DESIGN CRITERIA AND GUIDELINES

FOR

FALLING OBJECT PROTECTIVE STRUCTURES (FOPS)

(FOR RUBBER-TIRED AND CRAWLER-MOUNTED FRONT-END LOADERS, DOZERS, AND TRACTORS; AND FOR MOTOR GRADERS AND WHEELED PRIME MOVERS)

PREPARED FOR

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF MINES

BY

WOODWARD ASSOCIATES, INC.
225 REDLANDS PLAZA
REDLANDS, CALIFORNIA 92373

PROGRAM FINAL REPORT

USBM CONTRACT NO. JO357110

WA REPORT 76-22F

FEBRUARY 20, 1976

USBM Contract No. J0357110

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DESIGN CRITERIA AND GUIDELINES FOR FALLING OBJECT PROTECTIVE STRUCTURES (FOPS)

Prepared for

U.S. Bureau of Mines
4800 Forbes Avenue
Pittsburgh, Pennsylvania 15213

By

Woodward Associates, Inc.
225 Redlands Plaza
Redlands, California 92373

PREFACE

This report describes the results of the activities of Woodward Associates, Inc. in performing U.S. Bureau of Mines Contract No. J035711, "Design Criteria and Guidelines for Falling Object Protective Structures." The effort funded by this contract was completed during the period from June 13, 1975 to January 30, 1976.

This contract was directed by Mr. James Ault, Technical Project Officer, Pittsburgh Mining and Safety Research Center, and Mr. Bill Pickens, Contracting Specialist, Pittsburgh Mining and Safety Research Center.

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SECTION 1.0

INTRODUCTION

Several federal and state agencies have promulgated regulations that require the installation of operator protective structures on mobile equipment used in mining, construction, agriculture and logging industries. These regulations cover many different types of vehicles, from small farm tractors to large rubber-tired front-end loaders, and require structures that help protect the operator from death or injury from vehicle overturns, from falling tree tops and logs, from falling rocks, and from tree limbs in clearing operations.

Two general types of vehicle operator protective structures have evolved over the past twenty years. The first of these is the "Roll-Over Protective Structure" or "ROPS" that is essentially a "roll bar" or "roll cage" that provides a relatively safe area for the vehicle operator if the vehicle should tip over and roll. The second protective structure is the "Falling Object Protective Structure" or "FOPS" that provides overhead protection against falling material. The terms "ROPS" and "FOPS" are often used interchangeably (sometimes inaccurately) with "cabs", "canopies", "roll bars", "protective structures" and other such descriptive names. In this report, "ROPS" describes the function of the structure; "FOPS" also describes a particular function. Thus a ROPS/FOPS could describe a cab or a canopy that provides both roll-over protection and falling object protection.

"MESA" is used as an abbreviation for the Mining Enforcement and Safety Administration; "USBM" is used to abbreviate the U.S. Bureau of Mines.

This report addresses several engineering and economic facets of possible ROPS/FOPS requirements in the metal-nonmetal mining industry. Specifically, the following areas are addressed.

1) It has been proposed by MESA that regulations be promulgated to require the installation of ROPS on certain types of mobile mining equipment manufactured after 1969 and used in the surface areas of metal-nonmetal mines. This proposed MESA ROPS regulation would require the installation of ROPS on many thousands of vehicles throughout the metal-nonmetal mining industry. The vehicle types that would be affected by this regulation include "all self-propelled track-type (crawler mounted) or wheeled (rubber-tired) front-end loaders; dozers; tractors, including industrial and agricultural tractors but not including over-the-road type tractors; and motor graders; and all wheeled prime movers, all as used in metal and nonmetal mining operations, with or without attachments."

   This report describes the population of these vehicles in use in metal-nonmetal mining operations by type and date of manufacture. The economic effects of the proposed regulation are also defined.

2) The promulgation of a ROPS regulation would require the installation of ROPS on mining equipment per a set acquisition schedule. The commercial availability of ROPS, both in terms of production capability and in terms of the ROPS manufacturers' ability to provide ROPS for the many different models of equipment affected by this proposed regulation, is reviewed in this report.

3) The future promulgation of a ROPS regulation for metal-nonmetal mining equipment is expected to cause a significant reduction in deaths and injuries to the operators of the subject mobile equipment. Though the proposed ROPS regulations would only apply to equipment used in surface areas of underground mines and surface mines, it is recognized that in underground mining, and certain areas of surface mines, operators of the same equipment types could be exposed to death or injury from falling objects.

   This report defines the "rock fall environment" in underground and surface mines and examines the operator protection available through the use of FOPS and combination ROPS/FOPS units.

4) If it is determined that a FOPS requirement is necessary in surface and underground mines, a performance criterion will have to be developed to guide the design of acceptable FOPS. This report outlines a certification procedure, and the analytical and test methods that verify the structural performance of the FOPS.

5) A question exists as to the feasibility of installing ROPS/FOPS on "machines of interest" that were manufactured before 1970. This report examines the availability of ROPS designs for pre-1970 equipment and reviews the concern about the frame strengths of pre-1970 equipment.

6) The installation of ROPS/FOPS on mining equipment may in some way interfere with the machine's ability to perform its intended work function. The operation of FOPS-equipped machines in underground mines has been examined.

The following descriptions of equipment and protective structures are given to assist the reader in understanding the material presented in this report. The equipment types studied during this effort are defined in MESA's proposed standard for roll-over protective structures (ROPS) as published in the Federal Register, Volume 39, No. 207, dated October 24, 1974. The proposed standards are to apply to "self-propelled, track-type (crawler mounted) or wheeled (rubber-tired) front-end loaders; dozers; tractors, including industrial and agricultural tractors but not including over-the-road type tractors; motor graders; and prime movers, all with or without attachments, with the exception of such self-propelled equipment that is operated by remote control." The above description of equipment types can also be categorized as follows:

- Front-End Loaders
  - Rubber-tired (Figure 1-1)
  - Crawler mounted (Figure 1-2)
- Dozers
  - Rubber-tired (Figure 1-3)
  - Crawler mounted (Figure 1-2)
- Tractors
  - Rubber-tired (Figure 1-4)
  - Crawler mounted (Figure 1-2)
- Motor Graders (Figure 1-5)
- Prime Movers (such as the off-road type used to pull scrapers, water wagons, etc.) (Figure 1-6)

The low-profile type of rubber-tired front-end loader called a Load-Haul-Dump (LHD) as shown in Figures 1-7 and 1-8 is not included as a "machine of interest" but is treated separately in this report.

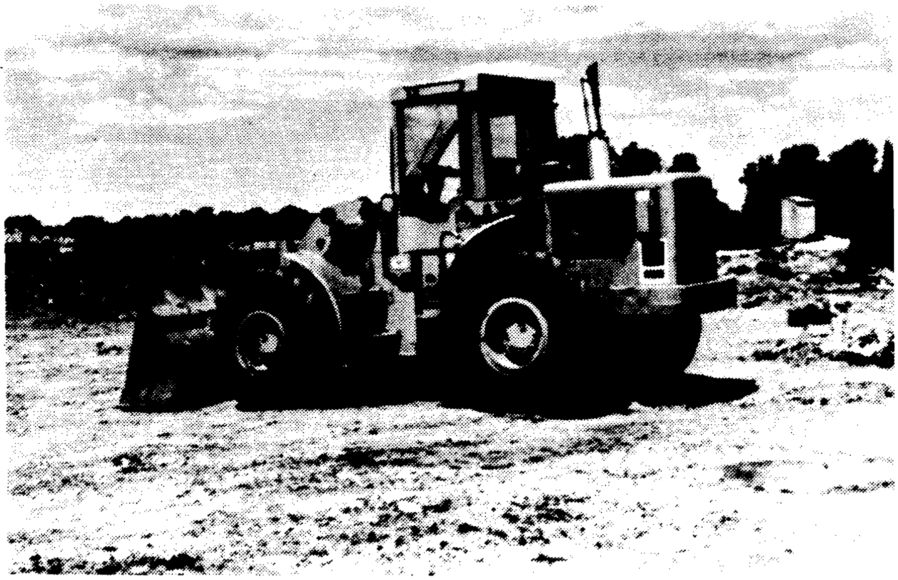


Figure 1-1. Rubber-Tired Front-End Loader

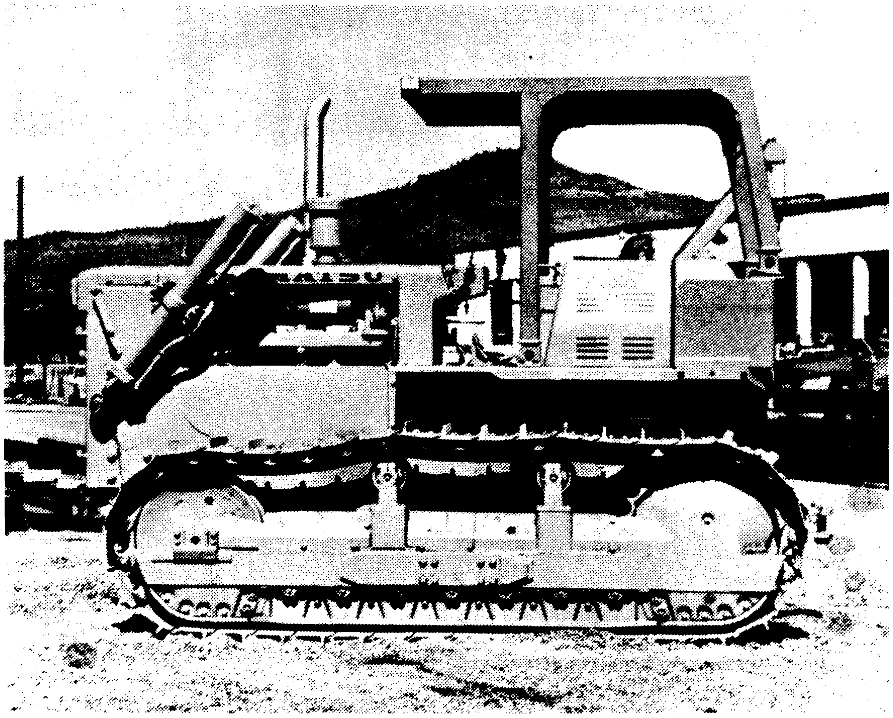


Figure 1-2. Crawler Tractor
(Dozer if equipped with blade;
Loader if equipped with bucket)

