

Information Circular 8947

Safety in the Use and Maintenance of Large Mobile Surface Mining Equipment

**Proceedings: Bureau of Mines Technology Transfer
Seminars, Tucson, AZ, August 16, 1983, Denver, CO,
August 18, 1983, and St. Louis, MO, August 23, 1983**

Compiled by Staff, Bureau of Mines



UNITED STATES DEPARTMENT OF THE INTERIOR

James G. Watt, Secretary

BUREAU OF MINES

Robert C. Horton, Director

This publication has been cataloged as follows:

**Bureau of Mines Technology Transfer Seminars (1983 :
Tucson, AZ, Denver, CO, and St. Louis, MO)**

Safety in the use and maintenance of large mobile surface mining equipment.

(Information circular / Bureau of Mines ; 8947)

Contents: Introduction / by Wm. Thomas Cocke--Solving the problem of getting on and off large surface mine mobile equipment / by Dennis A. Long--Collision protection technology / by William C. Yates--[etc.]

Supt. of Docs. no.: I 28.27:8947.

1. Strip mining--Safety measures--Congresses, I, United States. Bureau of Mines. II. Title. III. Series: Information circular (United States. Bureau of Mines) ; 8947.

TN295.U4 [TN29 1] 622s [622'.31'0289] 83-14429

PREFACE

This Information Circular summarizes recent Bureau of Mines research results concerning improved safety and health in the operation of large mobile surface mining equipment. The papers are only a sample of the Bureau's total research effort in this area, but they outline major portions of the program.

Eight of the ten technical papers reproduced here were presented at Technology Transfer Seminars on Safety in the Operation and Maintenance of Large Mobile Surface Mining Equipment given in August 1983 in Tucson, AZ, Denver, CO, and St. Louis, MO. Those desiring more information on the Bureau's surface mine health and safety programs in general, or information on specific situations, should contact the Bureau of Mines Division of Health and Safety Technology, 2401 E St., NW., Washington, DC 20241, or the appropriate author listed in these proceedings.

CONTENTS

	<u>Page</u>
Preface.....	i
Abstract.....	1
Introduction, by Wm. Thomas Cocke.....	2
Solving the Problem of Getting On and Off Large Surface Mining Equipment, by Dennis A. Long.....	3
Radio Wave-Transponder Collision Protection System, by William C. Yates, Guy A. Johnson, and James J. Olson.....	17
Novel Truck-Design Concepts, by Guy A. Johnson.....	30
Operator Alertness Studies, by Richard J. Wilson.....	34
Large ROPS and Operator Restraint Device Research, by Stephen A. Swan.....	45
Off-Highway Haulage Truck Maintenance Safety, by Dennis A. Long.....	55
Performance-Based Training for Mobile Equipment Operators, by Brett Collins, Kris Krupp, and Richard L. Unger.....	63
Stability Indicators for Front-End Loaders, by Gilbert Wray and August J. Kwitowski.....	67
Bulldozer Noise Control, By R. C. Bartholomae and T. G. Bobick.....	81
Improved Haul Road Berm Design, by Gregory G. Miller, Gary L. Stecklein, and John J. Labra.....	87

SAFETY IN THE USE AND MAINTENANCE OF LARGE MOBILE
SURFACE MINING EQUIPMENT

Proceedings: Bureau of Mines Technology Transfer Seminars,
Tucson, AZ, August 16, 1983, Denver, CO, August 18, 1983,
and St. Louis, MO, August 23, 1983

Compiled by Staff, Bureau of Mines

ABSTRACT

These proceedings consist of papers presented at Bureau of Mines Technology Transfer Seminars in August 1983 for the purpose of disseminating recent advances in mining technology in the area of large mobile surface mining equipment safety and health. The Bureau of Mines conducts several of these seminars each year in order to bring the latest results of Bureau research to the attention of the mining industry as quickly as possible.

INTRODUCTION

By Wm. Thomas Cocke¹

Problems relating to the operation of large mobile surface mining equipment were addressed in a Bureau of Mines Technology Transfer Seminar on Safety in the Operation and Maintenance of Large Mobile Surface Mining Equipment. The following papers were either presented at the seminar or relate to the subject. The topics covered are ingress-egress safety, collision avoidance, novel truck design, operator alertness studies, ROPS, operator

restraint devices, maintenance safety, operator safety training, improved haul road berm design, stability indicators for front-end loaders, and retrofit noise control for bulldozers.

The objective of the Bureau of Mines is to improve technology and make it cost effective so that its acceptance and use by the mining industry will occur voluntarily. For the results of Bureau research to be used, those results must be disseminated. That is the purpose of Technology Transfer Seminars.

¹Staff engineer, Office of Technical Information, Bureau of Mines, Washington, DC.

SOLVING THE PROBLEM OF GETTING ON AND OFF LARGE SURFACE MINING EQUIPMENT

By Dennis A. Long¹

ABSTRACT

Slip and fall accidents are a major cause of lost-time injuries associated with large mobile equipment in surface mines. An evaluation of the safety hazards associated with ingress and egress on these vehicles showed that most of the accidents occur at the point where personnel attempt to mount or dismount the machine at ground level. The major hazardous design conditions were identified as excessively flexible supports for lower steps or rungs, inappropriate ground-level-to-first-step distances, poor step

designs, access designs that use machine components as steps or walkways, and inadequate handrail and guardrail designs. Additional hazards are introduced by the lack of proper maintenance of ladder hardware and the work practices of operators in carrying articles onto the truck. Several improved systems were designed and tested for accessing large mobile mining equipment. These new systems have undergone long-term testing in operating mines.

INTRODUCTION AND STATEMENT OF THE PROBLEM

Mobile equipment manufacturers and mining companies both recognize the problem of getting on and off the large mining equipment operating in today's surface mines. Overall, there is a lack of design standards for ingress and egress systems, as evidenced by the diversity of ladder designs, and access systems appear to be added as an afterthought to the overall equipment design. In short, the system design concepts employed for most of the machine features are not generally applied in ladder access system designs.

The Bureau of Mines awarded contracts for on-site reviews to identify design deficiencies associated with access ladders currently used in operating surface mines. These reviews focused on handrail designs, step and ladder designs, ladder and step placements, ground clearance problems, environment-induced problems, and other factors.

This research identified the following significant ingress and egress system design deficiencies:

1. Inadequate handrail and guardrail designs that increase the difficulty of mounting and dismounting the vehicle.
2. Excessively flexible lower section supports for lower steps or rungs on ladders that make ascent or descent difficult and hazardous.
3. Inappropriate ground-level-to-first-step distances that require personnel to take unsafe positions to climb onto equipment.
4. Step designs that permit mud, snow, ice, grease, and oil accumulations and thus result in hazardous footing.
5. Access systems that require the use of equipment components as primary steps, such as the track on dozers and shovels.

¹Mining engineer, Twin Cities Research Center, Bureau of Mines, Minneapolis, MN.

The ingress-egress problem involves two distinct mobile equipment types. The first category includes haulage trucks and front-end loaders. These vehicles utilize either vertical or nearly vertical ladder access systems positioned in the vicinity of the cab. Analysis has shown that the chief hazards in the ladder designs are found in the first steps

of the ladder, where the operator mounts or dismounts the machine. The second category includes tracked vehicles, such as dozers, shovels, and draglines. These vehicles have one common hazard: The primary access system usually involves using the track component as a step or walkway.

SAFETY HAZARD ASSESSMENT

Evaluation of the safety hazards associated with mobile equipment in surface mines confirmed that slip and fall accidents account for a substantial proportion of vehicle-related accidents. Slips and falls while ascending or descending the machines constitute over one-third of all lost-time accidents associated with the operation of haulage trucks, front-end loaders, track dozers, shovels, and draglines. These five equipment types account for 80 pct of the mobile equipment found in U.S. surface mines.

A review of Mine Safety and Health Administration data revealed that almost 2,000 slip and fall accidents occurred on surface mine mobile equipment during the 1978-79 2-year period. These accidents accounted for almost 30,000 lost employee days. The average slip and fall resulted in 15.3 lost days. The characteristic

injuries resulting from ingress-egress activity are cuts, lacerations, contusions, fractures, sprains, and strains. The hands, fingers, back, legs, and feet are the body parts most frequently injured in these accidents.

The slip and fall accident reports were further analyzed to determine where in the process of mounting or dismounting the machine operators or maintenance personnel are getting hurt. This further breakdown revealed that over 40 pct of all surface mine slip and fall accidents were attributable to the first step onto the vehicle as the operator attempted to mount or dismount the vehicle. The hazard is greater on track dozers, which experience nearly 60 pct of all slip and fall accidents occurring during the attempt to mount or dismount the vehicle.

HAULAGE TRUCKS AND FRONT END LOADERS

CURRENT DESIGN PROBLEMS

Off-highway haulage trucks usually have ladders mounted on the front of the truck adjacent to the left side of the engine compartment (figs. 1-2), with the angle of inclination between 75° to 90° (vertical). On some truck models the bumper is used as part of the ladder structure (fig. 3). The ladders used on almost all front-end loaders are located directly alongside the cab. Some front-end loaders use movable or retractable ladders in which the operator must pull down the ladder unit to mount the vehicle.

The problem of vehicle ground clearance is critical within the open pit mine environment, and mobile mine vehicles are typically designed to ensure about 3 ft of ground clearance. However, the lower portion of the primary ladder assembly must be below this level for the operator to reach the first step, which places the first two steps in a vulnerable position at the front corner of the truck. At this position the ladders are subjected to frequent damage from objects in the roadway and from striking guide berms or other obstructions.

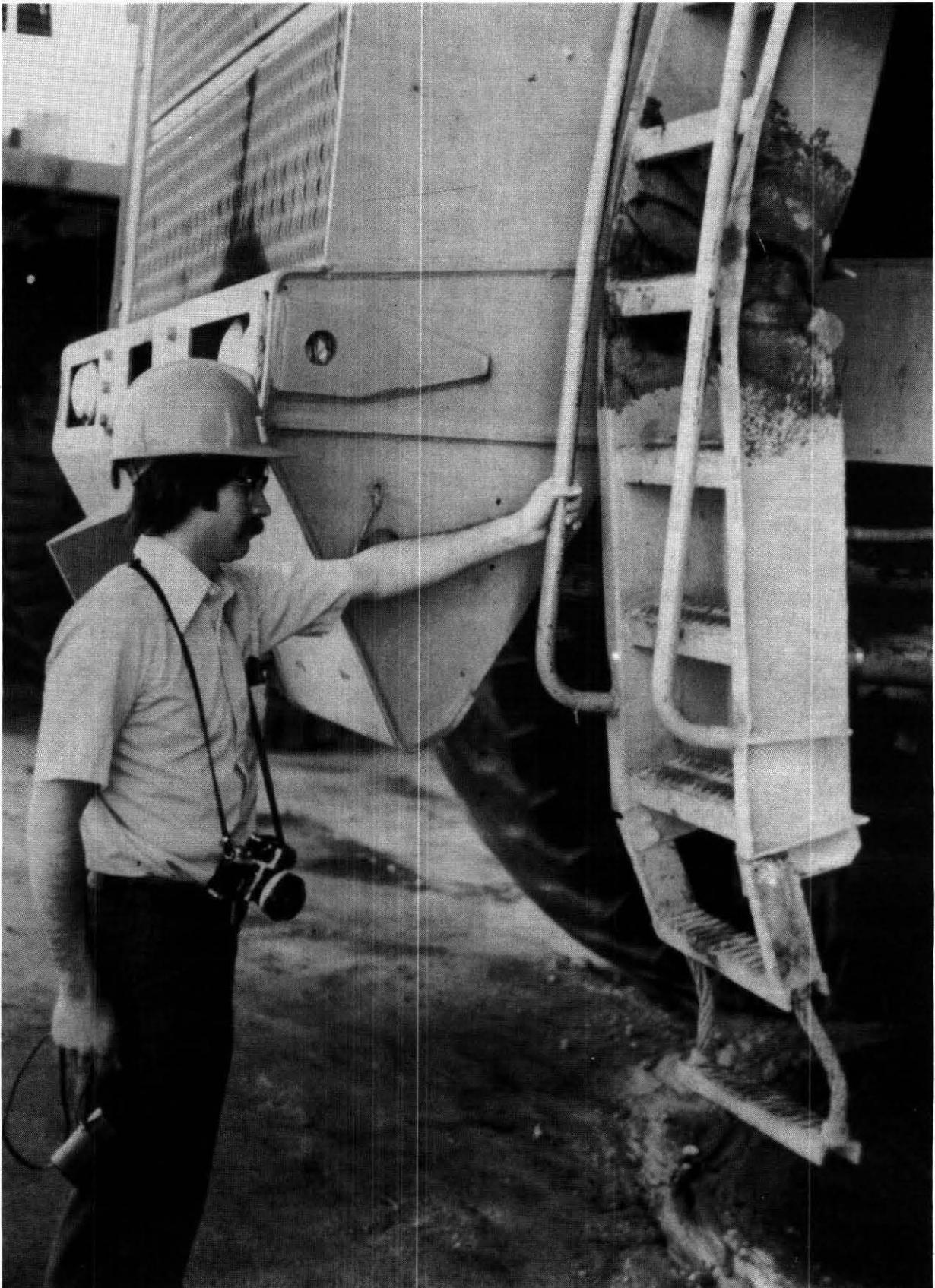


FIGURE 1. - Typical ladder on off-highway haulage truck.

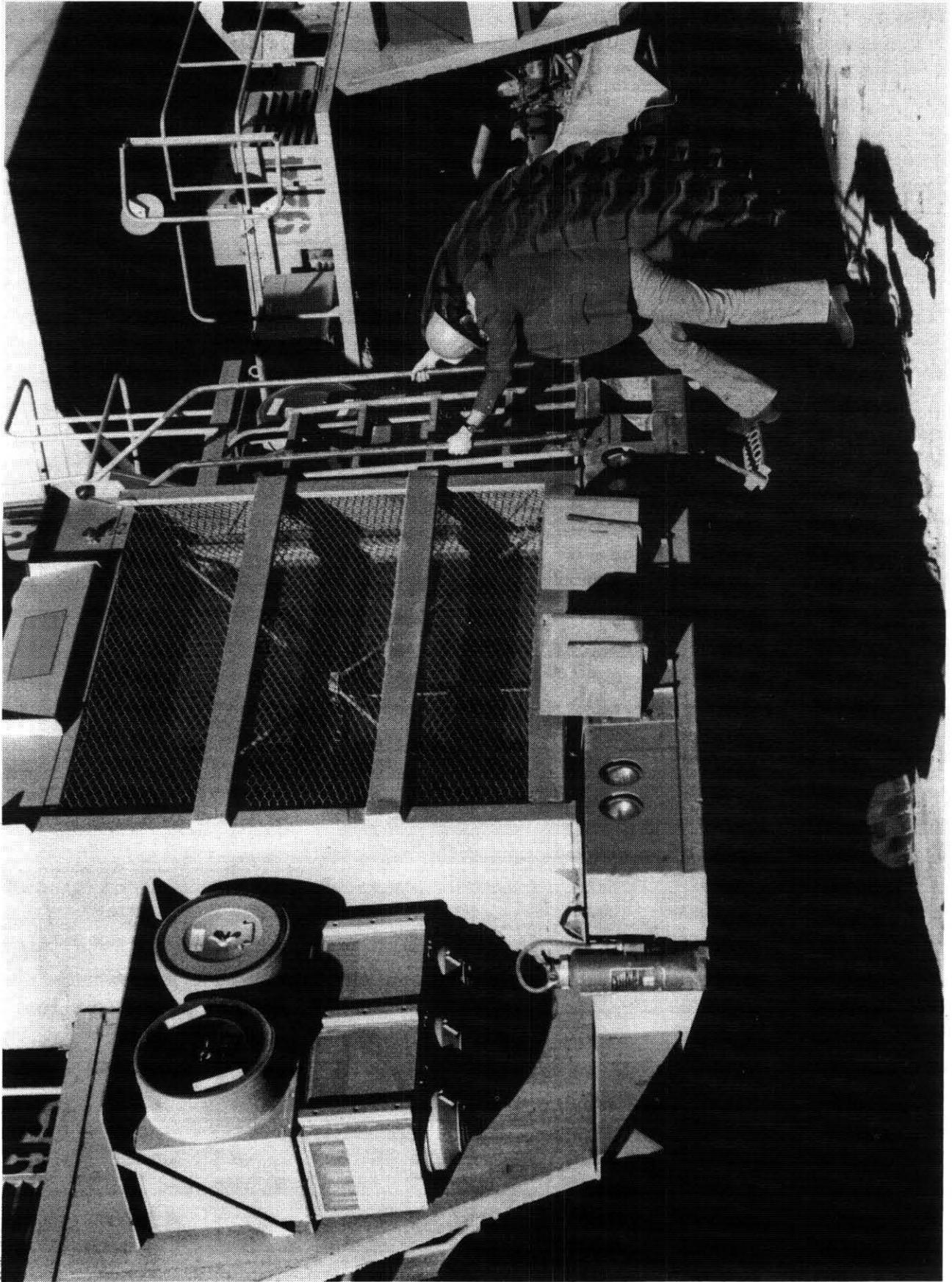


FIGURE 2. - Mounting typical ladder on off-highway haulage truck.

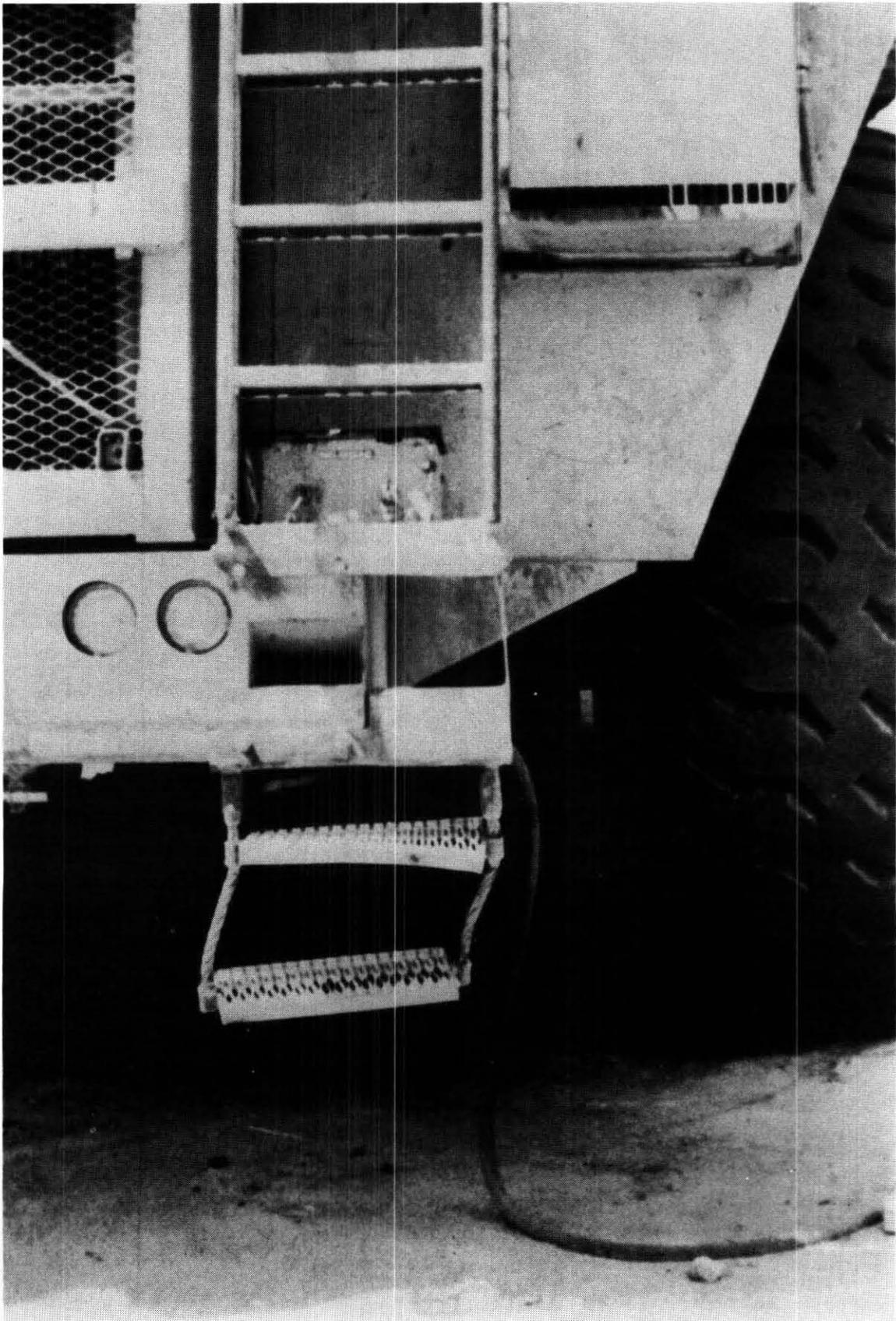


FIGURE 3. - Truck ladder using bumper as part of ladder system.



FIGURE 4. - Wire-rung lower truck ladder.

The prevalent solution to this problem is to suspend the lower one or two steps on a cable which is then mounted to the bumper or the rigid section of the ladder. These wire rope or cable steps are invariably knocked out of position and do not return to their initial configuration (figs. 4-5). The height of the lower rung above the ground ranges between 36 and 42 in. The flexible ladder supports for the lower steps, and the fact that they are still too high for the operator to safely mount and dismount the machine, contribute to slipping and falling accidents.

DEVELOPMENT OF AN IMPROVED, SPRING STEP LADDER

In 1978 the Bureau of Mines began work to design and develop improved

ingress-egress systems for surface mine mobile equipment, with the primary goal of solving the problem of lower ladder design. Several primary lower ladder designs were subjected to human factors field evaluation and structural testing demonstrations. As a result of the initial field demonstrations, the Bureau concluded that a four-spring design (figs. 6-7) could appreciably reduce slip and fall accidents on haulage trucks and loaders. The prototype lower steps substantially reduced the height of the first step and were much more rigid when stepped on or off. Because of their high stiffness coefficient and the pre-tensioning of the springs, the prototype lower steps closely maintained both step distance and angular inclination of the ladder.

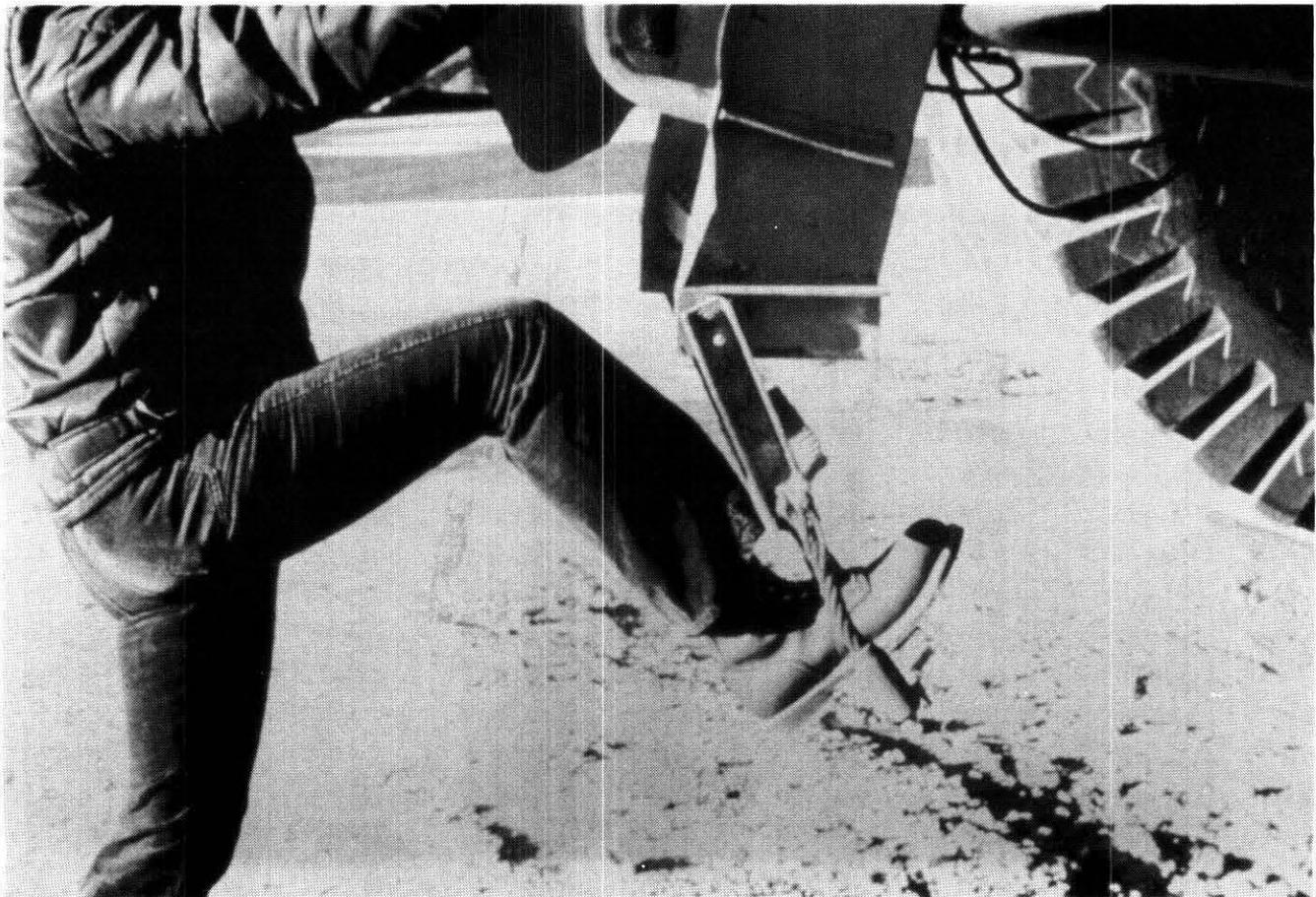


FIGURE 5. - Closeup of wire-rung lower truck ladder.



FIGURE 6. - Bureau of Mines spring step.



FIGURE 7. - Bureau of Mines spring step striking a boulder.

Since 1978 some 30 spring steps have been field-tested at 13 mines on 27 surface mine vehicles. The maintainability of the spring ladders varied widely from mine to mine. At some mines the ladders sustained damage after 3 or 4 weeks, while at other mines, ladders remained on the trucks with little or no damage for more than a year. Failure of the spring step occurred owing to a variety of reasons. The most common reasons included shear at the point where the step is welded to the ladder, spring failure resulting from low ground clearance, and lack of operator or supervisory acceptance.

The results of the field testing indicated that the pretensioned spring step was a viable solution to the first-step access problem. However, the testing also showed that proper installation techniques, correct vehicle applications, and positive management support were important for long-term spring step survival.

Proper supervision and management support is essential for long-term success. Some of the test units that might have realized longer life through simple maintenance and repair were quickly replaced with the traditional "home-made" steps at the slightest sign of failure. Operator acceptance is also important, because in several cases it seems that the vehicle operator was putting the step to the test. The spring step unit is not indestructible.

HOW IT WORKS

The spring ladder concept is shown in figure 8. The unit consists of two steps constructed from grip strut material to minimize the accumulation of debris and provide an antiskid surface for good footing. The steps are joined with two pairs of spring assemblies and mounting brackets. The mounting brackets consist of a flat plate and a collar to support the spring, which is welded to the

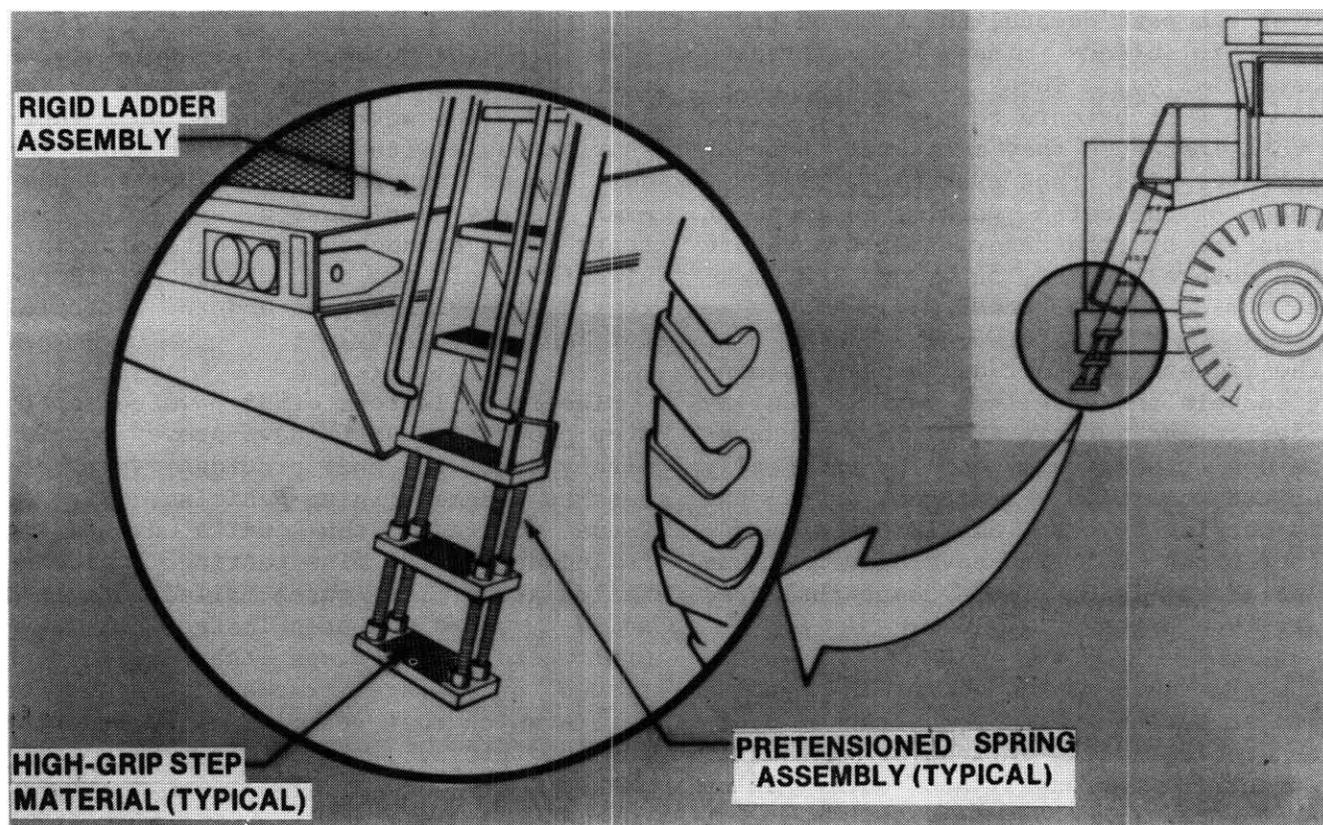


FIGURE 8. - Bureau of Mines pretensioned four-spring step.

flat plate. The springs are fabricated from stainless steel and pretensioned to 150 lb.

The spring step is a totally passive system and needs no activation by the operator. The steps support the weight of the operator with less than 2 in deflection. The ground clearance required for rigid ladders mounted on large mining equipment is commonly 36 to 54 in. Owing to the flexible and durable spring-mounted supports, the new ladders can be mounted with the bottom step about 30 in above the ground.

Other applications are also available for the spring step concept. On two trucks, a single-step spring ladder was installed in place of the standard oil check step. These ladders experienced no

damage during the program; however, these steps were mounted in a more protected area under the engine compartment. On certain lower capacity front-end loaders and haulage trucks, a single-step ladder was installed to extend the existing ladder.

The Bureau has made significant improvements in design and fabrication since the first version of the spring step. As a result of long-term in-mine testing, a new, more durable pretensioned spring step has been fabricated. The lower ladder unit has a modular design, allowing replacement of individual parts. Wherever possible, the double spring step should be used for optimum survivability. The improved ladders can be installed at reasonable cost on operating trucks or new ones.

TRACK DOZERS AND SHOVELS

CURRENT DESIGN PROBLEMS

Over the past decade, the size of track dozers in surface mines has increased substantially. Today operators must climb up 4 ft or more to mount the dozer. In most instances they must step onto or climb over the track assembly (fig. 9). Because of the harsh working environment encountered by the dozer, the tracks are often covered by mud, snow, or ice, making them an unsafe access way.

The ladder and stair units used on mining shovels and draglines vary in quality of design and safety. Many large excavators use electrically or hydraulically operated stairways for access up to the main decking or cab. Small to medium machines often utilize several variations of pulldown ladders or counterbalanced stair-type units (fig. 10).

The Bureau's work determined that an improved access system for tracked vehicles would result in a safer method of transporting personnel and materials up and over the track assembly.

DEVELOPMENT OF THE POWERED SAFETY STEP

In 1976 the Bureau chose to evaluate the powered safety step designed by Ted Rivinius. The work, conducted on a cost-sharing basis with Rivinius, included the development and fabrication of the powered safety step design. Then in-mine tests were conducted to determine survivability of the step prototype in the rugged mine environment and the potential for improved safety.

Mine installations of 35 powered safety step production units have proven conclusively that the unit provides safer access to tracked mining vehicles. Five of these powered step units eventually failed during the mine testing. One step failed after 5 yr, three failed between 1 and 2 yr, and one step lasted only several weeks. The steps that failed were tested on haulage trucks, scrapers, or dozers which must work in close, confining conditions.

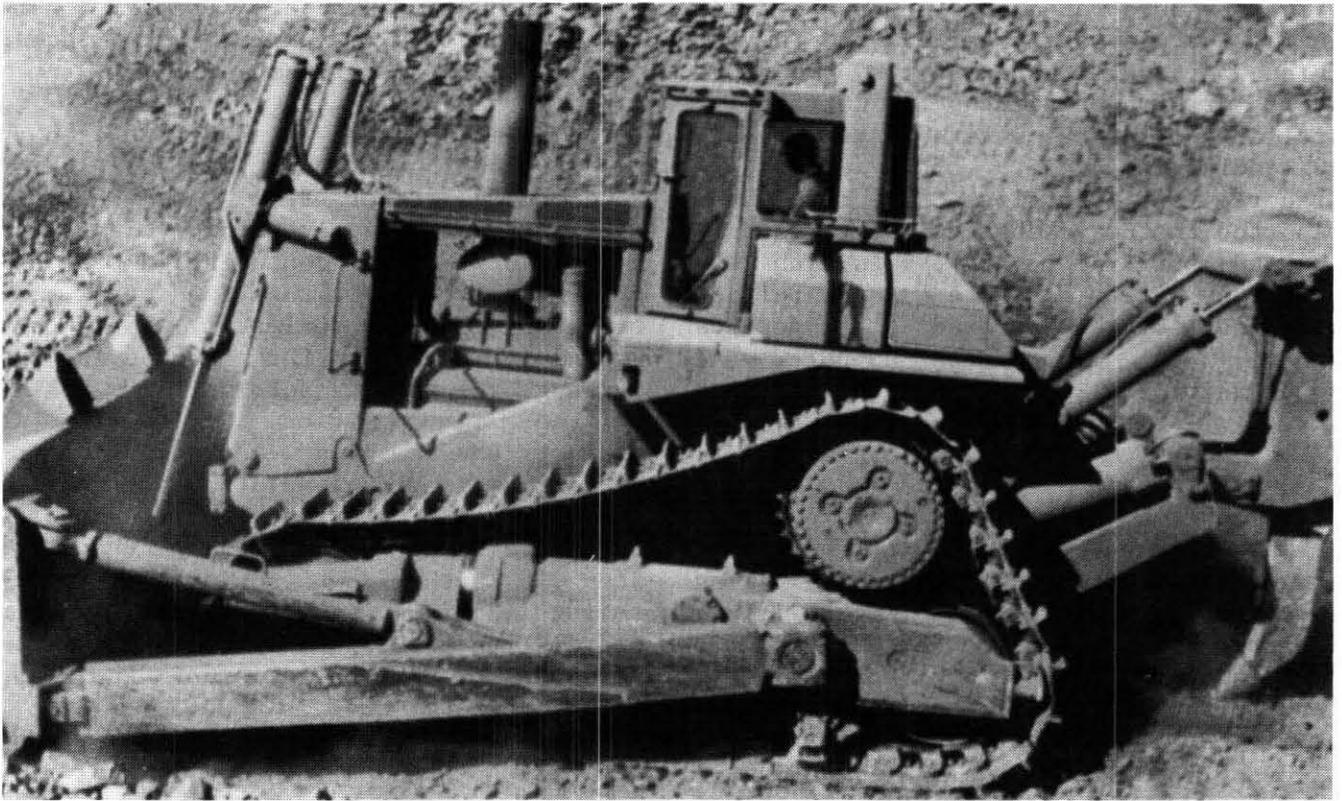


FIGURE 9. - Typical track dozer.

