Report No. CDOT-DTD-R-93-17

In Service Evaluation of Highway Safety Devices Experimental Project No. 7

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Final Report
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Prepared in cooperation with the
U.S. Department of Transportation
Federal Highway Administration

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16. Abstract

This report is an in-service evaluation of the following highway safety devices: Breakmaster End Terminals, installed on SH 82 south of Glenwood Springs, Crash-Cushion Attenuating Terminal (CAT) installed on SH 8 at the US 285 interchange south of Morrison, and 10-Gauge Guardrail, installed on US 24 south of Vail near Camp Hale.

The CAT and Brakemaster end terminals were evaluated for cost, ease of maintenance and repair, and performance in accidents. The data was obtained from the devices installed and from the experiences of other state departments of transportation.

Evaluation of 10-Gauge Guardrail was based on the experiences of Colorado Department of Transportation (CDOT) maintenance crews who maintained and repaired the guardrail.

Implementation:

The Brakemaster is recommended as a low cost terminal for areas of infrequent impacts. Repairs may cost more and take longer than for some terminals. The CAT experienced no impacts, so, based on information from other states, it is recommended that the CAT be evaluated further. 10-Gauge Guardrail is recommended in areas where guardrail is often replaced due to damage from snow plows.

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In-service Evaluation of Highway Safety Appurtenances

I. Study Description:

This study evaluates 10 gauge W-beam guardrail and two types of energy attenuating median guardrail end treatments.

Colorado uses 12 gauge W-beam guardrail to shield hazards along its roadways. During winter months, especially at higher altitudes where there is heavy snow accumulation, snow plowing operations and minor accidents caused by slick roads damage guardrails. The Colorado Department of Transportation (CDOT) hopes that the use of guardrails made from thicker material will reduce the number of guardrail sections that must be replaced due to this type of damage.

Guardrails and barriers are used to protect vehicles from hazards along the roadway. Energy attenuating end treatments reduce property damage and injury when a vehicle collides with the end of a barrier. This study evaluates two types of energy attenuating end treatments: the Brakemaster System and the Crash Cushion Attenuating Terminal (CAT).

II. Objectives:

The objectives of this study are to:

1. document installation of the three devices with respect to ease of construction and installation costs,
2. evaluate impact performance under real conditions,
3. describe routine maintenance and repair costs for each device.

CDOT report number CDOH-DTD-R-90-13[1], available from the CDOT Research Branch, documents the installation of all three devices described. This report evaluates the performance and costs of the guardrail and end treatments.

III. 10 Gauge W-beam guardrail:

A. Description:

The guardrail installed for this study is on US 24 south of Minturn near Camp Hale from MP 149.93 to MP 158.46 (maps pages 5 & 15). The following chart shows some characteristics of the different types of guardrail and the amount of each installed on this project.

	Thickness	Weight	Feet Installed
10 Gauge Galvanized	.1345 inch	234 pounds per 25' section	5,350'
10 Gauge Corrosion Resistant	.1345 inch	221 pounds per 25' section	4,150'
12 Gauge Galvanized	.1046 inch	185 pounds per 25' section	none
12 Gauge Corrosion Resistant	.1046 inch	170 pounds per 25' section	1,325'

Galvanized guardrail, the type used most often in Colorado, is flat silver/gray in color. Corrosion resistant guardrail, also referred to as self rusting steel or weathering steel guardrail, is reddish brown; the CDOT often uses this type of guardrail for aesthetic reasons because it blends into the landscape better than galvanized rails.

Figure 1 shows how galvanized rail and posts stand out; Figure 2 shows how the corrosion resistant rail mounted on wood posts blends into the landscape.

Figure 1

B.Installation:

The guardrail for this study replaced about 8300 feet of old cable guardrail and about 300 feet of old W-beam guardrail. The construction report[1] for this study completely describes the installation of the guardrail on this project.

C. **Evaluation:**

1. **Performance**

In the mountains, much of the damage to guardrails happens during the winter from snow plows hitting the rails as well as accidents caused by slippery roads. Snow plow operators sometimes scrape rails with the plow blade while trying to clear a road as completely as possible. Also wet snow is dense enough to bend guardrails when pushed off the side of the road.

Figure 2

During the two winters since it was installed, Maintenance has not needed to replace any 10 gauge rail because of damage done by plows or minor accidents. Large trucks did damage the rust resistant 10 gauge rail in two separate incidents; this required replacing about 400 feet of rail each time. The foreman for the area said the 10 gauge rail had been hit several times but was not damaged badly enough to need replacement. Figure 3 shows the damage done by snow plows to corrosion resistant guardrail.

