Mt. Vernon Canyon Runaway Truck Escape Ramp

Report No. CDOH-DTP-R-83-03

Robert L. Hayden
Colorado Department of Highways
4201 East Arkansas Avenue
Denver, Colorado 80222

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16. Abstract

A gravel arrester bed type Runaway Truck Escape Ramp was built on a 5.2% downgrade along I-70 in Mt. Vernon Canyon, Colorado. The ramp was completed in July 1979 and to date it has stopped fifty-three runaway or potentially runaway trucks. Only two trucks sustained damage and there were no injuries or fatalities in the escape ramp. During the same period at this location there were eighteen accidents involving runaway trucks that did not use the escape ramp, resulting in seven fatalities and twenty-four injuries.

A closed circuit TV surveillance system was included as part of the project, and twenty-three trucks were recorded on video tape as they used the escape ramp. Analysis of the tape indicated the rolling resistance to a truck in the gravel decreased as the speed increased. Further research is needed to verify and expand this finding for design purposes. Research is also needed to develop the methodology to predict the maximum probable entry speed of a runaway truck. Research is currently underway to predict the deterioration or contamination rate of the aggregate materials used in arrester beds.

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CONVERSION FACTORS
English to Metric System (SI) of Measurement

Quantity	English unit	Multiply by	To get metric equivalent
Length	inches (in) or (")	2.54×10^{1}	millimetres (mm)
		2.54×10^{-2}	metres (m)
	feet (ft) or (')	3.048×10^{-1}	metres (m)
	miles (mi)	1.609	kilometres (km)
Area	square inches (in^2)	6.452×10^{-4}	square metres (m^2)
	square feet (ft^2)	9.29×10^{-2}	square metres (m^2)
	acres	4.047×10^{-1}	hectares (ha)
Volume	gallons (gal)	3.785	litres (l)
	cubic feet (ft^3)	2.832×10^{-2}	cubic metres (m^3)
	cubic yards (yd^3)	7.646×10^{-1}	cubic metres (m^3)
Volume/Time (Flow)	cubic feet per second (ft^3/s)	2.832×10^{1}	litres per second (l/s)
	gallons per minute (gal/min)	6.309×10^{-2}	litres per second (l/s)
Mass	pounds (lb)	4.536×10^{-1}	kilograms (kg)
	ounces (oz)	2.835×10^{1}	grams (g)
Velocity	miles per hour (mph)	4.47×10^{-1}	metres per second (m/s)
	feet per second (fps)	3.048×10^{-1}	metres per second (m/s)
Weight/Density	pounds per cubic foot (lb/ft^3)	1.602×10^{1}	kilograms per cubic metre (kg/m^3)
Force	pounds (lbs)	4.448	newtons (N)
	kips (1000 lbs)	4.448×10^{3}	newtons (N)
Pressure	pounds per square inch (psi)	6.895×10^{3}	pascals (Pa)
	pounds per square foot (psf)	4.788×10^{1}	pascals (Pa)
Temperature	degrees fahrenheit (F)	$\frac{^{\circ}F - 32}{1.8} = {^{\circ}C}$	degrees celsius ($^{\circ}C$)

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INTRODUCTION

Since 1976 the Colorado Department of Highways has constructed nine runaway truck escape ramps. These resulted from a growing concern about the death and property loss caused by runaway truck accidents on steep grades. Virtually all states having mountainous terrain have experienced such problems, but Colorado, with 2181 miles of mountainous roads on the state highway system experienced above normal increases in the number of truck runaways. Analysis of truck accidents on steep grades identified six critical locations:

- I 70 Mt. Vernon Canyon
- I 70 West of the Eisenhower Tunnel
- I 70 West of Vail Pass Summit
- US40 West of Rabbit Ears Pass Summit
- SH141 North of Slick Rock Hill Summit
- US160 West of the Wolf Creek Pass Summit

During a three year period 15 persons were killed and 81 injured in 152 runaway truck accidents on these grades. The total economic loss was over 5 million dollars. Even if the driver survived the accident, the truck was frequently demolished and other vehicles were sometimes run over, sideswiped, or hit head on. Environmental damage, especially to streams, occasionally occurred when tank trucks carrying fuel or toxic chemicals ruptured.

The first escape ramp in Colorado was built on US 40 on the west side of Rabbit Ears Pass near Steamboat Springs. It was opened in December 1976 and has been used by 60 runaway vehicles. The entire $302,000 construction cost was probably recovered in one incident: On March 13, 1980 a runaway school bus carrying 33 passengers experienced brake and transmission failure and entered the escape ramp at 60 miles per hour. It stopped safely with no injuries or vehicle damage. The Rabbit Ears ramp has also safely stopped several runaway gasoline tank trucks and one truck loaded with 54,000 pounds of high explosives.

The immediate success and driver acceptance of the Rabbit Ears Pass escape ramp prompted the Colorado Department of Highways to complete construction as soon as possible at the other 5 sites. Two ramps were constructed at each of the Eisenhower Tunnel, Vail Pass, and Wolf Creek Pass locations, and one ramp at both Slick Rock Hill and Mt. Vernon Canyon. The latter runaway truck escape ramp was selected for a special research program because it was constructed on a downhill grade.

Interstate 70 through Mt. Vernon Canyon is the last mountainous highway segment encountered by an eastbound motorist before reaching Denver. The highway drops 4800 vertical feet over the 44 miles between the Eisenhower Tunnel and the mouth of Mt. Vernon Canyon. Truckers who use their brakes instead of their transmissions to control speed on the long downgrade frequently overheat or burn out their brakes before reaching Denver. Most of the runaway truck accidents have occurred at the mouth of the canyon at a 5 degree left curve. Between May 1976 and May 1979 there were 30 accidents, resulting in one fatality and 26 injuries.

The possibility of constructing an ascending grade escape ramp just before the curve was ruled out because of the terrain and geometric constraints. I-70 at that location is cut into the north side of the canyon, 80 feet above Mt. Vernon Creek. A concrete retaining wall was constructed along the outer edge of the curve. In some cases the wall reduced the severity of accidents by preventing trucks from rolling down the embankment, but it did not eliminate the runaway truck problem. The wall eventually became so battered by runaways that extensive repairs were needed. Finally, a negative grade, gravel arrester bed runaway truck ramp was designated for a tangent section about 1.7 miles above the curve.

Because of the unusual design and because of an initial lack of driver acceptance, the Colorado Department of Highways wished to explore several operational aspects and characteristics of the ramp. These included: rolling resistance, aggregate performance and contamination, deceleration, maximum entry speed, stopping distance, and effects of the curved approach to the arrester bed. The monitoring system was a crucial factor in this study, and in any future research, such a system must be carefully designed because of the importance of the data that can be collected on entry speed and truck handling characteristics.

ESCAPE RAMP DESIGN

The purpose of a runaway truck escape ramp is to decelerate a truck at a rate gradual enough to prevent injury to the driver or major damage to the vehicle. To do this, a force must be applied to the vehicle. This may be gravity, rolling resistance or a combination of the two. Most ramps, seven of those in Colorado, rely on both forces. The most commonly designed ramps leave the mainline on the right side just before a curve to the left and transition from a descending to an ascending grade. They are surfaced with 4 to 12 inches of pea gravel. The gravel serves to decelerate the vehicle and prevent it from rolling backwards after it has stopped.

The Mt. Vernon Canyon escape ramp was built on the right side of the east-bound lanes of the existing six lane interstate on the same 5.2% downhill grade. The downgrade required that the resistance force needed to stop a runaway truck had to be supplied solely by the rolling resistance of the truck tires in pea gravel. The ramp was designed to stop a fully loaded truck (80,000 lbs.) travelling at 100 mph. Assuming a friction coefficient of 0.20 G's, the arrester bed had to be 2000 feet long. This presented a serious problem since that is the length of the longest tangent section available in Mt. Vernon Canyon, so the approach had to be built on a 5 degree left curve. The arrester bed is not visible to a driver when he first enters the approach.

There were no unusual problems encountered in the construction of the escape ramp and it was ready for use in July 1979. The most illustrative sheets from the construction plans are included in Appendix A. These show the general layout of the facility as well as specific construction details. Also refer to the photographs in Appendix D.

TV SYSTEM DESIGN AND CONSTRUCTION

A closed circuit television system was incorporated into the Mt. Vernon Canyon project to provide qualitative and quantitative information about vehicle dynamics in the gravel arrester bed. The system consisted of four video cameras, a sequential switcher, a time and date generator, a timer, and a video tape recorder and monitor. The whole system was controlled by a series of induction loops installed beneath the escape ramp. The system was activated when a vehicle drove over the first loop located in the paved approach 800 feet from the start of the gravel bed. This started the timer, which ran for a preset time interval, turned on the video tape recorder, and sent a pulse to the video switcher to record the image from Camera #1. It took 5 seconds for the rotary head of the tape recorder to reach full speed and produce a good quality picture. However, the travel time of a runaway vehicle over the 800 foot distance from the first detector loop to the beginning of the gravel was long enough for the tape recorder to reach operating speed. Camera #1 was located at the beginning of the gravel and only showed the ramp approach. Cameras #2, #3, and #4 were located, respectively, 600 feet, 1200 feet and 2000 feet from Camera #1. Induction loops positioned 50 feet in front of the first three cameras sent a pulse to the video switcher. Therefore, just as a runaway truck left the field of view of one camera, the detector switched to the next so that a runaway could be followed all the way through the gravel.

Another series of 22 induction loops, spaced at 100 foot intervals were designed to give quantitative information about vehicle speed and deceleration. The detectors connected to these loops sent a signal to the date and time generator, which was modified for this installation. The time function was altered from the standard hours, minutes, and seconds mode to instead show minutes, seconds,and tenths of seconds. The date function was modified to show a two digit sequence count (00 to 99) every time one of the 22 loops was activated. When the system worked properly, it was possible to generate plots of runaway truck distance-time, speed-time, and deceleration-time.

The surveillance system was installed during the summer of 1979. The saw cuts for the detector loops were made in the asphalt approach and in the asphalt base of the arrester bed before the gravel was placed. The wires were run through polyvinyl chloride (PVC) pipe to cast-in-place concrete junction boxes on the south side of the retaining wall. PVC conduit was also used to connect the junction boxes with the equipment cabinet. The four cameras were mounted on light standards, and all the other equipment was installed in a metal traffic signal cabinet mounted on a concrete base behind the retaining wall near the beginning of the ramp. No unusual problems were encountered during construction except for a gound loop problem that distorted the video signals. This was rectified by installing a ground loop corrector.

TV SYSTEM OPERATING PROBLEMS

The system appeared to be working properly by late September 1979 and was accepted by the state. Almost immediately, however, problems began to arise. The series of 22 loops that were supposed to indicate vehicle position malfunctioned, and the TV system locked onto Camera #3. The contractor diagnosed the lock up problem as failure of the video switcher, but after two additional switchers were tried the problem persisted. Camera #3 was disconnected during this time since Cameras #1 and #2 were expected to show most of the action, however Camera #1 also began to lock up which made TV surveillance system virtually useless. The problem was finally traced to improper grounding of the cameras, but it was never possible to make the 22 loops that indicate vehicle position operate properly.

CDOH personnel made a number of changes to the system in an attempt to improve operating performance and reliability. As stated, one of the problems encountered was the failure of the 22 position loops to function properly. The source of the problem was thought to be the inability of a single traffic loop detector to power all 22 loops. They were, therefore, divided into three separate circuits with a separate detector for each circuit.

An additional loop was also added to the paved approach 200 feet from the beginning of the gravel arrester bid. This was wired into the Camera #1 circuit because trucks sometimes missed the first loop when entering the approach. The second loop, therefore, was needed to activate the system. This helped in getting video tape of most of the vehicles. Unfortunately, trucks that activated the video recording system at this second loop had already entered the gravel before the rotary head on the tape recorder had reached full operating speed. This resulted in loss of data on truck handling characteristics in the critical transition area between the asphalt paved approach and the gravel arrester bed.

From the opening of the Mt. Vernon Canyon Truck Escape Ramp in July 1979 there were problems caused by unauthorized vehicles using the facility. Many of these were four-wheel drive recreational vehicles which make up a relatively large percentage of total registrations in Colorado. The drivers were attracted by the gravel and left deep ruts from spinning their wheels in it. This increased maintenance efforts and costs to keep the gravel smooth, and required an unnecessarily large number of trips to the installation to change the video tape.

The Colorado Division of Highways and the Colorado State Patrol both became concerned about the safety hazards that these motorists created since a vehicle stuck in the gravel could cause a driver to avoid using the escape ramp. The gravel rutting also posed a danger to a truck driver trying to bring his runaway vehicle back under control. This was shown on a video tape of one truck entry. The beginning of the arrester bed was badly rutted. As a result, the truck bounced rather severly and was thrown to the left when it hit the ruts, but it did manage to stop safely.

TRUCK ESCAPE RAMP USE

The 59 reported uses of the Mt. Vernon Canyon Escape Ramp are summarized in Appendix C. In addition, the following narrative describes the higher speed entries. On several occasions, trucks entered the ramp accidentally or as a precautionary measure, however, they are not described below since they do not reflect useful data about the operational characteristic of the ramp.

July 30, 1979 - This was the first use of the escape ramp, and it occurred only two weeks after the gravel had been placed in the arrester bed. Entry speed was 60 to 65 mph by the driver's estimate. The truck travelled 510 feet through gravel, jackknifed out onto the shoulder, went 320 feet on the shoulder, then reentered the gravel and safely stopped in 94 feet. An investigation conducted by the Colorado State Patrol revealed the tractor had good brakes, but the brakes on the trailer were worn out. Since the driver applied his brakes in the ramp, this may have caused the trailer to push the tractor out of the gravel.

August 24, 1979 - The truck brakes would not hold, and as it picked up speed, the driver kept upshifting to avoid blowing the engine. The truck was on the shoulder to avoid colliding with other vehicles. It entered the ramp at a driver estimated speed of 70 to 80 mph and stopped in 738 feet.

January 13, 1980 - The truck entered the escape ramp at a driver estimated speed of 50 mph and stopped in 475 feet. The entry was at 4:30 pm on a Sunday in the midst of heavy traffic returning from the ski areas. It is unlikely that the truck could have gone much further without having a collision with another vehicle.

March 5, 1980 - The driver missed a shift and could not get the transmission back into gear. He entered the ramp at an estimated speed of 70 mph and stopped in 417 feet.

March 13, 1980 - The truck entered the ramp at an estimated speed of 55 to 60 mph and stopped 547 feet into the gravel. The driver stated he was going too fast and was not familiar with the road ahead.

June 12, 1980 - The driver overheated his brakes and entered the gravel at 55 mph (speed from video tape analysis). The truck bounced severly at the ramp entrance when it hit ruts left by unauthorized vehicles, fishtailed for a few hundred feet, and stopped after travelling 800 feet into the arrester bed.

June 12, 1980 - This was the second use of the ramp on the same day. The truck entered at an estimated 70 to 75 mph and stopped in 435 feet.

July 5, 1980 - The trailer brakes overheated and the engine blew. The actual speed (from video tape) was 36 mph, the driver's stated speed was 80 mph, the truck stopped in 324 feet. The truck hit the retaining wall which resulted in bent tie rods and smashed fuel filters.

August 14, 1980 - The driver lost air pressure, entered the ramp at an estimated 80 mph, and stopped in 1020 feet. The driver commented that the curved approach was "bad."

October 17, 1980 - The truck entered the ramp at 65 mph (from video tape analysis) and stopped in 1000 feet. The video tape showed the truck maintaining an almost perfectly straight path through the arrester bed.

May 8, 1981 - The driver overheated his brakes, entered the ramp at 75 mph (from video tape analysis), and stopped after travelling 889 feet.

May 31, 1981 - The truck entered the arrester bed at 61 mph (from video tape analysis) and stopped in 600 feet.

September 28, 1981 - The truck lost air pressure and entered the escape ramp at an estimated speed of 78 mph. It travelled 912 feet before stopping.

December 14, 1981 - The truck entered the ramp at an estimated speed of 59 mph, travelled 450 feet through the gravel, and then collided with the right side retaining wall. The impact bounced the trailer out of the ramp and onto the shoulder. The driver corrected for the trailer swing and hit the retaining wall again. The vehicle came to rest on its wheels after travelling a total distance of 705 feet. A tie rod on the tractor was broken, but the driver was not injured. The arrester bed was covered with one inch of snow at the time.