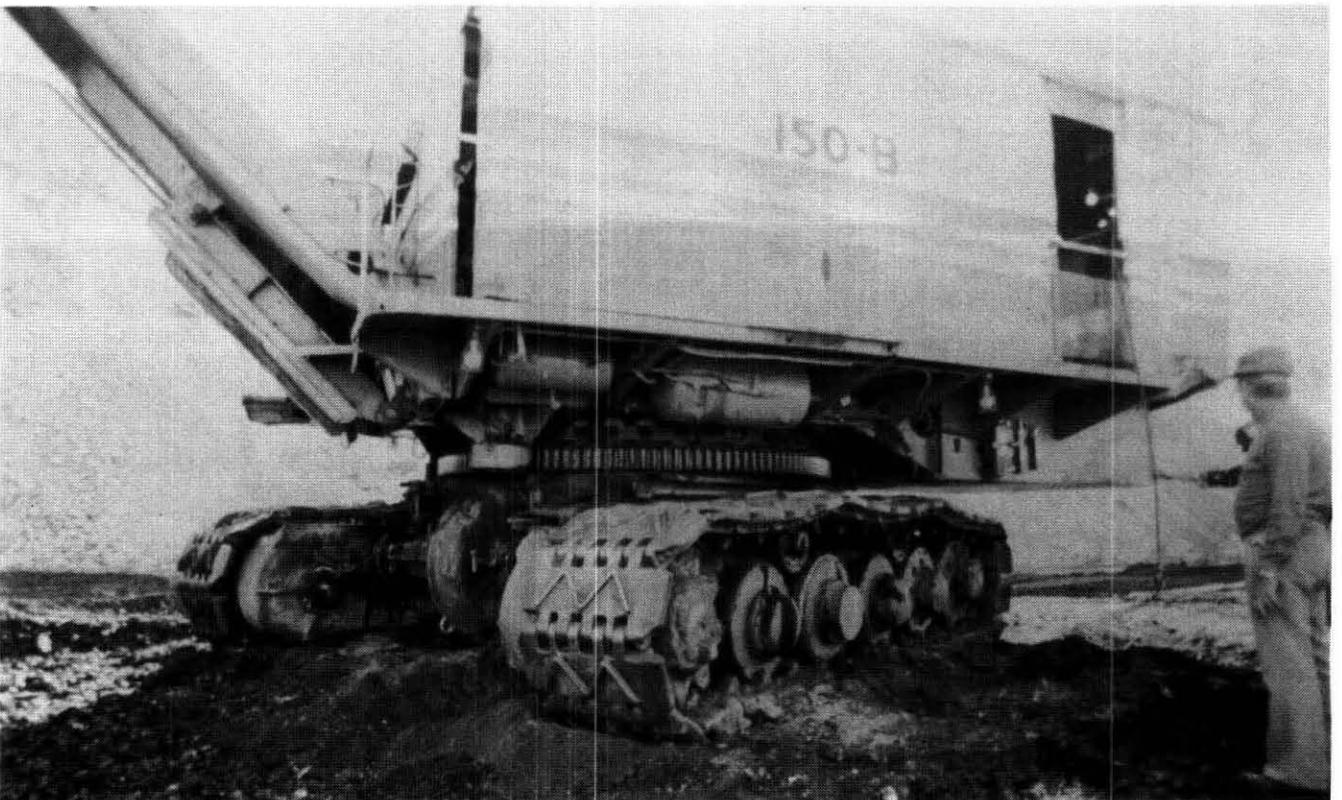


FIGURE 10. - Typical loading shovel.

To date 30 powered step units are still in active use as installed on the machines. Several step units have seen over 5 yr of continued use. Current installations of the powered step include 18 loading shovels, 9 track dozers, 2 graders, and 1 dragline. The mines have reported that maintenance is surprisingly low and survival is high. As with any prototype safety hardware, successful application of the powered step depends greatly on management support and supervision.

HOW IT WORKS

The powered safety step is a hydraulically powered device to lift personnel and materials from the ground to working levels on large equipment (figs. 11-12). The primary application of the powered step is on the large track dozers, shovels, and draglines. The powered unit eliminates hazardous blind steps and

makes it unnecessary for operating personnel to climb on irregular surfaces, such as the track or push arm.

The powered safety step is powered by a self-contained electric-hydraulic unit. Power comes either from the vehicle's auxiliary power supply or from the step's own battery source, depending on the application. When in the "down" position, the step rests approximately 15 in from ground level. When the machine is operating, the step is automatically locked in the "up" position, protecting it against any damaging contact with obstructions. Visual alarms and machine interlocks are provided where necessary to prevent machine operation when the step is in the "down" position. On rotating machines, such as draglines and shovels, an electrical interlock is provided to prevent operation of the swing motors when the step is down.

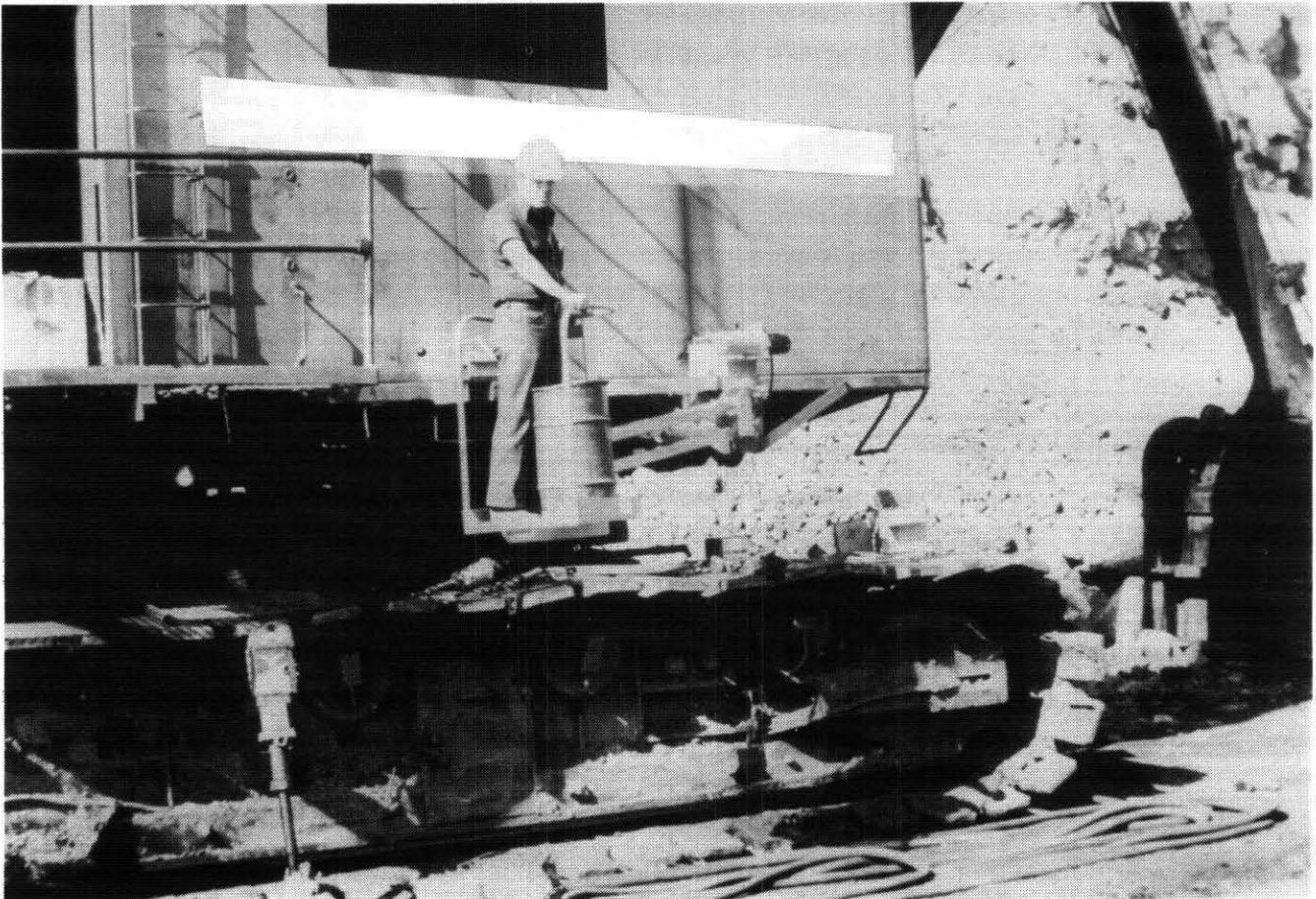


FIGURE 11. - Powered safety step on a loading shovel.

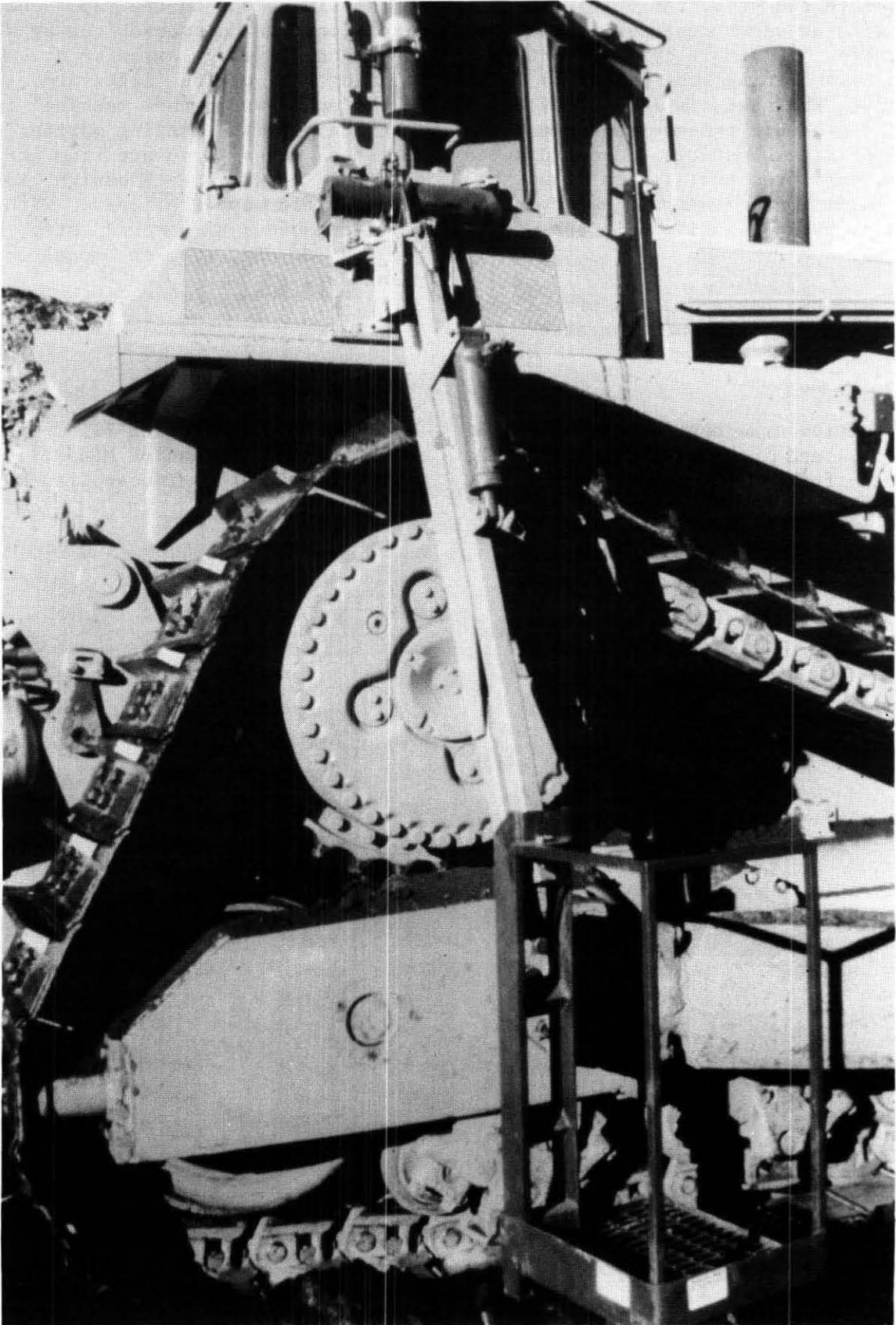


FIGURE 12. - Powered safety step on a track dozer.

To operate the step, the unit is activated with an electrical switch located on the step. A single cylinder attached between two lifting arms smoothly lifts the step. The step is lowered by activating a pressure-release solenoid. An in-line orifice controls downward speed and prevents free fall. On most machines, additional control switches are located at ground level and in the operator's cab.

There are two basic designs of the powered safety step. One operates only

in two dimensions in the "up" and "down" directions. The second, using a linkage and bearing arrangement on the mounting end of the lift arms, rotates the step towards the machine in conjunction with the lifting motion. Thus, the step moves in an arc from ground to platform level. Each design is suited for specific applications. With minor modifications, a powered step can be adapted to any type or model of large machinery.

AVAILABILITY

Construction drawings, specification of materials, and other information are available for both the pretensioned spring step and the powered safety step.

For information contact Twin Cities Research Center, Bureau of Mines, 5629 Minnehaha Ave. South, Minneapolis, MN 55417.

RADIO WAVE-TRANSPONDER COLLISION PROTECTION SYSTEM

By William C. Yates,¹ Guy A. Johnson,² and James J. Olson³

ABSTRACT

In cooperation with the Anaconda Copper Company, the Bureau of Mines developed and in-mine, on-vehicle, proof-of-concept tested a prototype, interactive radio wave-transponder system as a method of improving collision protection for large mobile mining equipment. The system uses detuned radio wave generators mounted on

small mine vehicles to generate continuous radio waves. When the small vehicles are within the front-right or rear blind areas of a large haulage truck, the radio waves are detected by transponder units mounted on the truck. The prototype system then warns the haulage truck driver of a potential collision.

INTRODUCTION

This paper updates technology development efforts previously reported⁴ and involves a follow-on evaluation, conducted on a cooperative basis by the Anaconda Copper Company and the Bureau of Mines, of a second-generation prototype collision protection system at the Twin Buttes Mine south of Tucson, AZ. This

project is a part of the Bureau's program to develop reasonably priced, reliable collision protection technology. The prototype hardware tested at the Twin Buttes Mine represents the most successful proof-of-concept testing completed to date.

INSTRUMENTATION

DESCRIPTION OF RADIO WAVE-TRANSPONDER SYSTEM

The prototype instrumentation tested constitutes an interactive radio wave transponder system designed by Bureau and Anaconda engineers during the past few years. The system works by using ruggedized detuned radio wave generators mounted in small mine vehicles. Radio waves continuously sent by small vehicle are sensed by transponder units mounted

on the right front and rear of large haulage trucks. The truck driver is then alerted to possible collision hazards by warning lights and a buzzer in the cab. The key to making the system work is to keep the signals from the detuned generator strong enough to be sensed by the transponder units, yet have the signals fade quickly enough with distance to eliminate false alarms.

After the initial short-term, on-vehicle testing of the first-generation radio wave-transponder collision protection system at Anaconda's Butte Mine in Montana in 1981, several changes were made to correct shortcomings identified during the testing at the Butte Mine. Three of the most significant changes were (1) to remount the receiver in a conductive enclosure with tabs to facilitate easier mounting, (2) to change the antenna cable from coaxial to a two-wire shielded cable, and (3) to relocate the system's in-cab warning unit in a separate small box for ease in mounting.

¹Process control engineer, Anaconda Minerals Co., Tucson, AZ.

²Supervisory mining engineer, Twin Cities Research Center, Bureau of Mines, Minneapolis, MN.

³Deputy research director, Twin Cities Research Center, Bureau of Mines, Minneapolis, MN.

⁴Yates, W. C. Development and Evaluation of Pit Truck Safety Devices. Pres. at SME-AIME Ann. Meeting, Feb. 14-18, 1982, Dallas, TX, SME Preprint 82-16, 7 pp.

INSTALLATION AT THE ANAMAX TWIN
BUTTES MINE

After laboratory checks of the improved system in fall of 1982, arrangements were made for installation of the system components on mine haulage and personnel vehicles at Twin Buttes. This second-generation prototype system included the following components: two dual-channel receivers, three low-frequency transmitters, four receiver antennas, two display panels and cables, four transmitter antennas complete with cable, and four receiver antenna cables.

The two dual-channel receivers were installed in two 150-ton-capacity haulage tracks, numbers 43 and 51. The major criterion of selection for the small vehicles was frequent encounters with haul trucks. Accordingly, two of the low-power transmitters were installed in pickup trucks used by the mine electricians, and the third was installed in the mine's radio service van.

The receiver antennas were mounted to special brackets welded to the haul trucks. The antennas were about 6 ft high and were located on the front right (figs. 1-2) and the center rear (figs. 3-4) of the haul trucks. The receivers were mounted under the buddy seat of the respective haul trucks and were secured with four 1/4-in bolts welded to the floor (fig. 5). Cab layouts dictated the installation of the system's display boxes in the respective trucks. The right side of the dash in unit 43 provided adequate space for the box and allowed ease of viewing by the driver (figs. 6-7). Dash space in unit 51 was limited, and the display box was mounted above the right door (fig. 8). This position is observed by the driver when the right backup mirror is used.

Rear antenna cables were routed from the cab, following existing cables and hoses, down along the truck frame, over the rear axle housing to the location of

the antenna. The cable to the front antenna was routed along the existing cables by the instrument control housing, then forward and down to the antenna located on the radiator shroud. Standard tie wraps held the cables in place.

Twenty-four-volt power for the receivers was supplied from a pi-section filter in the haulage truck's electrical system. The voltage was switched from the truck electrical system. The power supply cable shield was initially left disconnected at the supply end. The receiver end was grounded to the receiver chassis.

The low-power transmitter-antenna system was mounted on the top of the two pickup trucks and the radio service van. A magnetic-mount base antenna was placed on the truck roof, roughly over the center of the passenger compartment. Coaxial cable was routed over the roof, down the back of the pickup cab, through an existing hole near the bottom of the cab, and under the floormat to the location of the transmitter. A speaker bracket was used to mount the transmitter to the dash (fig. 9). This location allows drivers to view the system-on light, which assures them that the transmitter system is functional.

The installation of the instrumentation system and initial adjustments on the electronic components to allow startup of the in-mine testing program were completed in early November 1982. The front distance adjustment for the two haul trucks was determined by the front blind area. This area varies depending on the size and brand of the truck. Typically, however, this distance was adjusted to a 12-ft separation between receiver and transmitter antennas.

The rear antenna separation was initially adjusted to 25 ft, the maximum for the original receiver configuration. Later in the test program, the distance was increased to about 36 ft by modifying a jumper on the range detector board.

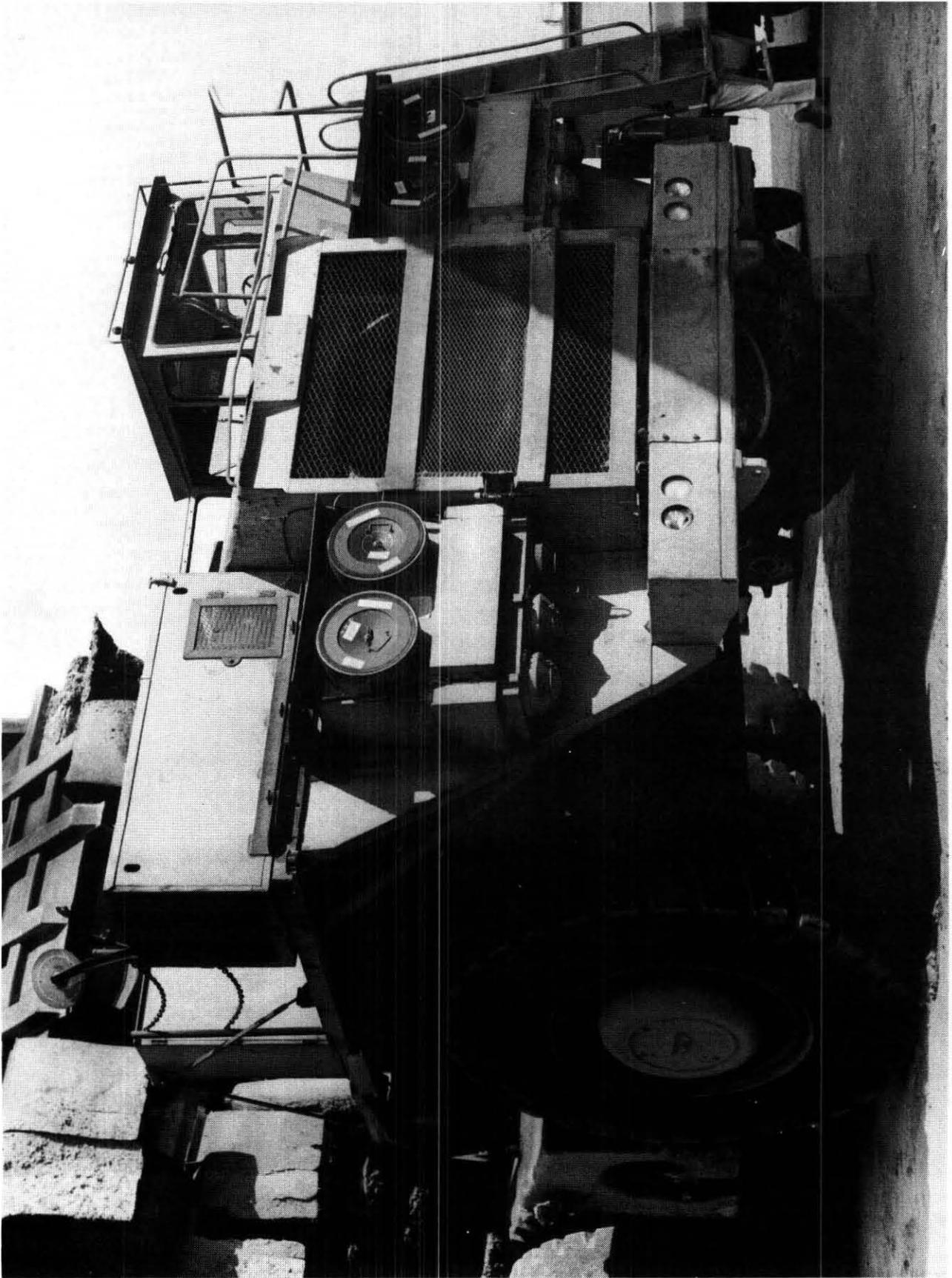


FIGURE 1. - Front view, unit 51.



FIGURE 2. - Front antenna, unit 51.



FIGURE 3. - Rear view, unit 51.

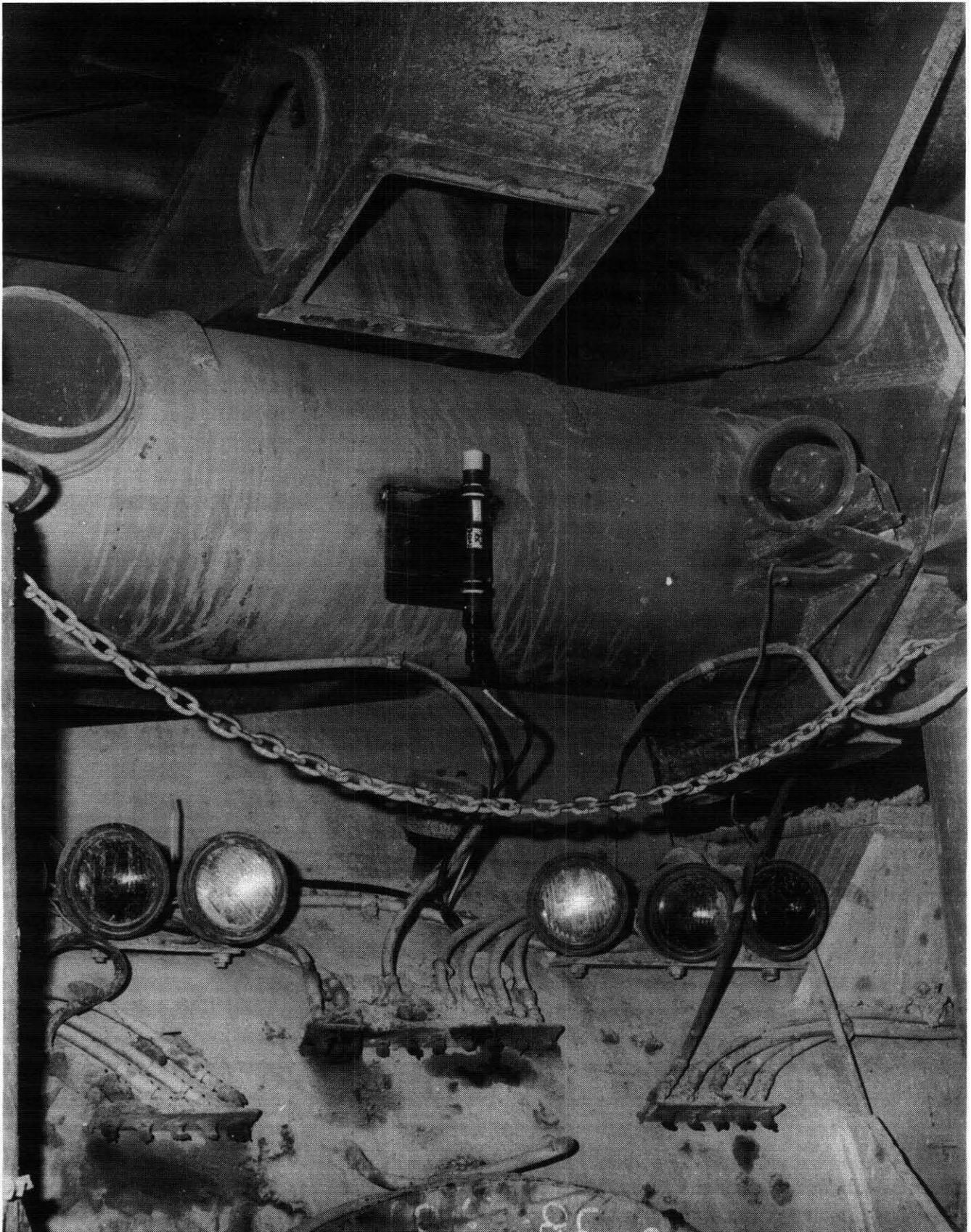


FIGURE 4. - Rear antenna, unit 43.



FIGURE 5. - Floor-mounted receiver.



FIGURE 6. - Display panel, unit 51.

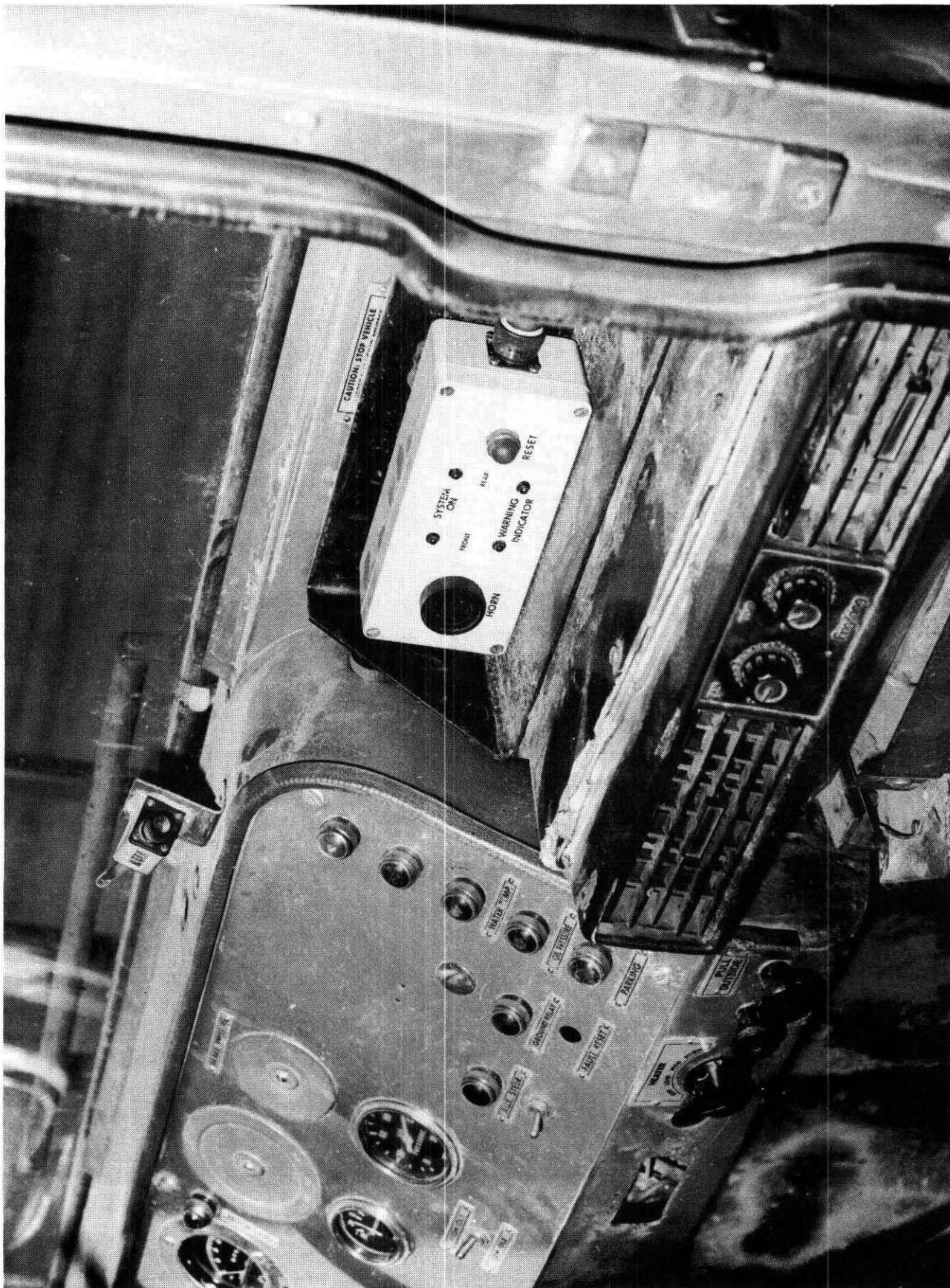


FIGURE 7. - Display panel, unit 51, driver's view.

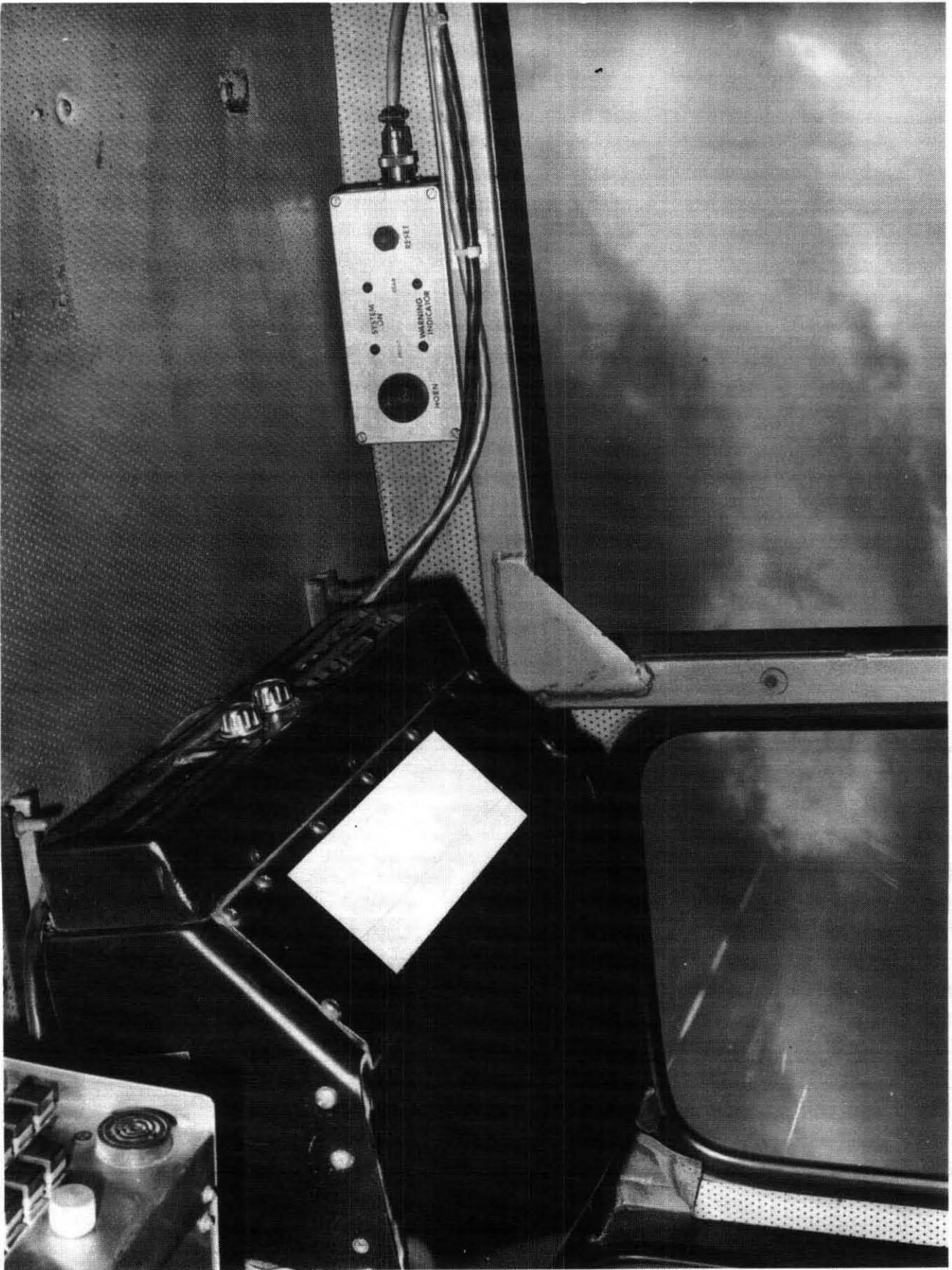


FIGURE 8. - Display panel, unit 43.

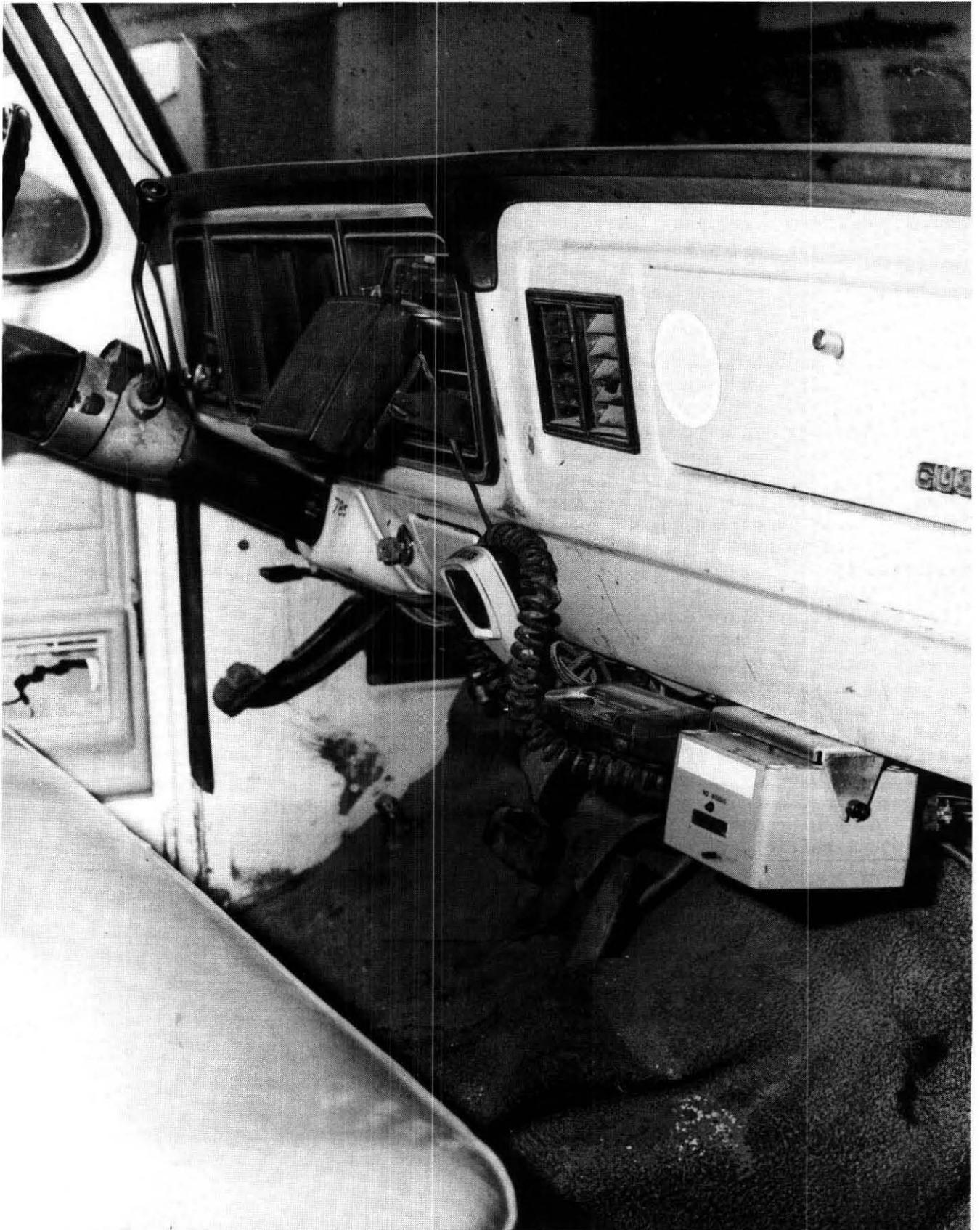


FIGURE 9. - Pickup transmitter mount.

SHAKEDOWN TESTS

Initial tests of the system disclosed an electrical "noise" problem with unit 51, which generally affected only the rear antenna. This truck had a General Electric UHF communications transceiver mounted in the cab that uses a dc-to-dc switching inverter which emits large amounts of radio frequency interference. The interference appeared to mix with the collision protection system's internal frequencies and caused periodic false

FIELD TEST RESULTS

Because of operational schedules in the mine, the radio wave-transponder system on unit 51 was not tested during ore hauls. The components mounted on unit 43 were subjected to a mine haulage test period of about 2 months. Although some false alarms did occur when the dynamic brakes on unit 43 were used, the problems did not seriously impact the field evaluations.