Figure 3

Readers will notice the flattening of the rail at the second post from the right and the wavy appearance farther along.

2. Repairs

According to the maintenance crew that works in this area, 10 gauge rails are as easy to work with as 12 gauge rails. The crew likes the heavier rail because it does not damage as easily. The increased weight (about 50 pounds per 25' section) and stiffness of 10 gauge rails do not make these rails any more difficult to work with than 12 gauge rails.

Figure 4 shows the relative thickness of 10 gauge and 12 gauge materials. A 12 gauge end treatment is bolted to a section of 10 gauge W-beam guardrail. The thicker 10 gauge material can be seen on the nut side of the bolts. The foreman for the Eagle area, which includes this project, has requested that 10 gauge rail be used on some safety projects to be done in the area.

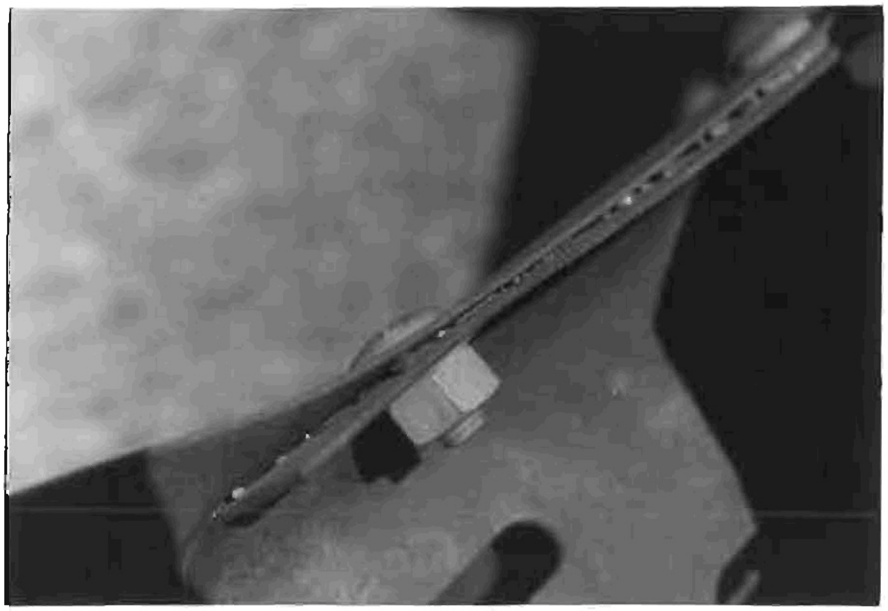


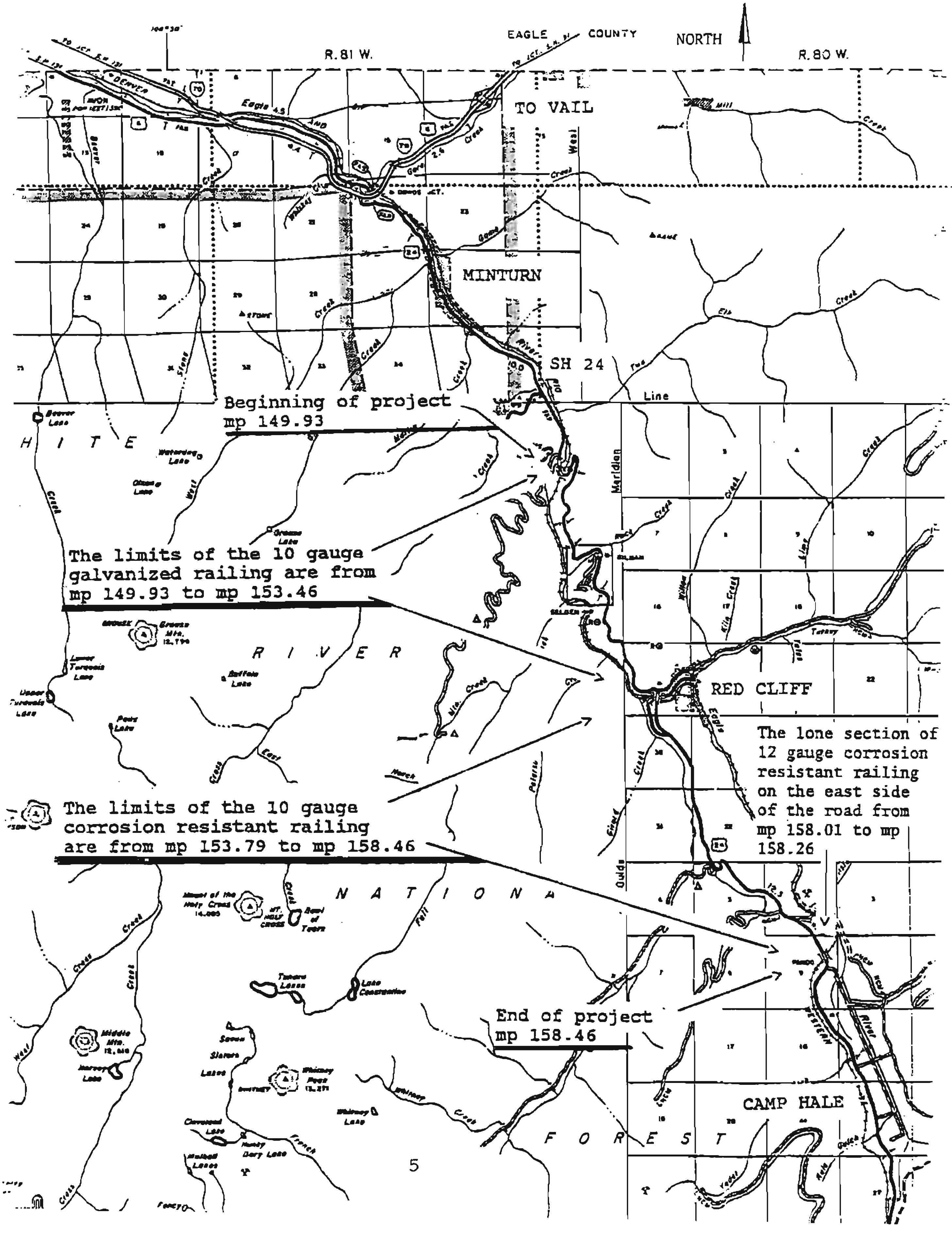
Figure 4

D. Costs

GUARDRAIL PRICES (FOR THIS PROJECT)	Cost per 25' section (including hardware)	Cost per foot
10 Gauge Galvanized	$78.75	$3.15
10 Gauge Corrosion Resistant	$81.25	$3.25
12 Gauge Galvanized	$73.75	$2.95

E. Recommendations

Based on experiences at the site on US 24, installation of 10 gauge W-beam guardrail is recommended where plowing operations and relatively minor accidents bend, flatten, and disfigure 12 gauge guardrail.



EAGLE COUNTY
NORTH
R. 81 W.
R. 80 W.
TO VAIL
MINTURN
SH 24
Beginning of project
mp 149.93
The limits of the 10 gauge
galvanized railing are from
mp 149.93 to mp 153.46
RED CLIFF
The lone section of
12 gauge corrosion
resistant railing
on the east side
of the road from
mp 158.01 to mp
158.26
The limits of the 10 gauge
corrosion resistant railing
are from mp 153.79 to mp 158.46
End of project
mp 158.46
CAMP HALE

IV. Brakemaster™ System Attenuating Terminal

A. Description

The Brakemaster is an energy attenuating terminal designed to protect narrow hazards in areas where the frequency of impacts is low (drawing page 7). It is a non-gating system and can withstand angle hits to the side and redirect a vehicle rather than allow it to penetrate the system. The Brakemaster meets all requirements of N.C.H.R.P. Report No. 230[4].