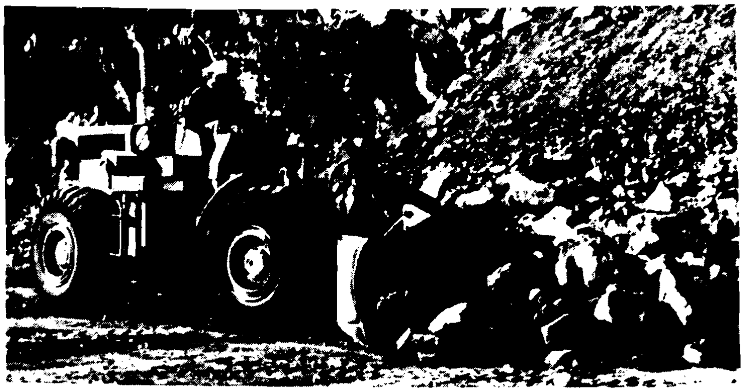


Figure 1-3. Rubber-Tired Dozer

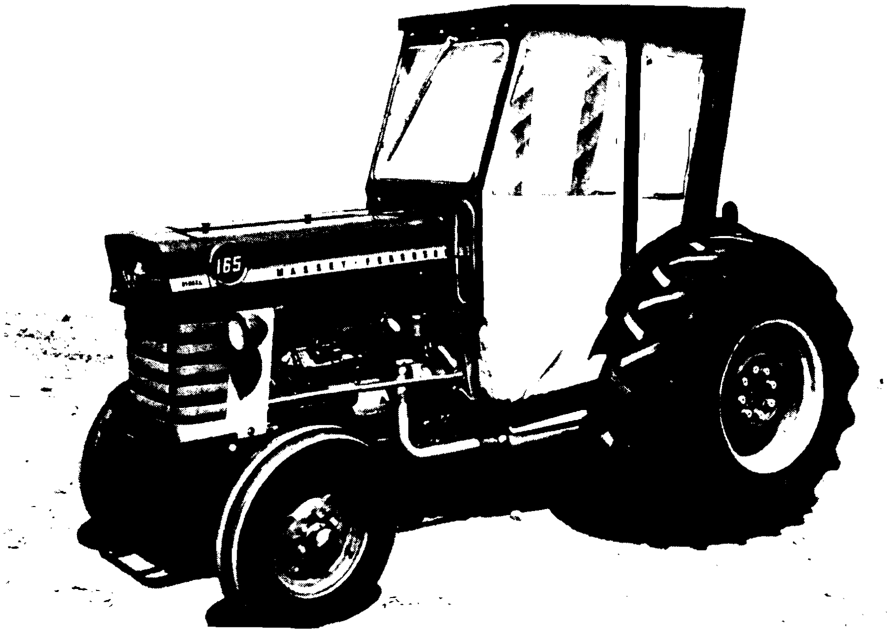


Figure 1-4. Industrial Tractor

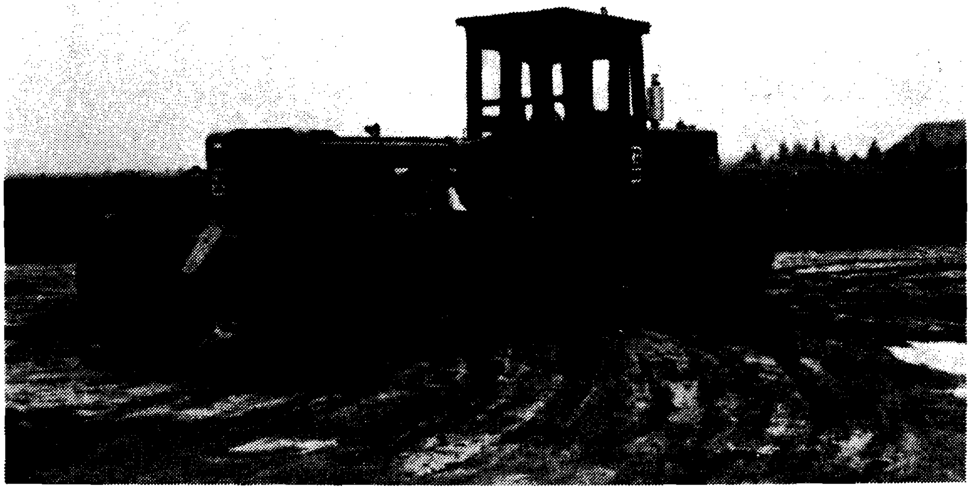


Figure 1-5. Motor Grader

Figure 1-6. Prime Mover Pulling Scraper

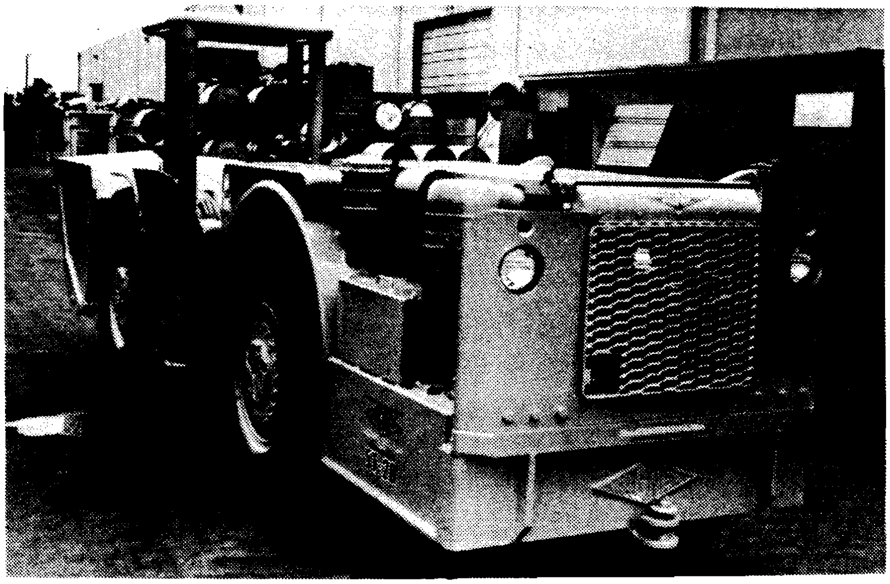


Figure 1-7. Wagner Load-Haul-Dump (LHD)

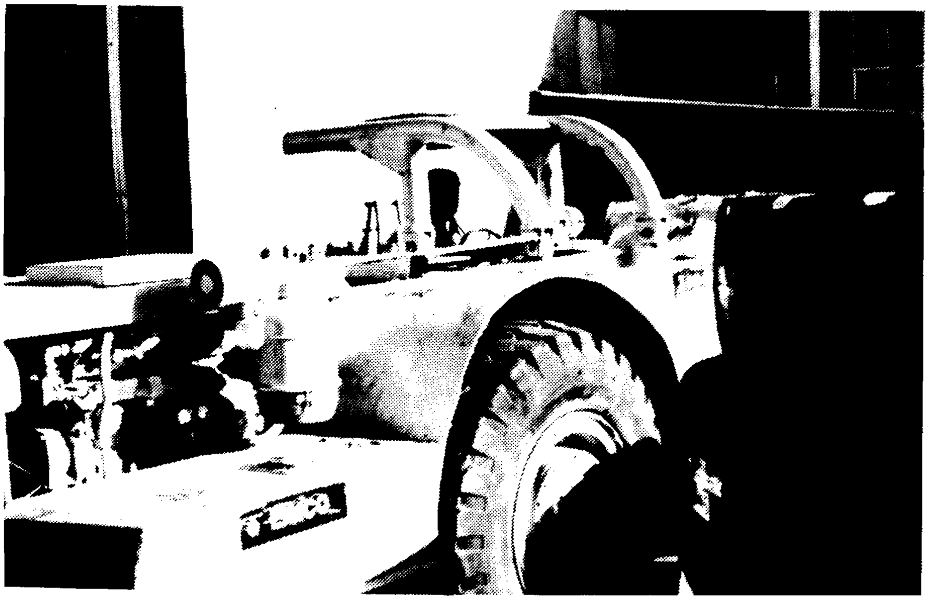


Figure 1-8. Eimco Load-Haul-Dump (LHD)

In the text of this report the terms "equipment", "vehicles", "machines" and "machines of interest" are used somewhat interchangeably in describing the different pieces of equipment studied. The types of equipment covered by this study could also be referred to as "construction equipment used in mining."

The protective structures referred to in this report are of two general functional types – a roll-over protective structure or "ROPS" that provides operator protection in the event that the vehicle overturns, and a falling object protection structure or "FOPS" that protects the operator from falling objects. The terms "cab" and "canopy" are often used to describe the physical construction and appearance of the protective structure; "ROPS" or "FOPS" describes the structural design of the protective structure. In some cases (for instance, a sheet metal cab designed for protection against weather) the cab or canopy is not protecting against accidents but serves some other purpose. A cab is usually a fully enclosed operator area and a canopy is a covering over the operator's area. Figure 1-9 depicts a ROPS canopy; Figure 1-10 shows a ROPS cab. In the case of these two illustrations, a FOPS capability is also built into the top of each unit.

Many mines have purchased or fabricated protective structures for their mining equipment. These structures are often designed to meet specific requirements in the mines in which they are used. Figure 1-11 illustrates three examples of canopies installed by mine operators.

MINE VISITS

During the performance of this program it was necessary to visit several mines to discuss specific rock fall hazards, review detailed accident information, assess operational impacts of FOPS regulations,

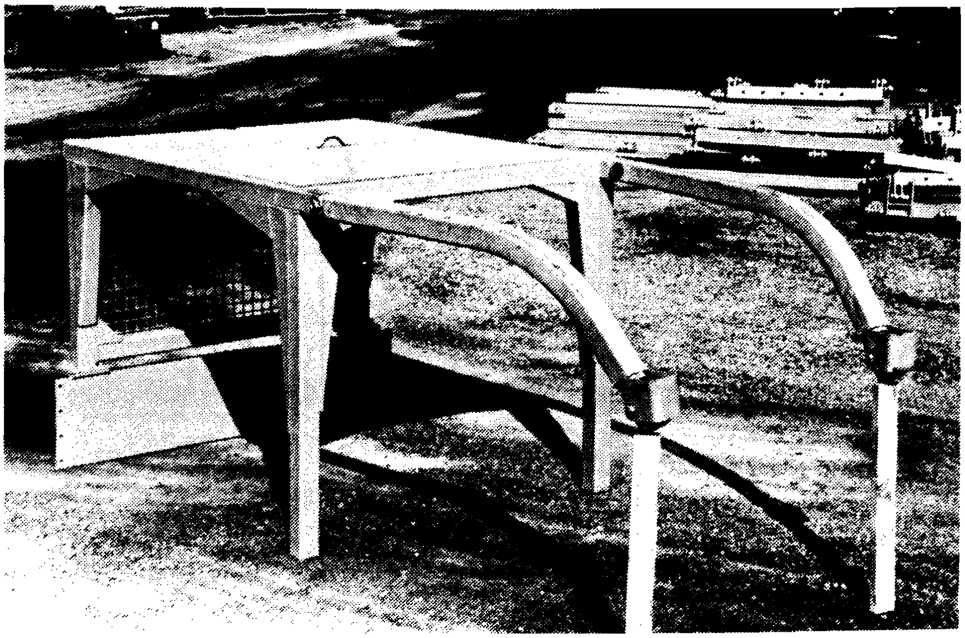


Figure 1-9. ROPS Canopy (Rome Manufacturing Co.)

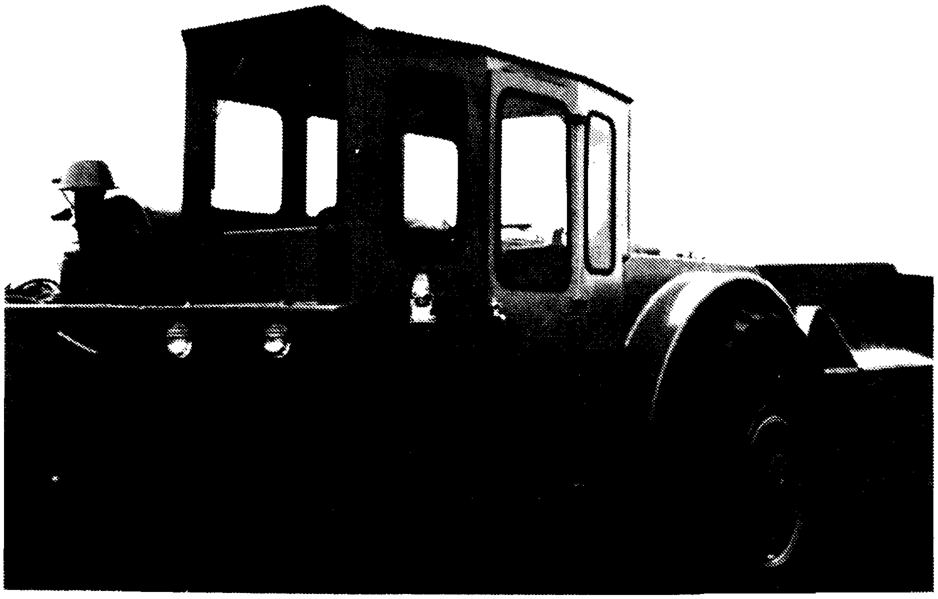


Figure 1-10. ROPS Cab (Young Corporation)