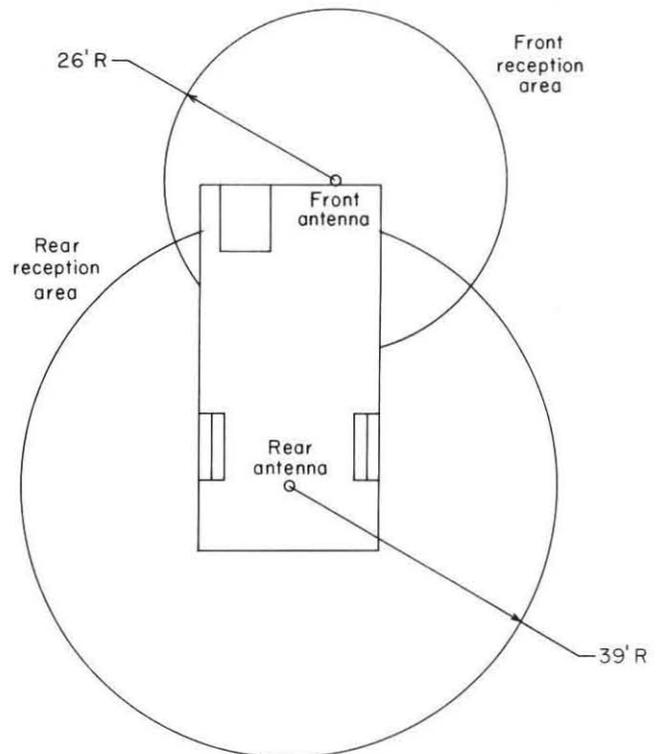
The right-front alarm distance was adjusted so as to activate prior to the disappearance of the small vehicle into the blind area of the haul truck. The rear alarm distance was established at about 39 ft. This distance, although excessive on the sides of the truck, was necessary to provide adequate distance at the rear when the truck was backing. Because the haul roads at Twin Buttes are quite wide, sufficient passing clearance was available so few alarms occurred as the haul truck and small vehicles passed. In more congested areas, such as the crusher or shovel locations, more frequent alarms occurred. These, however, generally indicated that the small vehicle was approaching the haul truck too closely, and this is exactly the condition the collision protection system is engineered to sense. The final encounter pattern used in the test is shown in figure 10.

The ultimate test occurred when one of the mine personnel, unfamiliar with the ongoing tests, was assigned to drive unit 43. He was engaged in backing when the alarm sounded. Not knowing the purpose of the signals, he stopped the vehicle

alarms. Unit 43, on the other hand, had a Motorola UHF communications transceiver which did not emit a high level of interference. No false alarm problems were caused by this transceiver.

A number of different remedies were tried on the system components onboard unit 51 to eliminate the noise problem. The most successful solution was to enclose the antenna wiring in conduit. This modification greatly reduced extraneous radio wave signals.

and called a mechanic. Upon arrival at the scene, the mechanic found that the haul truck had nearly backed into an unoccupied pickup truck and had indeed stopped just in time to avoid a collision. Considering that only two pickups and one haul truck had active prototype hardware, this encounter was rather fortuitous and clearly demonstrated the value of the collision protection system.



RADIO WAVE - TRANSPONDER

FIGURE 10. - Radio wave-transponder receiver pattern.

CONCLUSIONS

Mounting of the second-generation, prototype collision protection system at Twin Buttes was simple and straightforward. No problems were encountered in the installation of either the receiver or the transmitter. One detail of particular importance to prospective users is the requirement to cut the cables to the exact length needed to minimize noise pickup in the mine.

The present alarm pattern and distance setting gave the operator adequate warning of encroaching vehicles at the mine site. Operator acceptance was good. The only problem with the system was that of noise. Although a GE radio proved to be the principal source of noise, other sources, such as the dynamic brakes on the haul trucks, also caused some problems. As it appears impossible to remove all sources of noise in such large and complex equipment, the only apparent

practical solution to the noise problem is to increase the receiver noise immunity in as simple a manner as possible. Some gain on the signal-to-noise problem could be obtained by a slight increase in transmitter power with an accompanying decrease in receiver sensitivity.

Proof-of-concept testing of this type of collision protection technology is now complete. Each mine wanting to utilize such automation technology will have to modify each system to site-specific conditions (weather, etc). As tests at the Twin Buttes Mine have made clear, the next generation of hardware must have considerably more noise immunity. Other design parameters in the present system appear adequate, and the system helped prevent a potentially serious mishap, the backing over of a mine personnel vehicle by a haul truck.

NOVEL TRUCK-DESIGN CONCEPTS

By Guy A. Johnson¹

ABSTRACT

This paper summarizes a feasibility analysis of novel design concepts for large haulage vehicles. A preliminary design of a completely novel, 170-ton-capacity truck configuration is presented as a case example.

The objective of this study was to produce cost-effective, novel truck designs that reduce the inherent dangers associated with current designs of large haulage units. The novel design technology provides industry with an alternative to retrofit technology.

INTRODUCTION

During any particular year in the surface mining industry, off-highway haulage trucks are involved in accidents accounting for more fatalities and lost-time injuries than any other type of mobile mining equipment. The accidents can take many forms, each with a different injury potential. Haulage trucks can collide with each other. They can collide with and run over smaller vehicles, other mine equipment, and even workers. The trucks can overturn while traveling the haul road or while unloading at the dump site. Operators can receive sprains, strains, cuts, and bruises as a result of being bounced around in the cab during haulage

cycle operations. In addition, operators and other workers receive injuries as the result of slipping and/or falling while getting on and off the truck, or while performing maintenance or service functions.

Table 1 summarizes off-highway haulage-truck-related injuries that occurred in surface mining operations during 1978 and 1979. The data are classified according to accident type, location of the accident, and total number of resulting fatalities and nonfatal injuries. The data for this Bureau of Mines accident analysis were obtained from mining industry injury and illness reports submitted to and compiled by the Mine Safety and Health Administration (MSHA), Health and Safety Analysis Center, Denver, CO.

¹Supervisory mining engineer, Twin Cities Research Center, Bureau of Mines, Minneapolis, MN.

TABLE 1. - Surface mining haulage truck accident summary (1978-79)

Accident type	Location			Result		
	Haul road	Dump site	Load site	Other	Fatality	Injury
Collision with--						
Haul truck.....	58	10	18	3	3	86
Other vehicle or machine	13	2	5	1	3	18
Electrical wire.....	0	1	0	1	1	1
Person.....	0	3	3	2	5	3
Rollover.....	74	39	0	5	11	107
Ran off road.....	20	0	0	0	0	20
Fire.....	6	0	0	3	0	9
Operator injured in cab ¹ ..	214	18	35	27	0	294
Nonoperating events.....	27	12	35	334	0	408
Total.....	412	85	96	376	23	946

¹Excluding previous categories.

SHORT- AND LONG-TERM SOLUTIONS

The Bureau of Mines, MSHA, equipment manufacturers, and mine operators have tried many approaches to reduce the growing number of accidents associated with large haulage trucks. The Bureau first sponsored research to develop and test retrofit technology to improve visibility systems, improve ingress-egress systems, improve bumper designs, improve fire detection and suppression, and improve collision detection and avoidance.

Longer term, high risk work was also initiated to reduce the inherent hazards associated with current designs of large haulage trucks. All of these projects have been carried out in cooperation with mining companies, equipment manufacturers, and/or academic institutions to assure that the research results cost effectively met the generic needs of the industry.

DESIGN ALTERNATIVES

Because of the poor field of vision afforded operators of large haulage trucks, the trucks are frequently involved in accidents such as front-right turns over unseen smaller vehicles, backing into other haulage vehicles, and backing over a dump. The field of vision afforded an operator is a function of the cab location in relation to other haulage truck structures. The field of vision can be improved through direct visual aids, such as mirrors or the recently developed Bureau of Mines, downward-looking, Fresnel lens blind area viewers. Other concerns regarding cab location are ingress-egress-related injuries and, to a lesser extent, operator injuries from being "bounced around" during travel. With these relationships in mind, seven novel cab location concepts were developed and evaluated. Five of the concepts involved relocating the cab on a typical rear-dump haulage truck. Two involved locating the cab in a completely different vehicle configuration.

Details of the feasibility analysis are contained in the contract final report "Novel Cab Design Concepts To Improve Large Haulage Vehicle Safety" (contract J0295013) by Woodward Associates, a copy of which can be consulted at the Bureau's research centers in Minneapolis, MN, Denver, CO, Spokane, WA, and Pittsburgh, PA.

The results of the evaluation indicated that safety would be improved only marginally (and in one case, slightly impaired) by relocating the cab from its present location on rear-dump configurations. Since greater safety potential could best be obtained by redesigning the entire truck structure, this second project objective was pursued. This work involved generating and evaluating the feasibility of a novel haulage truck configuration: a front-dumping, midengine, 170-ton truck.

CASE HISTORY EXAMPLE: A FRONT-DUMPING, MIDENGINE CONFIGURATION

While attempting to maintain or exceed the performance and economy of ownership and operation parameters of current haulage trucks, a preliminary design analysis was performed to address each of the major hazardous situations associated with haulage truck operations, as shown in table 2. Table 2 lists the safety features incorporated into the front-dumping mid-engine configuration shown in figure 1. Table 3 gives the general specifications of the novel vehicle's design. Complete

design specifications are contained in the final report prepared by Woodward Associates.

To generate the concept, a typical large haulage truck was first broken down to its major components (fig. 2). The components selected for further analysis were then packaged in a configuration that maintained high productivity potential while also providing improved safety features (fig. 3). This design concept

TABLE 2. - Safety improvements of the design

<u>Situation</u>	<u>Design feature</u>
Collision.....	Increase in field of vision. Location of cab away from impact points.
Rollover.....	Cab location protected by body and frame. Wide stance, four-wheel independent suspension.
Ingress-egress..	Cab location (low).
Operator security inside cab.	Truck suspension. Seat design. Overall interior design. Isolated cab.
Maintenance and service.	Ease of access to all systems, components, and service ports and areas.

TABLE 3. - General specifications of novel vehicle design

Body capacity, cu yd:	
Struck.....	73
2:1 heap.....	142
Body capacity, tons....	170
Dimensions, ft:	
Height.....	17
Width.....	22
Length.....	42
Wheelbase.....	20
Turning circle, ft.....	83.5
Weight, tons:	
Empty.....	170
Loaded.....	340
Engine:	
Type.....	KTA-3067-C
Gross horsepower.....	1,600
Transmission.....	GTA-15, W/GE776C
Tires.....	40:00-57



FIGURE 1. - Front-dumping, midengine, 170-ton-capacity truck concept.

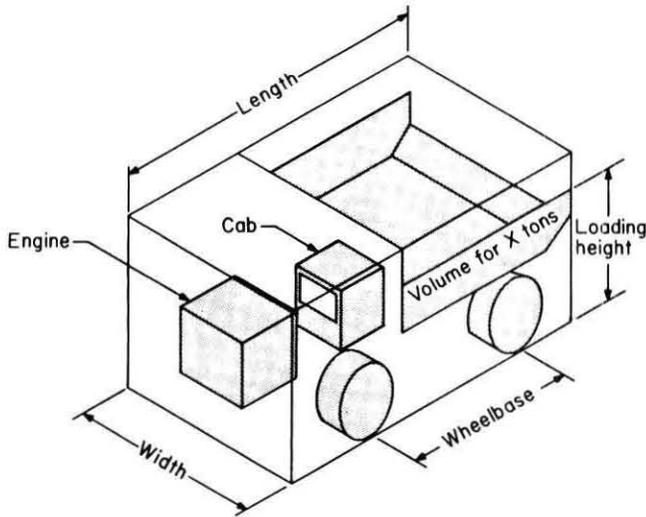


FIGURE 2. - Major components of a typical large haulage truck.

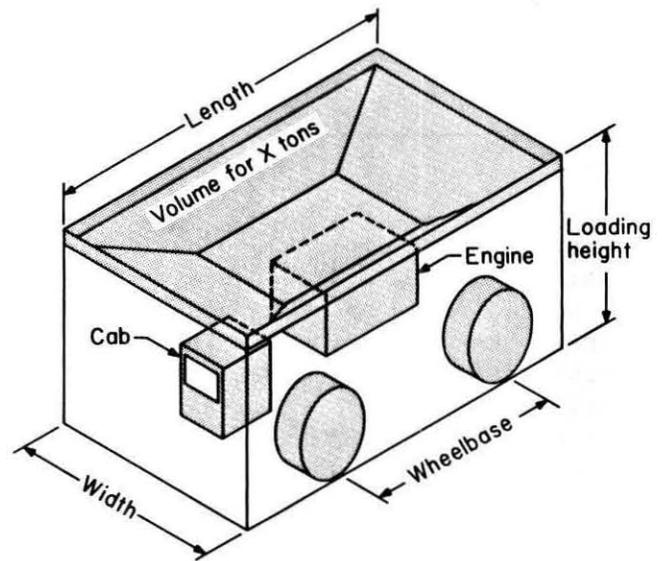


FIGURE 3. - Components of a safer, more productive novel haulage truck design concept.

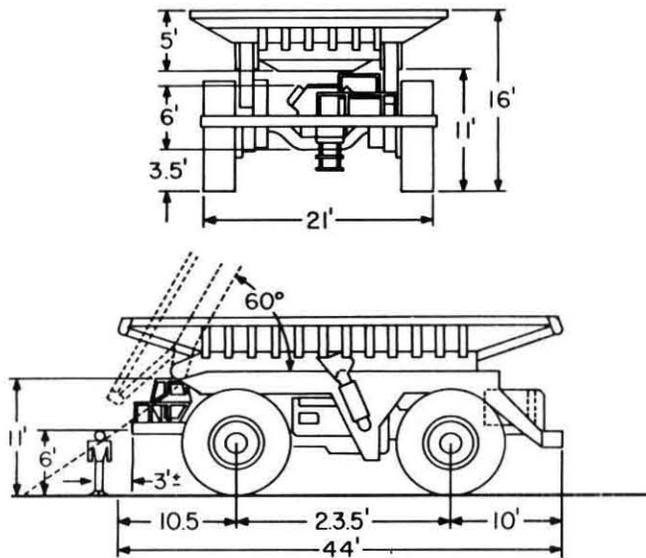


FIGURE 4. - Dimensions of the novel concept.

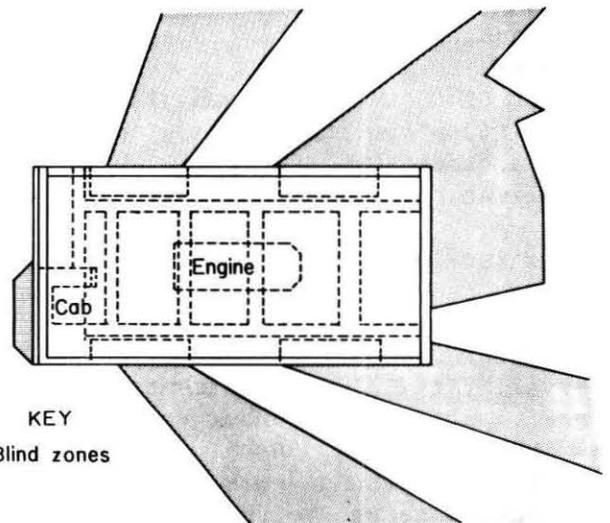


FIGURE 5. - Anticipated direct field of view of the novel concept.

utilized only components currently used by the manufacturing industry. Figure 4 depicts the dimensions and front-dumping feature of the design concept. Figure 5 shows the anticipated direct field of view from the cab of the vehicle. This improved field of view, plus the

structural protection around the driver, will improve his or her safety. The mid-engine design, with its inherent ease of maintenance plus the improved field of view, should also make the vehicle more productive.

CONCLUSION

Although the history of off-highway haulage truck development indicates a resistance to innovation and change, novel design technology as exemplified by the

170-ton-capacity haulage truck configuration developed in this case study can provide improved safety potential without sacrificing performance.

OPERATOR ALERTNESS STUDIES

By Richard J. Wilson¹

ABSTRACT

Mobile mine equipment accidents attributable to a lack of alertness on the part of the equipment operator are of growing concern to the mineral industry. An investigation into the potential for monitoring certain physiological factors as a means of determining states of decreased alertness was undertaken by the Bureau of Mines. Various oculomotor activities such as eyeblink rates, eye closure duration, and the timing of

eyeblinks relative to a presented stimulus were monitored. Changes in pupil size were also recorded. Both blink rate and eye closure duration proved to be sensitive to the nature of the task. Blinking was also found to be timed so as to least interfere with the incoming information presented in the series of tests. Measures of pupillary diameter change were not found to be correlative to alterations in levels of alertness.

INTRODUCTION

Accidents attributable to inattentive or unalert operators of large mobile mining equipment are of growing concern to the mining industry. The ever-increasing size of loading and haulage vehicles magnifies both the severity and the cost of accidents associated with their utilization.

An analysis of recent (1979-80) Mine Safety and Health Administration accident data revealed that mobile mine equipment accidents account for an estimated 20 pct of all fatal mining accidents (coal, non-coal, surface, and underground) (3).² In 42 pct of these cases, inattention or lack of alertness was listed as a contributing cause to the fatality. This figure might actually double if accurate, reliable methods of determining the causes of accidents were available. Basic, long-term scientific investigation is required to identify methods and technologies capable of remotely monitoring an operator's state of alertness and thus help eliminate a major cause of vehicle-related accidents.

Inattentiveness or lack of alertness can be defined as a state of mind in which a person is unable to respond appropriately to an unexpected situation. This broad definition covers the range of simple daydreaming to being asleep at the wheel. This lack of alertness may be caused by any number of factors including sleepiness, fatigue, the influence of alcohol or drugs, and emotional factors that have a deleterious effect on an individual's performance capabilities. It should be noted that in the ongoing research effort the causal factors are not under investigation. It is only the detection of the reduced state of alertness that is of concern.

A review of the relevant literature was conducted to ascertain what has been done historically in the study of alertness. Most of the prior articles dealt with the causal effects noted previously. Little conclusive information that correlated an individual's state of alertness with some monitorable physiological factor was available. The two areas that appeared to offer some potential for serving as predictors of levels of impaired performance were oculomotor and pupillary phenomena.

¹Mining engineer, Twin Cities Research Center, Bureau of Mines, Minneapolis, MN.

²Underlined numbers in parentheses refer to items in the list of references at the end of this paper.

OCULOMOTOR PHENOMENA

Many investigations into various oculomotor phenomena (eyeblinks, eye movements and closures, etc.) have been conducted. As early as 1927, Ponder found that under constant conditions individuals tend to maintain a relatively constant rate of blinking (8). It was also reported that blink rates did not vary whether blinks were counted in total darkness, or in dim or normal lighting. Prior studies have also found a correlation between eyeblinks and a person's level of attention. Kennard concluded that blink rates increased during periods of inattentiveness and blinks occurred typically at the moment of relaxation of attention (5). Other studies have shown a decrease in blink frequency from the baseline rate during periods of increased mental activity (1). Wide variability in results from numerous other studies, however, prevents drawing any universal

conclusions concerning blink rates and attentiveness.

The time at which blinks occur rather than blink rates has also been investigated, although to a lesser extent. Drew found that changes in difficulty of a task correlated with changes in the time distribution of eyeblinks (2). Kennard reported that when subjects were given observation tasks, blinking was inhibited in all cases (5). Confirmation of these results was obtained by Peng (7).

In summary, all investigators found that blink rates vary significantly across subjects. Some correlation exists between within-subject changes in blink rate and level of alertness. Furthermore, blink timing and possibly the waveform of the blink appear to be sensitive to task demands (9).

PUPILLARY HIPPIUS

Changes in light intensity are known to produce alterations in the size of the pupil. It is less well known that pupil diameter can also be affected by internal factors such as interest value or task difficulty. Attentiveness to interesting material or the solution of difficult problems both were shown to lead to pupillary dilation (4). Spontaneous changes in pupil diameter can also occur without visual input. Pupillary hippus is defined as the relatively slow change in the size of the pupil in the absence of external stimulation (10). Yoss demonstrated pupillary hippus to be

associated with both states of drowsiness and a neurological condition known as narcolepsy (12-13).

Previous experimental studies have indicated a correlation between inattentiveness or states of drowsiness or fatigue and the occurrence of various oculomotor activities and pupillary hippus. The relationships are not clearly defined or understood, but a good potential appears to exist for utilizing these physiological factors as indicators of a mine equipment operator's state of alertness.

LABORATORY INVESTIGATION

The Bureau of Mines initiated a research program to define the predictive relationships between oculometric and pupillary phenomena and an individual's state of alertness. The study was conducted by Washington University, St. Louis, MO (10). Twenty subjects, all college-age adults, were selected from a pool generated by the Sleep Research Laboratory of St. Louis University. The

test subjects participated in a vigilance testing program in which they were required to respond to a series of simple visual and auditory stimuli. By examining the accuracy of the responses, an indication of the subject's level of attention as a function of time on task was obtained. The test procedures for the visual and auditory vigilance testing are described in the following sections.

VISUAL

The visual vigilance testing was self-paced with feedback about erroneous responses. The test utilized a stimulus-response unit, designed by Wilkinson (11), which presented the subject with a square array of four lights (fig. 1). An array of similarly arranged response buttons was placed directly below the lights. The subject was instructed to push the button corresponding to the light in the array that was lit. As the subject depressed the button associated with a particular light, that light went off and another light came on. The position of the next light was randomly determined unless the subject responded incorrectly, in which case the light remained on until the correct response was made. Each subject performed this task for 10 min without interruption.

AUDITORY

The auditory vigilance testing was paced by the experimenter without feedback as to the accuracy of the responses. A tone of 200- or 300-ms

duration was presented at 2-s intervals. The subject was instructed to simply discriminate between the tones and lift a finger from a response pad when the 200-ms tone was heard. Each subject performed this task for 32 min without interruption.

TEST PROCEDURES AND INSTRUMENTATION

Eyeblinks were monitored by placing Ag-AgCl electrodes in conjunction with differential amplifiers above and below the subject's right eye as shown in figure 2. Data were recorded on analog tape that was subsequently played into a computer for analysis. A program developed specifically for the analysis of the eye movement data identified blinks and evaluated their amplitude and closure duration. An amplitude criterion that was fixed at 50 pct of total blink amplitude was applied to the data to identify closure duration.

Pupillary information was monitored by means of a closed-circuit television (CCTV) camera. During the vigilance testing, the subject was seated with his

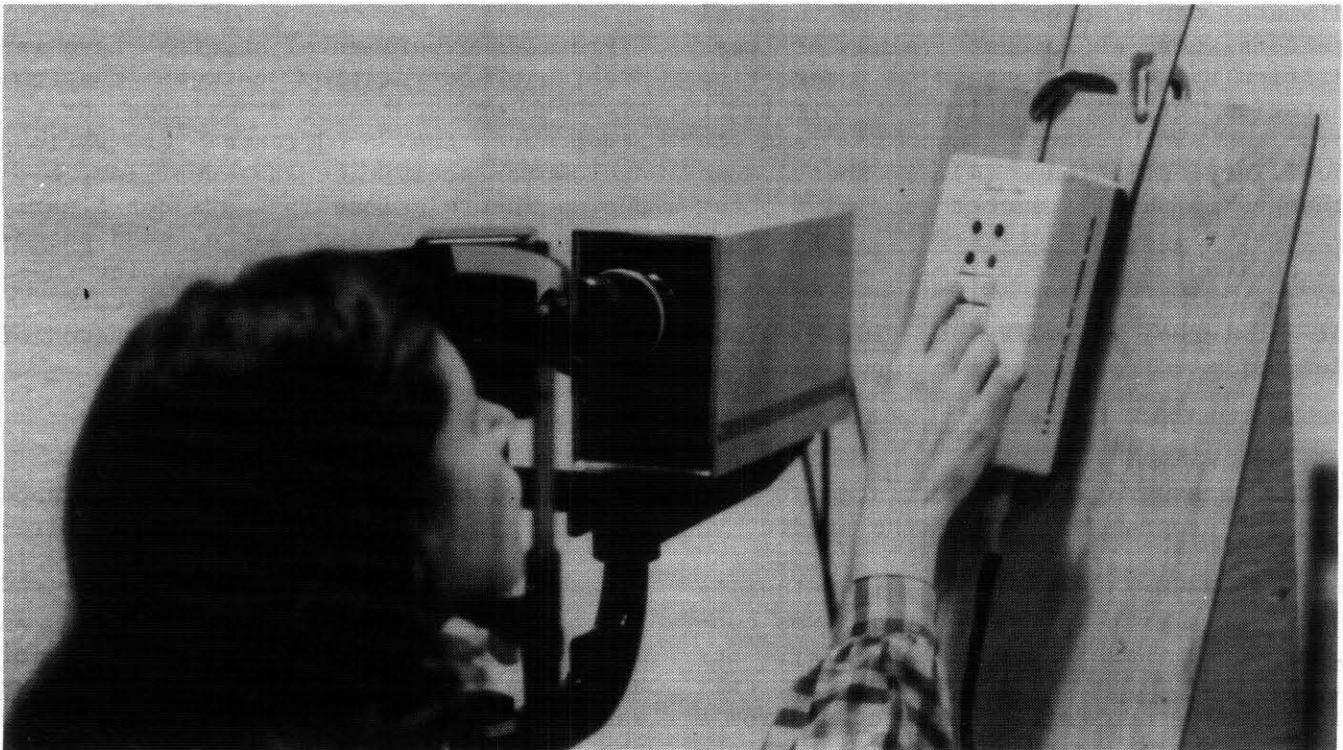


FIGURE 1. - Wilkinson stimulus-response unit.

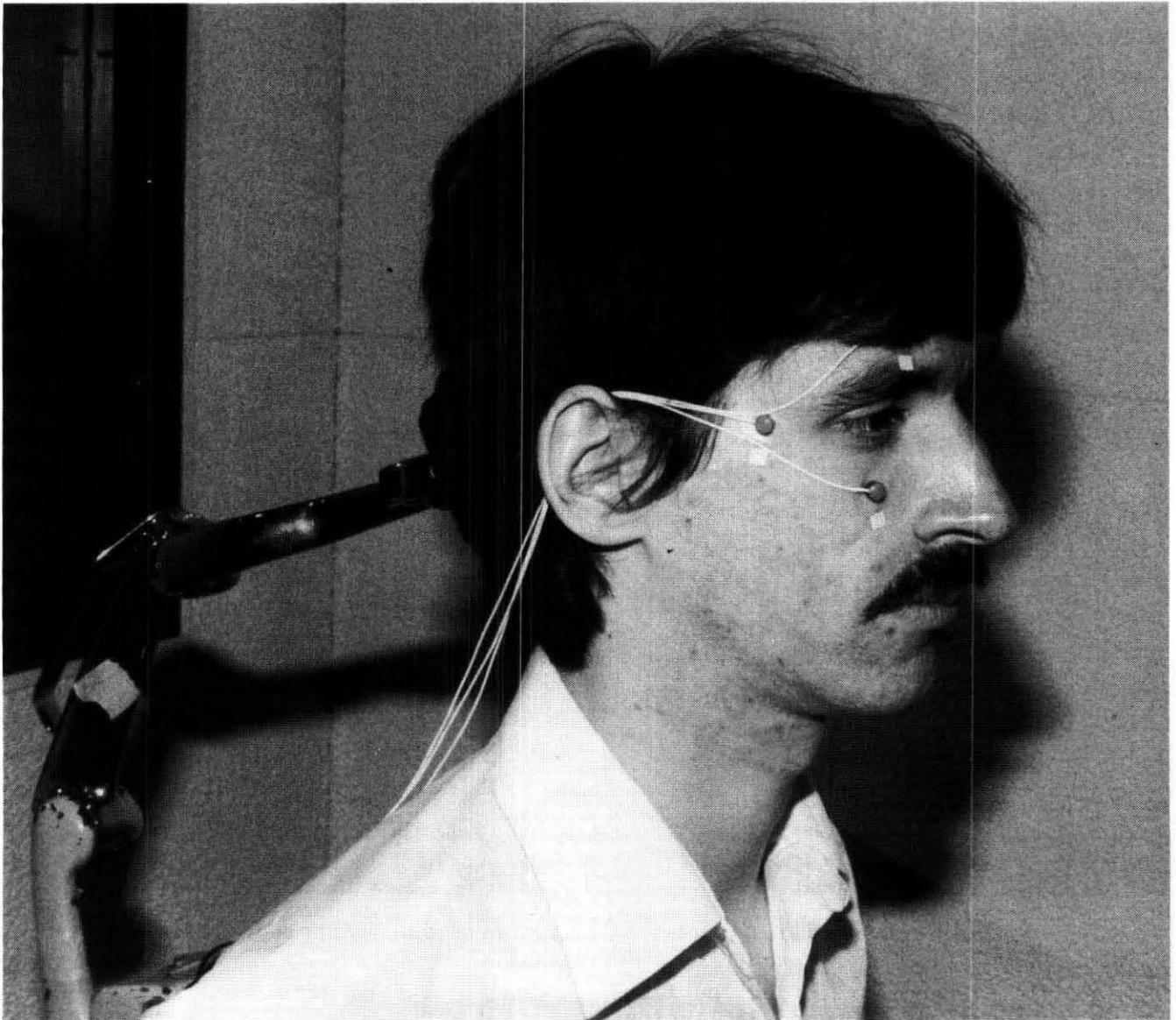


FIGURE 2. - Ag-AgCl electrodes used to monitor vertical eye movements.

or her head positioned in a restraint (fig. 3). The CCTV was aligned to observe the pupil of the subject's left eye, and pupil size information was obtained from the television monitor. Measurements were taken over 1-min intervals at specified points in the testing program. The pupillometer was calibrated by positioning circles of known diameter in the head restraint and adjusting the image on the monitor. All data were recorded on both strip charts and analog tape for subsequent data reduction.

A typical example of the strip-charted data for the auditory vigilance testing

is shown in figure 4. The lower channel depicts both the stimuli presentation and subject's response. As indicated on the figure, a downward deflection of the pen represents the presentation of the tone with the width of the square wave corresponding to the duration of the signal. The subject's response is displayed as an upward deflection of the pen. As can be seen in this example, the subject correctly discerns the third signal as being 200 ms in duration and responds appropriately. However, no response is recorded for the next signal, which is also 200 ms in duration.

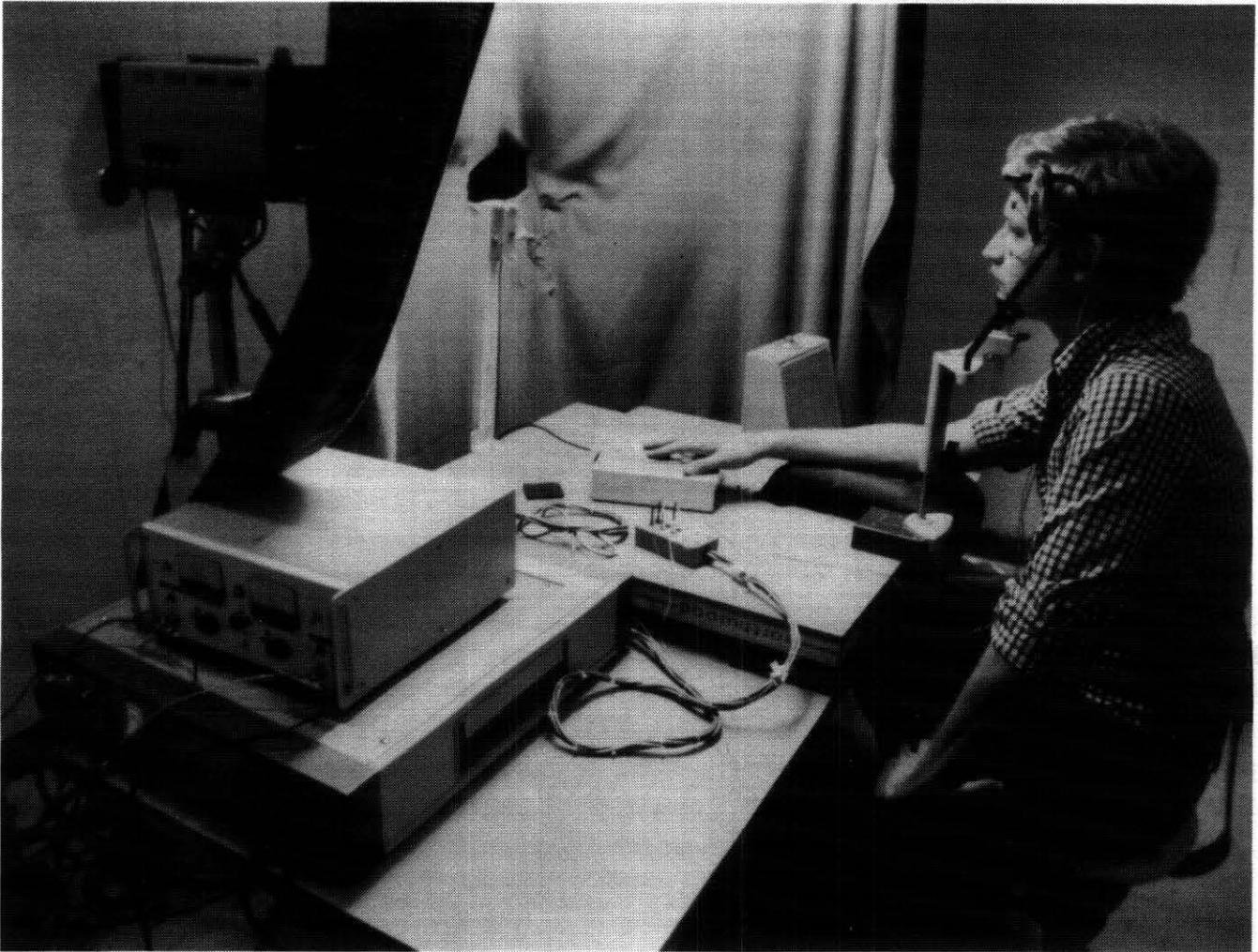


FIGURE 3. - Head restraint and CCTV camera used to monitor pupil size.

The middle channel recorded pupillometric information. Upward deflections are associated with pupillary constrictions. The square waves seen in this plot are attributable to eyeblinks. True changes in pupil diameter are indicated by the gradually changing slope of the baseline.

The upper channel recorded vertical eye movements such as blinks and closures. In the example shown, a long-duration closure occurs in the middle of four blinks.

RESULTS

Blink Rate

The most apparent result from the study was that there was significant inhibition of blinking during the visual vigilance testing. Figure 5 shows the blink rates exhibited during both visual and auditory vigilance testing and during a period of rest. It can be seen that the test subjects blinked more frequently during the rest period (17.0 blinks/min) and auditory test (17.3 blinks/min) than

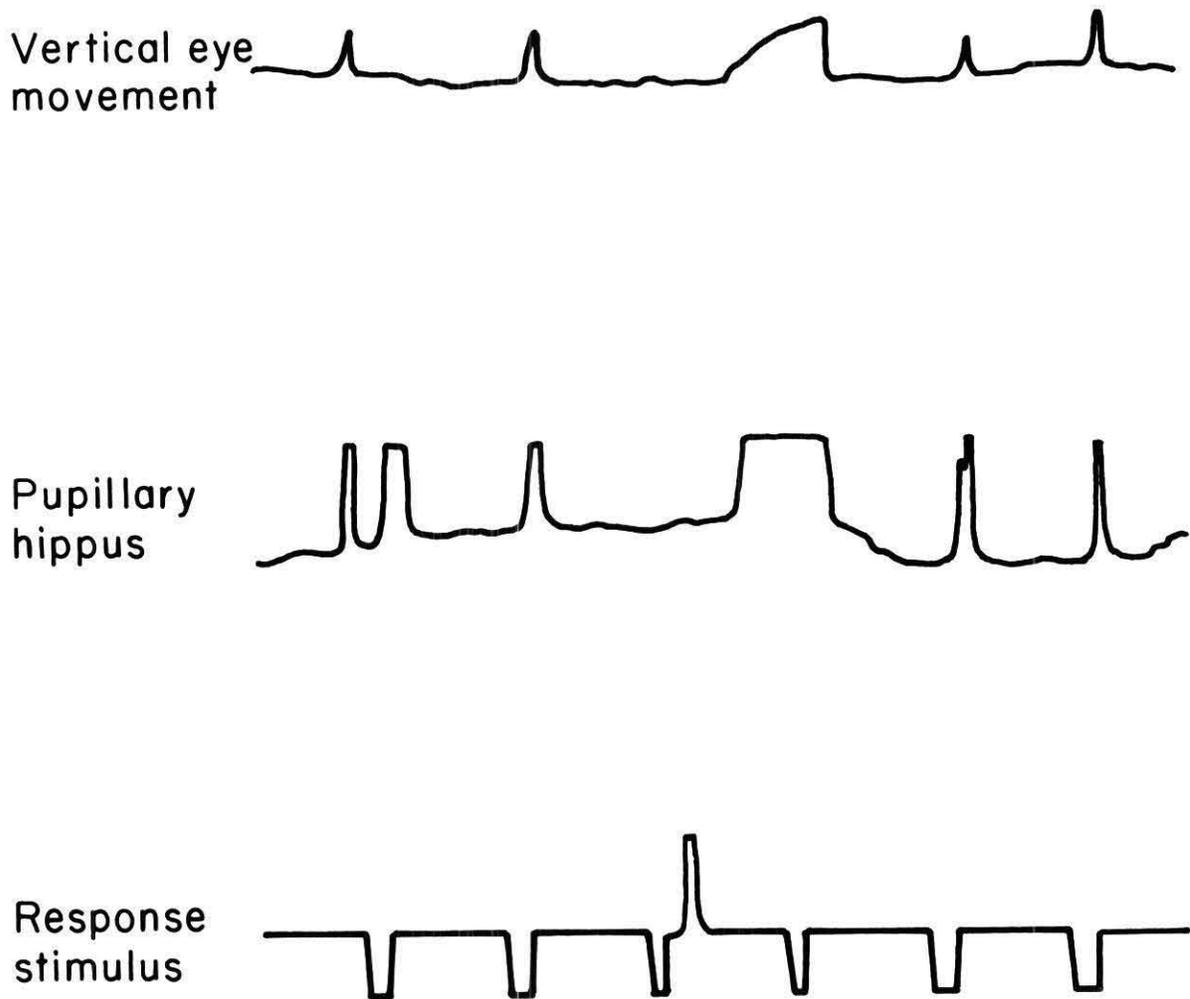


FIGURE 4. - Sample strip chart from auditory vigilance testing.

during the visual test (10.5 blinks/min). No significant difference in blink rate was apparent between the rest period and the auditory test. As was expected, the performance of a task involving visual input led to a significant reduction in blink rate. Blink rate also tended to increase over time as the test progressed, but these changes were not shown to be significant.

