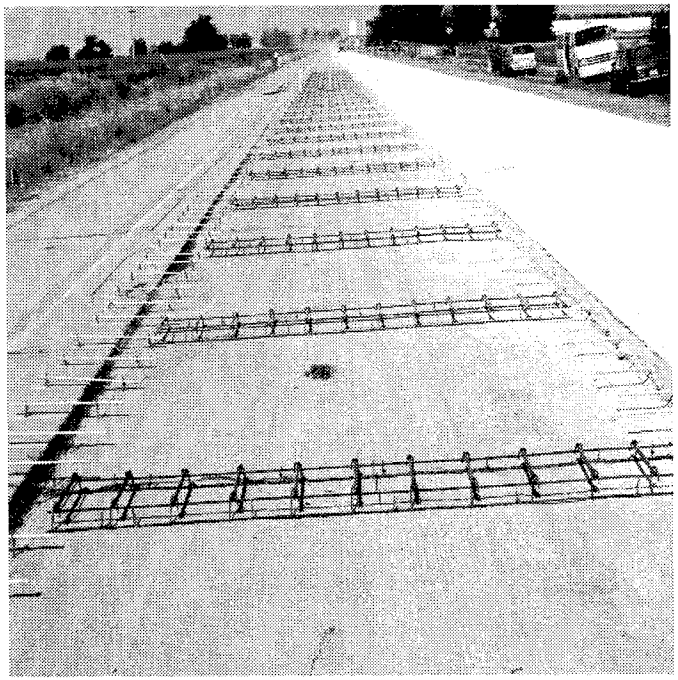
The Research Branch was asked to monitor construction of the rumble strip being placed with this new device and determine the effectiveness of the newly-placed rumble strip by comparing the accident data before and after placement.

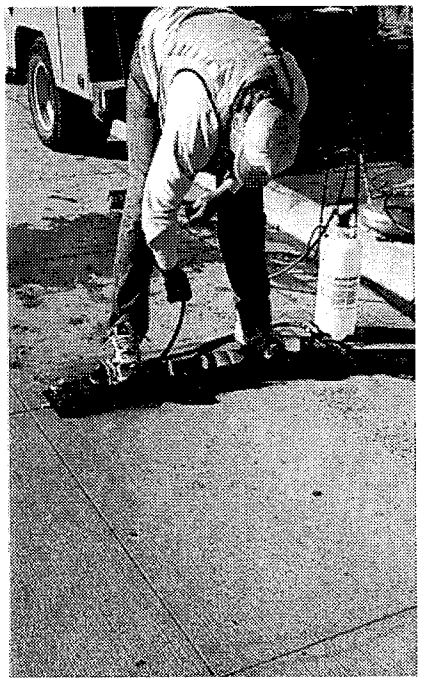
Rumble strips are known for their effectiveness on shoulders, but have never been used to delineate traffic lanes in Colorado. This study will evaluate the safety effectiveness of such a treatment and potential roadway maintenance problems.

Principal Investigator: Dave Price
Study Manager: Skip Outcalt

From left to right: testing for particulate matter; a white topping project; and evaluating the IA Vacuum Tester.

1996 - 1998
Completed Research Studies
with Implementation Statements





CDOT/CTI-96-1

Long-Term Performance Tests of Soil-Geosynthetic Composites. Kanop Ketchart and Jonathon Wu, University of Colorado at Denver. This research was performed for and paid for by the Colorado Transportation Institute. The Colorado Transportation Institute closed in 1996.

This report describes the development of a testing device and test protocol to measure the performance of a geosynthetic-reinforced (GRS) retaining wall. Both a modified performance test and a test procedure for the investigation of long-term behavior of soil-geosynthetic composites were developed.

Implementation statement: This study showed that soil-geosynthetic composite behavior is different than what is assumed in conventional analysis. The development of a rational, verified, and simple analysis to replace the conventional analysis is the subject of current on-going research studies conducted by CDOT, and has been proposed for a new NCHRP study. (For related implementation information see CDOT-DTD-97-2, "Long-Term Field Performance of Geosynthetic-Reinforced Soil Retaining Walls.")

