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Maintenance Work Zone Safety Devices Development and Evaluation

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Abstract

This report presents the findings of tests and evaluations of several new work zone safety devices. The devices were conceived earlier in Project H-108, during a nationwide design competition.

The prototypes of the 25 devices were designed, developed, fabricated, tested, evaluated, and refined. The devices were organized into seven groups: barriers, warning devices, rumble strips, delineation devices, lighting devices, signs, and promising concepts.

Twelve devices successfully passed the evaluation stage: the Salt Spreader/Truck Mounted Attenuator Interface, the Portable Crash Cushion, the Ultrasonic Detection Alarm, the Infrared Intrusion Alarm, the Queue Length Detector, the Portable Rumble Strip, the Direction Indicator Barricade, the Opposing Traffic Lane Dividers, the Snowplow Blade Markers, the Flashing Stop/Slow Paddle, the Portable Sign and Stand, and the Remotely Driven Vehicle.

Executive Summary

New protection and traffic control devices to protect workers in short-term (1 to 12 hour duration) work zones were designed, developed, fabricated, tested, evaluated, and refined.

One of SHRP's contracts (H-108) was to develop ideas for new and more effective methods to protect maintenance workers from the hazards of traffic. Concepts for new devices were sought during a design competition. This competition solicited innovative ideas in ten categories. One hundred twenty-six proposals were received. The proposals were evaluated by the project staff and an expert task group (ETG). Thirty-seven concepts were awarded prizes. Seven ideas came from the project staff. These forty-four concepts were researched and designed. The concepts were organized into seven groups:

- barriers,
- warning devices,
- rumble strips,
- delineation devices,
- lighting devices,
- signs, and
- promising concepts.

The forty-four concepts were refined into twenty-five devices recommended for further development in this contract (H-109). Multiple ideas (i.e., more than one design of a portable speed bump) were reduced to a single device. The following is a list of the devices recommended by SHRP project H-108:

- S.CAI Barrier
- Personnel Protection Trailer
- Moveable Barrier End Treatment
- Aluminum Can Truck Mounted Attenuator
- Salt Spreader/Truck Mounted Attenuator Interface
- Portable Crash Cushion
- Ultrasonic Detection Alarm
- Infrared Intrusion Alarm
- Pressurized Pneumatic Tube Alarm
- Queue Length Detector
- Traveled Way Rumble Mat
- Portable Rumble Strip
- Rumble Stripe
- Moving Taper
- Portable Soft Barricade
- Direction Indicator Barricade
- Opposing Traffic Lane Dividers
- Maintenance Vehicle Floodlight
- Snowplow Blade Markers
- Diverging Lights

- Flashing Stop/Slow Paddle
- Flagger Gate
- Portable Sign and Stand
- Truck Mounted Message Box
- Remotely Driven Vehicle

The specific objectives of SHRP Project H-109 were:

To develop *new* and *more effective* ways to protect workers in short-term maintenance work zones from the hazards of nearby traffic.

To secure the detailed design, fabrication, testing and evaluation of prototype work zone safety devices.

To produce training courses and manuals on such matters as the evaluation of site specific work zone traffic controls, on the evaluation of the effect of traffic controls on traffic through the work zone, and on the use of new devices and procedures.

Project H-109 entailed design, development, fabrication, testing, evaluation and refinement of the prototype work zone safety devices. Project H-109 continued with the concept devices from H-108, continuing the design and development, and concentrating on fabrication, testing and evaluation of the prototype work zone safety devices.

The first step was the development of an evaluation plan for the devices. The evaluation plan included descriptions of the devices, the descriptions of the areas of testing to be conducted on the devices, the individual tests to be conducted for each device, and the evaluation criteria and measures of effectiveness for each test for each device. The evaluation method was a sequential, logical process that included several decision points where the device was either further refined and redesigned or abandoned.

The next step was the fabrication of the devices. A fabrication plan was written for each device.

Each fabrication plan included detailed drawings of each device, the quantity to be fabricated, a cost estimate for the fabrication, a schedule of the fabrication and the potential fabricators, if not part of project staff. Each plan was submitted to SHRP for approval.

The third task was the evaluation of the devices. Ten different test types were formulated. However, not all ten test types were used to evaluate each device. The test types were:

- human factors,
- computer simulated impacts,
- environmental/material testing,
- electronic evaluation,
- scale model impacts,
- operational testing,
- full-scale crash testing,
- full-scale crashworthiness testing,
- closed track testing and
- open highway testing.

Performance factors for each test type were developed in order to determine the effectiveness of a device relative to established limits of deflection, in the case of the full-scale crash testing, or relative to a standard traffic control device, in the case of closed track or open highway testing.

Decision points for continuing or dropping a device were included in the testing and evaluation phase of the project. For example, if a new device was not superior to a standard device in at least one performance area, it would not pass that phase of testing and would be redesigned or dropped.

The fourth task was the development of specifications and implementation plans for the devices that successfully completed the evaluation. Detailed drawings, specifications and production plans were developed to facilitate the commercialization of the products. Some training and operation manuals were drafted prior to the open highway testing in order to obtain critiques from the highway workers using the devices.

Twelve devices successfully passed the evaluation stage. Each of the seven general categories of devices are represented by these devices. The successful devices are the: the Salt Spreader/Truck Mounted Attenuator Interface, the Portable Crash Cushion, the Ultrasonic Detection Alarm, the Infrared Intrusion Alarm, the Queue Length Detector, the Portable Rumble Strip, the Direction Indicator Barricade, the Opposing Traffic Lane Dividers, the Snowplow Blade Markers, the Flashing Stop/Slow Paddle, the Portable Sign and Stand, and the Remotely Driven Vehicle.

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Background

Highway maintenance work is dangerous. Maintenance crews must repair roads while cars and trucks pass by at high speeds, only feet away from the work zone. The increasing need for repairs to existing pavements and structures while controlling an increasing traffic flow makes work zone safety a great concern of maintenance workers and highway users. Highway organizations need new and more effective ways to meet the need for flexible, mobile, economical and safe work zones.

Project H-108

SHRP's Maintenance Work Zone Safety research was created to develop new and more effective ways to protect maintenance workers from the hazards of nearby traffic.

SHRP sought concepts for new devices by holding an international design competition. Ten designations of challenge areas were chosen, based on observations of accident and operational problems in work zones and on an industry survey of existing equipment and materials.

One hundred twenty-six proposals were received from 28 states and three foreign countries. The creators of thirty-seven of the proposals received cash prizes. The H-108 project staff and the Expert Task Group (ETG) contributed seven designs.

Forty of these proposed designs were researched and designed. The design effort resulted in the abandonment or combination of some concepts. Twenty five devices were recommended for further development under SHRP Project H-109, Maintenance Work Zone Safety Devices Development and Evaluation.

Project H-109

SHRP Project H-109 continued the design and development of new protection and traffic control devices for use in short-term work zones, and concentrated on the fabrication, testing, evaluation and refinement of these prototype work zone safety devices.

Most of the devices required further design work. Shop drawings and specifications for the devices were created, then used to fabricate prototypes for testing and evaluation. Some fabrication was performed by the project team, while other fabrication was performed by machine shops and fabrication houses.

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Testing and Evaluation of Devices

Development of the Evaluation Plan

The evaluation plan established the basis for testing each of the devices evaluated under H-109. This plan included the performance factors that were evaluated, the types of tests performed, the number of tests, the test locations, and the method of the evaluation of each device.

Ten types of tests were planned for the 25 devices. The evaluation plan covered all devices and tests.

Devices to Be Tested

The 25 devices shown in table 1 were categorized into seven study areas: barriers; warning devices; rumble strips; delineation devices; lighting devices; signs and promising concepts. Originally, all devices were to be fabricated and evaluated concurrently. Due to the varying complexity of the devices and to move some devices onto a "fast track" for early development, not all devices were fabricated at the same time.

Performance Factors

Each device was evaluated according to a number of performance factors related to the intended purpose and application (table 2). Each device was first tested for its effectiveness. For example, the Flagger Gate was tested for its effectiveness as a traffic control device before it was crash tested.

The level of performance needed for a device to be tested further varied with the type of test. For example, there are established limits of barrier deflection and occupant impact velocity and acceleration that a barrier device must meet before use. While traffic control devices must meet basic requirements in their design (for example, lettering must be legible from a car traveling at the speed limit, many traffic control devices were evaluated against standard traffic control devices. For example, the Flagger Gate would not pass the closed track traffic control tests if it were not superior to the standard flagger paddle in at least one performance area.

Each device had a testing program specifically tailored to its purpose. However, the tests had many characteristics that were uniform regardless of the device is tested. These general characteristics and test descriptions are discussed in the following sections.

Table 1. H-108 Prototype Devices

Study Area	Device
Barriers	S.CAI Barrier Personnel Protection Trailer Movable Barrier End Treatment Aluminum Can Truck Mounted Attenuator Salt Spreader/Truck Mounted Attenuator Interface Portable Crash Cushion
Warning Devices	Ultrasonic Detection Alarm Infrared Intrusion Alarm Pressurized Pneumatic Tube Alarm Queue Length Detector
Rumble Strips	Traveled Way Rumble Mat Portable Rumble Strip Rumble Stripe
Delineation Devices	Moving Taper Portable Soft Barricade Direction Indicator Barricade Opposing Traffic Lane Dividers
Lighting Devices	Maintenance Vehicle Floodlight Snow Plow Blade Markers Diverging Lights
Signs	Flashing STOP/SLOW Paddle Flagger Gate Portable Sign and Stand Truck Mounted Message Box
Promising Concepts	Automatic Guided Warning Vehicle

Operational Testing and Laboratory Testing

The operational testing and laboratory testing was the first stage of the evaluation of the devices. These tests consisted of the basic checks of performance and operational ability such as environmental/material testing, electronic evaluation and operation testing, in addition to more complicated and advanced testing such as human factors testing, computer simulated impacts and scale model impacts.

These first six phases of the evaluation process were grouped together for discussion.

Table 2. Test Types and Performance Factors

Test Types	Performance Factors
Human Factors	Driver Comprehension
Computer Simulated Impacts	Structural Adequacy Vehicle Trajectory Occupant Risk Appurtenance Deflections
Environmental/Material Testing	Fatigue Corrosion Energy Absorption Stability
Electronic Evaluation	Sensor Range Reflective Surface Sensitivity Battery Life Fail Safe
Scale Model Impacts	Structural Adequacy Vehicle Trajectory Occupant Risk Appurtenance Deflections
Operational Testing	Deployment/Retrieval Maneuverability User Friendliness Fail Safe Operational Safety Adverse Environment
Full-Scale Crash Testing	Structural Adequacy Vehicle Trajectory Occupant Risk Appurtenance Deflections
Full-Scale Crashworthiness Testing	Compartment Intrusion Vehicle Control Debris Fire
Closed Track Testing	Detection Legibility Response Time Conspicuity Higher-Order Perception Compliance Adverse Responses Misperceptions
Open Highway Testing	Traffic Flow and Control Field Operations Worker Exposure Adverse Responses Misperceptions

Human Factors

Human factors evaluations occurred only when needed. The Diverging Lights and the intrusion alarms were evaluated in human factors testing. Human factors evaluations were also used in the development and review of the closed track traffic control study plan and procedures.

Computer Simulated Impacts

Computerized mathematical models can simulate vehicular impacts on barrier devices. Computer simulation has several advantages. First, simulations can quantify performance factors such as structural adequacy, vehicle trajectory, occupant risk, and appurtenance deflections. Mathematical models can identify the design deficiencies of a barrier system before full-scale crash testing begins. Finally, the simulations can locate the critical impact points of a barrier system, which can reduce the number of full-scale crash tests needed to evaluate that system.

Computer simulations were conducted to determine the critical impact points for the proposed testing of the Personnel Protection Trailer. These simulations identified the impact points and angles that would cause the greatest translation of the rear of the trailer and the greatest midspan load along the sides of the trailer. Due to the high costs of fabrication and redesign to create a prototype trailer for crash testing, this device was dropped from development.

Environmental/Material Testing

Mechanical tests were used to evaluate the performance of a device or its associated materials under environmental conditions. These conditions included vibration, exposure to corrosive mediums, absorption of kinetic energy, and stability. Environmental testing was conducted on the warning devices to ensure that the devices were not affected by adverse conditions. Devices were also evaluated for their durability in field conditions.

Electronic Evaluation

Many of the devices required electronic evaluation prior to closed track testing. Devices were tested to determine characteristics such as component life, component durability, environmental security, device operation and fail-safe evaluation.

The component life evaluation tests assessed the expected life of the components such as the battery, capacitors and semiconductors. These tests were used to upgrade the life and reliability of the device.

The component durability tests subjected the devices to environmental variations determined to be typical of its intended application. The devices were shock and vibration tested.

Each device was evaluated to assure that it was weatherproof. Weather simulations included rain and dirt exposure.

The general device operation was evaluated. Each device was deployed and functionally tested in simulated operations without performing closed track or open highway tests. The functional limitations of the devices were assessed in this simulated field environment and the operating procedures were fine-tuned to account for unexpected problems in the deployment, calibration, adjustment or operation of each device.

Fail-safe evaluations were conducted after the above tests and prior to the closed track and open highway tests. Failure tests of components of the devices were conducted to determine the effect these failures have on the operation of the devices.

Scale Model Impacts

Scale model impact testing uses vehicle impacts on devices smaller than the field model to evaluate crashworthiness. Scale model impact testing minimizes the number of full-scale crash tests on a device. The scale model impacts reduce the number of deficiencies in a design prior to full-scale acceptance testing.

The simple design of the Portable Crash Cushion eliminated the need for these tests. No development work was performed on the Moveable Barrier End Treatment. Therefore, no scale model impacts were conducted during this project.

Operational Testing

Operational testing was conducted to ensure that the devices performed their required basic functions. This included: operating at highway speeds for trailers; operating correctly during deployment and retrieval; and remaining in place. The tests were conducted without other traffic in the area.

Maneuverability tests were used to ensure that moving devices could be safely operated in a highway environment. Tests included backing, operation at low speeds, and at highway speeds.

Professional drivers operated various size vehicles at various speeds to test the devices. For example, to test the effect of the rumble strips on vehicle steering, a test driver rode a motorcycle over the rumble strip at a variety of speeds. To test how well the strips remained in place, the driver skidded a truck across the rumble strip.

The electronic warning devices were tested on a motorcycle traveling faster than 55 mi/h (25m/s) to determine whether the devices detected the small, fast-moving vehicle.

Further details of these tests are located in section six.

Full-Scale Crash Testing

All full-scale tests were conducted and evaluated in accordance with the National Cooperative Highway Research Program Report number 230 (NCHRP 230). Details of the conduct of the tests are given in the following sections. Details of the tests themselves are located in section six, in the subsection concerning the Portable Crash Cushion.

Test Facility

These tests were conducted at ENSCO's test facility located in Georgetown, Delaware. The test appurtenance was fabricated and installed at the facility. A reverse tow system was used for test car propulsion, with the test speed controlled by the tow car. A guide wire system was used to steer the test vehicles along the impact trajectory path.

Test Vehicles

The test vehicles were 1979 model year for the large sedan (4500-lb vehicle [2045-kg]) and 1982 model year for the minicompact sedans (1800-lb vehicle [818-kg]). The vehicles were weighed on delivery, instrumented, ballasted, and weighed again to ensure that they met the requirements of NCHRP 230 (4500 ± 200 lb [2045 ± 91 kg] test inertial for large sedan, 1800 ± 50 lb [818 ± 23 kg] test inertial for minicompact sedan). Measurements were made before testing for comparison to deformation measurements.

Each vehicle was equipped with a triaxial accelerometer package mounted on the lateral centerline of the vehicle at the longitudinal location of the center of gravity. Roll and yaw rate gyroscopes were located on the same mounting block as the accelerometers. Contact switches were mounted on the front bumper of the vehicle to mark the impact on the analog tape recorder and to trigger strobe flashes for film analysis.

Data Acquisition System

The major components of the data acquisition system were a Metraplex Series 300 FM data multiplexer and a Honeywell 5600C tape recorder. The Metraplex system was used to condition and multiplex vehicle transducer data. This information was transferred to the Honeywell recorder through several coaxial cables. Two other data channels were recorded on the tape to measure vehicle impact speed.

The multiplexed data were recorded in direct mode with a bandpass of 300 Hz to 300 kHz. The speed trap data were recorded in a frequency modulated mode with a bandpass of 0 to 20 kHz.

The analog data was processed off line using ENSCO's IBM PC microcomputers. The multiplexed data was demultiplexed using a Metraplex 8-channel demultiplexer equipped with wow and flutter compensation control. As the data was demultiplexed, it was passed through an analog Society of Automotive Engineer Class 180 filter and each channel was digitized at a sample rate of 1000 Hz. The test data was then analyzed by ENSCO using the microcomputer and several general purpose highway research analysis programs.

Photography

A minimum of five high-speed (500 frames per second) 16 mm cameras and one real time (24 frames per second) 16 mm camera recorded the crash tests. One camera was placed on board to record dummy movements during the impact. In addition, 35 mm black-and-white print film and 35 mm color slide film were shot of the test appurtenance and the test vehicle before and after testing.

After each test, the high-speed and real-time films were combined into a comprehensive film, fully documenting the test. Accompanying each film was a brief label with the test number and test conditions clearly identified. In all tests, the test number, vehicle weight, velocity, angle of incidence, the project number, and any other pertinent test features were identified on a test card and shown on a sufficient number of frames of the film to allow a viewer, unfamiliar with the testing, to follow the test.

Anthropomorphic Dummies

For all tests, an uninstrumented dummy was placed in the driver seat, unrestrained by lap or shoulder belts. For the large sedan tests, a second dummy was placed in the passenger seat, restrained. The unrestrained dummy provides visual data on the kinematics of an occupant.

Test Conduct

Each test was conducted in accordance with the procedures set forth in NCHRP 230. Each test was carefully documented with still photographs and 16 mm movies of the vehicle, device, test and results of the test. Checklists and logs were used in the conduct of each test. These covered all areas of pretest preparation such as the test vehicle, tow system, vehicle guidance system, instrumentation, camera equipment, and the data acquisition system.

The test program was under the control of the test director, who oversaw the test setup. Other test crew members included a tow car driver, an instrumentation operator and a documentary camera operator.

Data Analysis

After each test, all pertinent data were reduced to hard copy form. This included developing the film and making copies to avoid damaging the original print. Movie data were analyzed to determine the important vehicle/appurtenance dynamic characteristics. Items of interest include vehicle stability (roll and yaw angles), vehicle-appurtenance interactions (to look for any unusual behaviors), and other variables such as vehicle speed, appurtenance deformation, impact angle, and exit angle.

Vehicle data were analyzed using an ENSCO PC microcomputer and ENSCO's general purpose highway research programs. Appropriate filters were used in analyzing vehicle information, The final output of each test was reported in a format similar to that recommended in NCHRP 230. Besides the NCHRP 230 report data analysis output (flail space output including delta V and ridedown acceleration), 50 millisecond accelerations, changes in vehicle velocity, and vehicle momentum were reported for each test.

Vehicle crush depth was reported using the National Highway Transportation and Safety Administration length of damage technique documented in the "Dynamic Crash Test Reference Guide, Version II". The measurement points were equally spaced along the length of the damaged area in order to generally describe the damage penetration profile. The maximum static crush distance (damage penetration) will also be measured and reported, regardless of its location. End, top and lateral view photographs were taken of the full length of each damaged vehicle. The vehicle trajectory after impact will also be measured and reported in a plan view format.

Test Evaluation

All crash tests were evaluated to the criteria of NCHRP 230. Figure 1 shows NCHRP 230 Table 6, directly reproduced from NCHRP 230. All tests must pass criteria A, D, E, H and I. Criteria F (occupant impact velocity and ridedown acceleration) and the peak 50 millisecond acceleration are optional but were reported.

Evaluation Factors		Evaluation Criteria	Applicable to Minimum Matrix Test Conditions (see Table 3)
Structural Adequacy	A.	Test article shall smoothly redirect the vehicle; the vehicle shall not penetrate or go over the installation although controlled lateral deflection of the test article is acceptable.	10, 11, 12, 30, 40
	B.	The test article shall readily activate in a predictable manner by breaking away or yielding.	60, 61, 62, 63
	C.	Acceptable test article performance may be by redirection, controlled penetration, or controlled stopping of the vehicle	41, 42, 43, 44, 45, 50, 51, 52, 53, 54
	D.	Detached elements, fragments or other debris from the test article shall not penetrate or show potential for penetrating the passenger compartment or present undue hazard to other traffic.	All
Occupant Risk	E.	The vehicle shall remain upright during and after collision although moderate roll, pitching and yawing are acceptable. Integrity of the passenger compartment must be maintained with essentially no deformation or intrusion.	All
	F.	Impact velocity of hypothetical front seat passenger against vehicle interior, calculated from vehicle accelerations and 24 in. (0.61m) forward and 12 in. (0.30m) lateral displacements, shall be less than: Occupant Impact Velocity-fps Longitudinal: $40/F_1$ Lateral: $30/F_2$ and vehicle highest 10 ms average accelerations subsequent to instant of hypothetical passenger impact should be less than: Occupant Ridedown Accelerations—g's Longitudinal: $20/F_3$ Lateral: $20/F_4$ where F_1, F_2, F_3, and F_4 are appropriate acceptance factors (see Table 8, Chapter 4 for suggested values).	11, 12, 41, 42, 43, 44, 45, 50, 51, 52, 54, 60, 61, 62, 63
	G.	(Supplementary) Anthropometric dummy responses should be less than those specified by FMVSS 208, i.e., resultant chest acceleration of 60g, Head Injury Criteria of 1000, and femur force of 2250 lb (10 kN) and by FMVSS 214, i.e., resultant chest acceleration of 60 g, Head Injury Criteria of 1000 and occupant lateral impact velocity of 30 fps (9.1 m/s).	11, 12, 41, 42, 43, 44, 45, 50, 51, 52, 54, 60, 61, 62, 63
Vehicle Trajectory	H.	After collision, the vehicle trajectory and final stopping position shall intrude a minimum distance, if at all, into adjacent traffic lanes.	All
	I.	In test where the vehicle is judged to be redirected into or stopped while in adjacent traffic lanes, vehicle speed change during test article collision should be less than 15 mph and the exit angle from the test article should be less than 60 percent of test impact angle, both measured at time of vehicle loss of contact with test device.	10, 11, 12, 30, 40, 42, 44, 53
	J.	Vehicle trajectory behind the test article is acceptable.	41, 42, 43, 44, 45, 50, 51, 53, 54, 60, 61, 62, 63

Figure 1. Safety Evaluation Guidelines
(reprinted from Table 6 of NCHRP 230)

Full-Scale Crashworthiness Testing

The following seven devices were evaluated in a full-scale crashworthiness test program:

- Ultrasonic Detection Alarm
- Portable Soft Barricade
- Direction Indicator Barricade (pop-up version)
- Flagger Gate (impact on arm)
- Infrared Intrusion Alarm
- Portable Sign and Stand
- Flagger Gate (impact on base)
- Redesigned Flagger Gate (impact on arm)

These devices were crashworthiness tested to evaluate the impact characteristic of each device and to demonstrate that they do not present a hazard to the workers or to the motoring public.

Details of the conduct of the tests are given in the following sections. Details of the tests are located in section six.

Facility

These tests were conducted at ENSCO's crash test facility located in Georgetown, Delaware.

Test Vehicle

The test vehicle used for the crashworthiness testing was a 1985 hatchback Dodge Colt (mini-compact sedan). The vehicle was weighed on delivery, instrumented, ballasted, and weighed again to ensure that it met the requirements of NCHRP 230 (1800 ± 50 lb [818 ± 23 kg] test inertial weight). The final inertial weight of the Dodge Colt was 1813 lb (824 kg), and the gross weight of the vehicle with an anthropomorphic dummy was 1978 lb (899 kg).

The vehicle was equipped with contact switches mounted on the front bumper to trigger strobe flashes for movie film analysis. Table 3 lists the important vehicle parameters of the test car used for these tests.

Table 3. Test Vehicle Parameters

Item	Quantity
Empty Weight	1876 lb
Ballast	None, 63 lb removed
Total Test Vehicle Weight	1813 lb
Total Gross Vehicle Weight	1978 lb
Vehicle Length	158 in
Vehicle Wheelbase	93.7 in
Wheel/Tire size	P155/80R13

1 lb = 0.45 kg, 1 in = 2.5 cm

Photography

Photographic coverage was provided by two high-speed (250 frames per second) 16 mm cameras and one real time (24 frames per second) 16 mm documentary camera. In addition, 35 mm black-and-white prints and 35 mm color slides of the test device and the test vehicle before and after testing were taken.

After completion of the test program, the high speed and the real time documentary film were combined into comprehensive films to document the test program. At the beginning of each film, the test number, test conditions and test parameters for each individual test are identified.

Anthropomorphic Dummies

For all tests, an uninstrumented dummy was placed in the driver's seat with both the lap and shoulder harness attached.

Test Conduct

Each test was conducted in accordance with the procedures set forth in NCHRP 230. Still photographs and 16 mm movies documented the vehicle, device, test and the test results. A detailed set of checklists and logs covered all areas of pretest preparation such as the test vehicle, tow system, vehicle guidance system, instrumentation, camera equipment, and the data acquisition system.

The test program was under the control of the test director, who oversaw the test setup and verified each item from the checklists. Other test crew members included a tow car driver, an instrumentation operator and a documentary camera operator.

Data Analysis

After the completion of the tests, all pertinent data was reduced to hard copy form. The films were processed and copies were made to avoid damage to the original print. Movie data was analyzed to determine the important vehicle/device dynamic characteristics. Items of interest include vehicle stability (roll and yaw angles), vehicle-device interactions (any unusual behaviors), and other variables such as speed, impact angle, exit angle, and device deformation.

Test Evaluation

All crash tests were evaluated with the help of NCHRP 230 criteria, reproduced previously in figure 1. This table shows the guidelines used to evaluate each device. All of the crashworthiness tests must pass test evaluation criteria D and E from this figure.

Additionally, the device must not present a hazard to workers in the work zone following an impact by an errant vehicle. This was designated as the "work zone hazard criterion." Each crashworthiness test was required to pass this criterion.

Closed Track Testing

Instrumented vehicle testing was conducted on an unused airport runway to avoid the safety and liability problems of using experimental traffic control devices on public highways. Subjects drove through a series of simulated work zones in roadway settings arranged to ensure interpretation of only one device at a time. Subjects also saw standard devices currently in use. This was used as a reference to evaluate the effects of the new devices. Ninety-six subjects were used in these tests. The subjects were chosen to replicate the normal driving population.

Two measures of effectiveness were: (1) the driver and (2) the vehicle.

Primary driver measures were:

Device Recognition Time - The elapsed time from the moment when a test device comes into the subject's field of view until the subject recognizes it as a device that may affect his driving.

Device Interpretation Time - The amount of time required for the subject to interpret an appropriate response to the device.

Interpretation Correctness - Whether the subject responded correctly to the device.

Interpretation Problems - Whether the subject misunderstood the message of the device.

Helpfulness Rating - Categorical response to the following question:

How helpful was this device to your driving?

1. Very helpful
2. Helpful
3. Not very helpful
4. Not at all helpful

A numerical score for each device was based on the above ratings.

Safety Rating - Categorical response to the following question:

In your opinion, use of this device would make highways...

1. Much safer
2. Somewhat safer
3. A little safer
4. No safer at all

The following vehicle behavioral measures were determined from vehicle instrumentation installed in the car driven by test subjects.

Approach Speed - Speed of the vehicle at the time that the device first came into the driver's view.

Arrival Speed - Speed of the vehicle when the vehicle arrived at the device location.

Approach Speed Profile - Difference between the above two speeds.

Device Approach Time - Elapsed time between the approach and arrival speed measurements.

Speed Variance - The mathematical variance function based upon a set of speed measurements taken between the approach and arrival speed points.

Details of the closed track test results for individual devices are subsequently discussed in section six.

Open Highway Testing

Devices that passed the closed track testing then were evaluated under actual highway conditions by state maintenance forces. Table 4 lists the devices evaluated in open highway testing and the locations of the testing.

Table 4. Open Highway Testing: Devices and Locations

Device	Locations
Snowplow Blade Markers	Washington State
Portable Speed Bump	Iowa
Flashing Stop/Slow Paddle	New York, Texas, Virginia
Portable Sign and Stand	Texas
Ultrasonic Detection Alarm	Arizona, Iowa, Missouri
Infrared Intrusion Alarm	Arizona, Iowa
Direction Indicator Barricade	Maryland
Opposing Traffic Lane Divider	Illinois, Mississippi
Queue Length Detector	Missouri
Remote Driven Vehicle	Minnesota

Details of the conduct of the testing are given in the following sections. Details of the tests themselves are located in section six.

Three types of open highway testing were conducted: stationary, moving, and flagging. A stationary maintenance work zone is normally in place from 1 to 12 hours. During moving operations, workers and equipment move down the road without stopping. Intermittent moving operations, also known as mobile operations, are included as a type of moving operation. Flagging coordinates conflicting traffic movements over a section of highway for two directions of travel or can warn, guide, and control drivers past a potentially hazardous highway section where workers or equipment may conflict with traffic. Maintenance accidents studied in SHRP Project H-108 showed that work in the traveled way was the most hazardous.

Open highway testing of these devices was performed in actual maintenance work zones. The devices were evaluated under different highway and traffic conditions by states that were willing to participate in the studies.

The FHWA requires states to request permission to test or evaluate a new device, if it is to be recognized as a traffic control device in the Manual for Uniform Traffic Control Devices (MUTCD). The study team working with the cooperating states requested and received FHWA permission to conduct open highway tests of the devices.

Before open highway testing began, state maintenance forces were trained to operate and use the devices. When maintenance forces became proficient in operating a device, they used it in a maintenance work zone under open highway conditions. Standard agency procedures were used to conduct the maintenance. Some operations were videotaped by the study team to evaluate the operation and its effect on traffic. When the maintenance operation was completed, a critique and evaluation of the device was conducted at the maintenance yard office to discover any safety and operation problems. The videotapes of the operation were shown to the workers who were asked questions about the performance of the device. Comments and suggestions on improvements to the device were also solicited.

The data collected in the open highway tests were used to compare the effectiveness of the device to the effectiveness of current practice. The conclusions of the open highway studies were used to improve the devices. Minor changes to the design and production specifications made the devices more user friendly. Results of the open highway testing will lead to proposed standards for new traffic control devices or changes to current standards in the Manual on Uniform Traffic Control Devices (MUTCD).

3

Implementation of Devices

Time and budget constraints limited the Open Highway testing and evaluation of these devices. Further evaluation of the devices is necessary before they are fully implemented. The Federal Highway Administration (FHWA) is currently conducting these evaluations.

Six devices-the Portable Rumble Strip; the Flashing Stop/Slow Paddle; the Opposing Traffic Lane Divider; the Portable Sign and Stand; the Direction Indicator Barricade; and the Remotely Driven Vehicle-are commercially available. The FHWA plans to purchase these devices to loan to the states for evaluation, and will instruct the states on the use of the devices.

Six other devices-the Infrared Intrusion Alarm; The Ultrasonic Detection Alarm; the Queue Length Detector; the Portable Crash Cushion; the Diverging Lights; and the Snowplow Blade Markers-need further refinement and a commercial vendor before they are evaluated by the states.

Plans and specifications for some of these prototypes are available to states or commercial fabricators. User manuals on the Open Highway testing also are available. Their use may be limited, however, because the devices continue to be modified.

Use of these devices on the highway affect the standards in the MUTCD. The Flashing Stop/Slow Paddle, the Opposing Traffic Lane Divider, and the Direction Indicator Barricade are presently under consideration by the National Committee on Uniform Traffic Control Devices.

4

Conclusions

Twelve devices (of twenty five initially) successfully passed the evaluation stage. Each of the seven study areas are represented by these devices. The successful devices are: the Salt Spreader/Truck Mounted Attenuator Interface, the Portable Crash Cushion, the Ultrasonic Detection Alarm, the Infrared Intrusion Alarm, the Queue Length Detector, the Portable Rumble Strip, the Direction Indicator Barricade, the Opposing Traffic Lane Dividers, the Snowplow Blade Markers, the Flashing Stop/Slow Paddle, the Portable Sign and Stand, and the Remotely Driven Vehicle.

These devices are ready for implementation. Some of them require further refinement, and will benefit from the additional research, testing and evaluation gained through widespread usage.

5

Recommendations

The following is a list of the devices that require additional refinement, research, testing and evaluation and the areas in which this work is required.

Portable Crash Cushion: A redesign of the power source for the components and a redesign of the axle system to allow for the placement of the device at a hazard.

Ultrasonic Detection Alarm: The only concern is that Polaroid has recently made changes in the ultrasonic ranging unit and the electrostatic transducer. Whether these changes will affect the current design is unknown. This new Polaroid setup should be investigated.

Infrared Intrusion Alarm: The Infrared Intrusion Alarm should be evaluated by maintenance crews in highway work zones. The location and time of use of each unit should be recorded as well as any false alarms that occur. If an errant vehicle intrudes into the work zone, full details of the incident and the performance of the Infrared Intrusion Alarm should be documented. Any problems with charging the units or low batteries should also be noted.

Queue Length Detector The only concern is that Polaroid has recently made changes in the ultrasonic ranging unit and the electrostatic transducer. Whether these changes will affect the current design is unknown. This new Polaroid setup should be investigated.

Portable Rumble Strip: Further open highway evaluation should take place. This evaluation should focus on optimizing the spacing, placement, and number of bumps to be used for different types of roadways and work operations.

Direction Indicator Barricade: Based on both closed track and open highway testing of the Direction Indicator Barricades, the features of the directional arrow design should be combined into a drum-type device affording the size, conspicuity, and durability of the conventional drum. The recommended device is a flat-faced drum incorporating a black directional arrow on a reflective white background. It is recommended that production models of the device be made of plastic or other light-weight material. In order to include this reversible-direction advantage into a "directional indicator drum", it is recommended to have the arrow panel slide between grooved slots on the upper portion of the drum, so that the arrow can direct traffic to the right or left.

Opposing Traffic Lane Divider: The newly-redesigned Opposing Traffic Lane Dividers are now available from several manufacturers. Evaluation of the device should continue.

Snowplow Blade Markers: The aircraft wing lights were not durable for snow plowing operations. Vibration and shock absorbing mechanisms may remedy this, and should be investigated. Markers should be mounted as high as possible on the plow blade. Alternative mountings on the truck should be considered.

Flashing Stop/Slow Paddle: Open highway evaluation of the device should continue.

Portable Sign and Stand: Open highway evaluation should continue.

Remotely Driven Vehicle: Open highway evaluation should continue. Further work should be conducted to reduce the complexity and cost of the system. This work may produce a modularized kit available to a broad base of users at a reasonable cost.

Diverging Lights: This device still holds promise but the tradeoff between intensity and recognition must be discovered. Further research is needed as to determine whether the Diverging Lights will increase safety.

Flagger Gate: Consideration should be given to making a breakaway arm for the current device. The design of the Flagger Gate mounted in the bed of a pickup truck should be investigated.

6

Development and Evaluation Process by Device

Twelve devices (of twenty five initially) passed the evaluation stage. Each of the seven study areas are represented by these devices. The successful devices are: the Salt Spreader/Truck Mounted Attenuator Interface; the Portable Crash Cushion; the Ultrasonic Detection Alarm; the Infrared Intrusion Alarm; the Queue Length Detector; the Portable Rumble Strip; the Direction Indicator Barricade; the Opposing Traffic Lane Dividers; the Snowplow Blade Markers; the Flashing Stop/Slow Paddle; the Portable Sign and Stand; and the Remotely Driven Vehicle.

Table 5 shows the evaluation results for all the devices. The following text contains detailed discussions of the development, testing and evaluation of each device.

Table 5. Evaluation Results

Device	Evaluation Results
Salt Spreader/Truck Mounted Attenuator Interface	Successfully passed evaluation criteria
Portable Crash Cushion	Successfully passed evaluation criteria
Ultrasonic Detection Alarm	Successfully passed evaluation criteria
Infrared Intrusion Alarm	Successfully passed evaluation criteria
Queue Length Detector	Successfully passed evaluation criteria
Portable Rumble Strip	Successfully passed evaluation criteria
Direction Indicator Barricade	Successfully passed evaluation criteria
Opposing Traffic Lane Dividers	Successfully passed evaluation criteria
Snowplow Blade Markers	Successfully passed evaluation criteria
Flashing Stop/Slow Paddle	Successfully passed evaluation criteria
Portable Sign and Stand	Successfully passed evaluation criteria
Remotely Driven Vehicle	Successfully passed evaluation criteria
Diverging Lights	Operational Testing not successful
Flagger Gate	Crashworthiness Testing not successful
S.CAI Barrier	Operational Testing not successful
Personnel Protection Trailer	Not fabricated
Moveable Barrier End Treatment	Not fabricated
Aluminum Can Truck Mounted Attenuator	Not fabricated
Pressurized Pneumatic Tube Alarm	Operational Testing not successful
Traveled Way Rumble Mat	Operational Testing not successful
Rumble Stripe	Operational Testing not successful
Moving Taper	Not fabricated
Portable Soft Barricade	Operational Testing not successful
Maintenance Vehicle Floodlight	Operational Testing not successful
Truck Mounted Message Box	Operational Testing not successful

Salt Spreader/Truck Mounted Attenuator Interface

Figure 2 shows the Salt Spreader/Truck Mounted Attenuator (TMA) Interface.

Background

In many states, salt and sand spreaders are used for snow and ice control during the winter months. In some states, these vehicles are used only for spreading salt or sand. In many states, however, trucks used in the summer as dump trucks are converted in the winter by the addition of a spreader unit in the dump section of the body. In the summer, these trucks are equipped with a TMA. While TMAs do not eliminate rear-end accidents, they do reduce the severity of these accidents. When the spreader units are placed in the trucks, however, the spinner assembly and the spreading of salt or sand can physically interfere with the TMA.

Device Description

The Salt Spreader/TMA interface is a tubular steel frame adapter between rear-spreading salt spreaders and commercially available TMAs. The interface is a modification of current TMA mounting hardware designs. The Salt Spreader/TMA interface has an opening in the center that allows the spreader assembly to pass through. All of the structural and hydraulic members are mounted on either side of the spinner assembly opening. The size of the opening can accommodate for different spreader assembly sizes. The interface has a hydraulic package to tilt the TMA for transport. When the spreader is not on the truck, the interface compresses to approximately the same size as current TMA mounting hardware designs. This interface and the mounting features permit the use of a TMA year-round.

Design and Fabrication

The interface has undergone a full design iteration. Fabrication quotes were in process when Energy Absorption Systems, Inc. (EAS) was consulted concerning possible sharing of the development and evaluation of this device.

Operational Testing

The project staff sought to develop the Salt Spreader/TMA Interface and collaborate with EAS on the operational testing and open highway testing. EAS researchers had been working on a similar device and wished to evaluate the project staff plans for the device.

The Salt Spreader/TMA Interface was passed to EAS for development, testing, evaluation and marketing since a current manufacturer of TMAs would be best able to market the device. The project staff ceased development at that time.

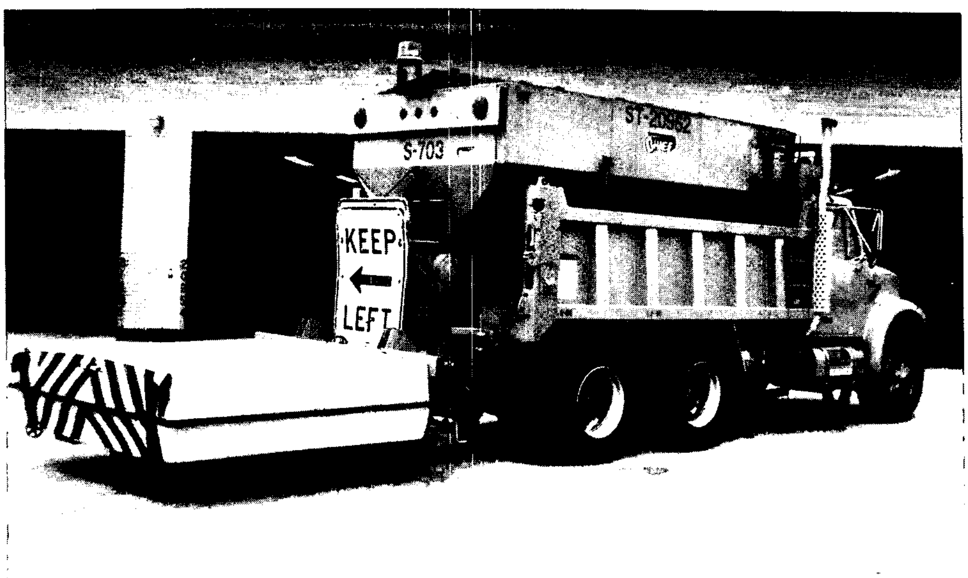


Figure 2. Salt Spreader/TMA Interface

Portable Crash Cushion

Figure 3 shows the Portable Crash Cushion.

Background

Sand barrel crash cushions are used to attenuate the impacts of vehicles into roadside hazards. Sand barrel crash cushions are often used at locations such as bridge piers, lane abutments and the ends of narrow and wide hazards to protect vehicle occupants from directly striking the hazard. When the array is impacted, the energy of the impacting car is utilized to move the sand contained in the barrels.

A crash cushion array consists of up to thirteen plastic barrels filled with sand. The placement of a total array can be a time consuming, and therefore hazardous, operation. The time required to place an array barrel by barrel eliminates the use of a sand barrel crash cushion in a temporary work zone.

Device Description

The portable crash cushion is a specially designed tilt-bed trailer that carries a sand barrel crash cushion array on an articulated platform. The trailer can move the crash cushion into a closed lane upstream of a stationary maintenance operation. This is done by positioning the trailer and sliding the pallet off the tilt-bed onto the roadway. This provides in-lane protection for pedestrian maintenance workers. The portable crash cushion is an alternative to shadow vehicles during stationary maintenance operations. Also, the Portable Crash Cushion does not roll ahead on impact, as do the shadow vehicles.

Design and Fabrication

The portable crash cushion is an easily placed and retrieved array of impact attenuating sand barrels. This goal was achieved by designing a tilt-bed trailer and a pallet system capable of holding the sand barrels in place during transport, drop-off, and retrieval. The pallet system consists of a set of eight steel plates. Each plate is 85 in (2.16 m) wide, 43.5 in (1.10 m) long and 3/16 in (0.48 cm) thick. The plates have two hinges at each plate connection to link them into a chain. The entire length of the system is 30 ft, 4.5 in (9.26 m). 13 sand modules are bolted to the steel pallet using two wooden washers and one steel washer. There are 1-in (2.54-cm) rings welded onto the pallet to ensure that the modules do not slide on the pallet upon impact.

Operational Testing and Lab Testing

The operational and lab testing efforts on the portable crash cushion was extensive. The pallet system was tested to ensure that the sand barrels would not fracture or rupture during roadway transport conditions. A sample pallet was constructed and a 1400-lb (636-kg) barrel and a 2100-lb (955-kg) barrel were attached to the pallet. The pallet was then statically raised to an angle of 50 degrees. This was performed to ensure that the washer/bolt attachment method would not fail or cause failure in the sand barrel. The pallet was than oscillated in an approximate one-half -Hz, 1-ft to 2-ft (0.3-m to 0.6-m) cycle to check for any road vibration and/or

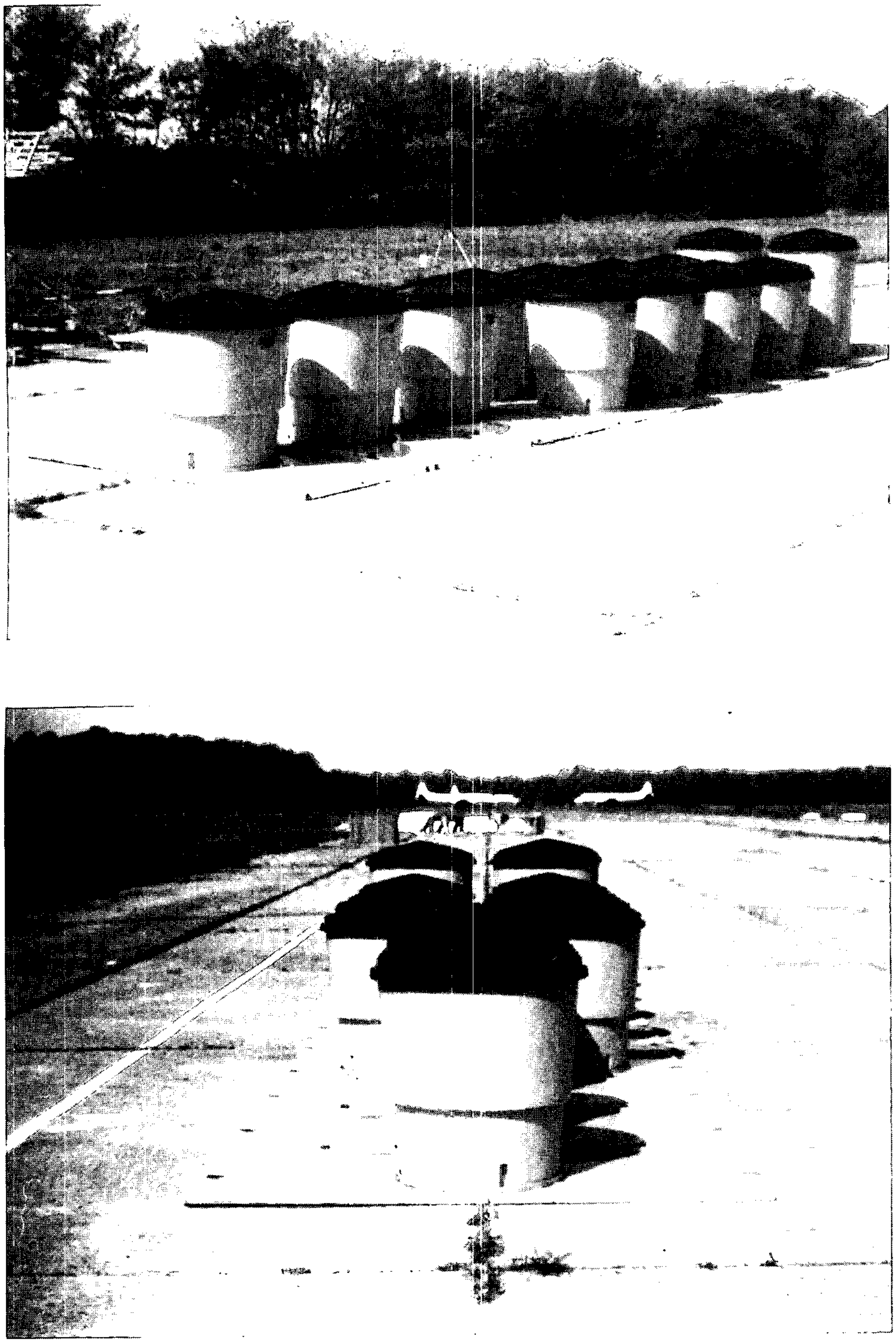


Figure 3. Portable Crash Cushion

movement failure in the barrels. To check the ultimate strength of the sample system, the pallet was raised to 80 degrees before the sand barrels failed.