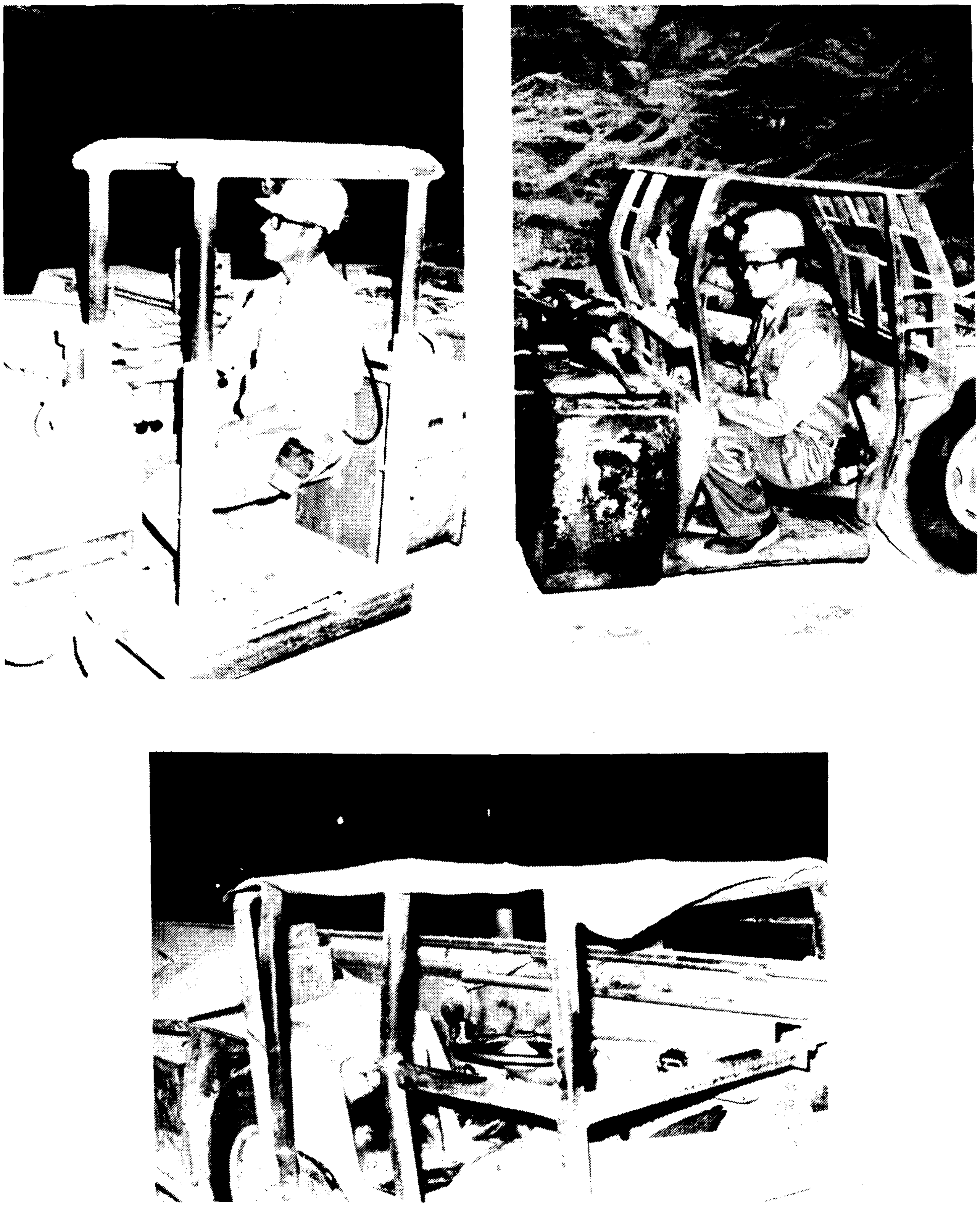


Figure 1-11. Falling Object Protective Structures (FOPS)

study shop-built FOPS, and to investigate other aspects related to the use of FOPS. The following mines provided much needed information during field visits. We thank them for their excellent cooperation.

Allied Product Co., Montevallo, Alabama	Montevallo Quarry
Anaconda Co., Butte, Montana	Berkeley Mine Continental East Mine Kelley Mine Steward Mine
ASARCO, Wallace, Idaho	Coeur Project Mine Galena Mine
Bing Materials Co., Gardnerville, Nevada	Bing Mine
Bunker Hill Co., Kellogg, Idaho	Bunker Hill Mine Crescent Mine
Citadel Cement Corp., Birmingham, Alabama	Birmingham Quarry and Mill
Cortez Mining Co., Cortez, Nevada	Cortez Mine
Domtar Chemicals, Inc., Louisa, Louisiana	Cote Blanche Mine
Duval Corp., Carlsbad, New Mexico	Nash-Draw Mine
Georgia Marble, Tate, Georgia	Cove Mountain Mine New York Mine Tate Quarry Whitestone No. 1
Homestake Mining Co., Lead, South Dakota	Homestake Mine
Kennecott Copper Corp., Bingham Canyon, Utah	Bingham Canyon Mine
MacGuire Farm, Mosinee, Wisconsin	Salzman Pit
Mobile City Road and Bridge Department, Irvington, Alabama	Boe Pit

N.L. Industries, Newcomb, New York	Tahawus Mine
St. Joe Minerals Corp., Balmat, New York	Balmat-Edwards Mine
Southern Talc Corp., Chatsworth, Georgia	Earnst Mine Rock Cliff Mine
Sunshine Mining Co., Kellogg, Idaho	Sunshine Mine
Union Carbide, Grand Junction, Colorado	Deremo-Snyder Mine Sunday Mine
White Pine Copper Co., White Pine, Michigan	White Pine Mine

SECTION 2.0

SUMMARY OF PROGRAM STUDY AREAS

Falling Object Protective Structures (FOPS), cabs, or canopies are required on electric face equipment used in underground coal mines. These operator protective structures have proved their worth in underground coal mines with over one hundred saved lives credited to their use. The structural performance requirements for these canopies were developed after detailed investigation of the nature of roof falls in coal mines and an extensive laboratory test program.

Equipment operators working in surface and underground metal-nonmetal mines are also exposed to injury or death from falling objects. The Bureau of Mines, recognizing the differences in rock fall characteristics between underground coal mines and the surface and underground metal-nonmetal mines, planned an investigation to determine the structural performance requirements of Falling Object Protective Structures (FOPS) to be used in the metal-nonmetal mines.

Concurrent with the effort to develop the structural criteria for FOPS, the Bureau of Mines initiated an effort to define the population of mining equipment that would be affected by a regulation requiring the installation of FOPS. This equipment population determination was primarily concerned with self-propelled track-type (crawler mounted) or wheeled (rubber-tired) front-end loaders; dozers; tractors, including industrial and agricultural tractors but not including over-the-road type tractors; motor graders; and prime movers.

The equipment population information, together with FOPS cost data, could be used to estimate the economic implications of any proposed FOPS regulation. The equipment population information could also be used to estimate the mining industry costs of complying with proposed ROPS regulations. In June 1975 the Bureau of Mines awarded USBM Contract No. J0357710, "Design Criteria and Guidelines for Falling Object Protective Structures (FOPS)", to Woodward Associates, Inc., Redlands, California, to prepare information that would allow MESA to determine the possible approaches to implementing a FOPS regulation in metal-nonmetal mines.

The primary tasks of this program were as follows:

1) Characterize rock falls in surface and underground metal-nonmetal mines.

2) Determine the required structural performance of FOPS to provide operator protection from rock falls in surface and underground metal-nonmetal mines.

3) Gather information on the equipment population that might be affected by future FOPS and ROPS regulations.

4) Assess the industry costs of complying with future FOPS and ROPS regulations.

These tasks were accomplished during the period between June 13, 1975 and January 31, 1976. In performing these tasks, Woodward Associates, Inc. relied heavily on the results of a USBM Fall-of-Ground and Equipment Survey that supplied information from over 600 mining operations, on work conducted previously for the Department of Labor's Occupational Safety and Health Administration, and on falling object protective structure and roll-over protective structure design efforts previously conducted for the U.S. Army and commercial customers.

Figure 2-1 summarizes the results of analyzing fall-of-ground accidents for surface and underground mines. The rock fall kinetic energy that will be transmitted into the protective structure has been tabulated and the expected frequency determined. For example, it is estimated that 40-45% of all rock falls in surface mine areas will transmit kinetic energy levels less than 40,000 ft-lb into the FOPS. Likewise, it is estimated that about 55-65% of the underground rock falls will have kinetic energy levels less than 40,000 ft-lb. This information is used to help evaluate the protection afforded by possible FOPS performance criteria. Section 4.1 and Appendices A4, A5, and A6 discuss the rock fall characterization and accident analyses studies in detail.

Table 2-1 lists FOPS performance standards now in effect. A FOPS performance standard that provides significantly more operator protection has been developed. This new FOPS performance standard will provide protection for the operators of "machines of interest" with gross weights above about 30,000 pounds against large rock falls that transmit energy levels equivalent to 40,000 ft-lb into the FOPS unit. Figure 2-2 illustrates the energy absorption range of FOPS units that are designed to meet the recommended Woodward Associates, Inc. (WAI) FOPS performance in addition to the performance criteria required for SAE ROPS units (ROPS designed to meet Society of Automotive Engineers standards). The WAI FOPS performance criteria can effectively combine the requirements of the SAE ROPS performance standard (SAE J1040a) and the SAE FOPS performance standard (SAE J231) with a minimum top load energy requirement to effect a protective structure that will provide excellent operator protection during vehicle overturn, large rock falls and small "spike" rock falls. Protection is also provided for side impact accidents. Table 2-2 reviews this new proposed FOPS performance standard.