March 12, 1982 - The truck entered the escape ramp at an estimated speed of 75 mph. The trailer and tractor right side driver brakes were not working and the tractor left rear driver brake was locked. The vehicle struck the retaining wall before reaching the arrester bed, slid along the wall for 48 feet, turned onto its right side, and slid against the wall on its side for another 239 feet. The trailer sheared off two light standards and part of the load (lumber) went over the retaining wall. The truck was severly damaged but the driver was uninjured.

March 20, 1982 - The runaway truck entered at a driver estimated speed of 90 mph and travelled 822 feet before stopping. The driver stated he was "bounced around."

May 26, 1982 - The driver burned out his brakes, entered the ramp at an estimated speed of 70 mph, and stopped after travelling 615 feet.

July 30, 1982 - The truck entered the ramp at an estimated 62 mph and travelled 686 feet before stopping. The driver said that the tractor "fished a little bit."

August 24, 1982 - A two axle truck towing a two axle trailer lost air pressure for the brakes. It entered the arrester bed at an estimated 70 mph and went 342 feet.

October 27, 1982 - The truck entered at an estimated 70 mph and travelled 456 feet. The driver stated it was "hard to hold, but it stayed in straight."

November 4, 1982 - The driver experinced transmission failure, so entered the ramp at an estimated 40 mph and travelled 384 feet. The truck "pulled to the right after first entering the ramp, then slowed down gradually", according to the driver.

November 8, 1982 - The runaway truck entered the escape ramp at a driver estimated speed of 65 mph and stopped 655 feet into the gravel. There were no brake shoes on the right front and left rear dual wheels on the trailer.

November 17, 1982 - The driver experienced loss of air pressure, entered the ramp at 40 to 50 mph, and stopped in 465 feet.

December 8, 1982 - The driver overheated his brakes and took the escape ramp at 50 mph. The truck stopped in 274 feet but "rocked side to side" when it first entered the arrester bed.

ROLLING RESISTANCE AND DECELERATION RATES

The rolling resistance and the decelration rate that the gravel arrestor bed material imparts to a runaway truck is one of the key parameters needed for design. The presently accepted value, based upon a limited amount of research, is 0.2G's where G is the gravitational acceleration parameter of 32.2 feet per second per second (ft/sec.^{2}). This value has been incorporated into the Colorado Roadway Design Manual for the design of runaway truck escape ramps. 0.2G's is considered a conservative estimate which will provide a factor of safety. For design purposes, the rolling resistance, maximum anticipated entry speed, and the escape ramp geometry determine the necessary length of the arrestor bed. A low estimate of the actual rolling resistance will result in an uneconomical ramp overdesign and a high estimate will result in a facility that may not be able to safely stop runaways within its length. The design value of 0.2G's for the rolling resistance has been assumed to be a constant that is speed independent. Other researchers have suggested that this may not be true, but the instrumentation needed for verification was not incorporated into a ramp until the Mt. Vernon Canyon installation was operational.

The TV surveillance system for Mt. Vernon Canyon was designed to provide this kind of information. The traffic loop detectors spaced at 100 foot intervals beneath the ramp were intended to produce a pulse that would increment a counter signal visible on the TV screen every time a truck activated one of the loops. A time generator, capable of displaying elapsed time to the nearest tenth of a second was integrated into the system. It, like the loop counters, produced an output on the video screen.

If the system had worked as planned each runaway truck would have been recorded on video tape for analysis. Also had the loops worked properly, it would have been possible to determine the time at which the runaway passed over each detector, and a very precise distance-time plot could have been produced. In actual operation, however, the loop detectors performed poorly, either not producing pulses to advance the counter, or producing stray pulses that erroneously advanced the counter. Fortunately, the time generator performed adequately most of the time, and there was another method to determine the position of the truck. The delineator panels on the left side and the light standards on the right were visible in the tape recorded image, and the distance of these landmarks from the beginning of the gravel arrester bed was measured in the field.

The distance-time curves shown in Figures 1 through 5 were produced by plotting the position of each runaway truck as a function of time. The distances were determined from the video tape by estimating when the runaway was adjacent to each light standard or delineator panel. There was some uncertainty in this approach because of parallax, especially when the truck was distant from the camera, but the results seem to be reasonably good, although not as precise as the data that would have been generated by a properly working loop system.

In Figure 1 through 5 the distance shown is in feet and the time is in seconds. The speed-time curves (speed in ft/sec) were derived by applying standard methods of graphical calculus to the distance-time curves. The deceleration curves (in ft/sec^2) were produced from the speed-time data in the same way.

Figures 1 through 4, which represent data from loaded 5 axle tractor-semitrailer rigs, all indicate that the deceleration increases with time, or more precisely, the deceleration rate increases as the speed decreases. Figure 5, which is for a two axle, 6 tire moving van weighing only 20,400 pounds, indicates a constant deceleration. The rate for this vehicle was approximately 9.3 ft/sec^2, which is reasonably close to the terminal deceleration rate for the heavy 18-wheelers. More data on lighter trucks would be needed to show whether this event was representative, but from a practical standpoint, the big trucks should definitely be used as the design vehicle for escape ramps.

The observed deceleration rates have to be adjusted for gravity to determine the rolling resistance of the gravel. At Mt. Vernon, which is on a 5.2% downgrade, gravity works "against" the gravel in the sense that the force from the gravel is operating against the direction of the truck's travel and the force of gravity is working in the direction of travel. The correction factor for Mt. Vernon is given by the term sine (arctangent 0.052) which is 0.052 G's. The actual rolling resistance (G's) can be determined from the deceleration rates (ft/sec^2) by dividing the latter by G (32.2 ft/sec^2) and adding the adjustment factor of 0.052 G's. This has been done in Figure 6 where the G-value for the gravel has been plotted against speed for the events of Figures 1 through 5.

Figure 6 must be interpreted and used with caution. Curves 1, 2, 3, and 4, which are for heavy tractor-semitrailer units all converge to a rolling resistance of 0.36 as the speed reaches zero, but at high speeds they diverge widely. This could be related to the condition of the gravel at the ramp entrance or to completely unknown factors. The design value of 0.2 G seems to be a good average for entry speeds as high as 100 ft/sec (68 mph), but it could produce an inadequate design for higher design speeds. The rolling resistance for higher entry speeds cannot be estimated with the data available from Mt. Vernon Canyon.