The trailer was then transported over roadway conditions to evaluate the handling of the trailer at roadway speeds, slow speeds, and in backing maneuvers.

During the operational testing of the tilt-bed trailer and the performance testing of the drop-off and retrieval winch, it was discovered that the battery system, which powered the hydraulic pump that tilted the bed and the electric winch, was not sufficient for repeated cycles without recharging. Even with repeated recharging, a single battery would lose the ability to power the system after repeated cyclings. The redesigned system should include multiple batteries or an auxiliary power system, such as a stand-alone generator.

Full-Scale Crash Testing

ENSCO Test 2036-FS1-92

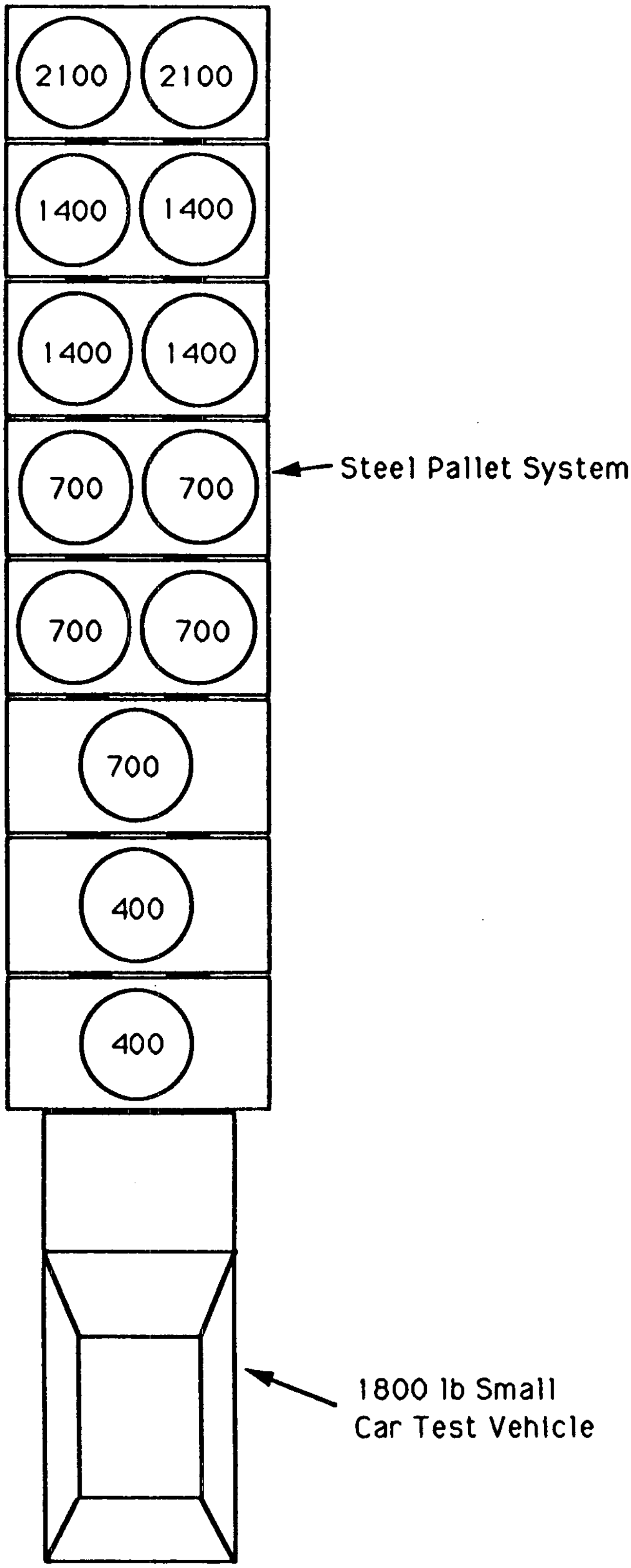
Test Device

The sand modules were placed on the pallets in a previously crash tested and proven standard module array. Each pallet was one row of the array. The sand module array configuration was as follows:

Row or Pallet #	Number of Modules	Module Weight [lb]
1	1	400
2	1	400
3	1	700
4	2	700
5	2	700
6	2	1400
7	2	1400
8	2	2100

1 lb = 0.45 kg

The modules tested were the Energite III Modules made by Energy Absorption Systems Inc. The 400-lb (182-kg), 700-lb (318-kg) and 1400-lb (636-kg) modules consist of a one-piece outer container and a lid. The 400-lb (182-kg) and 700-lb (318-kg) modules have an inner cone to ensure that the module's center of gravity is at the proper elevation to prevent vehicle ramping. The 1400-lb (636-kg) modules is filled completely and does not require a cone. These modules are 36 in (91 cm) tall, 36 in (91 cm) wide at the top, and 27.5 in (70 cm) wide at the bottom. The 2100-lb (955-kg). module consists of only an outer container and a lid, and is also filled completely. The 2100-lb (955-kg) modules are 45.25 in (107 cm) tall, 36 in (91 cm) wide at the top, and 30.25 in (77 cm) wide at the bottom. The attenuator system was set on a concrete road and positioned for a head-on impact. Figure 4 shows the test site layout. Figure 5 shows pretest photographs of the impact attenuator system.



The circles represent the sand barrels. The numbers represent the weight of the barrels, in pounds.

1 lb = 0.45 kg

Figure 4. Portable Crash Cushion Layout, Test 2036-FS1-92

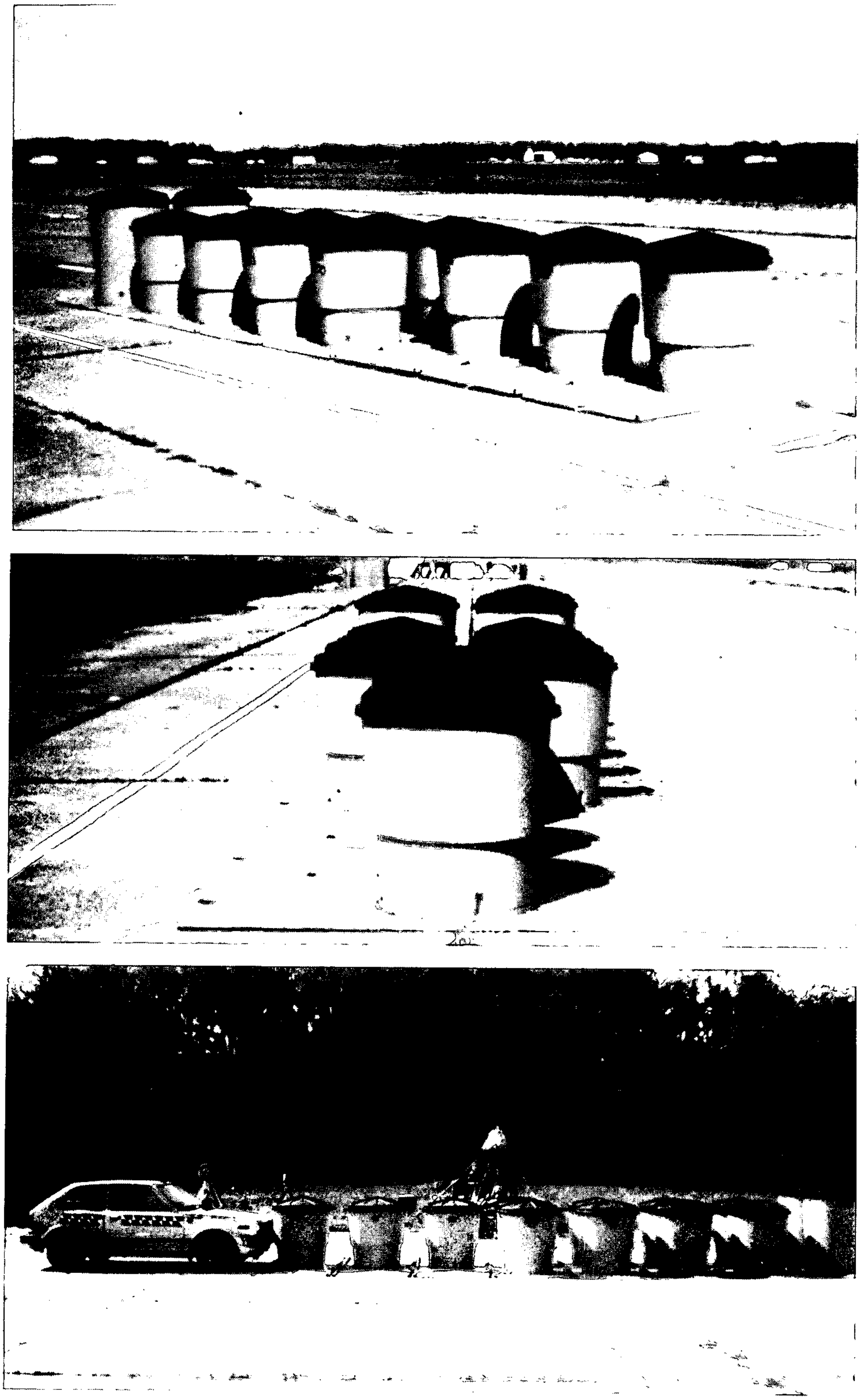


Figure 5. Portable Crash Cushion Before Test, Test 2036-FS1-92

Test Vehicle

The test vehicle was a 1982 Honda Civic. The target inertial vehicle weight was 1800 ± 50 lb (818 ± 23 kg). The vehicle weighted approximately 1750 lb (795 kg) empty and 50 lb (23 kg) of ballast was added. The inertial weight of the vehicle was 1800 lb (818 kg).

One anthropomorphic dummy was placed in the driver's seat of the vehicle. The dummy was unrestrained. The gross weight of the vehicle was 1956 lb (889 kg). X-, y- and z-axis accelerometers were mounted in the car along with roll and yaw rate gyroscopes. Photographs of the test vehicle before testing are shown in figure 6.

Impact Description

Review of the high speed films, speed trap and fifth wheel data indicated that the test vehicle impacted at 60.6 mi/h (27.1 m/s) and 0 degrees. This review also indicated that the vehicle centerline was aligned with the centerline of the attenuator.

Upon impact, the rear of the vehicle pitched upward approximately 15 degrees while the vehicle was slowing. The vehicle penetrated approximately 23 ft (7 m) into the attenuator, stopping between rows 6 and 7. The vehicle yawed approximately 50 degrees clockwise (as seen from above) while the rear wheels were in the air. The vehicle did not rebound. The front of the vehicle came to rest on the pallets between rows 6 and 7 while the rear of the vehicle rested on the ground. The pallet slid 6 in (15 cm) forward and 1 in (2.5 cm) to the left from its starting position.

A summary of test conditions and results are shown in figure 7. Data analysis was performed. The x- and y-axis, 100 Hz data plots are shown in figure 8.

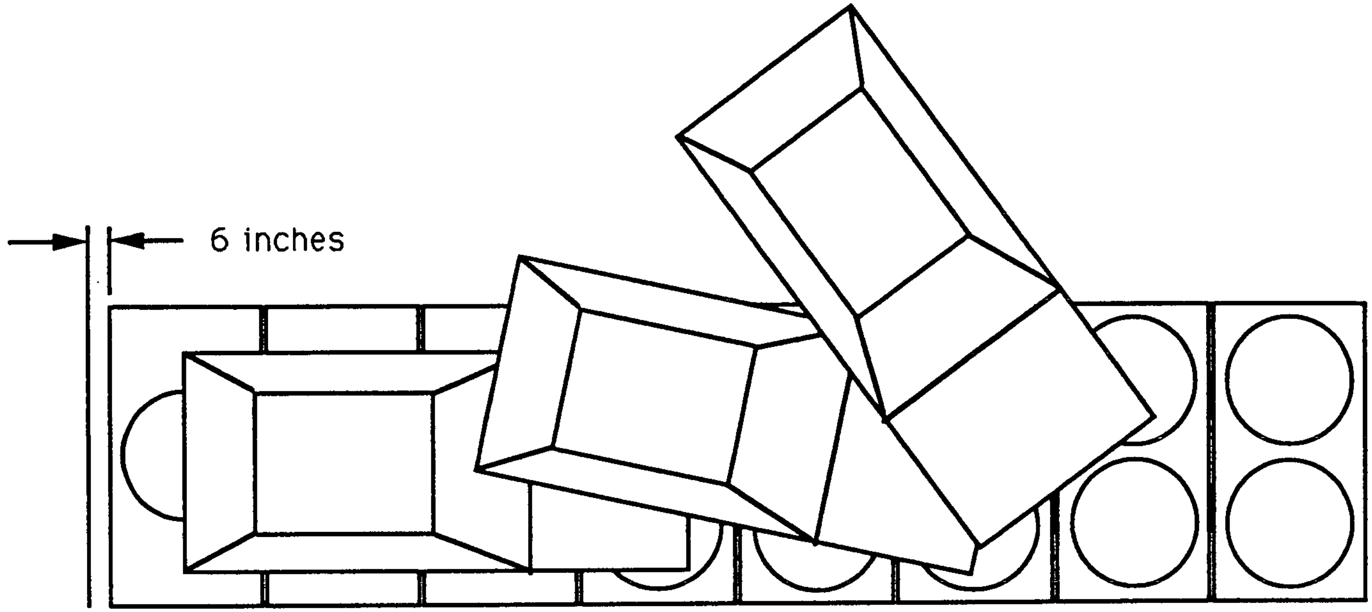
Vehicle Damage

Damage occurred only to the front end of the vehicle. The crush was uniform across the front of the vehicle. Most of the damage occurred above the bumper. The vehicle hood and front fenders were buckled. The vehicle grill and radiator were pushed back into the engine. The vehicle sustained little suspension damage. The windshield was broken 3 in (7.6 cm) from the top due to the impact of the dummy's head. Photographs of the vehicle after the crash test are shown in figure 9.

Attenuator Damage

The impact attenuator performed as designed. The sand modules in rows 1 through 5 were destroyed completely. The modules broke apart just above the module retaining rings. The bottom portion of the modules were still attached to the pallets. The pallet system itself and the three washers were undamaged and reusable. The sand modules on pallet 6 were broken and pushed over, but were not shattered. The sand modules on pallet 7 were deformed and cracked, but still contained most of their sand. The left sand module on pallet 8 was cracked at the top but was still filled with sand, and the right sand module was undamaged. Photographs of the impact attenuator after the crash test are shown in figure 10.

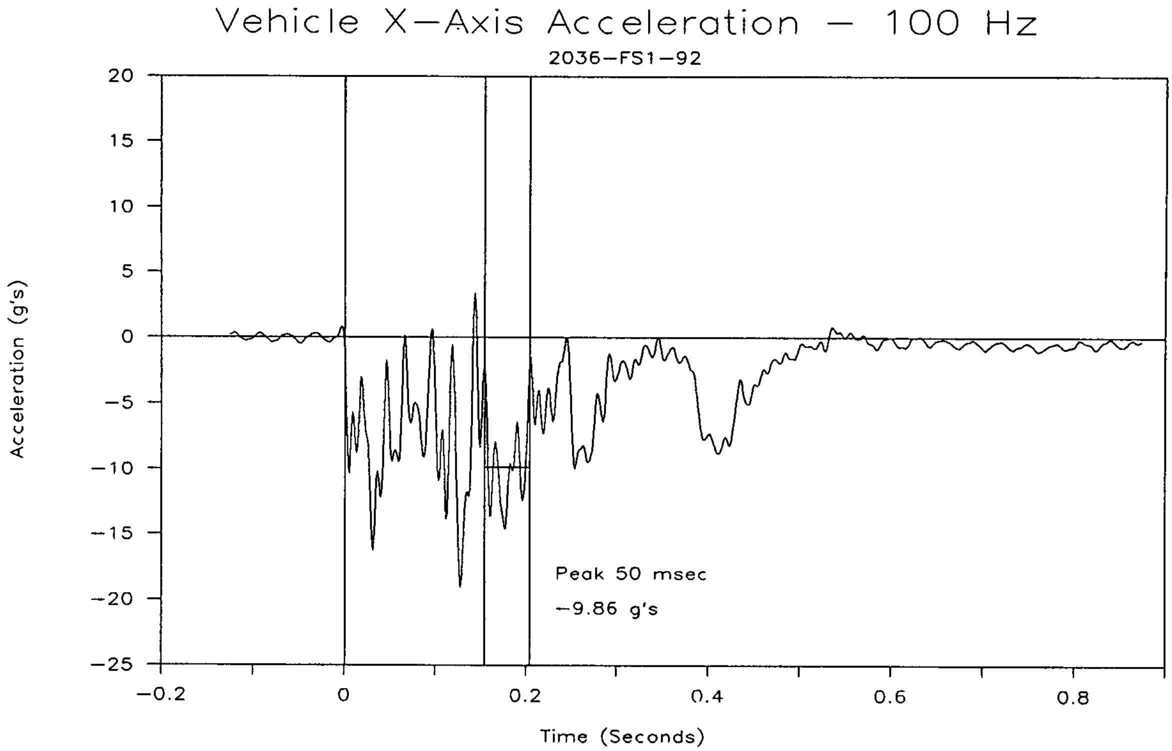
Figure 6. Photographs of the Vehicle Before Test, Test 2036-FS1-92



Date:	29 April 1992		
Weather:	Clear 65° F		
Test Vehicle:	1982 Honda Civic		
Device Configuration:	Portable Crash Cushion impact attenuator. 8 pallet system with 13 Energite III sand module array. System is 364.5" long and 85" wide. System placed on concrete road.		
1. Vehicle Weight:			
Planned, Inertial:	1800 ± 50		
Actual, Inertial:	1800		
2. Number of Occupants:	One		
3. Occupant Model:	Part 572 50 percentile male		
4. Occupant Location:	Driver Seat, Unrestrained		
3. Impact:	<u>Speed</u>	<u>Angle (a)</u>	<u>Location</u>
Planned:	60.0 mi/h	0°	Center of Attenuator
Actual:	60.6 mi/h	0°	Center of Attenuator
6. Rebound:	No Rebound		
7. Total Speed Change:	60.6 mi/h (88.9 ft/s)		
8. Total Momentum Change:	4970 lb-s		
9. Vehicle Damage Index: (SAE J224a)	12FDEW1		

10. NCHRP 230 Test Number:	52	
11. NCHRP 230 Impact Severity:		
$\frac{mV^2}{2}$	220.8 kip-ft (Target: $216^{-21,+37}$ kip-ft)	
12. Vehicle Analysis:	<u>Observed</u>	<u>Design/ Limit Value</u>
<u>NCHRP 230</u>:		
Longitudinal:		
Delta-V at 2 ft:	-31.6 ft/s	30/40 ft/s
Ridedown Acceleration:	-16.0 g's	15/20 g's
Lateral:		
Delta-V at 1 ft:	no impact	20/30 ft/s
Ridedown Acceleration:		15/20 g's
<u>TRC 191</u>:		
Peak 50 ms acceleration:		
Longitudinal:	-9.9 g's	
Lateral:	-1.0 g's	
13. Test Results Conclusion:		
NCHRP 230:	**MEETS ALL CRITERIA.**	

Figure 7. Full-Scale Test Summary for the Portable Crash Cushion, Test 2036-FS1-92



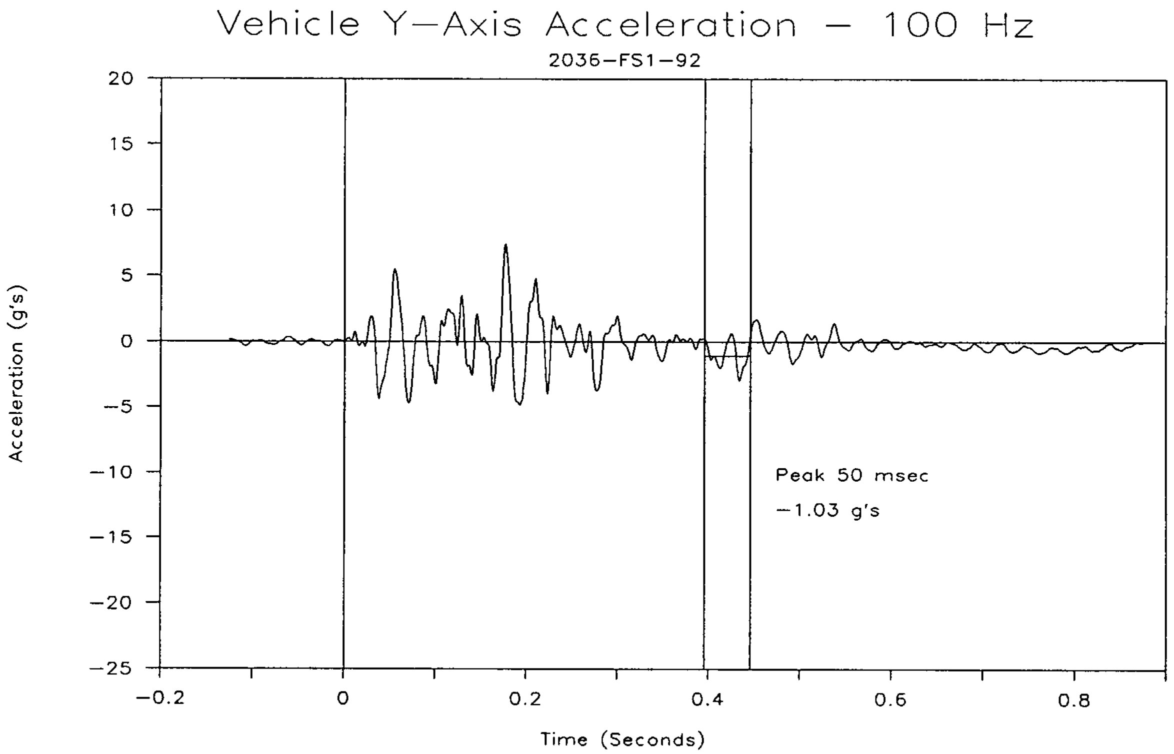


Figure 8. Vehicle Acceleration During the Test of the Portable Crash Cushion, Test 2036-FS1-92

Figure 9. Photographs of the Vehicle After the Crash of the Portable Crash Cushion, Test 2036-FS1-92

Figure 10. Photographs of the Portable Crash Cushion After Crash, Test 2036-FS1-92-91

Dummy Damage

No observable damage to the dummy occurred. The occupant impact velocity and accelerations were within the limits specified in NCHRP 230.

Test Evaluation

This test was evaluated using the criteria for NCHRP 230 test 52. The following is an item-by-item evaluation using this guideline.

- <u>NCHRP 230:</u>
  - c. The test article exhibited acceptable performance.
  - d. Detached elements presented no undue hazard to the passenger compartment or to other traffic.
  - e. The vehicle remained upright during and after the collision. Integrity of the passenger compartment was maintained.
  - f. Delta-V and Ridedown values are within acceptable criteria.
  - h. Vehicle trajectory and stopping position did not intrude into adjacent traffic lines.
  - j. The vehicle was stopped by the test article.

  The Portable Crash Cushion successfully met the evaluation criteria.

ENSCO Test 2036-FS2-92

Test Device

The Portable Crash Cushion attenuator system was the test device, as described previously. Figure 11 shows the test site layout. Figure 12 shows pretest photographs of the impact attenuator system.

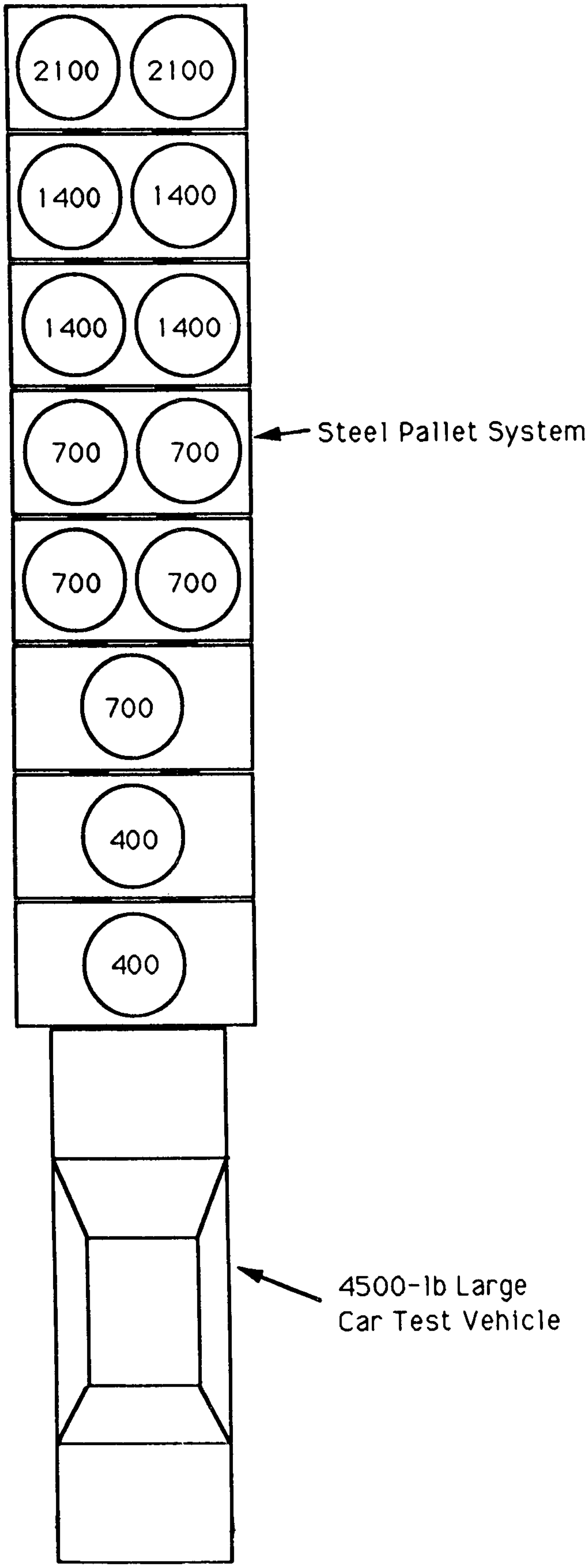
Test Vehicle

The test vehicle was a 1979 Chrysler Newport. The target inertial vehicle weight was 4500 ± 200 lb (2045 ± 91 kg). The vehicle weighed approximately 3913 lb (1779 kg) empty. 450 lb (205 kg) of ballast was added to the vehicle. The inertial weight of the vehicle was 4363 lb (1983 kg).

Two dummies were placed in the vehicle. The driver dummy was unrestrained while the passenger dummy was restrained. The target gross vehicle weight was 4500 ± 300 lb (2045 ± 136 kg). The gross weight of the vehicle including the dummies was 4685 lb (2130 kg). X-, y- and z-axis accelerometers were mounted in the car as well as roll and yaw rate gyroscopes. Photographs of the vehicle before the crash test are shown in figure 13.

Impact Description

Review of the high speed films, speed trap and fifth wheel data indicated that the test vehicle impacted at 60.2 mi/h (26.9 m/s) and 0 degrees. This review also indicated that the vehicle centerline was aligned with the centerline of the attenuator.



The circles represent the sand barrels. The numbers represent the weight of the barrels, in pounds.

1 lb = 0.45 kg

Figure 11. Portable Crash Cushion Layout for Test 2036-FS2-92

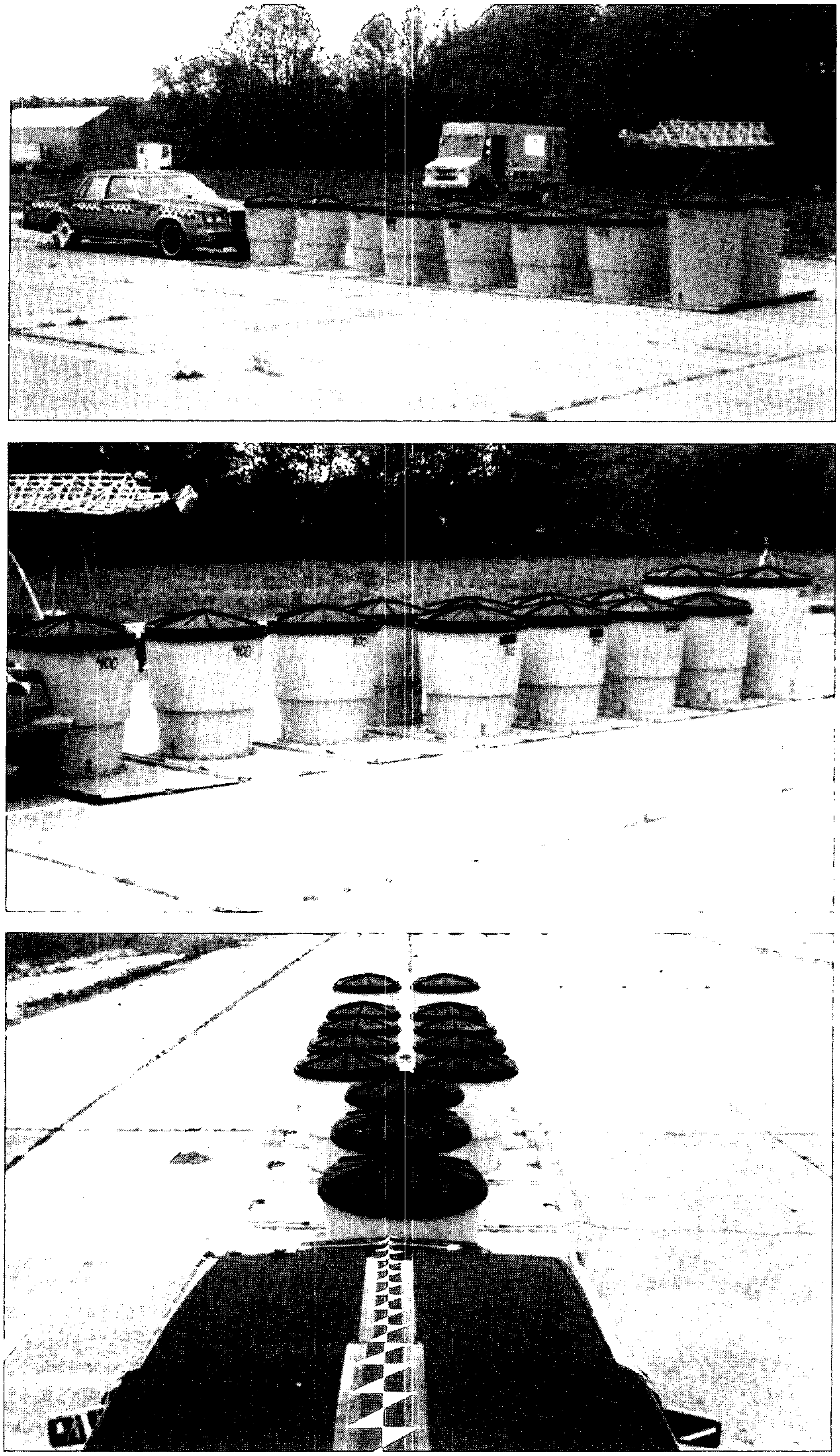


Figure 12. Photographs of the Portable Crash Cushion Prior to Crash, Test 2036-FS2-92

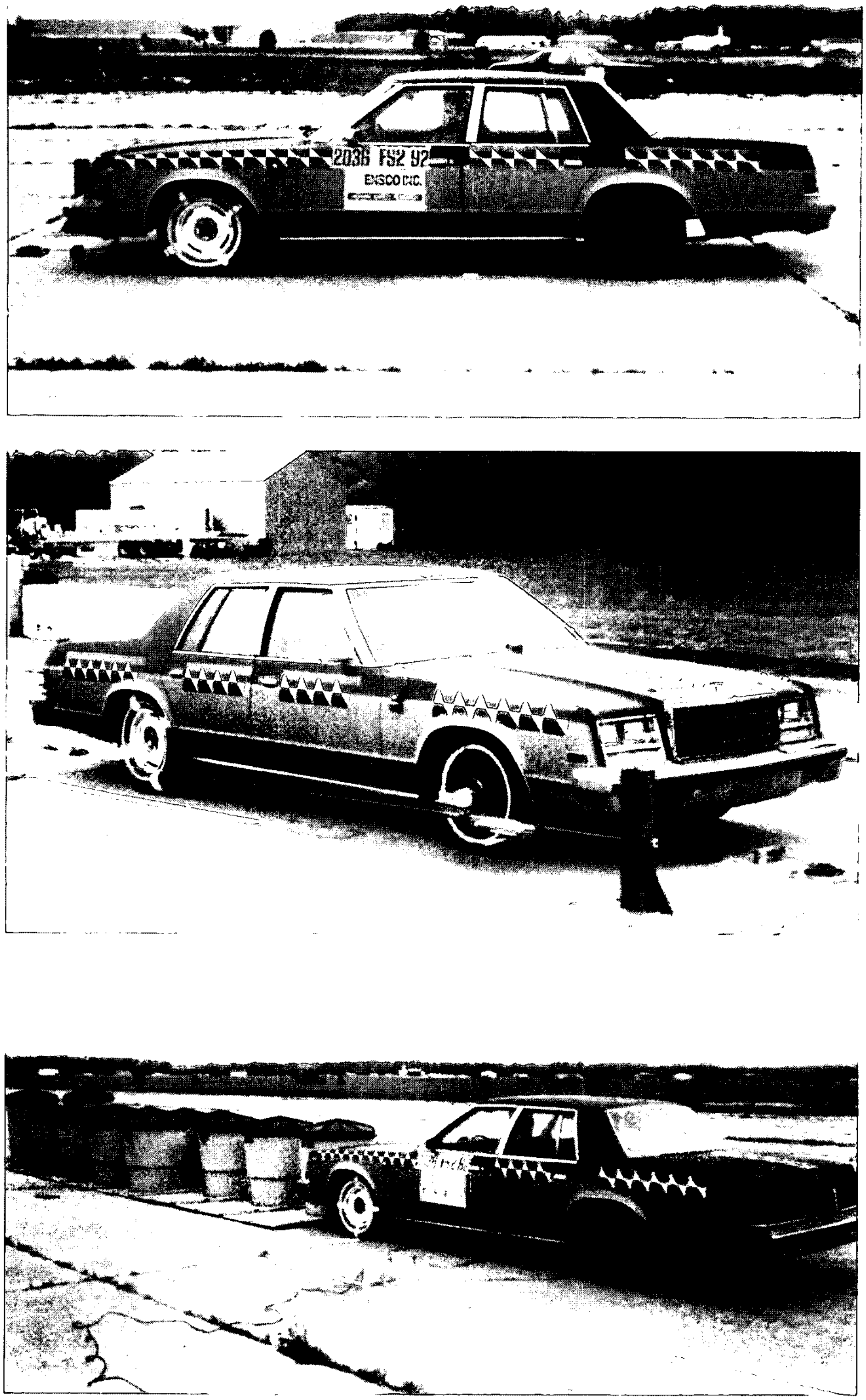


Figure 13. Photographs of the Test Vehicle Prior to Crash, Test 2036-FS2-92

Upon impact, the rear of the vehicle pitched upward approximately 7 degrees while the vehicle was slowing. As the vehicle broke through the sand module array, the hood bent backward on its hinges until it hit the windshield. The vehicle penetrated approximately 29 ft (8.8 m) into the attenuator, stopping on top of pallet 8 (1 ft [0.3 m] away from the end of the system). The vehicle yawed approximately 6 degrees counterclockwise (as seen from above) while the rear wheels were in the air. The vehicle did not rebound. The front wheels of the vehicle came to rest on the hinges between rows 7 and 8. The left rear wheel came to rest on pallet 5 while the right rear wheel came to rest on the ground. The pallet slid 92 in (2.3 m) forward from its starting position.

A summary of test conditions and results are shown in figure 14. Data analysis was performed. The x- and y-axis, 100 Hz data plots are shown in figure 15.

Vehicle Damage

Damage occurred only to the front end of the vehicle. The crush was uniform across the front of the vehicle. The vehicle hood and front fenders were buckled. The vehicle grill and radiator were pushed back into the engine. The vehicle sustained little suspension damage. The windshield broke because the hood hit it. Photographs of the vehicle after the crash test are shown in figure 16.

Attenuator Damage

The impact attenuator performed as designed. The sand modules in all 8 rows were destroyed completely. The modules broke apart just above the module retaining rings. The bottom portions of the modules were still attached to the pallets. The pallet system itself, and the three washers for each module, were undamaged and reusable. The bulk of the attenuator debris (sand and module pieces) came to rest within an area 25 ft (7.6 m) behind the pallet system. Photographs of the impact attenuator after the crash test are shown in figure 17.

Dummy Damage

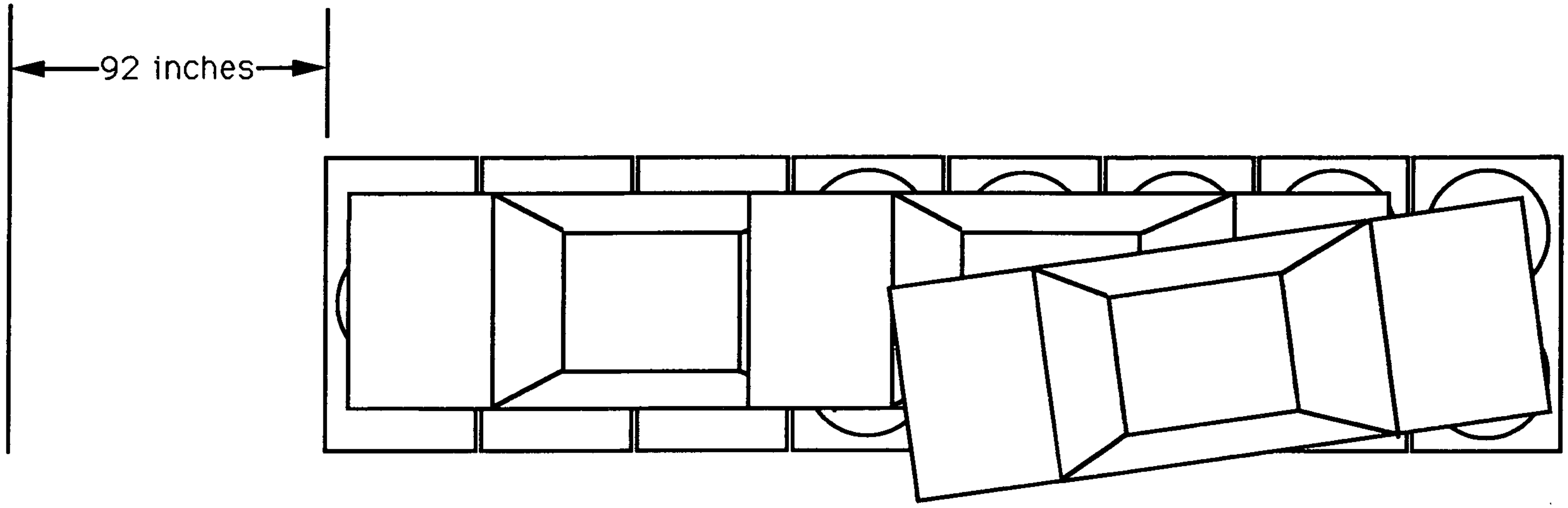
No observable damage to the dummies occurred. The occupant impact velocity and accelerations were within the limits, specified in NCHRP 230.

Test Evaluation

This test was evaluated using the criteria for NCHRP 230 test 50. The following is an item by item evaluation using this guideline.

- NCHRP 230:

  c. The test article exhibited acceptable performance.
  d. Detached elements presented no undue hazard to the passenger compartment or to other traffic.
  e. The vehicle remained upright during and after the collision. Integrity of the passenger compartment was maintained.
  f. Delta-V and Ridedown values are within acceptable criteria.
  g. Vehicle trajectory and stopping position did not intrude into adjacent traffic lanes.
  h. The vehicle was stopped by the test article.



Date:	5 May 1992
Weather:	Clear 65° F
Test Vehicle:	1979 Chrysler Newport
Device Configuration:	Portable Crash Cushion impact attenuator. 8 pallet system with 13 Energite III sand module array. System is 364.5 in long and 85 in wide. System placed on concrete road.

1. Vehicle Weight:

Planned, Inertial:	4500 ± 200
Actual, Inertial:	4363
Planned, Gross:	4500 ± 300
Actual, Gross:	4685

2. Number of Occupants: Two
3. Occupant Model: Part 572, 50 percentile male
4. Occupant Location: Driver Seat, Unrestrained; Passenger Seat, Restrained
3. Impact:

	Speed	Angle (a)	Location
Planned:	60.0 mi/h	0°	Center of Attenuator
Actual:	60.2 mi/h	0°	Center of Attenuator

6. Rebound: No Rebound
7. Total Speed Change: 60.2 mi/h (88.3 ft/s)
8. Total Momentum Change: 11960 lb-s
9. Vehicle Damage Index: (SAE J224a) 12FDEW2
10. NCHRP 230 Test Number: 50
11. NCHRP 230 Impact Severity:

$\frac{mV^2}{2}$ 528.2 kip-ft (Target: $541^{-53,+94}$ kip-ft)

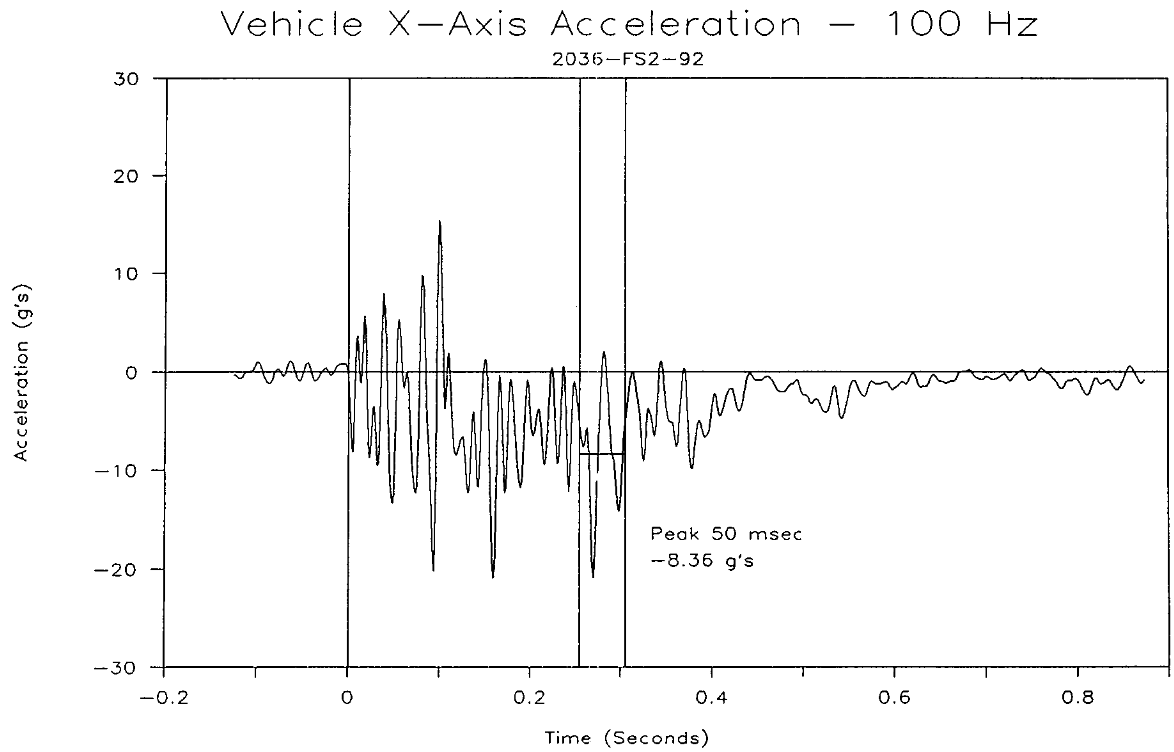
12. Vehicle Analysis:

	Observed	Design/ Limit Value
NCHRP 230:		
Longitudinal:		
Delta-V at 2 ft:	-27.7 ft/s	30/40 ft/s
Ridedown Acceleration:	-16.3 g's	15/20 g's
Lateral:		
Delta-V at 1 ft:	no impact	20/30 ft/s
Ridedown Acceleration:		15/20 g's
TRC 191:		
Peak 50 ms acceleration:		
Longitudinal:	-8.4 g's	
Lateral:	1.1 g's	

13. Test Results Conclusion:

NCHRP 230: **MEETS ALL CRITERIA.**

Figure 14. Full-Scale Test Summary for the Portable Crash Cushion, Test 2036-FS2-92



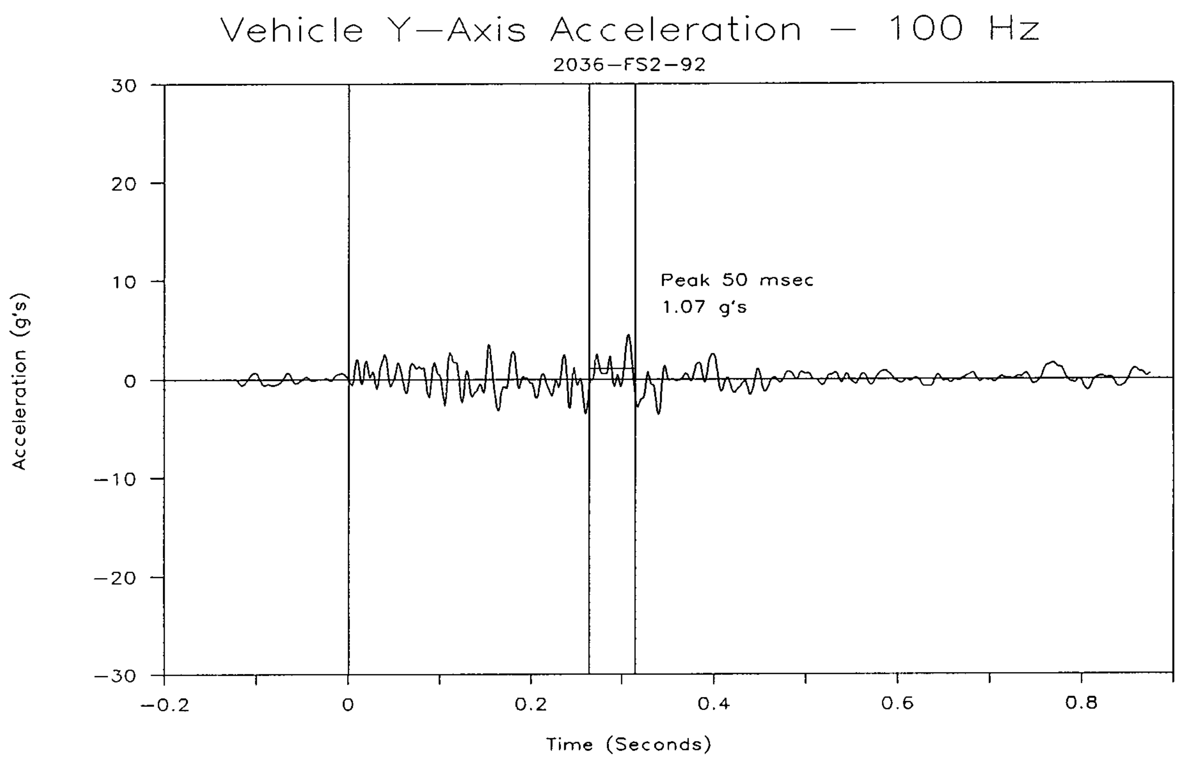


Figure 15. Vehicle Accelerations for the Portable Crash Cushion, Test 2036-FS2-92

Figure 16. Photographs of Test Vehicle After Crash Test 2036-FS2-92

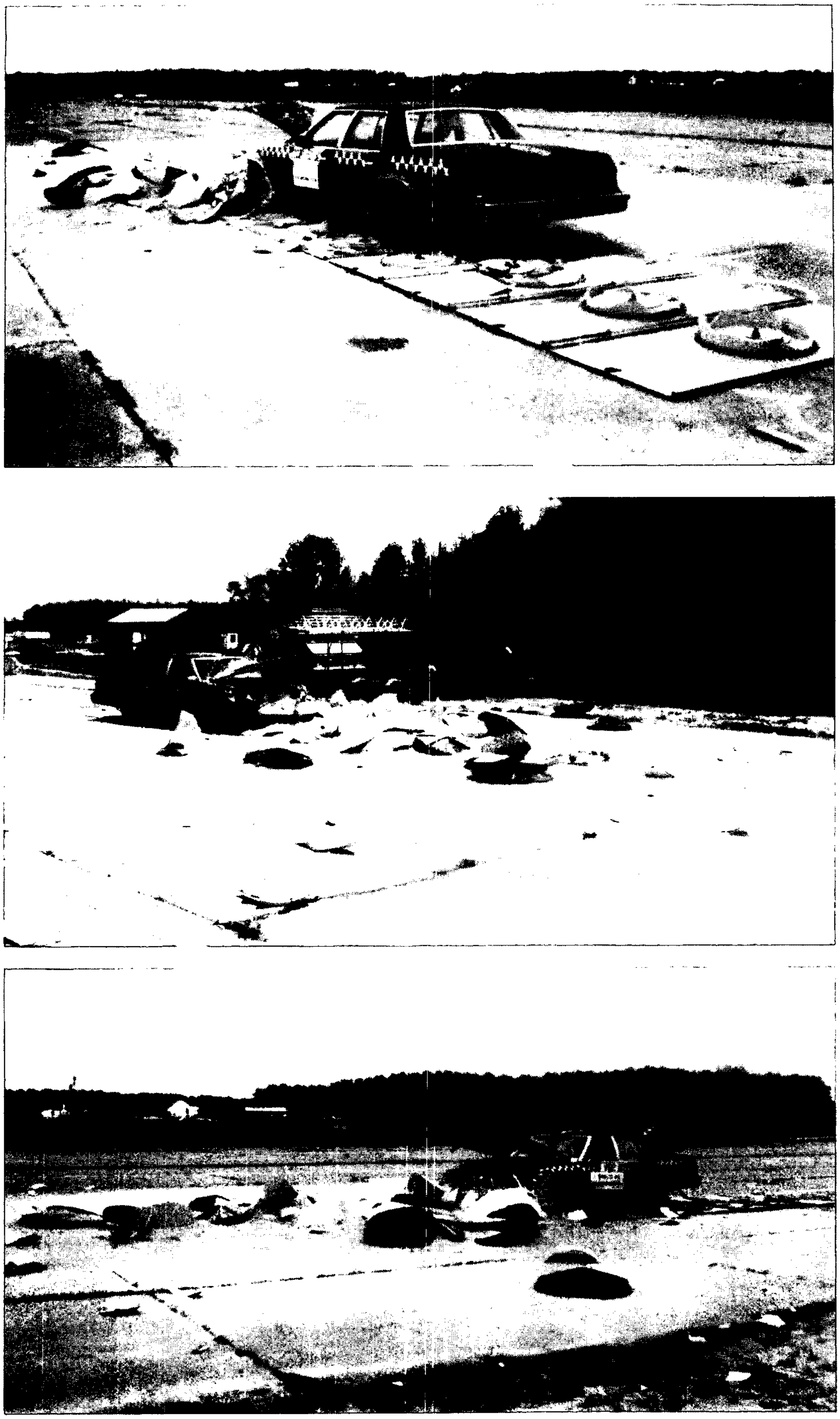


Figure 17. Photographs of the Portable Crash Cushion After Crash, Test 2036-FS2-92

The Portable Crash Cushion successfully met the evaluation criteria.