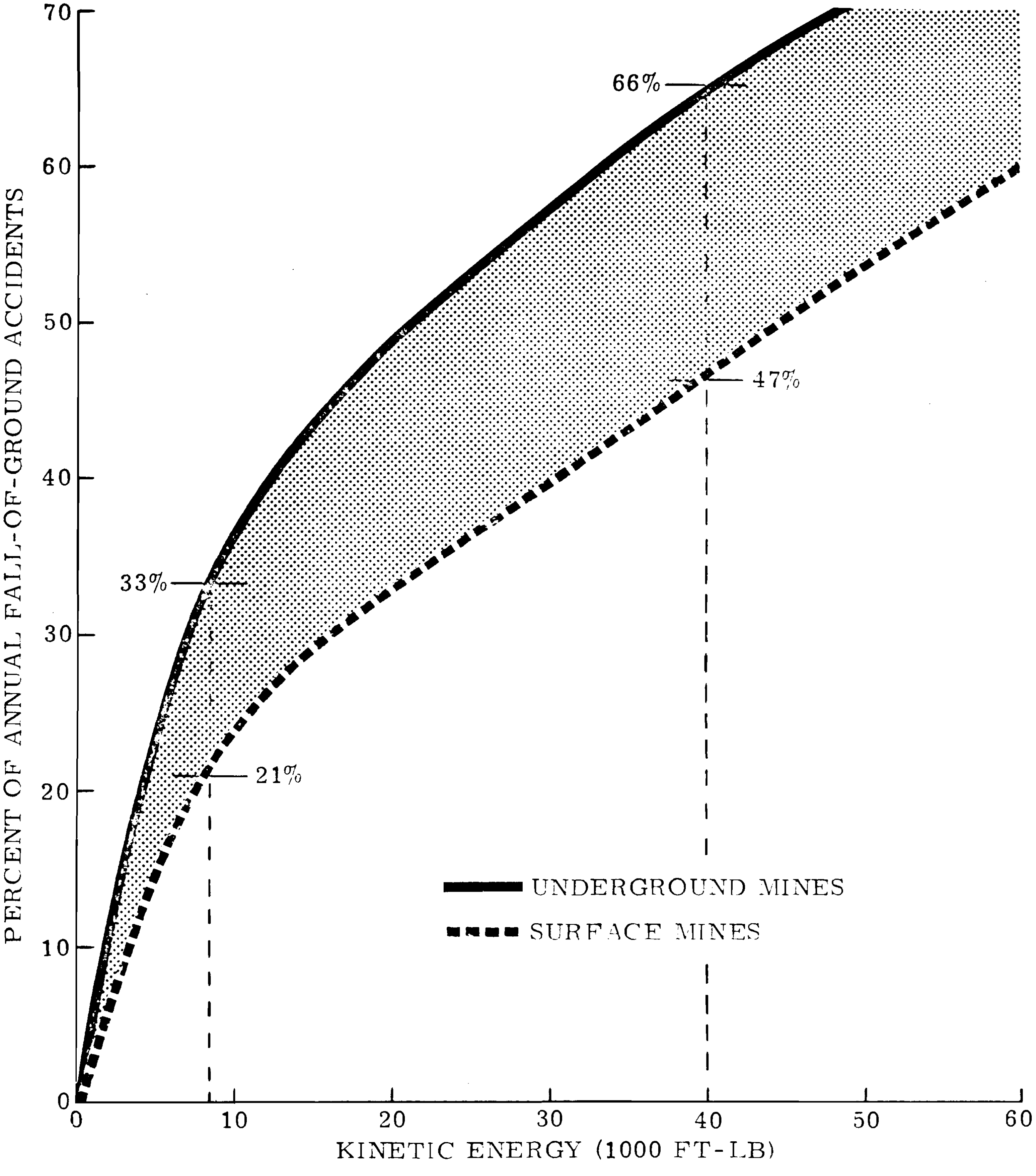
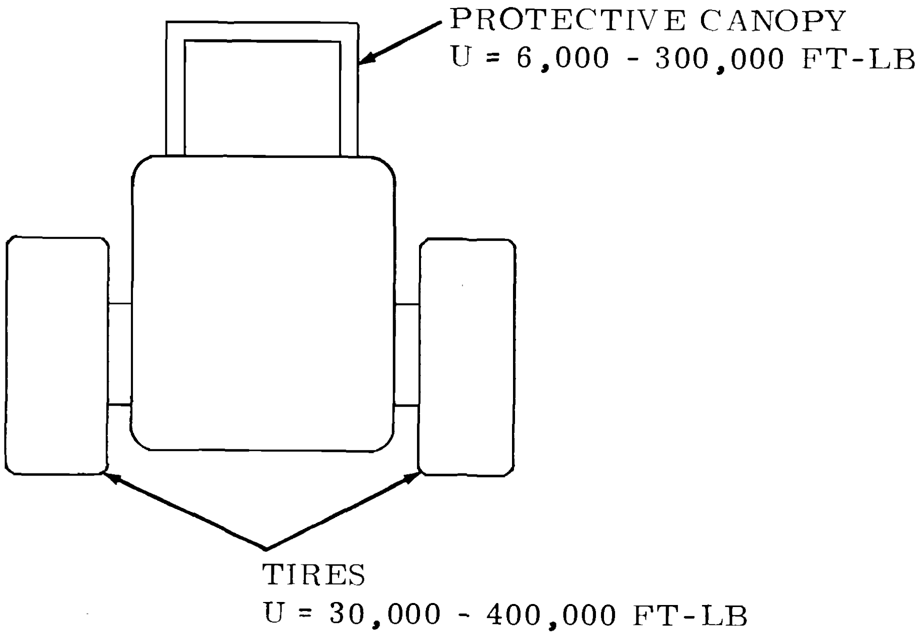


Figure 2-1. Rock Fall Kinetic Energy vs. Percent of Total Rock Falls

Table 2-1. Falling Object Protective Structure (FOPS) Performance Standards

Performance Standard	Type of Equipment	Kinetic Energy	Test Procedure	Test Type
SAE J231	Crawler tractors, crawler loaders, rubber-tired loaders, motor graders, rubber-tired prime movers, off-highway dump trucks, skid-steer loaders and industrial tractors	8500 ft-lb	A 500 pound shaped steel mass is dropped 17 ft. on to the FOPS top. The impact area must be over the operator area and away from roof structural members.	Destructive Dynamic
SAE J167	Industrial tractors, agricultural tractors	1000 ft-lb	A solid steel sphere weighing 100 pounds is dropped 10 feet. As with J231, the impact area must be over the operator area and away from roof major structural members. A "crush test" is also performed to demonstrate that the canopy can support two times the tractor gross weight.	Destructive Dynamic
SAE J1040a	Same as SAE J231	Strain energy varies with vehicle size	In addition to complying with a side-load requirement, the ROPS must support one times the vehicle gross weight.	Destructive Static
Corps of Engineers	Same as SAE J231		ROPS must comply with SAE J1040a or analytically support a load of two times the vehicle gross weight if not subjected to SAE J1040a test.	Destructive Static
Corps of Engineers	Light industrial tractors	1000 ft-lb	ROPS must also comply with SAE J167	Destructive Dynamic
MESA	Electric face equipment	Approx. 5000 ft-lb	Canopy must elastically support 18,000 pounds or 15 psi, whichever is lesser.	Non-Destructive Static
SAE J334a	Industrial tractors, Agricultural tractors	Strain energy varies with vehicle size	ROPS is struck with pendulum weight (4410 lbs) from both side and rear.	Destructive Dynamic



Vehicle	FOPS Energy Absorption	Frame/Tires Energy Absorption	System Energy Absorption
Light Industrial Tractor (GVW = 5,000 lb)	6,000- 15,000 ft-lb	10,000- 40,000 ft-lb	15,000- 55,000 ft-lb
Front-End Loader (GVW = 30,000 lb)	40,000- 80,000 ft-lb	80,000-120,000 ft-lb	120,000-200,000 ft-lb
Front-End Loader (GVW = 150,000 lb)	100,000-300,000 ft-lb	200,000-400,000 ft-lb	300,000-700,000 ft-lb
Crawler Dozer (GVW = 60,000 lb)	50,000- 80,000 ft-lb	Small	50,000- 80,000 ft-lb

Figure 2-2. Energy Absorption Capability of ROPS/Vehicle Systems

Table 2-2. Proposed FOPS Performance Standard (WAI)

Gross Vehicle Weight Over 30,000 Lb

- FOPS must be certified per Appendix A1, "FOPS Certification Procedures." FOPS must demonstrate the capability to absorb 40,000 ft-lb of kinetic energy through either one of the static tests described in Appendix A3, "FOPS Test Procedure," or through engineering analysis as described in Appendix A2, "FOPS Design Guides."
- FOPS must be tested to satisfy the requirements of SAE J231.
- ROPS/FOPS must also be tested to satisfy the requirements of SAE J1040a.

Gross Vehicle Weight Under 30,000 Lb

- FOPS must be "substantial."
- FOPS must be tested to satisfy the requirements of SAE J231 and SAE J167.
- The top load capability should be the maximum possible consistent with the structural limitations of the vehicle frame and the FOPS/frame attachments.
- ROPS/FOPS must also be tested to SAE J1040a or SAE J334a.

Summary of Static Load Requirements (from Section 4.2, "Development of FOPS Design Criteria")

Gross Vehicle Weight	FOPS Design Configuration	Distributed Top Load	Center Ninth Top Load	Energy Absorption Capability
>30,000 lb	Four-post	74,000 lb	36,000 lb	>40,000 ft-lb
	Two-post	74,000 lb	74,000 lb	>40,000 ft-lb
<30,000 lb	All	Maximum level consistent with vehicle frame capability	Maximum level consistent with vehicle frame capability	Depends on vehicle frame and tire capability

Table 2-3 lists current state and federal ROPS regulations.

These regulations often refer to SAE Standards and Recommended Practices that were in effect on the date that the particular regulation was promulgated. The SAE ROPS Recommended Practice currently in effect is SAE J1040a. This SAE Recommended Practice incorporates material previously published as SAE J320, J394, J395, J396, and J1011. Section 5.0, References, lists SAE ROPS Standards and Recommended Practices that have been and/or are in effect at this time.

Table 2-4 describes the mining equipment population that could be affected by a ROPS/FOPS regulation. The results of the USBM Fall-of-Ground and Equipment Survey have been analyzed and estimates of the total numbers of mining machines have been prepared. These estimates are given by machine type and by date of manufacture. The equipment numbers given in the front-end loader category do not include load-haul-dump machines. The total number of LHD units in use in underground mines is estimated at about 600 of which about 60% have some form of protective structure installed.

Tables 2-5 and 2-6 provide estimates of the costs involved in complying with ROPS/FOPS regulations.

Table 2-3. Federal and State FOPS Regulations

Agency	Regulation	FOPS Performance Requirement
Mining Enforcement and Safety Administration	Part 55 – Health and Safety Standard – Metal and Nonmetallic Open Pit Mines, paragraph 55.14-13 (February 25, 1970)	Forklift trucks, front-end loaders, and bulldozers shall be provided with substantial canopies when necessary to protect the operator.
Mining Enforcement and Safety Administration	Part 56 – Health and Safety Standard – Sand, Gravel, and Crushed Stone Operators, paragraph 56.14-13 (February 25, 1970)	Same as above.
Mining Enforcement and Safety Administration	Part 57 – Health and Safety Standard – Metal and Non-Metallic Underground Mines – paragraph 57.14-13 (February 25, 1970)	Same as above.
Mining Enforcement and Safety Administration	Part 75 – Coal Mine Health and Safety, paragraph 75.1710-1	Canopies or cabs must possess minimum structural capacity to support elastically: (1) a dead weight load of 18,000 pounds, or (2) 15 psi distributed uniformly over the plan view area of the structure, whichever is lesser. (On self-propelled electric face equipment.)

Table 2-3. Federal and State FOPS Regulations (Cont)

Agency	Regulation	FOPS Performance Requirement
Mining Enforcement and Safety Administration	Part 77 – Coal Mine Health and Safety, paragraph 77.403	When necessary, all rubber-tired or crawler mounted self-propelled scrapers, front-end loaders, dozers, graders, loaders, and tractors used in surface coal mines or surface areas of underground coal mines shall have substantial FOPS. FOPS meeting SAE J231 criteria are "substantial."
State of California	Construction Safety Orders, paragraph 1596	Roll-over protective structures "must also give reasonable operator protection against falling or rolling objects."
Corps of Engineers	General Safety Requirements, paragraph 18.A.19	All bulldozers, tractors, or similar equipment used in clearing operations shall have substantial canopies to protect the operator from falling or flying objects as appropriate to the nature of the clearing operation undertaken.
Corps of Engineers	General Safety Requirements, paragraph 18.A.20	ROPS for light industrial tractors must also comply with SAE J167 FOPS requirement.

Table 2-3. Federal and State FOPS Regulations (Cont)

Agency	Regulation	FOPS Performance Requirement
Bureau of Reclamation	Safety and Health Regulations for Construction, paragraph 9.6.1	Canopy shall have an overhead covering of at least 1/8 inch steel plate on equipment less than 28,000 pounds gross weight and 3/16 inch steel plate on equipment over 28,000 pounds gross weight.
Occupational Safety and Health Administration	Subpart W – Roll-Over Protective Structures; Overhead Protection, paragraph 1926.1003	Industrial tractors must comply with SAE J167 FOPS requirement.