CDOT-DTD-SDHYD-R-96-2

Efficiency of Sediment Basins: Analysis of the Sediment Basins Constructed as Part of the Straight Creek Erosion Control Project. Rick Moser, Staff Bridge. This report is a courtesy printing of a project evaluation of an experimental feature. The research was performed by Staff Bridge.

This study reviews sediment basin construction and their efficiency at controlling the adverse environmental impacts of erosion, sedimentation, and water pollution caused by runoff from highway systems. Eleven sediment basins were constructed and monitored on an area between I-70 and Straight Creek. The sediment basins were successful in removing the majority of sediment from the runoff, capturing 985 tons of sand and sediment.

Implementation statement: This report is being used as a resource document for the possible use and/or placement of the sediment basins in other locations.

CDOT/CTI-96-3

The Roles of Facing Connection Strength, Truncated Base, and Embedment in Mechanically Stabilized Backfill Walls. William Schiebel, CDOT; Albert Ruckman, MSB Design and Construction; Robert Barrett, CDOT; and J.T.H. Wu, University of Colorado at Denver. This research was performed for and paid for by the Colorado Transportation Institute. The Colorado Transportation Institute closed in 1996.

This report documents the performance of two 15-foot high geosynthetically-reinforced, block-faced earth features or mechanically stabilized backfill (MSB) walls. One of the walls featured concrete blocks, the other featured blocks made of compressed rubber tire chips. These walls experienced minor deflection and the embedment, or non-embedment of the walls, has had no effect on the stability of the constructed walls.

Implementation statement: CDOT research on the role of facing connection strength for mechanically stabilized earth (MSE) walls has resulted in waiving the AASHTO connection requirement in the CDOT revision of section 504 as follows: "for low strength geotextile or woven geofabric reinforced walls, except for the top one block, every block shall be connected by friction with either a main or a tail reinforcement...."*

In a current study with Dr. Wu, guidelines for allowing the use of truncated MSE bases will be developed. A numerical analysis method is needed to check the design of the truncated base. A finite element program and/or a slope stability program can be used to check the truncated base design. Staff Bridge is considering a truncated base wall design for a secondary road. This project can be set up as an experimental project to have the Research Branch monitor its performance.

CDOT design engineers comprehended our research findings that the embedment is not relevant for the internal stability analysis of MSE walls but could be critical for global stability analysis. Therefore, for MSE walls with no global stability problem, CDOT specifications limit the embedments to just 18" for the scour protection of the leveling pad.

**While the report refers to MSB (backfill) walls, the preferred terminology now refers to them as MSE (earth) walls.*

CDOT/CTI-96-4

Erosion Control and Revegetation Techniques Using Mechanically Stabilized Earth Slopes. William Schiebel, CDOT; Albert Ruckman, MSB Design and Construction; Robert Barrett, CDOT; and Jeff Rodencal, Tensar Earth Technologies. This research was performed for and paid for by the Colorado Transportation Institute. The Colorado Transportation Institute closed in 1996.

This CTI research reviews commonly used erosion control and vegetation techniques on mechanically stabilized earth slopes. Two geogrid reinforced embankments were constructed to provide test slopes with a 1:1 grade, each with a north, south, east, and west exposure. The report recommends that when spatial restrictions will allow and where aesthetic options are needed, the vegetation MSE slope should be considered due to its lower cost if irrigation can be provided to supplement precipitation as necessary to establish plant growth. Sediment loss from the test slopes was controlled in all test sections regardless of the success of the vegetation. The erosion control systems described in this study were effective in reducing soil loss on 1:1 slopes to a negligible amount.

Implementation statement: This technique has not been used on a CDOT project due to lack of information on this possible alternative.

CDOT-R-CSU-96-5

Roadside Vegetation Management. Paul Kohlhepp, Thomas Sanders, Cara Tackett, and Richard Walters; Colorado State University.