Open Highway Testing

To date, the Portable Crash Cushion has not been tested on an open highway. The device should be successful, given the results so far.

Conclusions and Recommendations

The Federal Highway Administration and two private manufacturing companies are interested in building the Portable Crash Cushion.

Design modifications are required. The first modification needed is on the power source for the tilt-bed and winch in order to provide a source of power, that will not require frequent recharging.

The second modification is to redesign the axle system so that the trailer can deliver the crash cushion array in either a forward or backward configuration. The trailer currently is configured so that the 400-lb (182-kg) sand barrel slides off the trailer first, in order to protect a work zone lane. Configuring the trailer to drop the 2100-lb (955-kg) barrels first would allow for the array to be positioned in front of a stationary structure, where there is no clearance room for the truck and the front of the trailer.

Ultrasonic Detection Alarm

Figure 18 shows the Ultrasonic Detection Alarm.

Background

Many work zone accidents are caused by vehicles that drive into a closed lane, through taper devices, and into the work area. Many of the drivers of these vehicles never slow or try to avoid work vehicles. The workers killed and injured in these accidents had no warning to alert them to the danger. The Ultrasonic Detection Alarm was developed to warn workers of an intruding vehicle and to give them a chance to escape.

The use of motion or proximity sensors to detect errant vehicles in work zones was selected for further evaluation and development. A literature review was conducted on motion detectors led to the selection of the Polaroid ultrasonic transducer was selected. The Polaroid transducer was a basic ultrasonic sensor which needed little modification to fit our application. The detector system uses existing technology, and required only minor changes to interface with a communications system and warning sirens.

Device Description

The Ultrasonic Detection Alarm (USDA) warns maintenance workers of errant vehicle in work zones. The USDA detects an errant vehicle entering the work zone by using sound waves. This device is placed at the beginning of the buffer space. When a vehicle intrudes into the work zone, it passes in front of the detector. The ultrasonic unit senses it and activates a siren to alert the workers to the oncoming errant vehicle.

The detection unit consists of a sensor, an interpretation circuit, a tone encoder, and a transmitter. The receiving unit consists of a receiver, a tone decoder, and a horn. When a vehicle or another object passes in front of the sensor, the interface board recognizes the sensor output and creates an electronic signal. The electronic signal is then passed through the interpretation circuit to the tone encoder. The tone encoder generates a warning tone of 1 kilohertz (kHz). This signal is sent out by the transmitter that is set to operate on citizen band (CB) channel 30. This signal is received by a radio in the receiver unit which is set to operate on the same channel as the transmitter. The received tone is then passed through a tone decoder. If the decoded tone matches a preset tone within the receiver, the horn is activated. This warning should give the workers four to seven seconds to escape.

Safety features have been incorporated to ensure that if the device fails, it alerts the workers.

Design and Fabrication

Detector Fabrication

The USDA was built around a low-cost, readily-available ultrasonic ranging device available from Polaroid. The ultrasonic ranging device is a non-contact method of detecting a vehicle.

The following section is a technical description of the ultrasonic transducer. The next section describes the driver board that was used to control and interpret signals from the transducer. The third section describes the interface board. The tests that were conducted on the devices to

Receiving Unit Detection Unit

Figure 18. Ultrasonic Detection Alarm Units

evaluate their suitability for field use are documented. Problems encountered in these tests are also discussed.

Technical Data

Three primary components made up the ultrasonic unit. Two of the basic units are purchased from Polaroid; the ultrasonic ranging unit (URU) and the electrostatic acoustic transducer (ET). The third component is a custom-designed driver circuit.

The URU has a useful detection range of 0.9 to 35 ft (0.3 to 10.7 m). The URU requires a 6-volt DC power source that is capable of providing a 2.5 ampere pulse for about 1 millisecond. In operation, a pulse of 56 cycles of a 49.41 kHz signal is transmitted towards a target. Once the transmission occurs, the URU converts from a transmitter to a receiver. The pulse takes a finite length of time to travel through the air and its signal strength decreases as it travels through air and is attenuated. To compensate for this, the gain on the URU receiver increases with time. If the pulse strikes a target within the 35-ft (10.7-m) range, it is echoed back to the URU where a detection flag is generated. If no target is present, there will be no echo and the URU transmit and detect cycle is restarted.

The ET is attached to the URU and acts both as a loudspeaker to transmit the signal and as a microphone to receive the signals. Foil is stretched over a grooved plate, creating a capacitor that is excited by the signal transmitted from the URU. In response, the foil vibrates, causing an equivalent frequency to be transmitted through the air. This is the ultrasonic signal that is reflected by objects within the detection range. Upon return, the signal again excites the foil, causing a change in capacitance. This change is then amplified for detection. The ETs used in the units are resistant to most environmental effects.

Driver Board Design

The driver circuit provides all of the input signals to the URU and receives all of the output signals from the URU. The driver circuit was used to step up the normal URU transmit/receive cycle from 5 Hz to 10 Hz. This was done to increase the detectability of small, high-speed vehicles, such as motorcycles. The driver circuit was designed to accommodate up to two URUs.

The driver board generates the VSW signal, receives the XLG signal, receives the FLG signal, performs a comparison of the incoming signals with other signals generated on-board, and provides a timed output pulse. The following paragraphs describe each of these functions in detail. A block diagram of these circuits is provided in figure 19.

VSW Signal: The VSW signal provides the power to the URU. The power applied to the URU starts the transmit and receive cycle. The cycle completes and the VSW signal turns off, then back on again to restart the cycle. The VSW signal turns off and on at a rate of 10 Hz.

XLG Signal: The XLG signal is generated when the transmit cycle is initiated on the URU. This signal is used to generate a one-shot time base that is used as a reference for later comparison with the FLG signal. This time base can make the detection window larger or smaller. All timing starts at 0.9 ft (0.3 m) The time base may enlarge the window up to 35 ft (10.7 m). The time base is usually set at about 12 ft (2.7 m) so that the device monitors only the traffic lane.

FLG Signal: The URU also generates the FLG signal. This signal indicates the detection of a return echo and is used to create another signal with the correct polarity for comparison with the XLG signal.

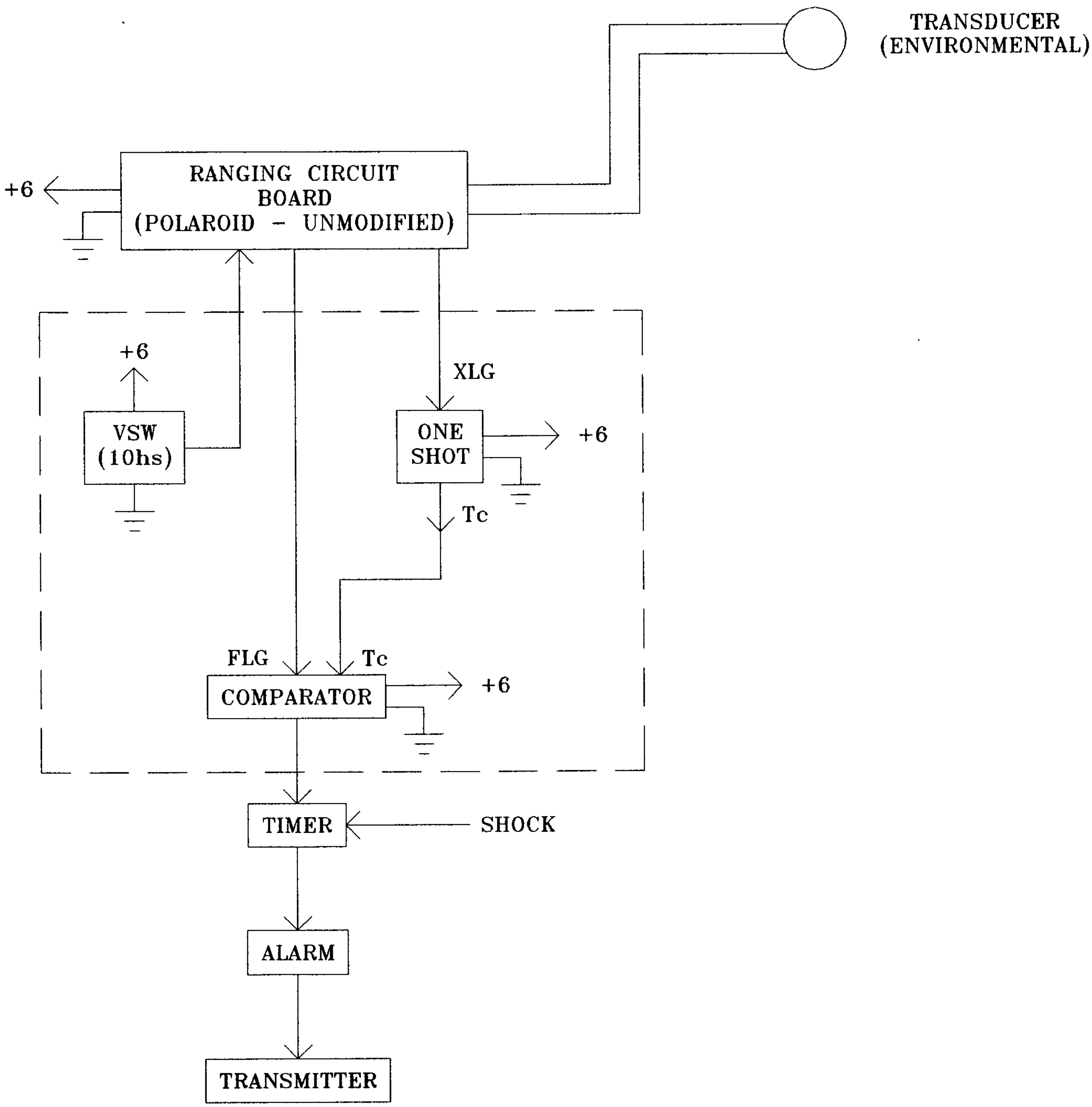


Figure 19. Ultrasonic Detection Alarm Circuit Block Diagram

Comparator: This circuit compares the XLG and FLG signals from the URU. If the XLG signal changes state before the FLG, the device would not detect an intrusion within the set point of 12 ft (3.7 m). If the FLG signal changes state first, an intrusion within the set point of 12 ft (3.7 m) has been detected and an alarm is generated. The comparator output is used to trigger the alarm.

Timer: The timer circuit receives output from the comparator. If the comparator output changes, indicating an alarm condition, the timer is triggered. The timer output drives a relay that operates the alarm signaling device. The timer stretches the detect pulse to provide a stable and usable alarm output signal.

When the alarm condition is present, the interpretation circuit has a high output and the tone encoder and walkie-talkie are activated. This means that a tone is placed on a CB band for another walkie-talkie to receive. A single 1-kHz tone was chosen over dual tones.

Ultrasonic Intrusion Interface Circuit

The ultrasonic intrusion interface circuit monitors the output of the timer. As soon as a signal is detected, the output from the timer circuit is buffered to provide enough current in the alarm signal to drive a relay. The relay then operates both the transmitter and an alarm indicator light. The power circuit to the transmitter can be interrupted to allow for functional testing using only the indicator light. The interface circuit also provides the same support for a low battery indicator light.

Receiver Fabrication

A walkie-talkie matching the one used in the detector was put into the receiver unit to pick up the tone placed on CB channel 30 by the detector's walkie-talkie. A tone decoder was tied into the walkie-talkie's speaker. If a tone that is 1 kHz and the proper duration, the tone decoder activates a relay that sounds the horn. The horn used in the prototype created a siren that was 110 decibels with seven different tones. The horn could only be turned off by resetting the detector and then the receiver.

Device Modifications

The decoders and encoders that were used in the original design were of the type used in touch-tone phones. In this system, two tones are passed on a carrier and have to be matched for the receiver to activate. This proved too sensitive for our application. The unit would hesitate on accepting the signal because the carrier (CB radio) was poor. However, single tone encoding proved to be effective.

The horn was evaluated by maintenance workers in the yard and on the highway in simulated work zones. The highway workers said that the horn was not loud enough for them to hear. Because of the worker's complaints, the horn was changed to a 120-dB model. This horn worked well, could be easily heard, and was directional enough not to disturb traffic.

Operational Testing and Lab Testing

A large number of field tests were conducted using the Ultrasonic Detection Alarm on both a test track and in real traffic streams (not in work zones or construction areas). The unit passed all tests without trouble. The unit detected a high-speed motorcycle passing through the ultrasonic beam. The unit did create false alarms. These false alarms appeared to be related to temperature and humidity.

The false alarm problem was very difficult to solve. It seemed to be caused by the ambient temperature and humidity. Since none of the components exhibited a sensitivity to humidity or temperature within normal ranges, the only possible cause was the ultrasonic signal.

An extensive literature search was conducted in an attempt to explain this phenomenon. The literature supported the robustness of the ultrasonic method of detection and indicated that the ultrasonic parameters were correct for this application. Ambient temperature influences the speed of the ultrasonic signal in air, but not enough to have caused these false alarms. A 45°F (7°C) change in temperature affects the speed of the ultrasonic signal by only 4.3 percent and has no other effects. Relative humidity affects the attenuation of the signal in the air, but does not cause the ghosts or reflections typically associated with false alarms. The ultrasonic design uses low-frequency ultrasonic signals that should not be affected by wind or other types of air turbulence. No other ultrasonic characteristics were relevant to this problem. Some obscure data, however, indicated that the combined influences of temperature and humidity were non-linear in nature and therefore might be somewhat unpredictable. The data from Polaroid were presented too simply to explain this problem. A series of experiments were designed to test the validity of this hypothesis.

The tests required control over environmental variables. An environmental chamber within which temperature and humidity could be varied was constructed. A framework enclosed an open area large enough to be used as a detection area for the USDA. This framework was covered with an impermeable material so that the environment inside could be controlled. This test chamber had a single door made from a large overlap of the impermeable material. Heaters and steam generators were then used to control the temperature and humidity of the test chamber. Temperature and humidity measurements were taken at various locations to assure that the environment was uniform and relatively constant. The limits of detection were then plotted both horizontally and vertically to map the areas where an object would be detected in the ultrasonic beam.

An initial round of five tests was conducted, varying the temperature and pressure for each test. False alarms occurred during all five of these tests. The data from these tests are presented in table 6.

The data are presented in order of decreasing beam length. Other data relative to this analysis are also presented. As can be seen from the data, attenuation does not predict beam length, nor are the temperature and humidity reliable indicators. It is important to note that the beam length follows descriptions in the literature since it changes very little over a wide range of conditions. However, the beam width and height are severely affected by these same conditions. Apparently, data concerning the effects of ambient conditions on the ultrasonic signal were limited to beam length, since this is the key parameter for a ranging system. The effects on the beam width and height were ignored as they have no effect on the ranging accuracy of a device.

From these data, we assume that under field test conditions, the beam widened significantly. This caused reflections from the road surface under the correct ambient conditions. The design of the device was changed to use only a single Polaroid head with a higher angle. Vehicles still can be detected but the road surface cannot be seen, despite beam widening. The false alarms were eliminated when this change was made.

In an attempt to further understand this data and the associated phenomena, the results were plotted on a psychometric chart. Increases in both temperature and humidity increase attenuation but various combinations of temperature and humidity behave differently. Data found in the literature showed a relationship between the temperature, humidity, and the attenuation of the ultrasonic signal in air. These data were plotted and regressed to fit a cubic two-variable

Table 6. Effect of Temperature and Humidity on Ultrasonic Sensitivity

Temp	Relative Humidity	Beam Length	Beam Width	Beam Height	Predicted Attenuation
83°F	72%	184 in	58.75 in	96 in	.47
70°F	85%	181 in	57.75 in	NA	.48
79°F	46%	178 in	55.25 in	84 in	.57
77°F	53%	178 in	53.00 in	58.5 in	.56
63°F	78%	175 in	44.00 in	NA	.51

NA - Not Available
32°F = 0°C, 1 in = 2.54 cm

polynomial form. The fit between the data and the model was extremely good (figure 20). Notice that it illustrates the extreme non-linearity of the combined effects of temperature and relative humidity. Although this data also deals primarily with the beam length of a ranging system, the relative effects on the beam width and height can also be predicted, albeit some what poorly. More tests will be required if the effects of ambient conditions on the beam width are to be predictable. It is important to note that, although no predictive tools can be developed from the data, sufficient data existed to correct the problems identified in the field.

Operational Testing

The USDA was functionally tested on an abandoned road. For this test, several vehicles of various sizes passed in front of the unit. The unit functioned properly every time. The unit was then taken to a test track in Delaware for further evaluation.

In Delaware, a collection of vehicles (a semi-trailer truck, a large car, a pickup truck, a small car, and a motorcycle) were passed in front of the detector. Vehicle speeds varied from 20 mi/h (8.9 m/s) to 90 mi/h (40.2 m/s). The unit detected every vehicle at every speed. The vehicles made each speed pass several times. This was a good result since a small, high-speed object --such as the motorcycle-- could theoretically pass between sensing windows.

Crashworthiness Testing

ENSCO Test 2036-CW1-91

The crashworthiness of this device was determined by using only the aluminum housing ballasted with the correct mass to simulate the distribution of electronic components. The electronic failure mode testing was conducted as fail-safe bench testing with calculated damage (i.e., the worst case of damage to ensure reliability). This test was conducted at 60 mi/h (26.8 m/s), with the impact centered on the vehicle. Photographs taken before test 2036-CW1-91 are shown in figure 21.

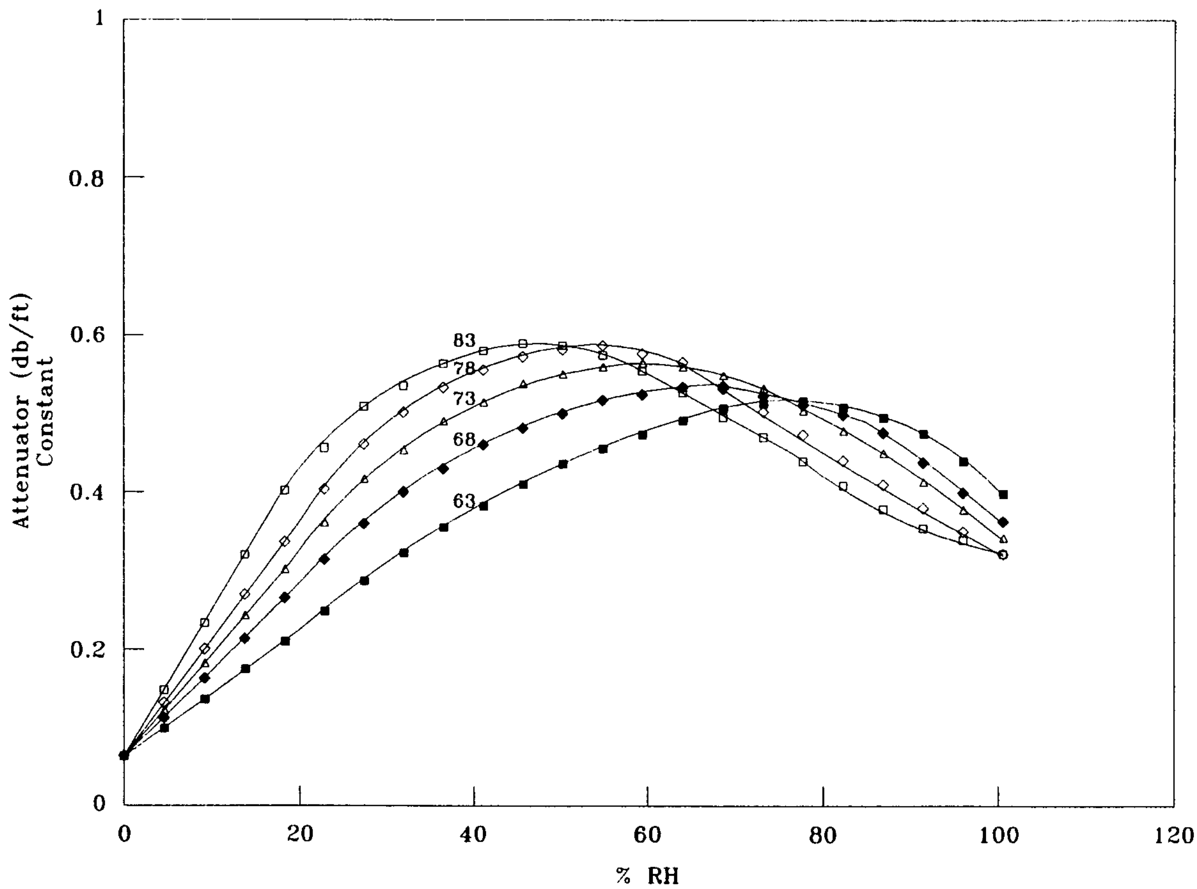


Figure 20. Predicted Attenuation for the Signal from the Ultrasonic Detection Alarm

Impact Description

Review of the high speed films and fifth wheel data indicated that the test vehicle impacted the device at 62 mi/h (27.7 m/s) and at 0 degrees. The review also indicated that the vehicle centerline was aligned with the device centerline.

Upon impact, the device (due to its small size and height) did not make contact with the front bumper. The vehicle rode over the top of the device and forced it beneath the vehicle's undercarriage.

The device slid along with the vehicle just ahead of the front axle. It then caught the joint of a concrete slab and the housing stopped. The car passed over the alarm housing, which caused significant denting to the floorboard and surrounding areas. As the housing came to a sudden stop, the vehicle pitched up approximately 8 degrees from the road surface.

The brakes were applied approximately 120 ft (36.6 m) downstream from impact. The vehicle yawed slightly and came to rest 270 ft (82.3 m) from the initial point of impact.

The test conditions and results are summarized in table 7.

Vehicle Damage

Damage to the vehicle was limited to cosmetic damage to the lower wind screen of the plastic front bumper, a slightly bent leading motor mount, minor dents on the passenger floor area and minor dents on the gas tank.

Device Damage

The Ultrasonic Detection Alarm was completely destroyed. The lid to the box was ripped off and the contents were scattered over a 50-ft (15.2-m) section of roadway. The main housing to the alarm was also flattened.

Photographs of the crash test vehicle and the ultrasonic detection alarm after test 2036-CW1-91 are shown in figure 22.

Test Evaluation

This test was evaluated using criteria D and E from NCHRP 230 and the work zone hazard criterion. The following is an item-by-item evaluation using these criteria.

NCHRP 230 Criterion D: Detached elements, fragments or other debris from the test article shall not penetrate or show potential for penetrating the passenger compartment or present undue hazard to other traffic.

This device met criterion D.

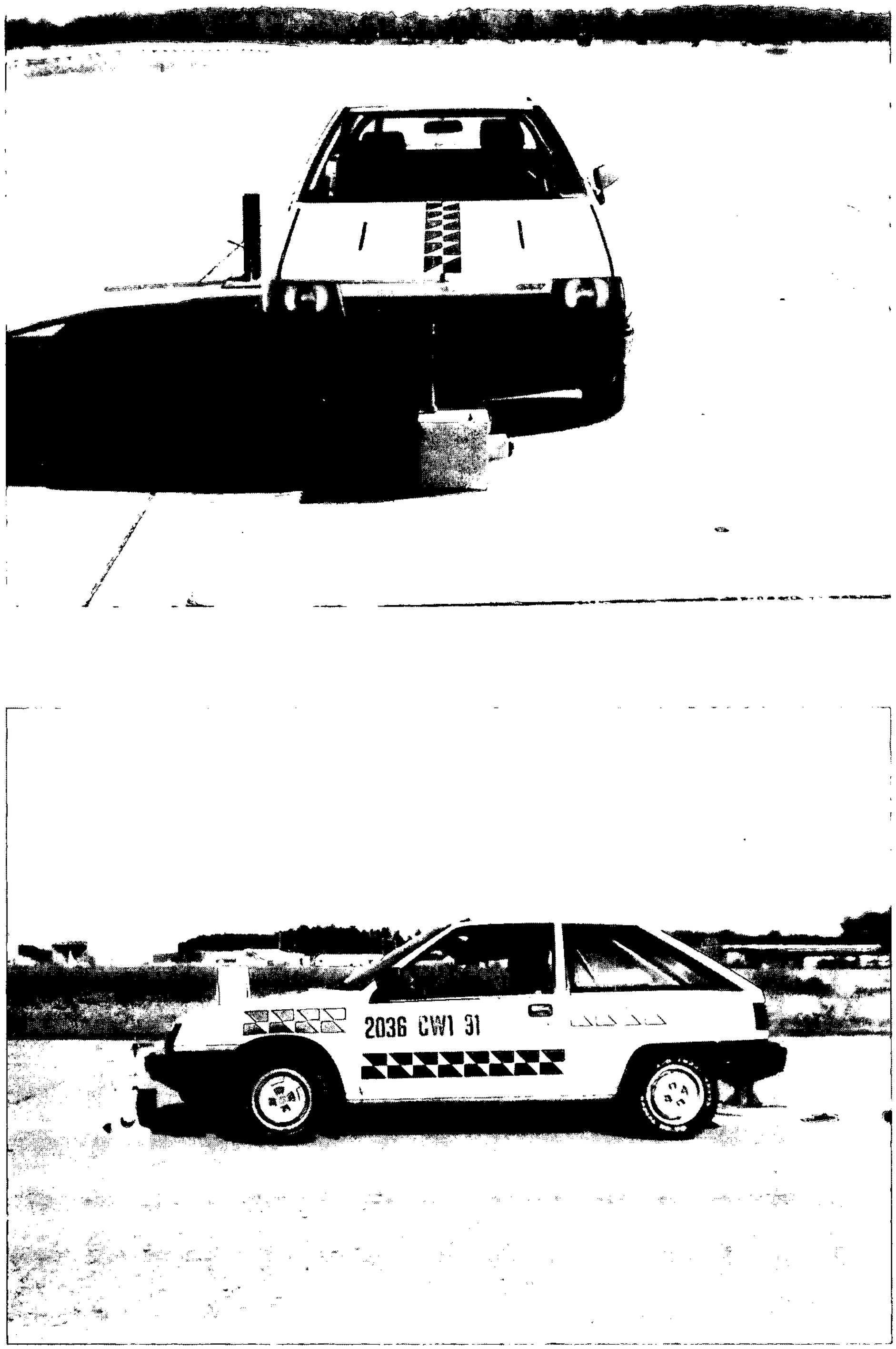
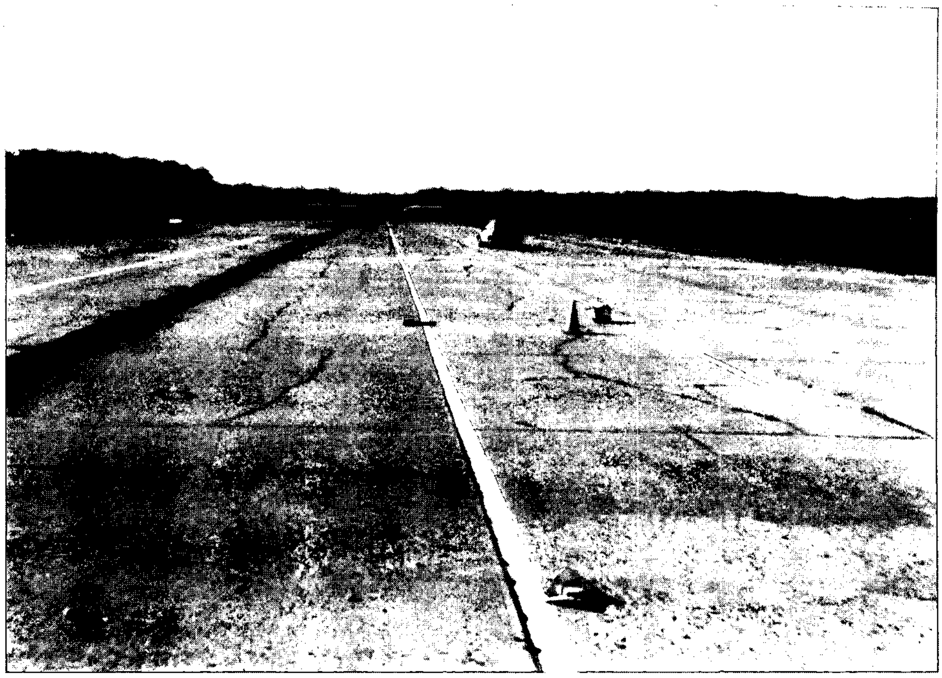


Figure 21. Ultrasonic Detection Alarm Before Test, Test 2036-CW1-91

Table 7. Crashworthiness Test Summary for the Ultrasonic Detection Alarm

Parameter	Value
Test Number:	2036-CW1-91
Date:	January 25, 1991
Test Vehicle:	1985 Dodge Colt
Test Device:	Ultrasonic Detection Alarm (small alarm enclosure)
Vehicle Weight:	
Planned, Inertial:	1800 ± 50 lb
Actual, Inertial:	1813 lb
Planned, Gross:	1950 ± 50 lb
Actual, Gross:	1978 lb
Number of Occupants:	One
Occupant Model:	Part 572 Anthropomorphic 50th percentile male
Occupant Location:	Driver Seat, Restrained
Impact Conditions:	
Planned Speed:	60 mi/h
Actual Speed:	62 mi/h
Planned Angle:	0°
Actual Angle:	0°
Planned Location:	Centered
Actual Location:	Centered
Test Results Conclusion:	This device successfully met the evaluation criteria.

1 mi/h = 0.45 m/s, 1 lb = 0.45 kg



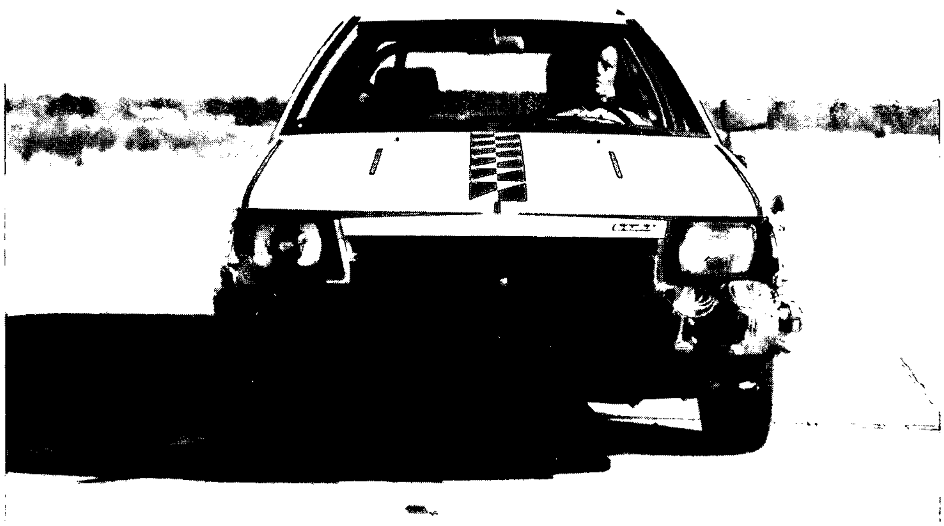


Figure 22. Ultrasonic Detection Alarm After Test, Test 2036-CW1-91

NCHRP 230 Criterion E: The vehicle shall remain upright during and after collision although moderate roll, pitching and yawing are acceptable. Integrity of the passenger compartment must be maintained with essentially no deformation or intrusion.

This device met criterion E.

Work Zone Hazard Criterion: The device must not present a hazard to workers in the work zone following an impact by an errant vehicle.

This device met the Work Zone Hazard Criterion.

This device successfully met the evaluation criteria.

Open Highway Testing

A manufacturer, COMARCO, became interested in the unit and made a prototype. The COMARCO unit was taken to the Arizona DOT for testing. The unit was continually plagued by false alarms. Because of this problem, the COMARCO unit was not tested elsewhere.

The GME unit was taken to Iowa for testing. Periodic false alarms occurred during cold, humid conditions. The unit was taken back for more laboratory tests. These tests are described in the section, "Problem Investigations." From these laboratory tests, it was determined that temperature and humidity had a greater effect than originally predicted. The unit was modified to use one sensor eye, and the angle of the eye was adjusted to compensate for environmental effects. GME staff took the modified unit to Missouri for more operational tests. The modified unit did not produce false alarms under any weather conditions. The unit did not fail under extreme conditions created in the test chamber (described above), where the temperature and humidity were varied radically.

Conclusions and Recommendations

The USDA design worked well and could now be mass produced. Polaroid recently made changes in the URU and the ET, however, and it is not known how these changes will affect the current design. This should be investigated.

Roadway workers should use the USDA for about a month. The number of times used, duration of use, time of day, type of traffic, number of intrusions, and number of false alarms should be documented. Worker's comments are extremely helpful. Figure 23 shows an evaluation form that could be used to record evaluations.

Ultrasonic Detection Alarm Evaluation Form

Testing Agency: ____________________

Contact Name: ____________________

Time Agency Possessed Ultrasonic Unit For Testing: ____________________

Date	Time and Duration Unit was Tested	Type of Traffic (ADT, % Trucks)	Number of False Alarms	Weather Conditions

Comments: ____________________

Figure 23. Sample Ultrasonic Detection Alarm Evaluation Survey

Infrared Intrusion Alarm

The Infrared Intrusion Alarm is shown in figure 24.

Background

Many work zone accidents occur when a vehicle enters a closed lane, plows through the taper devices and into the work area. Often, the drivers of these vehicles never slowed or tried to avoid the actual work zone.

The Infrared Intrusion Alarm (IIA) could save the lives of maintenance workers by warning them of errant vehicles. Infrared sensors have been used in many ways to detect intrusions. Most of these uses, however, are located indoors in relatively clean environments. Recent developments have increased the use of infrared sensors in dusty, outdoor environments. Infrared technology hence merited further investigation.

Device Description

The IIA is an infrared retroreflective device that can detect an errant vehicle entering the work zone. The device is placed at the beginning of the buffer space. If the infrared beam is broken, a loud siren is activated to which alert workers to an oncoming vehicle. When the beam is broken, a relay closes and creates an electronic alarm signal. The electronic signal is then passed through an interpretation circuit to a tone encoder. The tone encoder generates a warning tone of 1 kilohertz (kHz). This signal is sent out by a radio transmitter on citizens band (CB) channel 30. This signal is picked up by a radio receiver that passes the tone to a tone decoder. If the decoded tone matches a preset tone within the receiver, the horn is activated. This warning should give the workers between four and seven seconds to react.

The device's safety features also ensure that workers know if the device fails (low batteries, etc.).

Design and Fabrication

Detector Fabrication

Two infrared detectors from Allen Bradley were tested. These two sensors were: the diffused (or no reflector) sensor model number 42RLP4003B and the retroreflective sensor model number 42RLU4003B. The diffused sensor uses an object's natural reflection to return the infrared signal. This works well on vehicles with a good finish. The diffused sensor can not detect vehicles with black primer or dull finishes. The retroreflective sensor employs a reflective device. An infrared beam is directed at a reflector that reflects back to the sensor. If this beam is interrupted, a detection signal is generated. This unit detected vehicles every time at a variety of speeds. The retroreflective sensor was therefore selected for use in the IIA.

The sensor was incorporated into the device's sequence of operation as follows: When the sensor activates, a relay closes which sends a signal to the tone encoder. The tone encoder and the walkie-talkie would activate and create a tone on a CB channel for another walkie-talkie to receive.

A single 1-kHz tone was used instead of dual tones because the decoder for dual tone signals balked at the static on the carrier wave.

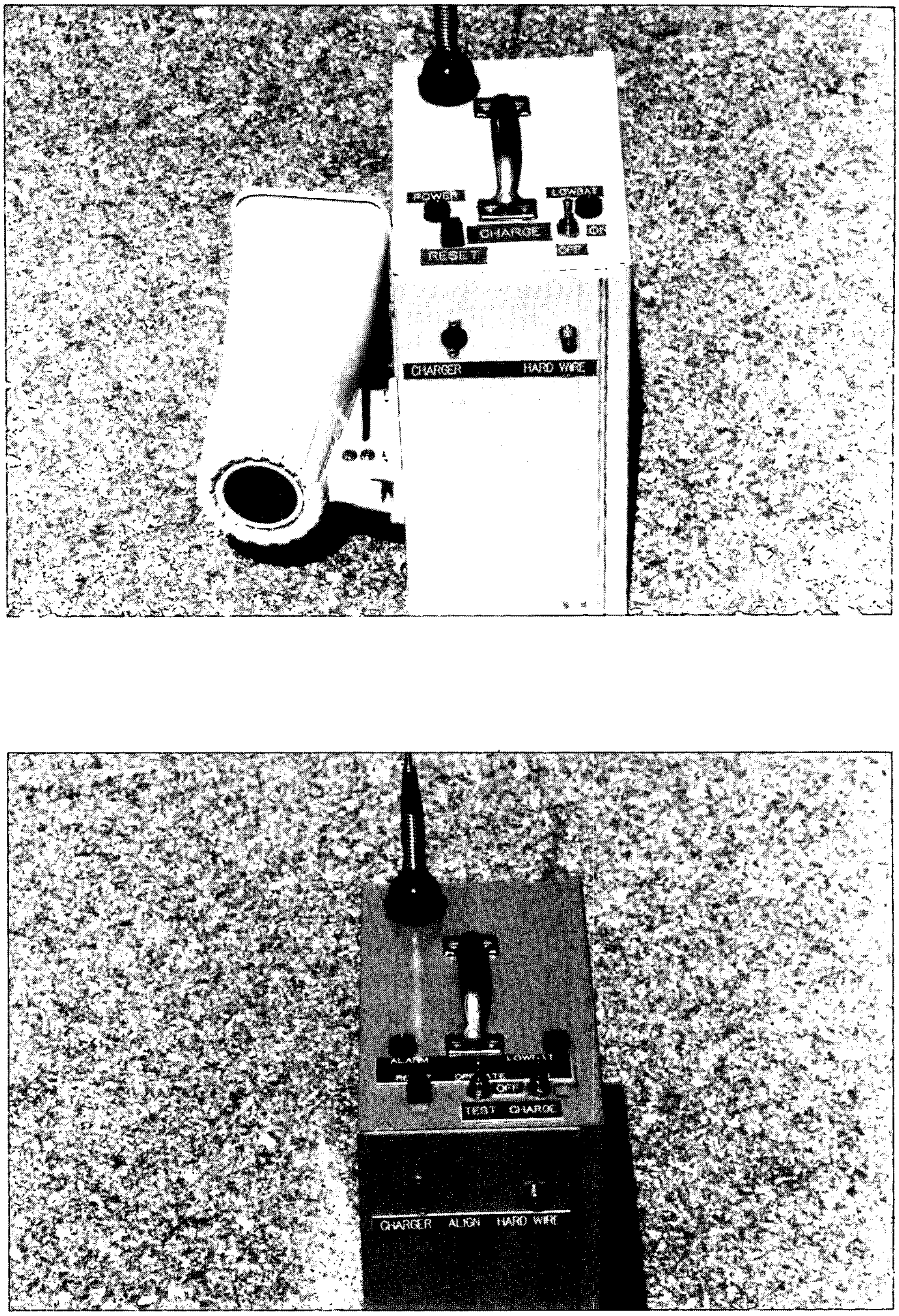


Figure 24. Infrared Intrusion Alarm Detector and Receiver

Receiver Fabrication

A walkie-talkie was put into the receiver unit to pick up the tone placed on CB channel 30 by the detector's walkie-talkie. A tone decoder was tied into the walkie-talkie's speaker. If the tone received was the proper 1-kHz tone and lasted for a specified time, the tone decoder would activate a relay and turn on the horn. The horn used in the prototype was 110 decibels (dB) loud and had seven different tones. The horn was hooked up so that it could only be turned off by resetting the detector and then the receiver.

Device Modifications

The decoders and encoders that were used in the original design were of the type used in touch-tone phones. Two tones pass on a carrier and must be matched for the receiver to activate. This proved too sensitive for this application. The unit would hesitate to accept the signal because the carrier (CB radio) was poor. However, single tone encoding proved to be effective.

The horn was evaluated by maintenance workers in the yard and on the highway in simulated work zones. The highway workers said that the horn was not loud enough. Because of the worker's complaints, the horn was changed to a 120-dB model. This horn worked well, could be easily heard, and was directional enough not to disturb traffic.

Operational Testing and Lab Testing

The IIA was functionally tested on an abandoned road. For this test, several vehicles of various sizes passed in front of the unit. The unit detected the vehicles and sounded the alarm every time. The unit was then taken to a test track in Delaware for further evaluation.

A variety of vehicles (a semi-trailer truck, a large car, a pickup truck, a small car, and a motorcycle) passed in front of the detector. Vehicle speeds varied from 20 mi/h (8.9 m/s) to 90 mi/h (40.2 m/s). These vehicles made several passes at each speed. The unit detected every vehicle at each test speed. This was a good result since a small, high-speed object might such as a motorcycle, pass between sensing windows.

Crashworthiness Testing

ENSCO Test 2036-CW5-91

The crashworthiness of this device was determined by using only the enclosure ballasted with a mass to simulate the distribution of the electronic components. The electronic failure mode testing was conducted as fail-safe bench top testing with calculated damage (i.e., the worst cases of damage to ensure reliability).

This test was conducted at 60 mi/h (26.8 m/s), with the impact centered on the vehicle.

Photographs taken before test 2036-CW5-91 are shown in figure 25.

Figure 25. Infrared Intrusion Alarm Before Test, Test 2036-CW5-91

Impact Description

Review of the high speed films and fifth wheel data indicated that the test vehicle impacted the device at 60 mi/h (26.8 m/s) and 0 degrees. The review also indicated that the centerline of the vehicle was aligned with the device centerline.

The housing of the hit the area just beneath the vehicle's front bumper where it caught and dragged for nearly 200 ft (61.0 m). As the vehicle stopped, the leading edge of the housing snagged on a pavement joint and the housing came to an abrupt stop. The vehicle traveled over the top of the unit, crushing the box. The vehicle bounced hard over the unit, which damaged the undercarriage. Ninety-five percent of the alarm debris was located within 5 ft (1.5 m) of the pavement joint that caused the box to stop. If the box had not caught on this pavement joint, the unit probably would have remained under the front of the vehicle until the vehicle came to rest.

The brakes to the vehicle were applied 80 ft (24.4 m) after initial impact. The vehicle came to rest 215 ft (65.5 m) from the point of impact. The vehicle traveled over the device approximately 180 ft (54.9 m) past the initial impact, then continued to roll for an additional 35 ft (10.7 m). The test conditions and results are summarized in table 8.

Vehicle Damage

There was only minor damage to the vehicle front end and undercarriage. The oil pan and the floorboard showed signs of contact with the unit.

Device Damage

The box was destroyed. Most of the parts were scattered within 5 ft (1.5 m) of the point where the unit was impacted. The antenna from the unit was wedged between the wiper arm and the windshield. It did not break or crack the windshield.