Blink Closure Duration

Blink closure duration, like blink rate, tended to increase as a function of time on task being performed. This trend, however, was not statistically

significant. Figure 6 shows that closure duration, as expected, was longer during the auditory task than during either the visual testing or the rest period when measured at 50 pct of full blink amplitude. There was no statistically significant difference between closure duration for the visual testing and the rest period. Thus, it can be concluded that blink closure duration is significantly affected by the type of task subjects are called upon to perform. A visually demanding task leads to a reduction in closure duration, while a task with no demands for visual processing leads to a significant increase in closure duration.

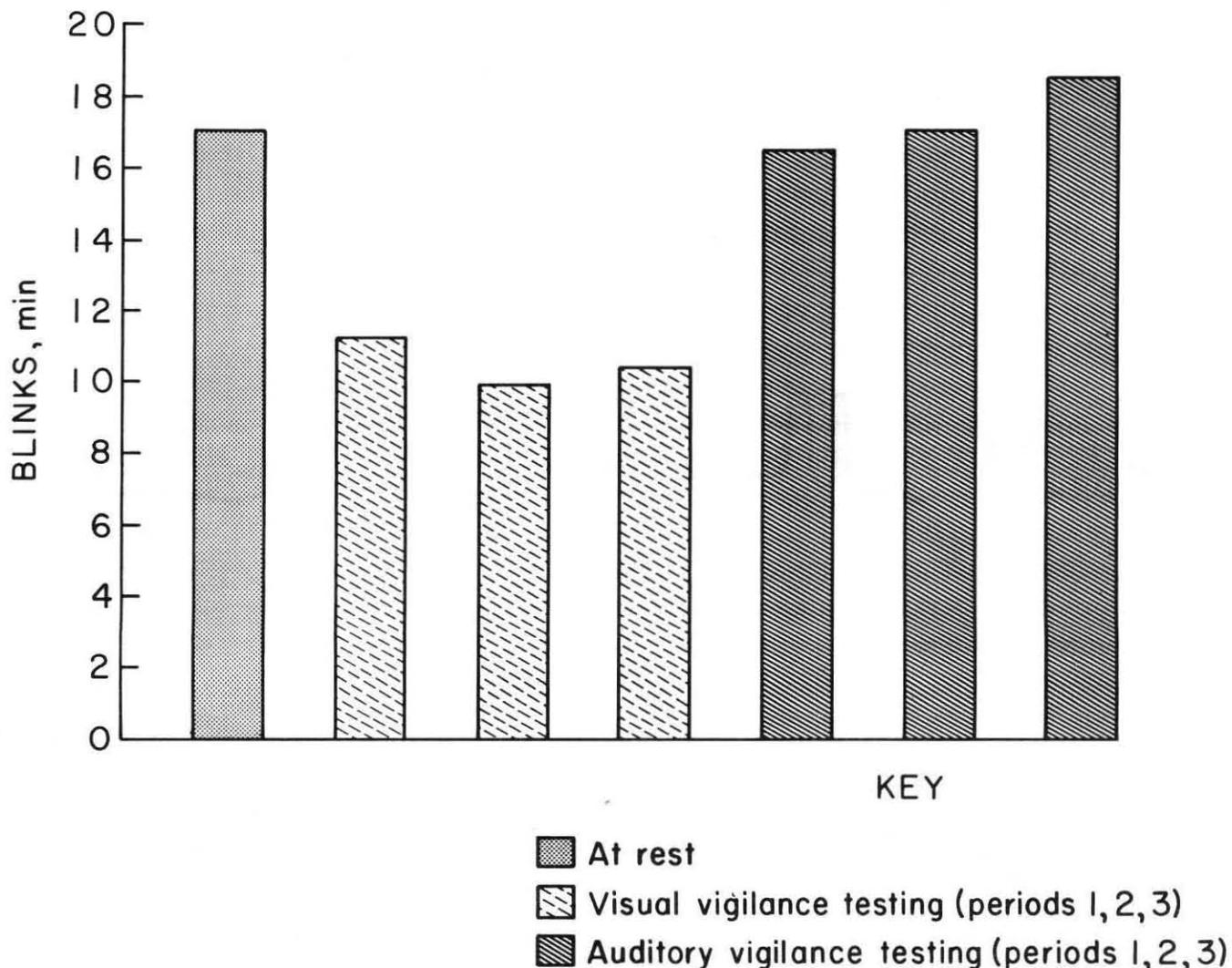


FIGURE 5. - Eyeblink frequency data.

Probably the most significant results were obtained by analyzing the eyeblink and closure data with regard to what was happening at the time the stimulus was presented. A special series of tests was conducted that required that the subjects respond to a 200-ms stimulus by lifting a finger from the response pad in the manner described previously. In these tests both auditory and visual stimuli were utilized. In the first test, the stimuli were presented at 2-s intervals, while in the second test, the interstimulus interval was varied from 0.8 to 3.2 s.

A graphical representation of the results is shown in figure 7. The plot presents the percentage of trials on which eyeblinks or closures occurred in association with either a correct response (hit) or a missed signal (miss). The results are discriminating in that, for both auditory and visual stimuli, the incidence of blinks or closures associated with correct responses is markedly less than that associated with missed signals. These limited data indicate that when an eyeblink or closure was observed to have occurred during

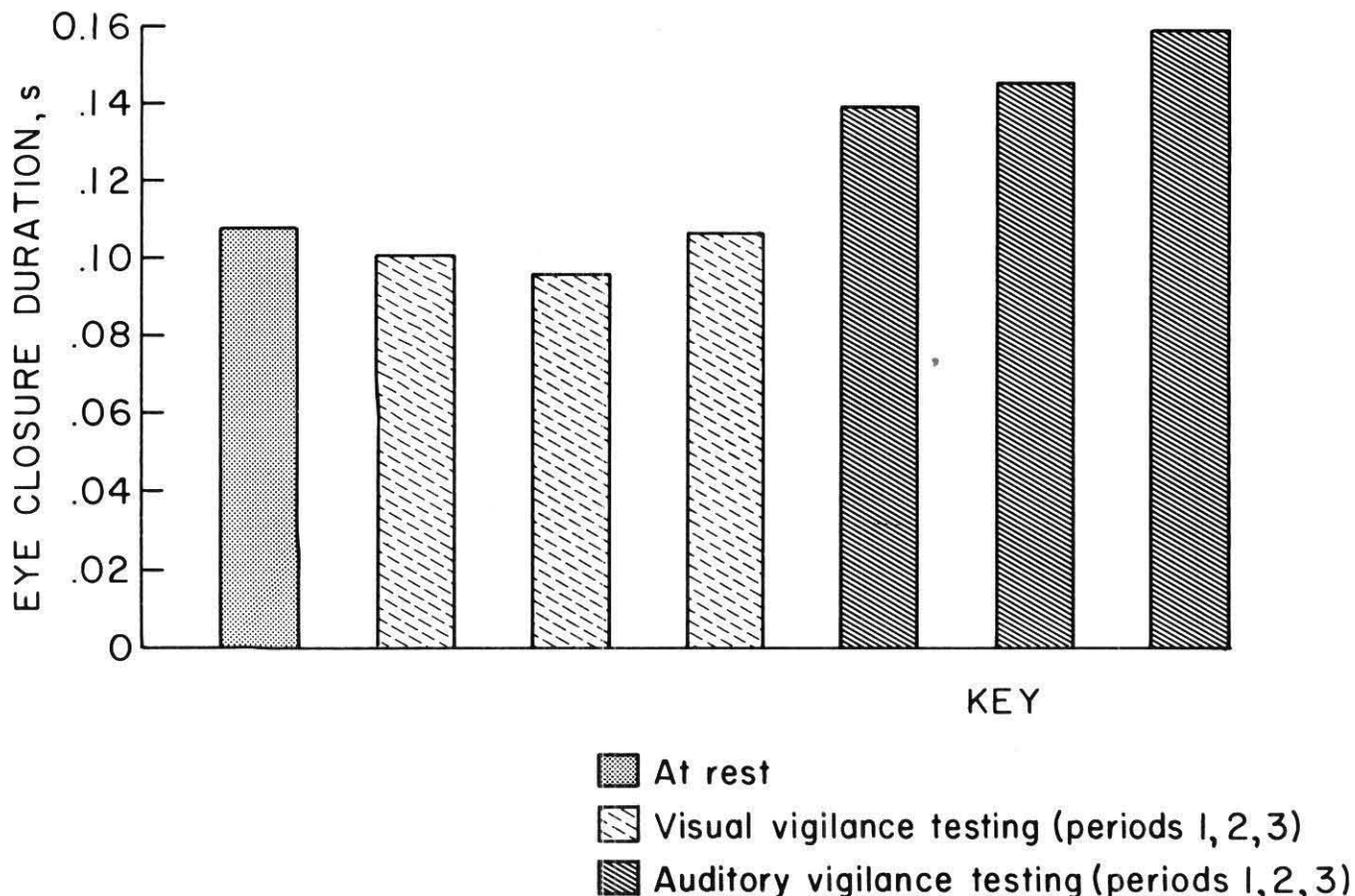


FIGURE 6. - Eye closure duration data.

presentation of an auditory stimulus, up to 60 pct of the time the signal was missed. Similarly, a visual stimulus was not responded to from 20 to 30 pct of the time.

Relating this information to the original problem of operator alertness, it can be postulated that if information is presented to the operator by either visual or auditory means at the time an eyeblink or closure is occurring, between 20 to 60 pct of the time the information will be missed and the operator will not make the required response. If the information presented was critical to the safe operation of the vehicle, a good possibility exists for the occurrence of an accident.

Blink Timing

An analysis of the eyeblink data was also made to determine if any

significance could be attached to the time that blinks occurred. As the interval between tones was fixed at 2 s in the auditory tasks, it was possible to evaluate the time of blink occurrence during this interval. The first analysis consisted of dividing the interstimuli interval into two 1-s periods and evaluating the number of blinks occurring in each period as a function of the performance test responses. Responses were divided into four categories as follows:

Hits--finger is lifted from response pad for 200-ms tone.

False alarms--finger is lifted for 300-ms tone.

Misses--finger is not lifted for 200-ms tone.

No response hits--finger is not lifted for 300-ms tone.

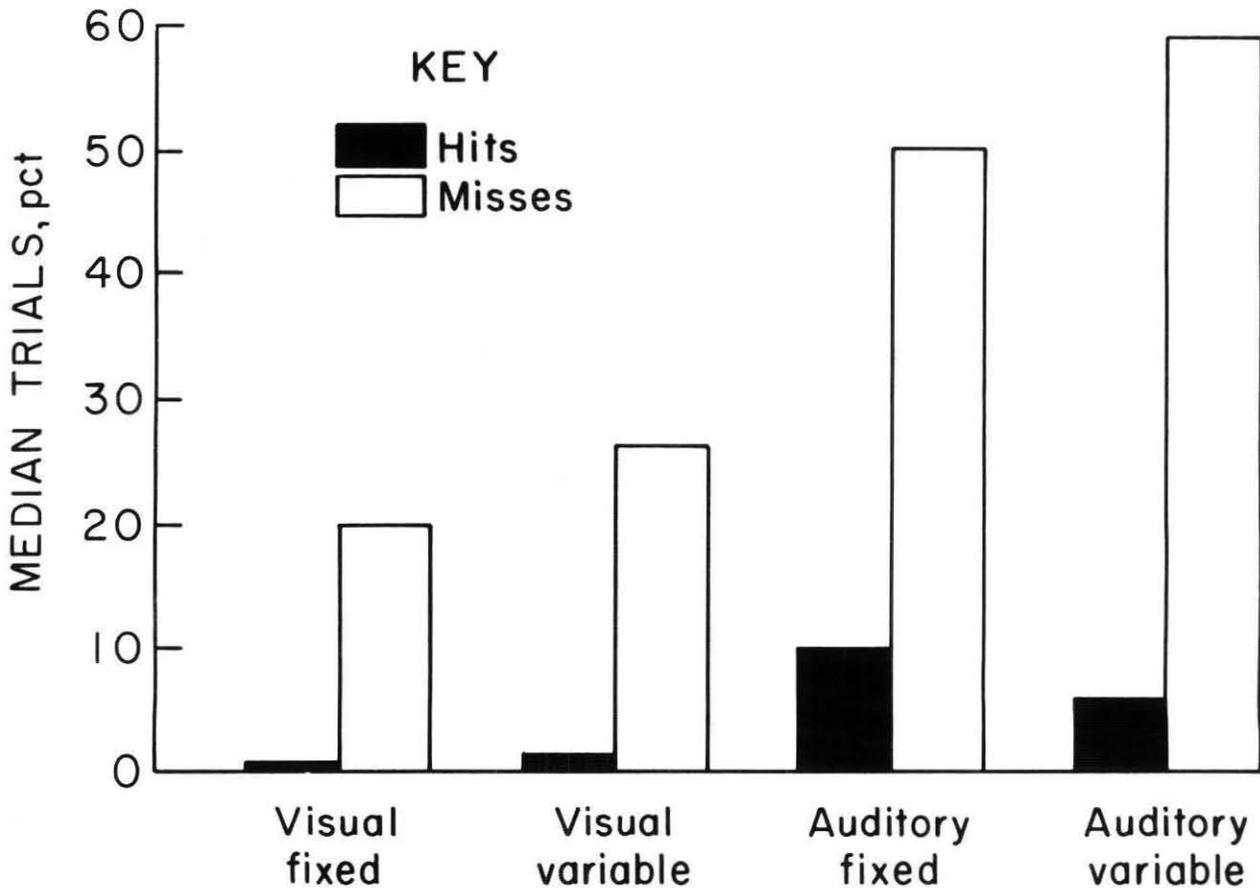


FIGURE 7. - Percent of trials on which blinks and/or closures occurred during stimulus presentation.

The data were analyzed for three separate 5-min periods during the beginning, middle, and end of the auditory vigilance test. As can be seen from table 1, the number of blinks occurring in the first second immediately following stimulus termination is in excess of the 50 pct that would be expected to occur if blinks were distributed in a random manner. It can be concluded that, for most subjects, blinking was maximized during the period immediately following termination of the tone. This correlated well with previous studies cited earlier, which reported that blinks occurred at the moment of relaxation of attention following stimulus termination (5) and were inhibited prior to stimulus onset (1).

Pupillary Hippus

Pupil diameter measurements were taken every 1.66 s over the 1-min monitoring intervals. Since the change in the pupil

TABLE 1. - Mean percentage of blinks falling in first second of a 2-s interstimuli interval

Test period and response	Number ¹	Mean	Standard deviation
Period 1:			
Hit.....	17	67	24.5
Miss.....	10	65	26.4
False alarm.....	13	82	18.5
No response hit.	7	74	14.0
Period 2:			
Hit.....	17	74	15.8
Miss.....	14	73	30.3
False alarm.....	8	75	26.7
No response hit.	17	78	13.1
Period 3:			
Hit.....	17	72	19.5
Miss.....	13	62	32.6
False alarm.....	5	65	41.8
No response hit.	17	73	15.8

¹Sample population of 20.

diameter over time was the matter of concern, Von Neuman's d^2 statistic was chosen to compare the data. The d^2 statistic is defined by the relation

$$d^2 = \frac{(X_i - X_{i+1})^2}{n-1},$$

where X_i and X_{i+1} are successive pupil diameter measurements and n is the total number of measurements in the data set. It is commonly used to compare variations between successive samples and is therefore a better measure for these data than the usual parametric measure of mean and standard deviation.

During performance of the auditory vigilance test, pupil diameter measurements were made as described previously over four separate time periods. The time

Consistent with previous investigations, the results from this study demonstrate the existence of significant task-related effects that influence eyeblink frequency rates. Performance of the visual vigilance testing resulted in a reduction in blink rate as compared with both a resting state and performance of the auditory vigilance testing. Although these results are far from conclusive, it can be hypothesized that during visual task performance a decrease in blink frequency rate is associated with the highest level of alertness.

The results of this experiment are more conclusive with respect to blink timing. The claim that blinks tend to occur when they interfere least with the processing of incoming information was supported. During the auditory task, blinks were reasonably tightly time-locked to stimulus termination. Clearly, this period occurs immediately after the most recent incoming information has been processed and farthest away from the expected presentation of the next stimulus. Finally, it was discovered that blink closure durations are also sensitive to task demands. This is important in that blink closure does not exhibit as much between-subject variability as blink frequency does. It is therefore

periods were 1 to 2, 9 to 10, 18 to 19, and 27 to 28 min for the 32-min test. Table 2 presents the results of the data analysis. It is readily apparent that no significant time on task effect is manifested. The distribution of d^2 is widely variable, and contrary to the expectation that time on task effects would lead to an increase, no increasing trend is apparent.

TABLE 2. - Von Neuman's d^2 statistic during performance of the auditory vigilance task, sample population of 11

Period	Mean	Standard deviation
1.....	2.85	2.83
2.....	1.54	1.33
3.....	2.18	3.39
4.....	1.68	1.45

CONCLUSIONS

conceivable, given a clearer understanding of the correlation between degree of alertness and eye closure duration, to develop some universal monitoring criteria applicable to the majority of mine equipment operators. Perhaps the most important results concern the effect that oculomotor activity has on the reception of sensory stimuli. It has been shown that between 20 and 60 pct of visual and auditory stimuli were not responded to when eyeblinks or eye closures occurred during the presentation of the stimulus. This is important in that an operator's inability to respond appropriately to an unexpected situation accounts for a significant portion of mobile-mining-equipment-related accidents.

The limited study undertaken concerning pupillary hippus revealed that the utilization of pupil diameter changes for identifying states of decreased alertness has more limited applicability than suggested by Yoss (12-13). Further investigation under conditions more closely following the previous studies of Yoss (12-13) and Lowenstein (6) would be required before any conclusive statements can be made. However, at the present time, pupillary changes seem to offer only limited potential as a real-time indicator of alertness.

REFERENCES

1. Baumstimler, Y., and J. Parrot. Stimulus Generalization and Spontaneous Blinking in Man Involved in a Voluntary Activity. *J. Experimental Psychology*, v. 88, 1971, pp. 95-102.
2. Drew, G. C. Variations in Reflex Blink-Rate During Visual-Motor Tasks. *Quar. J. Experimental Psychology*, v. 4, 1950, pp. 73-88.
3. Hubert, S. T. Driver Alertness Monitoring System For Large Haulage Vehicles (contract H0282006, Tracor MBA). Final Rep., November 1982, 118 pp.; available for consultation at Bureau of Mines, Twin Cities Research Center, Minneapolis, MN.
4. Janisse, M. P. Pupillometry: The Psychology of the Pupillary Response. Wiley, 1977, 204 pp.
5. Kennard, D. S., and G. H. Glaser. An Analysis of Eyelid Movements. *J. Nervous and Mental Diseases*, v. 139, 1964, pp. 31-48.
6. Lowenstein, O., R. Feinberg, and I. E. Loewenfeld. Pupillary Movements During Acute and Chronic Fatigue: A New Test for the Objective Evaluation of Tiredness. *Investigation in Ophthalmology*, v. 2, 1963, p. 138.
7. Peng, D. L., J. A. Stern, and L. N. Orchard. Chinese and American Readers: A Look at Information Processing Efficiency and Eye Movements. To be pub. in *Pavlovian J. Biolog. Sci.*, v. 18, 1983.
8. Ponder, E., and W. P. Kennedy. On the Act of Blinking. *Quart. J. Experimental Psychology*, v. 18, 1927, pp. 89-110.
9. Sirevaag, E. J., J. A. Stern, P. J. Oster, and L. C. Walrath. The Relationship of the Eyeblink to Aspects of Performance. WA Univ. Behavior Res. Lab Rep., St. Louis, MO, 1982, 33 pp.
10. Stern, J. A., and L. C. Walrath. A Study To Determine the Comparability of Pupillographic and Electrooculographic Measures in Determining Fatigue Effects in Truck Drivers (contract JO205064, WA Univ.). BuMines OFR 10-83, 1982, 65 pp.
11. Wilkinson, R. T., and D. Houghton. Portable Four-Choice Reaction Time Test With Magnetic Tape Memory. *Behavior Res. Methods and Instrumentation*, v. 7, 1975, pp. 441-446.
12. Yoss, R. E., N. J. Moyer, and R. W. Hollenhorst. Pupil Size and Spontaneous Pupillary Waves Associated With Alertness, Drowsiness, and Sleep. *Neurology*, v. 20, 1970, pp. 545-554.
13. Yoss, R. E., N. J. Moyer, and K. N. Ogle. The Pupillogram and Narcolepsy: A Method To Measure Decreased Levels of Wakefulness. *Neurology*, v. 19, 1969, pp. 921-928.

LARGE ROPS AND OPERATOR RESTRAINT DEVICE RESEARCH

By Stephen A. Swan¹

ABSTRACT

Rollover protective structures (ROPS) and seatbelts are required on all large self-propelled, track-type and wheeled mining equipment manufactured after July 1, 1969, used in mining operations. To keep a driver in this protective structure in the event of a rollover, seatbelts are also required.

Management and safety personnel realize the advantages of wearing seatbelts on ROPS-equipped machines; nevertheless, very few operators wear seatbelts. Some

of the reasons why operators don't wear seatbelts follow: They are not comfortable, they are not convenient to use, and the operator lacks knowledge of the advantages of wearing seatbelts.

This report delineates Bureau of Mines research to develop substantiated structural design data for large ROPS (for use by the Society of Automotive Engineers) and the interrelated area of restraint technology.

INTRODUCTION

The Society of Automotive Engineers (SAE), through Subcommittee 12--Machine Test Procedures of the Construction Machinery Technical Committee, develops rollover protective structure (ROPS) structural performance and test method criteria for use by industry in the design and performance certification of ROPS used on a wide variety of mobile construction and mining machines.

Certain types of mining, construction, earthmoving, agricultural, and forestry equipment are equipped with ROPS. The types of mobile machines commonly equipped with ROPS include crawler tractors and crawler loaders, motor graders, wheeled loaders and tractors, skid-steer loaders, and the tractor portion of tractor-scrapers. It is not uncommon to observe off-highway haulage trucks and water trucks that have ROPS installed.

The widespread use of ROPS in the United States, Canada, and other countries, is due to the relatively recent awareness of the extent of accidental rollovers of mobile equipment during field use. The development and implementation of accident data collection and

analysis activities by various Government and private groups has helped determine the numbers of injuries and deaths due to machine rollovers. Federal and State safety agencies have promulgated regulations requiring the installation of ROPS and seatbelts on these types of equipment in an attempt to reduce the number of injuries resulting from rollover accidents. Although these regulations require that the employer who owns the machine equip it with ROPS to provide a safer work environment for employees, most of the manufacturers of the machines are installing ROPS on the machines before they are shipped to their dealers.

The ROPS regulations promulgated by the Occupational Safety and Health Administration (OSHA) in 1972, by the Mine Safety and Health Administration (MSHA) in 1974 and 1977, by the State of California Division of Industrial Safety (Cal-DIS) in 1966, and by several of the Canadian Provinces base the ROPS structural performance capability on criteria developed by SAE. It is recognized within the SAE technical committees responsible for developing ROPS performance criteria that these criteria need frequent update (every 5 yr) to introduce needed improvements.

¹Mining engineer, Twin Cities Research Center, Bureau of Mines, Minneapolis, MN.

The use of ROPS as required by the current law has saved many lives. A review of rollovers involving 56 machines with ROPS and 62 machines without ROPS indicated over four times as many fatalities involving machines without ROPS. In addition, ROPS-equipped machines in many rollovers have prevented injuries, and therefore these events have never been reported. In addition indications are that none of the operators killed in rollovers of ROPS-equipped machines were wearing seatbelts. If the operators of the ROPS-equipped machines had used seatbelts, all of them might have survived the rollover.

Seatbelts installed on surface mining equipment are subjected to conditions

quite different from those in automotive applications. Although the trend is toward enclosed cabs, many pieces of equipment do not have cabs, or the cab doors and windows are kept open most of the time. Consequently, a seatbelt assembly installed on surface mining equipment must be capable of performing satisfactorily during and after prolonged exposure to the elements of the mine environment. In addition to the direct outdoor exposure, the seatbelt assembly may come into contact with hydraulic oil, fuel, dust, and other operational elements that can rapidly deteriorate its effectiveness.

ROPS PERFORMANCE

The objective of the Bureau of Mines ROPS work was to determine, within the limitations of the data available, whether or not ROPS are providing adequate protection to the operators of mining equipment. As part of Bureau contract J0285022, "Survey of Rollover Protective Structures (ROPS) Field Performance," conducted by Woodward Associates, Inc., the following results were obtained:

1. ROPS do the job for which they are intended. There has been a significant reduction in deaths due to mining and construction machine rollovers, as shown in table 1 for earthmoving equipment.

2. Many ROPS designs currently in use on equipment in the field have structural performance capabilities that significantly exceed the requirements given in SAE recommended practices.² This industry practice may have a positive influence on the excellent lifesaving record of ROPS.

²SAE recommended practice J1040(c), "Performance Criteria for Rollover Protective Structures (ROPS) for Construction, Earthmoving, Forestry, and Mining Machines," is available from Society of Automotive Engineers, Warrendale, PA.

TABLE 1. - ROPS effectiveness in earthmoving equipment rollovers, percent

	Machines equipped with ROPS (102 accidents)	Machines not equipped with ROPS (101 accidents)	Machines with ROPS status unknown (28 accidents)
No injury.....	37.3	13.9	35.7
Minor injury.....	25.5	13.9	10.7
Major injury.....	18.6	21.8	14.3
Fatality.....	14.7	48.5	21.4
Unknown.....	3.9	1.9	17.9
Total.....	100.0	100.0	100.0

3. This study was unable to confirm the adequacy of the structural performance criteria presented in SAE recommended practices. The ROPS that have saved lives in the mining and construction industries significantly exceed the minimum SAE requirements. It is possible that ROPS designed simply to meet the SAE recommended practices would provide less satisfactory operator protection.

4. If machine operators can be persuaded to wear their seatbelts and stay with the ROPS-equipped machine, their chances of surviving a rollover are many times greater than if they attempt to

jump or if they are thrown from the machine.

5. Different generic types of machines have been shown to experience different severities of rollover. There is a different "typical" or "standard" rollover for each type of machine and perhaps even some differences within some generic types. Therefore the ROPS performance criteria should be based on protecting the machine operator in a high percentage (say 95 pct) of the possible rollover accidents for each generic class of machine.

LARGE ROPS ROLL TESTING

The SAE ROPS criteria were developed by building ROPS, performing side and top-load tests on the ROPS when installed on the vehicle, and then rolling the vehicle equipped with the ROPS down a test hill. In the late 1960's, when these criteria were being developed, the largest machines were in the 140,000-lb range. As the machines became bigger, the SAE criteria were extended to cover these machines, but no actual roll tests were conducted.

The required energy curve representing force versus machine gross vehicle weight (GVW) was flattened as the machines became larger, since the operator's compartment became much smaller in relation to the size of the machine. Thus, designers projected that other parts of the machine, in addition to the ROPS, would absorb energy and provide protection.

In late 1977, a machine manufacturer performed rollover tests of a large wheeled loader and a large crawler tractor weighing approximately 200,000 lb. Original ROPS designs for both machines exceeded SAE J1040(b) performance criteria. The wheeled loader ROPS fractured and was essentially crushed by a 180° side roll down a slope. The crawler ROPS

survived rollover on a similar slope. The manufacturer redesigned the ROPS for both machines, exceeding SAEJ394 and SAEJ395 "small machine" ROPS performance criteria. Both machine ROPS then survived rollover testing.

These rollover tests have provided the first available test data on a large machine rollover. The tests have raised the serious question as to what criteria should be used for large (200,000 lb) machines and particularly very large (350,000 lb) machines. It must be remembered that these test data were the only information available at the time the Bureau's ROPS program was started and the conclusions drawn from these tests may be relevant only to the particular model and configuration of front-end loader and crawler tractor involved.

The Bureau obtained two large front-end loaders (FEL) (390,000 and 286,000 lb) from equipment manufacturers to provide data by actual rollover tests. On the recommendations of the original equipment manufacturers, the following were selected for testing under Bureau contract H02902020, "Development of ROPS Performance Criteria For Large Mobile Mining

Equipment," with Woodward Associates, Inc.:

1. Roll hill slope of 35°.
2. Roll hill length of 120 ft (to enable the largest machine to roll a maximum of 720°).
3. A penetration resistance of 1,800° psi for the roll hill.

All ROPS structures were instrumented to record 20 channels of strain, 6 channels of deflection, 3 channels of acceleration, 2 channels of roll rate, and 4 time channels. Three roll tests were conducted:

- a. First roll test (720°) for a 390,000-lb FEL (fig. 1).
- b. Second roll test (720°) of a 390,000-lb FEL (fig. 2).
- c. Roll test (720°) of a 286,000-lb FEL (fig. 3).

A factor that most significantly affects the loading on a ROPS during rollover is the overall ROPS-machine configuration as demonstrated during the third test using a 286,000-lb FEL. Since the ROPS configuration and/or the

combined ROPS-machine configuration were factors that caused lower than expected side loads, a configurational parametric study was undertaken.

A computer simulation of a rollover is being conducted using the ROPS impact instrumentation data obtained during the rollover testing. The following configurational parameters are being evaluated in respect to the gross vehicle weight (GVW) to determine ROPS performance:

1. Width of ROPS.
2. Width of machine (including tires).
3. Length of ROPS (at top).
4. Plan-view area of the ROPS top plate.
5. Area of ROPS viewed from the side (with cab if integral to ROPS).
6. Area of ROPS longitudinal cross members viewed from the side.

Available roll data are being obtained from the original equipment manufacturer. This project, which is nearing completion, will result in an updated SAE recommended practice for ROPS performance criteria.

OPERATOR RESTRAINT TECHNOLOGY

Once the protective structure around a driver is assured, in the event of a rollover, the need exists to increase the number of operators of surface mining equipment using restraint devices, such as seatbelts, that keep them inside the structural protection. Although ROPS and seatbelts are required on all mobile mining equipment, injuries are still occurring to operators who do not use the seatbelts for containment within the protective area of the ROPS during rollover. The three most common complaints registered by operators about seatbelts were fit, comfort, and convenience. Therefore these aspects of the restraint system were first addressed and analyzed. To

satisfy these criteria and retain the operator safely in the seat in the event of vehicle rollover, two new design concepts were developed. The first design uses a vehicle-sensitive retractor (VSR) which relies on a counterweight to activate the belt locking mechanism any time the gravitational forces displace the counterweight owing to vehicle attitude or acceleration-deceleration forces. The automotive VSR mechanism operates at approximately 0.3 g. For off-road vehicles it was adjusted to operate at 0.75 g. Simulated rough terrain tests and rollover tests indicated that this should be both a safe and an acceptable activation level.

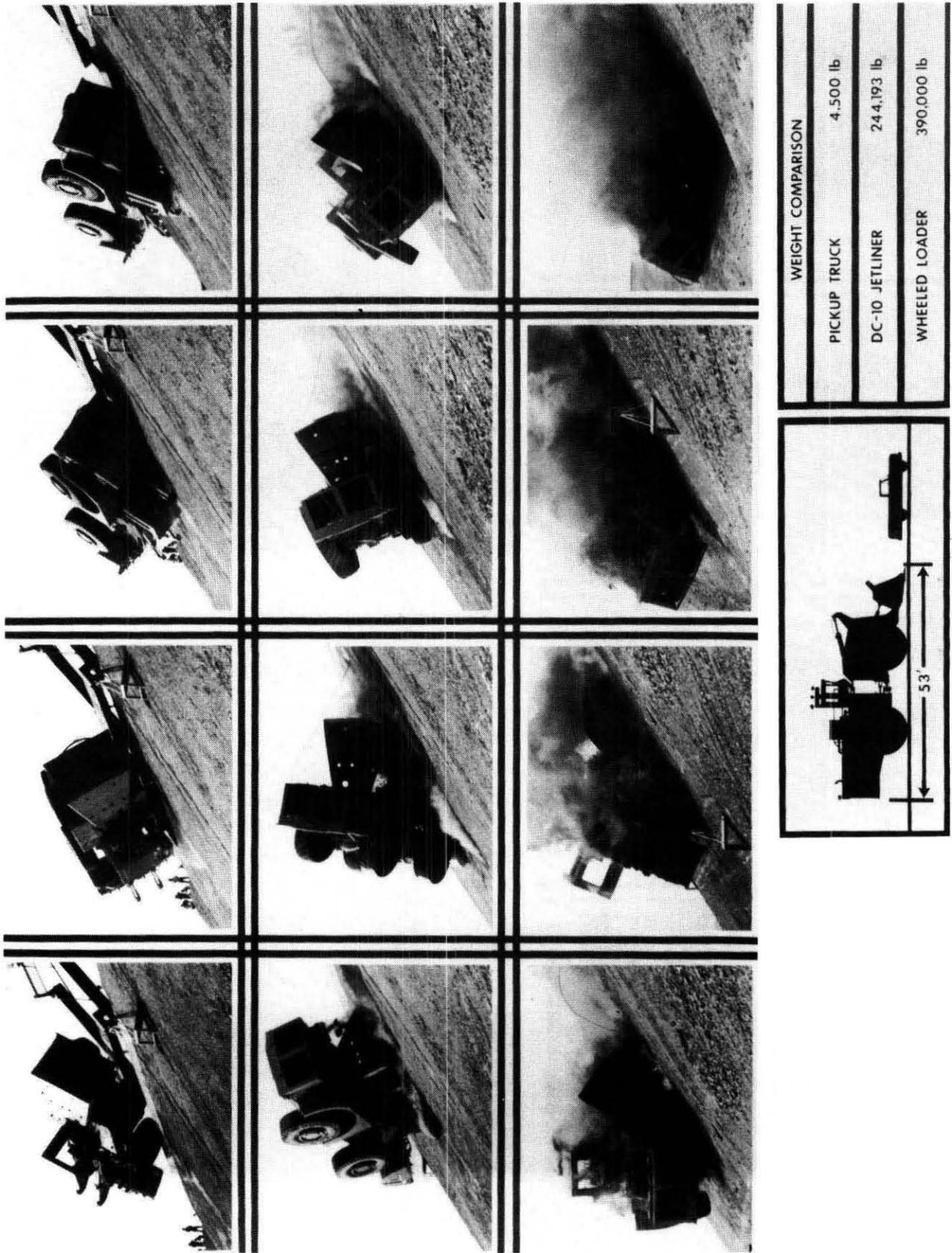
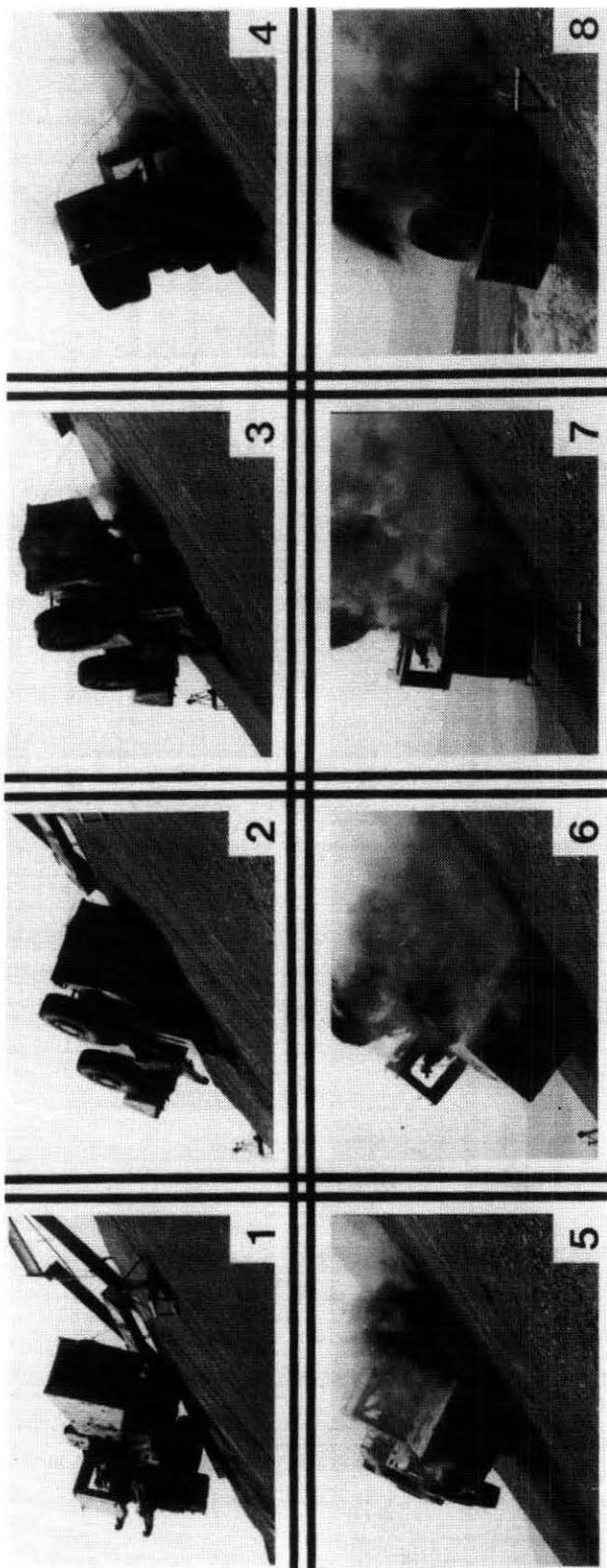


FIGURE 1. - First roll test of a 390,000-lb wheeled loader (720°).