This technical report documents roadside vegetation management practices recommended for CDOT. The report includes a review of the 1990 "Roadside Appearance" chapter of the CDOT Maintenance Manual and additional information obtained from seven states, two Colorado counties and a report by Auburn University.

Implementation statement: Although accurate and comprehensive, the manual was too academic and unrealistic for everyday use by CDOT Maintenance. It is available for reference in the CDOT Transportation Library. Copies were sent to Maintenance Sections statewide.

CDOT-DTD-R-96-6
Evaluation of Slope Stabilization Methods (US-40 Berthoud Pass). Construction Report. David Price.

This study is evaluating sixteen erosion control materials and installation techniques on Berthoud Pass. The materials being studied included erosion mats, mulches, and tackifers on three work zones. Each is being reviewed on their constructability and performance on the 1:1 slopes particular to this area.

Implementation statement: This is a construction report only, however, the research completed to date has been used for further stabilization projects on SH-40 Berthoud Pass.

CDOT-DTD-R-96-7
SMA (Stone Matrix Asphalt): Colfax Avenue Viaduct. Construction Report. Tim Aschenbrener, Staff Materials and Donna Harmelink.

This construction report documents and evaluates the placement of SMA on the Colfax Avenue viaduct. This project was the second project in Colorado to use the European SMA. Evaluations are continuing and a final report on all SMA projects is expected in 2000.

Implementation statement: Since CDOT's first SMA project in 1994, SMA has been used in limited projects very successfully. Currently a Task Force is developing a position statement for the appropriate use of SMA to incorporate into the CDOT Design Manual.

CDOT-DTD-R-96-8
Determining the Asphalt Cement Content of Bituminous Mixtures Using the NCAT Asphalt Content Oven. Randolph Reyes, Charlie MacKean, and Tim Aschenbrener, Staff Materials. This report is a courtesy printing of a report completed by and for Staff Materials.

Developing a test procedure for accurately measuring the AC content of bituminous mixtures using the NCAT asphalt content oven, or ignition oven, was the objective of this research. Numerous bituminous mixtures from paving projects were evaluated and the procedure that resulted in the most accurate and precise method of AC content determination was selected. The research resulted in several recommendations being made. These recommendations were incorporated into CDOT CPL-5120 "Determination of the Asphalt Binder Content of Bituminous Mixtures by the Ignition Method."

CDOT-R-96-9
HBP QC & QA Projects Constructed in 1995 under QPM1 and QPM2 Specifications. Bud Brakey, Staff Materials. This report is a courtesy printing of a report completed by and for Staff Materials.

This report is the forth annual update of a pilot project to construct hot bituminous pavements (HBP) under quality control and quality assurance (QA & QC) specifications. Meeting and/or exceeding these specifications is tied to incentive payments to the contractor. Failure to meet these specifications can result in a reduction of payment to the contractor. This update reviews the addition of a QC & QA Standard Special Provision that created a greater disincentive payment schedule and more stringent requirements.

CDOT-DTD-R-96-10
Long-Term Performance of Accelerated Rigid Pavements, Project CXMP 13-0006-07. Ahmad Ardani.

Described within this report is the post-construction evaluation of a fast track pavement project in Sterling, Colorado that was completed in 1989. The evaluation of this project lasted seven years and included visual inspections, measurements of faults, a profile measurement, a distress survey, and a set of falling weight deflectometer measurements. Continued use of the fast track concrete paving technique is recommended.

Implementation statement: The results of this study demonstrate that fast track concrete pavement can be as durable as conventional concrete pavement. CDOT has been using fast track concrete pavement construction primarily in urban settings to reduce construction time and minimize traffic delays for the travelling public.

CDOT-DTD-96-11
Determining the Degree of Aggregate Degradation After Using the NCAT Asphalt Content Tester. Randolph Reyes, Staff Materials. This report is a courtesy printing of a report completed by and for Staff Materials.