Photographs of the vehicle and the IIA after test 2036-CW5-91 are shown in figure 26.

Test Evaluation

This test was evaluated using criteria D and E from NCHRP 230 and the Work Zone Hazard criterion. The following is an item-by-item evaluation using these criteria.

NCHRP 230 Criterion D:	Detached elements, fragments or other debris from the test article shall not penetrate or show potential for penetrating the passenger compartment or present undue hazard to other traffic.

This device met criterion D.

NCHRP 230 Criterion E:	The vehicle shall remain upright during and after collision although moderate roll, pitching and yawing are acceptable. Integrity of the passenger compartment must be maintained with essentially no deformation or intrusion.

This device met criterion E.

Table 8. Crashworthiness Test Summary for the Infrared Intrusion Alarm

Parameter	Value
Test Number:	2036-CW5-91
Date:	February 4, 1991
Test Vehicle:	1985 Dodge Colt
Test Device:	Infrared Intrusion Alarm (IIA) (large alarm enclosure)
Vehicle Weight:	
Planned, Inertial:	1800 ± 50 lb
Actual, Inertial:	1813 lb
Planned, Gross:	1950 ± 50 lb
Actual, Gross:	1978 lb
Number of Occupants:	One
Occupant Model:	Part 572 Anthropomorphic 50th percentile male
Occupant Location:	Driver Seat, Restrained
Impact Conditions:	
Planned Speed:	60 mi/h
Actual Speed:	60 mi/h
Planned Angle:	0°
Actual Angle:	0°
Planned Location:	Centered
Actual Location:	Centered
Test Results Conclusion:	This device successfully met the evaluation criteria.

1 mi/h = 0.45 m/s, 1 lb = 0.45 kg

Figure 26. Infrared Intrusion Alarm After Test, Test 2036-CW5-91

Work Zone Hazard Criterion: The device must not present a hazard to workers in the work zone following an impact by an errant vehicle.

This device met the Work Zone Hazard Criterion.

This device successfully met the evaluation criteria.

Open Highway Testing

The IIA was evaluated by a maintenance group within the Arizona Department of Transportation. The St. David maintenance yard used the unit for 30 hours over 8 days with only 3 false alarms. In addition, the crew liked the unit, so the road test was considered successful.

The IIA was also tested in Iowa. The GME crew set up the unit beside the work zone. This was done to see if the unit would send false alarms due to ambient radio signals. The unit did not send any false alarms in approximately 3 hours of testing. Iowa DOT personnel observed these tests and decided that they also liked the unit.

Conclusions and Recommendations

The IIA works well and is easily used by road crews. More units should be produced so that further evaluations state DOTs can perform. FHWA is purchasing four units to be used as displays and test units in the regions.

Evaluation Recommendations: The IIA should be evaluated by maintenance crews in highway work zones. The location and time of use of each unit should be recorded as well as any false alarms that occur. If an errant vehicle intrudes into the work zone, full details of the incident and the performance of the IIA should be documented. Any problems with charging the units or low batteries should also be noted.

Queue Length Detector

The Queue Length Detector (QLD) is shown in figure 27.

Background

Work crews often are unaware of traffic conditions upstream of the work zone. The work zone may be so long that these locations can be seen, or the worker's vision may be obstructed. A traffic queue can form without the work crew's knowledge. This can be hazardous condition if the queue backs up to an area with restricted sight distance, or other operational or geometric conditions make it unsafe for a vehicle stopped on the road. The QLD is a device intended to warn workers of such dangerous conditions.

The primary function of the QLD is to detect the presence of a traffic queue. The QLD, when activated, alerts workers to the queue so the workers can take action. A personal alarm will alert a work supervisor so that traffic control can be changed to allow traffic flow to increase. This device is intended to be placed in advance of the work zone, according to maintenance operations.

Device Description

The QLD consists of an ultrasonic detector placed 700 ft (213.4 m) in advance of the work zone. A buzzer and an omni-directional flashing light are used with the detector. The purpose of the system is to inform workers of a queue of vehicles in advance of the work zone. This enables the workers to adjust advance warning signs, or a vehicle sign message to improve drivers' understanding of the work zone. Upon activation, the output from the ultrasonic detector is transmitted to the work zone receiver, which in turn activates the buzzer and flashing light, informing the workers of the development of a traffic queue.

When a vehicle passes in front of the sensor, the interface board creates an electronic signal. If the vehicle stays in front of the unit for 15 seconds or more, an alarm is activated. The electronic signal then passes through the interpretation circuit to the tone encoder. The tone encoder generates a warning tone of 1 kilohertz (kHz). This signal is sent out by the transmitter which is set to operate at CB channel 30. The signal is received by the work supervisor via a walkie-talkie. Features are incorporated in the device's design to increase efficiency and reduce false alarms.

Design and Fabrication

The QLD uses a low-cost, readily-available ultrasonic ranging system available from Polaroid. The ultrasonic ranging device is a non-contact method of detecting a vehicle. If traffic is moving -- indicated by cycles of detection and then no detection -- no alert signal will sound. If a vehicle is detected for a period of time that indicates a traffic queue, then an alert signal will sound so that the traffic control in the work zone can be temporarily altered to allow the traffic to pass more freely.

Since the QLD closely resembles the Ultrasonic Detection Alarm (USDA), much of this material will reference that section of this report.

The QLD employs a ultrasonic ranging unit (URU). Technical data for this device is detailed in the USDA section.

Figure 27. Queue Length Detector

The following section presents a description of the interface board for the QLD. The final section then describes the tests that were conducted on the device to evaluate its suitability for field use as well as to determine and correct problems identified in these tests.

When an alarm condition is present, the interpretation circuit has a high output. This causes the tone encoder and the walkie-talkie to be activated. This means that a tone is placed on a CB band for another walkie-talkie to receive. A single 1-kHz tone was chosen over dual tones because the decoder for dual tone signals balked at the static on the carrier wave.

QLD Interface Circuit

The QLD interface also monitors the timer output, but it uses the output to operate a resettable and adjustable counter circuit. This interface circuit consists of a stable oscillator and a three-stage counter circuit with overflow outputs. The output from the timer circuit operates a relay that toggles the counters between the reset and run modes. If the timer circuit is off (no vehicle is present), the counters are held in the reset state. If the timer circuit is on (vehicle is present), the counter circuit is in the run mode. As long as the vehicle is present, the circuit continues counting. If the vehicle is present long enough, the counter will overflow, providing an alert signal. If the vehicle passes through the beam before the counter overflows, the counter will be reset, starting over counting from zero when the next vehicle is detected. The time it takes the counter to reach overflow is determined by the frequency of the oscillator. Higher frequencies mean shorter times and lower frequencies mean longer times. By varying this frequency, any desired alarm time can be set.

The counter overflow also drives a timer circuit that is triggered by the presence of the overflow signal. This timer is then buffered to drive a relay providing power to a transmitter and indicator light, as described in the USDA section of this report. Similar provisions are also made for the low battery signal.

Device Modifications

The decoders and encoders that were used in the original design were of the type used in touch-tone phones. Two tones are passed on a carrier and have to be matched for the receiver to activate. This proved too sensitive for our application. The unit would hesitate to accept the signal because the carrier (CB radio) is poor. However, single tone encoding proved to be effective.

Operational Testing and Lab Testing

The USDA was field test on both a test track and in real traffic streams (not in work zones or construction areas). The QLD has an identical sensing mechanism as the USDA, so no further tests were necessary for the QLD. In general, the unit passed all tests without trouble except for false alarms that appeared to be related to the ambient temperature and humidity during the tests. The results of an investigation of these problems are given in the USDA section under the subheading "Problem Investigations." The modified QLD's functionality was tested on several vehicles of various sizes. The unit detected the vehicles and responded every time. The unit then was tested in Missouri by the GME crew.

Open Highway Testing

Both QLD units were modified before open highway testing began in Missouri. The redesigned unit did not fail under any weather condition. The unit did not fail even when the GME staff used the environmental chamber to vary the temperature and humidity quickly.

Conclusions and Recommendations

The QLD works well and could be mass produced. Polaroid recently made changes in the URU and the ET, however, and it is unknown how these changes will affect the current design. This should be investigated.

Portable Rumble Strip

The Portable Rumble Strip (PRS) is shown in figure 28.

Background

The PRS is intended to inform drivers of a work zone situation ahead where they may be required to stop. A PRS would typically be used for a flagger-controlled lane closure on a two-lane, two-way road where traffic alternates over the open lane. The PRS is a flexible mat placed on the road, with a raised "edge" to give drivers a slight jolt and an audible rumble effect when passing over the PRS. The mat is designed to be durable, relatively lightweight (so that it can be installed easily by two workers), and also to resist shifting due to traffic.

Device Description

The PRS, as it was fabricated in this project, is a rubber mat, approximately 18 in (45.7 cm) long by 10 ft (3.0 m) wide by 1.125 in (2.9 cm) tall. The mat is jointed in the middle, so it can be folded for easier movement and storage. The device weighs approximately 67 lb (30.5 kg), and is easy for two workers to handle. In profile, the PRS has a rapid rise on its leading edge, followed by a gradual downward slope on the trailing edge.

A commercial version of this device is about the same size, but is molded out of a flexible PVC material, and weighs 90 lb (40.9 kg). The focus of this report, however, will be the version that was produced, revised, and tested under this SHRP project.

Design and Fabrication

The latest design of the PRS consists of a set of 0.125-in (2.9 cm) thick neoprene rubber strips, glued on top of one another with epoxy adhesive. The dimensions of the bottom strip are 10 ft by 1.5 ft (3.0 m by 0.5m). The strips glued on top of this bottom strip are successively shorter, and glued towards the front of the device. This causes the PRS to have an overall profile that gives the driver a rapid jolt. Then trailing edge tapers.

Operational Testing

Professional drivers were hired to do the first set of operational tests on the PRS. The first set of tests required a professional driver's vehicle handling skills and ability to identify potential vehicle control problems. No previous research had been conducted on rumble strips permanently attached to pavements, but none had been done on temporary rumble strips such as the PRS. It was possible that there were unknown vehicle control problems with the use of these temporary rumble strips. Such concerns needed to be addressed before drivers encountered the device.

Tests were conducted to determine whether the PRS would alert a driver, create vehicle handling problems, or move from its location on the road. These tests also assessed the durability of the PRS. It should be noted that these original operational tests were conducted on the original design of the device. This design consisted of a row of raised pavement markers, glued to a rubber mat, and covered with permanent pavement marking tape. The revisions that occurred to this design, and the reasons for making these changes, are discussed below in the "Open Highway Testing" section.

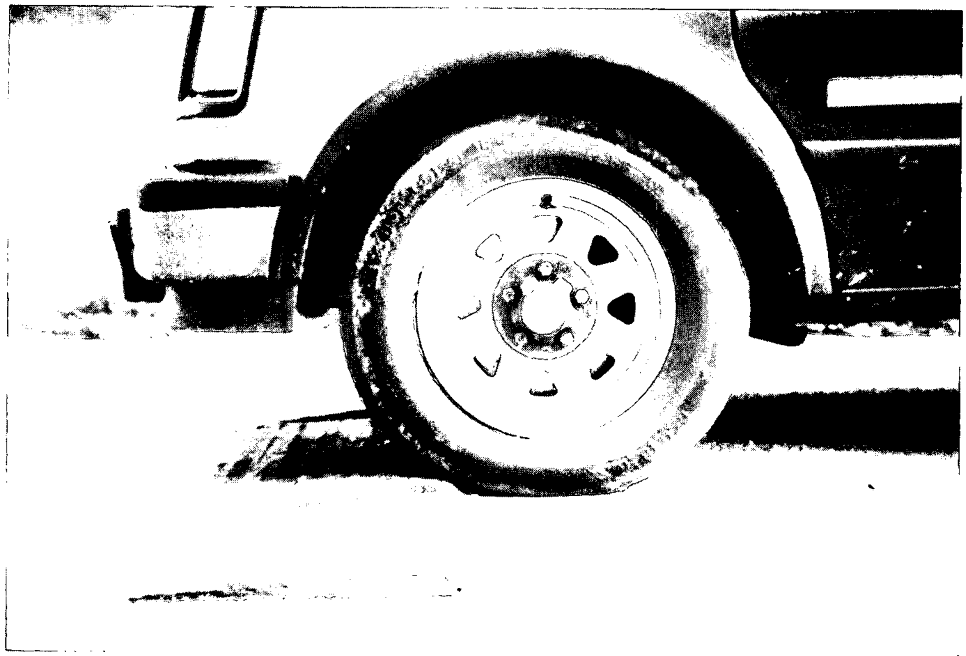


Figure 28. Portable Rumble Strip

Three types of tests were done. A professional driver performed each test which consisted of a series of runs from 20 to 70 mi/h (8.9 to 31.3 m/s) in 10 mi/h (4.5 m/s) increments. The driver first drove on the road without the PRS present in order to record ambient noise levels at each speed. The drivers then drove over the PRS. Last, the driver skidded vehicles over the PRS. Four vehicle types were used for each test: small car, large car/pickup truck, tractor-trailer combination, and motorcycle. The motorcycle used was of the type designed for highway travel, not a dirt bike. The driver drove each vehicle over the open road and then the PRS. Two video cameras and two noise meters were used to record data. One video camera and noise meter were inside the vehicle. The camera videotaped the test runs from the driver's point of view in order to document vehicle jolting, vehicle control, and to record comments by the test driver. The noise meter recorded the increase in noise that occurred from the use of the PRS. The motorcycle was not outfitted with the camera or the noise meter.

The second video camera and noise meter were placed along the roadway. The camera videotaped the vehicle from behind as it crossed the PRS to document jolting, vehicle control, and displacement. The second noise meter was positioned near the PRS to record the noise level when vehicles drove over the PRS.

The road section where the tests were conducted was straight and level. The open road test runs without the PRS were used obtain a base-line for noise, jolting action, and handling. The test vehicles were also skidded on the open road to obtain a base-line for their handling in a skid.

After each run, the PRS was checked to see if it had moved. The device was also inspected for damage after each run.

Research by others determined that the optimum spacing of pavement speed bumps for vehicle jolting was 125 in (318 cm) for speed bumps that were 0.5 in (1.3 cm) high. The 125-in (318-cm) spacing was used as a starting point for the research. The spacing was increased and decreased in 6-in (15.2-cm) increments until the optimum jolting effect was achieved. The spacing for optimum jolting was determined from test driver comments and from the videotapes. Optimum jolting should alert a driver by creating a jolting and bouncing of the vehicle, but should not create vehicle handling problems. Because optimum jolting spacing can vary by vehicle type and speed, these tests were used to establish spacing for the PRS for optimum jolting under the widest range of conditions.

The skid tests were done to identify vehicle control problems and to see if the PRS would become entangled in the vehicle's wheels or undercarriage. The PRS was also inspected for damage. The test drivers were instructed to start the skid just prior to reaching the PRS and to continue skidding across the PRS.

As mentioned above, the closed track tests were performed on an old design. Therefore, some operational testing of the different designs of the PRS was done by GME staff by placing the PRS on an abandoned road and driving over it. This was done to ensure that the new design did not pose any unforeseen safety problems. These tests were successful, and the new design was used in the next round of open highway tests.

Closed Track Testing

The PRS was tested for its effectiveness in alerting drivers of a flagger station. Drivers first passed a standard flagging operation without the PRS, turned around, then approached a standard flagging operation with the PRS deployed.

The results indicated that the PRS complicated driver responses to the innovative devices. Drivers consumed more time in their determination of the required action in response to both the Flashing Stop/Slow Paddle and the Flagger Gate. However this finding was not associated with the standard flagger paddle which was easily recognized. It is suspected that at least some of the increase in information processing time required is due to the novelty effect of new highway devices, as opposed to the easy recognition and familiarity with the standard flagger paddle.

Subjective ratings indicated that the drivers thought that the PRS would not improve safety on highways. The driver's behaviors, however, showed that the PRS caused in the longest advance brake activation distances. Drivers had slowed in response to seeing the device rather than the flagman or the paddle. The PRS also resulted in the maximum spot deceleration upon the approach to the device.

Open Highway Testing

Open highway testing of the PRS was performed by a maintenance crew from Marion, Iowa, just outside Cedar Rapids. This testing included training of the workers in use of the PRS, three different speed studies of the PRS's effectiveness in reducing vehicle speeds, and a period of approximately one month that the PRS was left with the crew and they were allowed to experiment with different placements and spacings of the PRS.

The original design of the device was tested.

One set of two bumps was taken to the Marion crew. GME staff conducted a brief training session for the workers and user's manuals were distributed. The crew experimented briefly with the bumps in the maintenance yard, picking them up, folding and unfolding them, and driving over the bumps. The bumps were then taken out to a maintenance work zone for testing.

The site for the first day of open highway testing of the PRS was a flagger-controlled lane closure on a rural two-lane, two-way roadway. For safety reasons, the devices were placed 200-250 ft (61.0-76.2 m) upstream from the flagger station for the first day of testing. This was to see if their use entailed any additional safety hazards for motorists. No such problems were encountered during the first day of testing. The devices were too close to the work zone, however, since they were in the traffic queue after only four or five vehicles and accumulated.

For this reason, the placement was increased to 700-750 ft (213.4-228.6 m) upstream from the flagger station for the second day of testing. Unfortunately, the devices tended to flip over in this configuration. On the second day, a radar unit was used to conduct a speed study on the cars passing through the work zone. The results of this speed study are summarized in table 9.

In table 9, "Approach" refers to the speed at vehicles in advance of the first work zone sign. "Before Device" refers to speeds collected 25-50 ft (7.6-15.2 m) upstream from the PRS, and "After Device" refers to speeds collected 25-50 ft (7.6-15.2 m) downstream from the PRS.

After the second day of open highway testing, the GME staff returned to Independence, Missouri, leaving the bumps with the Marion crew. The crew was encouraged to experiment with the bumps and write down any observations on their use or their effectiveness.

After a month of using the devices, the crew said that the PRS was the most effective when placed about 500 ft (152.4 m) upstream from the flagger station, that the PRS worked,. that the PRS helped motorists recognize the work zone signing, but that the PRS to be more durable.

Table 9. Car and Truck Speeds on Approach Before Device, and After Device 700-750 ft from Flagger Station

	Approach	Before Device	After Device
Cars:			
Sample Size	40	56	55
Average Speed (mi/h)	52.23	46.43	42.65
Standard Deviation (mi/h)	4.87	7.06	7.02
Trucks:			
Sample Size	5	6	6
Average Speed (mi/h)	44.20	34.83	30.33
Standard Deviation (mi/h)	5.70	4.74	5.74

1 ft = 0.30 m, 1 mi/h = 0.45 m/s

The work supervisors also were interviewed by GME staff. In general, they liked the idea of the devices and thought that the design that was tested was adequate, but could probably be improved considerably with a small amount of redesign and refinement.

They did say that the construction of the devices would have to be changed, since the devices required far too much maintenance to make their use practical. For this reason, GME staff modified the devices during the second visit to Marion. The permanent pavement marking tape was replaced by a layer of 0.0625-in (0.16-cm) thick neoprene rubber to cover the raised pavement markings. Unfortunately, there was not enough adequate adhesive to secure the smaller rubber mats covering the raised pavement markings to the base rubber mat. The looseness of the rubber covering caused the devices to be picked up or flip over more easily in traffic.

This modification was tried on the open road, however, and another speed study was conducted. The speed data during this study showed only a small decrease in mean speeds, probably due partially to the roadway and geometric conditions present at the site of testing. The bumps were located just after a very bumpy section of the roadway, and the motorists may have been somewhat inured to such effects. However, the devices did result in a lower standard deviation of the speed sample.

The insights from the Marion crew and the results from the open highway tests provided valuable guidance during the redesign for the devices. This redesign effort resulted in the current design of the PRS as described above. One prototype of this design was fabricated and again taken to Marion for open highway testing.

Results with the new design were excellent. The device did not flip over for the entire day, despite its placement upstream from the first work zone warning sign. The design was still very simple for two workers to move and install. GME staff also performed a third speed study at this time. Summary of the results is shown in table 10.

Table 10. Car and Truck Speeds on Approach Before Device, and After Device 700-750 ft from Flagger Station

	Without Devices Installed	With Devices Installed
Number of Vehicles	27	100
Number of Trucks	5	39
Average Approach Speed (mi/h)	55.74	53.91
Standard Deviation	5.32	6.20
Average Speed After Bumps (mi/h)	40.93	38.27
Standard Deviation	8.56	7.77

1 mi/h = 0.45 m/s

Conclusions and Recommendations

The following conclusions can be drawn based on the research performed on the PRS for this project:

- The current design of the PRS is economical, durable, and relatively lightweight.
- The device performs well on the road, and, to date, no circumstances have been found in which the current design of the device will flip over or present a hazard during normal operations.
- The device has consistently produced a measurable, if not statistically significant, reduction in speeds during open highway testing. Also, more often than not, it has resulted in more uniform speeds when compared with a standard flagging operation.
- According to driver interviews conducted by the Marion, Iowa work crew, use of the PRS increases driver recognition of work zone signing.

The following recommendations should be followed for further development of this device:

- More open highway evaluation should be done. This evaluation should focus on optimizing the spacing, placement, and number of devices to be used for different types of roadways and work operations.
- Further speed data should be collected. If possible, driver interviews should be conducted to determine the PRS's effectiveness, acceptability to drivers, and ability to increase driver's level of awareness of the work zone.

Direction Indicator Barricade

Figure 29 presents the hinged panel Direction Indicator Barricade (DIB). Figure 30 presents the sliding panel DIB.

Background

Barricades mark specific hazards or are employed in series to channelize traffic. The approaching driver must detect the barricades and recognize the warning function. Then the driver must recognize the location of the barricade relative to his path of travel, and determine the appropriate path to take. The DIB uses an arrow to provide directional path information to the driver. The diagonal striping currently used on the standard MUTCD barricade (the direction of which is supposed to indicate the path of travel) is replaced by a non-directional checkerboard pattern. The driver must recognize the directional indicator within the barricade, and determine of the direction in which it points.

Device Description

The DIB was designed to convey unambiguous directional information. Two prototype designs were tested. The first design consisted of a 24- by 12-in (61.0- by 30.5-cm) panel hinged to the center of the barricade, with an arrow on each side. The panel is flipped over to change the direction of the arrow.

The second design used two sliding panels that locked into place above the barricade panel each panel had its own arrow (left or right) panels. The size of this arrow was also 24- by 12-in (61.0- by 30.5-cm). The DIB was designed for use as a standard barricade.

Design and Fabrication

The DIB utilizes standard barricade dimensions as specified in Part VI of the MUTCD. That is, rail height and area of retroreflective sheeting on the rails is standard. The frame was made of metal tubing.

Closed Track Testing

Standard barricades were used as the baseline condition in both right- and left-lane closures. Test conditions consisted of two DIB designs for each left- and right-lane closure application. Tested DIB designs were both the hinged- and sliding-panel devices.

Drivers generally took longer to recognize and interpret the DIBs than the standard barricades. There are three likely explanations for this. First, the DIBs are more visually complex than the baseline standard barricade. Because of their larger size and dual design (i.e., the arrow plus the panel), there is simply more information to comprehend. Second, the arrow provides more information than striped panel. Therefore, the DIB required more interpretation time due to the increased complexity of the message. Finally, the novelty of the DIBs caused drivers to look at the devices longer before making their action decisions.

The DIBs were more likely to be correctly interpreted by drivers than the striped panel. The DIBs drew explicit responses (e.g., "right lane closed", or "merge left"), while more general responses (e.g., "lane

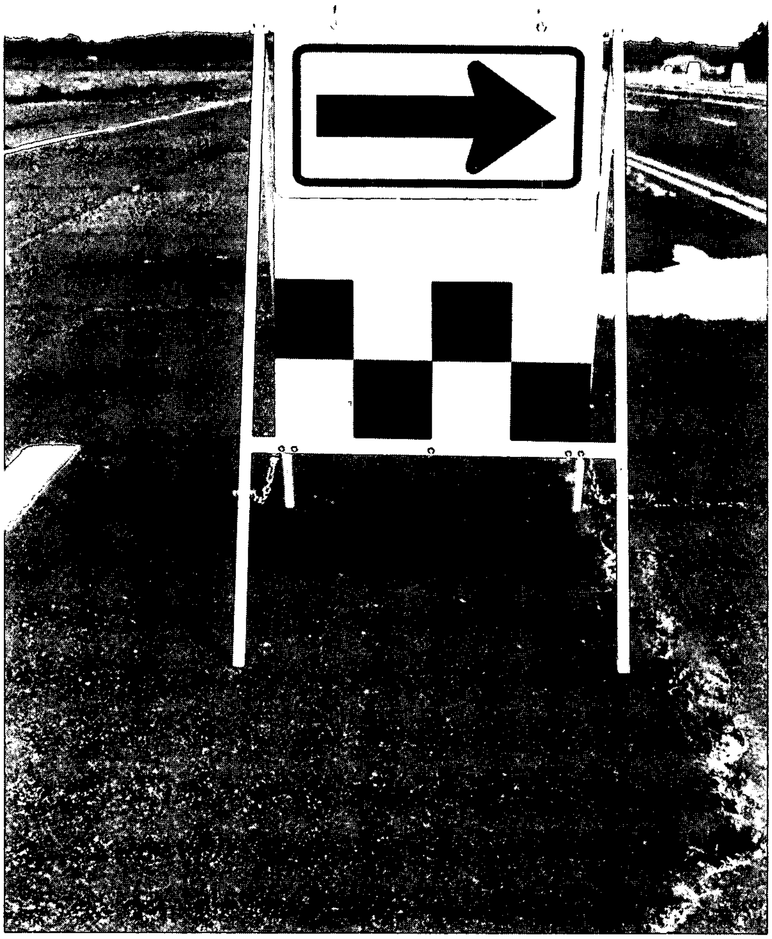


Figure 29. Hinged Panel Direction Indicator Barricade

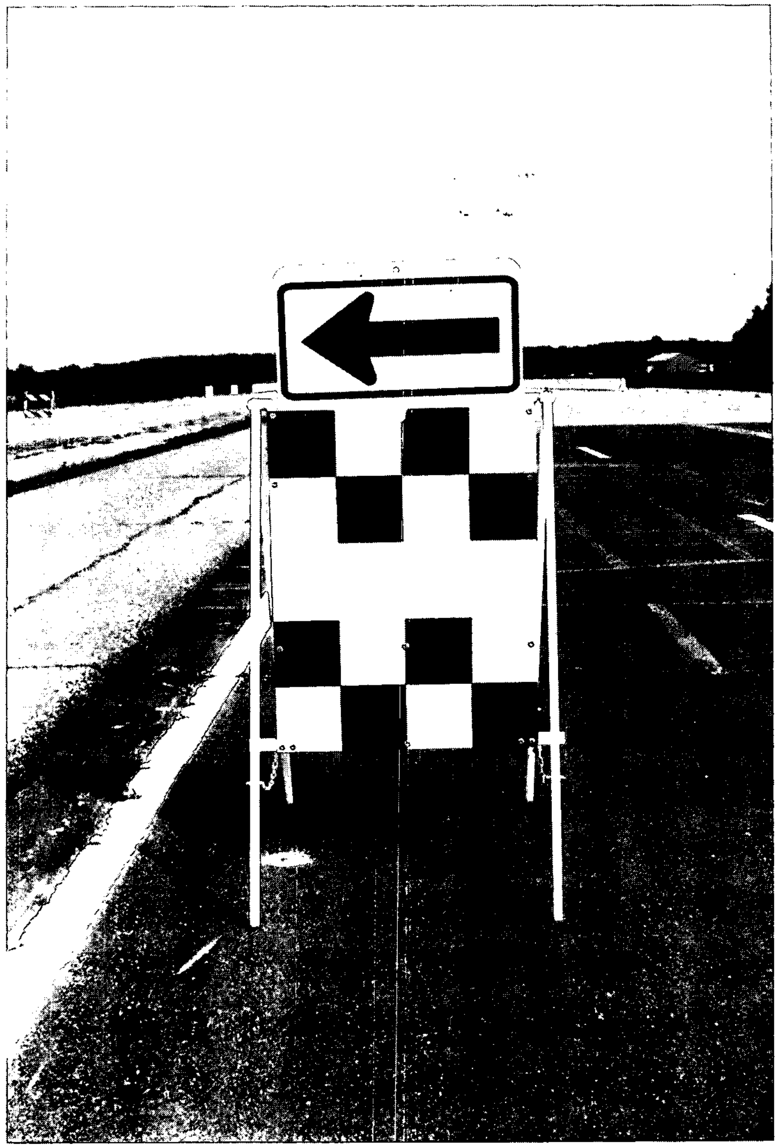


Figure 30. Sliding Panel Direction Indicator Barricade

closed") occurred with the standard barricade. Additionally, drivers rated the DIB more favorably, e.g., indicating that the devices were more helpful and could make highways safer.

The distance at which test subjects made their preparatory lane change maneuvers did not vary whether the standard or the DIB designs were deployed for lane closures. Likewise, vehicle behavior measures based on lateral acceleration and speed variance showed no significant differences. Therefore, the lane change effect of the DIBs was further investigated in open highway testing.

In summary, the DIBs demonstrated a benefit over standard lane closure treatments by providing improved lane closure guidance information. Test subjects rated DIB devices as significantly more helpful and safe. While the DIBs did require longer driver information processing times (likely due to their novelty effect), vehicle performance was not adversely affected.

Crashworthiness Testing

ENSCO Test 2036-CW3-91

The DIB is a barricade designed to provide improved directionality compared to standard barricades. Two alternative prototype designs were constructed.

The sliding panel design of the DIB was believed to be the worst case design. The design's additional height made it more likely to contact the test vehicle's windshield, causing vehicle damage. Only the worst case design was used for the crashworthiness evaluation. This test was conducted at 45 mi/h (20.1 m/s), with the impact centered on the vehicle. Photographs of the DIB and the vehicle before test 2036-CW2-91 are shown in figure 31.

Impact Description

Review of the high speed films and fifth wheel data indicated that the test vehicle impacted the device at 46 mi/h (20.6 m/s) and 0 degrees. The review also indicated that the centerline of the vehicle was aligned with the centerline of the test article.

Upon impact the device wrapped around the front end of the vehicle, including the hood area as well as the front bumper. The plastic arrow sign panel shattered on impact and dispersed near the point of impact. Several large pieces of the sign panel impacted the windshield but there was no damage, other than rub marks on the glass surface. The remainder of the sign panel flew over the vehicle's roof and was scattered over a 30 ft (9.1 m) area starting 25 ft (7.6 m) from the point of impact. The two 50-lb (22.7-kg) sand bags holding the barricade in place were also destroyed at impact.

After the initial impact, the frame of the barricade became caught beneath the vehicle's frame and the vehicle pushed the frame along with it. The onboard brakes were applied 140 ft (42.7 m) from impact, causing the vehicle to yaw. The frame and the vehicle came to rest 230 ft (70.1 m) from impact.

The test conditions and results are summarized in table 11.

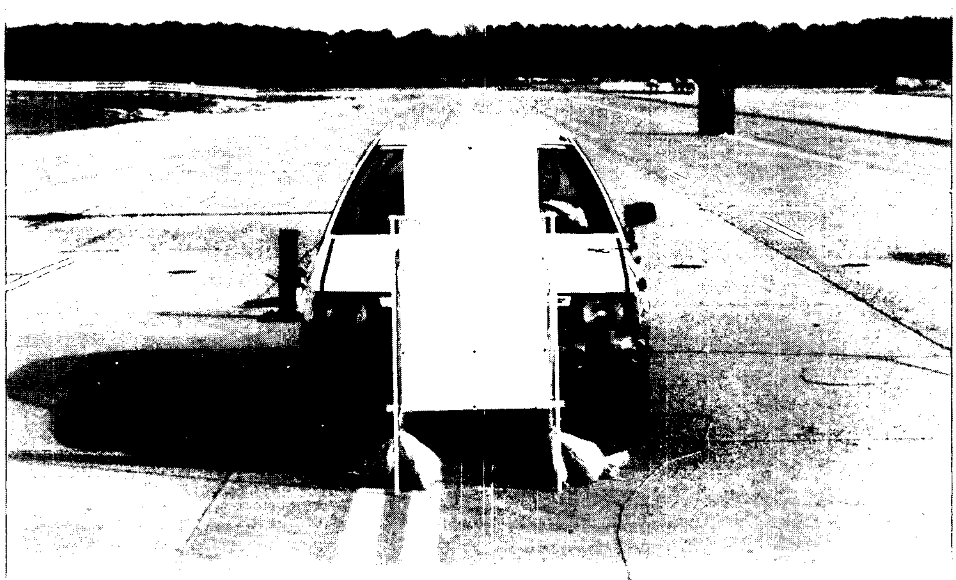


Figure 31. Sliding Panel Direction Indicator Barricade Before Test, Test 2036-CW3-91

Table 11. Crashworthiness Test Summary for the Sliding Panel Direction Indicator Barricade

Parameter	Value
Test Number:	2036-CW3-91
Date:	January 29, 1991
Test Vehicle:	1985 Dodge Colt
Test Device:	Direction Indicator Barricade (Sliding Panel)
Vehicle Weight:	
Planned, Inertial:	1800 ± 50 lb
Actual, Inertial:	1813 lb
Planned, Gross:	1950 ± 50 lb
Actual, Gross:	1978 lb
Number of Occupants:	One
Occupant Model:	Part 572 Anthropomorphic 50th percentile male
Occupant Location:	Driver Seat, Restrained
Impact Conditions:	
Planned Speed:	45 mi/h
Actual Speed:	46 mi/h
Planned Angle:	0°
Actual Angle:	0°
Planned Location:	Centered
Actual Location:	Centered
Test Results Conclusion:	This device successfully met the evaluation criteria.

1 mi/h = 0.45 m/s, 1 lb = 0.45 kg

Vehicle Damage

There was only minor damage done to the test vehicle, which consisted of additional breaking of the plastic grill area, slight deformation (dents) of the front bumper, minor dents and scratches on the hood and plastic scuff marks on the windshield.

Device Damage

The DIB was destroyed. The plastic sign panel shattered and the legs of the A-frame which holds the sign was bent so that it would no longer be able to suspend the sign from its cross member.

Photographs of the DIB and the test vehicle after test 2036-CW3-91 are shown in figure 32.

Test Evaluation

This test was evaluated using criteria D and E from NCHRP 230 and the work zone hazard criterion. The following is an item-by-item evaluation using these criteria.

NCHRP 230 Criterion D:	Detached elements, fragments or other debris from the test article shall not penetrate or show potential for penetrating the passenger compartment or present undue hazard to other traffic.

This device met criterion D.

NCHRP 230 Criterion E:	The vehicle shall remain upright during and after collision although moderate roll, pitching and yawing are acceptable. Integrity of the passenger compartment must be maintained with essentially no deformation or intrusion.

This device met criterion E.

Work Zone Hazard Criterion:	The device must not present a hazard to workers in the work zone following an impact by an errant vehicle.

This device met the Work Zone Hazard Criterion.

This device successfully met the evaluation criteria.

Open Highway Testing

Controlled before and after field tests were conducted at two Maryland U.S. 50 lane closure sites. Standard drums were applied as the "before" condition, and experimental applications of DIBs comprised the "after" condition. Field data collection techniques consisted of an automated pavement-loop vehicle detection system, videotape surveillance, and manual observation. The applied measure of effectiveness was "closed-lane violations", i.e., vehicles detected in the closure lane, at a point 200 ft (61.0 m) in advance of the taper. The automated data collection system could monitor the work zone for vehicle incursions around the clock.

Collected data consisted of: (1) 15-minute counts in advance of the lane closures, and (2) concurrent traffic volumes by lane. These data were analyzed to determine the significance of observed differences. Results of the statistical analyses revealed that traffic volumes (when controlled for time-of-day effects) did not significantly differ between test conditions.

Figure 32. Sliding Panel Direction Indicator Barricade After Test, Test 2036-CW3-91

Therefore, a valid determination of relative device (i.e., drums versus DIBs) treatment effectiveness was derived by directly contrasting the incidence of closed-lane violations.

Results indicated that no advance lane-change benefit was derived from the tested DIB configuration. An increase in closed-lane violations, associated with DIB presence, was observed during daylight conditions at one of the two test sites. No nighttime differences were observed.

A likely explanation for this finding is that the drums are bigger than the DIBs. This conspicuity is believed to have overridden the message effect of the directional arrow. Therefore, a modified version of the DIB was developed which incorporated the directional arrow (shown to be effective in the closed track testing) and the larger-size drum device configuration. This modified device is discussed in the next section of this report.

Conclusions and Recommendations

Closed track testing of the DIBs demonstrated a benefit associated with use of a directional arrow. The DIB more effectively conveyed to motorists information regarding necessary lane changes and was also considered more helpful and more likely to increase highway safety. However, the effectiveness of the directional arrow was overridden in open highway testing by the larger drum channelizing devices.

The closed track and open highway testing of the DIBs indicated that the features of the directional arrow design should be used with a drum-type device that is larger conspicuous, and durable. Thus, the recommended device is a flat-faced drum incorporating a black directional arrow on a reflective white background. It is recommended that production models of the device be made of plastic or other lightweight material.

The reversible-direction arrow panel could be incorporated into directional indicator drum, by attaching the arrow panel to the upper portion of the drum. In this manner, the panel can be inverted so as to present either a left- or right- facing directional message. The directional indicator drum is illustrated in figure 33. A variation of the DIB used by the Pennsylvania Department of Transportation consisted of a standard black-on-orange arrow panel (MUTCD designation, W1-6) combined with striped panels and mounted on PVC barricades. The devices pictured in figure 34 were deployed on I-295 south of Philadelphia.

Figure 33. Directional Indicator Drum

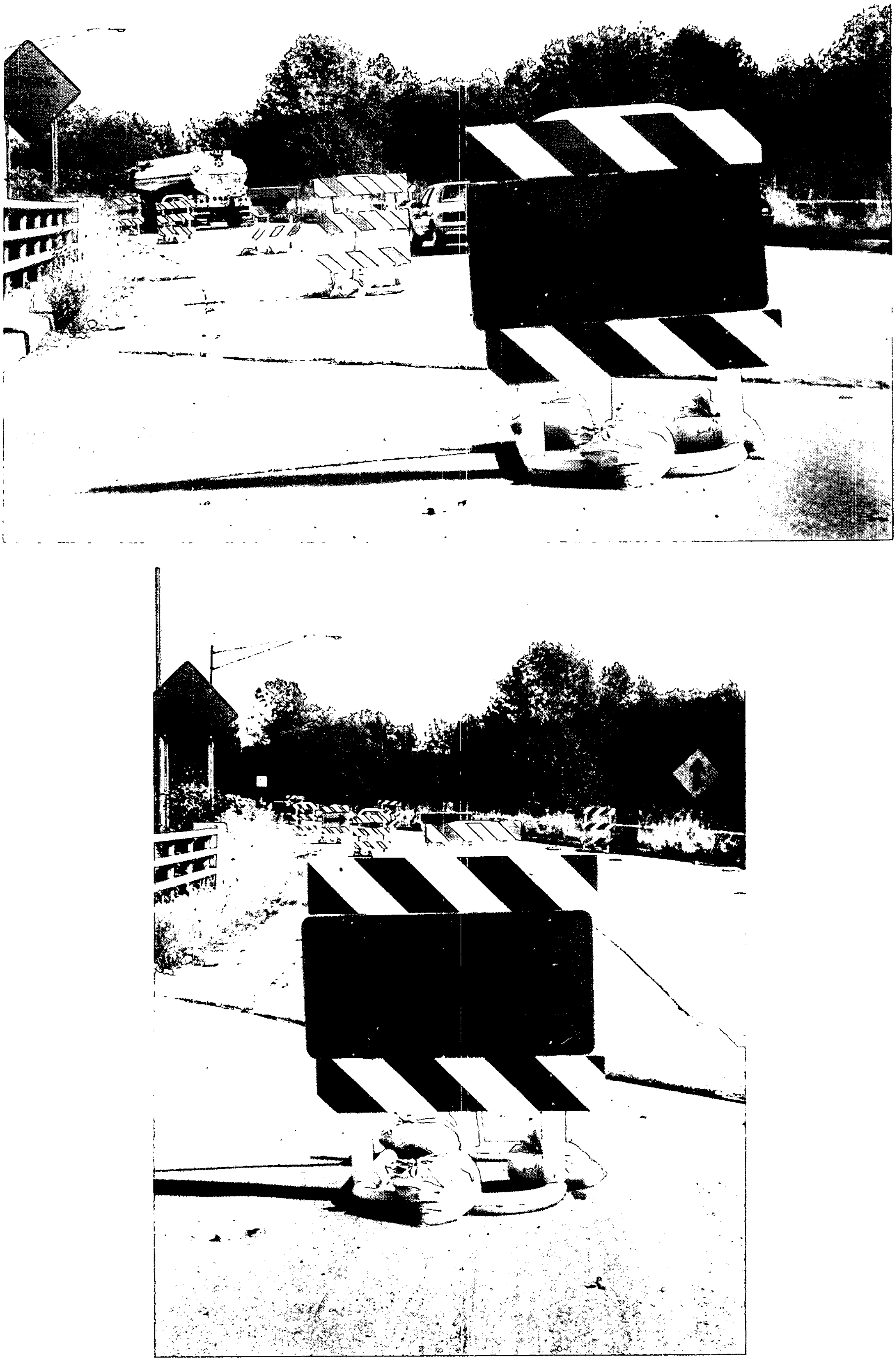


Figure 34. Pennsylvania DOT Direction Indicator Device

Opposing Traffic Lane Divider

The Opposing Traffic Lane Divider (OTDL) is shown in figure 35.

Background

The OTLD concept was investigated because maintenance work zones often temporarily change traffic patterns from their normal configuration. In these situations, it may be difficult for drivers to discern the proper travel path. The OTLD is a centerline delineator for maintenance work zones where additional travel path information must be conveyed to the driver. An example of this type of work zone is in an area where four-lane, divided traffic flow is changed to two-lane, two-way operation, so that work may be done on one side of the divided roadway.

Device Description

The OTLD is a two-way sign mounted on a 36-in (91.4-cm) tall tubular channelizer. The sign mounted on the channelizer is 12 in (30.5 cm) off the ground, and consists of a two-way arrow, indicating to drivers that there is two-way traffic in the work zone. The sign bears the two-way legend on both sides, so that drivers in both lanes of traffic may see the message. the arrows are black on a high-intensity orange sheeting, enclosed by a block border.

The tubular channelizer minimizes the damage done to the sign if a vehicle should hit the device. The heavy 8-in (20.3-cm) base of the channelizer, attached to the pavement with an adhesive, provides additional stability for the sign during impact. However, the device is still easily handled by one worker.

Design and Fabrication

The prototype of the OTLD consisted of a flat 20-in by 12-in (50.8-cm by 30.5-cm) plastic base that sat directly on the road surface. An upright 12-in by 18-in (30.5-cm by 45.7-cm) plastic sign was attached to this base using helical springs as the joint between the two parts. In this way, the sign would easily bend over when impacted by a vehicle, and the springs would raise the sign back to the proper position.

Several problems occurred with this design. There were functional and durability problems with the springs as they were fabricated. The costs were considerably higher than anticipated, and the FHWA felt that the sign was too close to the ground to be effective. More information about the evaluation of this design can be found below in the open highway testing section. The design shown in figure 35 was adopted as a result of that evaluation process.

The improved version of the device is being fabricated by a manufacturer in Texas.

Operational Testing

Operational testing of the OTLD was performed at the closed track test facility in Georgetown, Delaware. The operational tests determined the device's stability in the wind, and also the device's response when impacted by a vehicle. Crashworthiness testing of this device was not performed, since the operational testing included this factor.

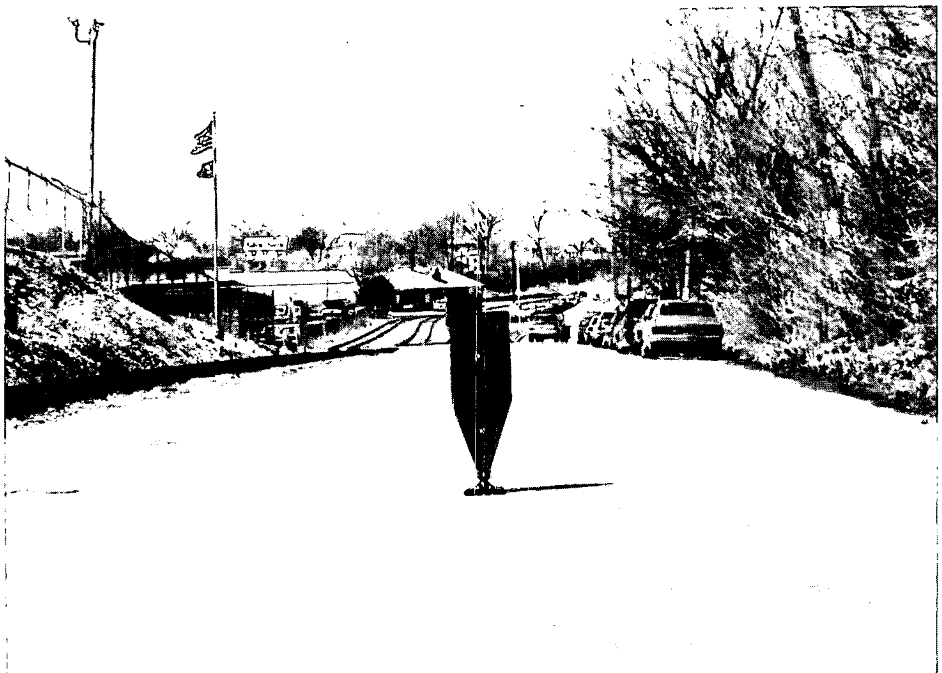


Figure 35. Opposing Traffic Lane Divider

The operational tests were performed on the prototype of the device. This prototype passed all of the criteria for the operational tests, and was therefore passed onto closed track testing.

Closed Track Testing

In the closed track setup, two devices were used that normally advise drivers that they are in an area with two-way traffic in a work zone. Standard 36-in (91.4-cm) high road tubes were applied in one area as the standard, or baseline, treatment. The OTLDs were set up in another area as the comparable experimental treatment.

The OTLDs met with generally favorable results. Drivers recognized more quickly that the OTLDs were meant to affect their driving and made earlier decisions regarding the appropriate response. Once the device was recognized, the time required to determine the appropriate action did not significantly differ between the standard tubes and the OTLDs.

In addition, drivers understood the message the OTLDs are intended to convey faster and better than that of the standard tubes. This fact validates the effectiveness of the two-directional arrow face design of the OTLD. As a result, the OTLDs received higher subjective ratings by drivers in terms of their helpfulness and potential for making highways safer.

Approach speeds, recorded 400 ft (121.9 m) from the devices, indicate higher approach speeds for standard tubes than for OTLDs. However, vehicle speeds in the vicinity of the devices did not vary between the standard tubes and OTLDs. This indicates a greater degree of slowing in response to the standard tubes. The obvious effect of these findings is that speed profiles differed between the two applied treatments. Accordingly, larger speed and acceleration variances were observed with the standard tubes.