MACHINE AFTER ROLL

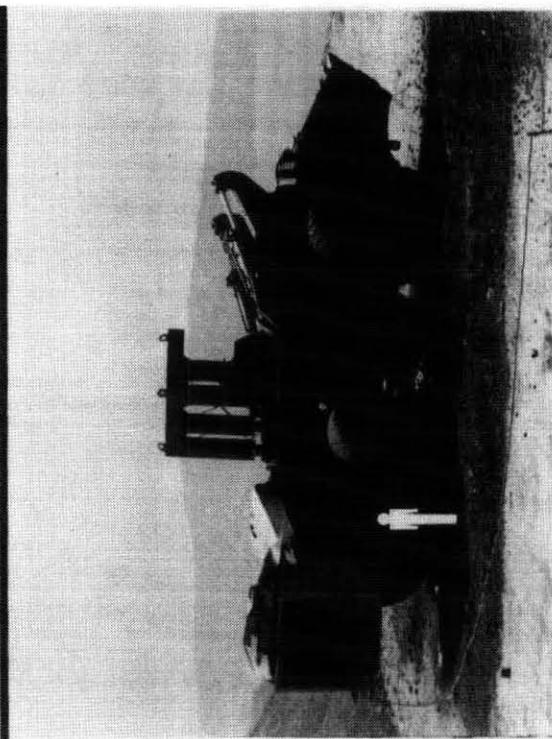


FIGURE 2. - Second roll test of a 390,000-lb wheeled loader (720°).

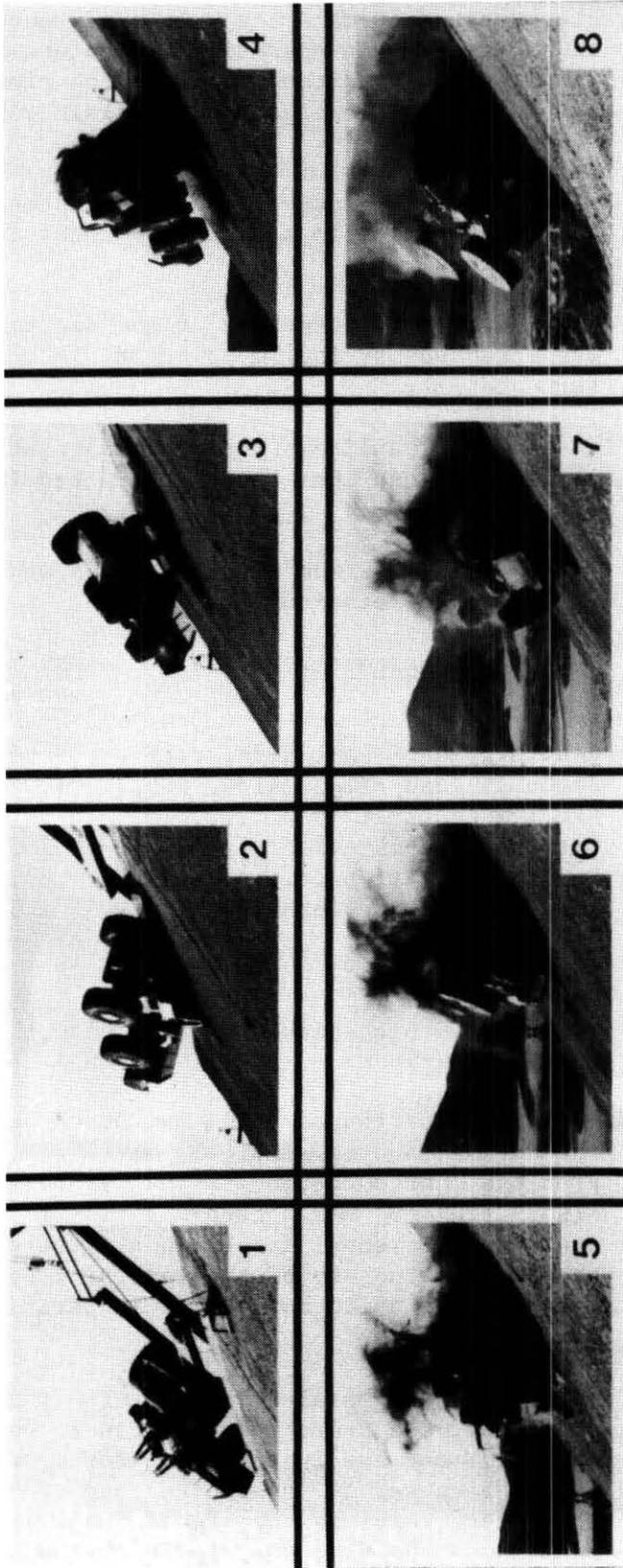


FIGURE 3. - Roll test of a 286,000-lb front-end loader (720°).

To evaluate this design, a seatbelt rollover test was conducted in conjunction with the ROPS rollover program, utilizing a 50th percentile anthropomorphic male dummy weighing 160 lb. Seatbelt loads were obtained for both the left and right sides of the belt. With the exception of the longitudinal head acceleration, these values were obtained during the first impact of the ROPS. The vertical acceleration of the dummy's head exceeded the limitation of the accelerometer, which was approximately 20 g. The maximum longitudinal head acceleration occurred after the first impact.

The average seatbelt load was approximately 5.7 times the weight of the dummy. This load level is not as high as might be expected from the head acceleration rates. This difference may be due to the fact that the acceleration rate and the roll direction of the machine must be considered in comparing the dummy head accelerations with the seatbelt loading. Maximum seatbelt loads along with maximum dummy head acceleration rates are shown in table 2.

The major advantages of the VSR system over present lapbelt systems were as follows:

VEST RESTRAINT SYSTEM

Recognizing that there are some problems associated with lapbelt-type restraining systems, namely the fear of entrapment, the restriction of movement, and the lack of comfort, the Bureau developed a second design concept creating a novel restraint system. The essentials of this system are a vest restraint system (VRS) shown in figure 4 and a tethered line or retractor-type anchoring device.

The VRS has an upper-body harness incorporated in the vest structure to give upper torso restraint in the event of vehicle rollover. This harness is made with standard 2-in seatbelt webbing and in-line adjusters. A quick-release safety buckle secures the vest and harness about the waist. D-rings sewn onto the vest webbing are the connection points for the anchoring device. The anchors, whether fixed-length tether or

1. The VSR belts provided mobility for the operator to make the necessary movements for vehicle operation, remained in an unlocked condition most of the time, and locked when extremes of terrain were encountered.

2. Tests indicate the belt assembly would also lock in a rollover condition as designed.

3. Operator acceptance of the seatbelt was enhanced by the improvement in comfort and fit.

4. The cleanliness aspect was greatly improved since the belts retracted for storage.

TABLE 2. - Maximum seatbelt loads and head acceleration

<u>Parameter</u>	<u>Maximum value</u>
Seatbelt load--left side....lb..	816
Seatbelt load--right side...lb..	1,013
Average seatbelt load.....lb..	914
Vertical acceleration.....g..	20.7
Side acceleration.....g..	8.14
Longitudinal acceleration....g..	2.83

retractor, use snaphooks to connect to the vest D-rings.

The combination of a VRS and an anchoring device should eliminate most of the problems encountered with lapbelts. Also, the VRS would become part of the operator's personal safety gear, thereby encouraging the use of the restraint systems more than do soiled or inoperative lapbelts.

A preliminary analysis of the VRS indicates that the prototype vest can be comfortably and easily adjusted for proper fit. Because of snaphooks and other attachment devices for tools and lunch buckets on the VRS, the operator's hands can be free during ingress and egress from the equipment. This improved way of carrying items aboard the vehicle will reduce slip and fall accidents.

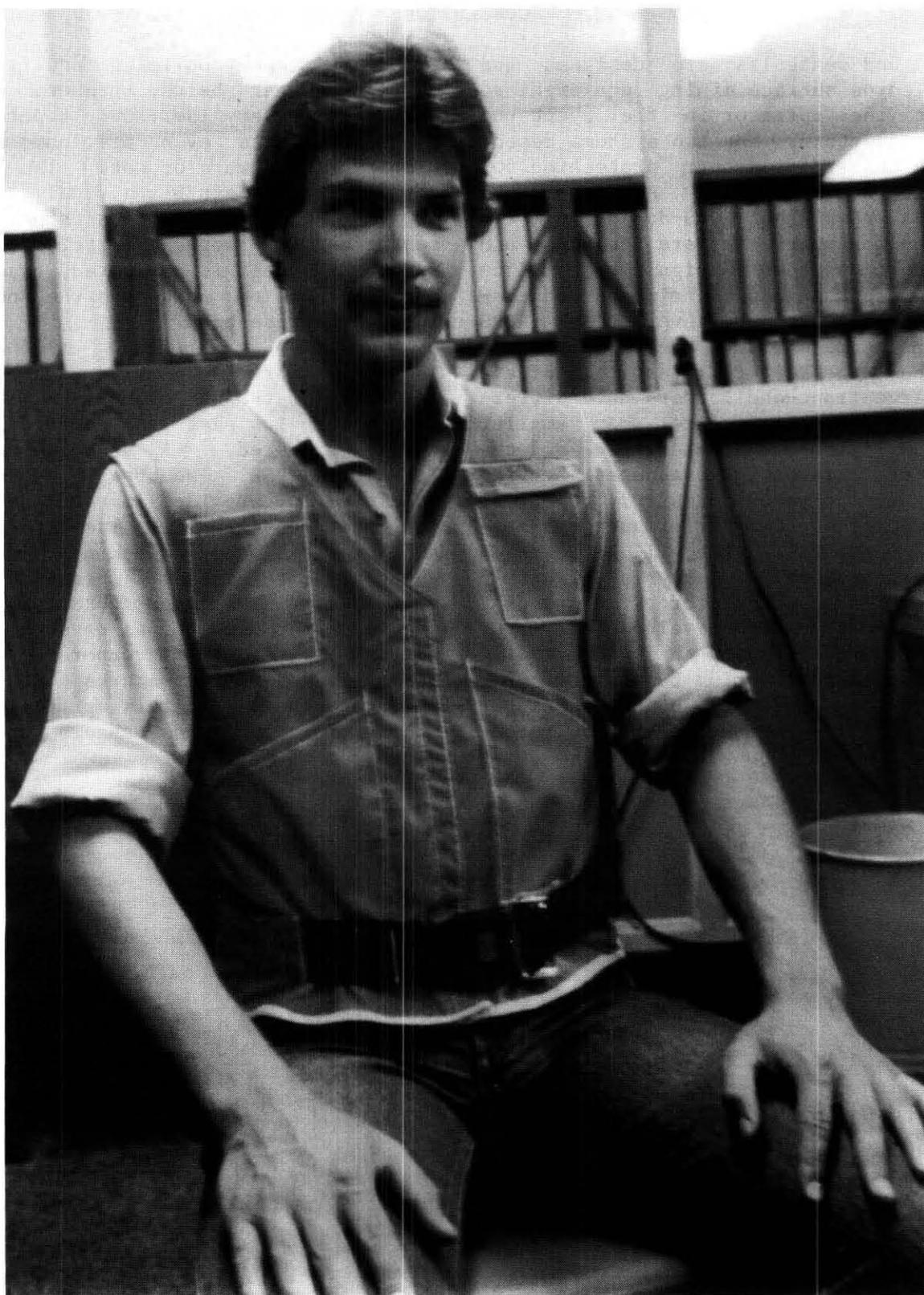


FIGURE 4. - Vest restraint system.

CONCLUSIONS

ROPS and seatbelts are designed and installed on surface mining equipment to protect the operator in the event of machine overturn. The two systems depend on each other for proper protection for the machine operator. Accident data analysis shows that ROPS do perform the function for which they are intended, and that there has been a significant reduction in deaths due to mining and construction machine rollover since ROPS have been required. Preliminary data from the large ROPS roll testing indicate that large front-end loaders have different roll characteristics than smaller machines. These characteristics and the test data are being evaluated by the Bureau and private industry. Owing to Bureau efforts, ROPS performance requirements for the first time will be based on rigorous engineering analysis of actual rollover data. Therefore the new SAE recommended practice developed from the information obtained by this project will have a sound engineering basis that will also provide operators of ROPS-equipped machines wearing seatbelts better protection in the event of rollover.

Despite company policies requiring that operators wear belts, present use of seatbelts is very low. Only 5 pct of the accident reports even mentioned whether seatbelts were worn or not. The rest of the forms were left blank. Only 2 pct of all the accident reports stated that seatbelts were worn. Therefore a new restraint system is warranted, based upon present lack of usage and the need for increased protection.

A preliminary subjective analysis of available restraint technology indicated that seatbelts must be comfortable and easily adjusted. A vehicle-sensitive retractor (VSR) seatbelt system was developed to provide improved comfort, fit, and convenience. The VSR system also provides manual locking capability. A second alternative is provided by a vest restraint system (VRS) that is issued to the operator as personal equipment. This system incorporates several attractive safety features that will encourage the person to keep it clean and well maintained and should therefore receive more use.

OFF-HIGHWAY HAULAGE TRUCK MAINTENANCE SAFETY

By Dennis A. Long¹

ABSTRACT

This paper assesses the haulage truck maintenance safety problem and reports in detail maintenance accident data for recent years. Further analysis quantifies the safety hazard in terms of job activities, truck components and systems, tools involved, and truck design.

Together with practical information obtained from industry experts, recommendations are presented to enable the mining industry to make changes where specifically needed to abate the increasing safety hazard to truck maintenance mechanics.

TRUCK MAINTENANCE PERSONNEL

Workers below the age of 31 were involved in 49.0 pct of all truck maintenance accidents. Workers with less than 6 months' experience in the particular job held at the time of the accident accounted for 27 pct of all accidents; and 59.0 pct had less than 3 years of job experience. Figure 1 gives the percentage of truck-maintenance-related accidents by job title. Maintenance personnel, including mechanics, helpers, and trainees, accounted for 65.0 pct of the accidents, while the mine equipment operators accounted for over 25 pct.

To examine the nature of the injuries, the Bureau classified the severity of haulage truck maintenance accidents by work days lost (table 1). Most maintenance accidents were not characterized by severe injuries, as 33.5 pct of the accidents involved no lost time and 41.3 pct involved between 1 and 15 lost days. Information from mine visits indicates that maintenance also accounts for a large number of unreported accidents.

The body parts injured in maintenance accidents are presented in figure 2, with the data grouped into major categories. Head and neck injuries accounted for 16.2 pct, and major body injuries, involving the chest, back, hip, or trunk, totaled 33.5 pct. Back injuries involved 16.1 pct and eye injuries 7.0 pct.

Maintenance injuries commonly involve the extremities, accounting for over one-half of all accidents. This includes hand (22.5 pct), leg (10.1 pct), and foot (7.3 pct).

TABLE 1. - Truck maintenance accidents by lost work days, U.S. surface mines, 1978-79, percent

0.....	33.5
1 to 5.....	19.6
5 to 15.....	21.7
15 to 30.....	8.9
30 to 60.....	10.1
Over 60.....	6.2
Total.....	100.0

Injuries most commonly resulted due to lack of proper training for the particular job being done at the time of the accident. Unsafe actions accounted for 71.5 pct of all accidents. This category includes taking an unsafe position, using equipment unsafely, nullifying safety devices, failing to use a platform or personal protection, and horseplay. About 41 pct of all accidents were due to the worker's taking an unsafe position, such as reaching beyond the lifting radius or attempting to climb a ladder with a heavy part in hand. Failure to secure caused 19.0 pct and included causes such as improper support of heavy parts and components or failure to secure the truck box.

¹Mining engineer, Twin Cities Research Center, Bureau of Mines, Minneapolis, MN.

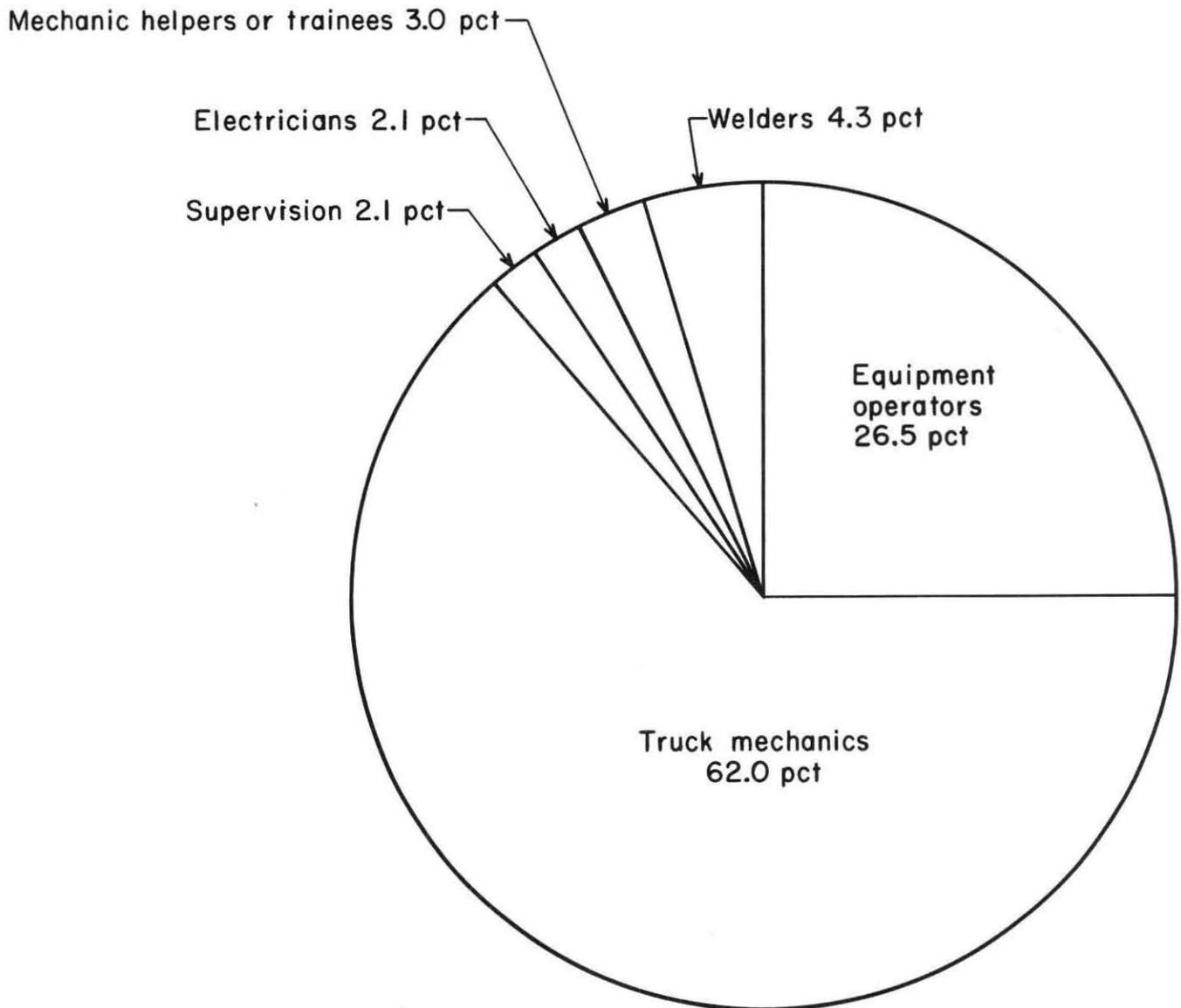


FIGURE 1. - Truck maintenance accidents by job title.

Because of the significant number of accidents due to unsafe actions taken by the truck mechanic, it is likely that a key safety problem is the lack of effective skill training. Further examination of the problem reveals that the maintenance people were commonly--

1. Performing tasks for which they were not formally or adequately trained. This includes both equipment operators doing maintenance-type work and maintenance mechanics tramping a piece of equipment to and from the shop. Over one-fourth of all haulage truck maintenance accidents involved equipment operators.

2. Not following prescribed procedures or safety precautions. This would include disregarding lockout procedures or nullifying a safety device.

3. Working with inadequate or improvised tools and equipment. Although the mechanic may be taking an unsafe action, there may not be any other way to get the job done.

Most maintenance training in the mines consists of safe work briefings followed by on-the-job experience under either a lead mechanic or a senior employee. Instruction varies and is based on the

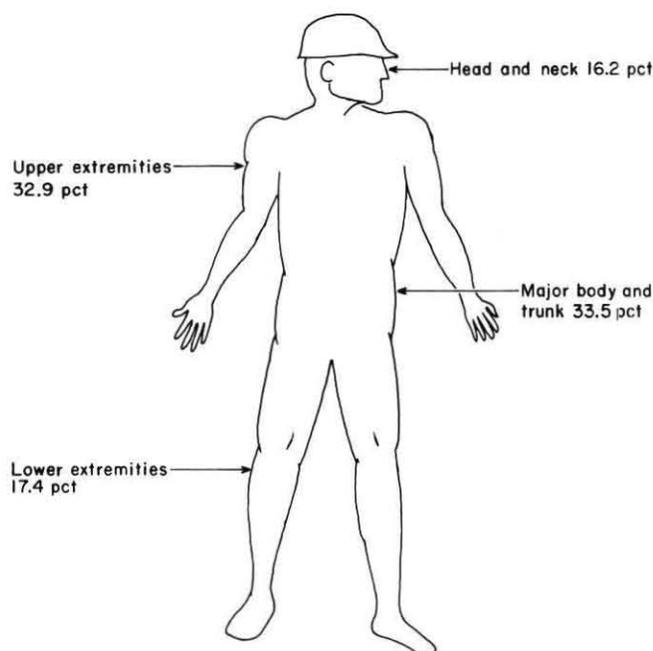


FIGURE 2. - Truck maintenance accidents by body part injured.

teaching skills of the supervisor. Experience is not necessarily the best teacher. Emphasis should be placed on recognizing specific hazards, knowledge of proper job procedures for the various truck models and systems, and correct use of tools and equipment.

Proper job procedures and tool use could be enhanced through easy-to-use troubleshooting guides. Fewer than half of the equipment manufacturers provide such guides for their products. Most of the available guides need to be improved substantially in terms of both effectiveness and ease of use. Only four major manufacturers were frequently praised for providing good to excellent troubleshooting guides.

TRUCK MAINTENANCE SHOPS AND AREAS

As expected, most accidents occur in the shop, where the maintenance usually takes place. Specifically, 70.7 pct of all haulage truck maintenance accidents occurred in the shop. The importance of accident location increases when it is considered that most maintenance activities take place within the shop

The second most frequently identified training need was for guidebooks for specific maintenance tasks, such as a manual on the haulage truck electrical system, cooling system, hydraulics, or electronic components. Again, several manufacturers have materials that can be purchased, but they cover only a limited number of maintenance tasks on a specific truck model. Some manufacturers have no effective manuals for their products. The following areas were identified by maintenance personnel for improvements in maintenance manuals:

1. Must be specific, complete, and up to date. Numerous manufacturers try to use one manual for all makes and models. This makes manuals complex and lengthy. Older models are dropped and new ones added without updating the manuals.
2. Must have a good cross-reference and index system.
3. Should include an effective troubleshooting guide.
4. Should provide updating capability so that technical corrections, improved maintenance procedures, and safety warnings can be brought to the attention of site personnel.
5. Should be compact and easily portable for use in working sections.

Mechanics should also be trained and qualified to operate the equipment they maintain. Although their job involves shuttling equipment in the shop area, mechanics are typically not trained to operate the machines and are not familiar with their safe operating limits.

facilities. Although 29 pct of the accidents studied occurred in the field, it is estimated that only about 10 to 15 pct of the maintenance work was done there. Thus, field maintenance work is two to three times more hazardous as shop work.

An important recommendation, to counter the hazards of field maintenance work, is to develop and use towing vehicles capable of moving disabled trucks to the shop. Towing a large haulage truck is very difficult, involving two or more support vehicles and additional personnel. But because of the high capital cost, only a few of the largest mining operations in the United States have specialized towing vehicles. Another solution might be to retrofit the truck so that it can be towed more easily.

Improved physical design of maintenance areas and equipment bays could help reduce accidents. Included here would be such factors as work space organization, housekeeping, illumination, ventilation, noise control, and transporting of parts. An effectively designed workspace could enhance productivity, allow more efficient use of tools, and improve safety. Roughly 30 pct of the accidents involved poor housekeeping practices.

Poor workspace organization was common in most of the mines visited, manifested as follows:

1. Handtools and small powertools strewn about or stored wherever space permitted, forcing people to climb over or reach around them.
2. Tools or parts not conveniently located, requiring people to search for them.
3. Shop floors covered with cables and hoses, presenting a tripping hazard.

TRUCK DESIGN FOR SERVICEABILITY

Some problems are caused by the poor design of the truck for routine or major maintenance. Design improvements would substantially reduce maintenance time and maintenance-related injuries.

The following are a few examples to illustrate the need for maintenance safety preplanning for large off-highway haulage trucks. On one 120-ton-capacity, electric-drive, rear-dump truck, the changing of a wheel motor was particularly time consuming and

4. The work performed on oil- or grease-splattered ground or in the field on unimproved rocky ground.

Because most truck maintenance shops must service larger trucks than they were originally designed for, there is often insufficient space between truck bays to use tire grabbers for forklifts.

Another important truck shop problem is communication. Large mining machines frequently have two or more people working on or around them at any time. It is important that these people be able to communicate their intentions and actions to each other. Numerous accidents have involved communications breakdowns. Inexpensive technology is available to resolve many of those problems. Simple solutions could include lockout equipment or proper tagging of trucks being worked on.

Because of the high incidence of handtool-related injuries, it is also recommended that emphasis be placed on tool maintenance. Mobile racks should be developed for special tools, since mechanics often improvise a tool set-up when the proper tool cannot be found. Dealers or distributors should be encouraged to stock proper tools. Often the tools are manufactured but are unavailable from the local distributor. Thus, the mine shop is forced to design and fabricate something on the spur of the moment.

hazardous. To remove the motor, it was necessary to remove the truck bed, the entire rear axle assembly, and the casing around the axle-wheel assembly to expose the broken unit. After the motor was removed and a new unit installed, the procedure was reversed for reassembly. Mine maintenance people suggest that this task could be easily performed and with much improved safety if access openings had been provided through the motor-axle housing.

Another example involved a 120-ton-capacity, bottom-dump truck. To change fan belts or certain hoses, either the radiator or the engine block had to be removed. Several minor injuries had been associated with this work. On certain larger trucks, personnel must crawl inside the rear axle housing to adjust the service brakes. Other examples of poor design related to routine maintenance were also identified. For example, minor slip and fall accidents result when people mount large trucks to fuel them. This hazard increases in rain, snow, or icy weather. Likewise, inspections of engine fluid levels and critical hydraulic hoses, and similar checks, are often difficult and hazardous to perform. The machine surfaces crawled on or over are typically coated with grease and are slippery.

By combining the truck maintenance accident data with field-gathered maintenance worktime, it was concluded that the most hazardous components to work on are the tires and wheels, truck body, suspension, and engine. The least hazardous components are brakes and drive train. Overall there is a direct correlation between accidents and the size and scale of the component or part to be worked on. Through analysis of the accidents and mine surveys, a number of design problems relevant to truck maintenance were identified:

1. Poor accessibility to machine parts or areas of the unit for routine or unscheduled maintenance tasks.
2. Inadequate access openings to permit a person to reach or climb in for repairs or to replace parts.
3. The need to remove or dismantle ancillary components in order to access the failed unit.
4. Inadequate or no provisions for the safe handling of heavy or large parts.
5. Inadequate tools to perform the required maintenance task.

6. The need to perform many repairs on the spot without the resources typically available in the shop area.

Because of the large size of many machines, these items interact to make field maintenance both difficult and hazardous.

In some cases, specific equipment modifications would help alleviate hazards. Usually, the changes would involve original equipment options to be offered by the truck manufacturers. However, new options that would enhance truck maintenance safety are often ignored, since the mine's safety department rarely influences truck purchasing decisions.

Improved truck design should be matched with redesign of components, procedures, tools, and manuals. The main design faults include the following:

1. Designing machines that require unskilled-to-skilled mechanics to perform complex sequences of tasks in order to keep equipment operational.
2. Requiring mechanics to manipulate large, heavy vehicle components in tight spaces with inadequate clearances, supports, and tools.
3. Designing equipment such that accessibility for routine maintenance tasks is overly complex, such as having to remove a large radiator in order to change a fan belt.
4. Providing inadequate access openings, clearances, and visibility for tasks to be performed.

A side-by-side comparison of older mobile mining equipment with newer models indicates that although changes in truck design have occurred, the majority of changes have related either to the equipment operator's safety and comfort or to the production features of the truck. Much work remains to be done in the area of maintenance safety.

TRUCK MAINTENANCE JOB PROCEDURES

Further analysis of the data determined the frequencies for the various causes of maintenance accidents. Table 2 lists accidents by activity of the injured. These generic activity descriptions were created to simplify the data analysis. Movement around the shop area and up and down the mobile equipment accounted for about one-fourth of the injuries. This number reflects the need for adequate work platforms, access steps, ladders, and good housekeeping.

TABLE 2. - Truck maintenance accidents, by activity of the injured, U.S. surface mines, 1978-79, percent

Installing part.....	23.2
Removing part.....	18.3
Servicing equipment.....	16.2
Inspection.....	15.2
Getting on and off equipment.....	14.9
Movement around shop area.....	10.1
Cleaning.....	2.1
Total.....	100.0

The job factors that contribute most to injuries include--

1. Lack of knowledge about correct material handling practices.

2. Limited aids for material handling such as lifting devices, jacks, and hoists.

3. Lack of effective training programs and work procedures for manual material handling, typified by the prevailing attitude that back injuries due to lifting "will not happen to me."

4. Inadequate workstands or platforms for support during tasks requiring reaching or lifting.

5. Inadequate use of personal protection equipment such as gloves, lifelines, or other protective devices. Over 21 pct of the injuries to the hands or fingers

would have been reduced or eliminated with gloves.

6. Lack of supervision.

Removing and replacing parts accounted for 41.5 pct of all accidents studied. Frequently, the weight of a part was taken on by the injured person at too great a distance from the body, resulting in strains, sprains, or crushed or lacerated fingers when it dropped. In most cases, removal and replacement of parts involves support equipment, but wire rope slings and chains tend to slip when they lift items by choking around them. A sudden movement can cause the sling to lose its grip and cause the part to fall free.

It is recommended that maintenance personnel be encouraged to use proper lifting equipment, or to add people for handling heavy parts and equipment, such as drivetrain, tires, and suspension. Improved job training and employee awareness of the weights and necessary handling equipment for different components and parts would help. Also, the manufacturers should emphasize possible hazards in manuals and through warning stickers placed on the equipment.

Fifteen percent of the accidents studied involved a fall from the truck frame, bumper, platform, or tire, owing to inadequate access or workstand. Portable stands are used widely in the industry, but they are usually designed for a particular maintenance task, such as changing oil filters. If a stand is used for another task, such as working on the starter, it may be either too high or too low. This places the mechanic in a difficult position and increases fatigue and the possibility of an accident. A single stand with adjustable height could take the place of several stands. Such a stand could be modeled after the racks used to drop differentials or transmissions.

Table 3 summarizes haulage truck maintenance accidents by their source, or the item that directly caused the injury. This information reveals that the truck body and/or large components directly inflicted about a third of the injuries. The work station, including makeshift supports, ladders, workstands, or the shop floor, was the source for 31.0 pct of the accidents.

TABLE 3. - Truck maintenance accidents, by source of injury, U.S. surface mines, 1978-79, percent

Truck body and/or large components	32.5
Work station.....	31.0
Tools and equipment.....	9.6
Shop area hazards.....	9.6
Truck parts.....	8.0
Tires, wheels, hubs, or rims.....	5.9
Heat or flame.....	3.4
Total.....	100.0

The truck body or large components accounted for about one-third of all accidents. Two fatalities occurred in 1980 as a result of failure to secure the truck box during maintenance. In addition, numerous near-misses and many injuries occurred near medium-size end-dump doors or tailgates. It is recommended that a definite means of securing truck boxes or tailgates be employed and that locking pins or similar devices be provided under the bed. One mine visited has fabricated a hook-and-eye system that is permanently installed on the truck.

One of the most hazardous maintenance tasks is the removal, repair, and replacement of large tires. In reviewing accident reports, it became obvious that procedures for de-airing, airing, removing, and replacing tires are inadequate. In about 12 pct of accidents studied, mechanics were injured when hit by pry-bars or wedge clamps, or by retaining rings damaged during previous repairs. Many mines have purchased tire-grabbing equipment, which aids in removal or replacement of tires, improving safety by

moving the tireman away from tires. Some companies have contracted outside sources for tire maintenance.

A review of tire maintenance practices indicates the following:

1. Protective screens are necessary for people working on or around large tires.

2. Tools used to mount and dismount tires are inadequately designed and require much physical exertion.

3. The lifting devices, such as modified forklifts, are inadequate in design and in their degree of control over the tire and wheel.

4. Inappropriate tools and unsafe equipment are used in the absence of proper tools.

5. Lack of an effective tire damage and wear guide makes it difficult to estimate the risk of tire explosions.

6. Inappropriate work practices or procedures are followed when working with high-risk tires. Sometimes tires are brought into the shop rather than to a designated remote area.

7. Often, little or no formal training is provided to tire maintenance personnel.

These and other factors contribute to the high risk associated with working with large tires. A number of steps have been taken by various mines to minimize these hazards. For example,

1. Many mines fabricate a special "cage" to protect against blowups during inflation and deflation.

2. One tire foreman devised a tire-mounting tool and had a local machine shop fabricate it. That shop now sells the unit to other mines in the area.

3. Many mines have constructed special, protected areas, where all tire work is completed. Should an explosion occur, workers in adjacent areas would be protected.

Over the 2-yr period (1978-79), tools and equipment were involved in about 10 pct of the total accidents. Table 4 lists accidents by tools and equipment. Handtools accounted for almost one-third of all injuries. Elevated platforms and servicing equipment such as jumper cables and airhoses were each involved in 15 pct of the accidents.

Maintenance of off-highway trucks is complex and specialized, and usually must be completed outside the realm of conventional hand and small power tools. Therefore, the design of special handtools could substantially improve maintenance safety. Without knowledge about or availability of specially designed tools, shop personnel often resort to unsafe practices and procedures, locally designed and/or

fabricated tools, and misuse of available tools.

The most important recommendation regarding handtools is for supervisors to take more responsibility for insuring that the right tools are used for the right job. Also, the importance of tool availability, maintenance, and proper storage is again emphasized.

TABLE 4. - Truck maintenance accidents by tools and equipment, U.S. surface mines, 1978-79, percent

Handtools.....	30.3
Elevated work platforms.....	15.3
Servicing equipment.....	15.3
Welding equipment.....	9.0
Push-pull equipment.....	9.0
Floor lifting equipment.....	7.5
Slings and chains.....	5.0
Support equipment.....	5.0
Power tools.....	1.2
Overhead lifting equipment.....	1.2
Cleaning equipment.....	1.2
Total.....	<u>100.0</u>

CONCLUSIONS AND RECOMMENDATIONS

The major factors in haulage truck maintenance accidents appear to be as follows:

1. Lack of safety awareness or inability to measure and judge the job requirement by either the employee or the supervisor.
2. Poor access to working spaces, which forces the employee to take an unsafe position.
3. Poor housekeeping.
4. Poor equipment condition.
5. Choice of the wrong tool or lack of proper tools.

The major goal of this paper has been to present truck maintenance recommendations that are both technically and economically feasible, and are likely to have a high impact on safety while being acceptable to the industry. The approach has been to determine where and how maintenance personnel have been injured and to suggest how to alleviate specific hazardous situations. Many of the recommendations included in this report are already practiced by those mines where top management's commitment to safety leads to excellent safety records.

PERFORMANCE-BASED TRAINING FOR MOBILE EQUIPMENT OPERATORS

By Brett Collins,¹ Kris Krupp,² and Richard L. Unger³

ABSTRACT

To help upgrade and standardize the quality of training in the mining industry, Woodward Associates, Inc., under contract to the Bureau of Mines, is developing and validating a performance-based training system for mobile equipment operators. The goals of the

training system are to reduce injuries and fatalities, reduce equipment maintenance replacement, and increase productivity of the overall mine operation. This paper presents the haulage truck training system as a case example.

INTRODUCTION

The benefits of skill and task training are now being realized by the mining and construction industries. More and more, training is turned to for increasing production and job satisfaction, and for reducing accidents, machine wear and abuse, and maintenance costs.

Historically, training in the mining and construction industries has meant using one of two approaches. One was to hire "qualified" equipment operators and assume that these individuals knew enough about mining practices and equipment operation that they needed no instruction beyond simple commands. In the other case, where such "qualified" operators were not available, training meant leaving the new hire with an employee of long and proven experience until that employee decided that the new hire was "trained." In neither of these cases were performance standards employed--not in the selection of experienced operators since the definition of "qualified" varies from supervisor to supervisor, and not in the criteria by which the "experienced trainer" is able to judge the new employee's developing skill.

To help upgrade and standardize the quality of training in the mining industry, a performance-based training system for mobile equipment operators is being developed and validated. This effort involves the application of proven adult educational methods to an industry that relies on very expensive, often large and diverse equipment which is operated in a hazardous and constantly changing work environment. The goals of training are to reduce injuries and fatalities, to reduce equipment maintenance and replacement costs, and to increase productivity of the overall mine operation.

Work on the development of this training system began in 1970. The system, as tailored for off-highway haulage truck operator training, is currently in use in an open pit copper mine in Arizona and two strip coal mines in Kentucky. Another version is in use at a highway truck driving school in California. A front-end loader version of the system is being validated in the field, and work is continuing on equivalent system applications for eight other generic mobile surface mining machines (e.g., dozers and scrapers). For the purpose of this paper, the haulage truck training system will be the example by which the system is presented.

¹Manager of engineering programs, Woodward Associates, Inc., San Diego, CA.

²Training specialist, Woodward Associates, Inc., San Diego, CA.

³Civil engineer, Pittsburgh Research Center, Bureau of Mines, Pittsburgh, PA.