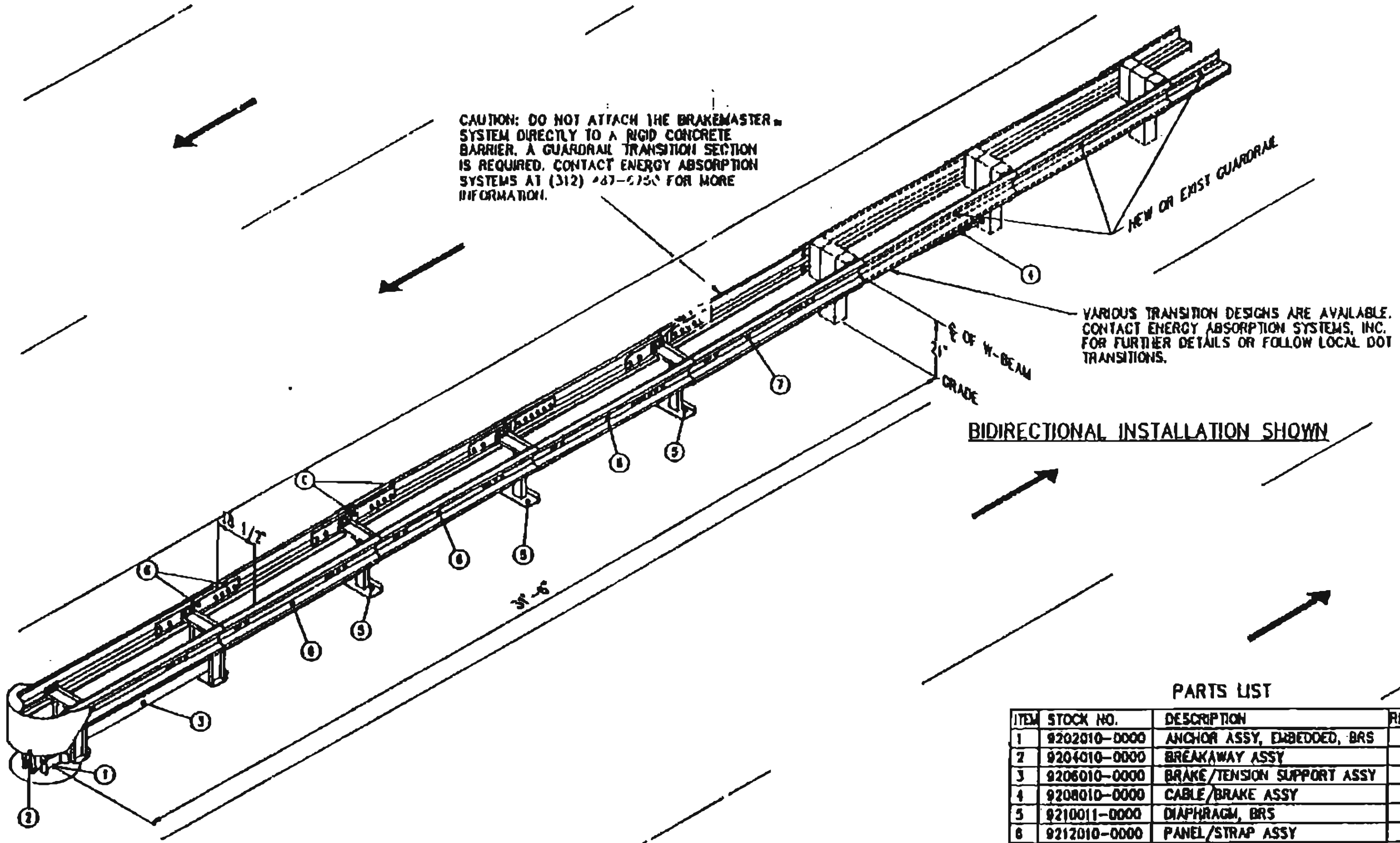
Energy Absorption Systems, Inc., recommends that its Brakemaster terminal for hazards up to three feet wide and located at the side of the road and/or in medians 20 feet or more wide[2]. The system is designed for use at speeds below 60 MPH and where redirection is essential. As Figure 5 shows, the Brakemaster terminals installed for this study are in narrow medians on a 55 MPH highway. It requires no deck and can be installed on concrete, asphalt, or strong soil[7]. The installation can be on a cross slope up to 8%.

Figure 5

In an end on impact, the Brakemaster absorbs energy through the use of a cable braking mechanism that is anchored in concrete buried below the nose of the terminal. The end of the cable anchor can be seen below the nose of the terminal in Figure 5.

B. Installation

For this study, the CDOT installed six Brakemasters on SH 82 south of Glenwood Springs between mile posts 2.5 and 12.5 (map page 13). All six terminals are on ends of concrete barriers in the median which is less than 10 feet wide. The Construction Report[1] for this study completely documents the original installation of the terminals.



BIDIRECTIONAL INSTALLATION SHOWN

PARTS LIST

ITEM	STOCK NO.	DESCRIPTION	REQ'D
1	9202010-0000	ANCHOR ASSY, EMBEDDED, BRS	1
2	9204010-0000	BREAKAWAY ASSY	1
3	9206010-0000	BRAKE/TENSION SUPPORT ASSY	1
4	9208010-0000	CABLE/BRAKE ASSY	1
5	9210011-0000	DIAPHRAGM, BRS	3
6	9212010-0000	PANEL/STRAP ASSY	6
7	9214010-0000	TRANSITION STRAP ASSY	2

MODEL NO. 106106BRSS

ENERGY ABSORPTION SYSTEMS, INC.
ENGINEERING AND RESEARCH DEPARTMENT

BRAKEMASTER GENERAL ASSEMBLY (BIDIRECTIONAL SYSTEM)

C. Evaluation

1. Performance

During 1991 there were three accident reports filed involving the Brakemasters on SH 82. The vehicles were travelling at 45 MPH, 45 MPH, and 65 MPH. There were no fatalities and only one injury. One damaged vehicle was driven away after the accident.