With the EPA phasing-out the use of solvents to remove asphalt cement from bituminous mixtures to perform aggregate gradations, an alternative method for this process was needed. This study determined if aggregate degradation took place and measured the possible degree of degradation after bituminous mixtures were heated inside the NCAT Asphalt Content Tester, or ignition oven. The evaluation found that the NCAT Asphalt Content Tester may be used for determining gradations of bituminous mixtures and that it can replace the use of chlorinated solvents in determining AC content and aggregate gradation. However, correction factors will be required for aggregate that degrades inside the NCAT Asphalt Content Tester.

CDOT-DTD-96-12
Evaluation of Rumble Treatments on Asphalt Shoulders. David Price.

This study evaluated the effectiveness of two types of rumble strips constructed on roadway shoulders. Rumble strips are a textured treatment constructed on the shoulder of the road to provide an auditory and vibratory warning to drivers leaving the roadway. The report concludes that both the rolled rumble strips and chip seal type rumble strips should be considered for installation when a payment is being overlaid.

Implementation statement: The results of this study were incorporated into Colorado M-standard M-614-1 - Rumble Strips.

CDOT-DTD-97-1
Avalanche Forecasting Methods: Highway 550. Arthur Mears, Arthur Mears, Inc.

This research project developed a methodology for calculating the severity of a particular avalanche activity. The study sought to investigate parameters that may be important in forecasting avalanches on Highway 550 and to suggest how

they may be used to forecast avalanches in the future. Results of the study show a positive correlation between length of centerline covered, volume of avalanche debris and the avalanche activity index. While volume is a better measure of maintenance requirement to keep the road open, the length parameter is a better measure of hazard because it more directly relates the probability of a vehicle being hit by an avalanche. The study also recommends a continued quantification of avalanche activity data collection after storm events, shear strength tests of snowpack, and the establishment of an automated weather station.

Implementation statement: Findings from this study were used to establish the current avalanche forecasting and hazard mitigation program at CDOT.

CDOT-DTD-R-97-2
Ground Access Assessment of North American Airport Locations. Lawrence Cunningham, James Gerlach, Mary Hirsh, and Holly Hodges; University of Colorado at Denver.

This research investigated ground access projects at other airports in North America to identify how multi-modal transportation planning is applied to varied transportation systems. It was expected that the experiences of other states and counties which are planning and operating multi-modal ground access systems would have application for Colorado. This study showed that public transportation alternatives to airport ground access do not capture large market shares. It also concludes that access plans are often implemented without the benefit of sufficient knowledge of the markets they serve. Where market share for public transportation is strong, two key factors have been assessed: origin/destination and customer needs.

Implementation statement: This report was used for background information by the Denver Regional Council of Governments in developing and updating transportation plans in the Denver Metropolitan Area.

CDOT-DTD-R-97-3
Special Polymer-Modified Asphalt Cement. Donna Harmelink.

This research project evaluated and compared the effectiveness of polymer-modified asphalt mixes in improving the performance of the roadway in relation to rutting and cracking as compared to CDOT standard mixes without modifiers. The study indicated that cracking is reduced when polymer-modified asphalts are used, however, the study did not conclude when a polymer is needed or whether it is cost effective. The introduction of the SHRP performance graded asphalt binder will make it easier for CDOT to better evaluate the effects of both temperature and traffic and their relationship to performance grading.

CDOT–DTD-R-97-4
Avalanche Detection Using Atmospheric Infrasound. A.J. Bedard, Jr., National Oceanic and Atmospheric Administration.

This report documents the testing of an infrasound detection system to detect snow avalanches in the southwest mountains of Colorado, due to the belief that snow avalanches produce sounds in the .5 to 5.0 Hertz range. The research results were encouraging, but further testing is necessary to better define the sound patterns produced by avalanches. At that time this type of system could be used in conjunction with a motorist warning system.

Implementation statement: Follow-up research is still needed to develop this system into a viable product. To date, research funding priorities have not placed this avalanche detection system high enough to complete its development.

CDOT-DTD-R-97-5
Experimental Evaluation of a Keyed Concrete Curb. William (Skip) Outcalt.