FIGURE 1
5 AXLE TRACTOR SEMITRAILOR - 78,100 POUNDS
MT. VERNON, 6-12-80

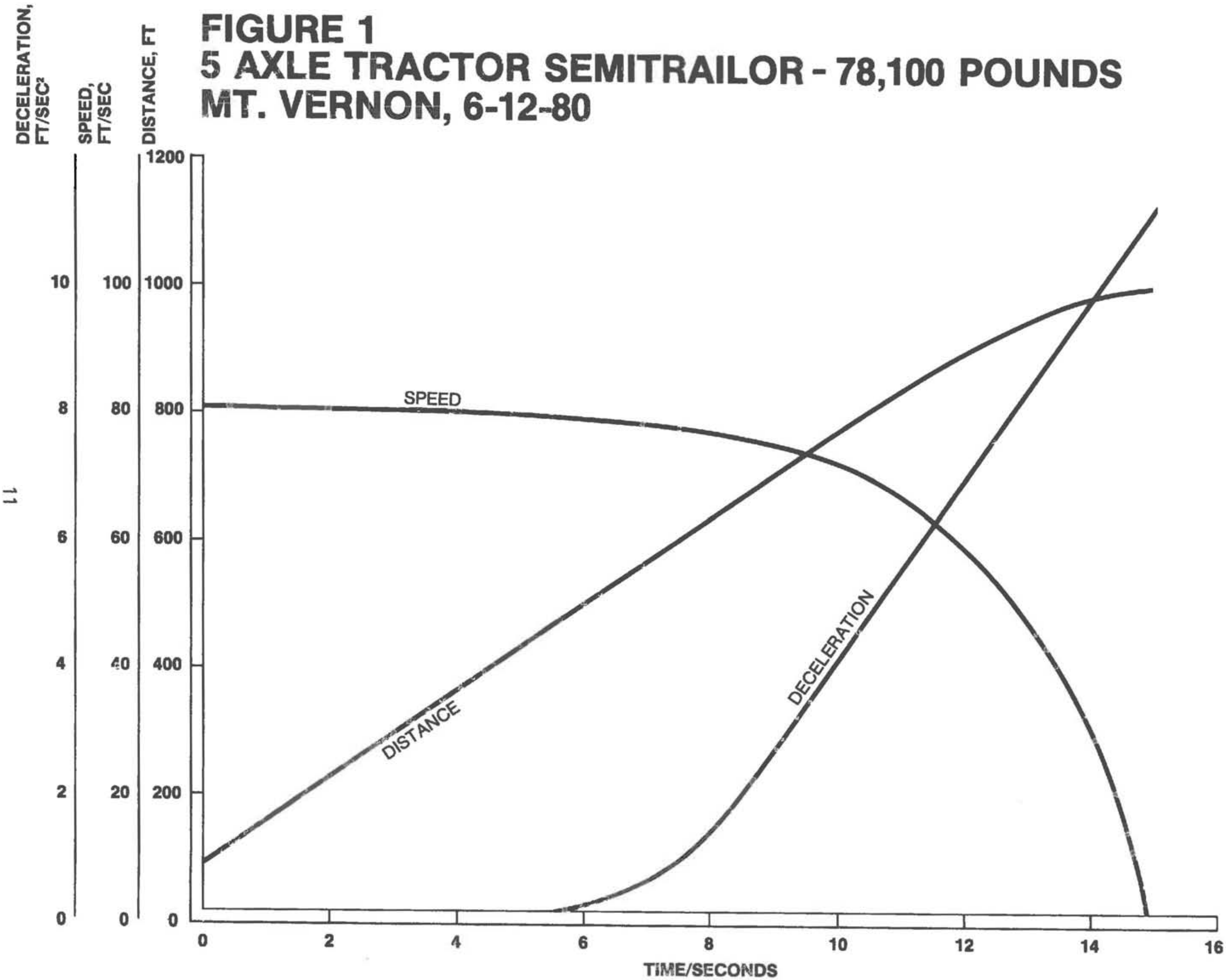


FIGURE 2
5 AXLE TRACTOR SEMITRAILOR-78,000 POUNDS
MT. VERNON, 10-17-80

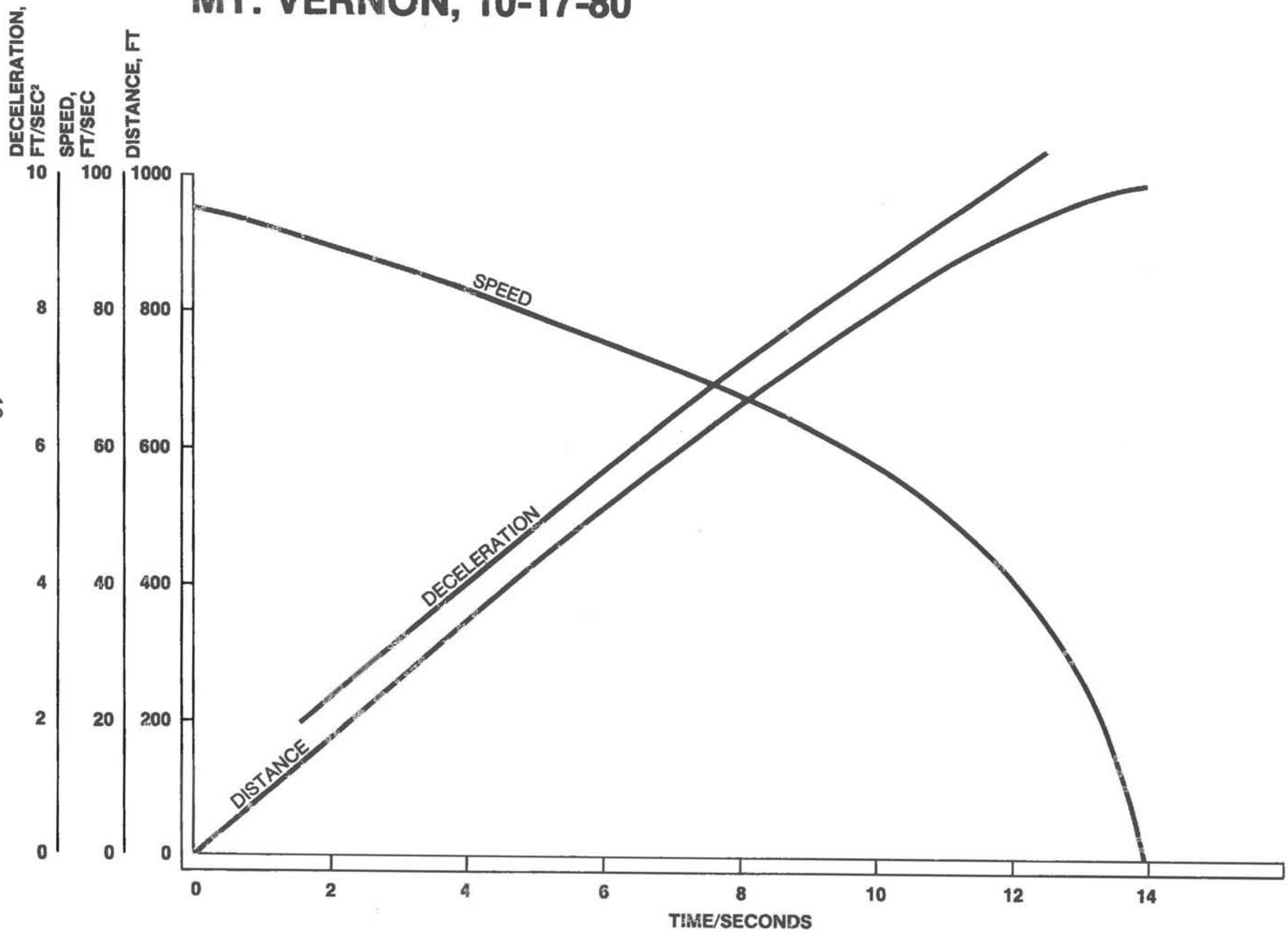


FIGURE 3
5 AXLE TRACTOR SEMITRAILOR - 74,000 POUNDS
MT. VERNON, 5-8-81

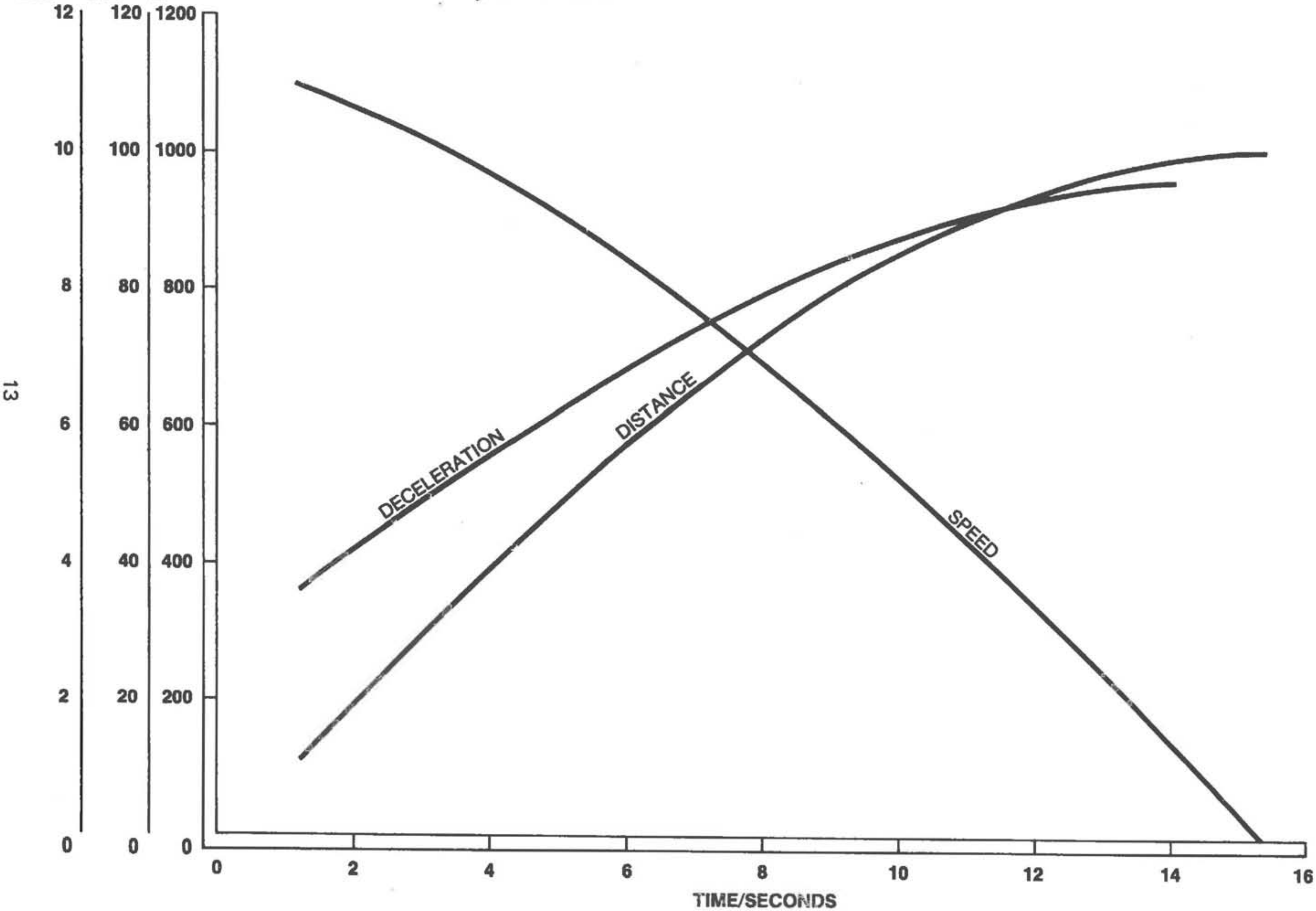


FIGURE 4
5 AXLE TRACTOR SEMITRAILOR - 77,300 POUNDS
MT. VERNON, 5-31-81

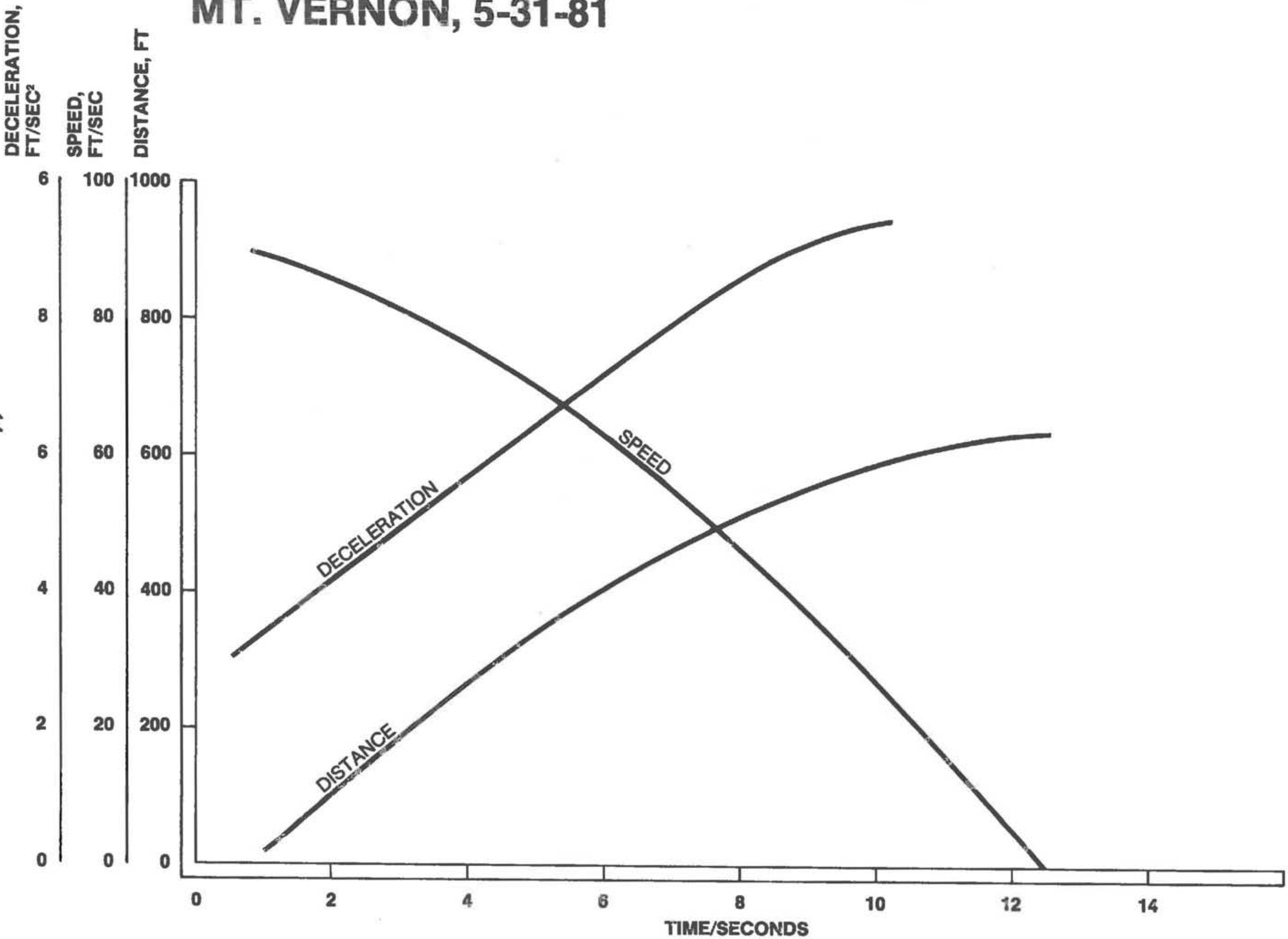


FIGURE 5
2 AXLE VAN - 20,400 POUNDS
MT. VERNON, 7-23-80

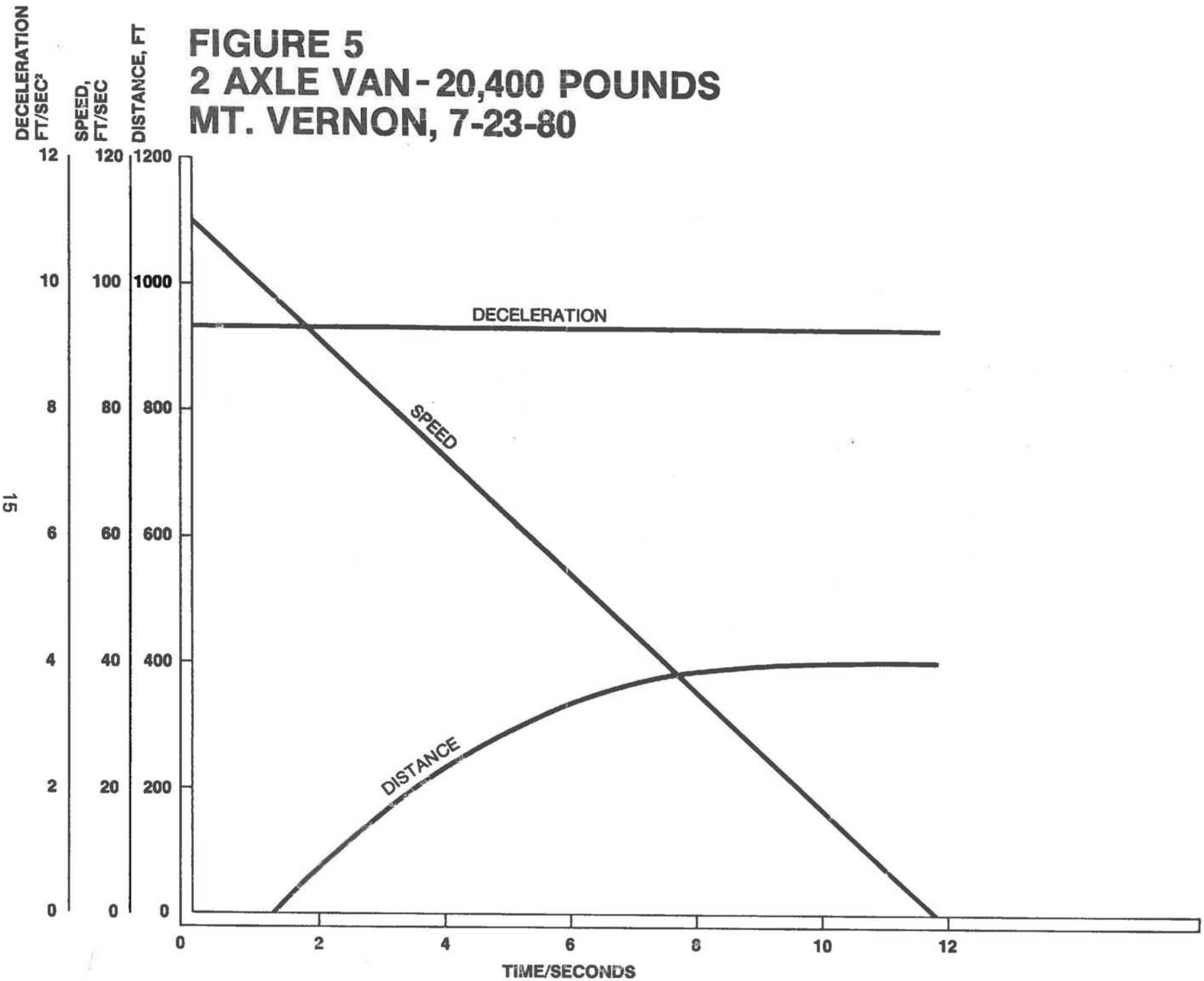
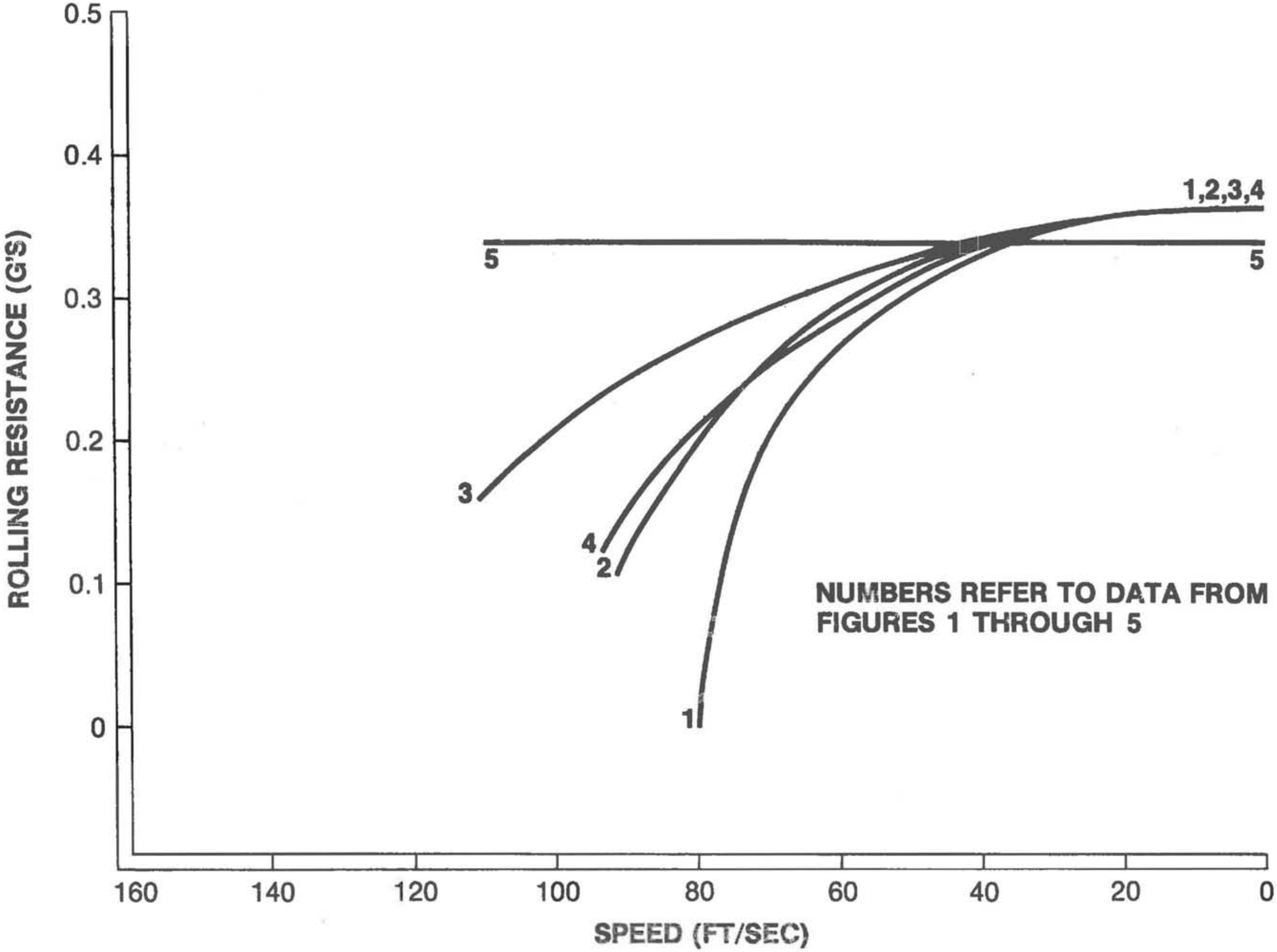


FIGURE 6



0.5
0.4
0.3
0.2
0.1
0
ROLLING RESISTANCE (G'S)
1,2,3,4
5
5
3
4
2
1
NUMBERS REFER TO DATA FROM FIGURES 1 THROUGH 5
160
140
120
100
80
60
40
20
0
SPEED (FT/SEC)

AGGREGATE CONTAMINATION

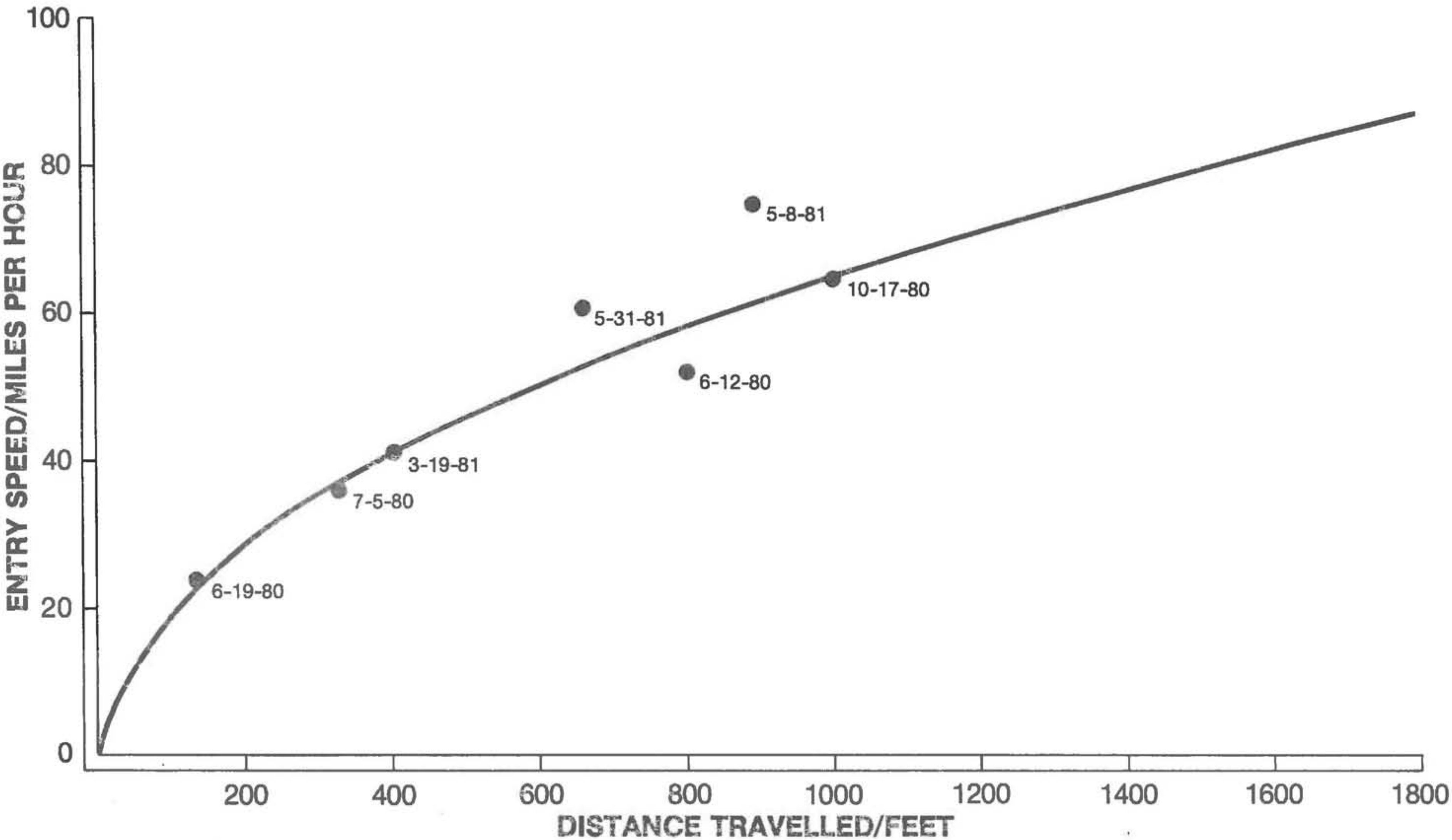
Aggregate materials for truck escape ramp arrester beds should be as round and uniformily graded as possible. These characteristics contribute to the material's ability to decelerate a runaway truck on a downhill ramp, or to prevent it from rolling backwards on a gravity ramp. The aggregate can, however, become contaminated and lose its effectiveness after a period of time. The source of contamination may be sand from winter maintenance activity or fine soil particles carried into the arrestor bed by flowing water. The fine material has a tendency to fill in the air spaces between the pieces of round aggregate. This makes a runaway vehicle ride over the top of the gravel, rather than sinking in and stopping.