Figure 6 shows a terminal after a minor impact. It also shows the conditions that led to most of the hits on the terminals in this study. The Brakemaster did the job well in every case reviewed for this study. In the 65 MPH accident, referred to above, people at the scene felt the terminal probably saved the driver's life.

Figure 6

2. Repairs

A hit on the end of the system can result in the need to completely replace the terminal or just replace damaged parts. On January 4, 1991, a 1984 Toyota pickup, travelling at 45 MPH, slid on icy pavement and hit the end of the terminal in Figure 6. The nose cover, laminated straps, several panels, and the breakaway arm and its accessories had to be replaced; however, the braking mechanism was not damaged and was not replaced. The repairs cost $2623 plus labor. There were no injuries, but the truck had to be towed to a repair shop.

Figure 7 shows a terminal damaged by a four foot boulder that rolled down from the hill beside the road. The nose and one panel had to be replaced. Materials cost was $978. A CDOT maintenance crew repaired the terminal in about one-and-a-half hours. There was no apparent damage to the boulder which can be seen behind the terminal.

The braking mechanism is usually reusable but must be returned to the factory for evaluation after an impact. Energy Absorption Systems, Inc., says the system is 20% to 40% reusable after a head-on impact.

D. Costs

Figure 7

The material replacement cost of a complete Brakemaster Terminal is $5370. This figure is reduced by $500 if the factory finds that the brake mechanism from the terminal being replaced is reusable. A complete replacement takes about 3.5 hrs for a crew of three. The labor costs at the time of this writing are $19.92 per hour for personnel and $6.08 per hour for a one-ton truck. A complete replacement would cost $5600 for material and labor. See appendix A for a cost comparison of the Brakemaster and GREAT systems.

E. Recommendations

On a highway where the posted speed limit is less than 60 MPH and a bi-directional end treatment is needed to protect a narrow hazard, installation of a Brakemaster system should be considered. Based on costs and performance of the six systems in use on SH 82, and on literature reviewed, the Brakemaster is an effective, low cost attenuating end terminal for use where impacts are infrequent.

V. Crash Cushion Attenuating Terminal (CAT)

A. Description

The CAT is an energy attenuating guardrail end treatment from the Syro Steel Company. It is designed to absorb energy from a vehicle impacting on the end of the terminal at speeds of up to 70 MPH by shearing metal slots in the rail sections and breaking off the wooden mounting posts as it collapses. In Figure 8 the slotted bolt holes in the first two sections of rail can be seen. The terminal is 31' 3" long and is made up of a nose section and two 13'- 6-1/2" sections of slotted w-beam guardrail. The first slotted section after the nose is 12 gauge rail; the second slotted section is 10 gauge (drawing page 12). Because the posts are set in tubes in the ground, the CAT cannot be installed on concrete or asphalt without first removing the pavement in the area where the terminal is to be placed. The system meets all requirements of N.C.H.R.P. Report No. 230[4].

Figure 8

B. Installation

A CAT terminal was installed on SH 8 at the interchange with US 285 near Morrison. The terminal is in the median just north of the US 285 overpass (map page 13). The speed limit is 20 MPH to slow traffic for the sharply curving ramp to eastbound US 285. The construction report[1] for this study completely documents the original installation of the CAT terminal.

C. Evaluation

1. Performance

There have been no accidents involving the CAT terminal on SH 8. The Indiana Department of Transportation published a report titled <u>VAT & CAT Attenuating Terminals</u>[3] that documents 20 accidents involving CAT terminals over a period of three-and-a-half years. There were 15 injuries and 3 fatalities in 20 accidents. None of the victims of the fatal crashes were using restraints in their vehicles. The CATs stopped the vehicles, but the deaths were caused by the victims being violently thrown around inside the vehicle or thrown from the vehicle.

In several of the accidents documented in the Indiana report, a vehicle struck a CAT the end of a terminal at an angle and passed over, under, or through the terminal. This would make the CAT unsuitable for use in areas where the median is very narrow and the terminal must prevent vehicles from crossing into oncoming traffic.

2. Repairs

Since the CAT terminal on SH 8 has not been hit, first-hand repair information is not available. Repairs would include replacing damaged metal parts and pulling broken post stubs from the soil tubes and installing new posts in the tubes. In cold weather, posts in areas where there is poor drainage may require thawing before the broken stub can be removed from the soil tube.