This report is a product evaluation of an experimental feature, keyed curbs, installed on US 24 in Colorado Springs. Keyed curbs are tied to the pavement by a key formed when the concrete curb is slip formed over a groove or "keyway"

that has been milled into the surface of the pavement. There is no sidewalk or fill behind the curb to add support; the keyed curb relies completely on the concrete and the keyed joint with pavement for its strength. As of January, 1997, CDOT has had a design detail for using the keyed curb as an alternative to standard methods. The most effective use of a keyed curb is on an existing pavement, where curbs are desired after construction has been completed. The keyed curb will also prove useful when installed on a shoulder of a road where water needs to be diverted to be effectively drained.

CDOT-DTD-R-97-6
Evaluation of the Iowa Vacuum Tester. Interim Report. William (Skip) Outcalt.

The Iowa Vacuum Tester is an apparatus that is used to detect defects in joint seals. The test involves wetting a joint with a soapy solution and applying a vacuum to the wetted area. If there is a failure in the seal, air will mix with the soapy solution and cause it to bubble. This study compares the results of evaluating the seal with the Iowa Vacuum Tester with the results obtained by an experience visual evaluator. The Iowa Vacuum Tester appears to have the most promise in evaluating joint seals on new construction sites, especially when combined with pull tests of the sealant. Too date the vacuum tester has only been tested in warm weather. The final evaluation will focus on the performance of the Iowa Vacuum Tester during cold weather. *(For the final report on the evaluation of the Iowa Vacuum Tester, see CDOT-DTD-R-98-5.)*

CDOT-DTD-97-10
Loading Test of GRS Bridge Pier and Abutment in Denver, Colorado. Kanop Ketchart and Jonathan Wu, University of Colorado at Denver.

The objective of this research was threefold. The first objective was to investigate the performance of a GRS bridge support system, including an abutment and a pier, subject to design loads. The second objective was to investigate the long-term performance of such a bridge support system under a sustained design load. The third objective was to examine the performance of GRS bridge abutment and piers when constructed in a less stringent condition. The report presents numerous measured results and discussions of those measured results.

Implementation statement: The outstanding performance of the reinforced bridge abutment in this study cleared the way for the design of geogrid-reinforced abutments in the new Founders/Meadows bridge over I-25. This bridge was the first of its kind built in the US. One of the features of this design is that it allows for more traffic space under it. This demonstration project also gave CDOT design engineers a tool to predict the movement of the Founder/Meadows bridge.

The observed behavior of the fortress pier alerted our engineers to the importance of the concentrated surface loading near the edge of the MSE walls. The study also supported the need for grouting the top four blocks, a practice incorporated in CDOT specifications. CDOT and Colorado county design engineers are encouraged to consider MSE pier construction in remote areas with difficult access by heavy equipment and for temporary needs.

CDOT-DTD-97-11
Synthesis on Faulted Pavements at Bridge Abutments. George Hearn, University of Colorado at Denver.

This synthesis showcases literature on the problem of faults in roadway pavements at bridge abutments. Faults are differences in elevation of approach pavements and bridge decks caused by unequal settlement of embankments and abutments. This synthesis collected and evaluated existing information and identified the need for new and/or expanded information on the cause of faults and existing technologies for the mitigation of faults. This synthesis was considered Phase I of a three-phase research project. *(Editor's note: No additional phases were completed or are expected to be completed at time of publication.)*

Implementation statement: While this study was underway, CDOT began a standard practice of using "flow-fill" for bridge approaches to control faulting. Since this process generally controls the faulting problem, interest in completing the next phases of this study was not supported.

CDOT-DTD-97-12

Long-term Field Performance of Geosynthetic-Reinforced Soil Retaining Walls. Phillip E. Crouse, Jonathan T.H. Wu, University of Colorado at Denver.