Geometric and pavement conditions associated with the test site may have accounted for some of the observed speed profile and acceleration variance difference. However, the significant result is that measured speeds adjacent to the devices did not differ between the standard tubes and the OTLDs.

The implication of these results for evaluation purposes is that overall speed and speed variance should be used to rate the OTLD's effectiveness. Traffic flow smoothness, rather than just slowing, is a better indication of the effectiveness of the OTLD.

Open Highway Testing

Initial open highway testing of the OTLD was conducted on a two-lane, two-way construction site near Waukegan, Illinois. The devices were placed along the centerline, and attached with bitumen adhesive tape. A computerized traffic detection system was used to collect traffic volumes and speed, and videotapes were made to obtain lateral placement data. Although easily installed, the devices were easily damaged by traffic. They were removed from the site after one day and one night.

Two traffic operational measures were collected, i.e., speed and lateral placement both at "test" and "control" locations. Separate analyses were conducted for cars and trucks. Findings are separately noted for speed and lateral placement as follows.

Traffic flow smoothness (speed variance) was used to assess driver response. While a significant site-specific speed variance effect was shown to characterize the test location, a slight operational improvement was nevertheless found to be associated with the OTLD devices.

Lateral placement data revealed that, although some inherent difference existed between the "test" and "control" site, the device effects were significant. That is, in the presence of the OTLD, cars and trucks traveled 17.0 and 18.4 in (43.2 and 46.7 cm), respectively, closer to the right curb in the 12-ft (3.7-m) urban arterial lane.

The research team redesigned the device after observing the results of the open highway testing. After a prototype had been fabricated, they learned that a device nearly identical to the prototype was already in production by a manufacturer in Texas (figure 35). It was obviously more cost-effective to use this device for further testing. The Mississippi DOT agreed to open highway test this new design of the device along a seven-mile construction zone on I-20 west of Jackson, Mississippi.

Three locations (two using standard devices, and one OTLD location) were designated to determine OTLD speed variation effects. Results indicated 85th percentile speeds occurrence of 61.8 mi/h (27.6 m/s) and 61.5 mi/h (27.5 m/s) in the "standard" zone, compared to 61.5 mi/h (27.5 m/s) in the presence of the OTLD. The absence of significant observed speed variance was interpreted to mean good driver recognition and interpretation.

Most drivers surveyed said that the standard delineator tubes indicated was "caution". Most drivers also said that the OTLD signs indicated that they were driving with opposing traffic. Most of the surveyed drivers failed to recognize the difference between the 200-ft (61.0-m) OTLD versus 100-ft (30.5-m) standard delineator spacing; this finding is interpreted as a benefit of the superior conspicuity of the OTLD.

Various problems occurred and were corrected during the evaluation period. Within approximately two weeks all of the OTLD sign supports had failed due to hardening in the rebound cables. Double steel cables were then applied; but further problems led to replacing these with standard tubular delineators. Another problem with the original 50 units was a failure between the base of the mounting device and the painted concrete median. This problem was easily overcome after it was determined that the failure was in the bond between the paint and the median itself. After spot removal of the median paint, the bases were again epoxied and anchored, and no further problems of this type were encountered.

A final concern of the Mississippi study was the additional labor required to place the mounting device with the OTLD symbol attached. Also, more installation time was required for the OTLDs.

Since the traffic operational evaluations demonstrated generally positive results associated with OTLD use, the design was modified in order to improve its durability.

Conclusions and Recommendations

The OTLDs have shown much promise for further use as an effective traffic control device. It appears that the devices can improve drivers' understanding of certain types of two-lane, two-way work zones. In addition, the OTLDs in the open highway tests, appeared to shift drivers away from the centerline which could reduce head-on collisions. The latest design of the OTLDs should also allow them to be used in a very economical manner, unlike earlier versions of the device. The tubular channelizer used for the new design of the device costs about $30, while the custom-manufactured spring in the prototype cost nearly $300.

The use of the new OTLDs should be greatly expanded. The device is already in mass production by a manufacturer in Texas.

The following procedures should be followed to evaluate the OTLD:

- As in the closed track testing described herein, the OTLDs should be compared with some baseline treatment at each site, such as standard roadway tubes or cones.

- The device's recommended use is for work zones where traffic has been temporarily diverted from the normal path, particularly those areas where the centerline is moved from its normal position.

- Use of driver interviews is recommended to evaluate drivers' opinions and feeling about the OTLDs. Drivers should be questioned as to what message they thought that each device conveyed and, having interpreted the message, how helpful for roadway safety they thought each device was.

- If possible, speed data should be collected for use of both the OTLD and the baseline treatment. Speeds should be measured on the approach and near the OTLD or baseline treatment. Approach speeds should be measured some 400-500 ft (121.9-152.4 m) in advance of the device being tested. Speed variance should be determined for both speed measurement locations. It is believed that, as more drivers correctly identify the device, approach speeds will decrease and speed variances will become much smaller.

- The first one-third of the two-lane, two-way work zone at one end should be delineated with either the OTLD or the baseline treatment. After the first few days, these would be replaced with the other device.

Snowplow Blade Markers

The Snowplow Blade Markers (SBM) are shown in figure 36.

Background

Visibility is a problem during most snowplowing operations. Falling snow or the snow cloud created by a plowing operation can obscure the plow. Although the majority of snowplow accidents involve cars that run into the rear of snowplows, many accidents occur when drivers hit the plow blade while meeting or passing a snowplow. Snowplow drivers also have trouble seeing the ends of the plow blade and sometimes hit guardrails or other roadside objects.

Device Description

The SBM are lights mounted at the ends of a snowplow blade to indicate the presence and extent of the blade. Each marker is made from 30-in (76.2-cm) tall rectangular steel channel with one clear bulb on top and two amber bulbs on the outside of the marker. The control box for the lights is located in the plow's cab and includes a dimmer for the clear bulb on top of the marker.

Design and Fabrication

The SBM were custom installed on each plow blade. The first installation was on an experimental plow blade developed for SHRP at the University of Wyoming in Laramie. The markers were installed by GME staff. The second and third installations of the markers were made on Washington State snowplows by Washington DOT personnel.

The light bulbs and fixtures used were shock-resistant and designed to be placed on the tips of aircraft wings.

Operational Testing

When the markers were first operationally tested in Laramie, Wyoming, videotapes were made of the operation under clear conditions during the day and night. These tests revealed that the clear top bulbs were too bright at night and were distracting to the snowplow driver. The best solution proved to be the addition of a dimmer for the clear bulbs. One bulb filament shattered due to vibration during plowing on clear pavement at low speed.

The plow was then driven to West Yellowstone, Montana to allow operational testing during snow conditions. These tests were conducted on two unused roads at the West Yellowstone Municipal Airport.

The purpose of the tests was to assess the visibility of the markers during snowplowing operations. The SBM were videotaped from behind and approaching the snowplow and from the cab of the snow plow. Tests were conducted during both day and night.

The SBM were effective at night in improving visibility of the plow blade. They were also visible during the day, but were obscured when the snow cloud, created while plowing deep snow at high speed, obscured the snowplow. The durability of the bulbs was fair during these tests, but four of the bulbs were replaced.

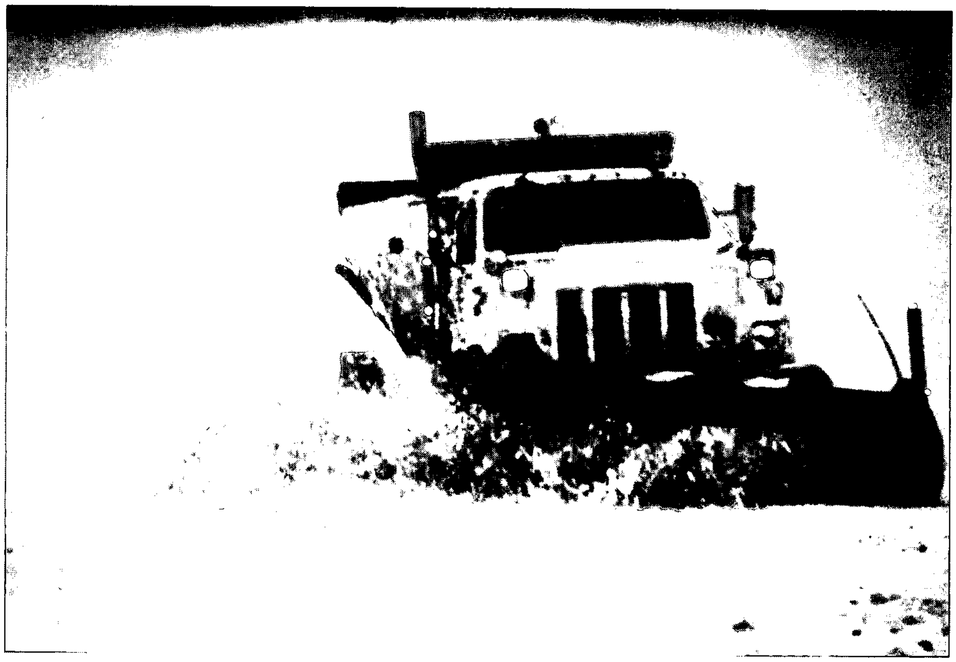


Figure 36. Snowplow Blade Markers

Of two drivers from the Wyoming DOT, one felt the SBM were helpful in locating the ends of the plow blade, while the second did not find the SBM aided his driving.

Open Highway Testing

The SBM were installed in two maintenance units in Washington state by state DOT personnel. The units were used in one unit in April, 1991 and in the other unit in January of 1992. GME staff observed the installation and limited use in April, 1991. Day and night plowing operations were videotaped. While both snowplow drivers said that the SBM were helpful, the bulbs durability was a problem. Five bulbs were replaced in about two hours of plowing operations.

The SBM installed in January, 1992 were mounted near the bottom of the plow blade. Results of the use of these markers at night are given below:

3 mi (4.8 km) of plowing - two bulbs out
7 mi (11.3 km) of plowing - one more bulb out, one socket out - replaced
15 mi (24.1 km) of plowing - four bulbs out, two sockets out
27 mi (43.5 km) of plowing - all bulbs out, four sockets out - replaced
33 mi (53.1 km) of plowing - all bulbs out, all sockets out but one - replaced
End of 99 mi (159.3 km) of plowing - all bulbs out, five sockets out

The plow driver felt that visibility (at night) was impaired with the lights on high, but was fair with the lights dimmed.

It is felt that the low mounting probably caused the sockets and bulbs to fail, especially with fixtures being vibrated out of their mounting. However, the overall bulb durability was not good enough to warrant further tests.

The poor bulb durability did not allow sufficient test period to gauge motorist response.

Conclusions and Recommendations

- While the SBM were not visible through a snow cloud, many snowplow drivers felt they were helpful in plowing near obstacles.
- The aircraft wing lights used were not durable for snowplowing operations. Some type of vibration and shock absorbing mechanism was needed.
- Mounting of the markers should be as high as possible on the plow blade. Alternative mountings on the truck should be considered.

Flashing Stop/Slow Paddle

The Flashing Stop/Slow Paddle (FSSP) is shown in figure 37.

Background

There are certain functions that must be accomplished by the flagger in a maintenance work zone. First, the flagger must alert the driver to the presence of a hazard and the need to take some action to avoid this hazard. Second, the flagger must be able to inform the driver as to the proper course of action to take. The combination flagger/paddle system must be visible from a distance so that the driver can detect the sign, recognize the work zone hazard that the flagger is trying to convey, and, finally, comprehend the proper action to take. All these functions must be accomplished so that the driver has sufficient time for a safe, controlled maneuver by the time he reaches the work zone. The conspicuity (or distance that the flagger is likely to be noticed) should be increased to the maximum level possible. The FSSP is intended to accomplish exactly this objective.

The FSSP allows the flagger to increase the conspicuity of the device. Rather than simply making the standard paddle brighter or more visible, the FSSP takes advantage of the human ability to judge the situation. Drivers are therefore aided by both the conspicuity of the FSSP device, and also by the more active role of the flagger.

Device Description

The FSSP looks like a standard flagger paddle (STOP on one side, SLOW on the other) that has two lights mounted above and below the STOP message. The FSSP is used in a flagging operation where the flagger stops or slows traffic. The flagger alerts oncoming traffic by pressing a button on the side of the FSSP, which activates the lights on the STOP face aimed at the traffic. The lights, powerful enough to be seen at distances up to 2,100 ft (640.1 m), flash alternately through 10 cycles.

The manufacturer's original literature for the device claims that it meets the following specifications:

Weight:	7.2 lb (3.3 kg)
Overall Height:	74 in (188 cm)
Sign Size:	18 in by 18 in (45.7 cm by 45.7 cm)
Battery Life:	
Standard Batteries:	350 cycles
High Capacity:	1,400 cycles
Lamp Life:	2,000 hours

In these specifications, battery life indicates the number of cycles of operation before requiring recharge. One cycle equals 2 lamps flashing, alternately, 10 times each for a total of 20 flashes. In terms of actual hours of operation, this means that, if the sign cycled every 2 minutes, standard batteries would last for approximately 11.5 hours before requiring a recharge, and high-capacity batteries would last about 46 hours.

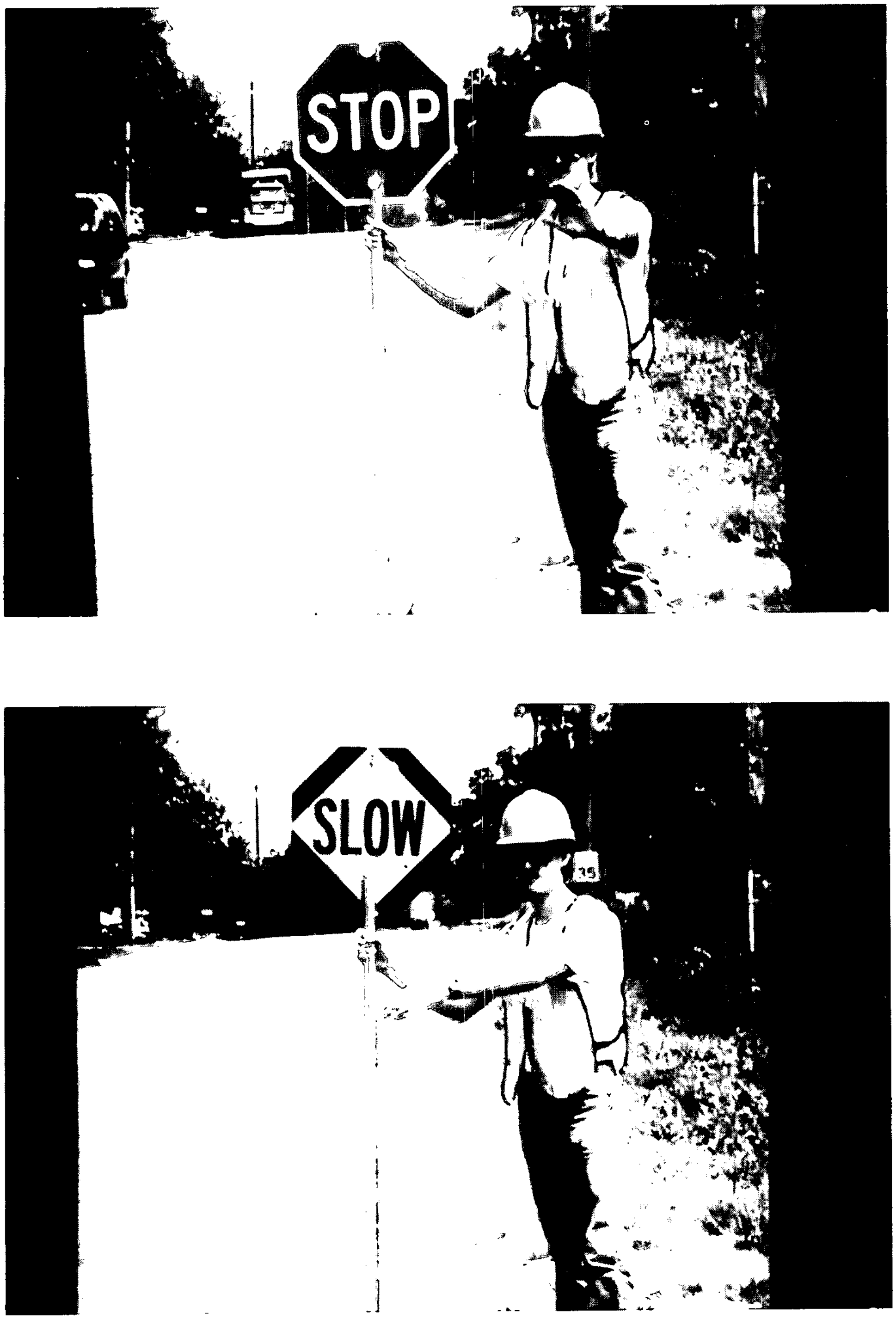


Figure 37. Flashing Stop/Slow Paddle

Design and Fabrication

Two prototypes of the FSSP were built and tested. The FSSP was designed to look as much like a standard flagger paddle as possible, so as to minimize the novelty effect associated with any new traffic control device, and also to maximize the extent to which the device conforms to existing MUTCD regulations.

The original concept for the FSSP included a "folding mask." This meant that rather than alternating between the "STOP" and "SLOW" messages by rotating the paddle, the messages were alternated by flipping a hinged mask on the paddle face. When folded back, the "STOP" face was seen; when opened, the mask obscures the "STOP", and "SLOW" (or some other desired message) is seen. The reverse of the paddle was intended to always show the "SLOW" message. The stated benefit of this design was to reduce confusion for drivers approaching from behind the flagger. The prototypes were built with the folding mask, but, the perpetual "SLOW" message was not placed on the back of the device.

The lights were powered by a rechargeable battery pack located in the staff. The location of the battery pack keeps the FSSP's center of gravity low, thus making the paddle easier to handle in windy conditions. A separate battery charger came with the device.

The FSSP employed high-intensity retroreflective sheeting on the STOP side, and fluorescent retroreflective sheeting on the SLOW side. For durability, light weight, and high strength, the paddle is constructed of anodized aluminum with stainless steel fasteners.

Closed Track Testing

The FSSP was evaluated during the closed-track tests performed on an abandoned airport runway in Georgetown, Delaware. The FSSP showed several positive results during these tests, though many problems with the device also emerged.

Information processing time increased with the use of the FSSP. However, the researchers concluded that this was most likely due to the novelty effect of the new devices, since all of the innovative flagging devices tested produced this increase.

Driver reactions to the FSSP were mixed. Because the device tested on the closed track employed red flashing lights, many drivers misinterpreted the FSSP as signaling a railroad crossing. The latest version of the device employs white lamps and probably will not cause this problem. In addition, test subjects' subjective ratings of device helpfulness and the extent to which test devices can make highways safer did not indicate that the FSSP would improve either of these areas.

Drivers required more recognition time for the standard flagger at night; however, this effect did not occur with the FSSP. Perhaps the most encouraging result, however, was that drivers exhibited the smoothest deceleration profiles with the FSSP compared to all other flagging devices tested.

Open Highway Testing

Open highway testing of the FSSP took place in New York, Texas, and Virginia. The overall results of these open highway tests have been very favorable, particularly in the workers' responses and willingness to use the FSSP. Results are separately discussed for New York, Texas, and Virginia.

New York

The FSSP and standard flagging procedures were observed at a stationary short-term maintenance site. Applied open highway testing techniques consisted of state highway personnel briefings and operational field studies.

The research staff briefed a New York Department of Transportation maintenance crew on the application of the FSSP both before and after the conduct of maintenance activity utilizing the studied flagging procedures. The briefing sessions raised two significant issues regarding operation of the FSSP as follows.

First, a two-sided message face was considered beneficial for the coordination of traffic flow in the opposite direction. Second, New York DOT maintenance personnel said that the battery recharging procedure should be modified so that the device directly plugged into an AC outlet for overnight recharging.

The field study design incorporated two objectives: (1) to determine driver responses to the FSSP in a manner which controlled for complicating influences on speed, and (2) to provide uniformity of results. Therefore, data were collected both in advance of and approaching the work zones. Two work zones were studied. Applied field observation procedures were: (1) manual speed data collection, and (2) videotape camera observations of traffic approaching the maintenance operations.

Speeds were manually timed for vehicles in advance of the work zone utilizing electronic stop watches with 0.01 second accuracy. Speed measurements were taken at two locations: (1) in advance of the work zone, prior to sight distance of the advance warning signs; and (2) approaching the work zone, as activity came into the driver's field of view. Table 12 depicts collected speed data results.

In addition to mean speeds, 15th and 85th percentile speeds were applied in order to distinguish between speed behaviors of the slowest and fastest speeds. As expected, approach speeds within driver sight of work zone activity were shown to be lower than approach speeds. This effect was evident with use of both the standard flagging procedure and FSSP. However, the observed speed reduction was less pronounced for the 85th percentile speed in the presence of the FSSP. This observation indicates that faster vehicles slowed to a lesser extent in the presence of the FSSP.

Observed speed variance was higher in the presence of the FSSP. This may be due in part to the fact that faster- approaching vehicles did not slow down as much slower-approaching vehicles. However, this effect is likely not due to the FSSP, as higher speeds were most frequently recorded for vehicles, not subjected to any traffic control measures.

The higher speed variance associated with the FSSP was explained by larger decelerations on the part of vehicles responding to the flashing lights. A review of the videotapes confirmed this effect.

Videotape surveillance revealed vehicle brake light responses and deceleration behavior. Each is separately summarized as follows.

Videotapes indicated that, in general, drivers braked immediately when of the flashing lights on the FSSP were activated. The only exceptions to immediate braking in response to the flashing lights were a few instances in which drivers had slowed in advance and were approaching the work zone at greatly reduced speeds.

Table 12. New York Speed Data Summary for the Flashing Stop/Slow Paddle

	Standard Flagger Paddle		Flashing Stop/Slow Paddle	
	Advance	Approach	Advance	Approach
15th Percentile	44.7	30.7	45.9	33.2
Mean	52.8	37.5	51.7	45.2
85th Percentile	53.9	44.3	59.8	57.3
Standard Deviation	7.32	6.60	6.49	10.54*

* Significant increase
Speeds are in mi/h. (1 mi/h = 0.45 m/s)

Videotaped vehicle deceleration behavior revealed a potential operational disadvantage associated with the FSSP. The drivers' immediate braking behavior in response to the flashing lights, produced some potential for rear-end collisions. This was of considerable concern. Subsequent field testing in Virginia refuted the fact that sudden deceleration responses to the FSSP were a problem.

Texas

Six new paddles, and one of the first prototypes incorporating the folding mask were taken to Texas maintenance yards for evaluation by workers. Two pairs of paddles were given to TX DOT employees for evaluation in actual maintenance work zones. Two members of the GME staff and one person from the paddle manufacturer met with TX DOT employees to discuss proper use of the paddles and the recommended evaluation plan that the state agency was to use.

The GME staff conducted a speed study while in Texas. The speed study took place with a crew from the Bastrop maintenance yard, about 35 mi (56.3 km) from Austin, Texas. The purpose was to compare the FSSP to the standard flagging device.

First, the devices were explained to the workers, who took them to a two-lane, farm-to-market highway for evaluation. The maintenance operation consisted of filling in eroded areas at the edge of pavement with an aggregate material. One lane was closed with a work vehicle and two flaggers. The flaggers, spaced about 660 ft (201.2 m) apart, were in radio communication with each other. They controlled traffic by alternating over the open lane. A dump truck with the tailgate painted white with orange diagonal stripes sloping down and outward from the center of the tailgate was parked adjacent to the flagger facing southbound traffic. Three advance warning signs (ROAD WORK AHEAD, ONE LANE ROAD AHEAD, and the flagger symbol sign) and the END ROAD WORK sign were placed in both the northbound and southbound directions. The entire work zone, which stretched between the two ROAD WORK AHEAD signs, was 2 mi (3.2 km) in length. The speed limit was 55 mi/h (24.6 m/s), the terrain was rolling, and traffic was light and free-flowing.

The studies were done from the period of 12:30 to 2:00 p.m. while the sun was behind the flagger. The faces of the flagger and FSSP aimed toward southbound drivers were shaded.

The first evaluation was to determine the distances at which the flagger could be identified as a person and as a flagger. At that time, the flagger was using a flag, Texas' preferred flagging device. The flagger could be identified as a person at 0.4 miles (2,100 ft [640.1 m]) and as a flagger at 0.2 miles (1,050 ft [320.0 m]). Another test showed that the lights of the FSSP could be seen from a distance of 0.4 miles (2,100 ft [640.1 m]). The evaluation was recorded using an 8 mm video camera mounted in the GME van.

The locations of speed data collection and distances of the signs and flagger were then recorded using the same video camera mounted in the van.

Three speed and braking distance (from the flagger) studies were conducted. The first was with the flagger using a bright 24-in (61.0-cm) flag. The second (speed only) study was done while the work crew was at lunch. No workers or work vehicles were present at this time, but the work zone signing remained in place. The third study was done using the FSSP. All studies were performed with southbound vehicles.

Using radar, speeds were collected at three locations in the work zone. The van containing the radar was parked off of the roadway approximately halfway between the flagger station (location 3) and the first speed location (location 1). That is, 1,100 ft (335.3 m) upstream of location 3 and about the same distance downstream of location 1. Location 1 was about 300 ft (91.4 m) downstream of the flagger symbol sign inside the work zone project limits and hidden from view of the flagger by a dip in the road. This was a distance of about 2,100 ft (640.1 m) from location 3.

The second speed location ranged from 500-900 ft (152.4-274.3 m) upstream of the flagger. This was the area where vehicles were braking in response to the flagger. A VHS video camera pointed in the direction of the flagger recorded vehicles as they drove past location 2 and location 3. The distance upstream of the flagger that a vehicle braked was identified by relating the vehicle's position to delineators and signs whose distances from the flagger were measured using a "walking wheel" distance measuring device.

Location 3 was at the flagger station. Vehicles were directed to either proceed past the flagger or to stop.

Table 13 presents the results of speed and braking distance studies. Three studies were conducted with the work zone signing in place: (1) control - no work being done and a flagger not present; (2) work being done and the flagger using a flag; (3) work being done and the flagger using the FSSP to control traffic.

The speed study results at location 1 showed that average speeds ranged from 56 to 58 mi/h (25.0 to 25.9 m/s) and the standard deviation ranged from 5 to 7 mi/h (2.2 to 3.1 m/s). These are considered equal because of the small sample sizes, which ranged from 21 to 25 vehicles. However, these sample sizes represent almost the entire population of vehicles driving through the work zone in the southbound direction.

At location 2, speeds decreased, probably because of three factors: a slight upgrade in the road, the presence of the study vehicle, and presence of the work activity. During the control study, drivers reduced their speed an average of 4 mi/h (1.8 m/s). In the other two studies, drivers reduced their average speed by 9 mi/h (4.0 m/s). The presence of the work activity caused drivers to reduce their speed an additional 5 mi/h (2.2 m/s). Standard deviations ranged from 5 to 6 mi/h (2.2 to 2.7 m/s). It is believed that the presence of the dump truck with the painted tailgate adjacent to the flagger station had an effect on traffic, since it was much larger, and more conspicuous, than the flagger.

Table 13. Texas Speed Data Summary for the Flashing Stop/Slow Paddle

	No Work/ No Flagger	Work/ Flag	Work/ Flashing Stop/Slow Paddle
Location 1[1]			
Sample Size	25	21	23
Mean	56	57	58
Standard Deviation	6	5	7
Location 2[2]			
Sample Size	29	23	23
Mean	52	48	49
Standard Deviation	5	6	6
Average Braking Distance from Flagger	n/a	753[4]	709[5]
Standard Deviation	n/a	124	125
Location 3[3]			
Sample Size	25	11	1
Mean	54	36	46
Standard Deviation	4	8	n/a
Vehicles Stopped (percent)	n/a	50 (11 of 22)	96 (25 of 26)

All speeds in mi/h (1 mi/h = 0.45 m/s)

1 Within Work Zone signing, 2100 ft (640.1 m) upstream of flagger
2 Location where vehicles braked in response to the flagger, 500-900 ft (152.4-274.3 m) upstream of flagger
3 At flagger station
4 Drivers exhibited random braking when the flagger was recognized
5 70 percent of the drivers, (16 of 23), braked when the lights of the Flashing Stop/Slow Paddle were activated

The flagger was directed to activate the lights on the FSSP at the location where the flagger wanted to alert oncoming drivers. Because of a dip in the road, vehicles were hidden from the flagger at this optimum location. Therefore, lights were activated at a location closer to the flagger. The distances from the flagger that drivers braked averaged to 753 ft (229.5 m) with the flag and 709 ft (216.1 m) with the FSSP. The standard deviations of the braking distances were 124 and 125 ft (37.8 and 38.1 m) , respectively. It is believed that the larger and brighter flag was more conspicuous than the FSSP and was the reason that drivers braked at an average distance of 44 ft (13.4 m) farther away from the flagger than with the FSSP. However, the FSSP, with the lights turned on, alerted oncoming drivers that there was activity in the road. When the lights of the FSSP were activated, 70 percent of the drivers responded by braking.

At location 3, during the flagging operation, the flagger directed traffic to either proceed past the station or stop to allow the other direction of traffic to clear the one-lane section. Without work on the road, traffic speeds averaged 54 mi/h (24.1 m/s), with a standard deviation of 4 mi/h (1.8 m/s), an average speed increase of 2 mi/h (0.9 m/s) over location 2. The speed increase is consistent with the rolling terrain on that highway. During the test with the flagger using a flag, 11 of 22 vehicles were directed to proceed. The average speed was 36 mi/h (16.1 m/s); a reduction of 12 mi/h (5.4 m/s) from location 2. During the test with the FSSP, all but one vehicle was stopped, so there were no meaningful statistics for this study.

After the speed studies were completed, the work crew was debriefed at their maintenance yard. Workers liked the FSSP and felt that it was a good device for alerting oncoming drivers. The two-sided paddle, similar to a standard flagger paddle with lights, was preferred over the one-sided FSSP incorporating the folding mask. The two-sided paddle enabled a flagger to see whether the other flagger is stopping or slowing traffic. This is especially important if there is no radio communication between flaggers.

Virginia

The FSSP and standard flagging procedures were observed at an intermittent maintenance site. Applied open highway testing techniques consisted of state highway personnel briefings and operational field studies.

The research staff briefed a Virginia Department of Transportation (VDOT) maintenance crew on application of the FSSP both before and after the conduct of maintenance activity utilizing the studied flagging procedures.

Results of the briefing sessions raised significant issues regarding design of the FSSP as follows. The standard paddle currently used in Virginia has a sign face which is 6 ft (1.8 m) above the pavement surface. This design is to afford visible to a number of following vehicles in an approaching queue. The sign face of the FSSP prototype was only 58 in (147.3 cm) above the pavement surface. The VDOT crew suggested that the prototype should be redesigned to be taller.

The applied field study procedure involved manual speed timing and videotape camera surveillance at advance and work zone approach locations, identical to the study performed in New York.

Table 14 depicts collected speed data results.

Two speed-related effects of the FSSP were apparent as follows.

First, overall vehicle population speeds (as evidenced by observed advance location speeds) were higher during times when the FSSP was in use. However, speeds approaching the work zone were lower in the presence of the FSSP. This finding attests to the ability of the FSSP to cause slowing of vehicles as the device and the work zone came into view.

Second, speed variance comparisons were made between advance and work zone approach locations. A higher speed variance was observed on the work zone approach with use of the standard paddle. A number of factors explain this observation. Due to the nature of the maintenance work being performed, the location of the FSSP frequently changed. Thus, the variety of approach roadway geometries, necessitated due to study of an intermittently moving operation, produced some variation in approach speeds. Due to the curvy geometry of the test roadway, the approach sight distance varied between work locations. As expected, higher speeds were observed on longer sight-distance approaches, and larger decelerations were observed on shorter sight-distance approaches.

A significant speed-related safety effect of the FSSP became evident as follows. Under the same roadway conditions which produced higher speed variance under conditions of standard paddle

Table 14. Virginia Speed Data Summary for the Flashing Stop/Slow Paddle

	Standard Flagger Paddle		Flashing Stop/Slow Paddle	
	Advance	Approach	Advance	Approach
15th Percentile	34.1	34.1	37.2	32.8
Mean	38.3	41.0	41.1*	38.4
85th Percentile	43.6	50.1	45.3	45.5
Standard Deviation	4.60	7.33**	4.66	5.35

* Significantly faster than Standard Flagger condition
** Significantly larger than the FSSP condition
Speeds are in mi/h. (1 mi/h = 0.45 m/s)

usage, a reduction in speed variance was observed with the FSSP. This observation indicates an improved safety condition by virtue of less speed variation of the approach to the work zone.

Videotape surveillance revealed vehicle brake light responses and deceleration behavior. Each is separately summarized as follows.

A review of the videotapes indicated that, in general, drivers immediately braked in response to the onset of the flashing lights on the FSSP. A few exceptions were observed whereby drivers slowed prior to FSSP activation and approached the work zone at reduced speeds.

Videotaped data revealed drivers' immediate braking behavior in response to the flashing lights, and occasional incidents of sudden deceleration were observed. However, the observed behaviors at this site gave no indication that rear-end collision could occur. No instances of locked brakes on following vehicles were observed.

Previous testing of the FSSP indicated that its use *increased* overall traffic speed variance. This was due to drivers' sudden slowing when the flashing lights were activated.

However, the Virginia field test addressed the problems of topography and two-lane, one-way work zones with short sight-distance approaches to flaggers. Drivers tend to disregard advance work zone signing. The flagger may be the only warning device to which the driver responds. In such a case, short approach sight distances result in sudden slowing, and increase the likelihood of an intrusion into the work zone.

The Virginia results, demonstrating a speed variance *decrease* with use of the FSSP, pointed out the utility of the device to induce smooth approach slowing behavior at short sight-distance work area approaches. The increased attention-gaining capability of the FSSP enabled the flagger to slow traffic when the sight distance was reduced. Smoother slowing can serve two purposes: (1) to reduce the likelihood of rear-end accidents due to sudden slowing, and (2) to reduce the likelihood of high-speed vehicles encroaching the work zone. These are significant safety benefits of the FSSP.

Conclusions and Recommendations

The attention-gaining capability of the Flashing Stop/Slow Paddle provides the flagger with the ability to choose the point at which to slow oncoming traffic. The effectiveness of the Flashing Stop/Slow Paddle to induce slowing of approaching vehicles at an advance location designated by the flagger has been demonstrated in field studies undertaken in New York, Virginia, and Texas. This feature is particularly advantageous under conditions of limited sight distance, where maintenance activity is more likely to surprise approaching motorists. The demonstrated safety benefit of this feature is to reduce the likelihood of rear-end accidents due to sudden slowing and to reduce the likelihood of high-speed vehicles entering the work zone.

The device is easy to use and maintain, and, though more expensive than the standard paddle is still a relatively inexpensive device. Price per unit should drop when it is produced in mass quantities.

The next stage of the evaluation of this device should consist of purchase and use by state and local highway agencies. If formal speed studies are performed, they should test the FSSP against the standard Stop/Slow paddle. The agencies that tested the prototype devices in the fields have had no problems with it, and most have expressed an interest in obtaining more of the devices. Figure 38 is an example of an evaluation sheet used by Texas DOT personnel.

In addition, the Federal Highway Administration (FHWA) is familiar with this device, and formal permission to experiment with this device was obtained from FHWA during the performance of this project. It should be a relatively simple matter for other states to obtain permission to experiment with the FSSP, since the results from the first set of experimentation were so promising.

Strategic Highway Research Program Contract H-108
Field Evaluation of Maintenance Work Zone Safety Devices

Device that was evaluated Rechargeable Flashing Stop/Slow Paddle

Person preparing report Phil Cooper

District where evaluation occurred District 15, San Antonio

Telephone number (512) 615-5867

Situation where device was used (e.g., road type, type of work performed, traffic volume, number of workers trying the device, etc.)

Blading premix and repairing base failures on two lane, two way roadway where only one lane was open to traffic. Traffic volume varied between 500 and 1500 VPD. One flagger was used on each end of work area.

What were the benefits derived from using the device?

Approaching vehicles would see the flashing lights and would start slowing down before reaching the flagger.

What problems or concerns were observed (e.g., operational problems with the device or traffic/safety problems occurring because of the device)?

No problems.

Recommendations for improving the device:

Make the signs reflective and have a dimmer switch on the lights for night operation.

Additional comments:

Employees that used the device said that this is the best yet and want some for immediate use.

Figure 38. Texas DOT Flashing Stop/Slow Paddle Evaluation Sheet

Portable Sign and Stand

The Portable Sign And Stand (PSS) is shown in figure 39.

Background

On two-lane roads without shoulders or with narrow shoulders, it is difficult to place temporary signs without encroaching on the traveled way. The PSS can be staked onto cut-and-fill slopes.

Device Description

The PSS is a portable, adjustable sign stand for 48-in (121.9-cm) neoprene signs. The sign is attached to a 1-in by 1-in by 4-ft (2.5-cm by 2.5-cm by 1.2-m) vertical tube. Two fiberglass crosspieces hold the sign rigid. The 4-ft (1.2-m) vertical tube fits into a tube on the stand. The stand assembly, when fully erect, stands 5 ft (1.5 m) high; with the sign attached, the entire unit is 8 ft (2.4 m) tall. The stand is adjustable so that it can be placed on side slopes of varying steepness. The sign and the stand fold to a compact size for transport and storage.

Design and Fabrication

The PSS has been used for several years in the Montana Department of Highways. The unit furnished to the project was built by a workshop in Butte, Montana.

Operational Testing

Since the PSS had been used successfully in Montana, no further operational tests were done in this project. Results of any wind stability tests conducted in Montana are unknown.

Crashworthiness Testing

ENSCO Test 2036-CW6-91

This test was conducted at 60 mi/h (26.8 m/s), with the impact centered on the vehicle. Photographs taken before test 2036-CW6-91 are shown in figure 40.

Impact Description

Review of the high speed films and fifth wheel data indicated that the test vehicle impacted the device at 62 mi/h (27.7 m/s) and 0 degrees. The review also indicated that the centerline of the vehicle was aligned with the centerline of the device

At impact, the vehicle's front wheels rode up the outstretched sign support legs, causing the legs of the stand to shear off. The legs passed to either side of the vehicle and landed approximately 30 ft (9.1 m) and 70 ft (21.3 m) from point of impact. The sign panel came over the hood of the vehicle and struck the windshield, damaging the windshield. There were two small gouges in the glass but no punctures in the windshield. The sign panel slapped down on the hood area and

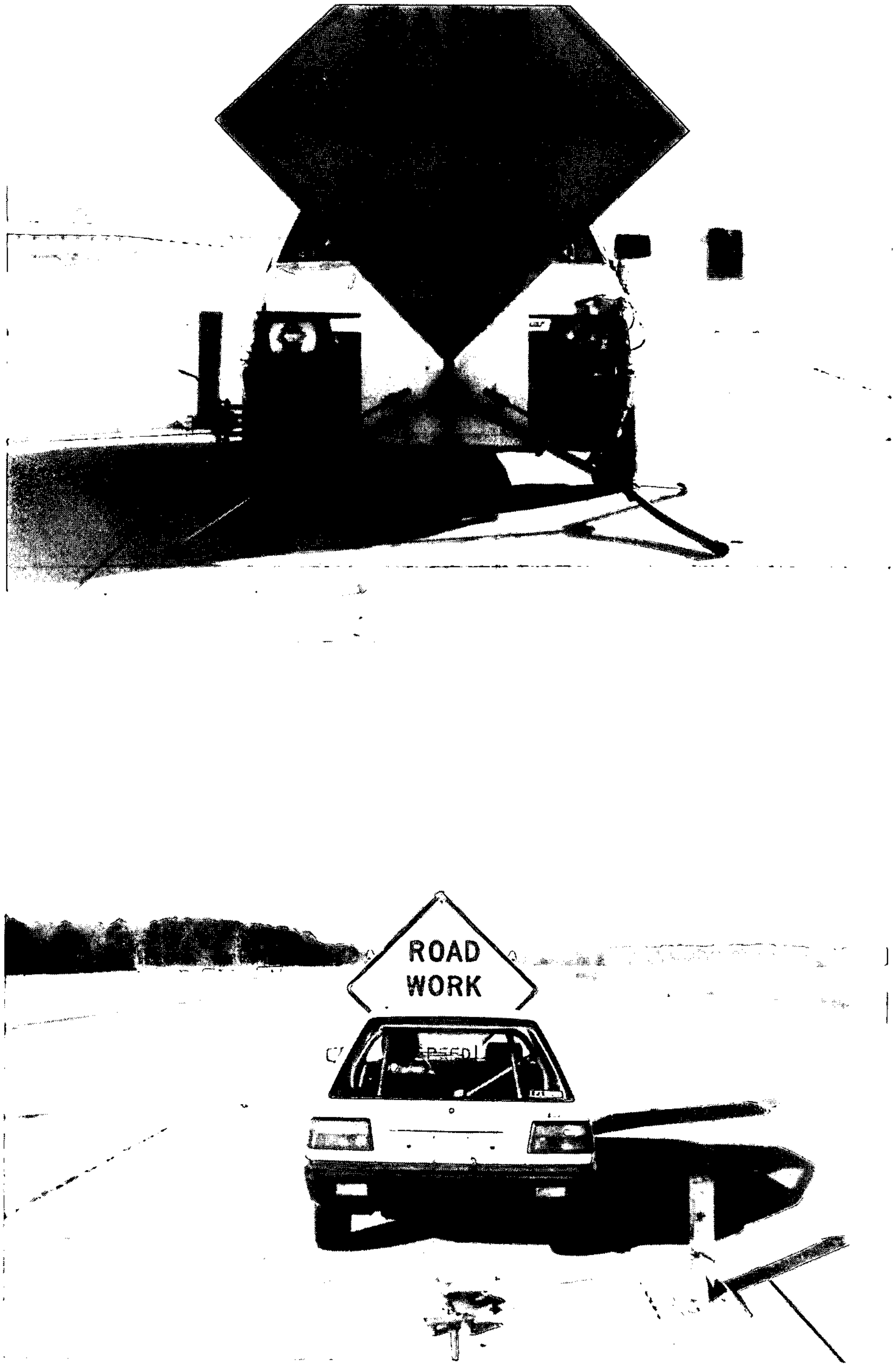


Figure 39. Portable Sign and Stand

Figure 40. Portable Sign and Stand Before Test, Test 2036-CW6-91

then was thrown over the vehicle, landing in the roadway 90 ft (27.4 m) from the point of impact.

The control wire for the onboard brakes was severed during the impact sequence, which caused the vehicle to travel approximately 2000 ft (609.6 m) before coming to a halt at the edge of the roadway. The impact with the device did not cause the vehicle to steer out of control. The car slowly drifted off to the shoulder of the roadway.

The test conditions and results are summarized in table 15.

Vehicle Damage

Damage to the vehicle was concentrated in the windshield area. The top of the sign support gouged two marks into the windshield, but there was no penetration. There were minor dents in the hood area. The front bumper showed indications of the impact with the vertical sign support.

Device Damage

Damage to the PSS was extensive. The two legs were sheared off at the base and the main center hub of the stand was bent. The sign panel was still in good condition with minor holes from sliding on the road surface. This damage could be repaired by welding the legs and patching the sign.

Photographs of the device and test vehicle after test 2036-CW6-91 are shown in figure 41.

Test Evaluation

This test was evaluated using criteria D and E from NCHRP 230 and the work zone hazard criterion. The following is an item-by-item evaluation using these criteria.

NCHRP 230 Criterion D: Detached elements, fragments or other debris from the test article shall not penetrate or show potential for penetrating the passenger compartment or present undue hazard to other traffic.

This device marginally met criterion D. Although the windshield was damaged during the test, there was little potential for passenger compartment penetration by the top of the sign support. This criterion is evaluated as marginal, in the worst case.

NCHRP 230 Criterion E: The vehicle shall remain upright during and after collision although moderate roll, pitching and yawing are acceptable. Integrity of the passenger compartment must be maintained with essentially no deformation or intrusion.

This device met criterion E.

Work Zone Hazard Criterion: The device must not present a hazard to workers in the work zone following an impact by an errant vehicle.

This device met the Work Zone Hazard Criterion.

Table 15. Crashworthiness Test Summary for the Portable Sign and Stand

Parameter	Value
Test Number:	2036-CW6-91
Date:	February 5, 1991
Test Vehicle:	1985 Dodge Colt
Test Device:	Portable Sign and Stand
Vehicle Weight:	
Planned, Inertial:	1800 ± 50 lb
Actual, Inertial:	1813 lb
Planned, Gross:	1950 ± 50 lb
Actual, Gross:	1978 lb
Number of Occupants:	One
Occupant Model:	Part 572 Anthropomorphic 50th percentile male
Occupant Location:	Driver Seat, Restrained
Impact Conditions:	
Planned Speed:	60 mi/h
Actual Speed:	62 mi/h
Planned Angle:	0°
Actual Angle:	0°
Planned Location:	Centered
Actual Location:	Centered
Test Results Conclusion:	This device successfully met evaluation criterion E, the work zone hazard criterion and marginally met criterion D..

1 mi/h = 0.45 m/s, 1 lb = 0.45 kg

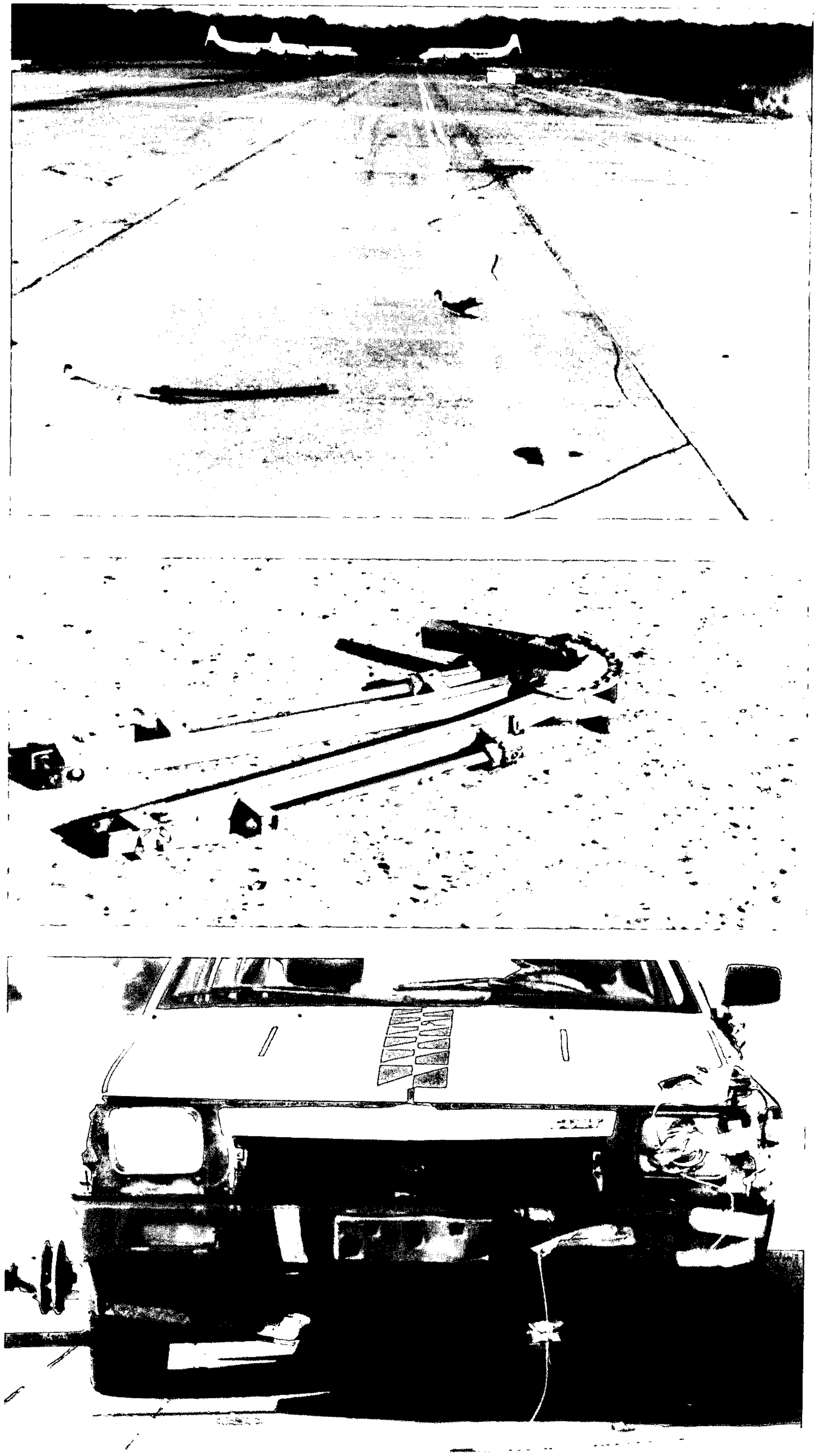


Figure 41. Portable Sign and Stand After Test, Test 2036-CW6-91

This device successfully met evaluation criterion E, the work zone hazard criterion and marginally met criterion D.