Table 2-4. Equipment Population[1] – Machines of Interest

Machine Type	Date of Manufacture								Total		Total
	Post-1969		1965-1969		1960-1964		Pre-1960				
	With ROPS	Without ROPS	With ROPS	Without ROPS	With ROPS	Without ROPS	With ROPS	Without ROPS	With ROPS	Without ROPS	
Front-End Loaders (Rubber-tired and crawler-mounted)	11,025	4,450	3,025	6,250	375	2,375	125	1,050	14,550	14,125	28,675
Dozers (Rubber-tired and crawler-mounted)	2,875	450	1,075	1,675	375	1,050	200	1,475	4,525	4,650	9,175
Motor Graders	425	300	50	725	50	525	125	975	650	2,525	3,175
Tractors	1,600	375	350	1,400	275	325	150	750	2,375	2,850	5,225
Prime Movers	675	325	600	600	100	400	25	275	1,400	1,600	3,000
TOTAL	16,600	5,900	5,100	10,650	1,175	4,675	625	4,525	23,500	25,750	49,250

(1) Data from Equipment Population Survey rounded to nearest 25 units.

Note: "ROPS" refers to a protective structure of some type; the particular performance or design criteria used is not defined.

Table 2-5. ROPS/FOPS Retrofit Costs
(SAE or COE ROPS with J231 FOPS)

Machine Type	Date of Manufacture				Totals
	Post-1969	1965-1969	1960-1964	Pre-1960	
Front-End Loaders (Rubber-tired and crawler-mounted)	$ 8,800,000	$11,900,000	$3,700,000	$1,500,000	$25,900,000
Dozers (Rubber-tired and crawler-mounted)	800,000	2,800,000	1,900,000	2,400,000	7,900,000
Motor Graders	480,000	1,150,000	770,000	1,450,000	3,850,000
Tractors	490,000	2,100,000	460,000	1,070,000	4,120,000
Prime Movers	590,000	1,060,000	810,000	390,000	2,850,000
TOTAL	$11,160,000	$19,010,000	$7,640,000	$6,810,000	$44,620,000

SAE – Society of Automotive Engineers

COE – Corps of Engineers

Table 2-6. Costs of Alternative ROPS/FOPS Retrofit Policies
(All types of "machines of interest" in surface and underground mines)

ROPS/FOPS Retrofit on Machines Manufactured After	Approximate Number of Machines Affected by Alternative Policy	Percent of Total January 1, 1976 Machine Population that is ROPS-Equipped	Cost of Retrofit Policy
January 1, 1970	5,900	60%	$11,000,000
January 1, 1965	16,550	81%	$30,000,000
January 1, 1960	21,225	91%	$38,000,000
All Machines	25,750	100%	$45,000,000

SECTION 3.0

CONCLUSIONS AND RECOMMENDATIONS

3.1 CONCLUSIONS

This study has developed information in the three general areas of accident analysis/rock fall characterization, ROPS/FOPS performance, and economic effects.

In general it can be stated that it is impractical to attempt to require FOPS or ROPS that will protect the machine operator against all possible rock falls or vehicle overturns.

There are accidents in which no practical protective structure will protect the operator; in some accidents the vehicle itself is completely destroyed. Massive rock falls have occurred in both surface and underground mines where thousands of tons of rock have fallen on equipment. The protective structures discussed in this report provide protection against rock falls up to a magnitude of two to three tons falling 7 to 10 feet or one ton falling about 20 feet.

In actual practice these protective structures would provide much greater protection than expected from the design calculations because a portion of the rock fall energy will be absorbed into the vehicle frame and tires. In the case of a large front-end loader, the actual rock fall energy that the FOPS could withstand could be over twice the energy absorption capability of the FOPS alone. Another important factor in predicting the protection afforded by FOPS is the structural integrity of the falling rock. Often the section of rock that falls is termed "bad ground" by the miners. It is rock that is fractured, unconsolidated, loose or in some other state to cause the miners to consider it abnormal or different than the rest of the ground in the area. Some rock falls are of "competent" or "solid" rock or of large pieces of competent rock. In the case of the "bad ground" type of a rock fall, the total energy transmitted into the FOPS is far below that expected by calculating the energy from the weight of the fall and the height of the fall. The rock fall section breaks up as it falls and only portions of the total fall impact the FOPS.

The figures in Sections 2.0 and 4.1 representing rock fall kinetic energy in surface and underground rock falls have been adjusted to reflect the lower expected energy transfer in large rock falls and rock slides.

Designing and installing ROPS/FOPS on the front-end loaders, dozers, graders, large tractors, and prime movers studied presents no unusual problems. The vehicle frames of these machines are generally quite strong in order to withstand the rigors of their work function; strong attachment areas are available. A different situation is evident when the small industrial and agricultural type of tractor is examined. These machines are used to transport personnel throughout mine areas and are used to tow small ore-carrying trailers in some mines. These tractors do not have the strong frames necessary to react the loads transmitted through the FOPS. The attachment of the FOPS to the tractor frame is also of marginal load carrying capability. The FOPS designed to meet the WAI FOPS performance criteria are overdesigned for the structural capability of these small tractors. The WAI FOPS performance criteria is valid on machines with gross vehicle weights of 30,000 pounds and above. A method of providing the same level of protection for operators of these small tractors is not defined in this report.

There is considerable evidence in the form of MESA mining accident records that supports the need for operator protection structures on specific types of mobile equipment used in metal-nonmetal mining operations. These MESA accident records describe deaths and injuries due to vehicle overturns, vehicle-vehicle collisions, vehicle-object collisions, fall-of-ground on machines, fly rock striking operators, and vehicles caught in rock slides. A properly designed protective structure, incorporating roll-over protection, falling object protection, and some measure of side protection, would save the machine operator in many of these accidents. This "all-protective" canopy or cab need not be a totally enclosed, uncomfortable fortress that limits visibility and creates new problems.

The ROPS/FOPS now used in the construction industry were resisted by both management forces and by the equipment operators when first introduced. Now, several years after these units have been in use, many of the construction contractors are very positive in their comments on the usefulness of ROPS/FOPS. The protection from the weather (rain, snow, etc.) afforded by a canopy or cab has resulted in increased productivity during inclement weather. Vehicle operators have become aware of the life-saving record of ROPS and are now accepting the fact that it is better to "ride out" a roll rather than trying to jump.

The ROPS/FOPS used on construction equipment can be used on similar mining equipment with the same positive effects on safety and production. Changes in FOPS performance criteria can be made to accommodate the higher energy rock falls experienced in mining operations with little or no change in ROPS/FOPS cost or appearance. Since the life saving performance of a ROPS is dependent upon keeping the machine operator contained within the "safety zone" of the operator's compartment it is mandatory that seat belts be installed and worn.

During the formulation of a new ROPS/FOPS regulation, factors in addition to increased safety must be evaluated. The economic impact of a proposed regulation and potential effects on mining operation methods must be studied. The operational effects on surface mining and in the surface areas of underground mines are minimal.

In underground mines, the requirement to install ROPS/FOPS could cause large changes in the use of mining equipment and the added height due to ROPS/FOPS installation could render many pieces of equipment unusable in the mine areas where they now work. The potential economic effects are very large in underground mines. If the mine height has to be increased to allow passage of ROPS/FOPS equipped machines then a considerable amount of valueless material has to be removed. This operation effectively lowers the value per ton of the ore being mined. As a simple example, assume that a mine is currently working a 3-4 foot thick mineralized zone, the back height is averaging 6 feet, and the ore is running $25 per ton (assume no upgrading). If the back has to be raised to a 10-foot average height, then 67% more material will have to be removed for the same amount of ore previously mined with the 6-foot high back (10 ÷ 6 = 1.67). Now 1.67 tons of material will be mined to capture the $25 worth of ore that was previously captured by mining one ton. The new worth per ton is $25 divided by 1.67 tons or $15 per ton. The mine operation may be incurring costs of $20 per ton to mine the ore, therefore this profitable operation would now be unprofitable and mine management would have to consider new mining methods or closing portions of the mine. Using smaller equipment and keeping the back height at 6 feet is another alternative. Smaller equipment is less productive than larger equipment (three 2-yard bucket front-end loaders will not move as much ore as one 6-yard bucket machine) and the cost per ore volume moved is greater with small machines than with larger machines. This alternative also has negative economic effects.

While the above example is over simplified, it does illustrate a problem encountered when considering ROPS/FOPS installation on underground machines. The accident history of underground machines does not support the need for roll-over protection. Since falling objects and side impacts are the primary reasons for providing operator protection for underground machine operators, the accident record for "machines of interest" used underground should be examined. In the three years of MESA accident records reviewed by WAI, "machines of interest" were involved in only two fall-of-ground accidents that resulted in death or injury.

In many of these rock fall accidents a FOPS would not have protected the operator since he was not in the operator station but was attending to some other activity nearby and would not have been under the protection of the FOPS. Operator protection from side impacts, roof impacts, collision with other objects, etc., is important in underground mines. No accident statistics were developed on this study to quantify the deaths and injuries due to machine accidents that did not involve fall-of-ground or roll-over but accidents that could be termed "tramming accidents" seem to occur with sufficient frequency to cause concern to many mine operators. Some mines have installed "low brow protection structures"; some have installed low profile canopies in an attempt to provide operator protection in underground mines. The installation of a FOPS type structure that does not unacceptably increase the machine height is desirable.

During mine visits, examples of protective structures that attempted to satisfy the need for low profile operator protection were examined. Figure 3-1 illustrates this type of protective structure. Before proceeding with a requirement to install some such device on underground equipment, the structural performance requirements needed to protect against side impacts must be defined. Since the machine mass is moving during many of these side impact accidents, it would appear that the performance criteria should cause the designer to prepare protective structure designs that have energy absorption capability directly related to equipment gross weight. A performance criterion for a side impact protective structure has not been developed during this study. A regulation requiring protective structures on underground mining equipment should contain a side impact performance criterion in addition to a top load performance criterion.

The use (or non-use) of seat belts in ROPS-equipped machines is a source of mine safety personnel concern. A seat belt must be worn by the operator to gain the maximum effectiveness of the ROPS system. Woodward Associates personnel have examined many construction industry accident reports where the operator of a ROPS equipped machine was thrown out and crushed by the ROPS during a roll-over. Seat belts are necessary to keep the operator inside the protected area.

Table 3-1 summarizes the conclusions reached in the accident analysis/rock fall characterization area. Table 3-2 reviews the conclusions relative to FOPS performance criteria and Table 3-3 presents the economic effects of possible ROPS/FOPS retrofit policies. These conclusions form the basis for the recommendations.