HAULAGE TRUCK TRAINING SYSTEM

The haulage truck training system is a structured method providing the knowledge and skills needed by operators of off-highway haulage machines. The three main characteristics of the training system are that (1) it is performance based, (2) it is instructor based, and (3) it provides experience in recognizing and handling normal, abnormal, and emergency operating conditions. Classroom teaching and on-machine demonstration and practice sessions are grouped into training elements whereby the trainee acquires basic operating skills before building up to the more complex, higher level skills. An outline of the haulage truck training system elements follows:

Education Orientation. - Introduction to mining and general mining techniques of the specific mine, and to the role of the haulage truck in that mine.

Personal Protection. - Role and proper use of personal protective clothing and equipment, and of rollover protective structures and falling object protective structures.

Preshift Procedures. - Introduction to machine systems, features, and controls; walk-around inspection procedures; preventive maintenance and fluid level checks; startup and shutdown.

Basic Operation. - Basic operation procedures and techniques, hazards connected with operation, abnormal operating conditions (e.g., low air pressure).

Advanced Operation. - Machine operation in the production cycle, special applications of the machine (e.g., dumping at the crusher), night operation, emergency operating conditions (e.g., brake failure).

Proficiency Demonstration. - Final review, practice, and evaluation of knowledge and skills covered in training program.

These elements are presented primarily in slide-tape formats which are supplemented by discussions, workbooks,

field demonstrations, practice sessions, and written and performance progress tests.

The training system relies on the instructor to ensure that it meets the needs of the trainees and of the facility. Although the instructional framework is provided, the instructor will provide significant input as follows:

1. Tailoring the program materials for the specific mine and equipment with which the trainee will be working.

2. Determining the appropriate timing of presentations and practice sessions.

3. Utilizing supplementary training aids and teaching-learning activities for remediation, as needed.

4. Making the important decision as to whether the trainee should be advanced to the next element and, thereby, the next skill level.

The training system is complete with guides, suggestions, and cues to help the instructor make some of these decisions (such as how to use the information from written and performance progress tests to determine if the trainee should advance). But the instructor is all important when it comes to making the training work; he or she is the one who knows the kind of performance to look for. In the hands of an effective instructor, the training system takes the trainee to the desired skill level efficiently and effectively.

The training system is performance based in that the trainee is continually evaluated as to developing skills and is not permitted to progress to the next element until he or she has demonstrated mastery of skills and knowledge at the present level. The in-field performance progress tests and the final proficiency demonstration are based on criteria that reflect the mine owner's requirements for performance, and no trainee is signed off as being "trained" until these criteria have been met.

To assist the instructor in both the teaching and the evaluation of new skills, a specially designed training aid called the on-board simulator of abnormal conditions (OBSAC) was developed for use with the training system. The OBSAC provides an opportunity for the trainee to experience and respond to the abnormal and emergency conditions that are often the cause of accidents associated with the operation of mining machines. The OBSAC is a suitcase-size unit connected to a modified, but full functioning, haulage truck via an umbilical cord. When the OBSAC is not plugged into the haulage truck, the machine performs and functions normally in production. Because the haulage truck can function as both a trainer and a productive unit, the concept of simulation becomes both cost effective and practical and, hence, highly desirable.

With the OBSAC, the instructor can alter gauge readings on the haulage truck's console to give the appearance of changing machine conditions and malfunctions. Actual machine functioning is not altered during such simulations of machine problems. While the specific machine gauges, indicators, and alarms that can be altered by the OBSAC vary from truck model to truck model, following are some of the more common components that are manipulated, and an example of what each can be made to represent:

<u>Gauge, indicator, or alarm</u>	<u>Malfunction</u>
Oil pressure.....	Oil leak.
Water temperature..	Radiator leak.
Voltmeter.....	Discharging battery.
Air pressure.....	Loss of air pressure (brakes).

The instructor can also use the OBSAC to actually reduce or degrade certain machine functions to provide the trainee with the invaluable experience of responding to a machine failure. For example, a haul truck operator-trainee can have an actual experience of trying to stop the truck when up to 50 pct of the service braking capability is lost. This simulated degradation is

accomplished via the BRAKE DEGRADE SWITCH on the OBSAC and occurs only as long as it is held in the ON position by the instructor. Full hydraulic pressure is immediately restored when the switch is released. A total loss of braking capability is not possible via the OBSAC, thereby allowing the instructor to retain control of the training environment and ensure safe use. Similarly, other truck features can be degraded (depending upon the truck model involved), including the hydraulic steering system and the truck's propulsion system.

A digital stopwatch is included on the OBSAC console to allow the instructor to document the lapsed time between the implementation of a malfunction or failure and trainee's recognition and response to the same. This particular feature is especially useful in teaching the importance of console scanning patterns for detection of potentially critical situations before they do in fact become critical. One example would be a simulated loss of hydraulic steering pressure, which automatically initiates an auxiliary hydraulic pump on some machines to provide about 15 s of emergency steering capability. If the loss of steering pressure and subsequent turning on of the auxiliary system is not immediately recognized, the limited emergency steering capability may be expended before the operator can bring the machine to a safe stop. The built-in timer can aid both the instructor and the trainee in knowing if the trainee's response is appropriate and/or adequate for the situation.

The OBSAC is integrated into all portions of the training system where actual machine procedures and operation are involved. For example, in the preshift procedures element, it can be used by the instructor to create an inappropriate prestart condition, such as insufficient control air, which must be detected and corrected before engaging the engine. In basic operating skills, it might be used to simulate a battery discharge during operation in the production cycle. When the operator-trainee is proficient in normal machine operation, the instructor could (in the advanced operation element)

degrade the brakes and observe how the trainee handles the situation. The trainee always has the benefit of immediate feedback as to whether or not the response was correct. The instructor also has a timely opportunity to provide additional instruction as to how the problem should have been handled.

Of course, the instructor must use the OBSAC with great care and discretion so as to avoid placing the machine, the trainee, him or herself, and others working in the training or production area in jeopardy. Practice is required in order to preserve credibility and effectiveness; in other words, malfunctions must appear to occur as they would under real malfunction conditions. For example, few systems malfunction suddenly. They will, instead, deteriorate gradually over a period of seconds, minutes, or even hours. A considerable knowledge of machine functioning is prerequisite to

the skillful use of the OBSAC as a training aid.

In addition to the training of new haulage truck operators, the haulage truck training system and the OBSAC are being used in annual refresher training of experienced haulage truck operators. Regular opportunities to practice skills that are seldom, if ever, needed insures that all haulage truck operators have acquired the appropriate skills to handle a given situation. Experimentally, this application is being taken one step further in the form of a haulage truck operator's rodeo, where operators compete with each other for prizes. The goal is to encourage professional attitudes and the continual upgrading of skills on the part of the operators themselves to further decrease machine abuse and accidents, while increasing overall mine production and promoting job satisfaction.

APPLICATIONS

This training system has also been successfully applied to other surface mobile mining machines. The front-end loader training system will soon be field-validated at which time it will be made available for general use. The front-end loader training system can employ the OBSAC in much the same way the haulage truck training system does, but with the restriction that it is only appropriate for front-end loaders with cabs of sufficient size and design to permit the installation of an appropriate buddy seat and seatbelt for the instructor. The use of remotely controlled versions of the OBSAC for machines that cannot be modified to safely accommodate the instructor has been investigated and is viable, although expensive.

The training system is also being applied to eight other generic types of surface mining equipment: track-type dozers (and front-end loaders), scrapers, rotary drills, carriage-mounted cranes, utility service trucks, shovels, forklifts, and motor graders. Preliminary studies and task analyses show the training system to be totally viable for all of these generic machine types. The OBSAC, with modifications, is appropriate for the majority of these machines. However, as with the front-end loader, extensive machine alterations might be more expensive and/or structurally difficult to accomplish than would currently be cost effective to implement.

SUMMARY

The haulage truck and front-end loader training systems are now available for general use. The availability and distribution of the OBSAC training aid is yet to be determined because of the model-specific considerations that must be incorporated into the construction of

each OBSAC unit and because of the instructor training necessary to ensure its safe and appropriate use. For more information, contact the Bureau of Mines, Pittsburgh Research Center, P.O. Box 18070, Pittsburgh, PA 15236.

STABILITY INDICATORS FOR FRONT-END LOADERS

By Gilbert Wray¹ and August J. Kwitowski²

ABSTRACT

This paper describes the development of a stability-indicating system for use in minimizing the occurrence of front-end loader (FEL) rollovers in mining. The development proceeded in three phases: definition of FEL stability-instability characteristics; design of a first-generation stability indicator; and design of a simplified, second-generation

stability indicator. Goals met by the final design include confirmation of a simplified methodology for detecting machine instability; the ability to be installed on new loaders during manufacture or on older loaders on a retrofit basis; and reliable, easily interpretable operation.

INTRODUCTION

Rubber-tired FEL's, originally intended as small machines for handling loose or stockpiled material, have rapidly increased in both size and number at surface mine operations over the past 15 to 20 yr. Statistics bear out the fact that FEL accidents form the largest single category of machinery-related accidents in surface mining. For the years 1975 through 1981, FEL's used by the mining industry were involved in 26 fatalities and numerous less severe accidents.³ The vast majority of the fatalities occurred as a consequence of the FEL's rolling over and either crushing the operator within the cab or the operator being struck by the machine after jumping or being ejected from the cab.

Rollover protective structures are required on FEL's as specified in the Code of Federal Regulations, Title 30, Part 77.403a, "Mobile Equipment, Rollover Protective Structures (ROPS)." Obviously, ROPS do not prevent the vehicle from rolling over, but offer protection to the

operator in the event that the vehicle does roll over. At present, FEL operators have only their own judgment against which to evaluate the stability or instability of their machines.

The Bureau of Mines, through contract J0395074 with the Stevens Institute of Technology, has responded to this problem with the development of a FEL stability indicator that provides the operator a reliable, easily interpreted display of the stability status of his or her machine. The stability indicator was designed to be a relatively low cost item capable of being retrofitted to older FEL's or incorporated into new loaders during their manufacture. Strain gage instrumentation is used to monitor the magnitude and rate of change of forces acting normal to the loader's wheels, with these forces being direct indicators of the machine's center of gravity relative to its stance on the terrain. The relative stability of the loader is conveyed to the operator through a display of green, amber, and red lights.

The development of the present stability indicator was undertaken in several stages; first, the stability characteristics of FEL's were analyzed and mathematically modeled; second, a first-generation stability indicator was built that compared the calculated analog

¹Chief, vehicle mechanics and development division, Stevens Institute of Technology, Hoboken, NJ.

²Civil engineer, Pittsburgh Research Center, Bureau of Mines, Pittsburgh, PA.

³Computerized sort of Mine Safety and Health Administration Health and Safety Analysis Center data conducted February 1983.

values to the measured values and issued a warning to the driver based on that difference as a safety margin; and third, the present device was produced, where the whole machine is used as the analog, and the results of the interpretation of the actual wheel loads on the ground are used to warn the driver of an impending overturn situation.

DEFINITION OF LOADER STABILITY CHARACTERISTICS

More than half of rollover accidents occur when the loaders are being trammed; that is, when they are being transported under their own power from one work area to another, when they are being moved from the working areas to maintenance shops and fueling stations, or when they are traveling over distances greater than those covered in normal loading and unloading operations. Generally, the loader operates at greater speed while tramping than it does during its normal work cycle. Eight out of ten tramping accidents occur on downgrades.

Front and side slopes contribute to an unstable operating mode of the FEL. Operator-controlled factors contributing to the loss of stability are the weight of the load in the bucket, the bucket height, the yaw angle of articulation, its velocity, and the degree of braking. While any one of these parameters could be a principal contributor, it is usually a combination of these factors that produces an accident.

The first step towards alleviating the rollover problem was to define and quantify the following critical combination of factors and conditions that are most pertinent to front-end loader instability:

Vehicle pitch angle

Vehicle roll angle

Bucket load

Bucket location

Vehicle articulation angle

Inertial loads (acceleration-deceleration, centripetal forces)

A device that is to indicate to an operator just how close the machine is to an overturning condition has to account for the combined influence of all these factors on the stability characteristics of the vehicle.

MATHEMATICAL ANALYSIS OF STATIC LOAD AND INCLINATION LIMITS

The basic calculations of the static overturn limits for FEL's have to include all the variations possible in vehicle geometry. These calculations can be divided into two parts: locating the center of gravity (CG) of the loaded machine and determining whether this CG location relative to the support points induces overturn.

Most FEL's have a three-point suspension system. The rear axle is pinned to the frame at or above the axle center, creating a transverse walking beam action. This pin joint represents a single suspension point. The other two points are the ground contact points of the front tires (fig. 1). With this type of suspension, the effective masses and CG's for pitch overturn are different from those for roll overturn. The vehicle will overturn about the front axle (nose down) if the CG of the *entire mass* is in front of a line connecting the front wheel ground contact points (fig. 2).

Roll overturn can arise if the CG lies outside the line joining either of the front wheel ground contact points and the rear suspension pin (fig. 1). In this latter case, the mass involved is that of the loaded vehicle less the mass of the rear axle unit. This mass is called the *main mass*.

There is, by design, a limit to the rotation possible about the rear axle (usually about 15°) after which the rear wheel contact point becomes the third

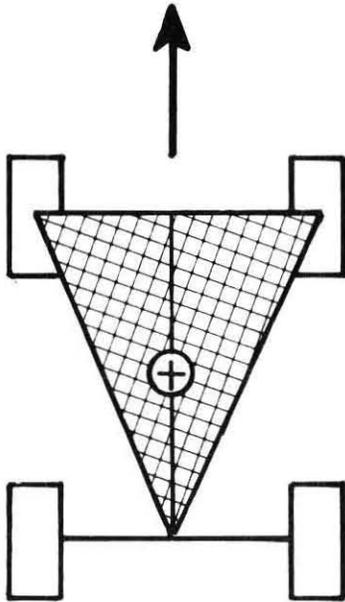


FIGURE 1. - Front-end loader suspension points under normal conditions.

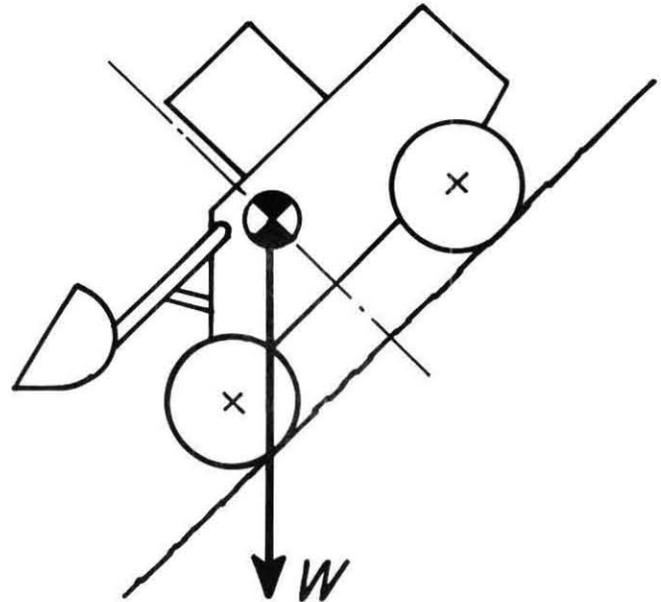


FIGURE 2. - Projection of center of gravity near overturn.

support point (fig. 3). A machine that has tipped enough to reach this limit will have enough momentum to overturn completely.

Three variables affect the CG location with respect to the vehicle. The first variable is the articulation angle. To obtain the variation of CG with articulation angle, the weight and CG

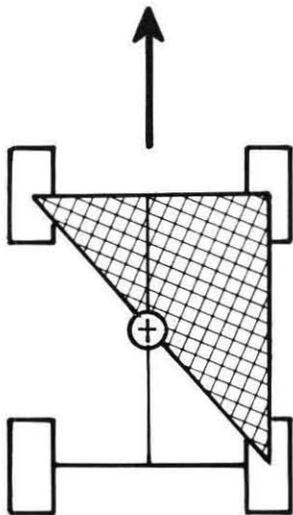


FIGURE 3. - Front-end loader suspension points near overturn.

locations of both the front and rear units are needed. To obtain the CG of the main mass, the mass of the rear axle and its tires (plus ballast) has to be subtracted. The other two variables entering into the CG computation are the bucket load and the position of the lift arm. From this information, the locations of each of the masses and the location of the CG's can be obtained in the standard manner of summing moments and dividing by the total weights. In addition, the position of the vehicle is identified by the pitch and roll angles (i.e., the angles between the gravity vector and the vehicle's x-y and x-z planes, respectively).

The CG is located with respect to a vehicle coordinate system whose origin is at the center of the front axle, with the x-axis pointing forward, the y-axis to the right, and the z-axis down (fig. 4). The mathematical procedure used is to locate the vehicle on a horizontal ground plane with a selected bucket load, lift arm position, and articulation angle. The ground plane is then inclined to a combined front and side slope, and the vertical projection of the vehicle CG is determined. If this projection falls

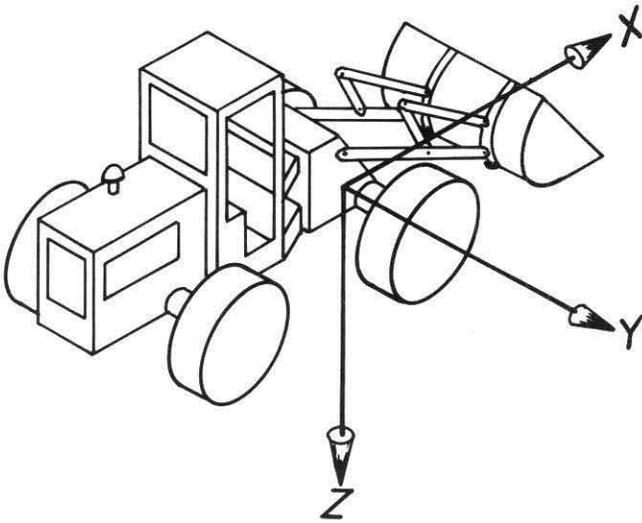


FIGURE 4. - Coordinate system used in analysis.

within the stability triangle, the machine is considered statically stable; if it falls outside the triangle, it is statically unstable.

A computer program was written to solve these equations iteratively, as the most economical procedure is to establish approximate limits of the machine and to refine the results by calculating small increments of change. The final pitch-rollover points are easily determined to within 0.2° . The final solutions to the stability equations are then plotted by the computer.

STATIC OPERATING ENVELOPES

Using the above procedure, the static stability limits as functions of pitch and roll angles were generated with the bucket load, articulation angle, and lift arm position as independent parameters. Figure 5 is a plot of the pitch angle versus the roll angle with the bucket load as a parameter for 0° articulation angle and with the lift arm at the "carry" position. The FEL is stable for any combination of roll and pitch angle within the stability "triangle." Figure 6 is a similar plot except that the lift arm is in the "full-up" position. As is expected, the operating envelope is

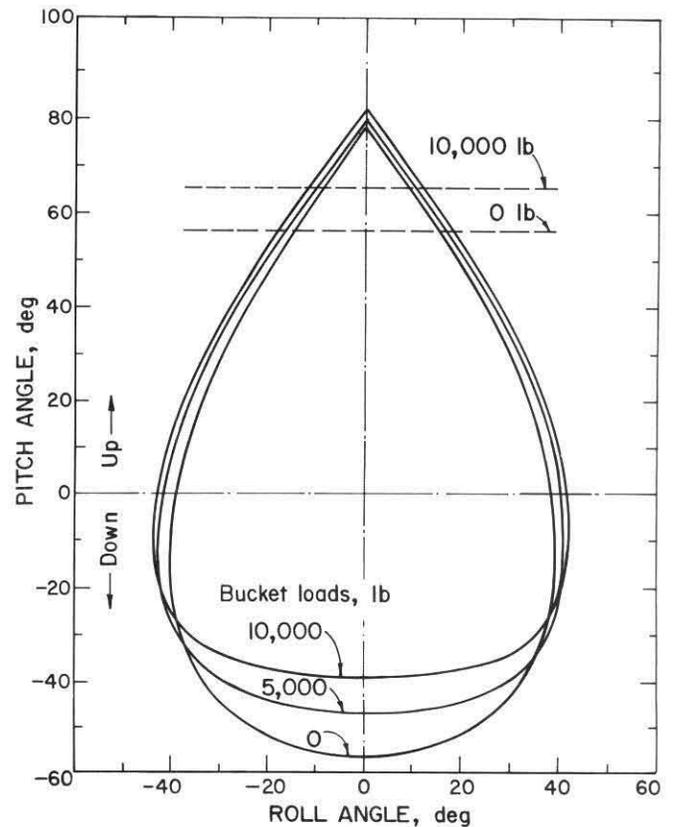


FIGURE 5. - Stability envelope for arm at carry and articulation = 0° .

reduced in size with the lift arm in the full-up position. Figures 7 and 8 show the stability envelope when the vehicle is articulated to 35° and are directly comparable with figures 5 and 6 (without articulation).

The articulation angle produces mirror image curves; the -35° articulation curve is inclined equally and in the opposite direction to the $+35^\circ$ articulation angle curve.

The curves readily show that it is necessary to sense and respond to all the parameters. To sense merely roll angle would have two opposite and unacceptable effects:

1. It could result in a warning device that is far too conservative and hence restricts the operation of the FEL to an unacceptable level and prevents its acceptance.

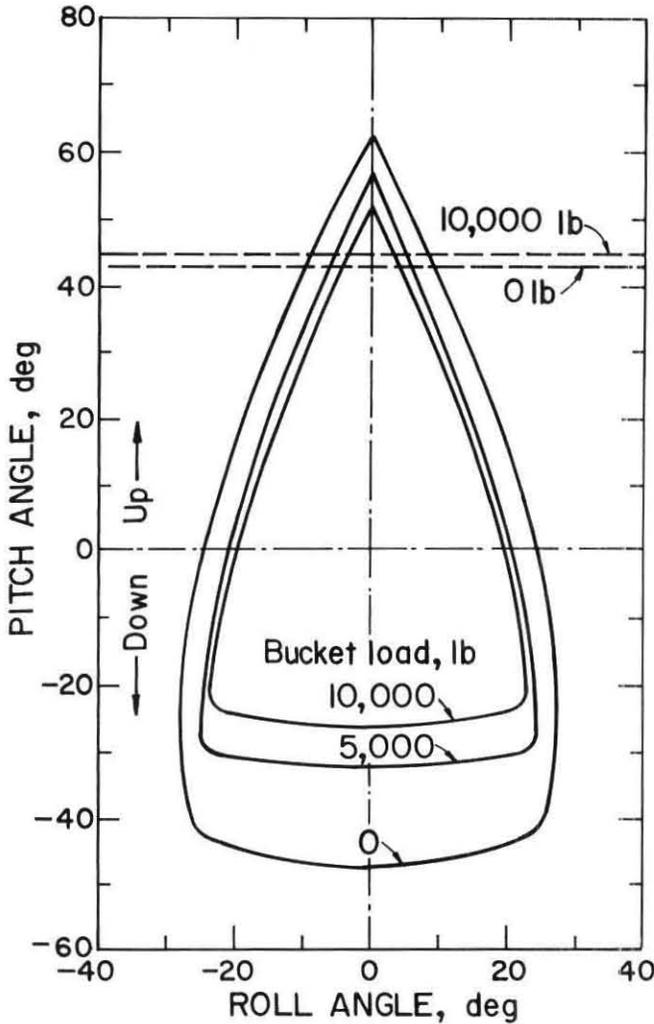


FIGURE 6. - Stability envelope for arm full-up and articulation = 0°.

2. It may not give a warning when it should, producing false confidence which might contribute to an accident.

These results have been compared with available experimental data from one of the manufacturers and have been found to correlate well (tables 1-2).

STATIC STABILITY CORRELATION EQUATION

To be able to construct the electronic logic circuitry for the first-generation stability indicator, the stability envelope had to be mathematically defined. However, describing all the curves with one equation was quite difficult because the curves are triangular in shape and lie in all four quadrants. All attempts

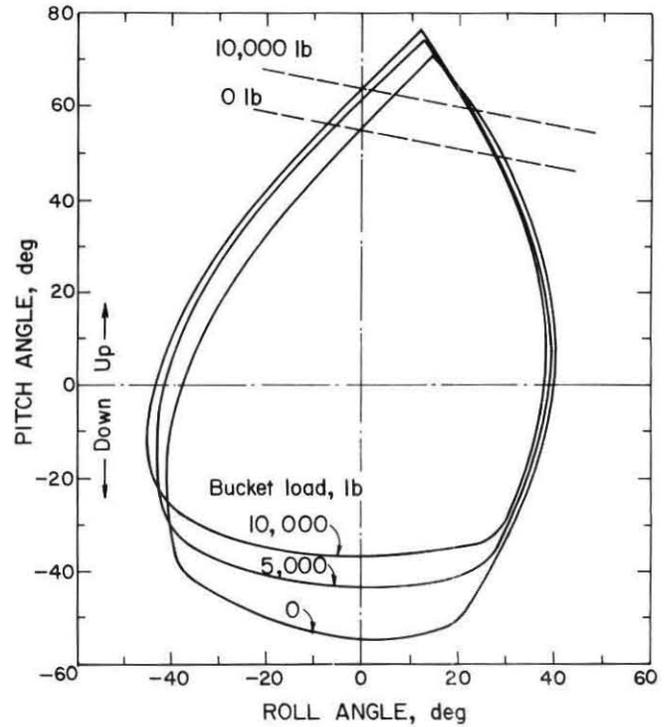


FIGURE 7. - Stability envelope for arm at carry and articulation = +35°.

at generating a correlation equation by utilizing a systematic, logical, theoretical approach failed. Therefore, an alternate solution was used.

An initial decision was made that roll angles greater than 30° (about a 60-pct side slope) and pitch angles beyond the

TABLE 1. - Center of gravity comparison

	Distance from reference axis, in	
	Manufacturer's data	Calculated values
Bucket empty, arm at carry:		
Longitudinal (x).....	60.9	60.9
Lateral (y).....	0	0
Vertical (z).....	-11.2	-11.2
Bucket loaded (10,500 lb), arm full-up:		
Longitudinal (x).....	82.9	82.9
Lateral (y).....	0	0
Vertical (z).....	-59.7	-59.7

TABLE 2. - Inclination limit comparison

FEL position	Side slope angle at overturn, deg	
	Manufacturer's data	Calculated values
Bucket empty, arm at carry:		
Facing up slope.....	56	56.4
Facing down slope....	56	58
Parallel to slope....	38	39
Bucket loaded (10,500 lb), arm full-up:		
Facing up slope.....	42	42.9
Facing down slope....	22	26
Parallel to slope....	19	19

range of +35° (up) to -25° (down) would be considered outside the normal range of operation. Separate limit detectors would be employed to trigger a warning light if any of these basic limits were exceeded, regardless of any other condition. The equation of a parabola that includes the effects of bucket load and lift arm position but not of articulation angle has the form

$$\theta_r = C_1 + C_2W + C_3 \theta_{arm} - (C_4\theta_p + C_5)^2,$$

where θ_r = roll angle,
 θ_p = pitch angle,
 θ_{arm} = lift arm angle,
 and W = bucket load,

C_1, C_2, C_3, C_4, C_5 = constants.

To correct for articulation angle (θ_{art}), replace

θ_p by $\theta_p \cos .4\theta_{art} - \theta_r \sin .4\theta_{art}$
 and θ_r by $\theta_p \sin .4\theta_{art} + \theta_r \cos .4\theta_{art}$,

and the prediction equation for the critical roll angle, including articulation angle and specific constants for a specific FEL becomes

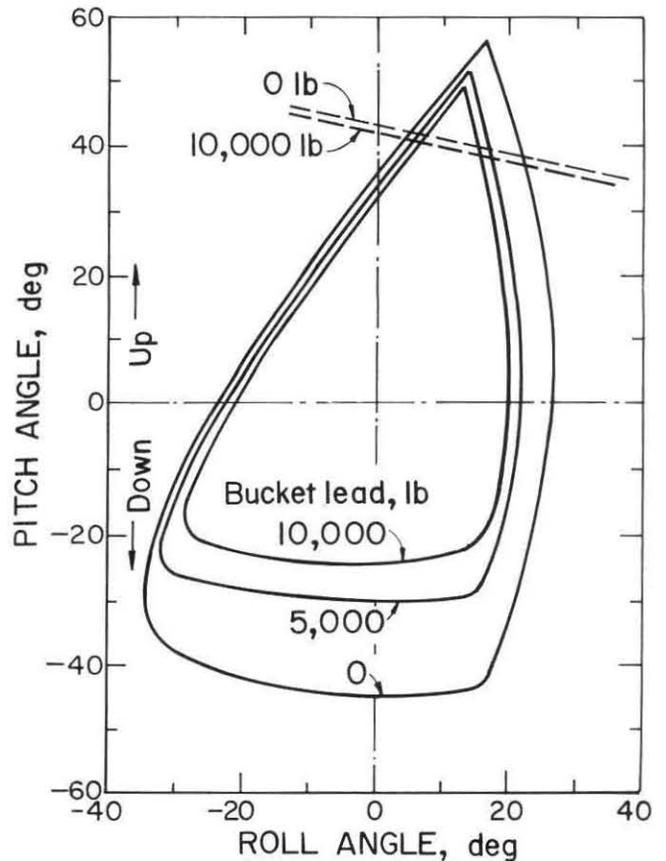


FIGURE 8. - Stability envelope for arm full-up and articulation = +35°.

$$\begin{aligned}
 \left| \theta_{r_{critical}} \right| &= 36.94 - 3.265 \times 10^{-4}W - 0.2239 \theta_{arm} \\
 &- [0.054 (\theta_p \text{Cos}.4\theta_{art} - r \text{Sin}.4\theta_{art}) \\
 &+ 2.1577]^2.
 \end{aligned}$$

The absolute value of $\theta_{r_{critical}}$ was used since the stability curves are mirror images and the equation is valid for either positive or negative

articulation angles. This absolute value of $\theta_{r_{critical}}$ was then compared with the corrected roll angle so that the safe operating range was represented by

$$\left| \theta_p \text{Sin}.4\theta_{art} + \theta_r \text{Cos}.4\theta_{art} \right| < \left| \theta_{r_{critical}} \right|.$$

Figure 9 is a correlation plot of the critical roll angle predicted from the equation versus the roll angle calculated by the computer program. The correlation is made for a fixed articulation angle of 20°, but for three bucket loads. The individual data points represent three

lift arm positions (carry, horizontal, and full-up) at various combinations of pitch angle. This prediction equation thus contains all of the terms that enter into the determination of static stability.

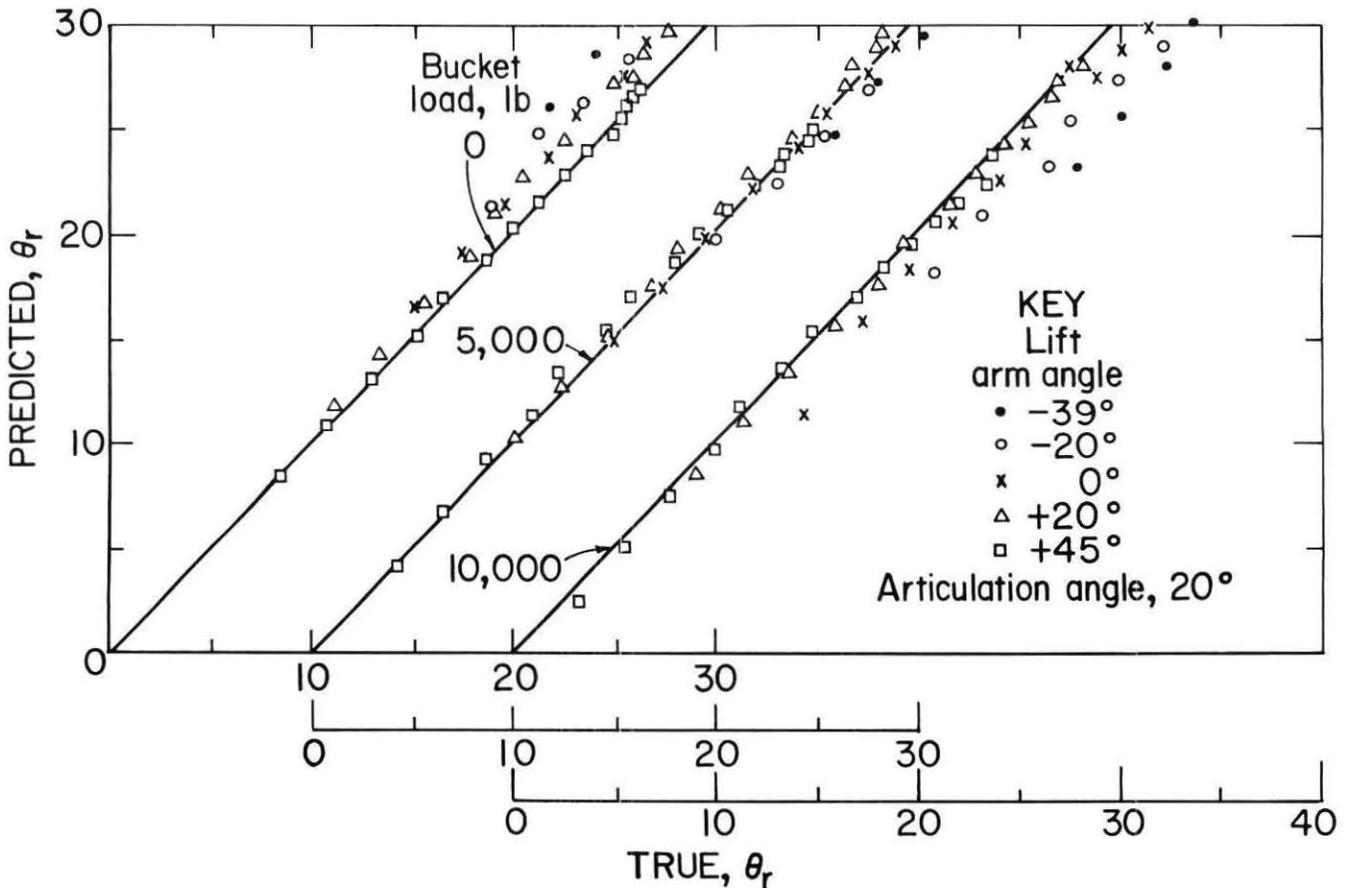


FIGURE 9. - Correlation of data between predicted and actual cases.

FIRST-GENERATION STABILITY INDICATOR

ANALOG CIRCUIT

An analog circuit was designed to solve the prediction equation. A block diagram of this circuit is shown in figure 10. The seven electronic circuit cards used are shown in figure 11. This analog computer was used to solve the correlation equation from sensor inputs, and then compare the existing roll angle to the critical roll angle, and give the driver a visual warning.

SENSORS AND TRANSDUCERS

The original approach to sense the pitch and roll angles by damped pendulum-type potentiometers was abandoned because their range of natural frequency coincides with that of FEL's, at approximately 2 Hz. Therefore, electrolytic sensors, using a semiconducting fluid in a circular tube and with a natural frequency greater than 10 Hz, were selected.

The articulation angle and lift arm position were sensed by single-turn rotary potentiometers. Special shaft bearing and seal designs made these potentiometers safe from salt spray, sand, dust, and fungus.

The bucket load was determined by sensing lift cylinder hydraulic pressure with a pressure transducer and combining it electronically with lift arm position.

The speed sensor was a dc tachometer-generator friction-coupled to the output shaft of the transmission.

WARNING INDICATORS

The driver's warning device consisted of four indicator lights. One was green, two were amber, and one was red. The analog circuitry accepted the five sensor inputs, calculated the angle at which the machine would roll over, and compared

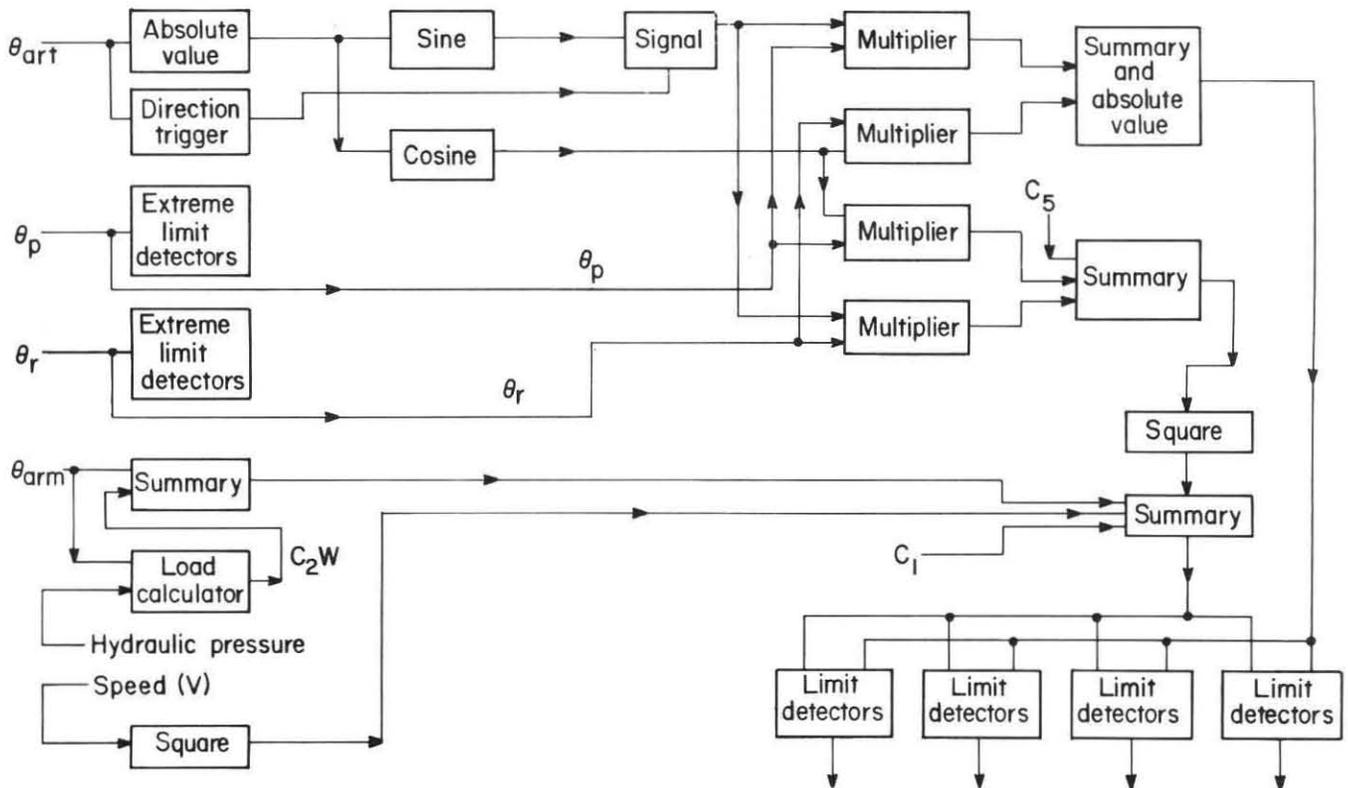


FIGURE 10. - Block diagram of signal processor.