Aggregate contamination at the Mt. Vernon Canyon Truck Escape Ramp has been minor and has not degraded the effectiveness of the facility after three and one-half years of service. The District Engineer has instructed maintenance personnel to keep a windrow of snow along the left side of the escape ramp during the winter, and this has prevented sand from migrating into the aggregate. The base beneath the gravel is also paved, which eliminated the possibility of soil particles entering the gravel.

The restoration of contaminated aggregate is expensive. It must be replaced with new material or removed, screened, and reused. Either alternative is expensive and a safety hazard can be created since the escape ramp must be taken out of service while the work is being done. It would be very advantageous to be able to predict when restoration is warranted, rather than taking emergency action after a failure indicates severe contamination. It may be possible to assess the condition of the aggregate by correlating entry speed with stopping distance for the heaviest trucks that enter the escape ramp. This has been done for Mt. Vernon as shown in Figure 7. The usages included in the figure are only those where the entry speed could be determined accurately from the video tape. Comparisons made between known actual entry speed and driver reported entry speed have shown that the drivers' estimate is unreliable. Drivers tend to overstate the entry speed but not by a predictable amount or percentage of the actual.

The TV surveillance system at Mt. Vernon Canyon is no longer operational, but should it be possible to install a device that will measure vehicle entry speeds, possibly utilizing the traffic detectior loops in the approach. Distance travelled for each entry will always be available since it is measured accurately by the Colorado State Patrol. By monitoring the distance travelled and the entry speed for the most recent usages, it should be possible to predict when corrective action is needed.

FIGURE 7
MT. VERNON CANYON
LOADED TRACTOR SEMITRAILOR ≈ 78,000 POUNDS



MAXIMUM ENTRY SPEED

Runaway truck entry speed, rolling resistance of the arrester bed material, and the geometry of the escape ramp are the three parameters that determine the design length. A reasonable estimate of the maximun anticipated entry speed is, therefore, a very important factor in determining economical and effective design. The distance that a given truck will travel into an escape ramp is theoretically proportional to the square of the entry speed, although the apparent variable rate of rolling resistance with speed may complicate the design. The Mt. Vernon site was designed for an entry speed of 100 mph. This value was provided by witnesses to truck wrecks at the curve at the mouth of the canyon and may be too high for the same psyshological reasons that make truckers who use escape ramps overestimate their entry speed. From analysis of the video tape, two trucks are known to have entered the escape ramp at close to 75 mph, which is the highest confirmed entry speed to date. This does not necessarily mean that a speed of 100 mph is not achievable, rather, it demonstrates the need for a reliable method to predict the maximum likely speed.

A possible methodology was developed by the Idaho Transportation Department (Reference 10). The report describes a calculator program that predicts trucks speed on a downgrade using as input highway geometry and vehicel aerodynamics. The program looks promising but needs verification.

TRUCK DRIVER PROFILE

Of the 59 drivers who used the Mt. Vernon Canyon Runaway Truck Escape Ramp, the number of years of mountain driving experience was available for 54, and the age was available for 57. The average age was 33 and the average mountain driving experience was 5 years.

Years Experience in Mountain Driving

None	Less than 2	2 to 5	5 to 10	10 or more
9	16	14	7	8

Age of Drivers

20's	30's	40's	50's	60's
22	24	8	2	1

The typical user of the escape ramp was in his twenties or thirties and had less than five year's experience in mountain driving. The most common reason for the runaway was that the driver burned out or overheated the brakes from excessive use. More experienced drivers use the transmission to control speed on downgrades.

Before I-70 was built in the early 1970's the route through Mt. Vernon Canyon was US40, a two lane highway with some sections of uphill climbing lane and a posted speed of 40 mph. US40 had the same grades as I-70 but more horizontal curves. There were, however, very few runaway truck accidents on the old highway. Perhaps drivers are not aware of how quickly a truck can pick up speed on a long, straight downgrade.

CONCLUSIONS AND RECOMMENDATIONS

In order to define the significant performance factors and operational characteristics of a downhill escape ramp, this study examined: rolling resistance, aggregate performance and contamination, deceleration, maximum entry speed, stopping distance, the curved approach in Mt. Vernon Canyon, and the data needed from a monitoring system. The following conclusions and recommendations are made:

1. The Mt. Vernon Canyon Truck Escape Ramp, which was built on a 5.2% downgrade, has been found to be effective in stopping runaway trucks. There have been 59 reported uses of the ramp since it was opened in July 1979. Some of the entries were unintentional and others were made at relatively low speed as a precautionary measure. Twenty-five entries were made at a high enough speed to strongly imply that those trucks would not have been able to safely negotiate the curve at the mouth of the canyon or to avoid an accident with other vehicles.

2. The performance of the closed-circuit TV surveillance system installed to monitor the escape ramp was less than expected. Deficiencies in the design, the quality of the equipment, the skill of the contractor, and the severe environment all had an adverse effect.

3. There has been little difficulty with contamination with the Mt. Vernon Canyon ramp because of the asphalt base. However, since the aggregate's rolling resistance is the single factor operating to stop a truck on a downhill ramp, contamination problems, their nature, and methods of prediction and prevention are key factors in design and maintenance of other downhill ramps.

4. Research is also needed on a reliable method to predict the maximum probable entry speed of a runaway truck at a proposed escape ramp location. The Mt. Vernon Canyon facility may be longer than necessary. No truck has ever travelled more than 1020 feet into the gravel and the array of impact attenuator barrels at the end has never been hit.

IMPLEMENTATION

The Mt. Vernon Canyon Runaway Truck Escape Ramp has been effective in stopping out of control vehicles. Twenty-five entries have been made at a high enough speed to suggest the liklihood that many of them would have been involved in property damage, injury, or fatal accidents. If the $942,000 spent on construction is allocated among these 25 vehicles the cost is $47,680 for each one over the 3½ year period that the escape ramp has been in existance. The value of a truck semitrailer, typical cargo, and life of the driver is worth much more than this amount.

The negative grade design is recommended for implementation at locations where there have been an excessive number of runaway truck accidents and an ascending grade gravity ramp is not physically or economically feasible. This recommendation is made based upon both adequacy of performance and the favorableness of the benefit/cost ratio.

Other highway agencies that may be considering a negative grade truck escape ramp might want to obtain a copy of the video tape that was produced for this study. Although the quality is poor on many of the entries, the tape does demonstrate the effectiveness of the Colorado design. A copy will be made if a blank VHS format video cassette is sent to:

Colorado Department of Highways
Research and Development Section
4201 E. Arkansas Avenue
Denver, Colorado 80222

REFERENCES

1. Crowe, N.C., Jr., Photographic Surveillance Study of Runaway Truck Escape Ramps in North Carolina, North Carolina Department of Transportation, September 1977.

2. Erickson, R. C., Jr., A History of Runaway Truck Ramps in Colorado, Colorado Department of Highways, 1980.

3. Indahl, George W., John J. Quinn and Kenneth C. Afferton, Vehicle Entrapment, New Jersey Department of Transportation, June 1976.

4. Versteeg, J.H., Truck Escape Ramps - Design and Testing, Oregon Department of Transportation, 1978.

5. Newton, James M., Roadside Truck Arrester Beds, Federal Highway Administration, Region 9, May 1981.

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8. Interim Guidelines for Design of Emergency Escape Ramps, Federal Highway Administration Technical Advisory T5040.10, July 5, 1979.

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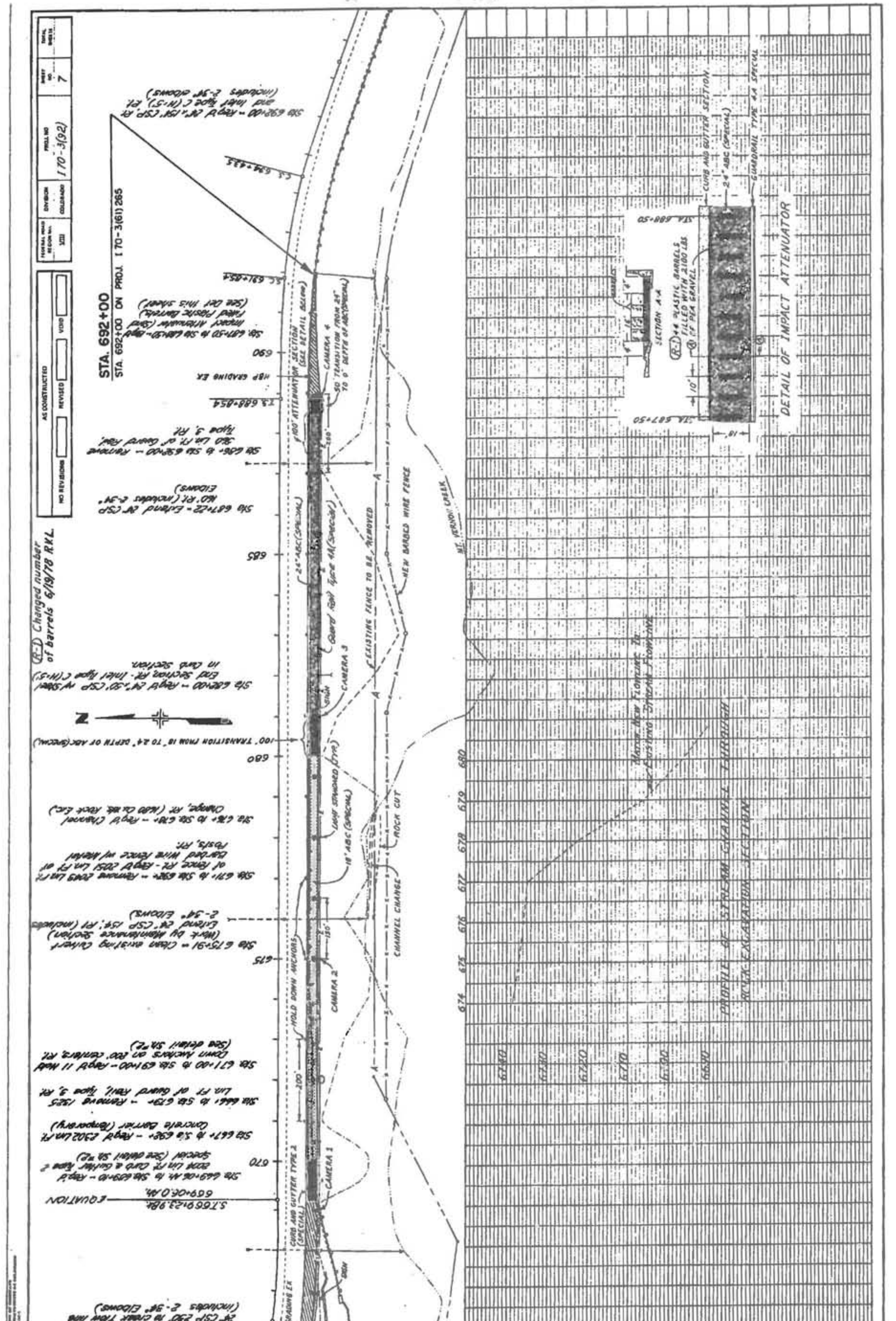
10. Stanley, A.F., A Calculator Program to Estimate Truck Coasting Speeds for Designing Gravel Arrester Beds, Idaho Transportation Department, November 1978.

11. Ballard, A.J. and E.C. Kimball, Jr., Heavy Vehicle Escape Ramps - A Review of Current Knowledge, Southwest Research Institute, April 1982.

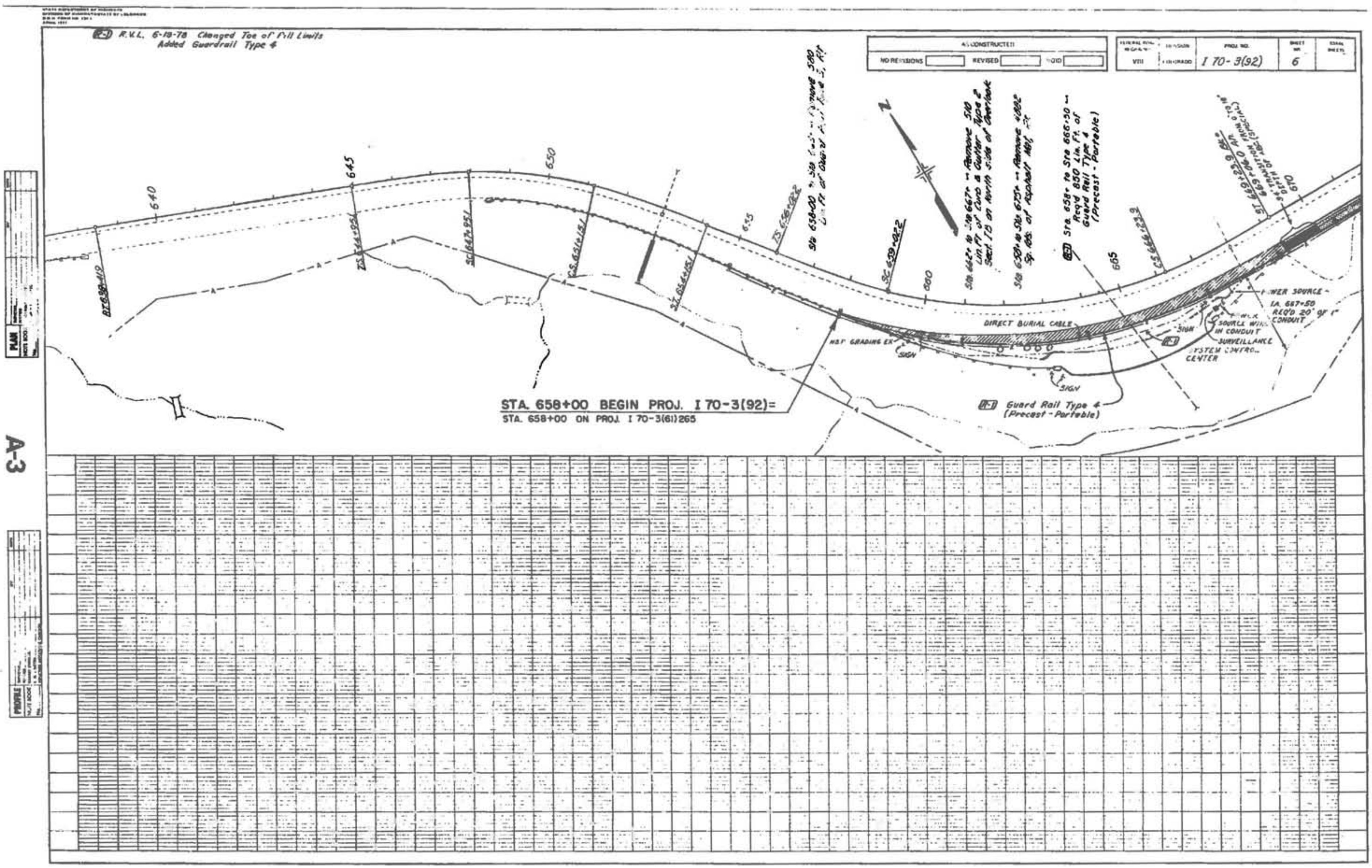
12. Roadway Design Manual, Colorado Department of Highways, January 1980.