Open Highway Testing

The PSS was open highway tested in Texas. An evaluation form was completed by a maintenance unit in Dallas. The maintenance people said it was a good device. The only problems noted were in securing the stakes when the device was folded up and unlocking the feet of the stand.

Conclusions and Recommendations

This device is well suited for placing signs on sideslopes and has been used extensively in Montana. It should be useful to most maintenance units working on roads with narrow shoulders.

Remotely Driven Vehicle

The Remotely Driven Vehicle (RDV) is shown in figure 42.

Background

The RDV was originally conceived as an Automated Mobile Warning Vehicle. The high cost of acquiring the necessary technology and design for such a device, as well as the sophisticated systems it required, prohibited the development of the Automated Mobile Warning Vehicle. Late in the project's first year, a member of the SHRP's executive committee from the state of Alabama, suggested that a remote control concept be developed for use in order to allow a work truck to act as shadow vehicle. A fatal accident in Alabama prompted this suggestion from the member. A brief study confirmed the feasibility of development and Minnesota DOT donated a maintenance vehicle for retrofit with the control systems and actuators.

Device Description

The RDV is an Ford L8000 dump truck that was modified for radio controlled operation. The RDV eliminates the need to have a driver in the shadow vehicle during highway maintenance operations. This prevents drivers from being exposed to rear end collisions while driving shadow vehicles. The RDV system is completely fault tolerant with multiple levels of safety systems.

During a highway maintenance operation, such as pothole repair, the shadow vehicle would be placed approximately 300 ft (91.4 m) behind the work crew. From this position the RDV operator could move the truck forward as required.

Design and Fabrication

The RDV system consists of a set of actuators, digital control circuits, a radio link and sensors to provide for the remote control of trucks that are being used as shadow vehicles. The system can be installed without extensive modifications to most shadow vehicles. A basic premise of the system is durability and safety. The RDV system has multiple levels of safety systems in order to greatly reduce the possibility of accidents due to equipment failure.

The RDV system uses an electronic enclosure mounted inside the cab of the truck. This enclosure contains the system safety circuits, and controllers for the actuators and any power supplies that might be necessary. The electronic equipment inside the enclosure is modular in order to facilitate maintenance and enhance reliability.

The radio control system implements the following vehicle functions from the hand-held transmitter:

- steering - full steering from lock to lock.
- brakes - proportional brake control.
- throttle - control vehicle throttle throughout its whole range.
- transmission - three position switch for neutral, park and drive.
- horn
- headlights
- parking brake
- flashers

Figure 42. Remotely Driven Vehicle

- emergency stop
- turn signals

Functional Requirements

The following requirements are built into the RDV system:

- The RDV equipment does not impair the driver controls when the truck is in a normal mode.

- The RDV system is protected against aberrant behavior such as power failures and air pressure loss. The braking system stops the truck automatically in case there is an air pressure loss or electrical power failure.

- The RDV system has an all weather capability from 20°F (-7°C) to 110°F (43°C). All external components are corrosion protected from road salt.

- The system electronics are modularized to allow for the quick replacement of a defective subsystem.

- The radio transceiver system has a range of 1000 ft (304.8 m). It uses rechargeable batteries.

- The RDV system has proximity sensors that detects objects that are 15 ft (4.6 m) in front of the truck.

Pneumatic System

All the actuators are pneumatically driven with position feedback for closed loop control. These actuators use the truck's air supply system which is modified to deliver a minimum of 100 lb/in^2. The RDV system is integrated into the truck's air brake system. In case of emergency conditions or equipment failure, the spring brakes on the truck activate automatically. An electrical failure or system pressure loss will also activate the spring brakes, making the RDV system inherently safe.

Safety Equipment

The truck's oil pressure, coolant temperature, and engine run status are monitored in order to preclude any system damage. The emergency brake system is designed such that regardless of either an air pressure loss or a electrical power failure, the emergency brake system engages.

The safety system is multi-layered. Primary protection safety is provided by the emergency stop hardware circuit. If this circuit finds any error conditions with the truck, the emergency stop system is engaged. If there is a communication problem with the radio equipment, the truck will stop. Sensors on the front of the truck can stop the truck if they detect some obstruction. Large push-button switches on both sides of the truck can be pressed to stop the truck. These switches work in conjunction with the emergency stop button on the transmitter. If the operator trips and falls, a tilt-switch inside the transmitter will detect this and the truck will stop. The last level of protection is built into the mechanical equipment. If there is a electrical power failure or an air pressure loss in the system, the air control valves will default to a position that will engage the spring brakes.

Overall, the system is designed to preclude any accidents due to equipment failure.

Reliability

The RDV is designed for enhanced ruggedness and reliability. All actuators are of premium industrial quality and tolerant of salt spray environments. Second generation systems will have the following enhancements: All connectors will have a 1000 hr. salt spray rating. The enclosures will be gasketed and will be constructed out of fiberglass, aluminum, or stainless steel. Wire runs between components will be minimized. Electronics will be mounted on circuit cards for added strength and rigidity. In case of circuit failure, the primary circuit card can be removed and replaced.

Transmitter/Receiver

The transmitter/receiver has extremely sophisticated anti-interference protocols. The transmitter is powered by NiCad batteries. A battery charger in the cab of the truck continuously charge the spare battery in case it is required. Currently, the transmitter has two joysticks for controlling throttle, brakes, and steering. The second generation transmitter will have a single joystick for controlling throttle, brakes and steering. The transmitter will be handheld, but will have a shoulder harness and chest strap for securing the unit to the operator.

System Usage

The RDV is located about 200 ft (61.0 m) upstream from the work zone. As the work crew moves along the work zone, the RDV system is moved forward. Typical operation scenarios are pothole filling, crack sealing and trash pickup. The current RDV has a maximum speed of 5 mi/h (2.2 m/s). This is so that the operator can move with the RDV, at normal walking speeds.

Operational Testing and Lab Testing

Operational testing of the RDV took place at ENSCO's Delaware test facility. The vehicle's entire regime of operating modes was tested. This included all vehicle operation modes, the range of transmission, emergency stop modes, safety stop sensor operation, safety equipment checkout and a general reliability checkout. The testing on the RDV was conducted over a period of approximately three weeks.

The next stage of the testing was to demonstrate the vehicle to Minnesota DOT personnel, to train these personnel with the RDV, and to deliver the completed item. When the truck was returned to Minnesota, project personnel traveled to Minnesota to conduct a further demonstration for the workers. This demonstration was attended by all levels of personnel in the Minnesota DOT maintenance division.

Open Highway Testing

Open highway testing was completed by Minnesota DOT personnel. ENSCO performed minor repair work on the vehicle since delivery to eliminate problems and malfunctions that have occurred as open highway work with the truck has been conducted. Following a flurry of work early on, the truck has had few problems with operation or reliability.

Conclusions and Recommendations

Highway workers like the RDV. Further work could eliminate the complexity and lower the costs of the system. It is hoped that the RDV can become a modularized kit available to a broad base of users at a reasonable cost.

Diverging Lights

The Diverging Lights (DL) is shown in figure 43.

Device Description

The DL consists of a horizontal array of six lamps to be mounted on a rear panel of a slow-moving maintenance vehicle. The lamps increase in size as they go from the center to the outer edge of the mounting panel. Figure 44 shows the four sequential phases of the DL. The four phases are:

1. two center lamps on
2. two lamps next to center on
3. two outside lamps on
4. all lamps off

The DL is designed to create the illusion that the driver is closing on the maintenance vehicle at a rate faster than the actual closing rate. It is hoped that drivers would respond earlier than usual in order to prevent an accident with a maintenance vehicle.

Design and Fabrication

One DL was built. The three sizes of lights were 4 in, 6 in and 12 in (10.2 cm, 15.2 cm and 30.5 cm). The lights were attached to a constructed aluminum frame with a plywood back member. A breadboard circuit card controller was designed and fabricated.

Operational Testing and Lab Testing

The control circuits for the timing of the flash sequence contained potentiometers to enable easy change of the sequence. The device was taken to Delaware for checkout and sequence adjustment. Initially, it had been planned to conduct a detailed human factors study of the flash sequence in a lab with a computer. However, after viewing the device and realizing that the device was conceived to simulate a maintenance vehicle's four-way flashers, it was decided to eliminate the study and determine the sequence through the use of good engineering insight.

Closed Track Testing

The DL was installed on a dump truck. The control test situation was that the test subject had previously encountered the same truck at this location traveling at crawl speeds without displaying the Diverging Lights. The "control" truck exhibited standard lighting (e.g., four way flashers). Vehicle measures were speed differences (i.e., test subject vehicle speed minus truck speed) and brake light activations (i.e., distance behind truck at which activation occurred). Driver-intrusive measures consisted of driver recognition, interpretation, and subjective preference ratings (e.g., helpfulness, safety value). The evaluation procedure involved comparison of measures with the standard truck without the DL.

Based upon the observations during the closed track testing, the DL produced improved driver recognition times and smoother decelerations compared to the use of standard four-way flashers.

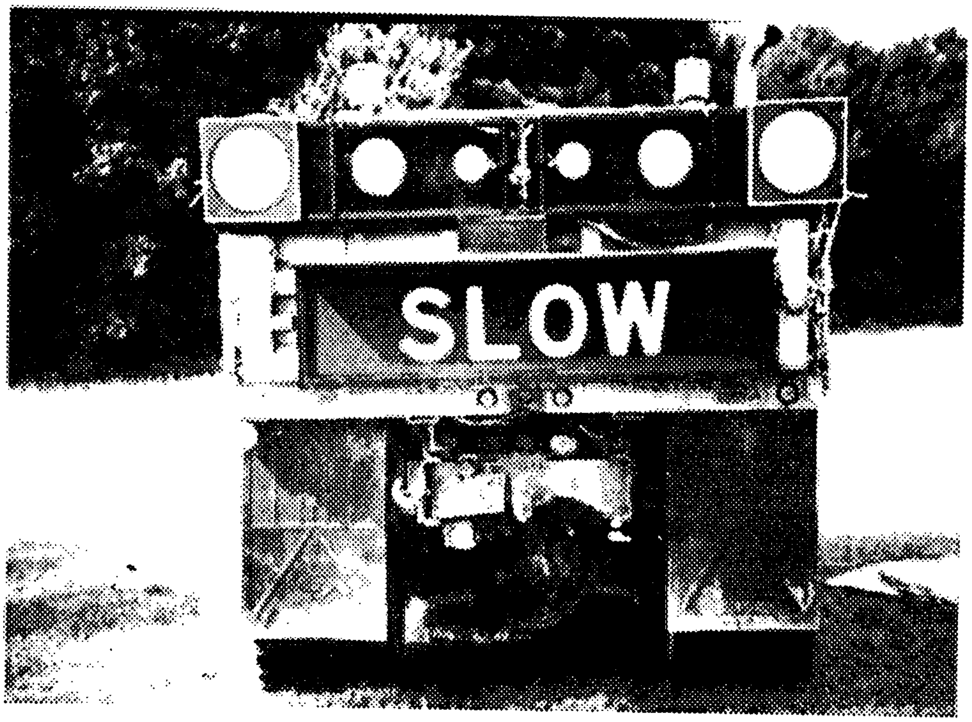


Figure 43. Diverging Lights

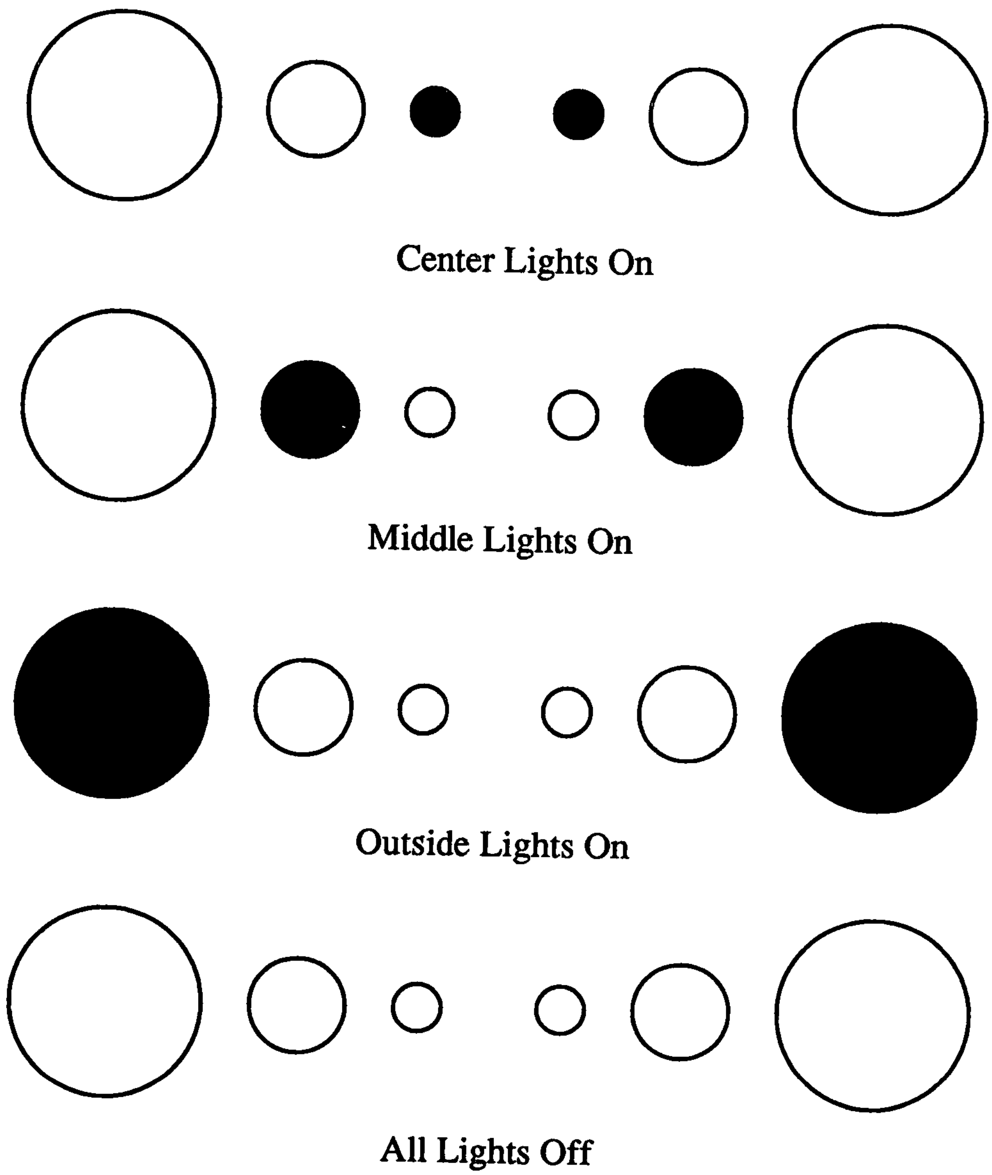


Figure 44. Sequential Phases of the Diverging Lights

Problems Encountered

Lack of brightness was a problem not solved. A manufacturer of lighting bar equipment in Connecticut was contacted to investigate a possible cooperative effort to increase the brightness of the DL. These devices were significantly brighter than the lights used in the DL, and could be seen for great distances, even in daytime operations.

An earlier study, however, had shown that as a light get brighter, the perception of it size and shape diminishes. For the DL, perception of the increasing size of the lights was critical to the desired response. If the brightness of the array was increased, the perception and recognition and thus, the effectiveness of the device might decrease.

Conclusions and Recommendations

The tradeoff between intensity and recognition must be discovered. Further research is warranted as to whether the DL is a viable safety device.

Flagger Gate

The initial design of the Flagger Gate is shown in figure 45.

Background

In most agencies, flaggers are instructed to move to the centerline of the road after stopping one or two vehicles. In this position they are vulnerable to vehicles violating their signal and are further from the shoulder and safety. They are also closer to opposing traffic.

The Flagger Gate keeps the flagger on the shoulder of the road while still placing the Stop sign where it is easily seen by most drivers.

Device Description

The Flagger Gate is a mechanically pivoting arm designed to be raised and lowered by flaggers to stop and slow traffic in work zones. It replaces the standard Stop/Slow paddle and reduces flagger exposure by keeping the flagger on the shoulder of the roadway. A series of gears automatically turns the Stop sign to traffic when the gate is lowered and turns the Slow sign to traffic when the gate is raised. This mechanism is patented by Graham-Migletz Enterprises, Inc. of Independence, MO.

Design and Fabrication

Two prototypes of the Flagger Gate were fabricated. The first, used in the closed track traffic control tests, is shown in figure 45. The second version was built because the base of first prototype cracked the windshield of the test vehicle in crashworthiness tests. The arm of the gate was lowered 6 in (15.2 cm).

A prototype was also designed to mount the Flagger Gate in the 4-ft by 8-ft (1.2-m by 2.4-m) bed of a pickup truck. This concept includes a motor to raise and lower the arm and controls to operate the arm from the cab of the pickup. The concept also calls for the gate to rotate over the pickup cab for traveling to the work site. The pickup truck would be equipped with a pickup truck attenuator.

Operational Testing

The Flagger Gate was moved and operated during closed track tests. Minor adjustments were made to ensure that each sign rotated a full 90° to the direction of traffic. The gate was moved a short distance by towing with a utility cart. After several weeks of use in operational testing, no maintenance problems were experienced in the operation of the Flagger Gate.

Closed Track Testing

The Flagger Gate was compared to the standard Stop/Slow paddle. Driver response to the Flagger Gate showed an increase in information processing time. This was probably due to the novelty effect of the Flagger Gate. The difference in the response was only 1.4 seconds. This additional time is not viewed as consequential since driver attention to the driving task was not diverted during this time.

Figure 45. Flagger Gate

Subject drivers did have trouble interpreting the Flagger Gate. Only three of 96 subjects associated the Flagger Gate with road work; others noted close resemblance to a railroad protection crossing gate. However, subjective ratings by drivers showed that the Flagger Gate was judged to be more helpful and more conducive to increased highway safety than standard devices. The Flagger Gate easier to recognize at night than the standard flagger device.

One benefit of the Flagger Gate was that drivers who recognized the device earlier exhibited fewer brake light applications on their approach to the device. This indicated less driver uncertainty in response to the device.

Crashworthiness Testing

ENSCO Test 2036-CW4-91 (Flagger Gate Arm Test)

Two tests were conducted on the Flagger Gate. This test evaluated the performance of the gate with the test vehicle impacting the closed gate arm at 45 mi/h (20.1 m/s), perpendicular to the gate arm. The second test is reported in the next subsection.

Photographs of the vehicle and the device before test 2036-CW4-91 are shown in figure 46.

Impact Description

Review of the high speed films and fifth wheel data indicated that the test vehicle impacted the device at 46 mi/h (20.6 m/s) and 0 degrees. The review also indicated that the outside left edge (driver's side) of the vehicle was in line with the tip of the Flagger Gate arm, as desired.

Upon impact, the arm of the Flagger Gate first struck the windshield approximately 6 to 8 in (15.2 to 20.3 cm) above the base of the windshield. This caused the windshield to shatter completely across and portions of the gate hardware punctured through the glass surface in several places. A large amount of glass was scattered throughout the entire vehicle. There was also minor denting of both A-pillars of the vehicle.

After impacting the windshield, the gate began to pivot upon one of the four wheels and the arm deflected up the windshield and over the roof. The gate rotated 90 degrees and rolled several feet down the road.

The brakes were applied to the vehicle 60 ft (18.3 m) past the point of impact and the vehicle came to rest 90 ft (27.4 m) downstream.

The test conditions and results are summarized in table 16.

Vehicle Damage

Damage to the vehicle was limited to the windshield area. This damage consisted of a shattered windshield and two small dents in the A-pillars. Glass was scattered throughout the interior of the vehicle.

Figure 46. Flagger Gate Before Test, Test 2036-CW4-91

Table 16. Crashworthiness Test Summary for the Flagger Gate Arm

Parameter	Value
Test Number:	2036-CW4-91
Date:	February 4, 1991
Test Vehicle:	1985 Dodge Colt
Test Device:	Flagger Gate (Arm)
Vehicle Weight:	
Planned, Inertial:	1800 ± 50 lb
Actual, Inertial:	1813 lb
Planned, Gross:	1950 ± 50 lb
Actual, Gross:	1978 lb
Number of Occupants:	One
Occupant Model:	Part 572 Anthropomorphic 50th percentile male
Occupant Location:	Driver Seat, Restrained
Impact Conditions:	
Planned Speed:	45 mi/h
Actual Speed:	46 mi/h
Planned Angle:	0°
Actual Angle:	0°
Planned Location:	Driver side edge of vehicle aligned with end of arm
Actual Location:	Driver side edge of vehicle aligned with end of arm
Test Results Conclusion:	This device **failed** the test due to the breaking of the windshield, the potential for penetration of the passenger compartment and the hazard to the operator of the gate.

1 mi/h = 0.45 m/s, 1 lb = 0.45 kg

Device Damage

There was a fair amount of damage to the Flagger Gate. However, this damage was repairable. Damage consisted of the bending of the safety latch and the breaking of the fiberglass arm. The safety latch allows the gate arm to be locked down or up in normal operation. With the latch bent, the gate would not raise after the test. The fiberglass arm was broken in several places across the impact zone.

Photographs of the Flagger Gate and the vehicle after test 2036-CW4-91 are shown in figure 47.

Test Evaluation

This test was evaluated using criteria D and E from NCHRP 230 and the work zone hazard criterion. The following is an item-by-item evaluation using these criteria.

NCHRP 230 Criterion D:	Detached elements, fragments or other debris from the test article shall not penetrate or show potential for penetrating the passenger compartment or present undue hazard to other traffic.

This device did **not** meet criterion D. The arm of the Flagger Gate impacted and broke the windshield, which shoed the potential for the penetration of the passenger compartment.

NCHRP 230 Criterion E:	The vehicle shall remain upright during and after collision although moderate roll, pitching and yawing are acceptable. Integrity of the passenger compartment must be maintained with essentially no deformation or intrusion.

This device did **not** meet criterion E. Integrity of the passenger compartment was not maintained. Glass from the broken windshield was scattered throughout the passenger compartment.

Work Zone Hazard Criterion:	The device must not present a hazard to workers in the work zone following an impact by an errant vehicle.

This device did **not** meet the work zone hazard criterion. The arm of the Flagger Gate rotated 90 degrees and the Flagger Gate rolled from the impact position. The worker operating the Flagger Gate could have been harmed by the movements of the Flagger Gate.

This device **failed** the test due to the breaking of the windshield, the potential for penetration of the passenger compartment and the hazard to the operator of the gate.

ENSCO Test 2036-CW7-91 (Flagger Gate Base Test)

This was the second test conducted on the Flagger Gate. This test evaluated the performance of the gate with the test vehicle impacting the base of the Flagger Gate at 45 mi/h (20.1 m/s), perpendicular to the gate arm.

Photographs of the vehicle and device before test 2036-CW7-91 are shown in figure 48.

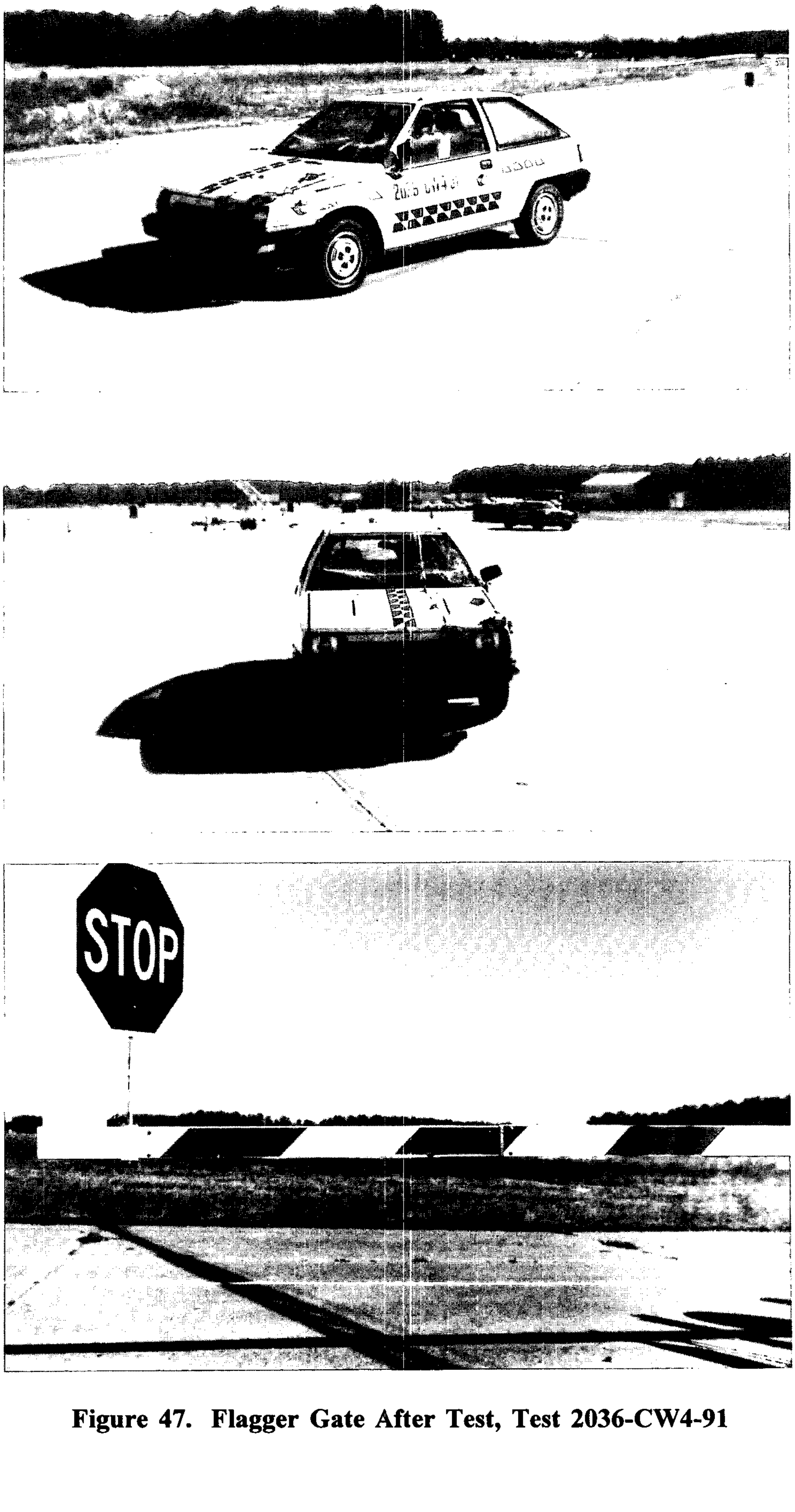
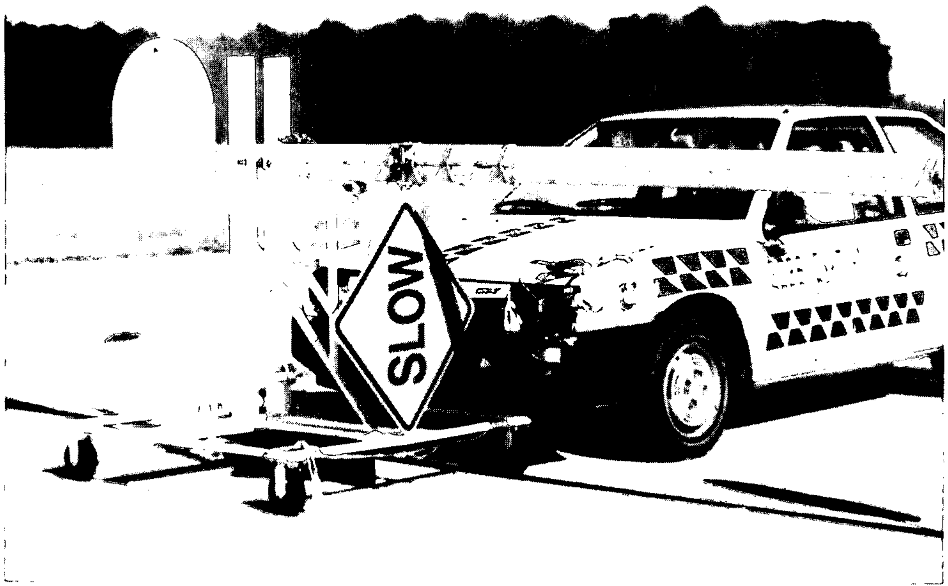


Figure 47. Flagger Gate After Test, Test 2036-CW4-91



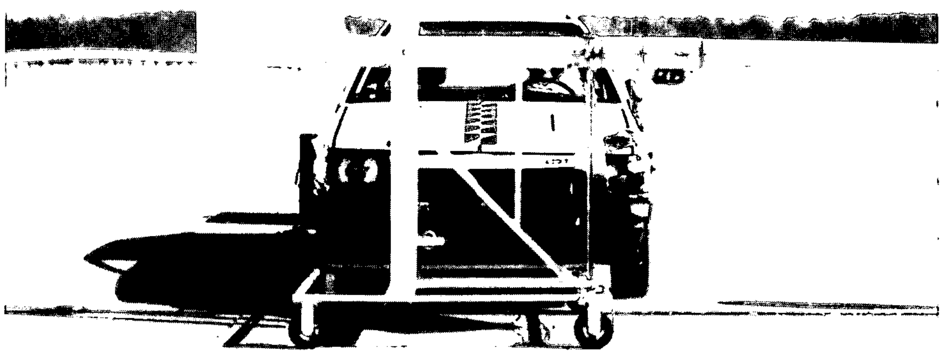


Figure 48. Flagger Gate Before Test, Test 2036-CW7-91

Impact Description

Review of the high speed films and fifth wheel data indicated that the test vehicle impacted the device at 45 mi/h (20.1 m/s). The review also indicated that the centerline of the vehicle was aligned with the centerline of the base of the Flagger Gate.

Upon impact, the device rotated nearly 80 degrees over the hood of the vehicle. This allowed the counterweight to strike the windshield and shatter the glass directly in front of the passenger side of the vehicle. The Flagger Gate then rotated down. The base of the frame around the perimeter of the gate then went under the front of the vehicle and became wedged beneath the vehicle. The arm bent backward on impact and eventually became wedged in the left rear wheel well. The onboard brakes were applied and both the vehicle and the Flagger Gate came to a stop approximately 180 ft (54.9 m) downstream from the initial point of impact.

The test conditions and results are summarized in table 17.

Vehicle Damage

Damage to the vehicle was moderate for this particular test. The front windshield shattered, a substantial dent was formed in the right A-pillar, and there was extensive damage to the hood, bumper, grill, as well as a hole through the oil pan beneath the vehicle. There were additional scuff marks along the left side of the vehicle where the gate arm swung across and became wedged inside the left rear wheel well.

Device Damage

The Flagger Gate was destroyed during this impact with the vehicle. The main frame of the base was bent and welds were broken. Two of the wheels for the gate were also bent. The gears and linkage that control the gate arm and the two signs were bent and misaligned. The Slow sign was destroyed as was the shaft to the Stop sign.

Photographs of the vehicle and device after test 2036-CW7-91 are shown in figure 49.

Test Evaluation

This test was evaluated using criteria D and E from NCHRP 230 and the work zone hazard criterion. The following is an item by item evaluation using these criteria.

NCHRP 230 Criterion D:	Detached elements, fragments or other debris from the test article shall not penetrate or show potential for penetrating the passenger compartment or present undue hazard to other traffic.

This device did **not** meet criterion D. The base and arm of the Flagger Gate impacted the windshield, breaking the windshield, showing potential for the penetration of the passenger compartment.

NCHRP 230 Criterion E:	The vehicle shall remain upright during and after collision although moderate roll, pitching and yawing are acceptable. Integrity of the passenger compartment must be maintained with essentially no deformation or intrusion.

Table 17. Crashworthiness Test Summary for the Flagger Gate Base

Parameter	Value
Test Number:	2036-CW7-91
Date:	February 12, 1991
Test Vehicle:	1985 Dodge Colt
Test Device:	Flagger Gate (Base)
Vehicle Weight:	
Planned, Inertial:	1800 ± 50 lb
Actual, Inertial:	1813 lb
Planned, Gross:	1950 ± 50 lb
Actual, Gross:	1978 lb
Number of Occupants:	One
Occupant Model:	Part 572 Anthropomorphic 50th percentile male
Occupant Location:	Driver Seat, Restrained
Impact Conditions:	
Planned Speed:	45 mi/h
Actual Speed:	45 mi/h
Planned Angle:	0°
Actual Angle:	0°
Planned Location:	Centered on Base
Actual Location:	Centered on Base
Test Results Conclusion:	This device **failed** the test due to the breaking of the windshield, the potential for penetration of the passenger compartment and the hazard to the operator of the gate..

1 mi/h = 0.45 m/s, 1 lb = 0.45 kg

Figure 49. Flagger Gate After Test, Test 2036-CW7-91

This device did **not** meet criterion E. Integrity of the passenger compartment was not maintained.

Glass from the broken windshield was scattered throughout the passenger compartment.

Work Zone Hazard Criterion:	The device must not present a hazard to workers in the work zone following an impact by an errant vehicle.

This device did **not** meet the work zone hazard criterion. The worker operating the Flagger Gate could have been harmed by the movements of the Flagger Gate.

This device **failed** the test due to the breaking of the windshield, the potential for penetration of the passenger compartment and the hazard to the operator of the gate.

ENSCO Test 2036-CW8-91 (Redesigned Flagger Gate Arm Test)

The Flagger Gate was redesigned to eliminate the problems discovered during the testing. The changes consisted of lowering the arm (to stop windshield penetration experienced during the arm test) and moving the counterweight to the bottom of the arm (to stop windshield penetration experienced during the base test). The remainder of the device was the same as the original design.

This test evaluated the performance of the redesigned gate with the test vehicle impacting the closed gate (arm) at 45 mi/h (20.1 m/s), perpendicular to the gate arm.

Photographs of the redesigned Flagger Gate and the test vehicle before test 2036-CW8-91 are shown in figure 50.

Impact Description

Review of the high speed films and fifth wheel data indicated that the test vehicle impacted the device at 46 mi/h (20.6 m/s). The review also indicated that the outside left edge (driver's side) of the vehicle was in line with the tip of the Flagger Gate as desired.

Upon impact, the arm of the Flagger Gate broke the windshield of the vehicle. The arm then deflected up over the top of the car, rotating upwards while yawing due to the impact. The Flagger Gate then rotated back down, while continuing to yaw. The Flagger Gate came to rest approximately 3 ft (0.9 m) downstream from the initial point of impact, after yawing approximately 150 degrees.

The test conditions and results are summarized in table 18.

Vehicle Damage

Damage to the vehicle consisted of the broken windshield and minor dents. The windshield was pushed back at the bottom where it was directly hit by the arm of the gate.

Figure 50. Redesigned Flagger Gate Before Test, Test 2036-CW8-91

Table 18. Crashworthiness Test Summary for the Redesigned Flagger Gate Arm

Parameter	Value
Test Number:	2036-CW8-91
Date:	June 11, 1991
Test Vehicle:	1985 Dodge Colt
Test Device:	Redesign Flagger Gate (Arm)
Vehicle Weight:	
Planned, Inertial:	1800 ± 50 lb
Actual, Inertial:	1813 lb
Planned, Gross:	1950 ± 50 lb
Actual, Gross:	1978 lb
Number of Occupants:	One
Occupant Model:	Part 572 Anthropomorphic 50th percentile male
Occupant Location:	Driver Seat, Restrained
Impact Conditions:	
Planned Speed:	45 mi/h
Actual Speed:	46 mi/h
Planned Angle:	0°
Actual Angle:	0°
Planned Location:	Driver side edge of vehicle aligned with end of arm
Actual Location:	Driver side edge of vehicle aligned with end of arm
Test Results Conclusion:	This device **failed** the test due to the breaking of the windshield, the potential for penetration of the passenger compartment and the hazard to the operator of the gate.

1 mi/h = 0.45 m/s, 1 lb = 0.45 kg

Device Damage

The Flagger Gate suffered only minor damage. There were scuff marks and minor abrasions to the arm. The rotating gears were misaligned after impact. The Stop sign shaft and mount were bent back due to the impact.

Photographs of the device and the vehicle after test 2036-CW8-91 are shown in figure 51.

Test Evaluation

This test was evaluated using criteria D and E from NCHRP 230 and the work zone hazard criterion. The following is an item by item evaluation using these criteria.

NCHRP 230 Criterion D: Detached elements, fragments or other debris from the test article shall not penetrate or show potential for penetrating the passenger compartment or present undue hazard to other traffic.

This device did **not** meet criterion D. The arm of the Flagger Gate impacted and broke the windshield, showing potential for the penetration of the passenger compartment.

NCHRP 230 Criterion E: The vehicle shall remain upright during and after collision although moderate roll, pitching and yawing are acceptable. Integrity of the passenger compartment must be maintained with essentially no deformation or intrusion.

This device did **not** meet criterion E. Integrity of the passenger compartment was not maintained. Glass from the broken windshield was scattered throughout the passenger compartment.

Work Zone Hazard Criterion: The device must not present a hazard to workers in the work zone following an impact by an errant vehicle.

This device did **not** meet the work zone hazard criterion. The arm of the Flagger Gate rotated 150 degrees and the Flagger Gate rolled from the impact position. The worker operating the Flagger Gate could have been harmed by the movements of the Flagger Gate.

This device **failed** the test due to the breaking of the windshield, the potential for penetration of the passenger compartment and the hazard to the operator of the gate.

Conclusions and Recommendations

- Consideration should be given to making the Flagger Gate arm a breakaway design.
- The pickup design of the Flagger Gate is shown in figure 52. This prototype should be built and open highway tested. The pickup truck should be equipped with a suitable attenuator.

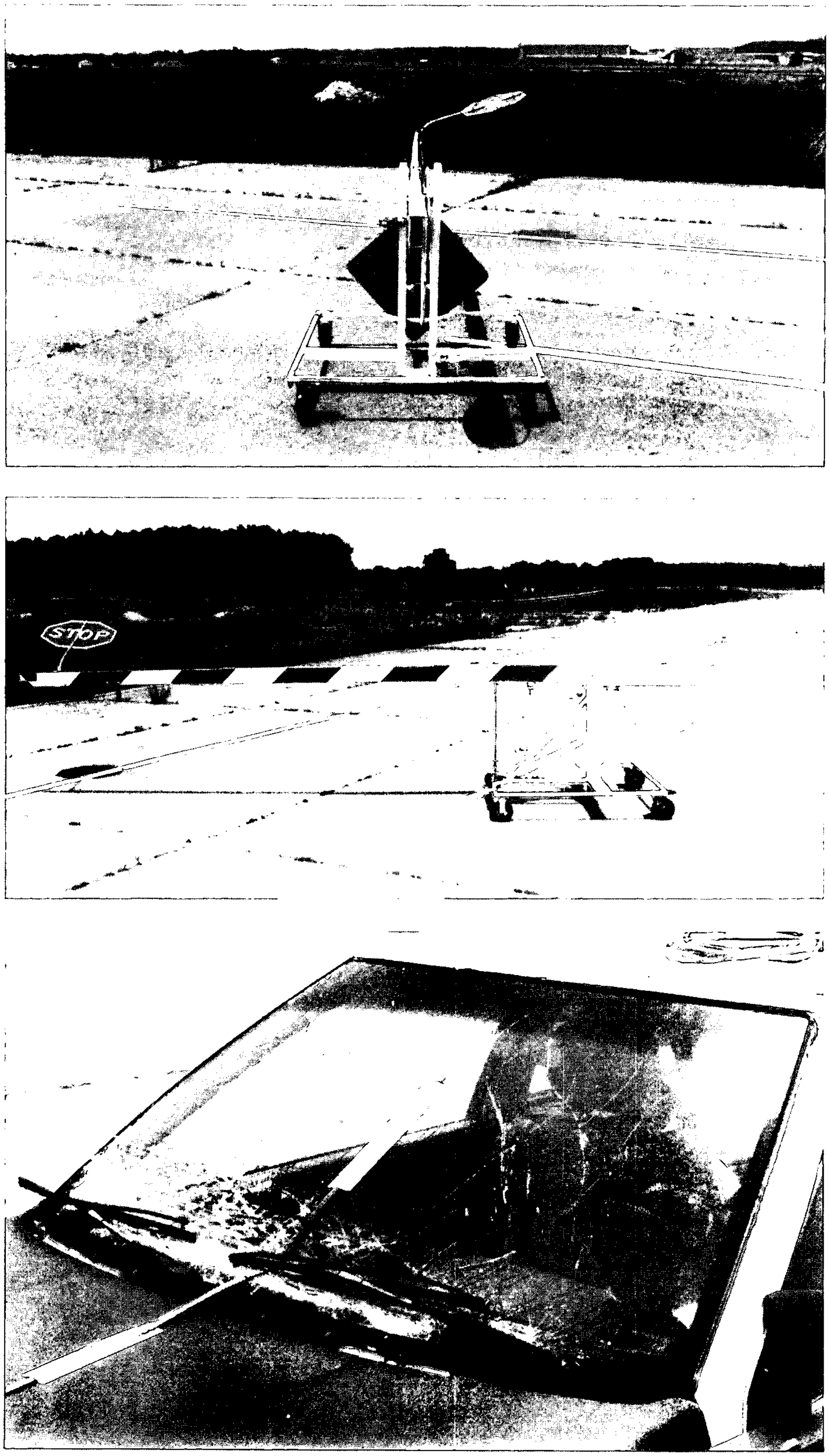
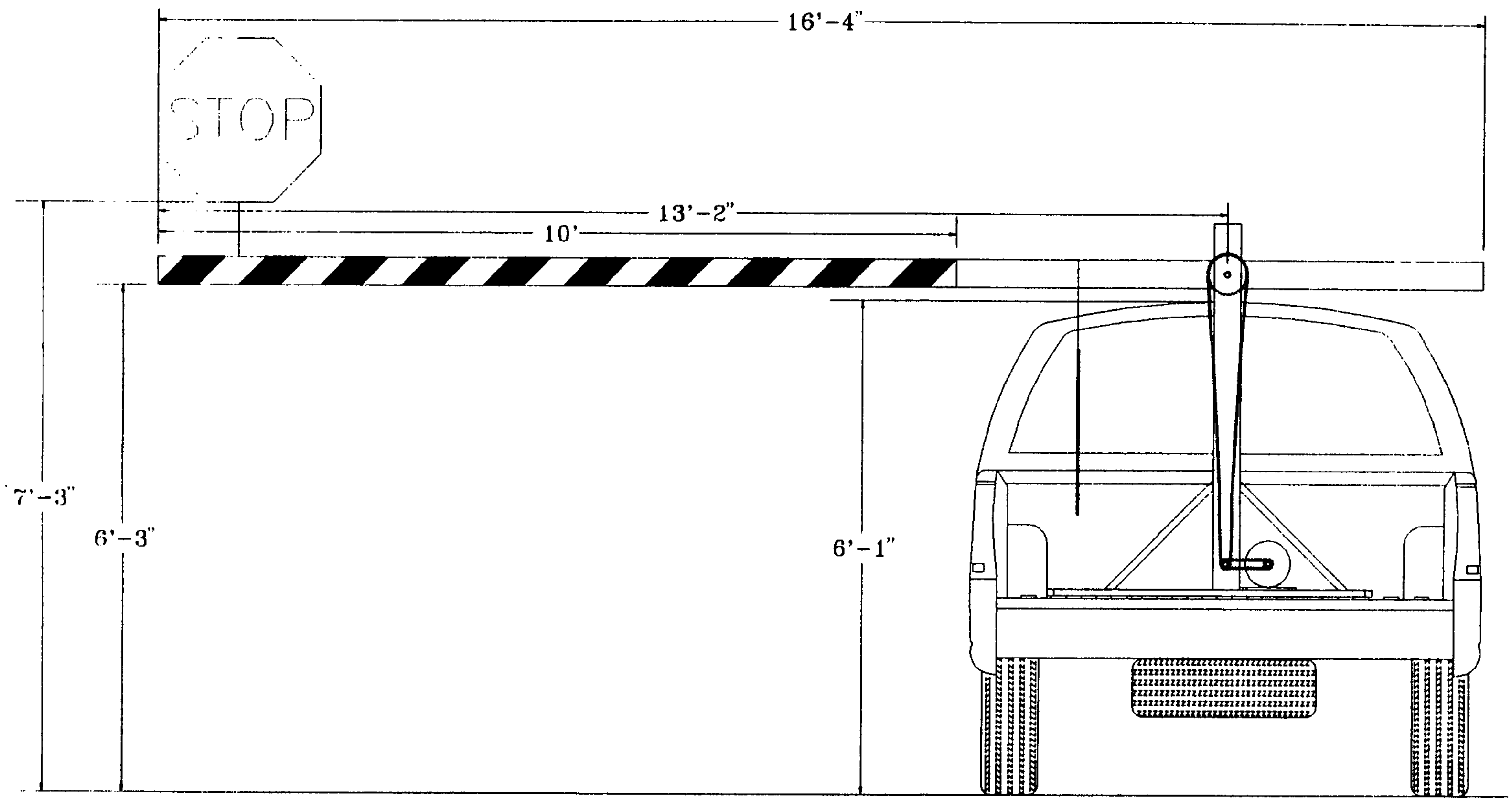


Figure 51. Redesigned Flagger Gate After Test, Test 2036-CW8-91



1 ft = 0.30 m,   1 in = 2.54 cm

Figure 52. Pickup Truck Design of Flagger Gate

S.CAI Barrier

The S.CAI barrier is shown in figure 53.