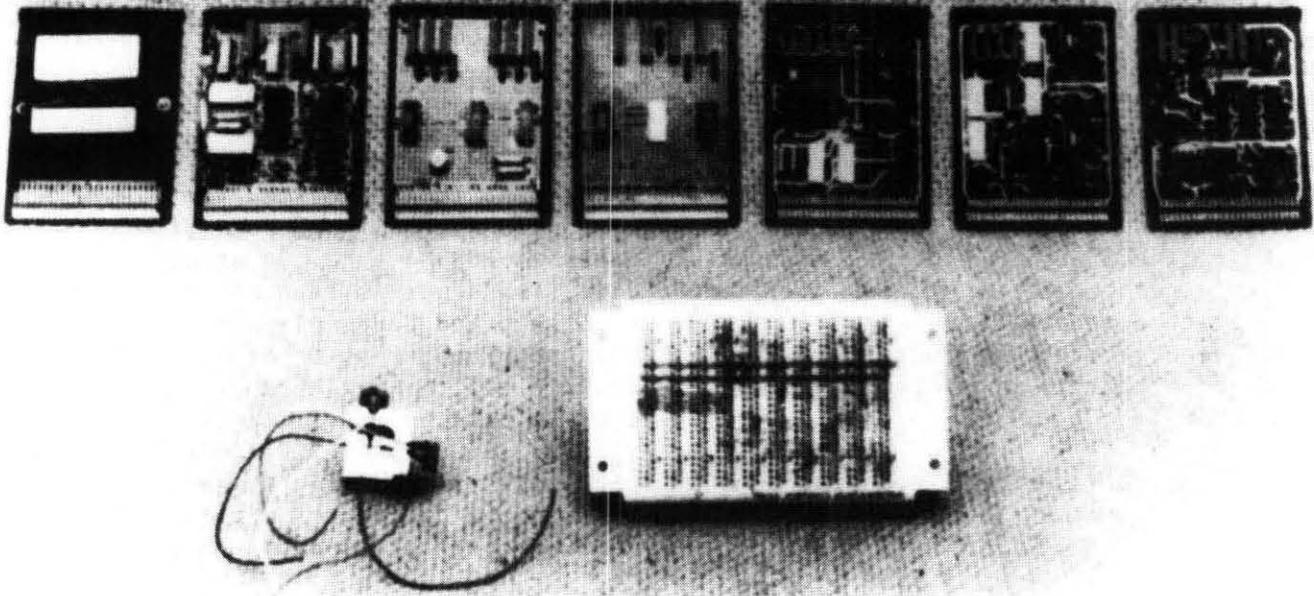


FIGURE 11. - Electronic circuit boards for first-generation stability indicator.

this value to the corrected roll angle. The difference between the calculated angle and the actual roll angle was represented by a voltage that was sensed by four level detectors. Each level detector was wired to one of the lights and was adjustable for proper level and sequencing.

EVALUATION

The above-described system was installed on three FEL's used in a rock quarry operation. During a 12-month test period, the units performed satisfactorily and were judged by the

operators as very useful operational tools. However, these first-generation units had several disadvantages, as follows:

1. They were costly to manufacture owing to the complexity of the electronics.
2. They were costly to install owing to the skilled labor required to install the sensors.
3. The system would not completely correct for the effects of inertia during braking, acceleration, or cornering.

THE SECOND-GENERATION STABILITY INDICATOR

In an effort to reduce the complexity and cost of the system, an alternate means of obtaining a signal or measuring a parameter that would indicate rollover instability was sought. As the FEL approaches rollover instability, the CG moves towards the outside of the "stability triangle" formed by the three support points. As this happens, the normal load on the up-slope wheel decreases and the normal load on the down-slope wheel increases. At the point of rollover

instability, the normal load on the up-slope wheel has been reduced to zero.

The task of designing a stability indicator has now been reduced to designing a method of sensing the normal load on each of the front wheels and using the lower value to trigger a warning system.

By utilizing strain gages, the bending stresses in the axle can be determined. To obtain the normal load from the

measured axle bending stresses, it is necessary to measure, or devise a system to cancel out, the bending stresses in the axle due to the tire side forces. These tire side forces are generated to resist the downslope forces acting on the FEL; they can also be generated during steering. The tire side force acting at the ground plane creates a bending moment in the axle which is proportional to the wheel radius. By measuring the axle bending stresses at two planes, they can be subtracted, which cancels out the effects due to tire side force, leaving a measurement that is proportional to wheel normal load.

Referring to figure 12, bending moment at plane 1 is

$$M_2 = NL(L_2) + SF(r).$$

Bending moment at plane 2 is

$$M_1 = NL(L_1) + SF(r)$$

$$\begin{aligned} M_2 - M_1 &= NL(L_2) - NL(L_1) \\ &= NL(L_2 - L_1) \end{aligned}$$

or
$$NL = (M_2 - M_1) / (L_2 - L_1).$$

The bending moments at planes 1 and 2 are measured using strain gages and, since the distance between the two planes is known, the normal load is determined.

AXLE SENSORS

To measure the bending strains on the FEL axle, it was decided that some form of bonded strain gage or strain transducer would have to be used. Since the output of a strain gage is represented by a voltage and the voltages obtained from the two planes must be subtracted, it was decided that a full-bridge configuration must be used in order to retain a usable signal level. A full-bridge configuration will produce four times the signal output of a quarter bridge and is inherently temperature compensated.

In an effort to find a simple, easily installed, field method of sensing the axle strains so as to reduce the overall system cost, several methods were tested and rejected or refined, as follows:

1. Strain gages bonded directly to the axle. These were field-tested and rejected owing to excessive installation

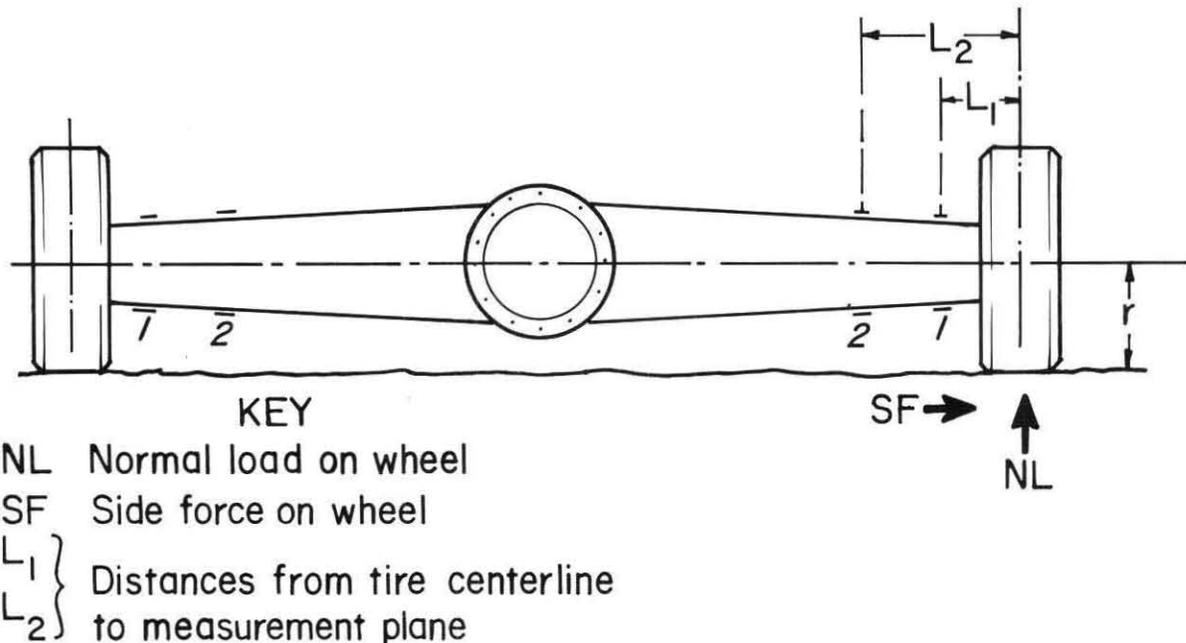


FIGURE 12. - Forces acting on wheel of front-end loader.

cost and cost of replacement or repair. Highly skilled labor was required.

2. Weldable strain gages directly spot-welded to the axle. These were field-tested and rejected owing to zero shifts caused by the lack of an extremely flat surface to mount on.

3. Strain link manufactured and strain-gaged in shop; installed by direct welding to the axle. These were field-tested and rejected owing to the difficulty of preventing gage damage due to heat conduction during welding.

4. Strain links manufactured and strain-gaged in shop. These are attached to mounting blocks which are welded to the axle using a welding fixture. This method was refined as described in the following paragraphs.

Two methods of attaching the strain links to the mounting blocks, bolting and bonding, are presently under test on a Government-owned JD-544 FEL at the Bureau of Mines facility in Bruceton, PA.

The strain link was designed so as to incorporate a mechanical gain of 3:1. This was accomplished by machining the surfaces and narrowing the cross section so that the elongation that should occur over a 1.5-in length is concentrated in a 0.5-in section where the strain gages are located. All strain gaging and intergage wiring is performed on the strain links at the time of manufacture so that the field installation consists only of attaching the strain link to the axle and connecting the output cable (fig. 13).

The attachment method was designed so as to require a minimum of expertise and time. Three mounting blocks for each transducer are held against the axle by a simple welding fixture, and the blocks are welded to the axle. The strain link is then either bonded or bolted to the mounting blocks, and the mechanical installation is complete (fig. 14).

At the present time, two fastening methods are being tested. The strain links on one side of the FEL axle are bolted to the mounting blocks using 3/8-in socket-head cap screws. The strain links on the other side of the axle are bonded to the mounting blocks. The bonding method is quite simple, using pre-packaged epoxy, and requires little skill. In addition, the strain link does not experience any zero shift, due to bolting torque, when it is bonded, thus reducing the electronic adjustments required.

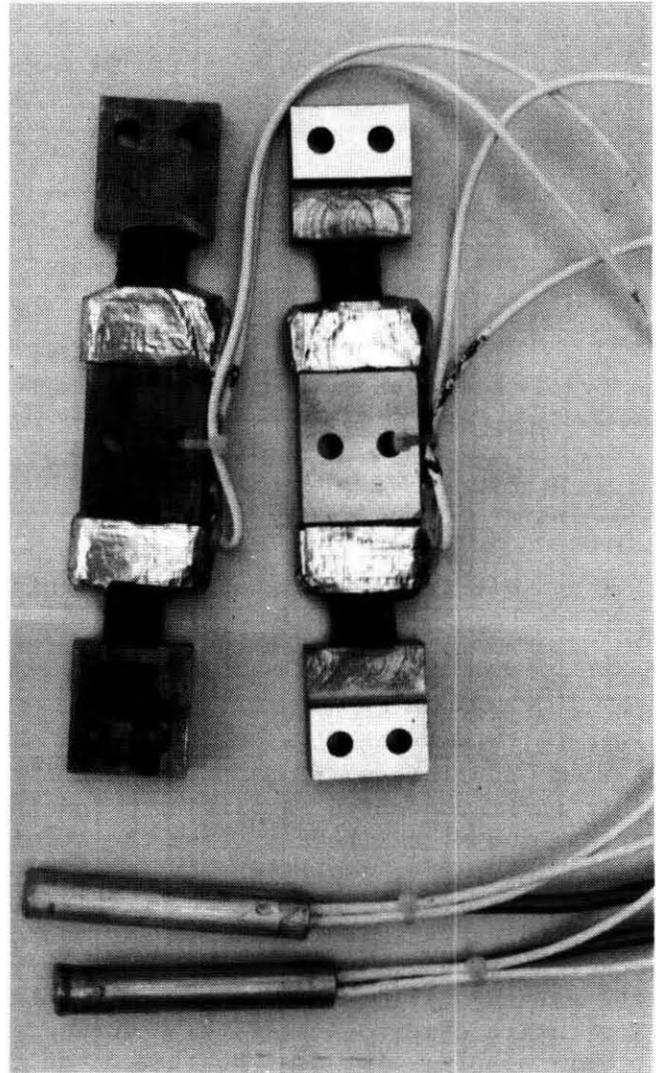


FIGURE 13. - View of strain links.

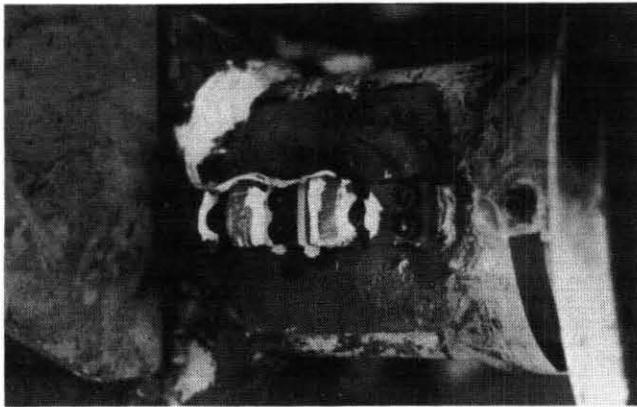
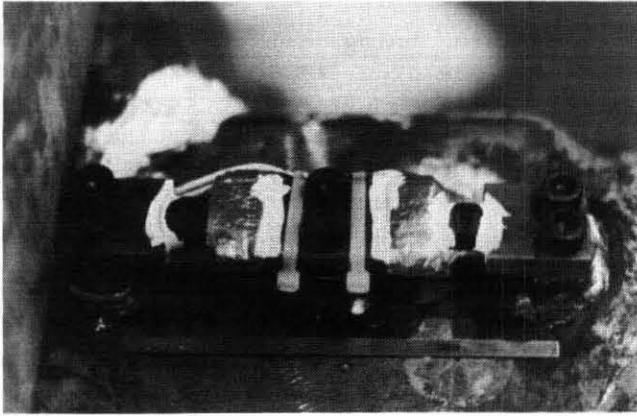


FIGURE 14. - Strain links installed on front-end loader axle.

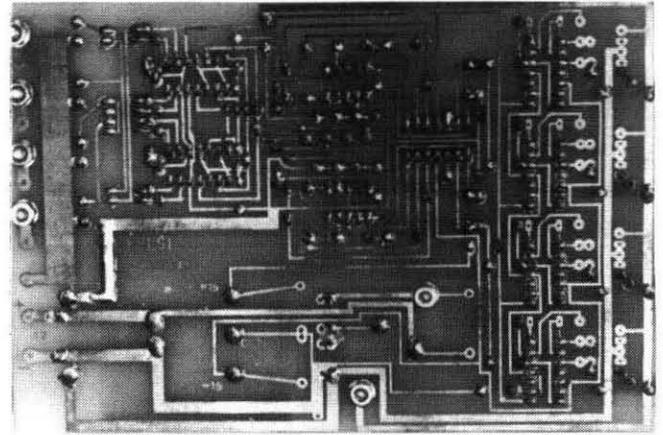
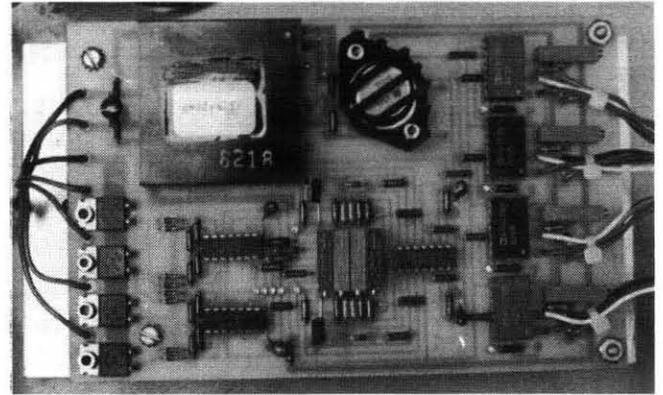


FIGURE 15. - Electronic circuit board for second-generation indicator.

ELECTRONIC SIGNAL CONDITIONING AND DISPLAY

The electronic signal conditioning package has been considerably simplified. It is no longer necessary to perform various computations to evaluate a lengthy correlation equation as was the case with the original system. The new system consists of four integrated circuit instrumentation amplifiers to increase the signal levels from the strain links, a buffer amplifier to sum (subtract) the signals from different planes, a differentiating circuit, a quad-comparator, power darlington's to drive the warning lights, and a power supply. The entire electronics system, including power supply, is now contained on a single 4-1/2- by 6-1/2-in printed circuit card (fig. 15). For simplicity and to expedite the initial field test, the single card is shown mounted in the same

National Electrical Manufacturers Association enclosure previously used (fig. 16), allowing the use of the existing wiring and connectors.

In an effort to take into account the effects of inertia and anticipate them, a differentiator circuit has been incorporated. This circuit accepts the normal wheel load as an input and outputs a signal proportional to the rate of change with respect to time of the normal wheel load, i.e., the first derivative. When the wheel load is positive but decreasing at some rate, the derivative will be a negative value whose magnitude depends on the rate of decrease. This negative-valued derivative is summed with the original signal to produce a new normal load signal, which is lower in value than the original, by some amount depending on the rate of decrease, and therefore turns on

the warning lights earlier. By using a diode to limit the derivative to only negative values, the warning lights respond "normally" for increasing wheel loads. Figure 17 shows a representative signal for wheel load which is varying as a 1.5-Hz sine wave. Superimposed on top

of the original signal is the "new" wheel load signal summed with its derivative. As can be seen, the voltage level is lower for the new signal when it is decreasing in value and is identical for increasing values.

CONCLUSIONS

Although field testing of the second-generation stability indicator has not yet been completed, all indications to date are positive. The design of the stability indicator--

1. Allows for its easy incorporation on new front-end loaders during manufacture.

2. Permits its installation on older loaders on a retrofit basis.

3. Has resulted in reductions of size, complexity, and associated cost to the limit of practicality.

Extensive testing of a prototype version of the stability indicator on a Government-owned FEL has shown--

1. The methodology of sensing machine stability as a function of normal wheel loads is practical and works.

2. The strain link method of sensing the normal wheel load provides an adequate signal of wheel load and removes the influence of side forces on the wheel.

3. The strain link method allows for a quick field installation using a minimum of highly skilled personnel.

4. The exact method of attaching the strain link, bonded or bolted, is yet to be decided based on the results of tests in progress.

Additional information on the above-described stability indicator may be obtained from August J. Kwitowski, Bureau of Mines, P.O. Box 18070, Pittsburgh, PA 15236, (412) 675-6474.

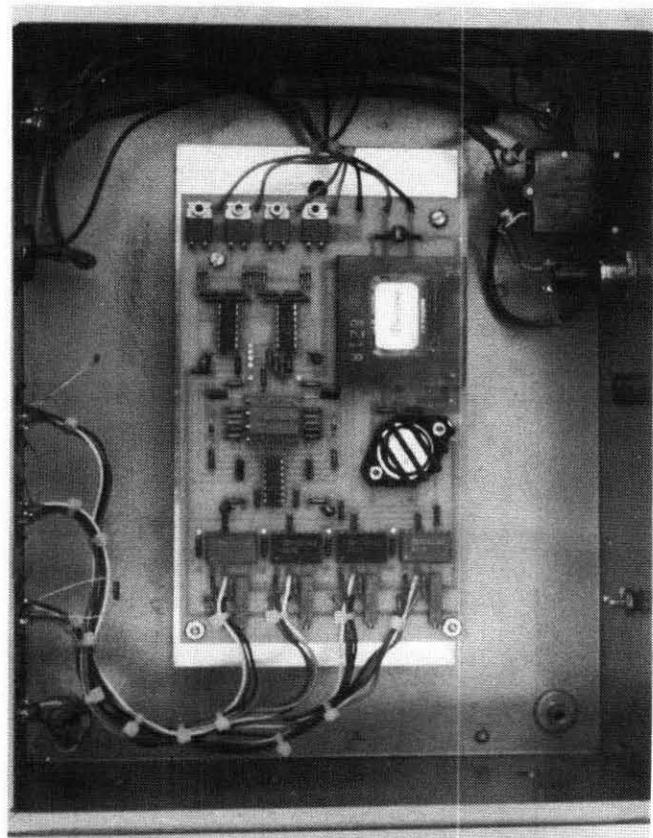


FIGURE 16. - Second-generation stability indicator mounted in original enclosure.

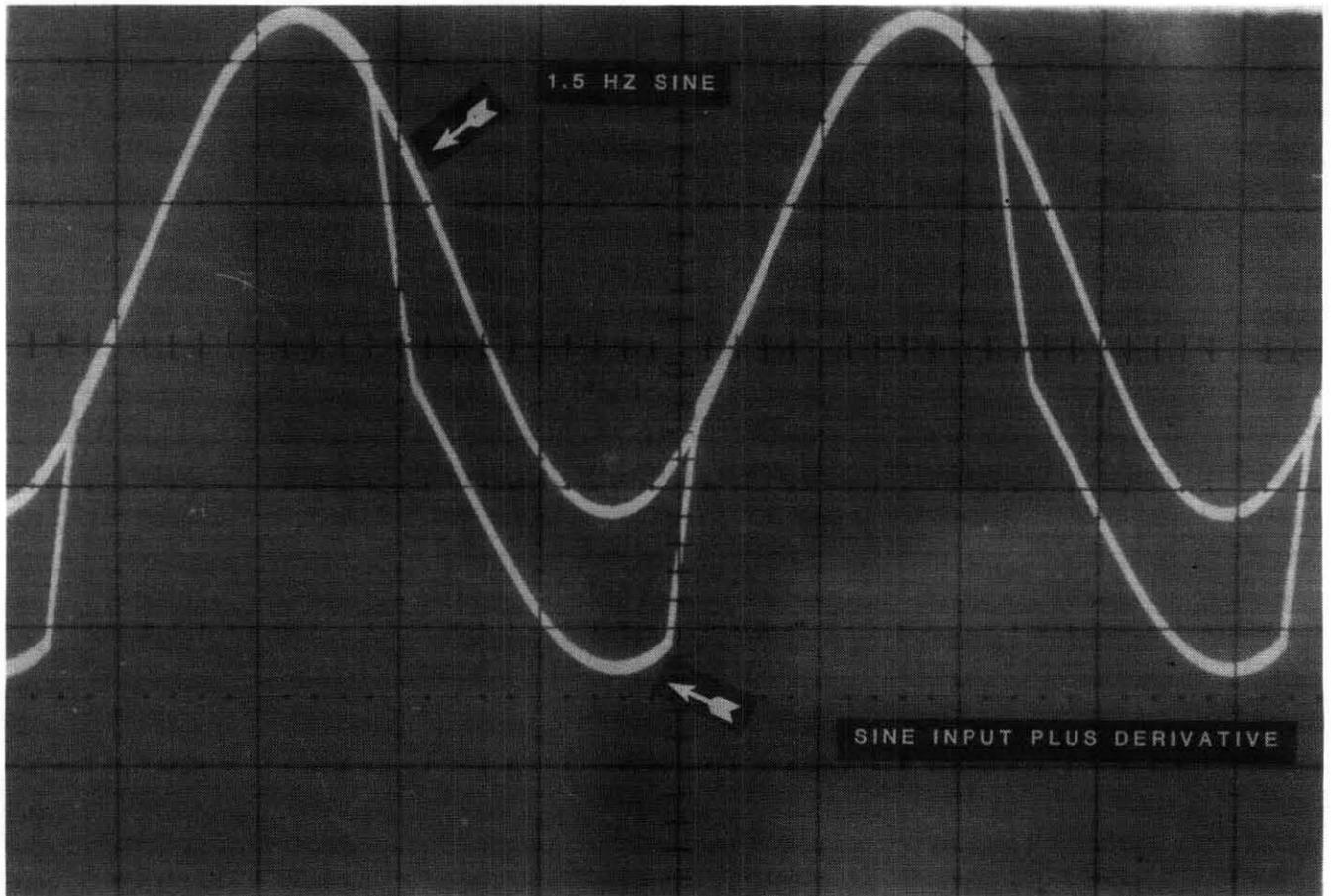


FIGURE 17. - Oscilloscope trace of normal load signal and normal load signal summed with its derivative.

BULLDOZER NOISE CONTROL

By R. C. Bartholomae¹ and T. G. Bobick²

ABSTRACT

Bulldozer noise is the most serious noise problem for surface miners today. Not only are bulldozers the most common type of mobile equipment, but the majority of their operators are also exposed to more noise than current Federal regulations allow. In 1977, the Bureau of Mines responded to this problem by developing retrofit noise control treatments that reduce the noise that reaches the

operator. These treatments were specifically designed to be readily installed in the field at low cost. In 1978, these treatments were installed on two Caterpillar D9G's and an International Harvester TD-25C in surface coal mines to demonstrate the noise reduction that can be achieved under actual production conditions. This paper presents the results of the field demonstrations.

INTRODUCTION

Table 1 shows the relationship between operator noise level and allowable exposure time mandated by the Federal noise regulations. Exposure to a continuous noise level of 90 dBA is permitted for no more than 8 h. For every 5-dBA increase in operator noise level, the allowable exposure time is cut in half. As an example, no more than 4 h of exposure is permitted when the noise level is 95 dBA. Also, there is an upper limit on noise intensity; exposure to continuous noise levels above 115 dBA is not permitted.

Simply put, miners are overexposed to noise when their actual exposure time exceeds the allowable time.

TABLE 1. - Permissible noise exposure

<u>Duration,</u> <u>h/d</u>	<u>Noise level,</u> <u>dBA</u>
8.....	90
6.....	92
4.....	95
3.....	97
2.....	100
1-1/2.....	102
1.....	105
3/4.....	107
1/2.....	110
1/4 or less.....	115

MINING NOISE CONTROL RESEARCH

The Bureau of Mines has an ongoing research program in support of the noise regulations mandated by the Mine Safety and Health Act of 1977. This research program has two basic objectives. The first is to assess the impact due to noise and vibration on mine worker occupational health. The second objective,

which is more ambitious, is to develop feasible noise control technologies aimed at improving those instances when mine workers are overexposed to noise.

Field surveys are used to assess the impact that noise and vibration have on mine worker occupational health. These surveys yield two kinds of technical information. They identify the prevalent sources of noise and vibration peculiar to the mechanized mining environment, and they provide an estimate of the mine worker population overexposed to noise. Stated differently, the results of these

¹Supervisory electrical engineer, Pittsburgh Research Center, Bureau of Mines, Pittsburgh, PA.

²Mining engineer, Pittsburgh Research Center, Bureau of Mines, Pittsburgh, PA.

surveys identify acoustical problems in mining equipment and help to define and rank mining noise control research problems.

In 1977, the Bureau of Mines conducted a noise survey of the surface coal mining industry.³ The results of this survey are presented in table 2. This table shows that bulldozers present the most serious noise problem in surface coal mining since they account for the most cases of equipment operator noise overexposure. In fact, about 48 pct of all cases of noise overexposure at surface coal mines are due to bulldozers.

TABLE 2. - Total noise overexposure by machine type, U.S. surface coal mines, 1977

<u>Equipment type</u>	<u>Pct</u>
Bulldozers.....	48.0
Front-end loaders.....	15.5
Haulage trucks.....	8.5
Highway trucks.....	.5
Scrapers.....	5.5
Draglines.....	8.0
Overburden drills.....	2.0
All others.....	12.0

The surface coal mine survey also provided information about the relative numbers of each kind of equipment, broken down by manufacturer. Table 3 gives this information for bulldozers. Better than 45 pct of the bulldozers used in surface

coal mining are Caterpillar D9's. Taken together, Caterpillar D9's and D8's account for almost two-thirds of the bulldozers in operation at surface coal mines today. Because of the large number of Caterpillar D9's in operation, the Bureau of Mines sponsored a research project in 1978 aimed at developing and, later, field-demonstrating feasible bulldozer noise control technology for two Caterpillar D9G's: one equipped with a rollover protective structure (ROPS) and no cab, the other equipped with a standard cab. In 1979, this noise control technology was also adapted to an International Harvester TD-25C.

TABLE 3. - Total bulldozer population by specific model, U.S. surface mines, 1977

<u>Specific model</u>	<u>Pct</u>
Caterpillar D9.....	47
Caterpillar D8.....	17
International Harvester TD-25.....	11
All others.....	25

It should be noted that the second most serious noise source in surface coal mining is the rubber-tired front-end loader. Because of some design similarities, the bulldozer noise control technology can be extended to rubber-tired front-end loaders. The Bureau has also sponsored a research project that demonstrated the applicability of the retrofit noise controls on front-end loaders.

NOISE CONTROL TREATMENTS FOR BULLDOZERS

Since this project involved treatment of in-service machines, modification of the noise sources on the dozers was specifically excluded from consideration. Instead, retrofit noise control

³Ungar, E. E., D. W. Anderson, and M. N. Rubin. The Noise of Mobile Machines Used in Surface Coal Mines: Operator Exposure, Source Diagnosis, and Potential Noise Control Treatments (contract J0166057, Bolt Beranek and Newman Inc.). BuMines OFR 98-79, 1978, 117 pp.; NTIS PB 299 538/AS.

treatments were developed to limit the level of noise reaching the operator through various paths. Two design criteria were applied to the noise control treatments that were developed. Obviously, they had to provide a measure of noise reduction for the operator; equally important was that, once installed, the modifications were not supposed to degrade the overall performance of the bulldozer. In other words, the treatments could not adversely impact the normal operation of the bulldozer or impose unusual maintenance requirements.

The instrumentation system used to record the sound pressure levels in the operator compartment consisted of a 1/2-in-diam condenser microphone mounted on a preamplifier. The preamplifier was powered by a portable battery box that was, in turn, connected to a stereo tape recorder. The preamplifier was suspended from the ceiling of the operator cab so that the microphone (fitted with a wind-screen) was approximately 6 in from the operator's right ear. The recorded magnetic tapes were analyzed using a one-third-octave-band real-time analyzer.

Two general types of tests were made: static and moving. The static tests were made with the dozer running at high idle and with the torque converter under load. The latter test (which emphasizes exhaust tones) requires that the dozer be put in first gear and the brakes applied to prevent it from moving. For either test, the engine was running at full throttle.

The in-motion tests were performed according to SAE Recommended Practice J-1166. For these tests, the tape recorder operator followed alongside the dozer using a long extension cable to connect the preamplifier and tape recorder.

RESULTS

The Caterpillar D9G dozer, which was equipped with a ROPS only, is shown in its final noise-controlled configuration in figure 1. The only treatments visible in the photograph are the muffler and the windshield that was installed to block the airborne noise between the engine and fan and the operator. The various treatments are itemized in table 4 along with the corresponding noise reduction that each treatment provided for the high-idle condition. Note that about 6 dBA of reduction was obtained by three major treatments: installing the windshield, applying the muffler, and installing the sound absorption material under the FOPS (falling object protective structure) canopy. The remaining 5.5 dBA of

The data recording system was calibrated before and after testing. Using a pistonphone, a 124-dB-at-250-Hz calibration tone was recorded on the tape and used to calibrate the real-time analyzer during the tape playback. After calibration, background sound level measurements were made to ensure that there were no other significant noise sources in the test area that would interfere with the measurements.

In general, it was found that uninterrupted airborne paths were the predominant way for noise to travel to the operator. Structure-borne noise was important only for the dash panel and cowling, which were directly connected to the engine. The most effective treatments, therefore, were those that blocked the line of sight between the main noise sources (the engine and fan) and the operator, and the sealing of all openings near the floor pedals and the operator's seat to reduce the noise from the secondary sources: the transmission and the final drive. Installation of sound absorption material in the operator's area, primarily on the underside of the canopy, was also an effective noise control treatment.

reduction was obtained by carefully sealing all openings and by isolating the dash and cowling from the vibrating engine. The cost of the entire treatment package was less than \$1,000 for materials and required about 100 employee-hours for installation.

The Caterpillar D9G dozer with the cab is shown in figure 2. The noise control treatments are located inside the cab and therefore are not visible in the figure. Table 5, however, lists the treatments that were utilized.

Following installation of the noise control treatments, the dozers were placed in service during March and April

1978. Both are currently operating in surface coal mines in the Eastern United States.

Noise dosimeter readings taken on the operator of the ROPS-only dozer indicated that the time-weighted average

noise was 93 to 94 dBA, during normal operation. This indicates that the dozer will be in compliance with Federal regulations, without requiring hearing protection for the operator, for 4-1/2 to 5-1/4 h/d. Dosimeter readings taken on the dozer with the cab gave the

TABLE 4. - Summary of noise control treatments installed on ROPS-only-equipped dozer (high idle)

No.	Treatment	Sound level, dBA	Noise reduction from baseline, dBA
1	None (baseline).....	105.5	0
2	Lexan windshield.....	101.5	4
3	Absorption under FOPS.....	102.5	3
4	Exhaust muffler.....	104	1.5
5	Windshield and absorption.....	100	5.5
6	Treatment 5, plus muffler.....	99.5	6
7	Treatment 6, plus dash seals and isolation.....	96.5	9
8	Treatment 7, plus floor seals.....	95.5	10
9	Treatment 8, plus seat seals.....	95	10.5
10	Treatment 9, plus tank seals and hydraulic valve cover.....	94	11.5

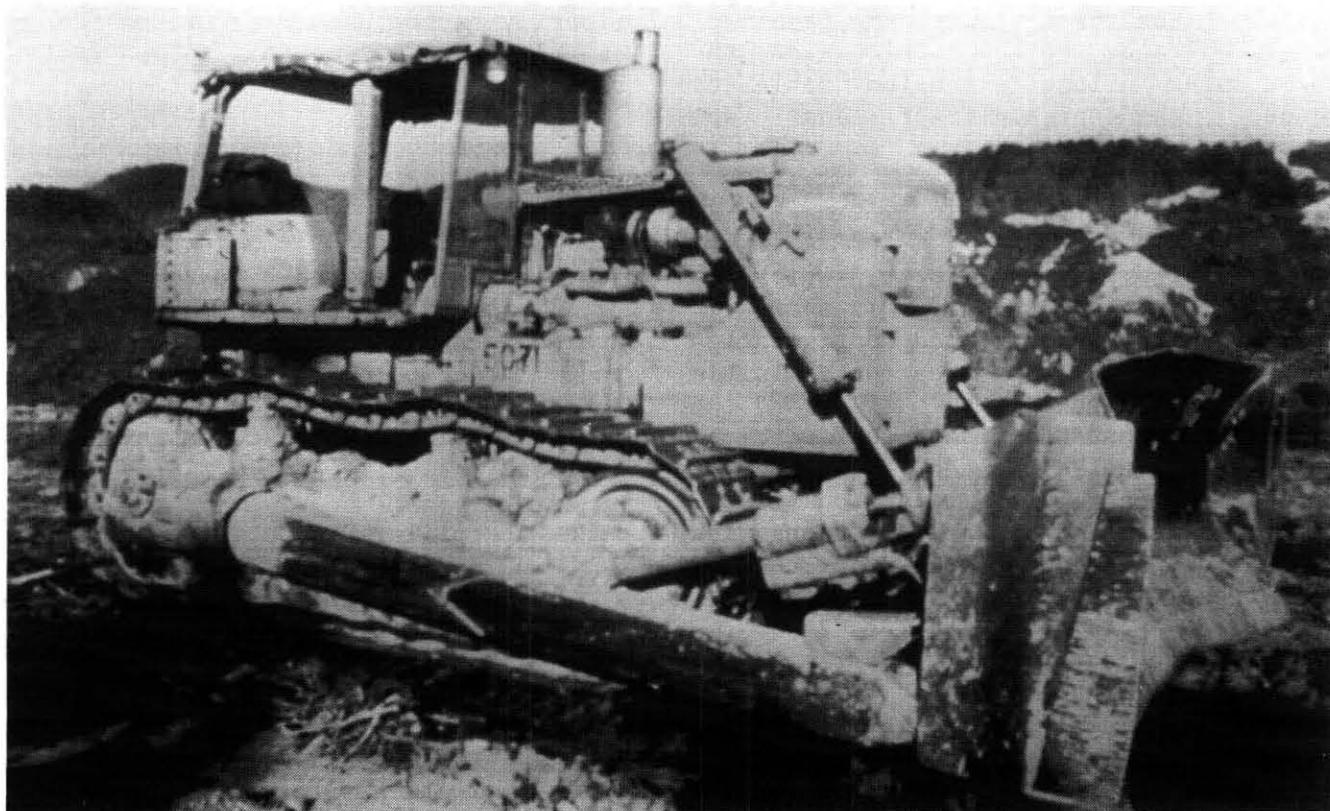


FIGURE 1. - Noise-controlled ROPS-only-equipped Caterpillar D9G.

time-weighted average noise level as approximately 90 dBA. This dozer, therefore, could be operated for a full 8-h shift.

Subsequent inspection visits indicated that the reduced noise levels could be maintained with relatively minor maintenance of the elastomeric seals.