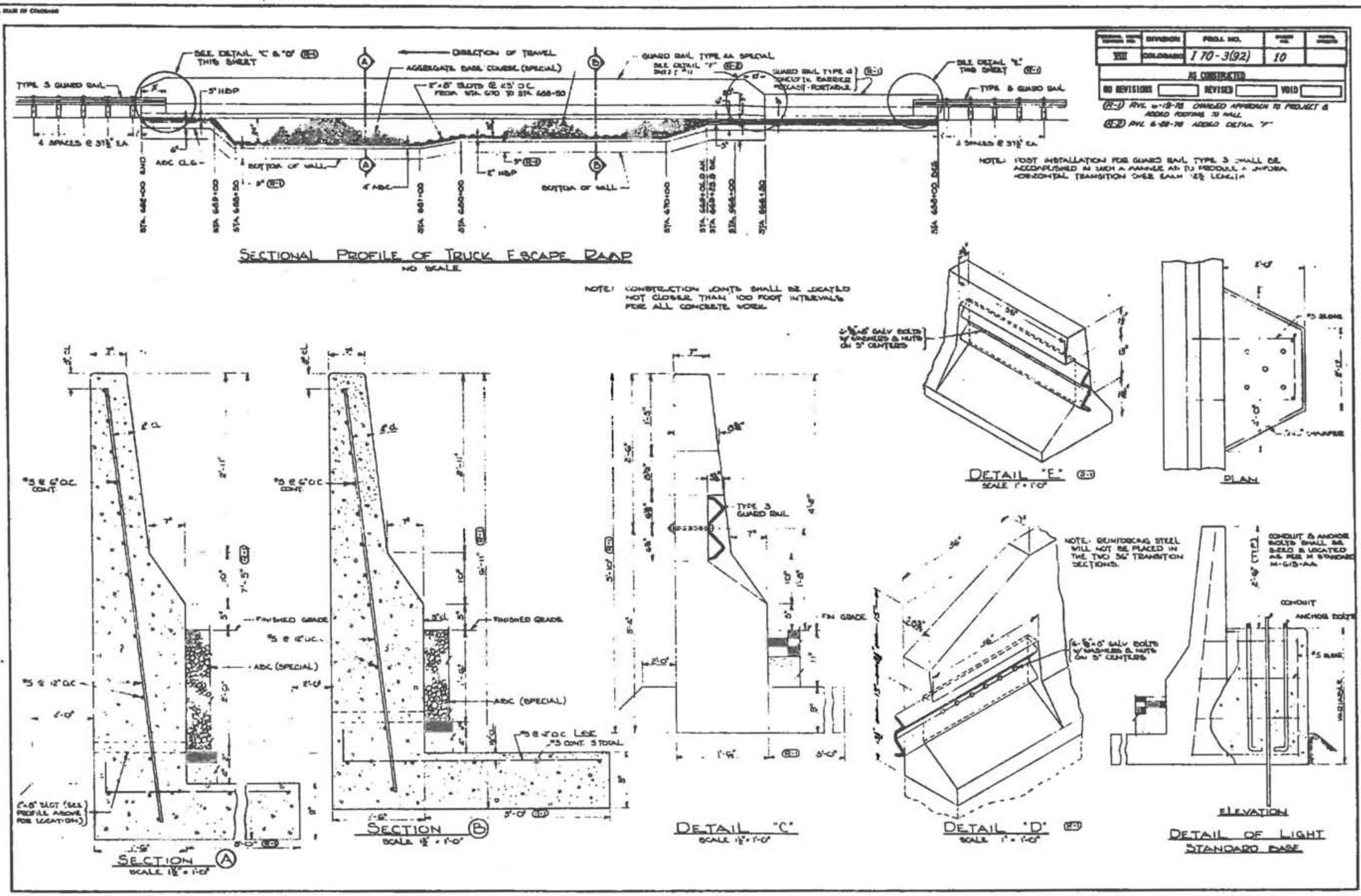
APPENDIX A

CONSTRUCTION DETAILS



STA. 692+00
STA. 692+00 ON PROJ. I 70-3(61) 265
R-1 Changed number of barrels 6/19/78 RKL
I 70-3(92)
DETAIL OF IMPACT ATTENUATOR


R.V.L. 6-18-78 Changed Toe of Fill Limits
Added Guardrail Type 4
AS CONSTRUCTED
NO REVISIONS
REVISED
VOID
VIII
COLORADO
I 70-3(92)
6
640
645
650
655
660
665
670
N
Sta 658+ to Sta 666+50 ~ Req'd 850 Lin. Ft. of Guard Rail Type 4 (Precast - Portable)
DIRECT BURIAL CABLE
SIGN
SOURCE WITH IN CONDUIT
SURVEILLANCE
CENTER
Guard Rail Type 4 (Precast - Portable)
STA. 658+00 BEGIN PROJ. I 70-3(92)=
STA. 658+00 ON PROJ. I 70-3(61)265
A-3
PLAN
PROFILE

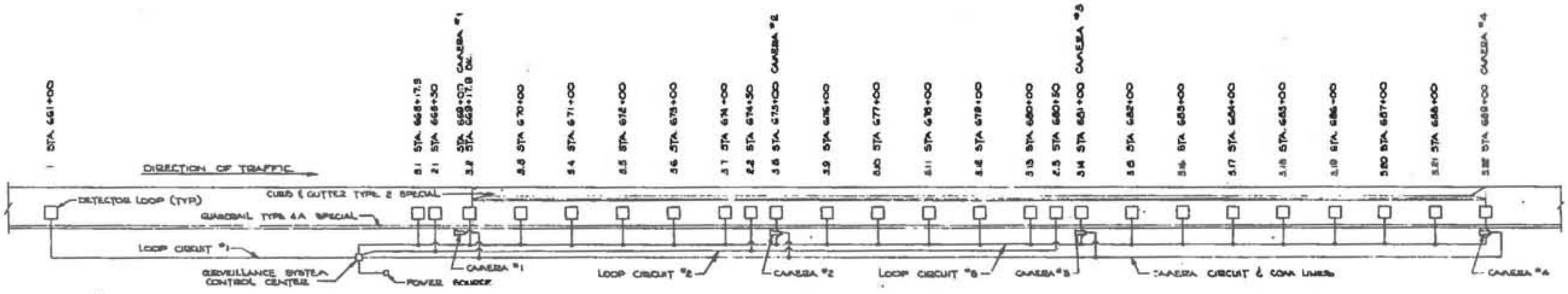

VIII
COLORADO
I 70-3(92)
10
AS CONSTRUCTED
NO REVISIONS
REVISED
VOID
SECTIONAL PROFILE OF TRUCK ESCAPE RAMP
NO SCALE
DIRECTION OF TRAVEL
AGGREGATE BASE COURSE (SPECIAL)
TYPE 3 GUARD RAIL
BOTTOM OF WALL
NOTE: CONSTRUCTION JOINTS SHALL BE LOCATED NOT CLOSER THAN 100 FOOT INTERVALS FOR ALL CONCRETE WORK.
FINISHED GRADE
ABC (SPECIAL)
SECTION A
SCALE 1½" = 1'-0"
SECTION B
SCALE 1½" = 1'-0"
TYPE 3 GUARD RAIL
FIN GRADE
DETAIL "C"
SCALE 1½" = 1'-0"
DETAIL "E"
SCALE 1" = 1'-0"
PLAN
NOTE: REINFORCING STEEL WILL NOT BE PLACED IN THE TWO 36" TRANSITION SECTIONS.
DETAIL "D"
SCALE 1" = 1'-0"
CONDUIT
ANCHOR BOLTS
VARIABLE
ELEVATION
DETAIL OF LIGHT STANDARD BASE

A-5

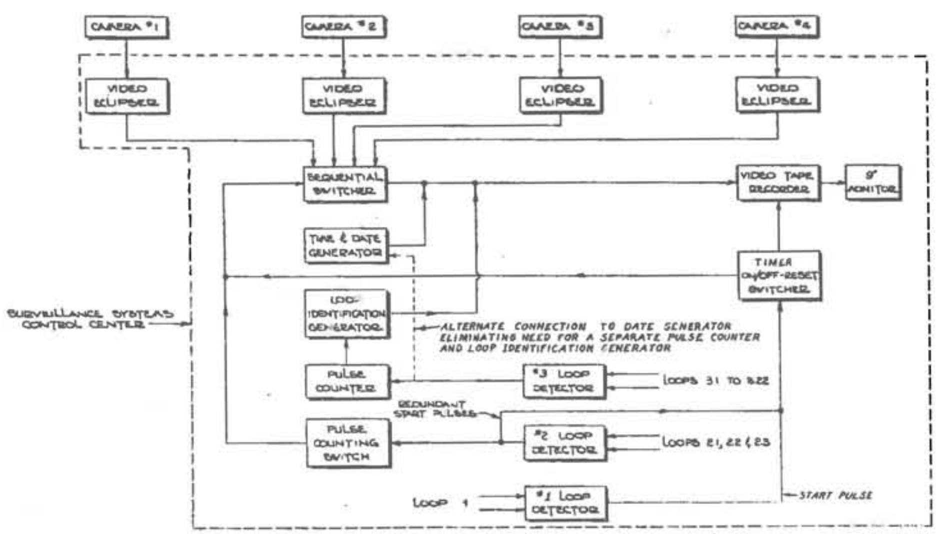
REGION NO.	DIVISION	PROJ. NO.	SHEET NO.	TOTAL SHEETS
VIII	COLORADO	I 70-3(92)	13	

AS CONSTRUCTED

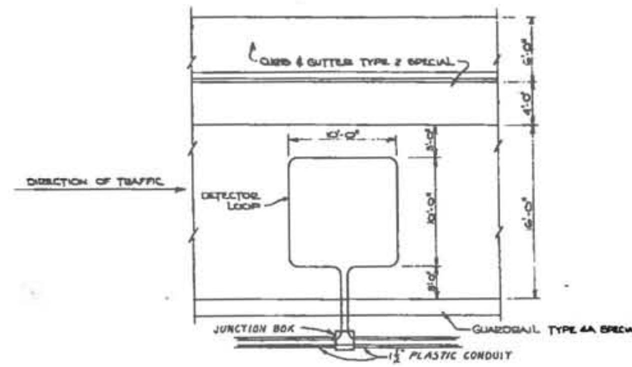
NO REVISIONS ☐ REVISED ☐ VOID ☐



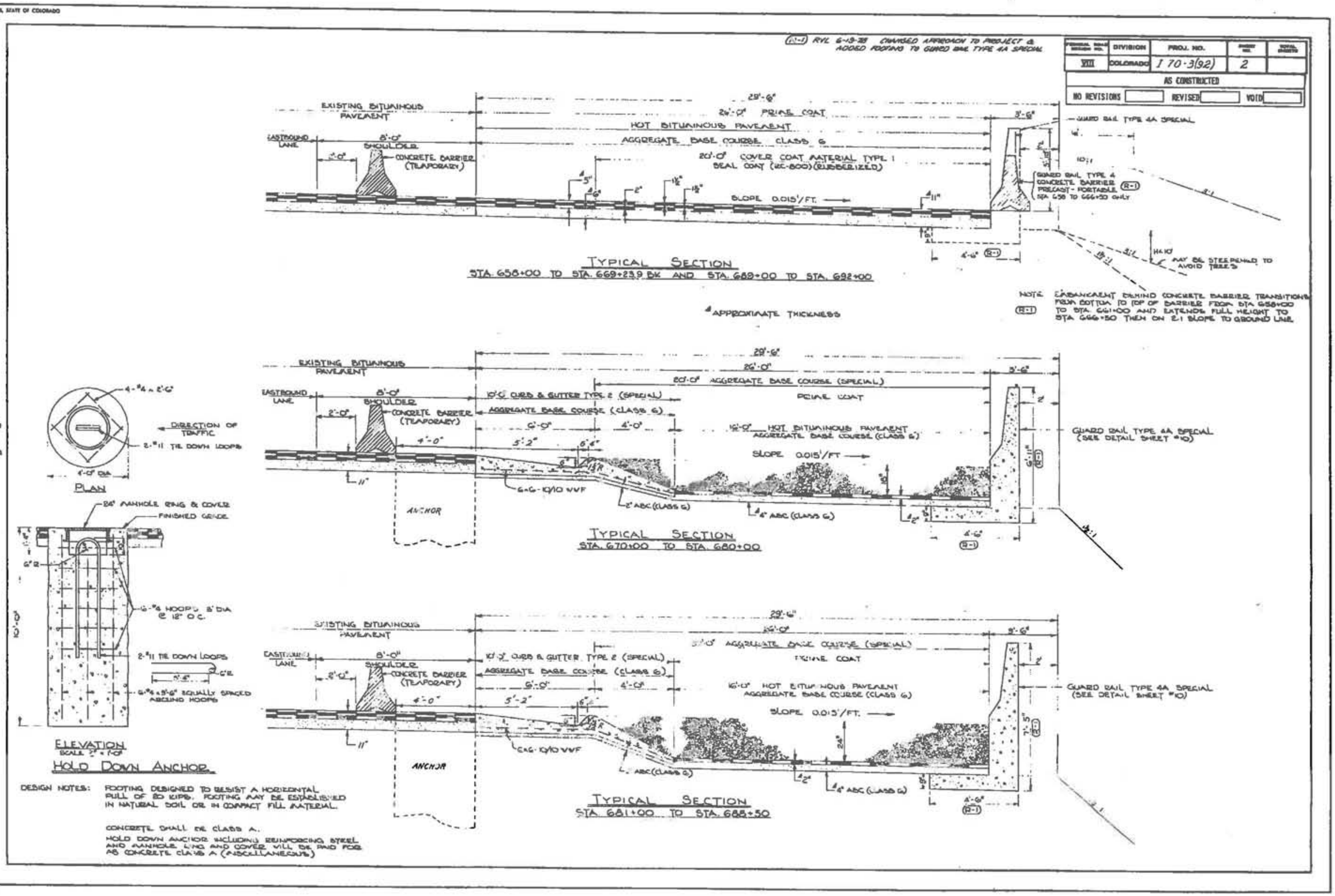
PLAN VIEW
DETECTOR LOOP & CAMERA LAYOUT



SURVEILLANCE SYSTEM FLOW DIAGRAM



DETAIL OF LOOP DETECTOR



DIVISION
PROJ. NO.
VIII
COLORADO
I 70-3(92)
2
AS CONSTRUCTED
NO REVISIONS
REVISED
VOID
RVL 6-13-78 CHANGED APPROACH TO PROJECT & ADDED FOOTING TO GUARD RAIL TYPE 4A SPECIAL
EXISTING BITUMINOUS PAVEMENT
EASTBOUND LANE
8'-0" SHOULDER
CONCRETE BARRIER (TEMPORARY)
29'-6"
26'-0" PRIME COAT
HOT BITUMINOUS PAVEMENT
AGGREGATE BASE COURSE CLASS 6
20'-0" COVER COAT MATERIAL TYPE I SEAL COAT (RC-800) (RUBBERIZED)
SLOPE 0.015'/FT.
GUARD RAIL TYPE 4A SPECIAL
GUARD RAIL TYPE 4 CONCRETE BARRIER PRECAST - PORTABLE STA 658 TO 666+50 ONLY
MAY BE STEEPENED TO AVOID TREES
TYPICAL SECTION
STA. 658+00 TO STA. 669+23.9 BK AND STA. 689+00 TO STA. 692+00
APPROXIMATE THICKNESS
NOTE: EMBANKMENT BEHIND CONCRETE BARRIER TRANSITIONS FROM BOTTOM TO TOP OF BARRIER FROM STA 658+00 TO STA 661+00 AND EXTENDS FULL HEIGHT TO STA 666+50 THEN ON 2:1 SLOPE TO GROUND LINE.
10'-0" CURB & GUTTER TYPE 2 (SPECIAL)
AGGREGATE BASE COURSE (CLASS 6)
20'-0" AGGREGATE BASE COURSE (SPECIAL)
PRIME COAT
16'-0" HOT BITUMINOUS PAVEMENT AGGREGATE BASE COURSE (CLASS 6)
SLOPE 0.015'/FT
6-6-10/10 WWF
2" ABC (CLASS 6)
4" ABC (CLASS 6)
ANCHOR
GUARD RAIL TYPE 4A SPECIAL (SEE DETAIL SHEET #10)
TYPICAL SECTION
STA. 670+00 TO STA. 680+00
TYPICAL SECTION
STA. 681+00 TO STA. 688+50
4-#4 x 2'-6"
DIRECTION OF TRAFFIC
2-#11 TIE DOWN LOOPS
4'-0" DIA
PLAN
24" MANHOLE RING & COVER
FINISHED GRADE
6-#6 HOOPS 3' DIA @ 12" O.C.
2-#11 TIE DOWN LOOPS
6-#6 x 9'-6" EQUALLY SPACED AROUND HOOPS
ELEVATION
HOLD DOWN ANCHOR
DESIGN NOTES: FOOTING DESIGNED TO RESIST A HORIZONTAL PULL OF 80 KIPS. FOOTING MAY BE ESTABLISHED IN NATURAL SOIL OR IN COMPACT FILL MATERIAL.
CONCRETE SHALL BE CLASS A.
HOLD DOWN ANCHOR INCLUDING REINFORCING STEEL AND MANHOLE RING AND COVER WILL BE PAID FOR AS CONCRETE CLASS A (MISCELLANEOUS)

APPENDIX B

COLORADO TRUCK ESCAPE RAMP DESIGN CRITERIA

TRUCK ESCAPE RAMPS - 909

901.1 General

Improvements in the alignment of mountain roads have resulted in steeper grades, flattened curves and higher speeds. This combination, along with higher truck volumes, has increased the number of runaway truck accidents. Well designed truck escape ramps can help reduce the number of accidents.