Background

Concrete Median Barriers (CMBs) are widely used to separate traffic lanes either from other through lanes or from work zones. They have been designed and tested for these uses and are proven to the highway community. However, they are not as portable as would be desired for short-term work zones.

Device Description

The S.CAI barrier is a hollow, plastic New Jersey-type barrier designed to be filled with water or sand to increase its mass, and hence, improve its performance by minimizing barrier deflection on impact.

Workers can set out a length of barriers by hand, and then fill each section with water. These barrier sections are deployed more quickly than the concrete barriers, and can reduce the time workers spend in the roadway. The S.CAI barrier can be filled with water by water trucks located behind the barrier. Each barrier segment has a drainage spout at its base. Water can be emptied from the segments using highway drainage structures to remove the water. It was hoped the S.CAI barrier would facilitate the use of barriers in maintenance operations where barriers are not normally used.

Design and Fabrication

The S.CAI barrier is manufactured in Spain and was shipped to the United States by the manufacturer. The manufacturer supplied 50 sections for evaluation.

Operational Testing and Lab Testing

Discrepancies were noted between the sections delivered and the drawings in the proposal. These discrepancies consisted of the connection detail between the individual sections. The proposal drawings showed a u-bar and hook connection that were integral parts of the longitudinal strength bar. The delivered sections featured a eye-style weldment attached to the longitudinal strength bar with a small screw. This connection did not provide the strength required to maintain longitudinal integrity of the sections.

Other discrepancies were noted in the sections themselves. As related by the manufacturer, the proposal units had been single units rather than production units. When production started, the design of the sections was modified either to aid production or to make production possible. The sections delivered were half shells, riveted together with the seam caulked. The section walls were also thinner than had been proposed. When tested to see if and how long the sections would hold water, the sections leaked profusely, not holding water for more than five to ten minutes. The section walls bowed and fractured due to the hydrostatic pressure of the water. The gasket fittings at the connection rods also leaked. Overall, the sections failed to hold water.

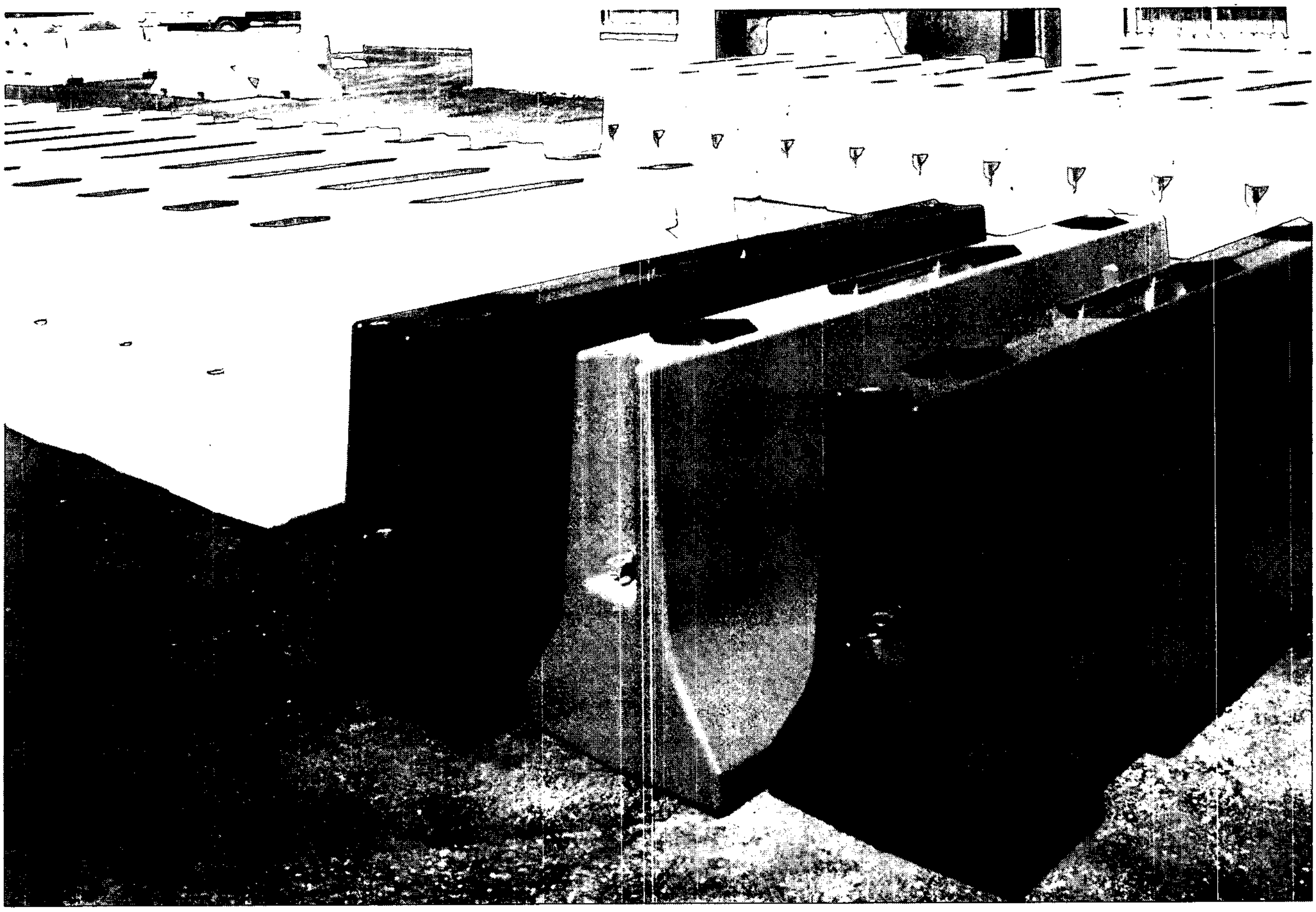


Figure 53. S.CAI Barrier

Attempts were made to procure additional and better sections from the manufacturer and to improve the sections on hand. These attempts met with limited success. The existing sections could not be made to hold water and additional sections could not be procured.

The S.CAI barrier was tested during the closed track traffic control tests as a delineation device. However, it was felt that the use of the barrier may be counterproductive in that it appears to be a rigid, semi-permanent barrier and in reality, is neither.

No additional testing with the S.CAI barrier was performed.

Conclusions and Recommendations

This device did not fulfill its design features. The project staff were informed that legal actions were being taken by a plastic barrier manufacturer in the U.S. Recently, another U.S. company, Energy Absorption Systems, Inc., marketed a similar device.

Given the legal proceedings and the market competition, the S.CAI barrier was not worthy of further investigation.

Personnel Protection Trailer

The Personnel Protection Trailer (PPT) is shown in figure 54.

Background

Accident data collected during the SHRP Maintenance Work Zone Safety (H-108) Project showed that work zone accidents involving pedestrian workers are, on average, the most severe of all types of work zone accidents. One solution, proposed by a research staff member for the Design Competition portion of the Maintenance Work Zone Safety Project, was the Personnel Protection Trailer (PPT).

The PPT was attached to the rear of a bobtail tractor and towed along during pavement maintenance operations such as pothole patching. The PPT provided a protected work area in which pavement maintenance workers were shielded from the hazards of passing traffic. The device was considered to be especially useful for these operations involving centerlane closures on high-speed, high-traffic-density freeways.

Device Description

The PPT consisted of two vertical reinforced steel panels forming its sides, a rear wall, and a pinned-hinge assembly between the side and rear walls. The area between the sides and between the hinge and rear wheel assembly was empty; there was no "floor" in the PPT. The area between the side walls formed a protected work area for pedestrian maintenance workers.

The dimensions of the PPT were 8.25 ft (2.5 m) wide for transportation purposes. The walls could hydraulically expand and lock to 10, 11, or 12 ft (3.0, 3.4, or 3.7 m) for roadway maintenance operations. The device was 53 ft (16.2 m) long and weighed approximately 52,000 lb (23,636 kg) to help minimize lateral deflection when hit by an errant vehicle.

The PPT also has an optional material box/pallet insert that attaches to the front hydraulics housing unit. The material box/pallet insert is for carrying patching materials, tools, and other items or materials that workers may need when working in the roadway.

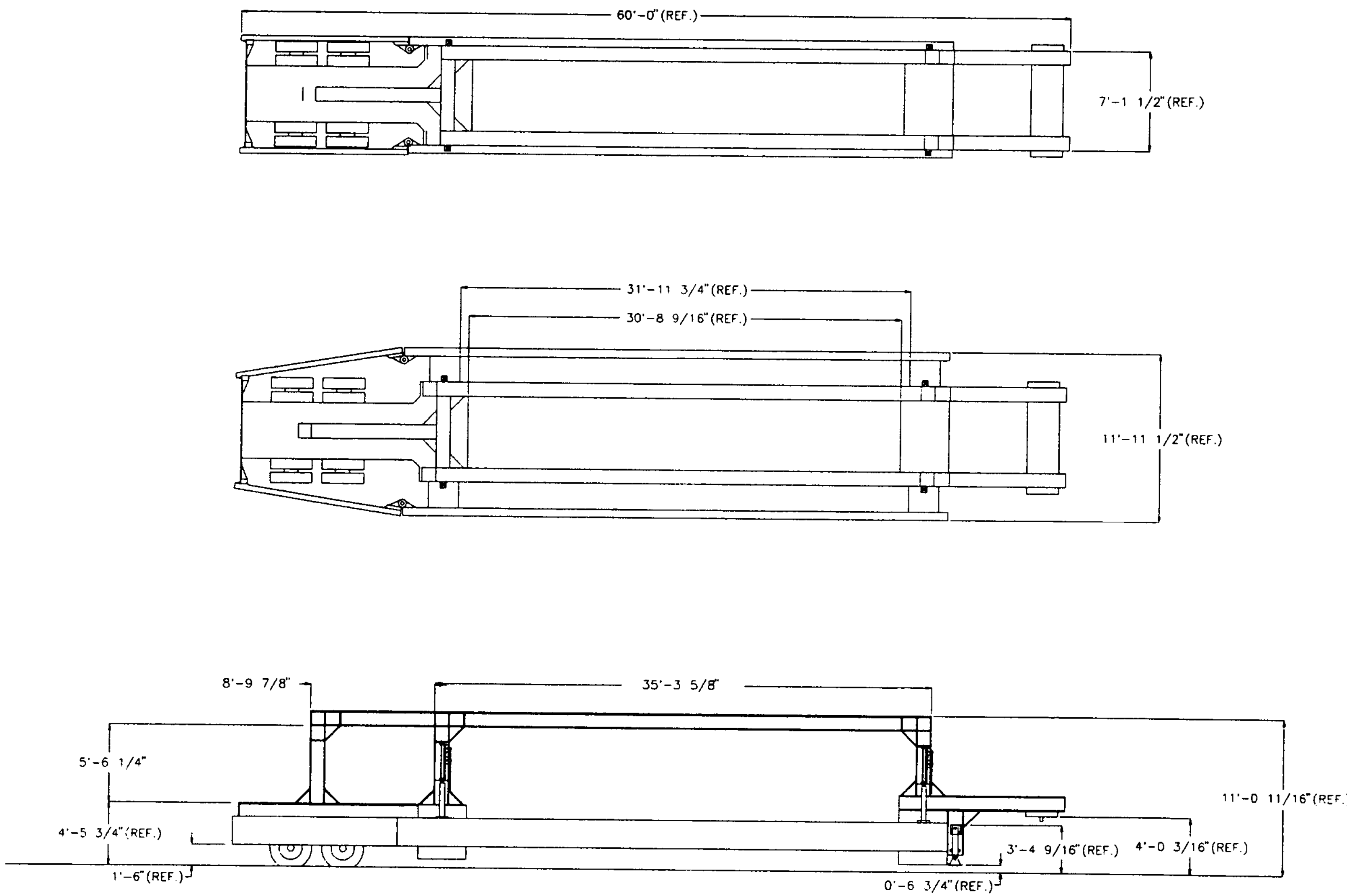
Design and Fabrication

The PPT was not fabricated. The reasons for not fabricating the device are discussed below.

Device Design

Many factors had to be considered during the design of the PPT. The PPT had to be a large and heavy barrier to errant vehicles in order to effectively protect workers. The device had to be equipped with standard hardware so that it could be fitted with an attenuator and pulled by a standard bobtail tractor.

The PPT was too large and heavy to be fitted with a standard attenuator, however. The Aluminum Can TMA was designed to be used with the PPT. Unfortunately, the Aluminum Can TMA was dropped from the schedule for lack of feasibility and budgetary reasons.



1 ft = 0.30 m, 1 in = 2.5 cm

Figure 54. Personnel Protection Trailer

The design from which the original fabrication plans were developed is depicted in figure 54. This design consists of a trailer 8.5 ft (2.6 m) wide, 60 ft (18.3 m) long with walls 2 ft (0.6 m) tall forming its sides. This design was calculated to weigh approximately 60,000 lb (27,273 kg).

At this point in the project, a number of redesigns of the PPT were undertaken. These redesigns fell into two basic categories: improving the original PPT design completed during the maintenance work zone safety project and drafting the plans for fabrication purposes.

One of the first tasks that was done was to improve the wall movement hydraulic circuit. The original design from the Maintenance Work Zone Safety Project incorporated a series of flow dividers with a two-spool parallel switching valve to evenly distribute hydraulic flow to the hydraulic cylinders. It was decided to eliminate the flow dividers and the two spool valves, and to replace them with an eight-spool parallel switching valve. This design change increased the reliability of the movement of the PPT walls by allowing a more even flow distribution between the cylinders.

The second task was to select a hydraulic power unit. The PPT design plans from the maintenance work zone safety project, showed an electric motor-driven pump, powered by a battery. The battery was to be charged by a portable generator set. The design was changed to a diesel engine-driven pump in order to eliminate the problem of keeping the battery charged, and to eliminate the generator and electric motor, thus increasing the reliability and decreasing the cost of the PPT.

A self-locking hydraulic cylinder would have eliminated the four locking cylinders on the PPT, the limit switches, and the associated circuitry, thus simplifying the PPT's operation. Unfortunately, after sizing and designing these new cylinders, it was determined that their cost was prohibitive ($14,000/unit). As a result, the original design was retained.

The vendor for the hanger and axle kit changed from the specified Fruehauf model. Fruehauf did not supply the necessary details and specifications for their axle kit, so a Hayes Axle Co. model was specified in its place.

Finally, the elimination of the Aluminum Can Truck Mounted Attenuator from evaluation required a design change to the PPT. The plans were redone to incorporate this design change.

After these redesigns were completed and a set of full-sized blueprints were obtained for the final design, computer simulations were performed to determine the optimum configuration to crash test the device. More information on this testing can be found below in the section titled, "Computer Simulation."

After the computer simulation was completed and the optimum test configuration had been determined, a full-size set of blueprints was created for the purpose of obtaining fabrication bids for the device.

When the PPT was originally designed, size and weight limitations for various States were not considered. It was generally thought that the device would simply be used as a piece of construction equipment, and therefore not be bound by the rules for commercial vehicles, or a special permit would have to be obtained to use the device. Upon investigation, it was discovered that special permits were not readily available. Therefore, the PPT needed to conform to the interstate size and weight limitations for the majority of states to avoid these problems. As mentioned above, the final PPT design was 60 ft (18.3 m) long and the weight of the steel alone was approximately 60,000 lb (27,273 kg).

The state survey found that the most common maximum length for a trailer (26 states) was 53 ft (16.2 m). The interstate weight limit for a tractor-trailer combination was 80,000 lb (36,364 kg). The PPT, with associated hardware and a 15,000-lb (6,818-kg) tractor, easily exceeded both of these limitations.

For this reason, another attempt was made to redesign the PPT, this time to downsize the PPT to fit within the size and weight limitations of the majority of the states. This redesign consisted simply of reducing the cross-sectional thickness of the structural components of the PPT's walls, while remaining within a tolerable safety factor of 2.5 for a lateral impact load of 80,000 lb (36,364 kg). The new design actually had a safety factor of 2.75. The other portion of this redesign called for shortening the rear section of the PPT and also shortening the center work area. In this way, the necessary weight reductions were achieved and work began on obtaining fabrication bids.

After the original fabrication bids had been obtained, project staff discovered that the redesign would not work properly. The rear section of the PPT had been shortened to such an extent that the sliding pin-and-hinge arrangement at the rear walls would not function correctly. In fact, there were several clearance problems with the placement of the hinge in the redesign.

A set of preliminary drawings for a redesign were drafted to correct these problems. It should be noted, however, that this redesign has not been fully analyzed, since the project budget for design work had already been exhausted. Further analysis of the latest design should be completed before fabrication of the PPT is even considered.

Fabrication Bids

Original estimates based on the volume of steel and a crude estimate of the labor involved placed the costs around $60,000. A bid was obtained from a machine shop in Virginia, and project engineers were used as part of the labor estimate. This bid was based on the set of blueprints obtained for the PPT before it was downsized as a result of the state survey. This estimate totaled $194,494.65.

Many members of the project staff felt that this was an unrealistic estimate. This bid was obtained with the cost of pre-cut steel, a fact which should have cut fabrication expenses considerably. The material cost before shipping and taxes was $85,068.75.

A new set of fabrication bids was sought. Since the vast majority of the engineering work had already been performed for the PPT, this work was done with the intention that the firms sought would be capable of taking over the entire process of producing the PPT. It was at about this time, however, that the state survey of size and weight limitations was undertaken, and the problems discussed above arose.

One manufacturer in the Kansas City area was contacted for a bid, but this firm felt that there were portions of the design that they could not handle, such as the rims, tires, painting, and the hydraulics and electrical system. Excluding these portions of the PPT, their bid was $97,000.

Project staff felt that cost savings would result from having one manufacturer obtain, test, and assemble all of the necessary components for the PPT, and paying this manufacturer at the end of completion of the project for the whole device in assembled form. For example, it was found that shipping the PPT from Kansas City to the crash facility in Georgetown, Delaware via railways would cost around $5,000. The original bid budgeted $21,289.57 for shipping and taxes associated with buying the material from separate suppliers and having it shipped to a specific machine shop.

There was an additional problem because the engineering work and analyses associated with downsizing the PPT had not been completely finished. For these reasons, a vendor was sought who would be capable of doing the engineering work related to downsizing the PPT, finding and obtaining all necessary materials for the PPT, and finally having the facilities to assemble the PPT at one location. The firm sought was also expected to have experience in design and assembly of large trailers such as the PPT. The company that was selected for this final bid was the trailer manufacturer Fruehauf.

After meeting with Fruehauf representatives and discussing with them some of the work necessary for completing fabrication of the PPT, these representatives went about finding an appropriate site to assemble a large, heavy device, with the support staff necessary to complete the work associated with creating a prototype. Fruehauf finally decided that a prototype of the PPT could be assembled at their plant in Alabama in 45-60 days. The bid entered for this work was $57,400, a cost more in line with the original project estimates than many of the other bids.

Computer Simulation

Computer-simulated impact tests of the PPT were completed in September of 1990. Standard structural adequacy tests were performed and results recorded for a variety of different configurations and impact points for the PPT. The simulations consisted of using a modified version of a successful barrier-modeling program authored by the Texas Transportation Institute for the FHWA project, "Barriers in Construction Zones" (FHWA/RD-86/094). This program was used to model the PPT/tractor system to determine lateral deflections.

After the program was debugged, the first step of the testing procedure consisted of running validation tests on the barrier model to check stability and accuracy. Theoretical situations with known solutions were checked, along with comparisons to actual crash tests. Results were good and reasonable for all tests performed.

After the barrier model was validated, calculations were made and modifications written in the barrier program to simulate crash testing of the PPT. Parameters that were calculated to simulate the PPT as a barrier system included weights, centers of gravity, moments of inertia, and spring constants and differential limits. Due to the complexity of the PPT and tractor structures, and time constraints for completing the simulations, a number of simplifying assumptions were made in these calculations.

These assumptions included resolving the PPT and tractor into rectangular prisms for the moment of inertia calculations. Weights and dimensions were assumed for the PPT axles and the tractor, due to uncertainty as to what specific tractor would be used to pull the PPT.

One of the most important considerations was the model's inadequacy in calculating X-direction deflection (roll-ahead). The original model was designed for long barrier systems which could not deflect far along their centerlines because they were impeded by other barriers. In actual practice, the system will deflect (roll-ahead) farther in the X-direction and that the y-direction deflections will therefore be even smaller. However, this lessened sliding in the y-direction will probably be offset by the fact that the PPT will begin to roll in the y-direction as well, once it has rotated significantly. These rolling deflections will be at lower velocity, and should not pose increased hazard to workers. Also, the rolling should dissipate additional energy, making overall impact severity diminish.

It was originally planned to account for the effect of rolling instead of sliding friction in the direction parallel to the PPT's centerline, but the time allowed for testing was insufficient for modification of the necessary routines.

Modifications were made in the program portions concerned with calculation of frictional forces and shear in the connector, and several computer runs were made. First, the point of impact was varied along the length of the PPT and truck to determine the critical impact point.

The results identified the critical point at approximately 50 ft (15.2 m) along the length of the PPT (10 ft [3.0 m] from the trailer hitch). Simulations were performed to determine if changing the clearance distance between the PPT and truck had a beneficial or negative effect. A run was also made with the landing gear down to determine what effect, if any, this had.

It is felt that the results of these simulations were useful in predicting the general effect various parameters have on overall deflection, and that the results have determined the point at which the PPT/tractor system should be crash tested.

Conclusions and Recommendations

After the difficulties of obtaining the fabrication bids, there was neither sufficient time nor funds available to complete the fabrication and crash testing of this device.

The computer simulations, however lead to the following conclusions concerning the PPT:

- The PPT could protect roadway workers effectively. Maximum lateral deflections were less than 1 ft (0.3 m) for all computer simulations. The longitudinal deflections (roll ahead) probably would be much larger in actual testing, but should not jeopardize workers.
- The critical impact point for crash testing of the PPT/tractor system is approximately 50 ft (15.2 m) along the PPT, 10 ft (3.0 m) from the trailer hitch.
- Either the clearance distance between the PPT and tractor should be minimized, or some means of resistance to differential rotation between the PPT and the tractor should be created. This should lower lateral deflections. When providing for moment capacity at the joint, however, it must be considered that this will cause increased shear force in the pin connector, and this should be designed accordingly.
- Operating the PPT with the landing gear down or with continuous friction at the roadway probably would have little or no positive effect on performance.

The following are recommendations for further areas of development for the PPT, should an attempt to build and test be made:

- A special attenuator should be designed and produced for the PPT before it is used in open highway testing. The PPT requires a special attenuator because it is too large and heavy for commercially available attenuators.
- If manufactured, the PPT should be made by a trailer company, such as Fruehauf, with the expertise and facilities to construct such an item cost-effectively.
- The PPT plans require further analysis to determine what effect the changes in sizing of some of the components may have on structural integrity, failure modes, the hydraulic system, etc.
- Full scale crash tests of the PPT should be performed--from the sides and also from the rear--with a specially designed attenuator to the PPT.

Moveable Barrier End Treatment

The Moveable Barrier End Treatment is shown in figure 55.

Background

A moveable barrier moves laterally to close a lane which provides more protection work zone. Highway organizations use moveable barriers for both work zones and for reversible lane control to maximize traffic flow. The barrier is linked at the end of every 3-ft (0.9-m) section. A specially designed vehicle moves the barrier is moved by lifting each section, shifting it laterally and placing it on the ground in the new, desired location. The mobility of the barrier system makes it adaptable to a short-term work zone environment. The barrier system leaves a blunt end exposed to motorists. Turning the barriers away from traffic could lead to impacts into the small radius of the barrier or even into a perpendicular section (if the barrier is turned to that extent).

Device Description

The Movable Barrier End Treatment is an end treatment for the Barrier Systems, Inc., Quickchange™ moveable barrier. Present end treatments used with the moveable barrier often take longer to move than it takes to transfer an entire length of moveable barrier sections. The movable barrier end treatment consists of eight steel barrels similar to those found on the Connecticut narrow impact attenuator. The barrels are 3 ft (0.9 m) in diameter, and are threaded together with four steel cables. The overall system length is 24 ft (7.3 m). A small truck and chain can slide the system laterally.

Design and Fabrication

The moveable barrier end treatment was designed such be as easily moved as the barrier itself. The design features eight 3-ft (0.9-m) diameter cylinders. The first seven cylinders have eye bolts or u-bolts mounted to the outside at four locations for the passage of restraining cables. The restraining cables link the system and provide strength during a lateral impact. The cables pass through to the inside of the eighth cylinder and terminate in a bracket that attaches to the standard joining bracket at the end of the barrier system. At the upstream end, the cables join to chains, which allows for less specific placement of an anchoring box. The anchor box is placed in line with the system, approximately 6 ft (1.8 m) in front the cylinders. The chains pass through the anchor box and back onto themselves. A chain tensioning device is used to attach the end of the chain back onto itself while tensioning the system. Proper tension is critical for the performance of the system in redirective impacts.

An anchor box is placed in a concrete footer and is a semi-permanent installation. This is the only portion of the end treatment system that is not portable (i.e., two anchor boxes are needed for anchoring the system at the unmoved and the moved locations of the barrier).

The moveable barrier sections tend to creep somewhat along the roadway. The end of the system might not be located at the same place when the barrier is from its location, then back again. To accommodate the creep, the chains have sufficient length to allow attachment to the anchor box over a span of approximately 3.5 ft (1.1 m). If there is not sufficient length to attach the chain or there is excess length that prevents a tensioned system, barrier modules should be added or removed from the moveable system to obtain the desired length and consequently, the desired end treatment system tension.

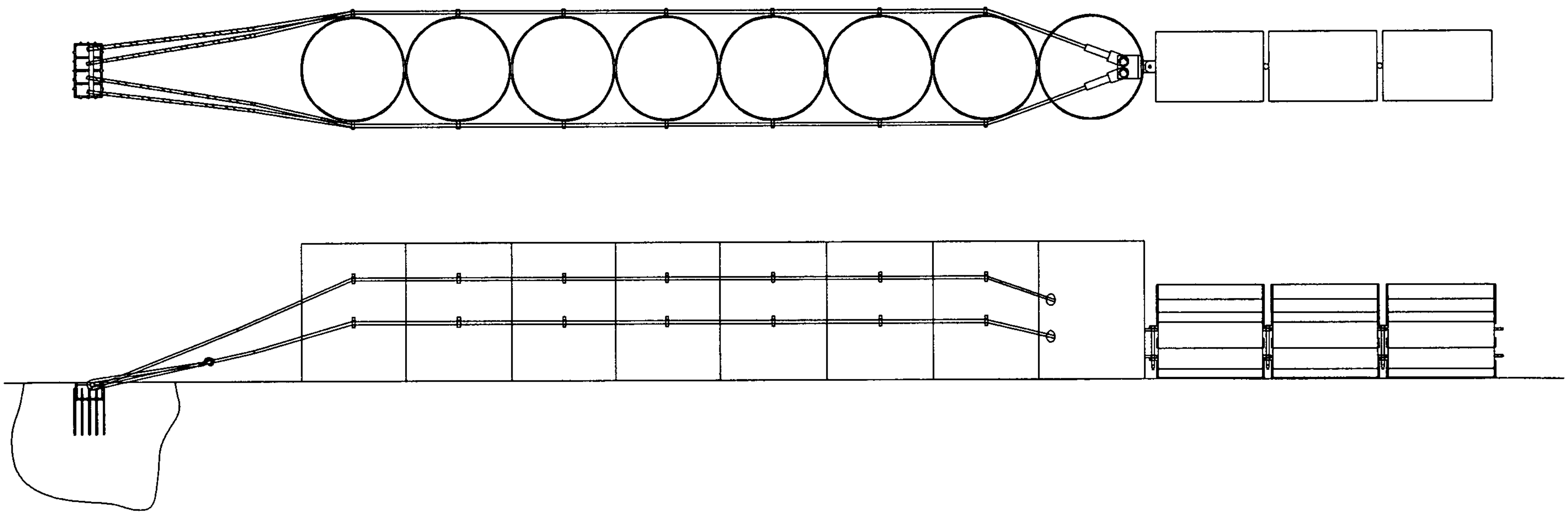


Figure 55. Moveable Barrier End Treatment

This device was not fabricated during the project.

Conclusions and Recommendations

The moveable barrier end treatment could protect motorists from the hazards of the blunt end of a barrier or from the sharp radius of a turn barrier system.

Aluminum Can Truck Mounted Attenuator

The Aluminum Can Truck Mounted Attenuator(ACTMA) is shown in figure 56.

Background

One of the most effective safety devices introduced into the highway community in recent years has been the truck-mounted attenuator (TMA). This device has proven its cost-effectiveness and ability to reduce the severity of accidents many times.

The device is still quite expensive. The price for a new unit averages $10,000. This amount puts the device out of the reach of many highway agencies' limited budgets. In addition, conventional TMAs have had some impact on the environment. In the past, when a TMA was hit, it would have to be replaced with an entirely new unit. Some of these units are made of unrecyclable materials such as hex-foam, plastics, and others. Some of the units consist of an aluminum honeycomb structure that is theoretically recyclable, but is in practicality very difficult for recyclers to handle and process.

Device Description

The ACTMA is intended to improve on the current TMA concept and solve the problems with TMAs mentioned above. The ACTMA uses an array of empty aluminum drink cans for the attenuator mechanism. It is designed to provide a crash cushion between maintenance vehicles and traffic in rear-end accidents. The advantages of this device are that it will be lighter, less expensive, and more easily recyclable than TMAs presently available commercially.

Design

The initial design for the ACTMA consisted of an array of aluminum drink cans, 9 cans high, 38 cans wide, and 17 cans deep. Each individual can has a height of 4.75 in (12.1 cm) and a diameter of 2.5 in (6.4 cm). The cans were to be arranged so that the longitudinal axis of each can is parallel to the line of impact of the TMA for a 0-degree rear impact with a maintenance vehicle. The cans were to be arranged in nine layers, with each layer of cans placed in a cardboard tray. The nine trays would be stacked vertically, and would be collectively wrapped in a burlap shroud. The wrapped array would then be placed in a fiberglass shell, which would be sealed using 0.25-in (0.6-cm) nuts and bolts.

The ACTMA would be attached to the maintenance vehicle by four mounting studs. In all other respects, the ACTMA was intended to function and operate like commercially available TMAs. Theoretically State DOTs could manufacture their own units by collecting aluminum drink cans in house, purchasing the other materials, and then assembling the TMA.

Operational Testing and Lab Testing

The design of the ACTMA discussed above was based on a number of simple static and dynamic crush tests of aluminum cans. A static crash test of a single aluminum can was performed by placing the can in a device to smash it and measure the crush force and deflection of the can. Next, a series of dynamic crush tests were performed on a single can by dropping a specific amount of weight onto the can from various heights.

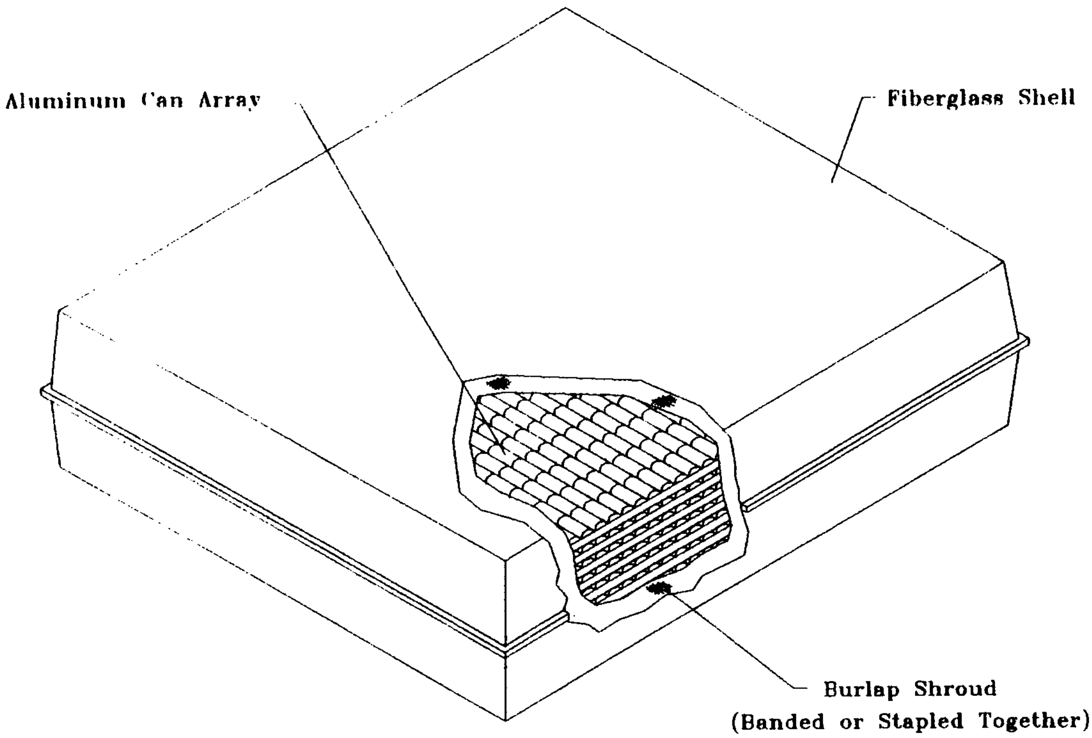


Figure 56. Aluminum Can Truck-Mounted Attenuator

From these two types of tests, a number was derived corresponding to a single aluminum can's energy-absorbing capacity. This number was used to extrapolate a reasonable weight and drop distance for a dynamic crush test involving a small system of 18 cans arranged in 3 layers of 6 cans each. The test results were good and close to expected results.

The results of the dynamic crush test of the aluminum can system were combined with the information gained in the first two tests to produce the initial design. At this time in the project, however, this particular device was postponed for development until the third year, and the initial design was not implemented. Instead, a number of other laboratory tests were conceived and performed during the second year in an attempt to determine the effect of various other parameters on the ACTMA's design.

During the course of the project, many members of the staff noted that there were many variables that could effect the ACTMA's performance.

- Different can types - There are a wide variety of designs of aluminum beverage cans. Some are thicker, thinner, have different types of rims, and so on. Project staff were concerned that a TMA constructed from cans intended for recycling might vary considerably in performance.

- Direction of can loading - It was assumed during the initial design that the cans would function more efficiently if they were loaded along their axes. Project staff, however, began to question the validity of this assumption without evidence from testing.

- Dividers - Project staff discussed the incorporation of some kind of dividers in the ACTMA for the purpose of distributing force more evenly across the face of the TMA. This would allow more of the cans in the array to contribute some energy-absorbing capacity during impact. This idea arose from an observation that, during the dynamic crush test of the can system, many of the cans that received the brunt of the impact were completely crushed, while many others survived nearly unscathed. Based on this observation, it was felt that a method to more evenly distribute the impact force would result in a smoother deceleration profile.

It became clear during the second year of the project that an optimum design for crash testing would be important, as crash tests are very expensive, and there would probably be little chance to retest the design. With the extra year afforded to staff members by the delay in the fabrication plan, effort was made to test the veracity of as many of the above points and assumptions as possible.

A method to determine the deceleration profile for the scaled impact tests was needed. Since no funds were available for purchasing the proper equipment to accurately determine deceleration, impact velocities, and other quantities, project staff decided that a video camera set for high speed shuttering would be used. Exact decelerations could not be determined in this way, but it would be possible to set the dynamic crush tests up so that rough deflection versus time curves could be created for comparative purposes between tests.

The first test was done simply to test the feasibility of the high-speed shutter setting of the video camera to determine a deceleration profile for the impact.

This test was a conditional success. It was found that the high-speed shutter setting captured the action during impact satisfactorily, but that the velocity of the drop weight required for a representative impact had to be relatively large compared with the 30 frames per second for a normal video camera. This results a relatively small number of frames depicting the actual impact.

However, project staff felt that the videos could be used to detect general trends for various aluminum can configurations.

The first two planned tests were intended to test and/or verify the correctness of the design assumption that the ACTMA would be more efficient with the cans receiving impact longitudinally, rather than laterally. Two "miniature TMAs" consisting of 48 cans each were constructed inside cardboard boxes. One of these systems was arranged with the cans in the array standing upright; the other system had the cans lying on their sides.

A dynamic crush test was conducted on each system of cans. Weights were raised on a pulley system directly above the can array to a known height; the weights were then released. The tests were videotaped; the cans were measured before and after impact to determine deflection.

Results of these two tests showed that the array of cans arranged laterally with respect to the impact direction may actually be the more effective system. The percentage of cans deformed with this system was much larger, and resulted in a much smoother deceleration profile for the weights during impact.

Project staff had now begun to question the validity of many of the early assumptions made during the initial design period for the ACTMA. It was decided that a more accurate method of determining design parameters was needed to make much further progress on the final design of the ACTMA for fabrication. However, it was decided that the expenditure of the additional funds necessary to complete this work could not be justified at that time. The research method proposed is described in more detail below under, "Conclusions and Recommendations."

A test to determine the effect of different types of beverage cans on the ACTMA was not performed because research on the ACTMA was discontinued. The open highway testing of the devices that had been fabricated during the first year of the project demanded the availability of key research team members.

Conclusions and Recommendations

The following conclusions have been reached concerning the ACTMA:

- The ACTMA could be a promising device and could increase the use of TMAs in the country and worldwide if successfully designed and engineered.

- The ACTMA still requires much testing and design optimization before full-scale crash testing is justified. A "first-run" of design optimizations including some small-scale crush testing and computer simulation could be performed for less than $10,000; a single full-scale crash test could cost $12,000.

- Based on some simple engineering calculations and estimations of the energy-absorbing capacity of aluminum cans, the project researchers feel that it is possible to build a full-scale ACTMA capable of performing as well as most currently available TMAs. Sophisticated analyses of the device's potential would be desirable before any money is spent for device development.

- The results of the few tests performed under this project make it apparent that obtaining an optimum orientation of the can array will be the critical factor in producing a successful device from this concept. It appears from the initial tests that the cans may be too stiff when loaded longitudinally, but might be too easily deformed when loaded transversely. For this reason, a successful system would probably consist of a combination of these two kinds of arrangement. It will be necessary, therefore, to procure some method of orienting the cans correctly, and ensuring that they remain properly oriented throughout impact, for successful crash testing. The use of cardboard trays or other dividers for this purpose is a patented process, held by Graham-Migletz Enterprises of Independence, Missouri.

- Another important factor will be that of can containment. One of the original concerns raised with this device was that the can array might not stay together well enough upon impact to perform effectively. In addition, the crush test done under this project with the cans loaded longitudinally corroborated this theory, as several cans were thrown free of the system. It is felt, however, that an effective divider system, along the with a burlap shroud can be used to solve this problem.

- It is believed that the ACTMA could be produced more cheaply than the cost of a commercial TMA.

The following are the recommendations of the research team concerning a future experimental plan for development of the ACTMA:

- The first step in furthering the development of the ACTMA would be to construct two small-scale systems for testing of cans receiving an impact axially versus transversely. This is identical to the tests already performed for this project, but more accurate tests, using standard crash testing instrumentation (accelerometers, high-speed film cameras, etc.), should be performed.

- The second step should be two or more impact tests, each with a TMA constructed of the same number of cans, in the same orientation, but with each TMA built with and only one type. One TMA could be constructed using only one brand of soft drink cans, another with only one brand of beer cans. The results should be compared with the results for the other types of cans, and also with the results for a TMA constructed of a variety of beverage cans.

- Next, some type of computer simulation of the impacts should be performed, and the results should be verified with the results of the actual testing. Results of the TMA system for decelerations, deflections, and other pertinent impact parameters should be obtained for both the scaled impacts and the computer simulations.

- If it can be shown that the software used can accurately simulate the real-world results, the software should then be used to model and simulate impacts with a full-scale ACTMA. Using what was learned through the performance of the earlier tests, a variety of promising configurations could then be tested. The use of metal or plastic dividers to more evenly distribute force might be included, or perhaps different combinations of can orientation in portions of the ACTMA could be studied.

- When an optimum configuration has been determined, full-scale 60 mi/h (26.8 m/s) NCHRP 230-compliant crash tests should be conducted, as well as a set of 45 mi/h (20.1 m/s) impacts (the speed at which most commercially available TMAs are tested).

Pressurized Pneumatic Tube Alarm

The Pressurized Pneumatic Tube Alarm (PPTA) is shown in figure 57.

Background

The use of pneumatic tubes to indicate the passage of a vehicle, either for counting or for warning, is not a new technology. The innovative feature of this device is in how this old technology is used. The PPTA uses a pressurized tube to sense either a vehicle's passage or device failure. An alarm sounds in either case, warning workers of impending danger, or that their safety device has failed.

A pneumatic tube is placed under low pressure by sealing the ends, installing a simple fill stem (like the fill stem on a bicycle tube), and pressurizing the tube with air at a few pounds per square inch. The tube pressure needs to be high enough to sense a pressure drop due to failure of the tube. The pressure also needs to be low enough so that the tube does not rupture or seep air when impacted by a vehicle.

Device Description

The PPTA consists of a tube, a detection unit, and an alarm unit. The detection unit consists of a sensor, an interpretation circuit, a tone encoder, and a transmitter. The alarm unit consists of a receiver, a tone decoder, and a horn. When the tube is struck by a vehicle, the sensor creates an electronic signal. The electronic signal passes through the interpretation circuit to the tone encoder. The tone encoder generates a warning tone of 1 kHz. This signal is sent out by the transmitter that is set to operate at CB channel 30. This signal is received by a radio that is set to operate on the same channel as the transmitter. The received tone is then passed through a tone decoder. If the decoded tone matches a preset tone within the receiver, the horn is activated.

Design and Fabrication

Design Concerns

The PPTA has to be very temperature tolerant. This is difficult since air pressure changes with temperature. During an eight-hour day, pavement temperatures can change drastically. Since this potential slow change in tube pressure, a quick pressure change will occur in the tube has to be the alarm criteria.

Another concern is that freeway traffic can wear out the rubber tube assembly very quickly. A road tube with no diffusion leakage, capable of surviving several thousand traffic impacts, is needed.

For these reasons, a simple air switch is inadequate. Nor will set pressure limit sensors work because of the pavement temperature changes mentioned earlier. Instead, the sensor needs to compensate for these temperature changes.

A sensor with an analog output for different pressure settings is needed, but the price of such a sensor must be considered.

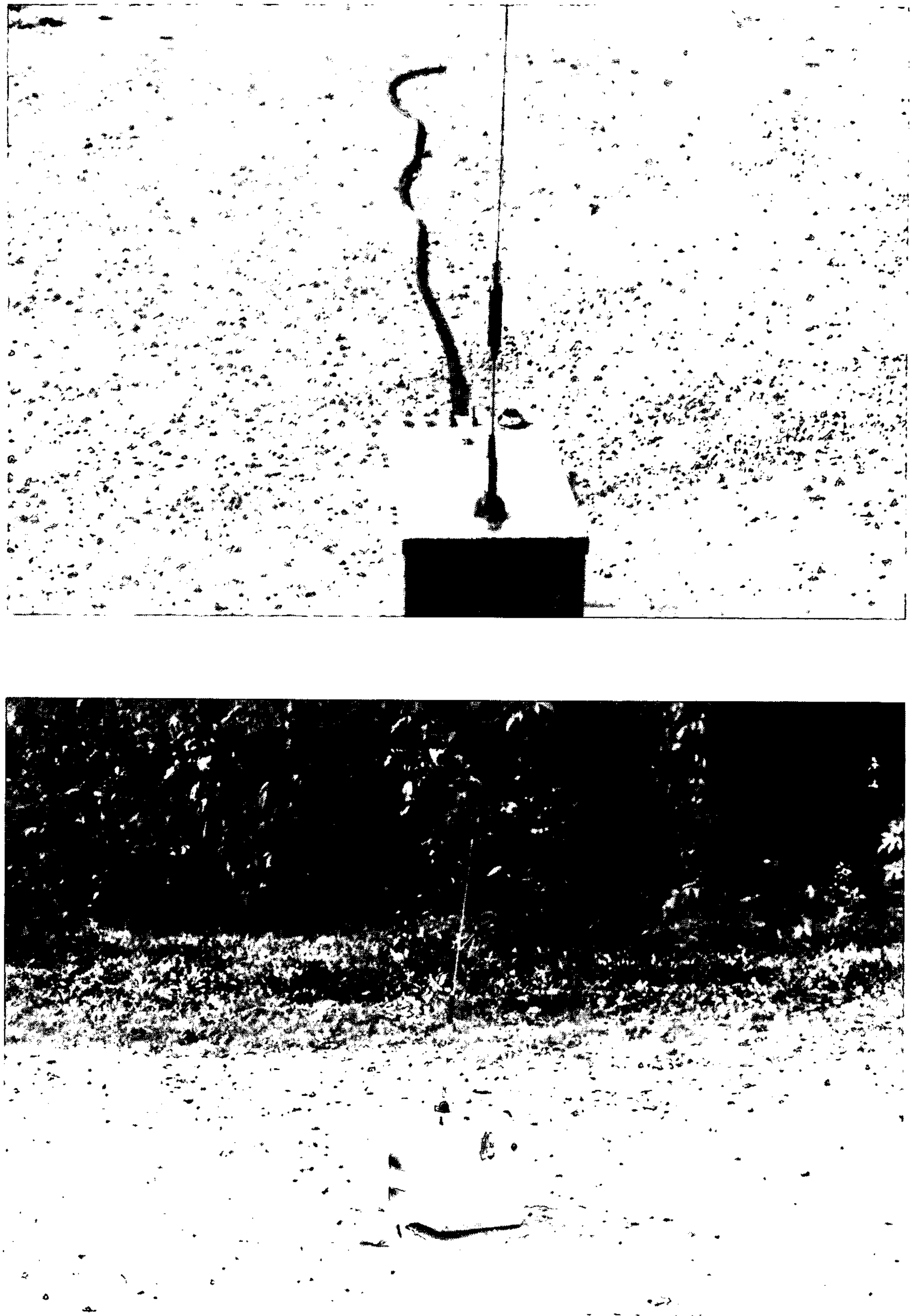


Figure 57. Pressurized Pneumatic Tube Alarm

Detector Fabrication

A standard road tube, commonly used for car counting, was used in the detector. Tests proved it held air pressure effectively. One end was plugged and sealed with a bolt and some silicon sealant. Quick disconnects were used to make a "T" in the tube, where the fill stem was attached, so the tube could be pressurized. Quick disconnects were also used to connect the tube to the pressure sensor.

The pressure sensor was an analog pressure gauge. This means that the voltage output of the pressure gauge varied with the pressure. This variance was checked with the use of an integrator circuit. If the sensor had no change, the integrator circuit would not have ground output. If the sensor had a change, the integrator circuit would give a high voltage output. If the integrator circuit had a high output, the tone encoder and the walkie-talkie would be activated. This means that a tone would be placed on a CB channel for another walkie-talkie to receive. A single 1-kHz tone was chosen to encode the signal because the decoder for dual tone signals balked at the static on the carrier wave.