TABLE 5. - Summary of noise control treatments involved on dozer with cab (high idle, doors closed)

No.	Treatment	Sound level, dBA	Noise reduction from baseline, dBA
1	None (baseline).....	100	0
2	Absorption under FOPS.....	98	2
3	Absorption and cab wall seals..	97.5	2.5
4	Treatment 3, plus floormats and pedal seals.....	95.5	4.5
5	Treatment 4, plus seat seals, hydraulic tank cover seals, and blade control seal.....	93.5	6.5
6	Treatment 5, plus dashboard treatment.....	89	11



FIGURE 2. - Noise-controlled cab-equipped Caterpillar D9G.

SUMMARY

1. The Bureau has demonstrated feasible retrofit noise control technology for bulldozers commonly used in surface mining.

2. The noise control treatments can be copied or adapted for their specific conditions by any surface mine in the country, using commercially available materials.

3. The noise control technology was extended to rubber-tired front-end loaders. The Bureau sponsored a research project that demonstrated the new application.

4. The results of the bulldozer noise control project have been disseminated to

the mining industry through a series of technology transfer workshops that were presented throughout the country. Detailed instructions, in terms of illustrated technical manuals and shop-quality drawings, are available in limited quantities from the Bureau. Single copies of the bulldozer noise control manual or the front-end loader noise control manual can be requested, in writing, from the Bureau of Mines, Pittsburgh Research Center, P.O. Box 18070, Pittsburgh, PA 15236. Each manual contains detailed instructions on fabrication and installation of the noise control treatments. The manuals also contain useful information on current Federal noise regulations, noise measurement techniques and instrumentation, and materials suppliers.

IMPROVED HAUL ROAD BERM DESIGN

By Gregory G. Miller,¹ Gary L. Stecklein,² and John J. Labra³

INTRODUCTION

Parts 55 and 77 of the Code of Federal Regulations, Title 30--Mineral Resources, require that "berms or guards be provided on the outer bank of elevated roadways" at metal and nonmetal open pit mines and at surface coal mines to prevent haulage vehicles from running off the haul road. The proper design and construction of haul road berms are not known, other than the current rule-of-thumb recommendation that berms be built as high as the axle height of the largest haulage truck using the haul road. However, interviews with mine personnel indicate that berms built to this height are ineffective in stopping runaway vehicles.

A wide variety of restraint systems are available. These systems are edge-of-road berms, guardrails, boulders,

concrete barriers, median berms, and escape lanes. Mine operators overwhelmingly prefer berms constructed of waste material because they feel that they are the least costly system since the waste material has to be transported along the haul road anyway. While the cost of the berm material may be negligible, additional costs are incurred owing to construction time and additional road width necessary to carry the berm.

To determine the proper design of safe haul road restraint systems, research was conducted by Southwest Research Institute⁴ for the Bureau of Mines on design requirements for edge-of-road berms, guardrails, boulders, concrete barriers, median berms, and escape lanes.

LOCATION OF RESTRAINT SYSTEMS

Restraint systems such as berms should be used on all elevated roadways to prevent vehicles from going over the road edge embankment. The design requirements are dependent on the maximum possible runaway vehicle approach conditions. It is obvious that certain locations along

the roadway such as downgrades and sharp turns must have restraint systems, but since mechanical failure, adverse weather, or human error can cause accidents, flat elevated roadways also must have them.

METHODS OF VEHICLE-BARRIER INTERACTION ANALYSIS

To determine the effectiveness of various restraint systems, the following approach was used:

1. Geometric-scale model simulations.
2. Full-scale field tests.

3. Computer simulation.

The runaway vehicle approach conditions of 30 mph and a 30° impact were considered maximum. While the speeds of most runaway haulage vehicles are lower, a berm designed to withstand these impact

¹Mechanical engineer, Spokane Research Center, Bureau of Mines, Spokane, WA.

²Mechanical engineer, Southwest Research Institute, San Antonio, TX.

³Computer analyst, Southwest Research Institute, San Antonio, TX.

⁴Stecklein, G. L., and J. Labra. Haul-road Berm and Guardrail Design Study and Demonstration. Volume I (contract HO282028, Southwest Res. Inst.). BuMines OFR 188-82, 1981, 186 pp.; NTIS PB 83-137091.

conditions will perform satisfactorily for either a lesser speed or a shallower impact angle. Since a loaded vehicle would impose the more stringent strength requirements on the berm, only the responses of loaded vehicles were evaluated.

GEOMETRIC-SCALE MODEL SIMULATIONS

Scale models of haulage trucks, edge-of-road berms, median berms, and escape lanes were constructed to provide correlation between field tests and computer simulation. The 35-, 85-, and 170-ton haulage trucks were selected as being a representative cross section of the haulage vehicle population. Using similitude, 1/20-scale model haulage trucks were constructed for each size truck. The primary parameters of interest were the mass moments of inertia about the roll, pitch, and yaw axes. These inertia values were not available from the truck manufacturers and therefore were determined experimentally since they were essential for determining the proper distribution of mass during model construction. The model trucks were fabricated using these data and truck manufacturer data.

For truck modeling purposes, small double-acting cylinders simulated the commonly used nitrogen-over-oil suspension. For practical purposes, rigid rather than pneumatic tires were used on the model. A locked steering system was used to represent vehicles without steering-turn self-correction. No attempt was made to model body strength. Ground clearances and general configuration of the haulage truck were modeled. Vehicle weight distribution, sprung and unsprung masses, and suspension characteristics were scaled from values obtained from various manufacturers.

Berm composition is different at every mine. To simulate the spectrum of possible berm compositions, scaled unconsolidated and rigid berms were investigated.

The unconsolidated berm was represented by a loose deposit of soil uniformly distributed to a specific height. Compacted clay material was used to represent a rigid berm. Model tests were also run at intermediate berm strengths.

FULL-SCALE FIELD TESTS

Field tests of haul road berms were conducted using a 35-ton haul truck. The relative ability of this material to restrain a 35-ton haul truck under varying approach conditions, berm heights, and compaction conditions was tested. Data collected included tire sinkage, wheel climb, and penetration along the direction of travel (fig. 1). Economic constraints of the field test program prohibited testing that would result in damage to the vehicle. As a result, small approach velocities were tested at various approach angles and then increased to the point where safety of the test was questionable. Results of the field test did not provide the information needed to predict the approach conditions at which rollover will occur. The field test information is, however, the basis for determining the correlation between the computer simulations and the scale model simulations.

COMPUTER SIMULATIONS

Computer simulations of vehicles interacting with edge-of-road berms were performed using a highway-vehicle-object-simulation model (HVOSM).⁵ This program predicts the response of a vehicle and the forces generated during the vehicle's interaction with a rigid nondeflecting surface as a function of vehicle impact speed and approach angle.

⁵Segal, D. J. Highway-Vehicle-Object-Simulation Model--1976. Vol. 4, Engineering Manual--Validation. Calspan Corp., Buffalo, NY, Report FHWA-RD-76-165, Feb. 1976, 460 pp.

EDGE-OF-ROAD BERMS

An edge-of-road berm is a mound of earth, usually constructed of mine waste, placed along the outer edge of an elevated roadway to prevent a runaway vehicle from leaving the roadway. Model tests, field tests, and computer analyses were used to determine how such berms should be constructed.

Berms are currently constructed of a wide range of overburden material. A rear-dump truck backs perpendicular to the road edge and dumps successive mounds of spoil along the road edge. The overburden material can consist of rock 12 to 18 in. in size mixed with soil. There are no special soil grading (sizing) procedures used to select berm material. The final shaping of the berm can be performed by a small front-end loader. If necessary, the bucket of the loader is used to tamp the berm material. Erosion of berms is a problem in areas with frequent or heavy rainfall. In these areas,

some berms are seeded to minimize erosion damage.

All earthen berms deform during impact by a vehicle. Analyses show that failure occurs when the berm is too small or too weak. A large runaway haulage vehicle can easily plow through or over such a berm. There is the possibility of a slope failure of the road edge when a haulage truck penetrates too far into the berm. Therefore, to prevent a haulage vehicle from coming too close to the road edge during collision with a berm, the berm is said to have failed when a vehicle's leading tire penetrates more than halfway through it. In this instance, the vehicle has "vaulted" the berm (fig. 1).

To prevent the vehicle from vaulting the berm, berms must be constructed to a height-versus-strength relationship that will assure vehicle restraint by redirection, penetration, berm climb, or rollover.

Redirection occurs when a vehicle interacts with a berm or barrier, usually at a shallow angle, and climbs it, only to slide down again to the roadway because of insufficient frictional contact. Penetration occurs when a vehicle contacts a weak berm and is stopped by the soil resistance forces created by the vehicle tires and body plowing through the berm. Climb occurs when a berm has sufficient strength to allow a vehicle to ride up the berm. The change in the elevation during climbing will cause the vehicle to stop.

Collision with a deformable berm is usually a combination of penetration and climb; as the leading vehicle tire penetrates the berm, the tire sinks, increasing rolling resistance, while climbing the berm. To prevent a vehicle from leaving an elevated roadway, a properly designed berm must be constructed with its onboard face at an angle that will cause a vehicle to roll over onto the roadway if the vehicle exceeds the

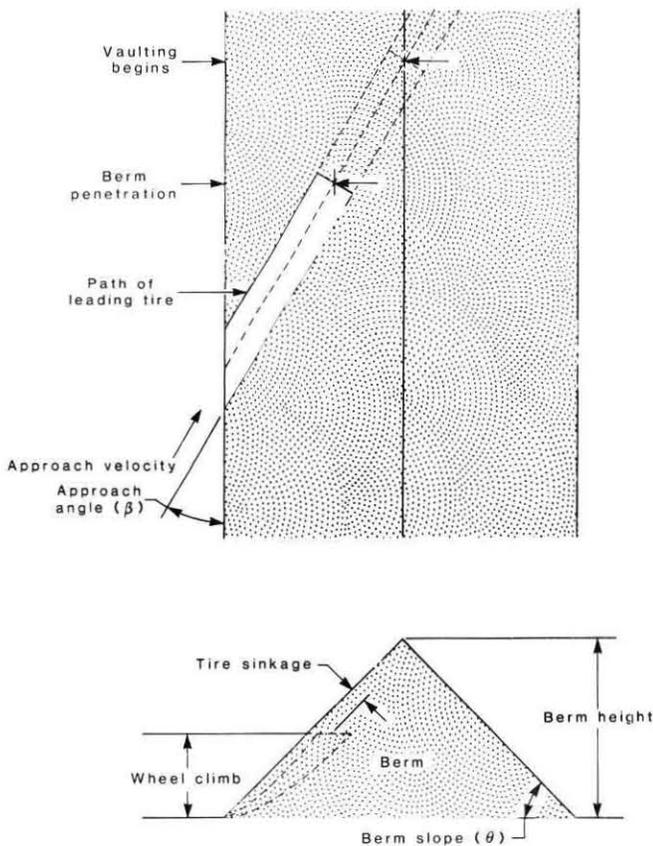


FIGURE 1. - Configuration of edge-of-road berm.

designed stopping potential of the berm. Rolling over onto the roadway is deemed better than vaulting over an elevated roadway.

A rigidly constructed berm represents an approximation of the minimum berm height required to restrain an errant haulage vehicle. Impacting a similar size berm constructed from a deformable material will result in a vehicle either penetrating the berm or vaulting over it. While the deformable material will offer increased rolling resistance, its reduced strength may allow a shear failure of the berm tip resulting from vehicle loading. Therefore, the smaller the berm size, the more rigid it must be.

Curves were prepared for the 35-, 85-, and 170-ton haulage trucks from the scale model simulations, computer simulations, and full-scale field tests. A convenient way of presenting the predicted berm height is as a multiple of the axle height of the largest haulage vehicle using the roadway. When this ratio is plotted against the tire sinkage value that corresponds to berm strength, typical curves represented in figure 2 result. When the berm is weak, a large berm height is required to stop an errant vehicle through the mechanism of berm climb and berm penetration. At intermediate berm strength, the kinetic energy of the vehicle is absorbed by berm climb, berm penetration, and, eventually, rollover; but now a much smaller berm is required. The smallest berm that can restrain a runaway vehicle has its strength increased by compaction. The smallest berm is the most economical to build because it does not require the excessive road width required by weak berms. An ideal high-strength berm has no tire sinkage, and the energy of the vehicle is absorbed by berm climb, as exhibited by redirection at shallow approach angles or by rollover onto the roadway at speeds in excess of berm stopping capability.

Figure 2 shows that the smallest allowable deformable berm for a 35-ton truck is one that is three times the axle

height at a strength of 3 in of tire sinkage measured at axle height on the berm. For an 85-ton truck, a three-times-axle-height berm is required at a strength of 2.3 in of tire sinkage measured at axle height on the berm. For a 170-ton truck, a four-times-axle-height deformable berm is required at a strength of 2.3 in of tire sinkage measured at axle height on the berm. These figures are conservative by at least one axle height over rigid berm requirements.

As a result of these simulations, berm height recommendations, for significantly compacted berms, can be categorized by the vehicle size. For vehicles whose load-carrying capacity is 85 tons or less, the compacted berm height recommendation is specified to be three times axle height; for haulage vehicles larger than 85 tons, the compacted berm height recommendation is four times the axle height.

Berms can be constructed and compacted in layers to meet these recommendations. The face of the berm should then be cut at a steep angle (40°) to minimize the

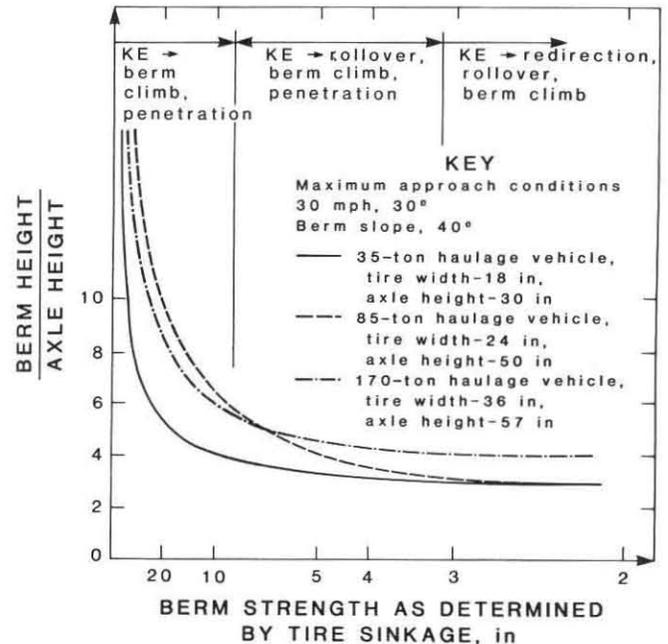


FIGURE 2. - Berm size requirement as a function of berm strength for 35-, 85-, and 170-ton haulage vehicles. (KE = kinetic energy)

ramp effect of the berm. This could be a problem when berms contain a considerable amount of rock and very little soil. In such cases using material with a specific grade (size) mix may be necessary.

QUALIFYING A BERM

Tire sinkage values obtained during the field tests were found to be representative of the berm strength and can be used for quantifying the berm size recommendations. The tire sinkage values are, however, somewhat subject to the surface condition of the berm. Therefore, care must be taken to assure that the surface effects are negligible.

This may be accomplished by maintaining a full load in the vehicle during the tire sinkage tests and by removing the surface layer of the berm, which may cause erroneous strength values.

A field technique for qualifying a berm for its capability in restraining a haulage vehicle is to drive a fully loaded vehicle forward up a berm at a 45° angle to a height equal to the axle height of the vehicle and then record the tire sinkage value (fig. 3). The value may then be checked against the size-strength curves of figure 2 to see if the berm is acceptable.

GUARDRAILS

Generally, berms constructed from available mine waste material will be less expensive than a guardrail installation. However, there are cases where a guardrail may be needed. For example, placing a guardrail along a haulage road that is too narrow to construct an adequate sized berm on may be less costly than widening the road.

The Barrier VII computer program⁶ was used to evaluate various guardrail

configurations. This program predicts the response characteristics of the vehicle, the deformation of the restraining structure, and the damage generated by the impact of the haulage vehicle. The result of a properly designed guardrail is the redirection of the errant vehicle.

⁶Powell, C. H. Barrier VII: A Computer Program for Evaluation of Automobile Barrier Systems. Univ. CA, Berkeley, CA, Report UC SESM 70-17, Aug. 1970, 210 pp.

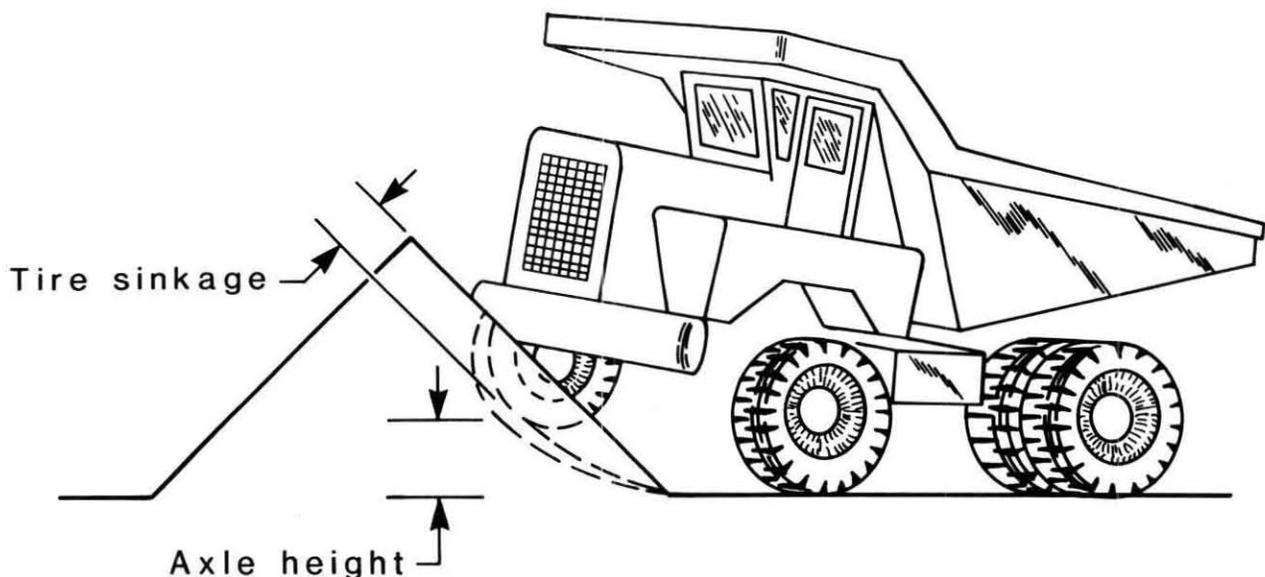


FIGURE 3. - Berm qualification test at a 45° vehicle approach angle.

Guardrails varying from a triple tubular beam to a simple I-beam or wooden post design were analyzed for effective restraint of haulage vehicles. The choice of a particular guardrail design depends on the vehicle's size, velocity, and angle of approach. Installation costs of guardrail limit their application to situations where there may not be enough room for berm construction, or where the installation may be considered permanent, such that higher initial cost can be

justified on the basis of lower maintenance costs.

A guardrail system was considered safe if its maximum rail deflection did not exceed half the width of the vehicle track (axle). For systems with shallow embedded posts, the barrier damage was more extensive than for those with extreme post depth. Table 1 is a summary of guardrail design concepts. Design specifications for table 1 are available from the work cited in footnote 4.

BARRIERS

A barrier is a berm with a near-vertical face constructed of material that is capable of absorbing the kinetic energy of a runaway vehicle by the

displacement of the berm itself, and the reaction between the berm and the road surface. There are two major types of barriers: (1) A rigid barrier made of

TABLE 1. - Summary of maximum approach conditions of rear-dump mine haulage trucks for guardrail design concepts

Approach	CSI ¹	Configuration ²	Approach	CSI ¹	Configuration ²
137,000-LB GROSS VEHICLE WEIGHT (GVW), 35-TON CAPACITY			541,000-LB GVW, 170-TON CAPACITY		
10 mph at 14°.....	100	A	10 mph at 7°.....	100	A
20 mph at 28°.....	500	B, H	20 mph at 13°.....	500	B, H
30 mph at 36°.....	1,000	C, I	30 mph at 16°.....	1,000	C, I
35 mph at 62°.....	2,000	D	30 mph at 29°.....	2,000	D
323,800-LB GVW, 85-TON CAPACITY			35 mph at 35°.....	3,000	E, F
10 mph at 8°.....	100	A	35 mph at 46°.....	4,000	J, K
20 mph at 17°.....	500	B, H	35 mph at 58°.....	5,000	J, K
30 mph at 21°.....	1,000	C, I			
35 mph at 33°.....	2,000	D			
35 mph at 47°.....	3,000	E, F			
35 mph at 65°.....	4,000	J, K			

¹CSI = Collision severity index, an empirically derived relationship commonly used for guardrail evaluation. It provides a numerical comparison of the demands placed on a barrier system as a function of the vehicle's mass, mass moment of inertia, impact speed, and approach angle.

²Configurations are defined as follows:

Double 3-tube guardrail with 60-in-high wood posts--

- A 72 in deep, 12 in wide.
- B 120 in deep, 12 in wide.
- C 144 in deep, 12 in wide.
- D 168 in deep, 14 in wide.
- E 120 in deep (with 10-ft by 28-in soil plate), 14 in wide.
- F 120 in deep (wide soil backup mass of 5 tons per foot), 14 in wide.

Single, wide, multiflange guardrail with 60-in-high posts--

- H 72 in deep, 12 in wide.
- I 120 in deep, 12 in wide.
- J 168 in deep, 14 in wide.

Single, wide, multiflange guardrail with 60-in-high concrete posts--

- K 120 in deep, 20 in wide.

concrete and earth, and (2) an encased barrier such as barrels, membranes, or shotcrete-encased earth. The design objective of barriers is to eliminate the possibility of a vehicle vaulting the berm, and to either redirect or arrest the motion of the vehicle. This is accomplished by providing a near-vertical berm face, with the energy of the vehicle impact being dissipated by displacement of the berm and the berm reaction with the road surface.

The advantages of the rigid-type barriers are (1) they can be designed to withstand severe impact without penetration, (2) they can be designed to cause negligible vehicle damage for impacts of low severity, and (3) they can be reused at other locations. The disadvantages are (1) that rigid barriers are relatively unyielding and tend to aggravate the deceleration environment of the vehicle occupant and (2) their material and installation cost is higher than that of conventional berms.

The advantages of the encased barriers are (1) reduced material cost compared to rigid barriers and (2) the yielding action of the encased berm will provide a less severe deceleration environment for the vehicle occupant. The disadvantages are (1) corrosion of the metallic elements resulting in maintenance problems and need for periodic inspection, if plastic barrels are not used, (2) labor requirements to construct the system, and (3) the encased barrier system would not be salvageable for reuse.

Computer analysis shows that barriers can provide effective vehicle restraint for the range of approach conditions and vehicle sizes studied during this project. Barriers should be used only in areas where maintenance of the restraint system will cause a great economic burden, such as heavily traveled, permanent haul roads.

BOULDERS

Large rocks (18 to 24 in) and large boulders (3 to 4 ft in diameter) are used as edge-of-road berms in quarries and are placed 4 to 8 ft from the edge of the road. A minesite visited had two incidents of vehicles being restrained by a boulder-type berm. In both cases, the vehicle was unloaded and appeared to have been stopped by high-centering on a boulder. Boulders would be used more often in eastern coal mines, but they are normally used as the rock core in the valley fill for improved drainage.

The ability of a berm constructed from a continuous line of large boulders to restrain or redirect a runaway vehicle was evaluated. Typically, and also fortunately, a vehicle impacting a row of boulders or a berm constructed from several large boulders is not stopped instantaneously. The vehicle's kinetic, rotational, and potential energy is dissipated in the work generated as the boulders slide along the road surface. The primary area of concern is the

distance associated with stopping various size vehicles by using typical-size boulders. It was assumed that boulders are not capable of developing a force sufficient to redirect a vehicle. Analysis shows that if boulders are sized to stop a vehicle in a short distance, they will probably cause considerable damage. If they are sized to reduce the deceleration forces, the distance that they must be placed from the edge of the road must increase. For example, if an empty 85-ton vehicle impacted a boulder berm at 20 mph and 20° , it would push the impacted boulders 80 ft along the impact angle. This distance would necessitate positioning the boulders about 25 ft from the edge of the road.

Therefore, boulders are not considered to be a very effective means of providing vehicle restraint, the main reason being the damage that may be incurred by the vehicle. A viable alternative to the independent use of boulders is the burial of the boulders in an earthen berm. In

this way, the boulders act to make the berm more rigid while eliminating the required boulder push distance. The

severity of impact is also significantly reduced.

MEDIAN BERMS

Median berms are unconsolidated material placed in the center of a haul road and are constructed in a manner that allows a runaway vehicle to straddle them, shearing off the portion of the berm above the vehicle's undercarriage, and eventually allowing the vehicle to come to a rest. The force required to shear the berm is dependent upon soil properties.

Median berms can be constructed narrow or wide. A wide berm allows the vehicle to straddle the berm, and its tires to roll on the lower berm material. In this way, increased rolling resistance of the soft berm material allows the vehicle to stop quicker. However, model tests have shown that straddling a wide berm can result in a vehicle overturning.

Additional tests were conducted employing a narrow berm that allowed the vehicle's rear track (axle) to completely straddle the berm. This requires some compaction of the berm to retain its desired height. The narrow berm stopped the vehicle in a shorter distance, particularly at higher impact speeds (fig. 4). The increased shear area and, to a lesser extent, the shear strength of the compacted material were responsible for the reduction in travel. Turning and misalignment of the vehicle were minimized by the restraining action of the narrow berm.

Based on the results of these model tests, a narrow compacted median berm is recommended because of the decreased potential for rolling the vehicle over.

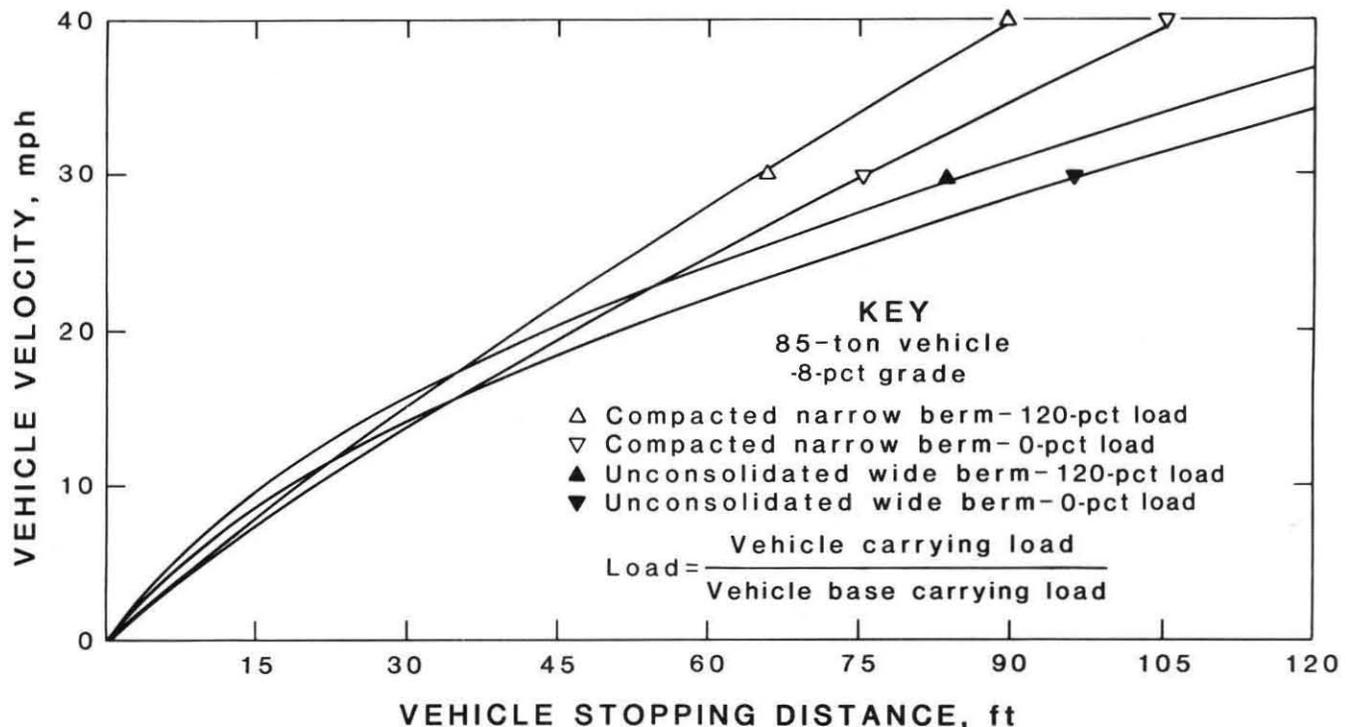


FIGURE 4. - Comparison of stopping distances on median berms for an 85-ton haulage vehicle on an 8-pct downgrade.

Entryways must be provided along the median berm to allow the driver to align the vehicle with the berm. A road grader

can shape the berm base to a width narrower than the vehicle's track.

ESCAPE LANES

The best alternative for effective vehicle restraint involves the use of escape lanes. They ideally perform their function without causing the vehicle to roll over. Model testing of an 85-ton vehicle was performed on an escape lane constructed of dry, fine-grained homogeneous sand and a lane constructed of compacted fire clay. The arrangement of the model test consisted of (1) accelerating a scaled model vehicle down a curved ramp to obtain various entry velocities, (2) allowing the moving model to enter the escape lane test bed, and (3) measuring its stopping distance at the various entry velocities and escape lane slopes. Figure 5 shows a comparison of these tests on a sand test bed with theoretical analyses. Some escape lane recommendations developed are--

1. Entry to the lane should be marked by appropriate signs.

2. Entry to the lane should be a smooth transition from the haulage road, thereby minimizing the steering requirements of the operator.

3. Width of the lane should be reasonably greater than the width of the largest haulage vehicle.

4. Depth of loose gravel or sand material should taper from a minimum at the entryway to two times the maximum ground clearance of any vehicle expected to utilize the escape lane.

5. The depth of the arresting material should be graduated along the initial entryway of the ramp so that a vehicle will not be stopped too abruptly.

6. Material used in the escape lane should be of an unconsolidating nature; pea gravel is the most common material used in public highway construction.

Regardless of the material used, it must be free-draining so that freezing will be delayed during cold weather and it will not readily compact. It must also be a material that can be readily smoothed out after use and that can be maintained with a minimum of effort.

7. The length of the escape lane should be based on the largest size vehicle traveling at a realistic maximum speed. The length of the lane will also be a function of the terrain; a lane located with a downslope would be longer than a lane located with an upgrade.

8. A barrier constructed from sand, gravel, or any available overburden material should be positioned at the end of the escape lane to prevent a vehicle from traveling over an embankment, in the event the vehicle is not stopped in the escape lane area.

9. The arrester bed material should also ensure that once a vehicle is stopped it will not roll back. Maintenance is necessary to keep the ramp in the proper condition. The ruts must be smoothed out and the surfacing material loosened frequently. As the material becomes infiltrated with dirt and other fine materials, it must be removed and replaced with clean material.

10. The optimum escape lane would consist of an uphill grade; however, in actual practice, the required location may be along a downgrade having the necessary length for stopping the vehicle.

11. Model tests showed that an escape lane with a median berm reduced the stopping distance approximately 50 pct for a fully loaded 85-ton vehicle traveling at 40 mph. But since the median berm would be hard to maintain, it should be used where the escape lane length is limited.

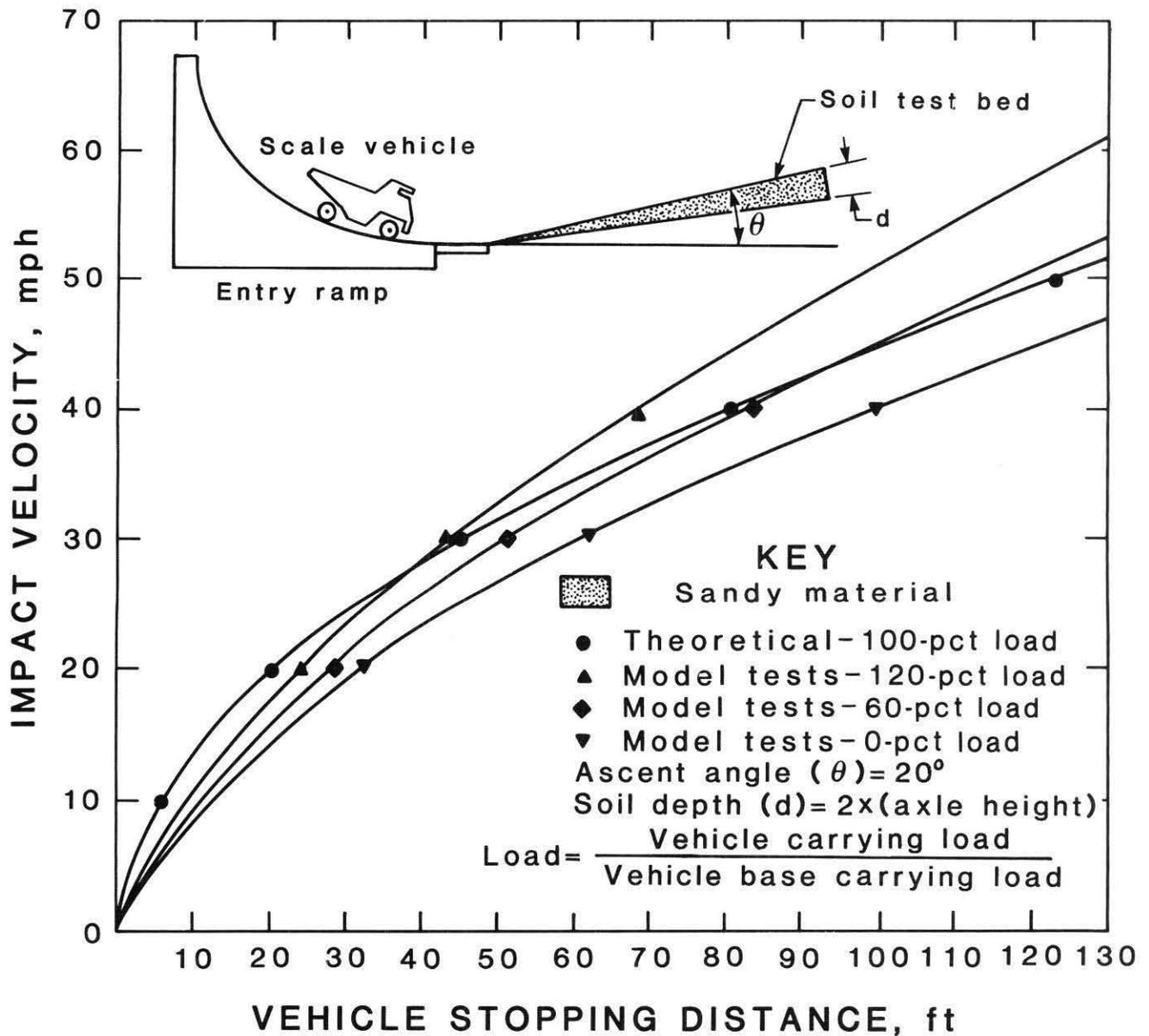


FIGURE 5. - Stopping distances for an 85-ton haulage vehicle on an escape lane impacting at various velocities on a 20-pct positive grade.

SUMMARY

Edge-of-road berms, guardrails, boulders, concrete barriers, median berms, and escape lanes were evaluated for their ability to redirect, restrain, or roll over onto the roadway a runaway haulage vehicle. Geometric-scale model simulations, full-scale field tests, and computer simulations were used, where possible, to evaluate each restraint system design at vehicle approach conditions of

30 mph, 30° impact, and carrying a full payload.

The results of this study indicate that the construction requirements of berms can be directly related to the size of the largest vehicle to be restrained, and the composition and state of compaction of the berm material. For significantly compacted berms, it is recommended that

berms be constructed to three times axle height for vehicles of 85 tons capacity or less; for vehicles larger than 85 tons, the berms should be constructed to four times axle height. Berms must be constructed to slopes greater than 40° . When berms cannot be constructed to a significant state of compaction, as indicated by tire sinkage qualification tests, the size of the berm must be increased according to the included recommendations to properly restrain a runaway haulage vehicle.

The choice of a particular guardrail design depends on the vehicle size, velocity, and angle of approach. Guardrail configurations were analyzed for their capability to redirect 35-, 85-, and 170-ton loaded haulage vehicles traveling up to 35 mph with a 60° approach angle. Although guardrails can redirect a large haulage vehicle, they are generally too expensive for normal haul road use and are restricted to permanent or narrow elevated roadways.

Barriers eliminate the possibility of a vehicle vaulting a berm. The vehicle is either redirected or stopped by the barrier's near-vertical face. Rigid barriers are almost indestructible and can be reused, but because of their high initial cost, their use is restricted to permanent or narrow elevated roadways, as in the case of guardrails.

A berm constructed from a continuous line of large boulders was evaluated. A runaway vehicle is stopped by impacting and pushing the boulders along the road surface. Analysis shows that too large a boulder will cause excessive damage to the vehicle upon impact; however, a boulder of acceptable size requires a considerable push distance. Therefore, boulders are not considered to be an effective restraint system unless they are buried in an earthen berm.

Median berms are sometimes placed in the center of a haul road to act as an additional restraining system. Analysis shows that a narrow compacted median berm is recommended over a wide median berm because it provides a shorter stopping distance and a reduced rollover potential when straddled by the runaway haulage vehicle.

Escape lanes are the best restraining system because they can stop a vehicle without rolling it over and without damaging it. The escape lane should be 25 pct wider than the truck and be constructed of loose draining gravel, with a depth that varies from a minimum at the entrance to twice the truck's ground clearance at the vehicle's estimated stopping distance to prevent abrupt stops and rollback.