909.2 Design

The following design criteria are suggested guidelines based on experience with existing ramps:

The approach to the ramp should take off of a left curve where possible. A right hand exit is desirable. A standard 3 to 5 degree tapered exit can be used, but a parallel lane exit will allow the truck more space to maneuver around slow moving vehicles and onto the ramp. It is important that the end of the pavement for the ramp be perpendicular to the direction of travel.

The stopping forces on the ramp are due to rolling resistance through pea gravel or a vertical increase in height. Figure 909-2A shows the variables involved in calculating a final speed or stopping distance on a ramp. Until better data is obtained, rolling resistance will be assumed to be 0.2 Gs. This implies that vertical distance is 5 times as effective as horizontal distance in stopping a truck, e.g., a 400 foot increase in elevation would have a stopping force equivalent to a 2,000 foot pea gravel ramp on a level grade.

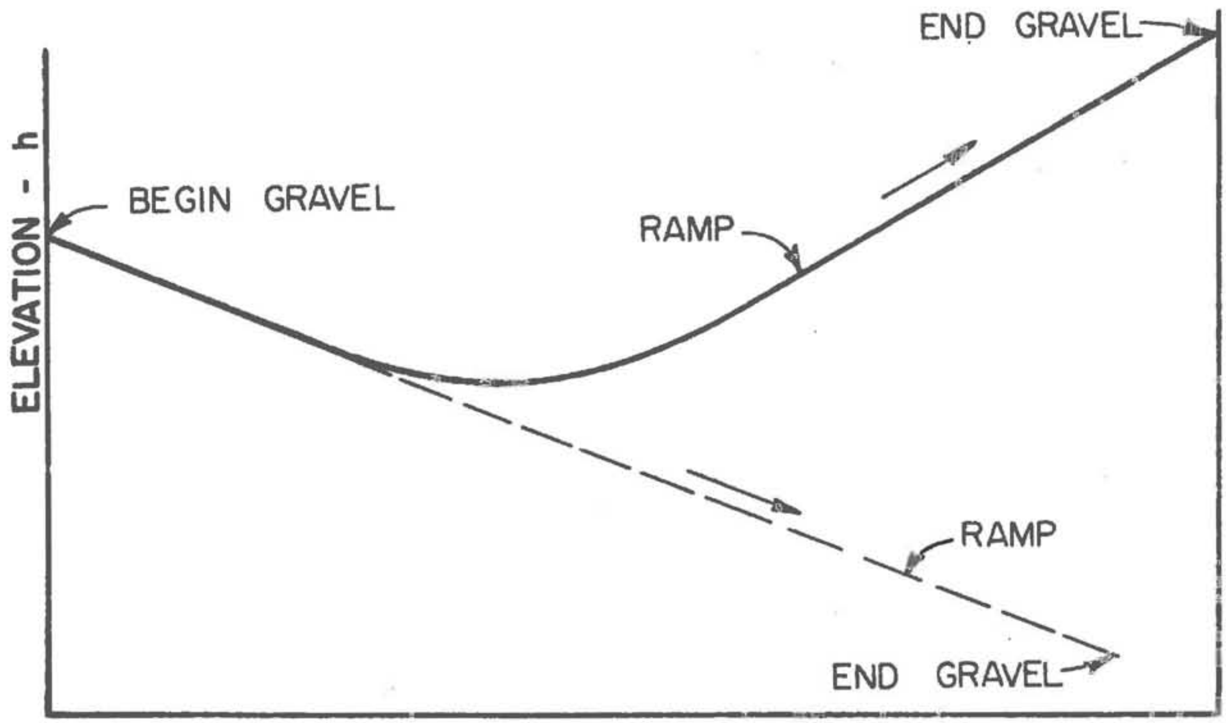
Figure 909-2B shows the vertical height and horizontal distance of gravel ramp required to stop a runaway truck. As an example, the dotted line shows that a ramp 1,800 feet in length which drops 60 feet in elevation from beginning to end would stop a truck traveling approximately 95 mph.

Minimum width of the escape ramp shall be 26 feet. This allows for two trucks in the ramp at any one time. A 10 foot access road parallel to the ramp should be provided to allow tow trucks to remove trucks from the gravel bed. Hold down anchors should be spaced every 300 feet along the access road to provide a tie down for the tow trucks.

The transition to a minimum 18" depth of pea gravel should occur in 100 feet. An acceptable gradation for pea gravel is:

Passing 1" Sieve	100%
Passing 3/8" Sieve	90 - 100%
Passing #4 Sieve	0 - 15%
Passing #8 Sieve	0 - 5%
Passing #200 Sieve	0 - 1%

TRUCK ESCAPE RAMP



$$\frac{mV_i^2}{2} = mgh + \frac{mV_f^2}{2} + mad$$

$$V_f = \frac{60}{88}\sqrt{\left[\frac{88}{60}V_i\right]^2 - 2gh - 2ad}$$

ASSUME $V_f = 0$ then $h = \dfrac{\left[\frac{88}{60}V_i\right]^2}{2g} - \dfrac{ad}{g}$, $d = \dfrac{\left[\frac{88}{60}V_i\right]^2}{2a} - \dfrac{gh}{a}$

V_f = FINAL VELOCITY - M.P.H.

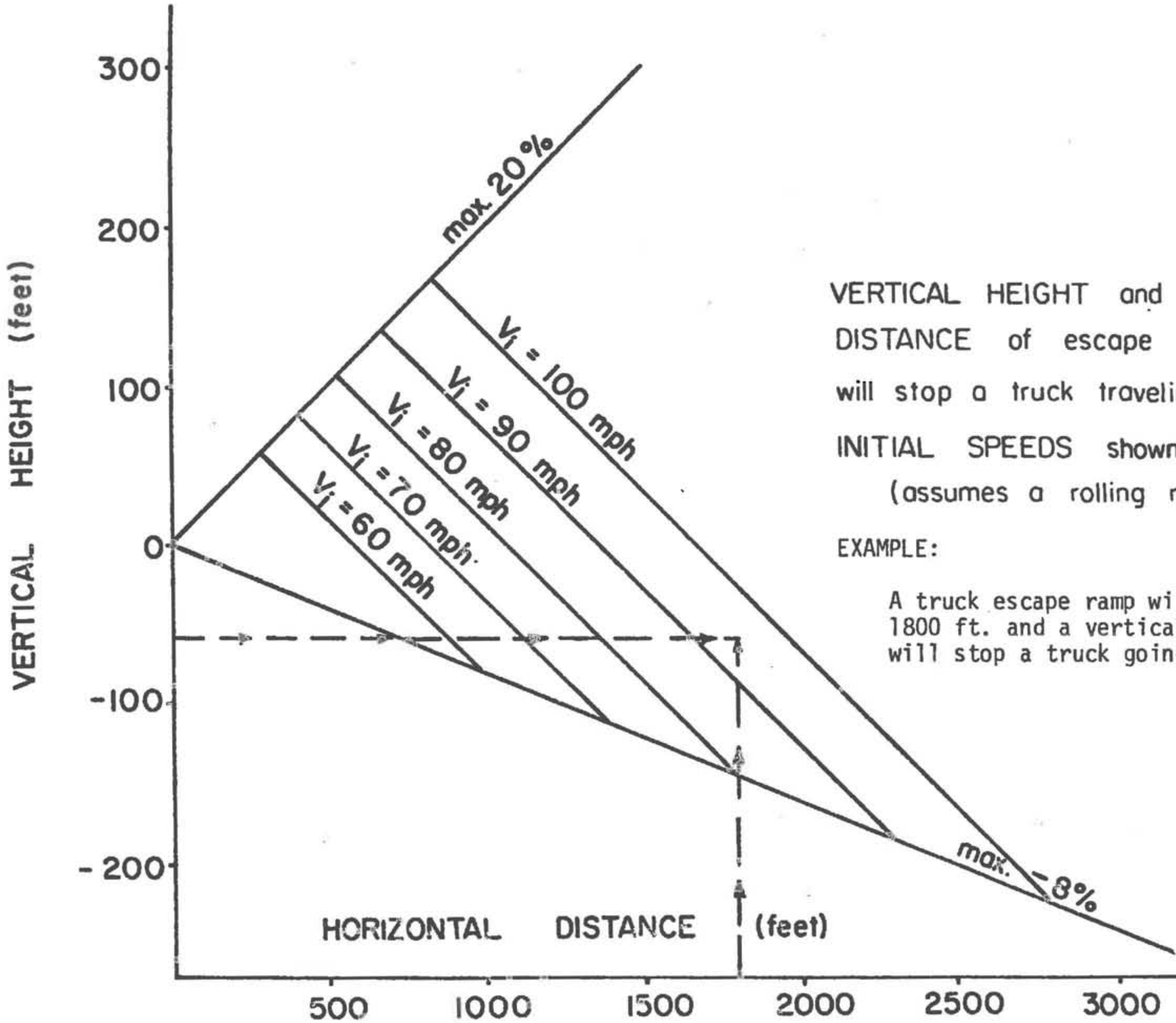
V_i = INITIAL VELOCITY - M.P.H.

g = ACCELERATION - 32.2 FT./SEC.^{2}

a = DECELERATION 0.2G IN GRAVEL (ASSUMED)

h = VERTICAL DISTANCE - END ELEVATION MINUS BEGINNING ELEVATION OF RAMP

d = HORIZONTAL DISTANCE TOTAL LENGTH OF RAMP



VERTICAL HEIGHT and HORIZONTAL DISTANCE of escape ramp which will stop a truck traveling at the INITIAL SPEEDS shown

(assumes a rolling resistance of .2)

EXAMPLE:

A truck escape ramp with a length of 1800 ft. and a vertical fall of 60 ft. will stop a truck going 95 mph.

FIG. 909-2B

Design speed for Interstate ramps should be 100 mph. Design speed for other ramps should be 40% higher than the design speed of the road above the ramp. A maximum grade of 20% on any portion of the ramp will minimize rollback problems.

Special guard rail or berms may be needed in some cases to contain the trucks within the ramps. Driving snow and snowplowing should be considered when using these designs. Drainage should be designed to avoid freezing problems with the aggregate. If the ramp length is constrained, a supplemental design using a 100 foot length of sand barrels on 10 foot centers can be used at the end of the ramp if the truck speed has been reduced to 30 mph or less.

909.3 Lighting and Signing

Lighting of the ramp is a desirable feature. High pressure sodium luminaires (37,000 lumen) spaced at 150 feet are recommended.

Signing is important to warn the driver of the possible problems ahead so that he may make the necessary checks of his vehicle before proceeding down the steep grades. Signing also directs him to the truck escape ramp should it be necessary to use it.

APPENDIX C

ESCAPE RAMP USE SUMMARY

MT.VERNON CANYON RUNAWAY TRUCK ESCAPE RAMP - DATA SUMMARY AND DATA AVAILABILITY

DATE	TYPE TRUCK	WEIGHT (LBS)	CARGO	ENTRY SPEED	DISTANCE TRAVELLED (FT)	VIDEO TAPE	LOOP DATA	PICTURES	COMMENTS
07/30/79	SEMI	66660	FURNITURE	65	924	NO	NO	YES	CONTROL PROBLEMS
08/24/79	SEMI	79220	POTATOES	75	738	NO	NO	YES	
09/26/79	SEMI	72260	WELDING EQUIPMENT	25	64	NO	NO	NO	ENTERED RAMP NEAR FAR END
10/14/79	SEMI	NA	RAISINS	50	114	NO	NO	YES	
10/20/79	VAN	NA	NA	50	80	NO	NO	NO	UNINTENTIONAL ENTRY
11/16/79	SEMI	71000	LUMBER	45	260	NO	NO	NO	
12/24/79	SEMI	77400	ONIONS	10	78	NO	NO	NO	
01/13/80	SEMI	77420	CEMENT SACKS	70	475	YES	NO	YES	
02/19/80	SEMI	35100	SPORTING GOODS	5	10	NO	NO	NO	UNINTENTIONAL ENTRY
02/20/80	SEMI	79650	APPLES	50	75	NO	NO	NO	
03/05/80	SEMI	75600	CANNED FRUIT	70	417	NO	NO	YES	
03/13/80	SEMI	65180	MEDICINE	60	547	NO	NO	NO	
04/19/80	SEMI	59500	FRUIT	40	148	NO	NO	NO	
05/20/80	2.5 TON	24000	FURNITURE	40	100	NO	NO	NO	UNINTENTIONAL ENTRY
06/12/80	SEMI	78100	PRODUCE	65	800	YES	NO	YES	
06/12/80	SEMI	66920	FEED SUPPLEMENT	75	435	YES	NO	NO	
06/19/80	SEMI	83000	MACHINERY	35	136	YES	NO	NO	
07/05/80	SEMI	77100	COW HIDES	80	324	YES	NO	NO	
07/23/80	VAN	20400	FURNITURE	50	400	YES	NO	NO	UNINTENTIONAL ENTRY
08/11/80	VAN	18000	HOUSEHOLD GOODS	40	150	NO	NO	NO	UNINTENTIONAL ENTRY
08/14/80	SEMI	72700	PRODUCE	80	1020	NO	NO	NO	
10/17/80	SEMI	78000	FROZEN VEGETABLES	70	1000	YES	YES	NO	GOOD QUALITY VIDEO TAPE
12/26/80	SEMI	29000	NONE	50	200	YES	NO	NO	
03/19/81	SEMI	79500	LUMBER	45	400	YES	NO	NO	
04/05/81	SEMI	73000	LETTUCE	40	482	YES	NO	NO	
04/25/81	SEMI	68000	BEEF	30	115	NO	NO	NO	
04/28/81	SEMI	77560	SALT	35	120	YES	NO	NO	
05/02/81	SEMI	55000	FILM	25	138	YES	NO	NO	
05/08/81	SEMI	74000	HONEY/SANDWICH BAG	70	889	YES	YES	NO	
05/18/81	SEMI	69000	I-BEAMS	35	294	YES	NO	NO	
05/31/81	SEMI	77300	POTATOES	70	600	YES	YES	NO	
07/05/81	SEMI	77000	CHERRIES	40	180	NO	NO	NO	
07/16/81	SEMI	77000	CARROTS	30	170	YES	NO	NO	ENTERED RAMP NEAR FAR END
08/01/81	VAN	36900	HOUSEHOLD GOODS	45	282	YES	NO	NO	
08/20/81	SEMI	69880	FERTILIZER	45	205	YES	NO	NO	ENTERED RAMP FROM SIDE

MT.VERNON CANYON RUNAWAY TRUCK ESCAPE RAMP - DATA SUMMARY AND DATA AVAILABILITY

DATE	TYPE TRUCK	WEIGHT (LBS)	CARGO	ENTRY SPEED	DISTANCE TRAVELLED (FT)	VIDEO TAPE	LOOP DATA	PICTURES	COMMENTS
09/03/81	SEMI	74940	MOBILE HOME AXLES	20	93	NO	NO	NO	ENTERED RAMP FROM SIDE
09/04/81	SEMI	71000	LUMBER	50	246	YES	NO	NO	
09/16/81	SEMI	76000	MEAT	25	50	YES	NO	NO	UNINTENTIONAL ENTRY
09/28/81	SEMI	26380	NONE	78	912	YES	NO	NO	
10/08/81	SEMI	37719	TOYS	40	395	YES	NO	NO	
10/08/81	SEMI	72000	PIPE	70	380	YES	NO	NO	
11/06/81	SEMI	78000	STEEL	10	50	NO	NO	NO	
12/14/81	SEMI	60000	TOMATO PASTE	59	705	NO	NO	NO	TRUCK HIT RETAINING WALL
12/16/81	SEMI	26780	NONE	40	528	NO	NO	NO	
01/28/82	SEMI	79300	OIL RIG PUMPS	35	148	NO	NO	NO	
03/12/82	SEMI	75000	LUMBER	75	227	NO	NO	NO	HIT WALL AND OVERTURNED
03/20/82	SEMI	74840	ASPHALTUM SACKS	90	822	NO	NO	NO	
03/23/82	SEMI	69000	PAPER BAGS	40	600	NO	NO	NO	
05/26/82	SEMI	77000	N/A	70	615	NO	NO	NO	
07/30/82	SEMI	70260	GENERAL CABLE	62	686	NO	NO	NO	
08/08/82	SEMI	72100	GRAPES	40	118	NO	NO	NO	
08/24/82	PICK-UP	35500	PORT-O-JONS	70	342	NO	NO	YES	
10/06/82	SEMI	76000	PRODUCE	60	390	NO	NO	NO	STRAIGHT
10/27/82	SEMI	72700	TOMATOES	70	456	NO	NO	NO	
11/04/82	TRUCK	42200	CHERRY PICKER,PIPE	40	384	NO	NO	NO	PULLED RIGHT
11/08/82	SEMI	49600	APPLES	65	655	NO	NO	NO	STRAIGHT
11/17/82	SEMI	78700	SHINGLES	45	465	NO	NO	NO	
12/08/82	SEMI	41600	POTATOES	50	274	NO	NO	NO	ROCKED SIDE TO SIDE
12/23/82	SEMI	76940	GLASS	30	400	NO	NO	NO	STRAIGHT

APPENDIX D

PHOTOGRAPHS

Long distance view of the Mt. Vernon Canyon Runaway Truck Escape Ramp. The overhead sign marks the beginning of the approach.