This study synthesized long-term performance data of full-scale geosynthetic-reinforced soil (GRS) retaining walls in the field. After an extensive literature review and survey, seven GRS retaining walls were selected for this study. Wall performance was assessed using a conservatism index (CI). In addition, an analytical equation was developed for predicting creep deformation of a GRS wall beyond the measurement period. It was concluded by the study that all GRS retaining walls with granular backfill deform very little due to creep and were stabilizing with time. It also found that the current design methodology to account for creep is overly conservative when well-compacted granular backfill is employed.

Implementation statement: CDOT has conducted extensive research on the creep of geosynthetic material confined in granular and fine soils. Although CDOT research findings contradict current AASHTO specifications, this research has had a strong impact of the use of reinforced soil technology. The FHWA report " Development of Protocals for Confined Extension/Creep Testing of Geosynthetics for Highway Application" FHWA-RD-97-143 recognized CDOT research findings and developed new protocols for confined creep testing of geosynthetics for highway applications. The FHWA report indicates that the confinement of geosynthetic reinforcement significantly limits the creep response. This phenomena was reported in CDOT research reports nearly ten years ago. The results of the FHWA report, which is part of a comprehensive study on the durability of geosynthetic materials, will eventually be incorporated into AASHTO specifications.

The CDOT structure committee voted to relax the creep factor and raise it by 30% for geogrid and geotextile reinforcements. This new percentage is reflected in the new CDOT specification on creep, still in the review process, and has been used on at least one project. With this new specification, CDOT has adopted one of the highest creep factors in the US.

CDOT-DTD-R-98-1
I-76 Truck Study. David Price.

This evaluation reviews the performance of a 140-mile section of I-76 in northeastern Colorado. This section of road was under evaluation because the region office had placed signs along the highway asking truck traffic to use the passing, or left lane, while travelling on this section in order to prolong the pavement's life. Moving the truck traffic did not show a definite advantage or disadvantage in increasing the life of the outside passing lane. It did, however, balance out the pavement distress between the two lanes and may be a temporary measure to prolong pavement life until reconstruction can begin.

Implementation statement: The procedures followed in this study have also been used for prolonging the pavement life in areas along eastern I-70.

CDOT-DTD-R-98-2
HBP Pilot Void Acceptance Projects in Region 2 in 1997. Interim Report. Bud Brakey, Staff Materials. This report is a courtesy printing of a report completed by and for Staff Materials.

This report covers three current void acceptance (VA) projects and compares them with previous VA and quality assurance and quality control (QA & QC) projects. It also summarizes all of the twelve VA projects, including nine that have been completed. The report has numerous conclusions and recommendations including the continued use of and increasing the number of VA pilot projects.

CDOT-DTD-R-98-3
1997 HBP QC for Pay Pilot Projects with Void Acceptance. Interim Report. Bud Brakey, Staff Materials. This report is a courtesy printing of a report completed by and for Staff Materials.

CDOT, with assistance from industry, wrote a pilot for quality control for pay (QCFP) specification for the 1997 construction season. Standard QC & QA HBP specifications were modified to make QC test (instead of CDOT acceptance) the basis for payment for the usual three elements – asphalt content, in-place density, and gradation. This new specification includes tests for determining the percent of air voids (AV) and voids in the mineral aggregate (VMA) which did worry some contractors. CDOT did not assess disincentive payments for pay factors of less than 1.0 for void properties. In addition, a special incentive pay formula, based on quality level analysis (QLA) of VMA and VA, was included.

CDOT-DTD-R-98-4
Hot Bituminous Pavement QC & QA Projects Constructed in 1997 Under QPM 2 Specifications. Sixth Annual & Final Report. Bud Brakey, Staff Materials. This report is a courtesy printing of a report completed by and for Staff Materials.

This report presents tables and figures which summarize the HBP quality level analysis (QL) for QA & QC projects completed in 1997 – the third season using the specifications. The QL for the elements (sieve analysis, asphalt content, and pavement density) and the item composites are summarized. The QL determines the pay factor (PF) and is also used to rank the contractor's performance. The QL specifications are performing satisfactorily and no significant changes are recommended for HBP QC & QA program.

CDOT-DTD-R-98-5
Evaluation of the Iowa Vacuum Tester. William (Skip) Outcalt.