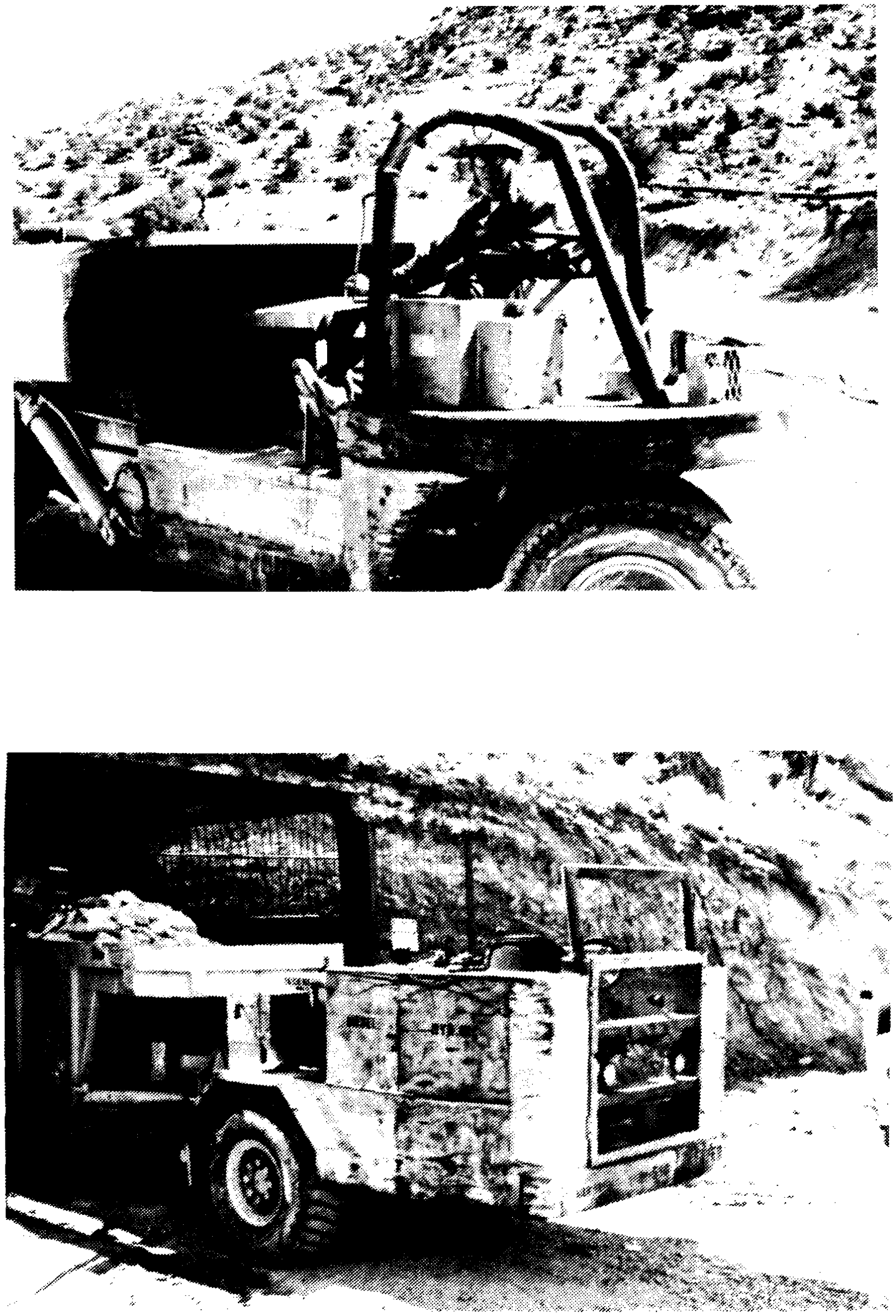


Figure 3-1. Protective Structures

Table 3-1. Conclusions — Accident Analysis/Rock Fall Characteristics

Accident Analysis

- Rock falls, or fall-of-ground accidents are responsible for approximately 7 deaths and 150 injuries per year in surface metal-nonmetal mines. Of these, approximately 3 deaths and 62 injuries occur to operators of the machine types covered by this study.
- Rock falls cause about 15 deaths and about 570 injuries per year in underground mines. Machine types studied on this program are involved in rock fall accidents claiming less than one death and approximately 28 injuries per year.
- Load-haul-dump units are involved in more underground rock fall accidents than for the total of all "machines of interest." These units operate in potential rock fall areas (forward of the supported roof) and have much greater exposure than do "machines of interest."

Rock Fall Characteristics

- Rock falls experienced in both surface and underground mines often involve large masses of material falling from significant heights. It is impractical to attempt to provide operator protection for every rock fall.
- The material involved in many rock falls is often not "competent" rock, that is, it does not have great structural integrity. It may fracture and break up upon impact or it may fall as a fractured layer. In surface mine rock falls, the material may be loose or unconsolidated. The actual kinetic energy transmitted into the FOPS may be considerably lower than that calculated using the total rock fall weight and the total fall height.
- Approximately one-half of the total rock falls in metal-nonmetal mines will transmit less than 40,000 ft-lb of kinetic energy into a FOPS structure.

Table 3-2. Conclusions – ROPS/FOPS Technical Area

- A FOPS meeting SAE J231 criteria provides acceptable operator protection for minimum of 21% of the rock falls in surface metal-nonmetal mines and approximately 33% of the rock falls in underground metal-nonmetal mines.

- A FOPS meeting structural performance criteria developed by WAI will provide operator protection for at least 40% of the rock falls in surface metal-nonmetal mine areas and 60% of the rock falls in underground metal-nonmetal mines. This FOPS performance criteria represents the maximum energy absorption design that is practical for these types of equipment.

- The WAI rock fall data collection technique recorded all rock falls reported and thus does not include many of the smaller rock falls that are not reported anywhere. The true percentage of actual rock falls for which these FOPS would provide protection is probably greater than the above numbers indicate.

- Providing significant levels of overhead protection for light industrial tractors is impractical. The FOPS capability normally provided with industrial tractor ROPS (SAE J167) does not provide adequate protection for the surface or underground rock fall environment. Light industrial tractors do not have the frame strengths necessary to survive the loads transmitted by rock falls.

- Test procedures and analytical methods are available that provide satisfactory verification of FOPS performance. Existing certification procedures are valid in some areas; a FOPS certification procedure for the WAI FOPS performance criteria has been prepared.

- The ROPS manufacturing industry has sufficient production capacity to meet the demands of the ROPS/FOPS regulations being considered by MESA and other federal and state regulatory agencies. Production capacity exceeds 300,000 ROPS/FOPS units per year.

- ROPS and FOPS designs are generally available for the machines of interest manufactured after 1965 and for many of the "heavy" machines from 1960.

Table 3-3. Conclusions – ROPS/FOPS Economic Area

- There are approximately 49,000 "machines of interest" in use in metal-nonmetal mining operations.
- Approximately 26,000 units of mining equipment could be affected by a ROPS or FOPS retrofit policy for metal-nonmetal mines.
- The costs of ROPS/FOPS retrofit policies could vary from about $11,000,000 to retrofit all "machines of interest" manufactured after 1969 to about $45,000,000 to retrofit all "machines of interest" regardless of date of manufacture.
- The cost of a ROPS/FOPS regulation for underground "machines of interest" could be very high in low back mines. Drastic changes in mine operation would be necessary to accommodate the added height to the machine.
- The population of load-haul-dump units is estimated at 600; about 240 do not have protective structures installed.

3.2 RECOMMENDATIONS

It is recognized that increased safety for miners is a primary goal for the U.S. Bureau of Mines and for the Mining Enforcement and Safety Administration. The implementation of the following recommendations will help achieve that goal. It has been demonstrated that, through evaluation of the operational and economic implications of different approaches to increased safety, a path can be defined that produces the desired increases in work place safety at minimum disruption of production and at acceptable cost levels. The effect of the recommendations presented in this section will not be to eliminate completely deaths and injuries due to accidents involving the machines studied. These recommendations, if implemented, will significantly reduce the deaths and injuries experienced in surface mines and surface areas of underground mines due to fall-of-ground, vehicle overturns, vehicle falls, and vehicle-object collisions. The costs to comply with these recommendations are judged to be reasonable. The effects on production are negligible.

The primary recommendation resulting from this study is to promulgate a MESA regulation similar to that proposed in the Federal Register, Volume 39, Number 207, dated October 24, 1974 but modified as the result of this investigation.

This regulation should only apply to surface mines and surface areas of underground mines. The ROPS and FOPS performance standards now available should be used as guidelines in requiring ROPS/FOPS on all "machines of interest" manufactured since January 1, 1965.

The selection of January 1, 1965 as the "date of manufacture" for machines that must have ROPS/FOPS will result in over 80% of the machines now in use being fitted with ROPS/FOPS. The selection of an earlier date would not add significantly to the number of machines covered but would cause undue and unwarranted financial hardships for some equipment owners. Generally it can be stated that the older machines are not worked as many hours per year as newer machines and therefore are not subjected to falling object or roll-over risk situations as much as newer equipment.

The selection of a later date of manufacture, Januay 1, 1970 for instance, would result in coverage of only 60% of the machines currently in use.

The regulation should state a date (January 1, 1978 is suggested) after which the ROPS/FOPS that are installed on new machines must meet the SAE ROPS performance criteria (SAE J1040a), the SAE FOPS performance criteria (SAE J231), and a new MESA FOPS performance standard. The time lag will allow ROPS/FOPS manufacturers the time necessary to verify that their current ROPS/FOPS meet this new USBM FOPS performance standard. Machines with gross vehicle weights under 30,000 pounds will not be fitted with FOPS that provide the minimum desired protection but no solution to this problem is readily available.

Table 3-4 summarizes the WAI recommendations.

Table 3-4. Recommendations

- ROPS/FOPS in Surface Areas – A MESA ROPS/FOPS regulation should require ROPS/FOPS on machines used in surface mines and surface areas of underground mines.
- ROPS/FOPS Retrofit Policy – A ROPS/FOPS regulation should be promulgated by MESA that requires the installation of ROPS and FOPS on all "machines of interest" manufactured after 1964. These ROPS should comply with the performance requirements given in SAE J1040a or in Corps of Engineers Manual EM385-1-1, March 27, 1972. The FOPS should comply with the performance requirements of SAE J231.
- ROPS/FOPS for New Machines – The ROPS/FOPS regulation should state that new machines manufactured after 1977 must have ROPS installed that comply with SAE J1040a and FOPS that comply with a MESA FOPS performance standard (developed from the WAI FOPS criteria included in this report). A new MESA certification procedure (developed from WAI procedure included herein) should be referenced as the performance verification method.
- Seat Belts – The ROPS/FOPS regulation should contain a requirement that seat belts be installed in machines and that it is the employees' responsibility to wear them.
- ROPS/FOPS in Underground Mines – It is recommended that crawler loaders, crawler dozers, rubber-tired dozers, motor graders, and scraper prime movers be exempt from any future ROPS/FOPS regulation effecting mobile equipment used underground.
- USBM should continue investigation into the need for FOPS on underground mining equipment. Mining machines that work in unsupported roof areas (roof bolters, gathering arm loaders, front-end loaders, LHD units, etc.) experience far more accidents of the type that a FOPS or side impact protective structure will protect against than do the front-end loaders, dozers, graders that generally work in supported roof areas.
- The use of FOPS in underground mines should not be viewed as a substitute for sound roof control engineering. Mobile temporary roof supports are an important part of the overall approach to providing protection for underground mining personnel.

Table 3-4. Recommendations (Cont)

- USBM should continue efforts toward increasing the validity and usefulness of the CANOPY computer program. The addition of a buckling subroutine and a plate-element subroutine should be considered.
- Efforts to educate machine operators on roll-over, falling object, and collision hazards should be initiated by MESA as a part of existing training programs.

SECTION 4.0

PROGRAM ACTIVITIES

The effort performed on this program has been divided, for reporting purposes, into six different subsections. Each subsection describes an area of research that was undertaken to gain information toward two general objectives. These primary objectives were: (1) definition of technical aspects of ROPS/FOPS usage on "machines of interest", including determination of a FOPS performance criteria that would provide operator protection superior to that provided by FOPS meeting the SAE J231 performance criteria, and (2) preparation of estimates of the equipment population that could be affected by ROPS/FOPS regulations and of the predicted costs to retrofit equipment with ROPS/FOPS.

The results of this effort were summarized in Section 2.0, Summary of Program Study Areas, and in Section 3.0, Conclusions and Recommendations.

The subsections are organized as follows:

- Subsection 4.1 – Characterization of Rock Falls
- Subsection 4.2 – Development of FOPS Design Criteria
- Subsection 4.3 – Equipment Population
- Subsection 4.4 – Commercial Availability of ROPS/FOPS
- Subsection 4.5 – ROPS/FOPS Retrofit Considerations
- Subsection 4.6 – Economic Effects of Possible Protective Structure Retrofit Policies

4.1 CHARACTERIZATION OF ROCK FALLS

This section is a summary of the work done to quantify the dimensions of rock falls experienced in metal-nonmetal mines. The data on rock falls is divided into surface and underground categories. Kinetic energy of rock falls is determined for use in FOPS performance requirement calculations.

Sources of Accident Information

The sources of information about the time and place of fall-of-ground accidents in metal and nonmetal mines are discussed in detail in Appendix A5.

Physical Data Collection

The methods of data collection are treated in detail in Appendices A4 and A5.

Important Definitions

The definitions of "accident", "fall-of-ground", and "machines of interest", as used consistently in this study, are given in Appendix A5.