The escape ramp as seen from the opposite side of I-70.

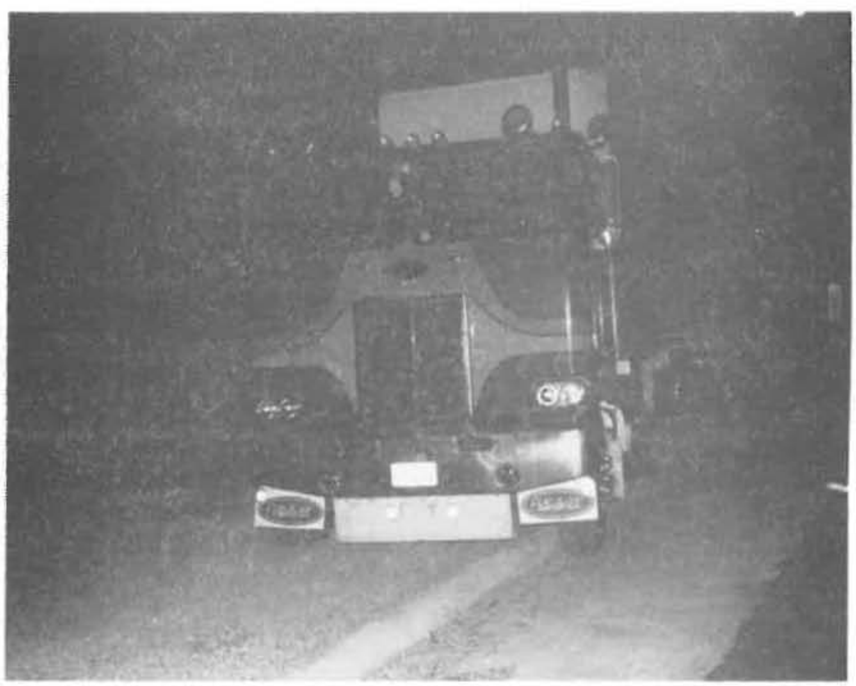
Looking down the escape ramp from the paved approach toward the gravel arrester bed. NOTE POLE MOUNTED VIDEO CAMERA.

One of four video cameras that were used to record trucks using the escape ramp.

View from behind the retaining wall showing the location of the video equipment cabinet.


The first use of the escape ramp was on July 30, 1979-two weeks after it was completed.

The second use was on August 24, 1979.

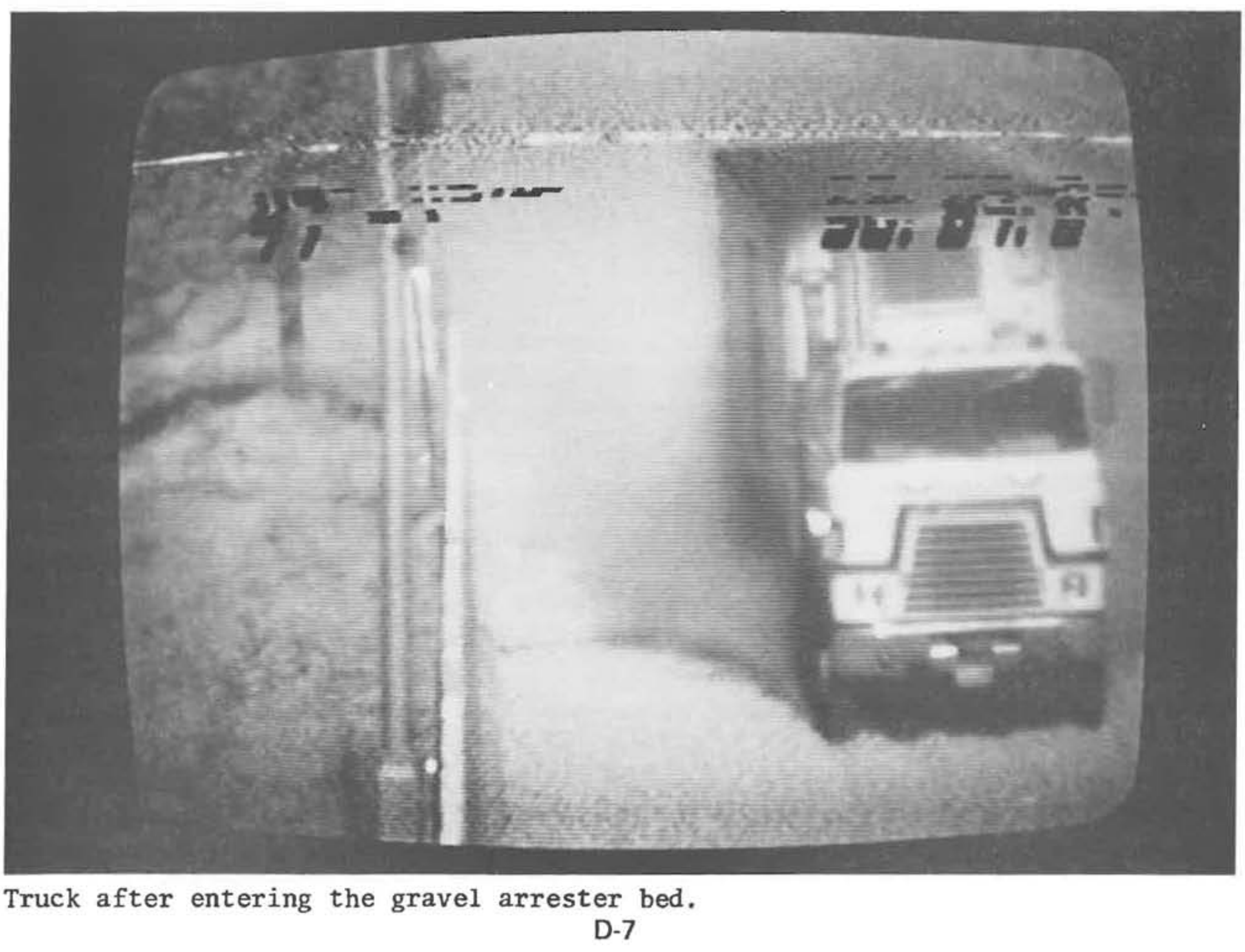


October 14, 1979.

January 13, 1980

Runaway truck in the approach travelling 54 mph.

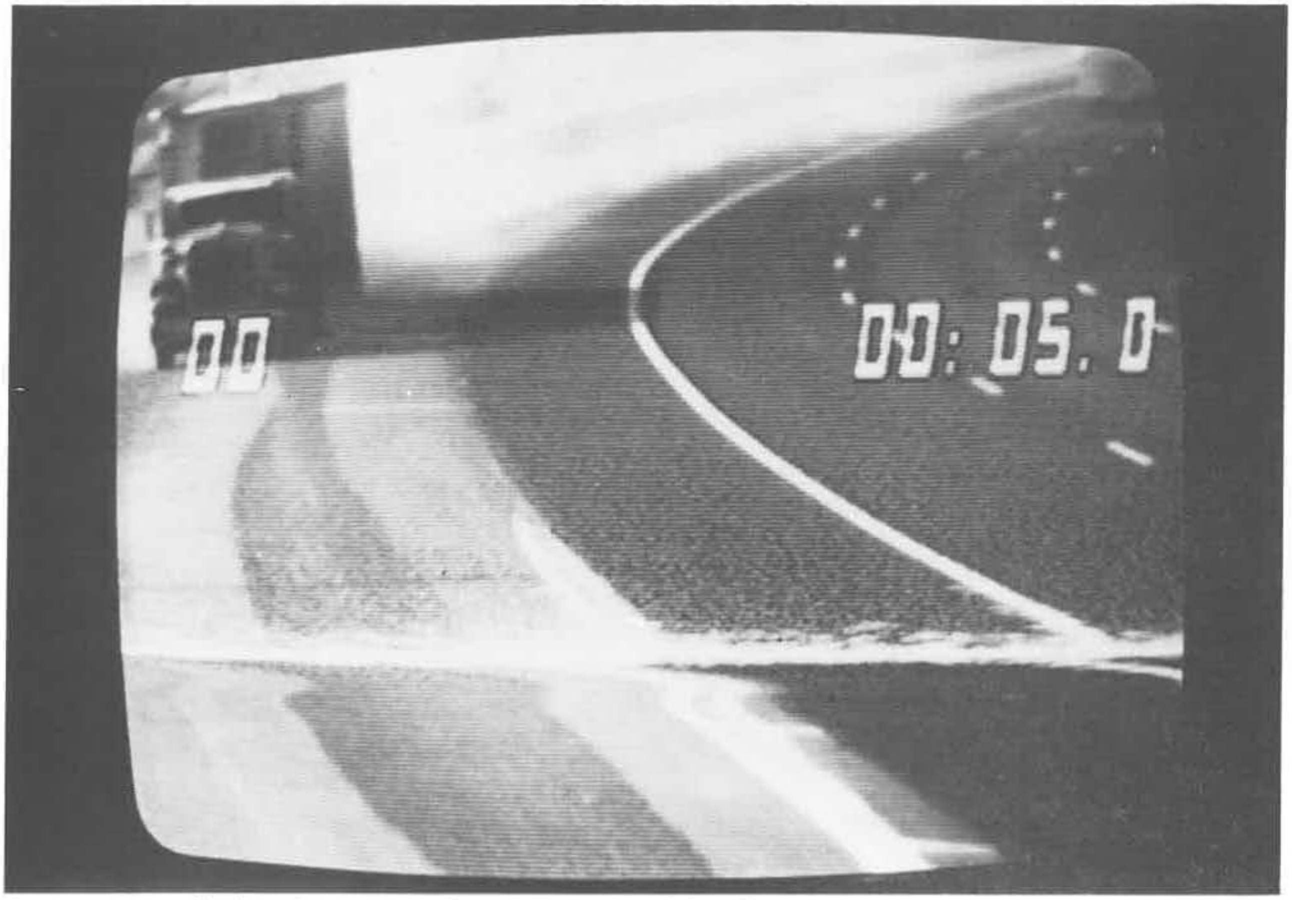
Truck in the approach just before entering the gravel arrester bed.



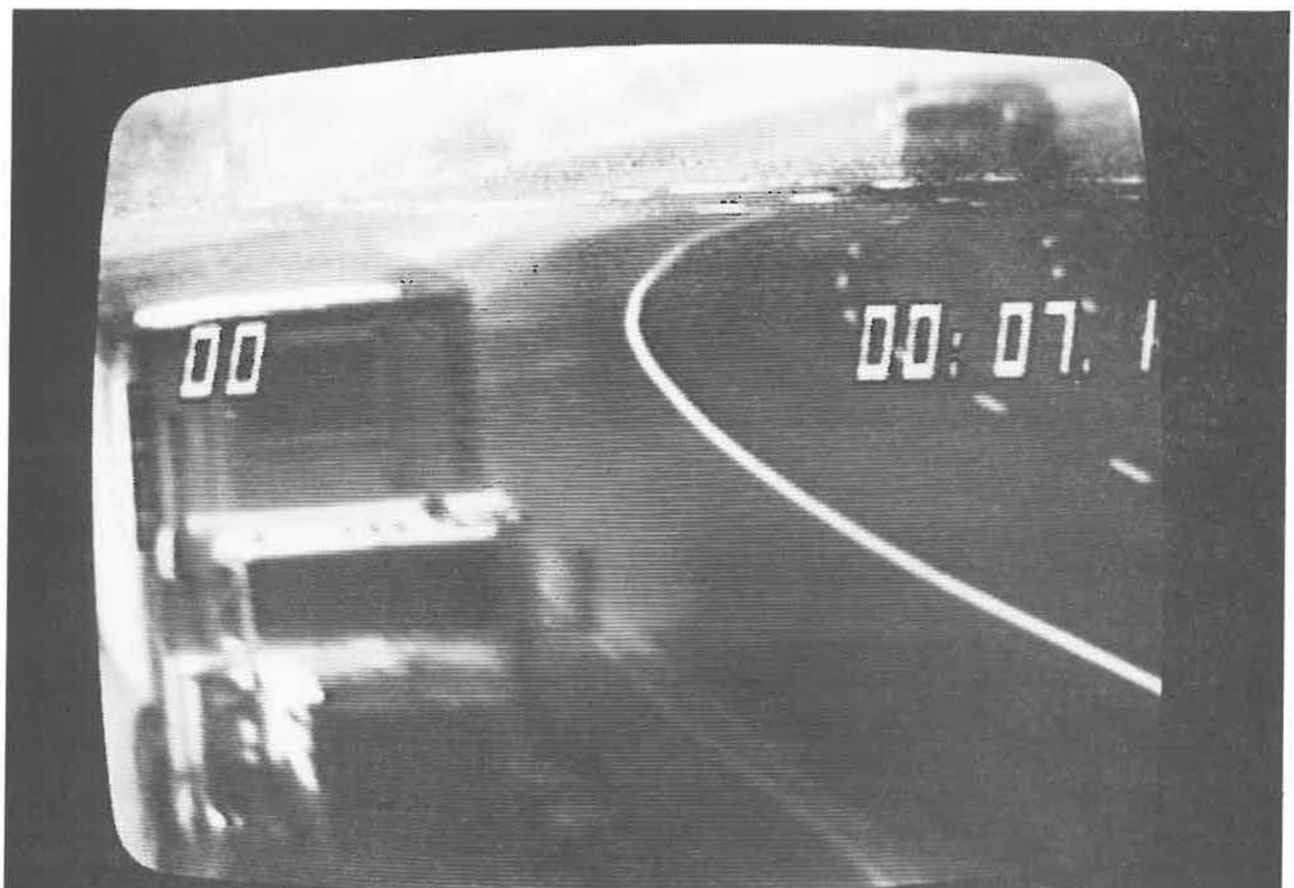
Truck after entering the gravel arrester bed.

Note the gravel spray being thrown from the wheels and the cloud of dust.