Damage to a terminal in a collision depends on the speed and weight of the vehicle, and the angle of impact. Since the terminal on SH 8 is in an area where the speed limit is 20 MPH, there should be only relatively minor damage if the terminal is ever hit.

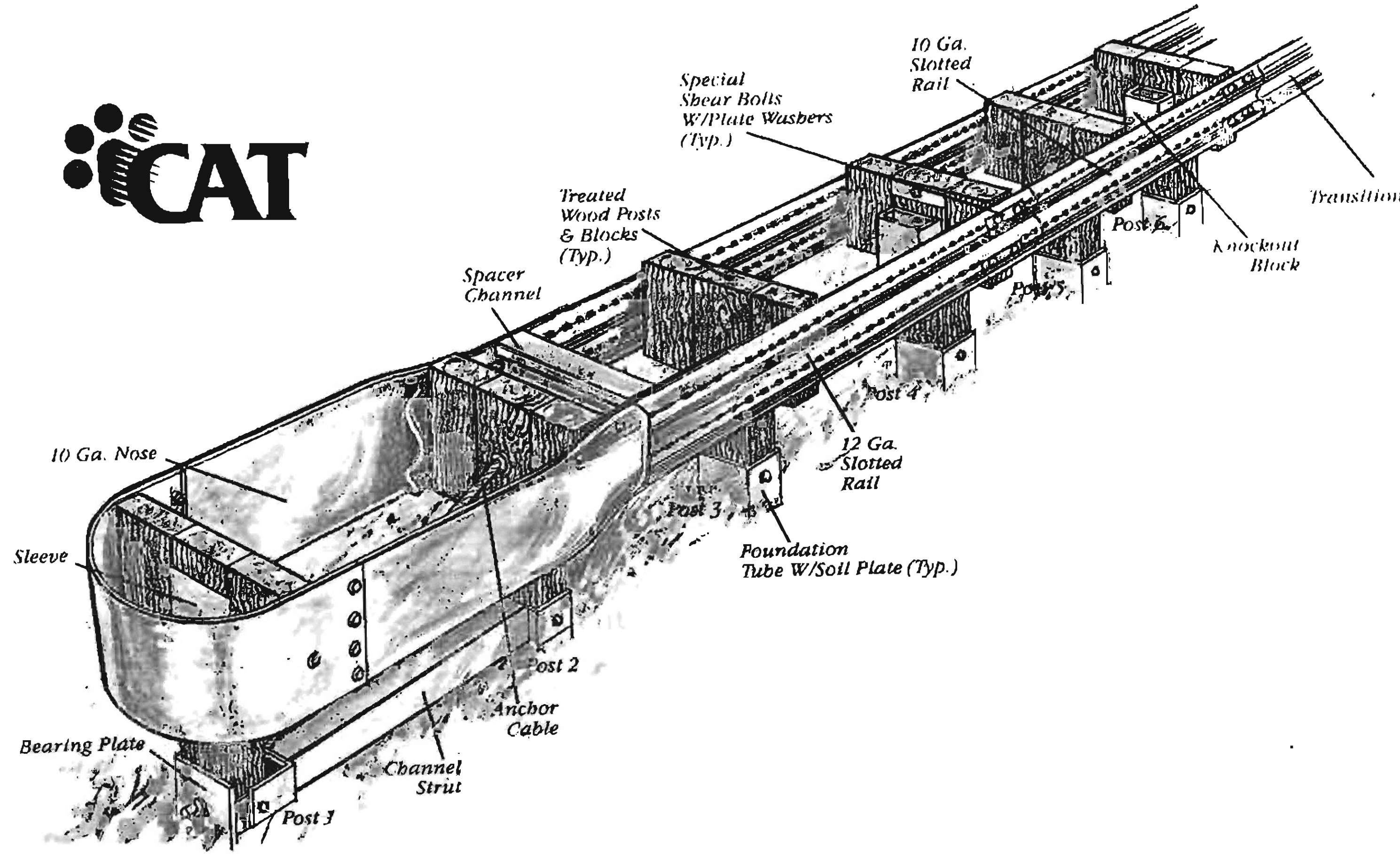
D. Costs

A new CAT terminal costs $4000 plus $2500 in labor to install it. The manufacturer claims that repairs usually cost between $100 and $1800 and take from one-half hour to three hours to perform.