The Iowa DOT developed the Iowa Vacuum Tester to determine if and where joint seals are leaking. This report is an evaluation of the Iowa Vacuum Tester here in Colorado and its comparison to results obtained by visual inspection only. To use the Iowa Vacuum Tester you must first apply a soapy solution to an area and then the vacuum. If there is a failure in the seal, air will pass through and bubbles will form on the top of the surface. The use of the Iowa Vacuum Tester is recommended. The tester is probably most useful in determining if seals on new projects will perform adequately. *(For the construction report on the Iowa Vacuum Tester, see CDOT-DTD-R-97-6.)*

Implementation statement: The Iowa Vacuum Tester is available for use by CDOT personnel. Contact Skip Outcalt at (303) 757-9984 if you would like a demonstration or would like to borrow the equipment.

CDOT-DTD-98-6
Simulation of 12 High Geosynthetic Reinforced Retaining Walls Under Surcharge Loading by Centrifuge Testing. James Klamerus and Hon-Yim Ko, University of Colorado at Denver.

This report examines thirteen centrifuge model tests on geosynthetic reinforced retaining walls. These tests determine the effects of backfill type, reinforcement shape (length), and degree of saturation on displacement and mode of failure under surcharge loading. Only one centrifuge showed signs of catastrophic failure so it is difficult to draw general conclusions on the failure performance of other tests. However, centrifuge modeling of geosynthetic reinforced retaining walls is considered to be a cost-effective method of producing meaningful results for developing a rational theory of safe and economical design guidelines.

Implementation statement: While this research was not conclusive in its results it did show how to design mechanically stabilized earth walls that do not fail even under a high gravity level. The only centrifuge test that failed was when fat clay was used as the reinforced backfill. This alerted CDOT to limit the amount of clay particles in backfill materials. CDOT specifications have strict limits on the percentage of -#200 sieve and the plasticity index of backfill materials.

CDOT-DTD-R-98-7
Colorado Study on Transfer and Development Length of Prestressing Strand in High Performance Concrete Box Girders. Daniel Cooke, P. Benson Shing, Dan Frangopol, University of Colorado.

This study reports on an investigation on the transfer and development lengths of Grade 270 (15.2 mm/.6 in) diameter prestressing strands spaced at 51 mm (2 in) on center in high performance concrete. The transfer length was determined by measuring concrete surface strain with mechanical strain gages. The development length was measured using an iterative testing process involving six flexural tests. The development length for these girders was determined to be

approximately 1524 mm (50 in). It was concluded that the ACI/AASHTO formulas over-estimate the transfer length of the girders by 18%, and the development length by 53%.

CDOT-DTD-98-8
Particulate Matter from Roadways. Chatten Cowherd, Midwest Research Institute.

This report presents the results of research to determine the relationships between the paved roadway surface dust characteristics and fine particle emissions and evaluates the emission control measures that reduce road surface silt loading. Several types of field studies were used in performing this research. The study found that sanding was responsible for a large share of reetrained dust emissions. It is now believed that sanding may cause up to 60-80% of winter reentrained dust emissions, approximately double what had been previously thought.

Implementation statement: The results from this intensive study support the continued increase in chemical deicing, along with a decrease in the application of sand and salt. A follow-up study funded jointly by local governments, the Denver Regional Council of Governments (DRCOG), CDOT, private sources and the Regional Air Quality Council is evaluating the effectiveness of alternative deicing materials and sweepers.

CDOT-DTD-R-98-9
Evaluation of Design-Build Practices in Colorado, IR (CX)70-4(143). Interim Report. Ahmad Ardani and Paul Jesaitis, Region 1.

This report summarizes the construction activities of a design-build project in CDOT's Region I. Under the Special Experimental Project No. 14, the FHWA approved the design-build concept to be used for the 12-mile reconstruction of I-70 from Airpark Road East. The goal of this research is to identify and document the pros and cons of the design-build practice and examine its overall applicability to CDOT. A final report will be issued 90 days after the completion of the project.