Receiver Fabrication

A walkie-talkie matching the one used in the detector was put into the receiver unit. The function of this walkie-talkie was to pick up the tone placed on CB channel 30 by the detector's walkie-talkie. A tone decoder was tied into the walkie-talkie's speaker. If the tone received was the proper 1-kHz tone and lasted for a specified time, the tone decoder would activate a relay and turn on the horn. The horn used in the prototype was 110 decibels (dB) and had seven different tones. The horn was hooked up so that it could only be turned off by resetting the detector and then the receiver.

Device Modifications

The first sensor used was not sensitive enough to create a sufficient change in the analog voltage output signal to be used by the integrator circuit. Other set point sensors were used, but the pressure changes were not dramatic enough to trigger an alarm unless the base pressure was set very close to the alarm trigger set point. When the triggering pressure set this close to the alarm point, a small temperature increase would set off the alarm more easily than a passing vehicle.

The decoders and encoders that were used in the original design were like those used in touch-tone phones. Two tones are passed on a carrier and have to be matched for the receiver to activate. This proved too sensitive for this application. The unit would hesitate on accepting the signal because the carrier (CB radio) was poor. However, single tone encoding proved to be effective.

The horn was evaluated by maintenance workers in the yard and on the highway in simulated work zones. The highway workers said that the horn was not loud enough for them to hear. Because of the worker's complaints, the horn was changed to a 120-dB model. This horn worked well, could be easily heard, and was directional enough not to disturb traffic.

Operational Testing and Lab Testing

As mentioned above, the sensors used were not sensitive enough for transition detection. Different pressure settings and analog amplification methods were tried. None solved the problem. Set point detection had problems with temperature changes during the day. Pressure levels, set point levels, and hourly pressure adjustments were tried, but temperature changes would still activate the sensor. With a less sensitive system, pressure settings could not be backed away from the set point without the device failing to detect the vehicle. Without technology more suited to this application, this device concept cannot be successfully implemented.

Conclusions and Recommendations

This device will not perform properly without a more sensitive sensor. The transmitter, the receiver/alarm, and the rest of the components are working on three other devices to date. If a new, more sensitive sensor becomes available, another attempt should be made to develop this device.

Traveled Way Rumble Mat

The Traveled Way Rumble Mat (TWRM) is shown in figure 58.

Background

Rumble strips are intended to alert inattentive drivers of potential hazards that may not be readily apparent, but which require substantial cautionary maneuvers or speed reductions. The generic name rumble strip is given to grooved or raised corrugations placed perpendicular to the path of vehicles and across the full width of the traveled way or on the edge of and parallel to the open traveled way. They produce an audible and tactile stimulus when a vehicle travels over them. Rumble strips are more effective for alerting drivers than for reducing vehicle speeds.

In work zones, rumble strips are used only in combination with other warning devices, such as signs, flashing lights, arrow panels, and barricades. Work zone rumble strips have been used in advance of workers and lane closures, including lane closures leading to crossovers. They have also been used on two-lane roads where one lane is closed and traffic alternates over the open lane. The geometric design of rumble strips has been developed for long-term applications. Maintenance work zone applications, however, require portability. Quick installation, removal, and reliability while in service are a must for maintenance work zone applications.

Rumble strips present other aspects of safety concern. The element of surprise to the driver and the dynamic disturbances to the vehicle may cause the driver to lose control. With the work crew located nearby, the placement and attachment of the rumble strips therefore requires extraordinary care.

During the SHRP Maintenance Work Zone Safety Project (H-108), three main areas were identified where the use of rumble strips in maintenance work zones would be desirable:

1. A lane closure or traffic shift, where traffic must modify its path.
2. A two-lane highway where one lane is closed and traffic is alternating over the open lane, and traffic must stop.
3. The transition area, buffer space and work space where traffic must be alerted that it is leaving the open traveled way and entering a closed area.

The TWRM was intended to meet the first of these objectives. The Portable Rumble Strip and the Rumble Stripe are intended to address the second and third areas, respectively.

Device Description

The TWRM is a rubber mat with hard ridges on the top side (wearing surface) and a smooth, softer underside (friction surface). The device causes tires to rumble and vibrate thereby alerting drivers. The device alerts drivers that they should prepare to perform a maneuver such as changing lanes or shifting laterally in their lane. The auditory rumble also alerts highway workers.

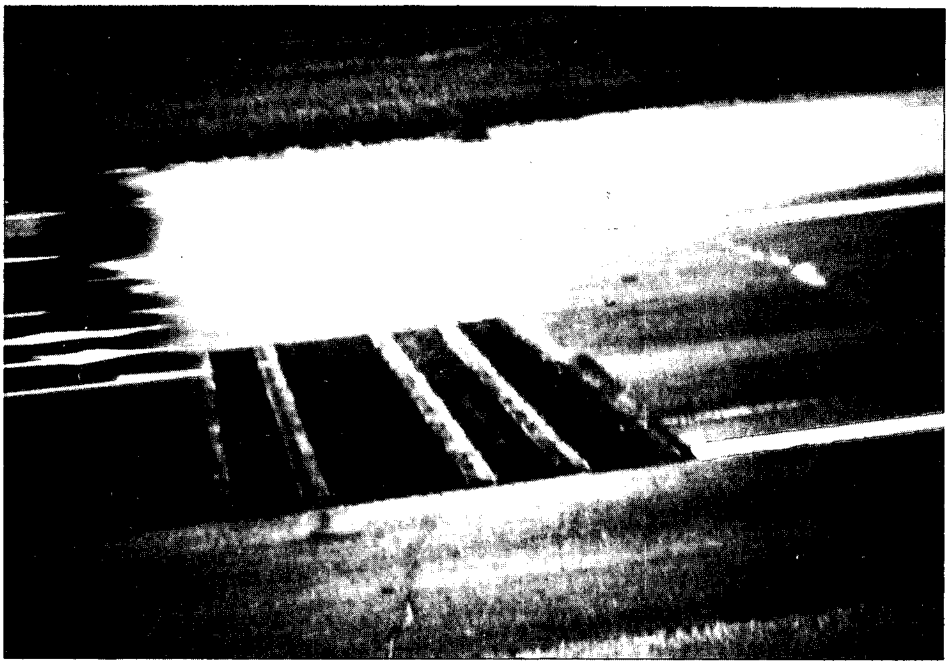


Figure 58. Traveled Way Rumble Mat

Design and Fabrication

The TWRM was fabricated using a neoprene rubber mat with hard ridges for the top side (wearing surface) and a smooth, softer surface for the underside (friction surface). Two 4-ft by 12-ft (1.2-m by 3.7-m) neoprene mats with three rumble bars each are placed so that they form a single 8-ft by 12-ft (2.4-m by 3.7-m) TWRM.

Operational Testing

A professional driver was hired to do the first set of closed track operational tests of the TWRM. The first set of tests required a professional driver for his vehicle handling skills and ability to identify potential vehicle control problems that may arise. Research has been conducted on rumble strips permanently attached to pavements, but none has been done on temporary rumble strips such as the TWRM. There may have been unknown vehicle control problems that might have arisen from temporary rumble strips. These problems needed to be identified before drivers encountered the devices.

Tests were conducted to determine whether the TWRM alerted the driver, created vehicle handling problems, moved from its location on the road, and to determine its durability.

Three types of tests were done by the professional driver. Each test consisted of a series of runs from 20 to 70 mi/h (8.9 to 31.3 m/s) in increments of 10 mi/h (4.5 m/s). The professional driver first drove on a road without a TWRM present. This was done to record ambient noise levels. The second test involved driving over the TWRM. The third test involved skidding over the TWRM. Four vehicle types were used for each test: a small car, a large car/pickup truck, a tractor trailer combination and a motorcycle. The motorcycle was one designed for highway travel and was not of the off-road variety.

Two video cameras and two noise meters were used to record data. One camera and noise meter were inside the vehicle. The camera videotapes the test runs from the driver's viewpoint. The purpose was to document vehicle vibration, vehicle control and to record comments by the test driver. The noise meter recorded the increase in noise that occurs from the TWRM. The motorcycle was not fitted with either the camera or the noise meter.

The other video camera and noise meter were placed along the roadway. The camera was positioned to videotape the vehicle as it crossed the TWRM to document vibration, vehicle control and mat displacement. The noise meter outside of the vehicle was positioned near the rumble mat and recorded the increase in the noise level when vehicles drove over the TWRM.

The test driver answered questions and provided comments after each run. In addition to the video camera and sound measurements, the driver judged the TWRM's performance. The driver also described the vehicle's handling. No safety or handling problems arose.

The road section where the tests were conducted was straight and level. The open road runs without the TWRM were used to set the base for noise, vibration, and handling. The driver skidded each test vehicle on the open road to establish a baseline for handling in a skid.

After each run, the TWRM was checked to see if it had moved.

The skid tests were conducted to identify vehicle control problems and to see if the TWRM would become entangled in the vehicle's wheels or undercarriage. The test driver started the skid just prior to reaching the TWRM and continued the skid across the mat.

The test driver's comments, the video tapes, and the noise measurements were analyzed to evaluate the performance of the rumble mat. Though the TWRM did not create vehicle handling problems, this particular design did not create enough of an audible or jolting effect to justify its further use. The TWRM was therefore dropped from the schedule for open highway testing.

Conclusions and Recommendations

This particular design did not perform as desired. A commercial product, intended for use as a permanent rumble strip, was attached to a rubber mat to make the TWRM. Researchers concluded that this device did not produce the desired jolt for use in a temporary work zones.

This device was very similar in configuration to the original design of the Portable Rumble Strip (PRS). As noted in the section of this report on the PRS, the original design of that device was unsatisfactory because of it tended to roll under field conditions. This device probably would experience similar problems in open highway testing.

The concept for this device -- a portable rumble mat to be used to warn drivers of an upcoming maneuver required -- is still considered a good one. Until some alternative material or technology is developed, this device cannot meet the rigorous requirements for a maintenance work zone device.

Rumble Stripe

The Rumble Stripe is shown in figure 59.

Background

Rumble strips alert inattentive drivers of potential hazards that may not be readily apparent, but which require substantial cautionary maneuvers or speed reductions. The generic name rumble strip is given to a group of grooved or raised corrugations placed perpendicular to the path of vehicles and across the full width of the traveled way or on the edge of and parallel to the open traveled way. They produce an audible and tactile stimulus when motorists drive over them. Rumble strips are more effective for alerting drivers than for reducing vehicle speeds.

In work zones, rumble strips are used only in combination with other warning devices such as signs, flashing lights, arrow panels, and barricades. Work zone rumble strips have been used in advance of workers and lane closures, including lane closures leading to crossovers. They have also been used on two-lane roads where one lane is closed and traffic alternates over the open lane. The geometric design of rumble strips has been developed for long-term applications. Maintenance work zone applications have the special requirement of portability. Quick installation and removal and reliability while in service are a must for maintenance work zone applications.

Rumble strips present other aspects of safety concern. The noise and the dynamic disturbances to the vehicle may surprise the driver, or cause the driver to lose control. The placement and attachment of the rumble strips therefore requires extraordinary care, particularly if work crews are nearby.

During the SHRP Maintenance Work Zone Safety Project (H-108), three main areas were identified where the use of rumble strips in maintenance work zones would be desirable. These three areas were as follows:

1. Traffic must modify its path (such as at a lane closure or traffic shift).
2. Traffic must stop (such as on a two-lane highway where one lane is closed and traffic is alternating over the open lane).
3. Traffic must be alerted that it is leaving the open traveled way and entering a closed area (such as the transition area, buffer space and work space).

The Rumble Stripe was intended to meet the third of these objectives.

Device Description

The Rumble Stripe is used at the edge of the open traveled way, along the transition of channelizing devices, buffer space, and work space. It delineates and separates the open traveled way used by the motoring public from the closed areas used by workers, work vehicles, and equipment. The Rumble Stripe is constructed of a relatively lightweight synthetic material for portability. It is applied in the transition area to guide errant vehicles away from the work area. The Rumble Stripe is placed adjacent to channelizing devices used on medium to long-term work zone operations.

The Rumble Stripe alerts motorists that they are driving off of the traveled way. A typical shoulder rumble strip design relies more on tactile stimuli rather than audible stimulus and may be

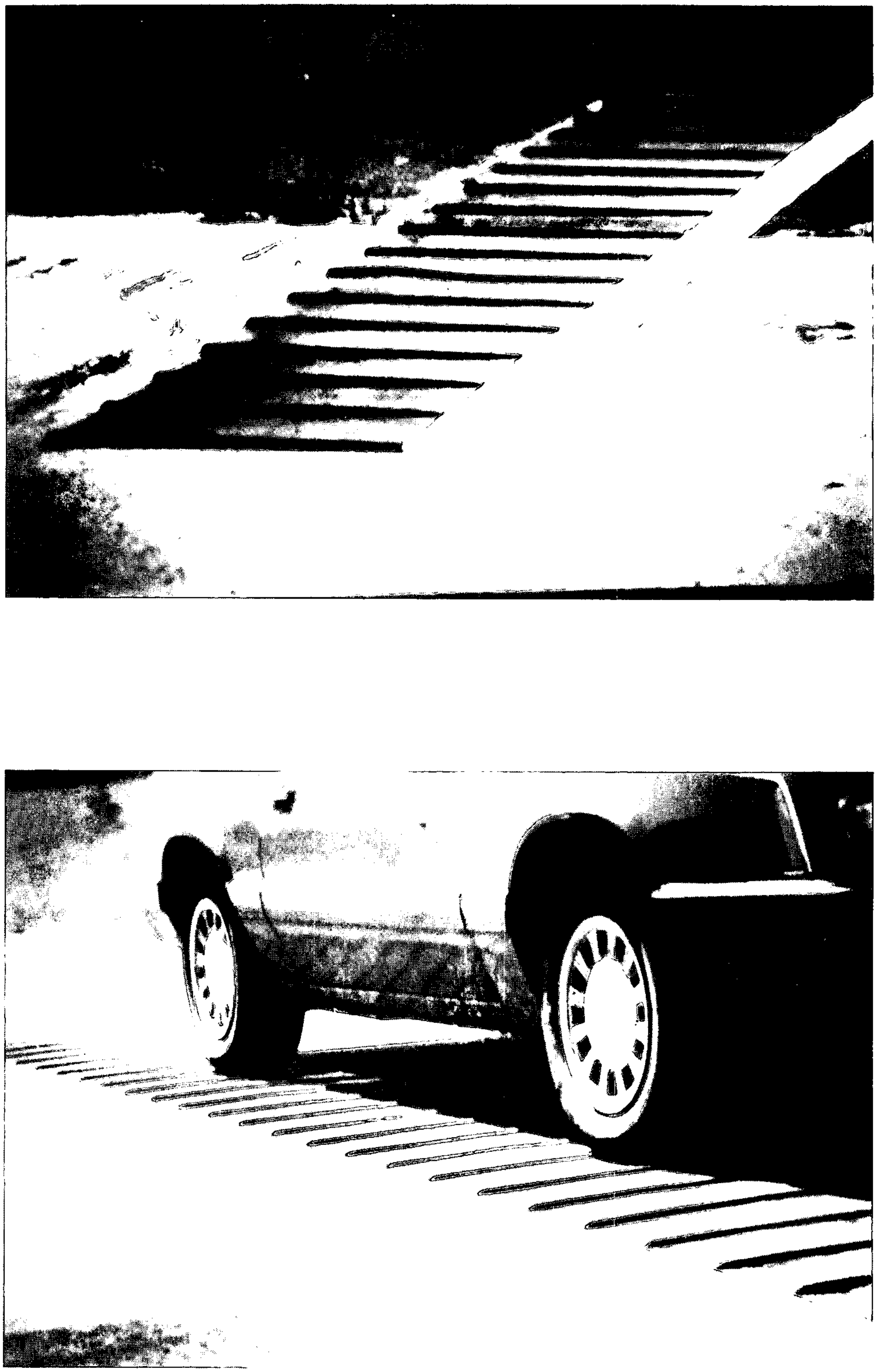


Figure 59. Rumble Stripe

as high as 0.75 in (1.9 cm) or as deep as 1 in (2.5 cm). Drivers complain about these types of rumble strips and even stop to check their vehicles for damage and mechanical failure after driving over them.

Design and Fabrication

The Rumble Stripe is a series of strips of synthetic material, 2 ft (0.6 m) wide by 20 ft (6.1 m) long with transverse ridges. If a driver begins to laterally encroach into a work zone, the Rumble Stripe is designed to alert the driver that he is leaving the open traveled way and to guide him away from closed areas. Rumble stripes are colored white for right lane closures and yellow for left lane closures corresponding to the standards for edge lines. They are laid adjacent to channelizing devices in the transition area and buffer and work spaces.

Operational Testing

A Professional driver performed the first set of closed track operational tests of the Rumble Stripe. Because no research had been conducted on the Rumble Stripe, the first set of tests a professional driver's vehicle handling skill and ability to identify potential vehicle control problems.

Tests were conducted to determine if the Rumble Stripe could alert a driver, create vehicle handling problems, move from its location on the road, and to determine the durability of the device.

Three types of tests were done. Each test consisted of a series of runs from 20 to 70 mi/h (8.9 to 31.3 m/s) in 10 mi/h (4.5 m/s) increments. The first test was done on the road without a Rumble Stripe present. This was done to record ambient noise levels. The second type of tests involved driving over the Rumble Stripe. The third test involved skidding over the rumble strip. Four vehicle types were used for each test: a small car, a large car/pickup truck, a tractor trailer combination and a motorcycle. The motorcycle was one designed for highway travel and not of the off-road variety. The test driver drove each vehicle over the open road and then over the Rumble Stripe. The skid tests were done last. Two video cameras and two noise meters were used to record data. One camera and noise meter were inside the vehicle. The camera videotaped the test runs from the driver's viewpoint. This was to document vehicle vibration, vehicle control and to record comments by the test driver. The noise meter recorded the increase in noise that occurred with the Rumble Stripe. The motorcycle was not fitted with the camera or noise meter.

The other video camera and noise meter were outside of the vehicle along the roadway. The camera was positioned to videotape the vehicle from behind as it crossed the Rumble Stripe. This was done to document vibration, vehicle control, and Rumble Stripe displacement. The noise meter outside of the vehicle was positioned near the Rumble Stripe and recorded the increase in the noise level when vehicles drove over the device.

In addition to the video camera and sound measurements, the driver judged the Rumble Stripe's performance. The driver also described the vehicle's handling.

The road section where the tests were conducted was straight and level. The open road runs without the Rumble Stripe were used to set the base for noise, vibration and handling. The test driver also skidded the vehicles on the open road to set the base for handling in a skid.

Next, the driver repeated the runs with the Rumble Stripe present. After each run, its location was checked to see if it had moved. The device was also inspected for damage. These test runs also tested the vibration of the Rumble Stripe and vehicle handling.
The third set was done to determine whether the Rumble Stripe would gently guide the vehicle toward the open lane as was intended. For this test, the driver let go of the steering wheel. The fourth set of tests involved driving the test vehicle over the inside, or high, edge (toward the closed lane) of the Rumble Stripe. The test driver drove along the inside edge in an effort to mount the tires up and onto the rumble strips. The action was similar to that of driving off of the edge of pavement dropoff and then trying to drive back onto the pavement.

The skid tests were done to identify vehicle control problems and to see if the Rumble Stripe would become entangled in the vehicle's wheels of undercarriage. The Rumble Stripe was also inspected for damage. The test driver started the skid just prior to reaching the Rumble Stripe and continued skidding across the Rumble Stripe.

The test driver's comments, the video tapes, and the noise measurements were analyzed to evaluate the performance of the Rumble Stripe. In general, the Rumble Stripe passed all of the planned evaluation tests described above. Noise and vibration levels were increased a significant amount, but not to the point where they would cause extremely poor driver reaction or vehicle handling problems. The Rumble Stripe also performed well for the professional driver tests -- both the operational tests and the skid test. The Rumble Stripe did become dislodged from the road surface during the skid tests, but this was considered acceptable since it did not become entangled in the vehicle's undercarriage or cause vehicle control problems.

After this initial round of tests was completed, a member of the Expert Task Group at SHRP for the project suggested that the Rumble Stripe should be skid tested under wet pavement conditions. In this test, the test vehicle rotated 90 degrees during the skid, obviously thrown out of control by the Rumble Stripe. This was considered an unsafe result, and the device was therefore not open highway tested.

Conclusions and Recommendations

During this project (SHRP H-109), researchers discovered that this device, as it was fabricated, caused vehicles to lose control when skidding over the device on wet pavement. This is a very hazardous condition, particularly near a maintenance work zone, where there is seldom positive protection for workers. Until this problem is resolved, this device is not recommended for use.

Moving Taper

The Moving Taper is shown in figure 60.

Background

The Moving Taper carries a row of traffic delineator cones configured in a taper. The device consists of 15 20-ft (6.1-m) semi-trailers that are rigidly attached and towed together by a maintenance vehicle. The design length is 300 ft (91.4 m). Additional semi-trailers could be added or removed to adjust the length of the taper, but the practical length is limited by the ability to see and steer the last trailer. The Moving Taper could be used in mobile and slow-moving maintenance operations, where tapers are not used due to time restraints. Each trailer is constructed of a single fiberglass I-beam which runs the length of the trailer. Cross beams are used for mounting the bowing actuators and the swivel casters. One cone is secured to each trailer just above the rear crossbar.

Device Description

The Moving Taper consists of 15 20-ft (6.1-m) sub-sections called trailers although they are joined rigidly to each other. The first trailer is attached to the left side of the tow truck bumper with a ball hitch, but the trailers flex rather than swivel with respect to each other to conform to the curvature of the road. The operator would be able to vary the curvature of the trailers, to select the direction that the trailers curve and to steer the wheels of the last trailer.

Design and Fabrication

The Moving Taper would be driven in a manner analogous to a rear-steering fire department ladder truck, but with a remote operator in the tow truck. The operator would be seated looking backward at the trailer, and use two rotary knobs to control the Moving Taper. One knob would steer the wheels of the last trailer. An electric actuator and servo controller mounted on the last trailer would respond. The tow vehicle supplies 110v AC power to the actuator, and the remote control knob adjusts a 4-20 milliampere current command signal to the servo controller. The use of current rather than voltage as a remote command would permit the trailer array to be long.

The operator's second knob would control both the direction and the degree of curvature. Pneumatic cylinders along both sides of each trailer would flex the trailers to achieve curvature proportional to the supply pressure, and the selection of active cylinders would control the direction of bowing. Special circuitry has been designed for a single knob control of both the electronically variable air pressure regulator and the solenoid direction valves. Turning the knob in one direction would cause proportional bowing to the left, and turning the knob in the opposite direction would cause proportional bowing to the right. The control of this device should be evaluated by using a minimum array of three trailers before the rest of the trailers are built. The anticipated operating speed of 15 mi/h (6.7 m/s) (appropriate for typical moving maintenance such as line painting) and need for only two control knobs favor the success of the device.

Each trailer, except for the first and the last trailers, would have the following equipment:

- Two pneumatic actuators to bend the trailer sub-sections with cables that attach to the rear crossbar and to the actuators mounted on the front crossbeam.
- A single fiberglass beam 20 ft (6.1 m) long.

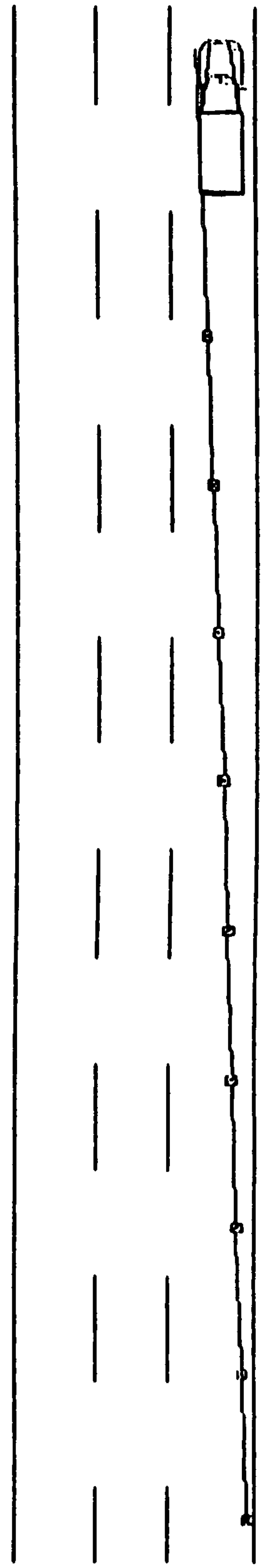


Figure 60. Moving Taper

- A single forward crossbar for mounting the pneumatic actuators.
- A single rear crossbar to support the caster wheels and to provide pick-up points for the bowing cables.
- Pneumatic lines, to supply the actuators, with quick-disconnect couplings at each end.
- Two joint channels mounted at either end of each trailer to join the trailers to each other.
- A cable reinforcement plate mounted on the inside of the rear crossbar.
- Rear crossbar reinforcement plates to add stiffness to the rear crossbar.
- Two pneumatic swivel casters mounted on the rear crossbar.

The first trailer would have a trailer hitch for attaching the Moving Taper to the tow vehicle. The rearmost trailer would have the following extra equipment.

- Brackets on each swivel for steering the wheels.
- An electric actuator and control unit for steering the wheels.
- A tie rod for coupling the steering angle of the two swivel casters.

Bolts would connect these parts to allow simple assembly of the units. Equipment to be placed in the Tow Vehicle would include:

- Gas powered air compressor with reservoir.
- Power supplies for the steering actuator and operator control equipment.
- Equipment box containing the solenoids for the actuators, an electronic pressure regulator, a DC-DC power supply, and mufflers for the solenoids.
- An operator control box with a pressure indicator, a potentiometer to control the direction and degree of bowing, and another potentiometer for the steering actuator. This box must be small enough to reside in the operator's hands.

A survey conducted to determine the likelihood of state acceptance of this device, the opinions of the SHRP and project staff, and the very high cost of this device, led to a decision not to proceed with any further testing or fabrication.

Conclusions and Recommendations

The Moving Taper is a feasible device. With the air-actuated trailers, the device would perform its design function. However, the lack of acceptance due to long setup and takedown times, and the high cost of the device outweigh its promise. This device probably will not be developed.

Portable Soft Barricade

The Portable Soft Barricade is shown in figure 61.

Background

Wind quite often over-turns the barricades or necessitates the use of several sand bags to stabilize barricades. Passing vehicles also can cause wind gusts, adding to normal wind conditions. The portable soft barricade was designed to allow its panels to rotate under wind loading and therefore be more stable in windy conditions.

Device Description

The Portable Soft Barricade is an A-frame barricade designed for stability in strong winds. In all other respects, it was designed to be used as a standard barricade. The A-frame design of the upright supports for the barricade is more stable than the single support upright typical of most barricades. Also, the two panels on each barricade rotate up to 20 degrees to help spill off wind without seriously degrading driver perception. This in effect reduces wind forces on the barricade, further increasing its stability. The barricade folds up so that it is flat, facilitating transportation and storage of the device.

Design and Fabrication

The barricade was fabricated with steel upright legs in an A-frame configuration. A one-piece plastic panel was covered with standard striped barricade sheeting, to resemble a standard Type II barricade. Stops on the bottom of the plastic panel kept it from rotating past the A-frame legs. This limited the rotation to 20° from perpendicular. The maximum spread of the legs was restricted by a chain attached near the bottom of both the front and rear legs.

Operational Testing

The device was first wind tested by placing the unit on a unused runway and marking the location of each leg. The barricade moved and overturned in wind gusts without the use of sandbags. The panel would rotate in response to the wind, the upwind set of legs would lift off the ground, and then the barricade would overturn.

There was no convenient way to use sandbags. Sandbags had to be placed on the chain at the bottom of the barricade legs. This blocked the forward rotation of the panel. When sandbagged devices were subjected to wind gusts of 20 to 25 mi/h (8.9 to 11.2 m/s) , the panel stops hit the legs, and caused the barricade to walk.

Crashworthiness Testing

ENSCO Test 2036-CW2-91

This test was conducted at 45 mi/h (20.1 m/s), with the impact centered on the vehicle. Photographs taken before test 2036-CW2-91 are shown in figure 62.

Figure 61. Portable Soft Barricade

Figure 62. Portable Soft Barricade Before Test, Test 2036-CW2-91

Impact Description

Review of the high speed films and fifth wheel data indicated that the test vehicle impacted the device at 45 mi/h (20.1 m/s) and at 0 degrees. The review also indicated that the centerline of the vehicle was aligned with the centerline of the Portable Soft Barricade.

Upon impact, the device wrapped around the front bumper and hood of the vehicle. The sign panel shattered upon impact and dispersed around the initial point of impact, with several of the larger pieces flying over the vehicle's roof. The two 50-lb (22.7-kg) sand bags, placed on the sign to give it stability, were destroyed on impact and the sand was scattered over the impact zone.

After the initial impact, the sign frame slid off the hood, to a position before the vehicle. There was no further contact between the sign frame and the test vehicle as both pieces came to rest.

The brakes on the vehicle were applied approximately 140 ft (42.7 m) past the initial point of impact. The vehicle came to rest nearly 220 ft (67.1 m) downstream. The A-frame continued sliding for another 70 ft (21.3 m) , a total distance of 290 ft (88.4 m) from point of impact.

The test conditions and results are summarized in table 19.

Vehicle Damage

There was only superficial damage done to the test vehicle. Damage was limited to minor scratches and dents on the hood surface where the sign frame made contact with the vehicle, and minor damage to the vehicle's plastic grill area.

Device Damage

The Portable Soft Barricade was destroyed during this test. The sign panel shattered into many small pieces. The A-frame stayed together but the lower legs were bent nearly 80 degrees.

Photographs after test 2036-CW2-91 are shown in figure 63.

Test Evaluation

This test was evaluated using criteria D and E from NCHRP 230 and the Work Zone Hazard criterion. The following is an item-by-item evaluation using these criteria.

NCHRP 230 Criterion D:	Detached elements, fragments or other debris from the test article shall not penetrate or show potential for penetrating the passenger compartment or present undue hazard to other traffic.

This device criterion D.

NCHRP 230 Criterion E:	The vehicle shall remain upright during and after collision although moderate roll, pitching and yawing are acceptable. Integrity of the passenger compartment must be maintained with essentially no deformation or intrusion.

This device met criterion E.

Table 19. Crashworthiness Test Summary for the Portable Soft Barricade

Parameter	Value
Test Number:	2036-CW2-91
Date:	January 29, 1991
Test Vehicle:	1985 Dodge Colt
Test Device:	Portable Soft Barricade
Vehicle Weight:	
Planned, Inertial:	1800 ± 50 lb
Actual, Inertial:	1813 lb
Planned, Gross:	1950 ± 50 lb
Actual, Gross:	1978 lb
Number of Occupants:	One
Occupant Model:	Part 572 Anthropomorphic 50th percentile male
Occupant Location:	Driver Seat, Restrained
Impact Conditions:	
Planned Speed:	45 mi/h
Actual Speed:	45 mi/h
Planned Angle:	0°
Actual Angle:	0°
Planned Location:	Centered
Actual Location:	Centered
Test Results Conclusion:	This device successfully met the evaluation criteria.

1 mi/h = 0.45 m/s, 1 lb = 0.45 kg

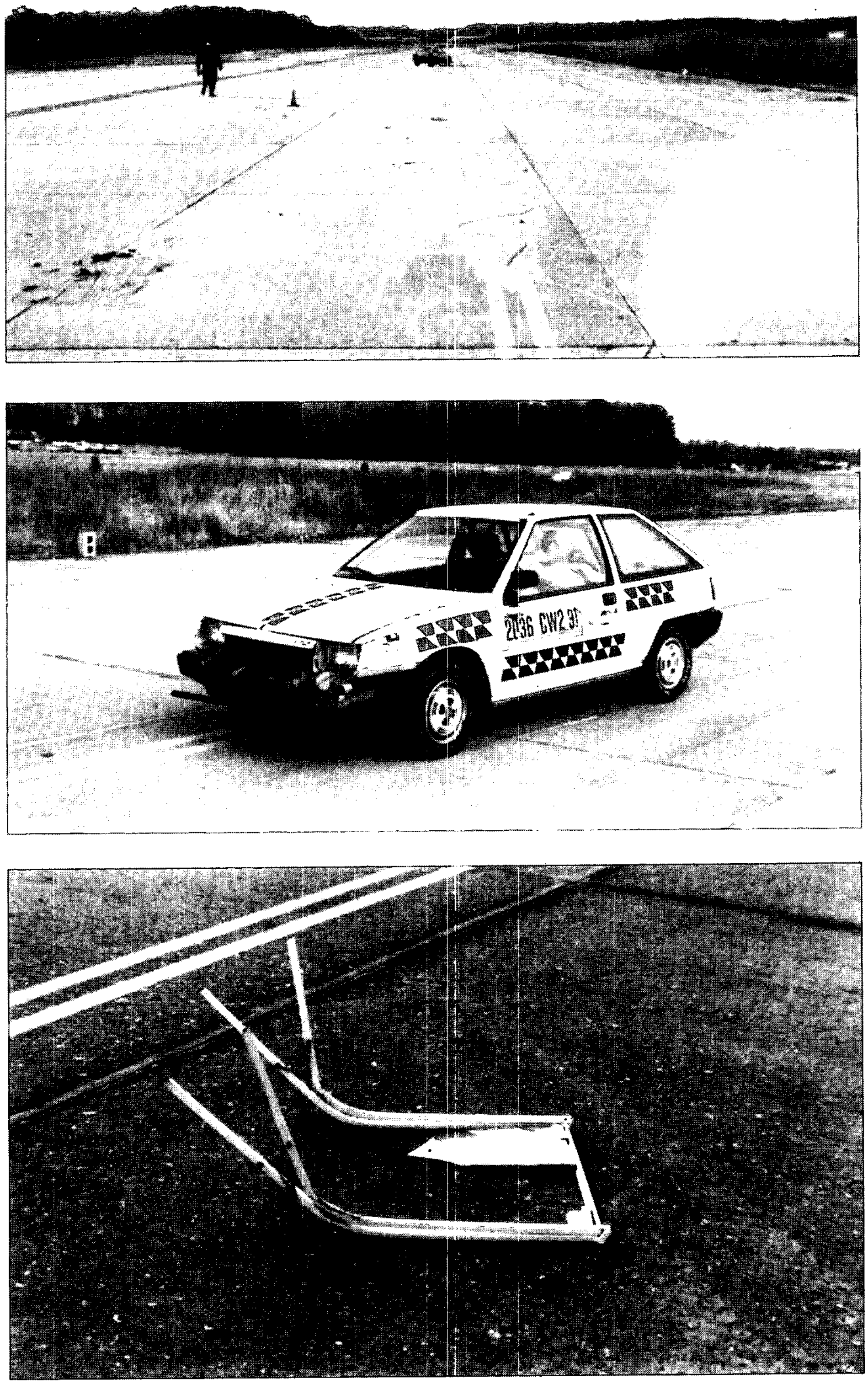


Figure 63. Portable Soft Barricade After Test, Test 2036-CW2-91

Work Zone Hazard Criterion: The device must not present a hazard to workers in the work zone following an impact by an errant vehicle.

This device met the Work Zone Hazard Criterion.

This device successfully met the evaluation criteria.

Conclusions and Recommendations

- The Portable Soft Barricades should have a system for attaching sandbags for stability.
- Some type of tension device or shock absorber should be used to keep the panel from hitting the barricade legs.
- For Type II barricades, two smaller panels may have greater stability than one large panel.

Maintenance Vehicle Floodlight

The Maintenance Vehicle Floodlight is shown in figure 64.

Background

The Maintenance Vehicle Floodlight is intended to help motorists see snowplows when they are obscured by blowing snow and spray. The device was conceived based on data from the SHRP Maintenance Work Zone Safety Project (H-108) accident study, where it was found that winter maintenance accidents represent the largest percentage of accidents in terms of hours spent on the road for various maintenance activities. In addition, rear-end accidents with snowplows are the most common type of winter maintenance accidents. Obviously, there is some problem with visual distance perception or closing speed determination due to the cloud of snow around the plow.

A driver approaching a snowplow must be aware of the presence of the plow ahead, and also must recognize the closing speed (i.e., that the plow is moving slowly relative to the motorist). The recognition must occur in time for the motorist to perform a safe adjustment of speed or path, particularly on a slippery roadway surface. The Maintenance Vehicle Floodlight is designed to make the snowplow easier to see from a distance under adverse visibility. Approaching drivers must recognize the light as indicating the presence of an obstacle, even if they have no immediate awareness that the object is a snowplow. The driver must also be able to judge the distance, speed, and closing rate of the plow in order to plan and execute braking or steering maneuvers.

Device Description

The device was created from a number of metal straps and a U-shaped bar made of steel square channel, arranged so that an array of floodlights could be mounted to point at the rear of the maintenance vehicle. The floodlights were also installed on movable mounts, so that they could be swiveled and turned to point in nearly any direction. The metal strap structure was also intended to be adjustable, so that different locations for the lighting array relative to the truck could be tried.

Design and Fabrication

The metal straps connecting the top of the U-shaped bar with the top of the vehicle were drilled with holes at various distances along their length to allow the bar to be rotated relative to its base point at the bottom of the vehicle's bed. The square channel bar with the floodlights was constructed with a sleeve arrangement so that the lights could be moved farther away from the base point of the bar at the bottom of the vehicle's bed. This allowed for easy adjustment of the position of the light bar.

Operational Testing

The prototype Maintenance Vehicle Floodlight was installed on the SHRP experimental snowplow at the University of Wyoming. Videotapes were made of the operation of the device under clear conditions during the day and night. The floodlight's placement and aiming was optimized during these tests. The plow was also driven on various terrain to make sure that the lights could take the vibration of the maintenance vehicle while plowing.

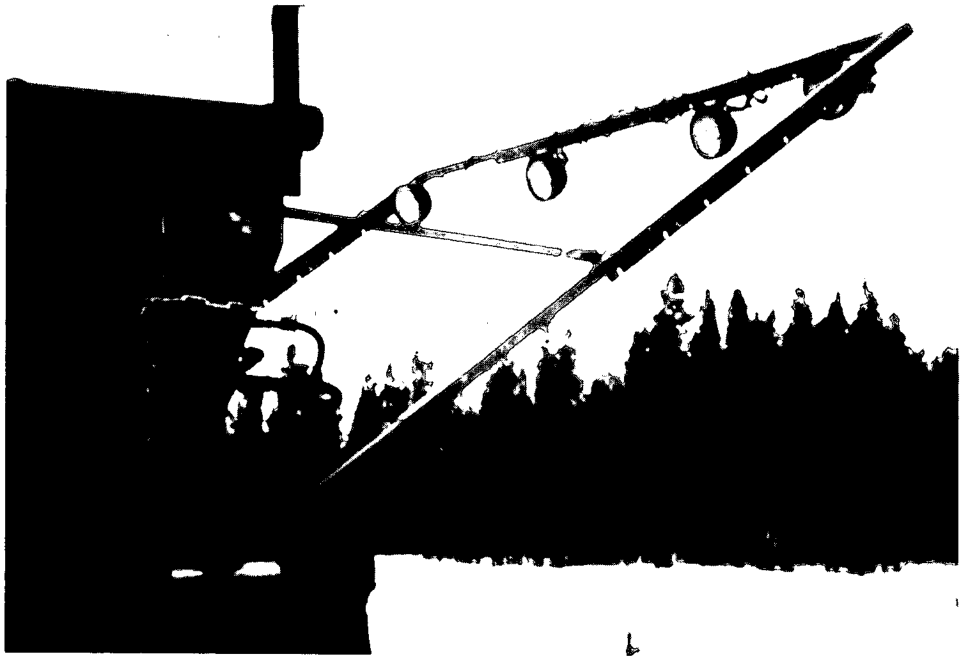


Figure 64. Maintenance Vehicle Floodlight

During the course of these tests, it became obvious that the Maintenance Vehicle Floodlight would not be visible under daytime clear skies. The device did illuminate the back of the truck at night, however, and it was hoped that the reduced ambient light levels normally associated with snowstorms would make it possible to see the effects of the Maintenance Vehicle Floodlight during these kinds of conditions.

After installation of the device on the University of Wyoming snowplow, the plow was taken from Laramie, Wyoming to West Yellowstone, Montana. Most of the tests were conducted on two unused roads at the West Yellowstone Municipal Airport. The roads were barricaded to keep traffic out. Data collected were simply videotapes made from a following vehicle and from the cab of the plow vehicle. Videotape drivethrough logs were made of the roads during clear conditions.

The videotape data shows that the floodlight did significantly increase visibility at night. The effect of the floodlight however, was completely washed out by ambient light during all daytime testing. It was also completely ineffective while the plow was obscured by the snow cloud created by plowing deep snow at high speed. There was even one test performed on an open section of Montana highway during the twilight hours while snow was falling. Even under these conditions, the Maintenance Vehicle Floodlight was deemed ineffective.

Conclusions and Recommendations

Since the entire plow was obscured in the operational testing, plans for further open highway testing were discontinued. The idea is good, and it certainly addresses an important problem with maintenance safety. While the physical implementation of the device designed in this project failed to accomplish its objective, it is possible that another implementation might succeed. Repositioning the lights above the truck or the use of spotlights (1-million candlepower or greater) might enhance the device's effectiveness. In addition, though no testing of this kind took place, it is felt that the device might be effectively used during foggy conditions.

Truck Mounted Message Box

The Truck Mounted Message Box is shown in figure 65.

Background

Trucks carrying materials to maintenance work zones must slow down while in traffic before entering the work area. Many times vehicles will follow these trucks into the work area. A device that could be activated near the work area to warn drivers that a truck was slowing could reduce this problem.

The Truck Mounted Message Box would work like a variable message sign to alert approaching drivers to the presence of mobile maintenance operations. For the device to be effective, it must be detected by the driver and be legible at an adequate distance. The meaning of the message must be comprehended. Once comprehended, the motorist must also understand the appropriate action to take. All of this must occur at an adequate distance from the maintenance operation so that maneuvers may be safely made.

Device Description

The Truck Mounted Message Box is an economical message sign consists of a 6-ft (1.8-m) long rectangular box with a clear plastic face panel, painted all black except for stenciled, 8-in (20.3-cm) high letters forming the word "SLOWING". High-intensity flashing lamps would reflect off of a polished aluminum backdrop to shine through the clear plastic letters, thus creating the effect of white flashing letters on a dark black background. The box would attach to the tailgate of a maintenance vehicle to convey necessary speed reductions or lane changes and to help avoid rear-end collisions between slowing maintenance vehicles and traffic.

Design and Fabrication

The lettering of the device had to be large and conspicuous. For this reason, the message had to be limited to eight letters. Unfortunately, it is difficult to convey a definitive message with only eight letters. Lighting was another consideration. Some specific concerns were: Would the light be enough to be seen in daylight? Would bright lights wash out the message? Would reflected light be as effective as direct light?

Some limitations of the device would be required as a trade-off for low cost and easy maintenance. These limitations included, for example, the restricted letter size and the use of stenciled letters rather than letters made up of lamps. Suggestions for redesigning the device would probably defeat the proposal's original concept for an inexpensive, easy-to-use changeable message sign for mobile maintenance zones.

The prototype was very similar to the design proposed, except that the proposal called for black letters on a white background, while the prototype had white letters on a black background. The box was constructed from 0.75-in (1.9-cm) marine plywood. The face panel was scratch-resistant plastic. The box was 18 in (45.7 cm) high, 10 in (25.4 cm) wide and 6 ft (1.8 m) long. The precut message boards were made from 0.25-in (0.6-cm) exterior A-B plywood, as were the individual letter templates and blanks. The unit used five high-intensity white bulbs to reflect light off of the polished aluminum interior surface and shine through the sign for approximately two seconds before flashing off for two seconds. The lamps are mounted in a rubber grommet for shock absorption.

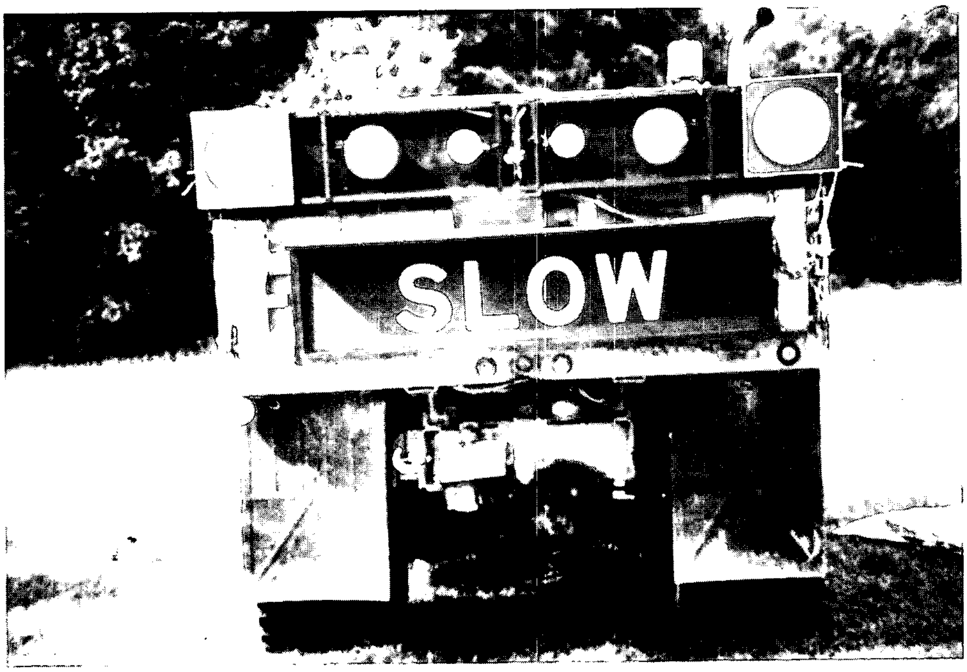


Figure 65. Truck-Mounted Message Box

As mentioned above, the only major change made to the proposed design was the message board. The message board was made of opaque white plastic, with the letters white and the background painted black. This change made the message board cheaper and lighter.

Operational Testing

The unit was attached to the back of a dump truck and viewed by the project staff during the day and at night. The unit was not visible as a lighted device during the day, and hardly visible at night. A variety of bulbs were tested ranging in power from 25 to 50 watts. The device's performance did not improve. Sealed beam headlights were used to replace the bulbs. Incandescent and halogen sealed beams ranging from 25 to 50 watts were tested. The best result was round white spots in the message at night; the worst was no improvement in performance. None of the operational tests were considered successful.

Recommendations and Conclusions

Though the concept of this device is very good, results of the operational tests did not justify more testing of this particular implementation of the concept. The addition of a generator or more costly lighting would have defeated the device's objective of providing an inexpensive, easy-to-use, changeable message sign for mobile maintenance work zones. If sufficient improvements are made in cheap, low wattage, high-intensity lights, this concept should be reexamined.

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