E. Recommendations

The CAT terminal is not recommended for use in a narrow median on a high speed highway where there is no run-out area to contain a vehicle that hit and passed over or through the CAT. Further evaluation should be done before the CAT terminal is accepted by the CDOT for general use on highways with narrow medians.

CAT

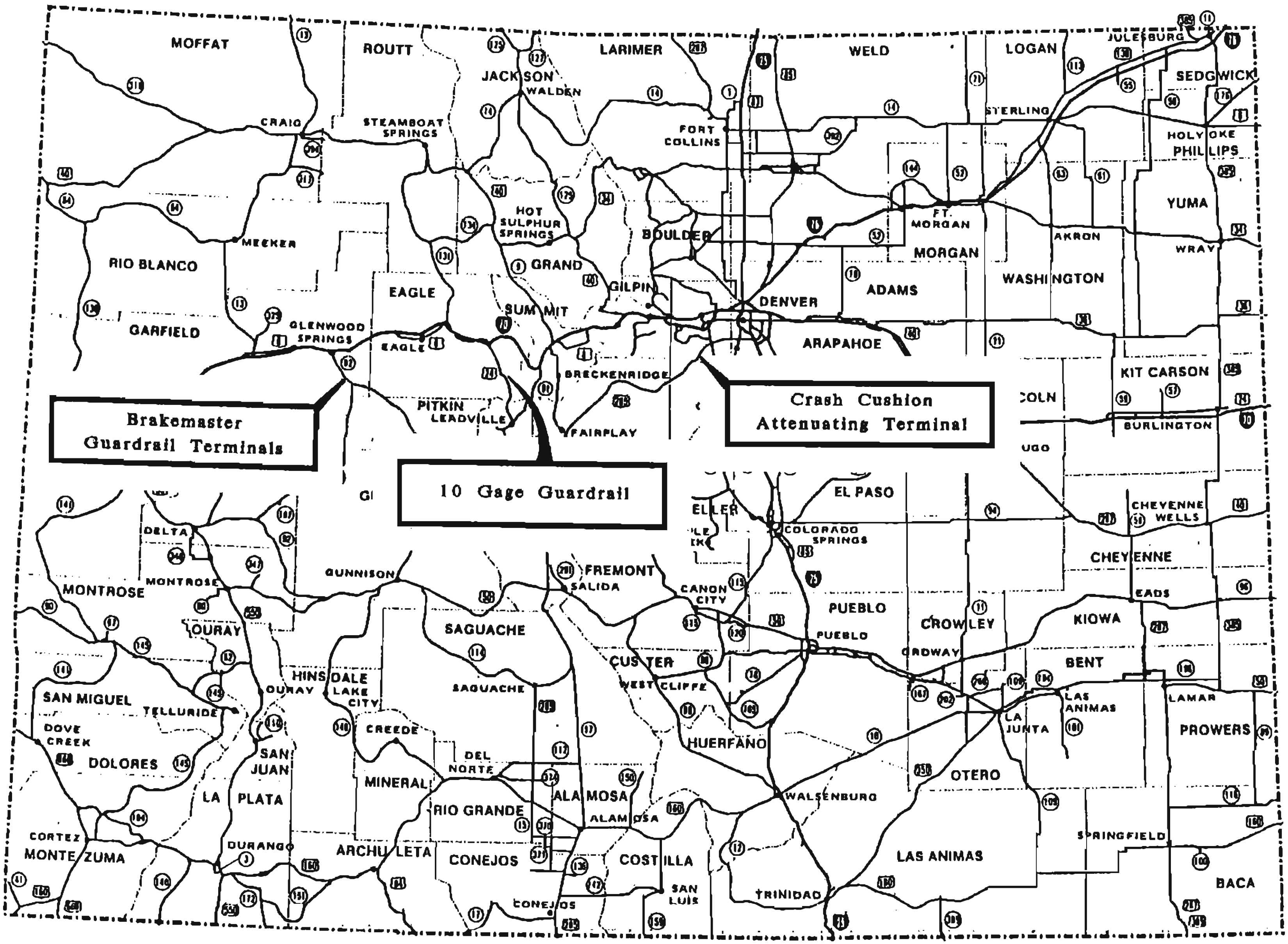


DESCRIPTION:

CRASH-CUSHION ATTENUATING TERMINAL

SYRO

Syro Steel Company



Brakemaster Guardrail Terminals
10 Gage Guardrail
Crash Cushion Attenuating Terminal
MOFFAT
ROUTT
JACKSON
WALDEN
LARIMER
WELD
LOGAN
JULESBURG
SEDGWICK
CRAIG
STEAMBOAT SPRINGS
FORT COLLINS
STERLING
HOLYOKE
PHILLIPS
HOT SULPHUR SPRINGS
YUMA
MEEKER
BOULDER
FT. MORGAN
AKRON
MORGAN
WRAY
RIO BLANCO
GRAND
WASHINGTON
EAGLE
GILPIN
DENVER
ADAMS
SUMMIT
GARFIELD
GLENWOOD SPRINGS
ARAPAHOE
EAGLE
KIT CARSON
BRECKENRIDGE
PITKIN
LEADVILLE
FAIRPLAY
BURLINGTON
EL PASO
CHEYENNE WELLS
COLORADO SPRINGS
DELTA
GUNNISON
CHEYENNE
FREMONT
MONTROSE
MONTROSE
SALIDA
CANON CITY
EADS
OURAY
PUEBLO
SAGUACHE
CROWLEY
KIOWA
PUEBLO
ORDWAY
HINSDALE
CUSTER
BENT
SAN MIGUEL
OURAY
LAKE CITY
SAGUACHE
WEST CLIFFE
LAS ANIMAS
LAMAR
TELLURIDE
DOVE CREEK
CREEDE
LA JUNTA
PROWERS
DOLORES
SAN JUAN
HUERFANO
DEL NORTE
MINERAL
OTERO
LA PLATA
ALAMOSA
WALSENBURG
RIO GRANDE
ALAMOSA
CORTEZ
MONTEZUMA
DURANGO
ARCHULETA
CONEJOS
COSTILLA
SPRINGFIELD
LAS ANIMAS
SAN LUIS
BACA
TRINIDAD
CONEJOS

F. End Notes

1. "Construction Report: In service Evaluation of Highway Safety Devices, Experimental Project No. 7 (CDOH-DTD-R-90-13)" by James M. Ali of the CDOT Research Branch, Denver Colorado, December, 1990.

2. Installation Manual from Energy Absorption Systems, Inc.

3. "VAT & CAT Attenuating Terminals" by Douglas E. Gendron, Research Engineer, Research Division, Indiana Department of Transportation, published August, 1992.

4. "NCHRP Report 230: Recommended Procedure for the Safety Performance Evaluation of Highway Appurtenances." TRB, National Research Council, Washington, D.C., 1981.

5. Galvanized Guard Rail is steel that has been coated with zinc by using a hot-dip process. AASHTO Designation: M 232-84 describes the materials used, thickness required, and testing procedures. "Standard Specifications for Transportation Materials and Methods of Sampling and Testing." Adopted by the American Association of State Highway and Transportation Officials, August 1986.

6. Corrosion resistant steel is described in AASHTO Designation: M 222-86 "High-Strength Low-Alloy Structural Steel". The atmospheric corrosion resistance of this steel is approximately two times that of carbon structural steel with copper (Cu 0.02% max.) and four times that of carbon structural steel without copper. "Standard Specifications for Transportation Materials and Methods of Sampling and Testing." Adopted by the American Association of State Highway and Transportation Officials, August 1986.

7. Strong Soil (10 to 60 blow counts per foot per ASTM D 1586)

APPENDIX A

A cost comparison of the Brakemaster system and the GREAT Crash cushion from Energy Absorption Systems, Inc. follows: Like the Brakemasters used on SH 82, the GREAT system is designed to protect narrow hazards such as the ends of dividers and guardrails. The CDOT has GREAT systems in several locations statewide. A GREAT system costs $17,000 originally and $2958 for a total repair. A total repair involves hooking a chain to the nose of the system and pulling it back into place with a truck or loader, and installing new foam cells which were crushed during the accident. The cells, which are contained between the guardrail sides of the system, are the energy absorbing part of the system. For a crew of three, if the repair takes three hours, it costs $3155 to completely repair a GREAT system. Including 3-1/2 hours of labor for a crew of three, it costs $5600 to totally repair to a Brakemaster system.

To find out how many times a Brakemaster would have to be repaired to equal the cost of a GREAT system: The original cost of a Brakemaster system plus X times a total repair equals the original cost of a GREAT system plus X times a total repair; where X is the number of total repairs which makes the costs equal for the two systems.

$$\$5600 + (\$5600 * X) = \$17,000 + (\$3155 * X)$$

$$5600X - 3155X = 17,000 - 5600$$

$$2445X = 11,400$$

$$X = 4.7$$

After 4.7 total repairs a Brakemaster terminal becomes more expensive than a GREAT system. This is why Energy Absorption Systems, Inc. recommends the Brakemaster for areas of infrequent impacts. (Impacts requiring less than total repair will increase the value of X.)