Implementation statement: The use of design-build methodology for awarding construction projects looks promising.

However, there is room for improvement in a fully implemented design-build concept. When early completion of a project is of significant value, design-build for project delivery becomes very attractive. For simple design-build projects with well-defined end results, the low-bid process is still the ideal since it minimizes the review of voluminous technical proposals. For larger and more complex design-build projects the "best value" concept (not necessarily the lowest bid) is more appropriate. The best value concept encourages innovation and allows the contractors to optimize their work force, equipment and schedules.

CDOT-DTD-R-98-10
Guidelines for the Thickness Design of Bonded Whitetopping Pavement in the State of Colorado. Scott Tarr, Matthew Sheehan, Paul Okamoto, Construction Technology Laboratories, Inc.

This report summarizes the development of procedures for the thickness design of bonded whitetopping pavements including an overview of the selected sites, design parameters, instrumentation, data acquisition, and analysis. Equations were developed to predict the critical stresses and asphalt strains. A mechanistic design procedure is described which allows the evaluation of whitetopping thickness and joint spacing. A modified procedure was developed incorporating an empirical approach based on the number of equivalent single-axle loads. The research concludes that a minimum subgrade modulus of 150 pci is required along with a asphalt thickness of 5 inches. However, these conclusions need to be verified by future work and the long-term performance of test sections.

Implementation statement: The newly-developed procedures for the thickness design of whitetopping have been used on a few whitetopping projects in Colorado. Prediction models developed during this research are part of a first-generation procedure which needs to be fine-tuned and validated after the collection of additional data from future projects.

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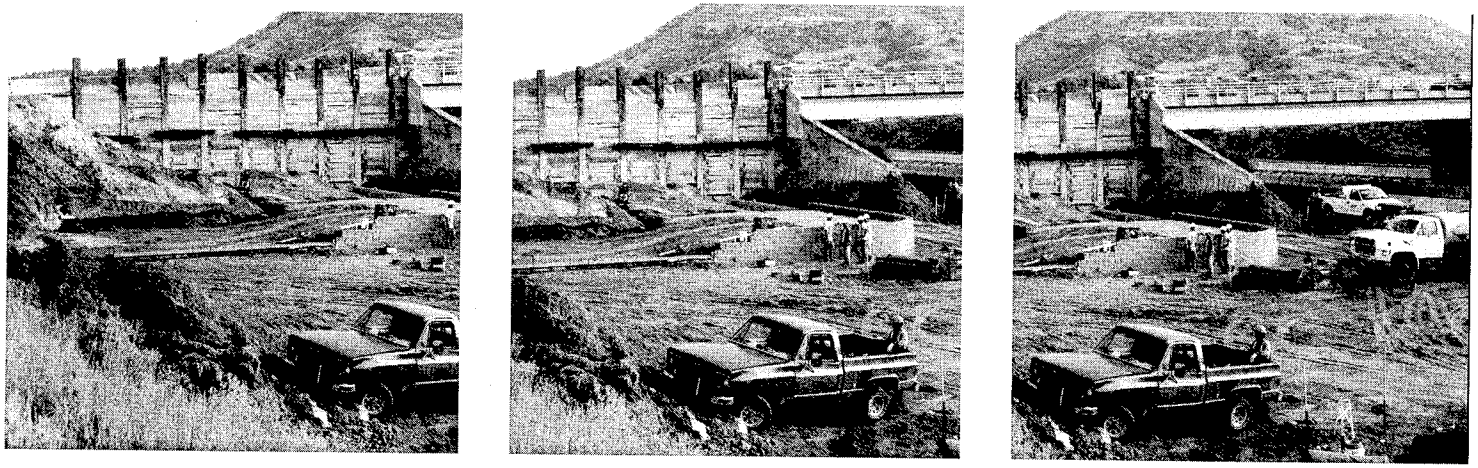

Reinforced soil abutments are under construction at the Meadows/Founders bridge over I-25 in Colorado Springs. For the related write-up and a photograph of the completed project see page 38.