Limitations of the Accident Data

A discussion of data limitations is given in Appendix A5.

There are other limitations which should be taken into account. They relate primarily to the accuracy of the basic data about the physical characteristics of falls, that is, to weight and distance data.

Consider how one would describe a fall ideally for energy calculations. The fall distance would be measured quite accurately, say to the nearest inch. The weight would be measured to the nearest pound. In addition, some accurate information about the shape of the fallen material would be necessary and, if it is non-cohesive, data which define its character should be known. Shape might be expressed as initial impact area in square inches. And finally, it should be known whether the material fell in a free-fall mode or as a sliding, pivoting or tumbling mass. If the fall was not a free fall, information about angles and friction losses would be required. Of course, data of these kinds which are accurate and detailed are possible only from controlled field tests or laboratory experiments. It is actual events with which this report is concerned and those events occurred in environments which are greatly different from the controlled test environment.

What are usually measured in an accident, if anything is actually measured at all, are the dimensions of the void created by the fallen material and the distance from what was believed to be the base of the material before it fell to the surface on which it came to rest. If the fall involved only one rock, or a few, the measurements might be made on the fallen material. Sometimes actual measurements are taken by mine safety officials or by federal and state mine inspectors. In many cases the information is estimated, and the dimensions used are feet of fall distance and size, and tons or hundreds of pounds of weight. More often, only a few of the needed data items are estimated at the time of the accident, or the time of the formal investigation, and the others are not estimated (or at least not recorded in the accident records). Only 22 of 152 MESA accident investigation reports used in this study had all of the needed data. The reason seems clear: neither the company safety officials nor the MESA officials need these data to form the judgments they normally must make regarding accident causes and accident prevention techniques for effective safety administration.

Data Analysis and Inferences

In order to deal properly with the reported information, it was necessary first to decide upon certain conventions which would be used in processing the data. Insofar as possible, data about each accident was expressed in terms which made it possible to perform some parametric analyses. Correction constants were employed in some cases to make the data more accurately reflect the true energy levels involved. The "ground rule" for selecting these constants was simply to choose those which would be most appropriate to obtain true energy levels within the constraint that no energy-related factor would ever be understated. All of the data processing procedures have been consistently conservative, that is, whatever bias exists in the final data is in the direction of higher than actual energy values. The details concerning the selection of correction constants appear in Appendix A5. An estimate of bias is included in the appendix cited.

In processing the data, the weight of the fall, as reported by the mine management or by the MESA accident investigation was always used as reported. No "correction constant" was applied to weight for two reasons:

1) No sound basis could be found for using a correction constant. A few of the respondents to the accident questionnaires gave fall volume information in addition to weight. In some of these cases, a calculation would show that one or the other was incorrect because, in order to have the weight reported, the density would have to be greater than it possibly could be in the ore body concerned. There

is very good evidence that volume (or length, width and thickness) is usually overestimated. However, in those few cases where there occurred this data anomaly, weight was taken to be correct.

2) Mining people customarily express production figures in weight terms. The majority of the questionnaires were answered in weight terms. A miner who moves a fallen rock, by hand or with a machine, will, because of his experience, make a more reasonable estimate of the weight than of any other descriptive factor.

Reported volume was available for many of the accidents. It is a good survey surrogate for weight if it is accurate and if the density of the material is known or can be satisfactorily estimated. The question of volume accuracy was given much careful consideration. The basic problem arises from the way in which the volume of an irregular object is usually measured or estimated. Typically, the points of greatest width, height and thickness are measured. The dimensional data were commonly given in feet, but with some words to express the shape, such as "egg-shaped rock." If the three dimensional numbers were simply multiplied to estimate volume, the volume figure would be much larger than the true volume. How this matter was treated is described in detail in Appendix A5.

The density of the fallen material was usually not known. It was estimated using data from standard references about ore densities, using the assumption that the material which fell had the same density as the ore being mined. This procedure produces a high estimate of the rock fall weight since the falling rock is of lower density than the ore in many cases.

The fall distances were reported in one of two ways: "total fall distance" or "distance material fell before striking victim." In order to express the total fall distance for kinetic energy calculations when only the fall distance to victim was given, it was necessary to add a correction constant of 6 feet. If the victim was operating a machine in a sitting position, the height of the top of the victim's head, as extracted from manufacturer's data on the machines, was used. In a few cases, information from the accident report was used to estimate the height of the top of the victim's head above the mine floor. For example, one accident report described the victim as being in a scaling tower which was 14 feet above the floor. The height of the top of the victim's head above the floor was taken to be 20 feet.

The "protection level" was defined as the height of the top of a protective structure above the plane on which a machine's wheels rest. In accidents which involved machines, a height was selected from the machine manufacturer's data or from ROPS manufacturers' data. It was, in the case of existing ROPS, the height of the top of the ROPS. If no ROPS data were available, the height of the top of the operator's head was used. If a non-riding machine was involved, or no machine was involved, the protection level was taken to be 6 feet, or 1 foot less than the fall distance, whichever was smaller, for underground accidents and 8 feet, or 1 foot less than fall distance, for surface accidents.

In order to estimate the portion of total kinetic energy which a protective structure must transform to be effective, it was necessary to model the fall and to make certain assumptions about the area of the top of the structure. This correction was required because some reported falls had plan form areas which were much larger than the canopy top. One of the largest of the existing ROPS was chosen for the model. It is a Young Corporation ROPS for the D9G Caterpillar dozer. The top of the ROPS is 66 inches wide and 90 inches long. However, 20 inches on one end of the length slopes downward at an angle of about 60 degrees. In the model and in the kinetic energy calculations for the protection level, the plan form area was taken to be 70 x 90 = 6300 square inches, or 43.75 square feet, and it was assumed that the entire area was flat.

The effective vertical dimension of the falling material is also necessary to calculate the load volume and the kinetic energy which a protective structure must transform. The vertical dimension of the load volume was taken to be the thickness of the fallen material as reported or, in the case of loose material falls in which no thickness was given, as 120 inches or 10 feet. The reasoning for this assumption is explained in some detail in Appendix A5.

All of the fall-of-ground data, as reported on the questionnaire or as extracted from MESA accident investigation reports, are shown in two tables in Appendix A5. One table gives the reported data for surface mines, the other for underground mines. Each of these tables also shows the results of the energy calculations for each accident and, in addition, identifies the machines involved in cases in which this information is known. The tables indicate whether the accident produced a fatality (F), a non-fatal injury (I), or no injury (N).

Fall-of-ground characterization data are portrayed in graphical form in this section. Figure 4-1 is a histogram which relates reported total fall distances, f, to the frequency of occurrence for fall-of-ground accidents in the sample of 198 accidents. The graph distinguishes between data from underground mine accidents and data from surface mine accidents so that the difference in frequency distribution is apparent. Figure 4-2 is a histogram which relates fall weight, W_2 (as