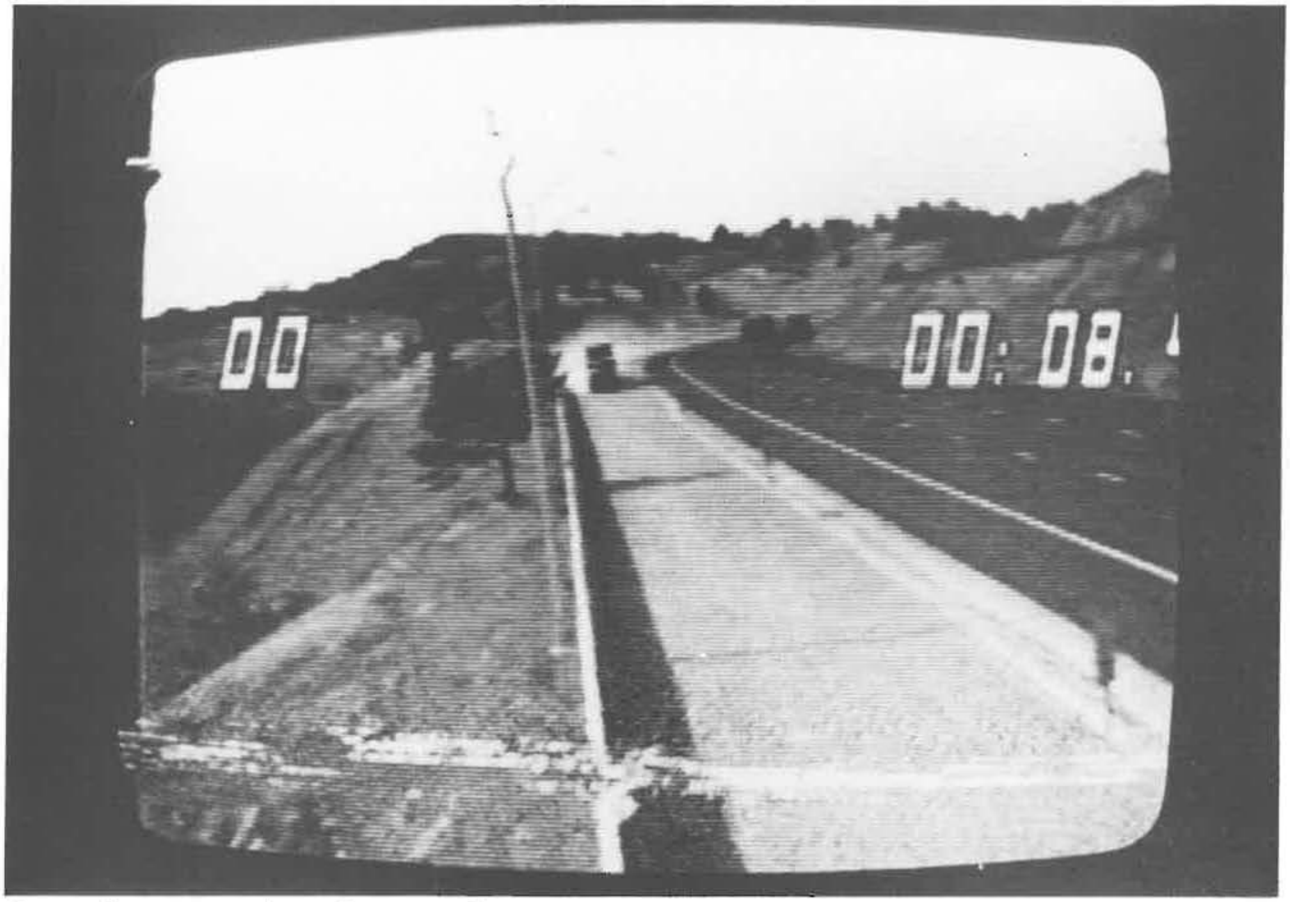
Truck safely stopped after travelling 800 feet through the gravel.



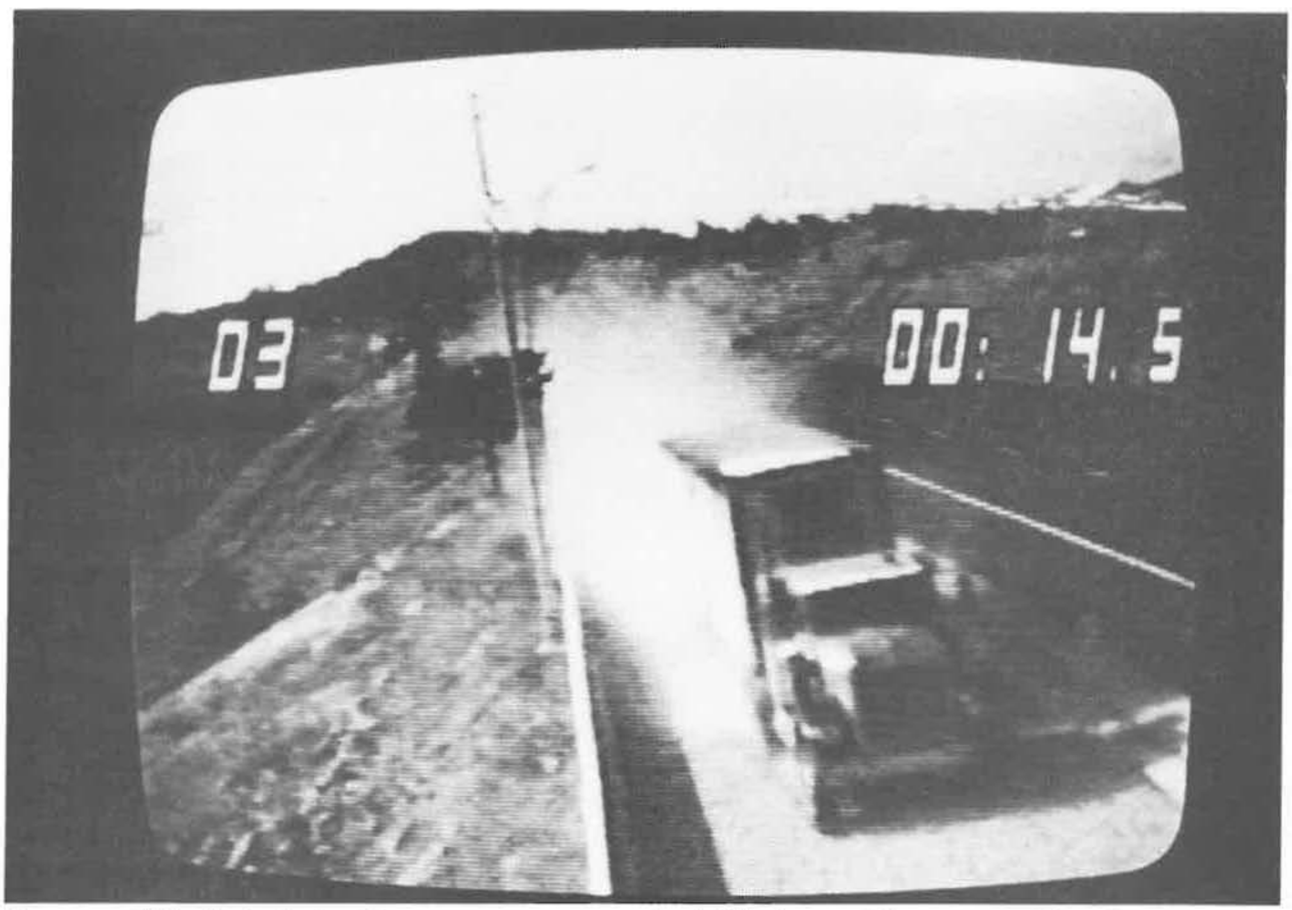
Runaway truck in the approach travelling 65 mph.



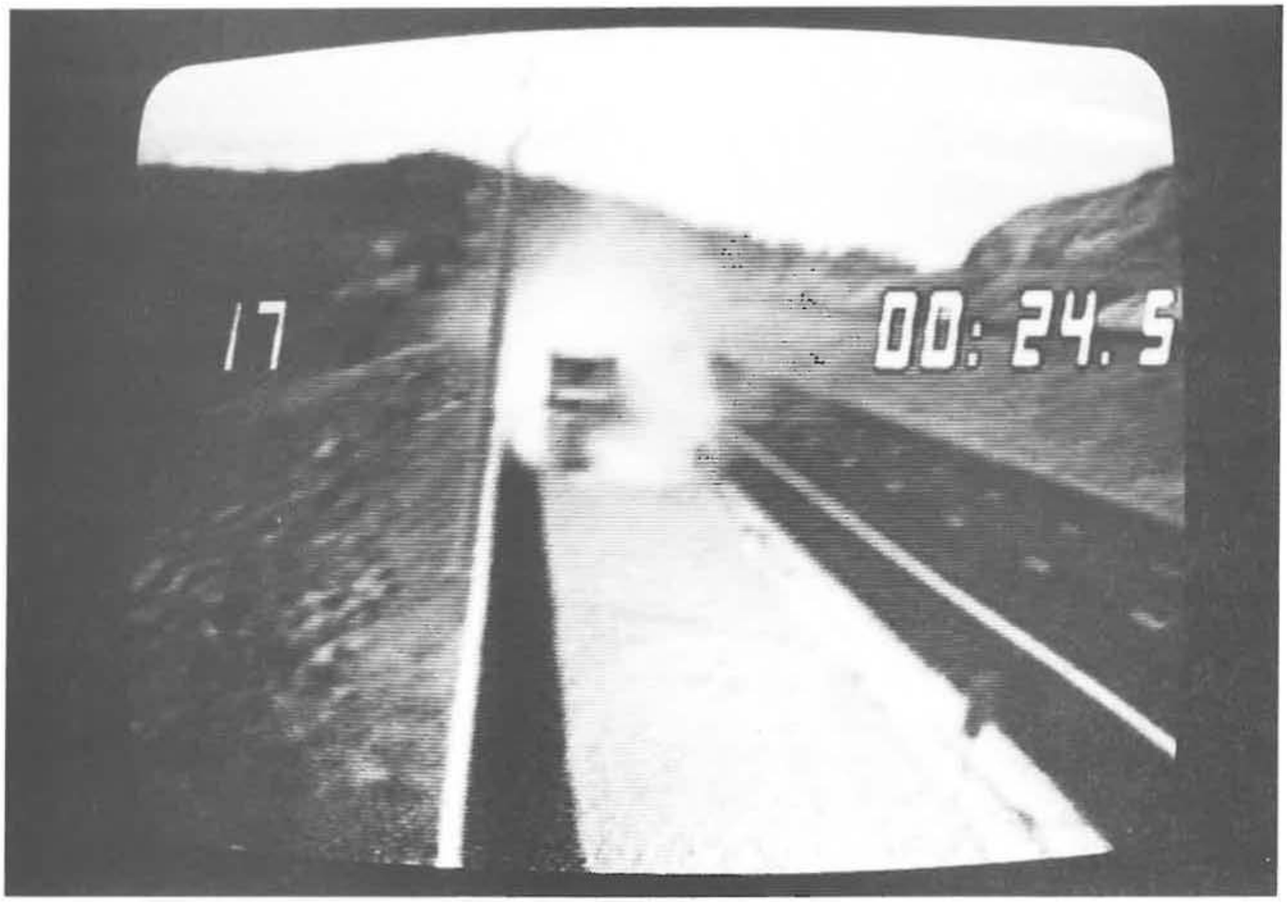
Truck just before entering the gravel.



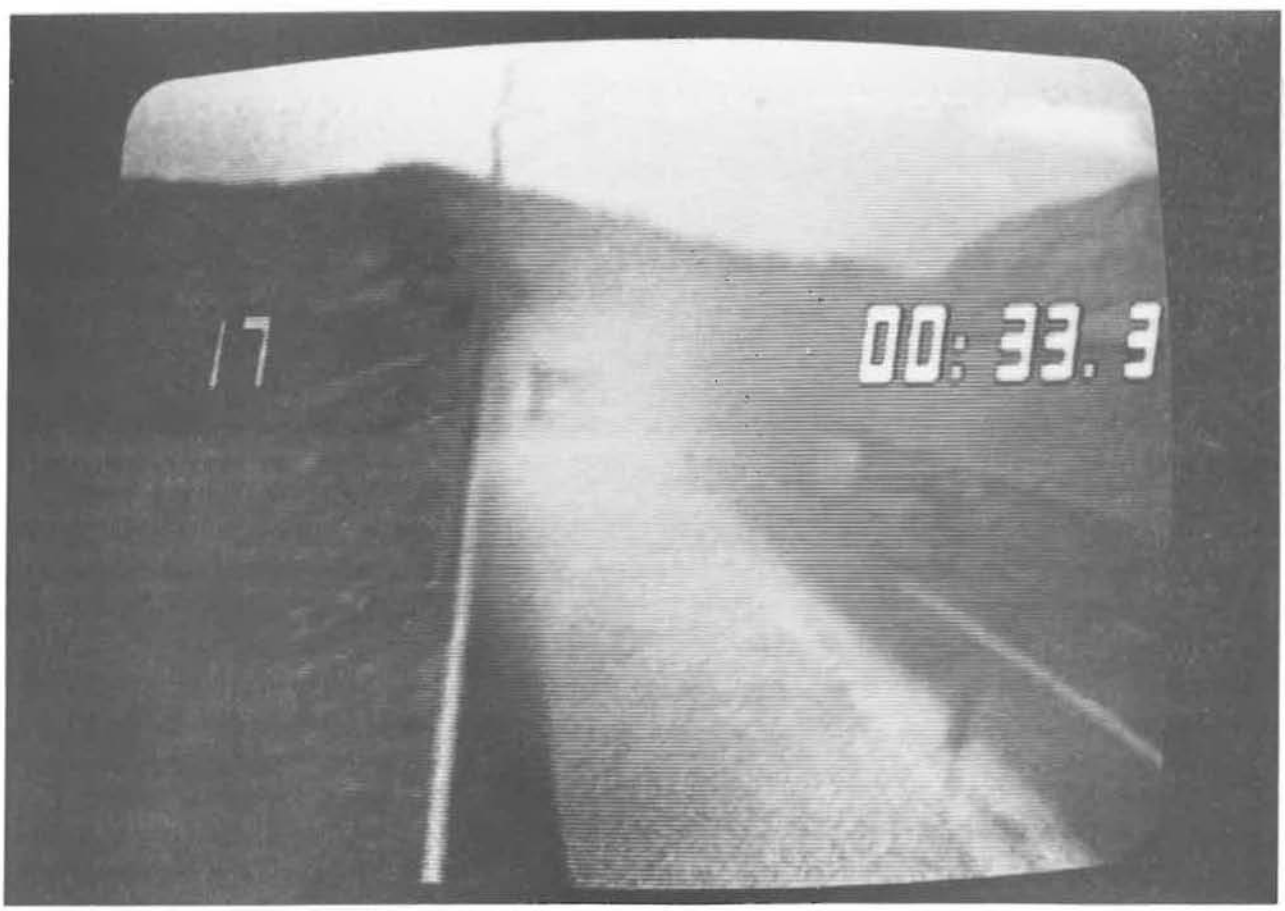
Just after entering the gravel.



Runaway 500 feet into the escape ramp and still travelling over 50 mph.



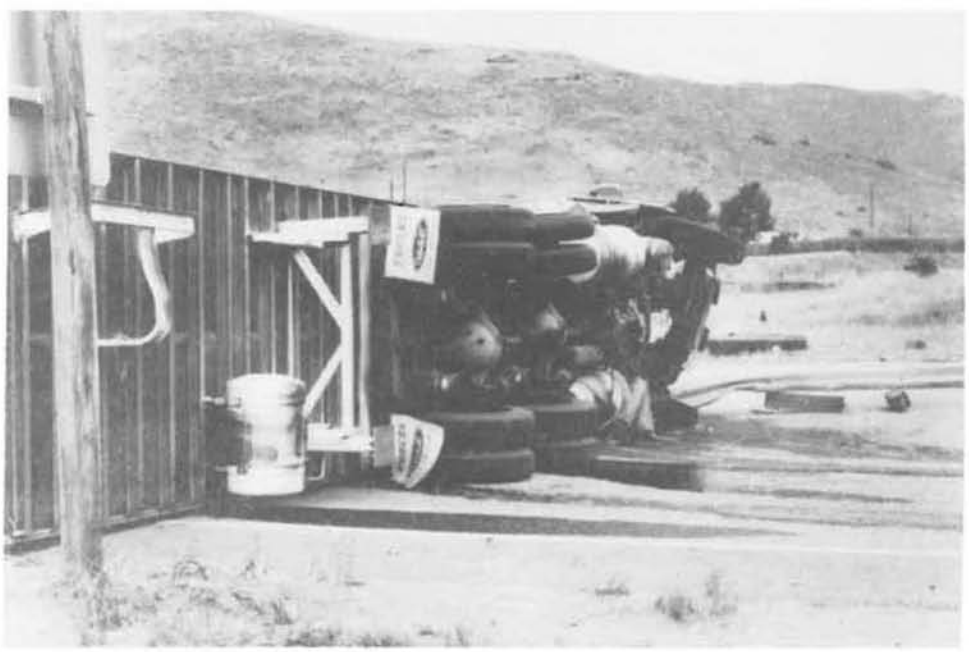
Truck just as it came to a stop after travelling 1000 feet into the gravel.



Truck overtaken by its own cloud of dust.

Truck stopped after dust has cleared.

Runaway truck that didn't use the escape ramp. The truck was completely destroyed and both drivers were killed.



Another runaway that didn't use the escape ramp. The driver was seriously injured.