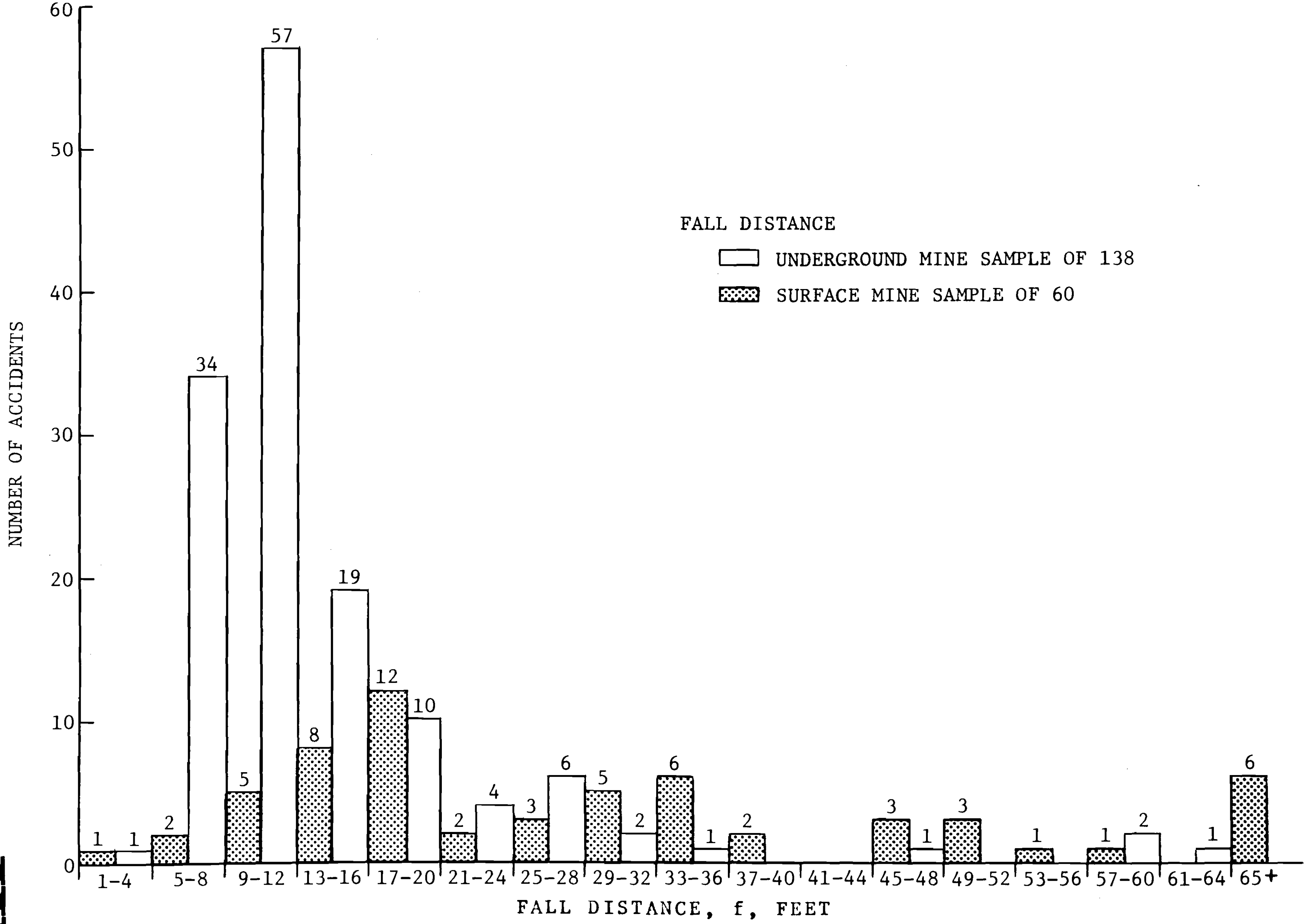


Figure 4-1. Fall Distance Frequency

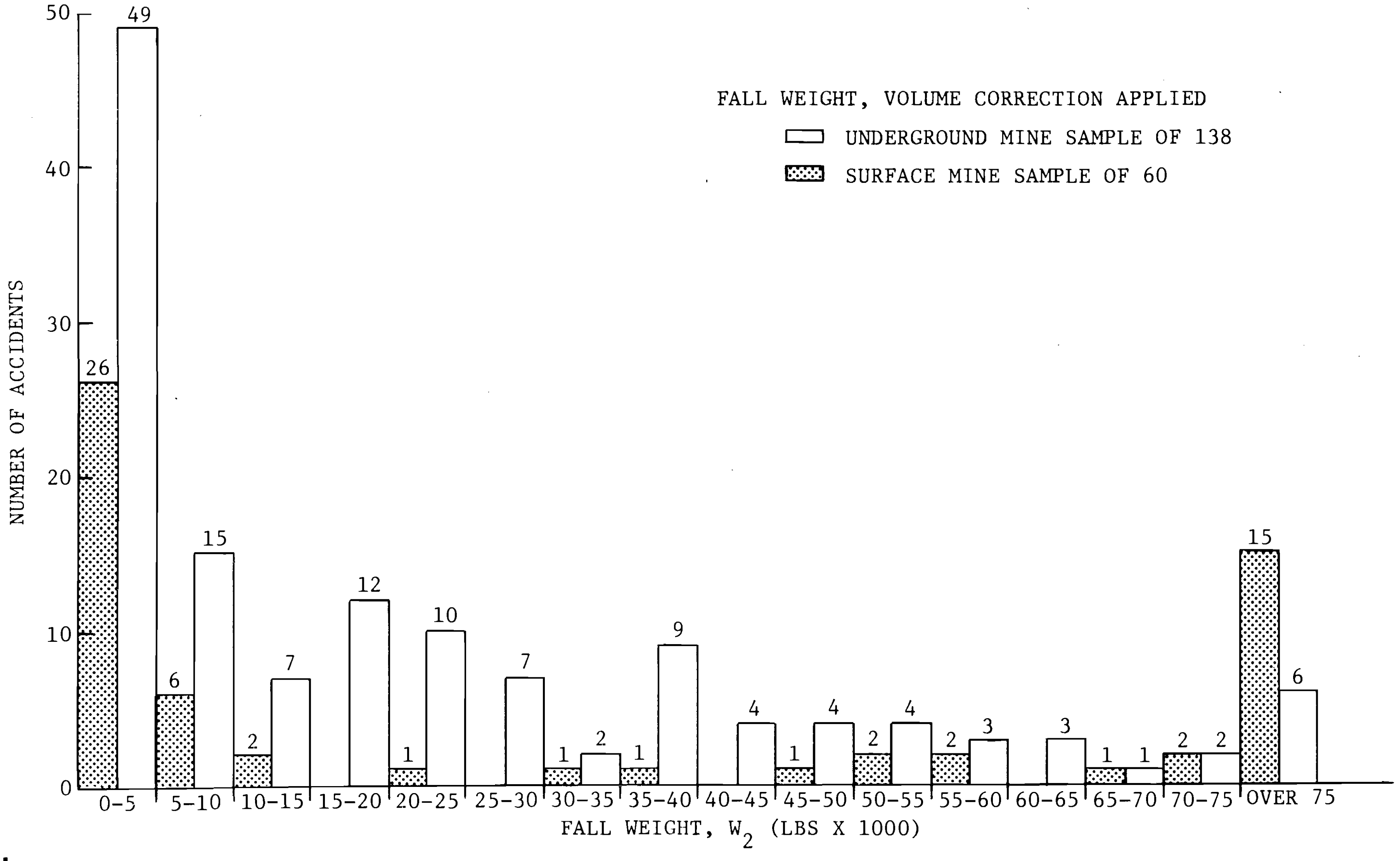


Figure 4-2. Fall Weight Frequency

adjusted where necessary by volume corrections), to the frequency of occurrence for accidents in the sample. As in the previous graph, underground mine accidents are distinguished from surface mine accidents.

The calculated kinetic energy values for accidents in the sample are portrayed in two cumulative percentage graphs, principally so that one may observe easily what percentage of the falls are below any selected kinetic energy value. Figure 4-3 gives the total fall kinetic energy data for fall-of-ground accidents in the sample. One curve is for underground mine accidents, the other for surface mine accidents. Figure 4-4 gives the fall kinetic energy at the "protection level." The upper curve is for underground mine accidents and the lower is for surface mine accidents.

The kinetic energy values for the estimated total annual number of fall-of-ground accidents are portrayed in cumulative percentage graphs in Figures 4-5 and 4-6. First, the annual population of fall-of-ground accidents was related to the sample data and to WAI estimates of the distribution by kinetic energy levels of the non-fatal injury and no injury accidents. This analysis produced the lower limit of each curve band in Figure 4-5. Then, estimates of the bias which exists in the kinetic energy calculations for the sample and for the population were made. These estimates produced the upper limits of the curve bands in Figure 4-5. In a sense, these curve bands are prediction curves. They predict what percentages of fall-of-ground accidents each year will be below any chosen kinetic energy value at the protection level, assuming that mining techniques and conditions do not change. Figure 4-6 presents the same information as Figure 4-5 in a slightly different form. The scale of the horizontal axis has been changed so that kinetic energy

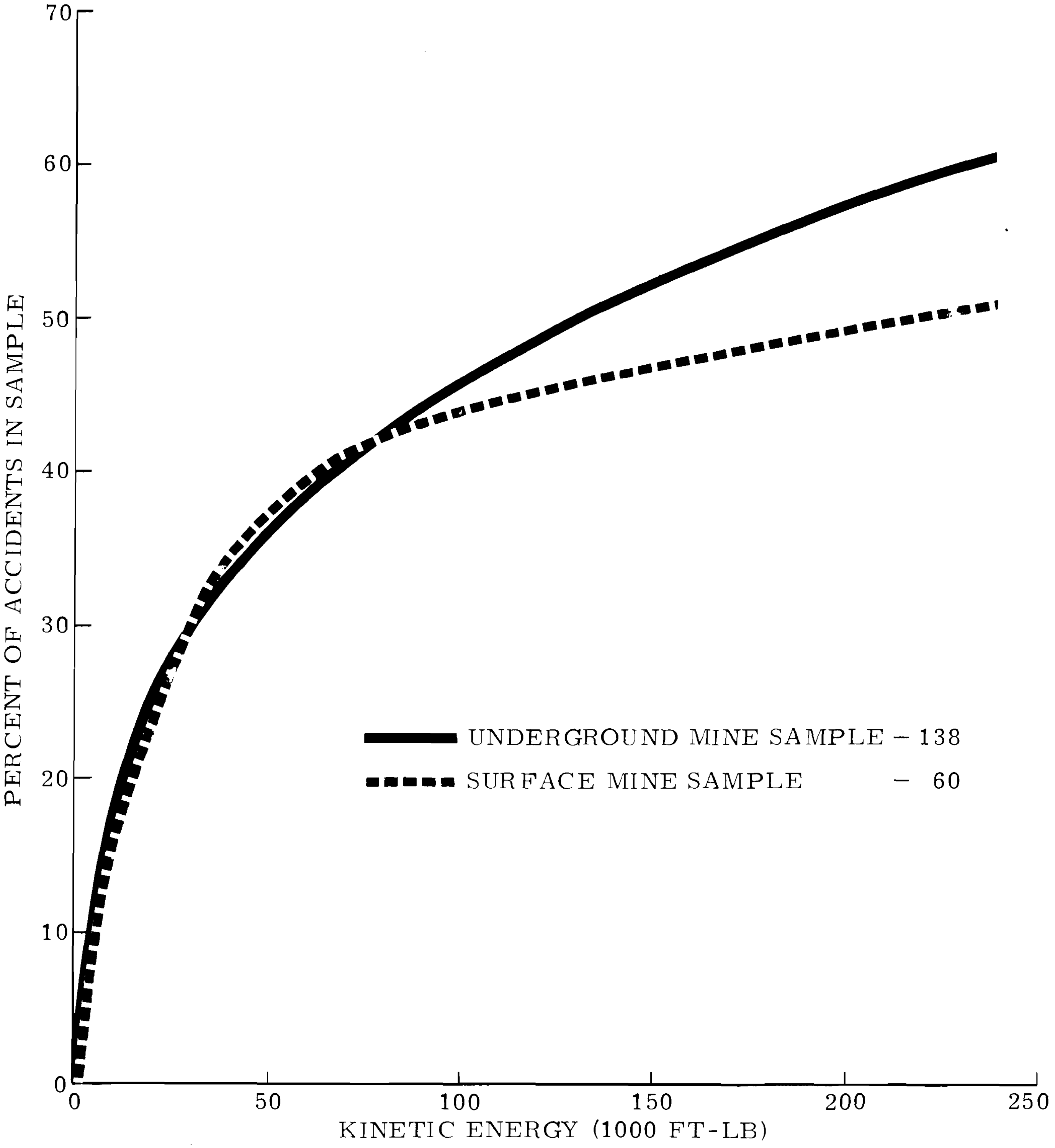


Figure 4-3. Total Rock Fall Kinetic Energy

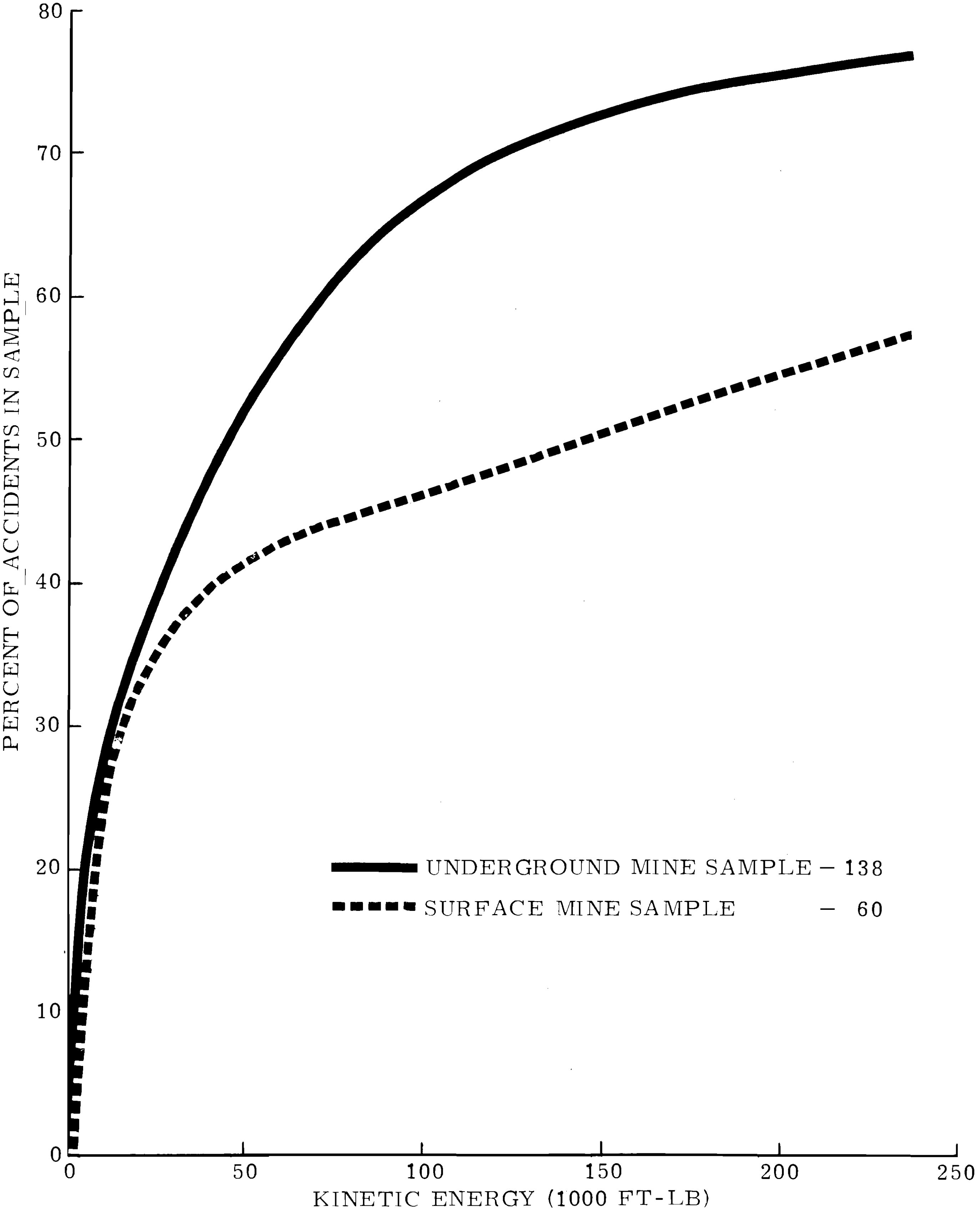


Figure 4-4. Rock Fall Kinetic Energy at FOPS Protection Level

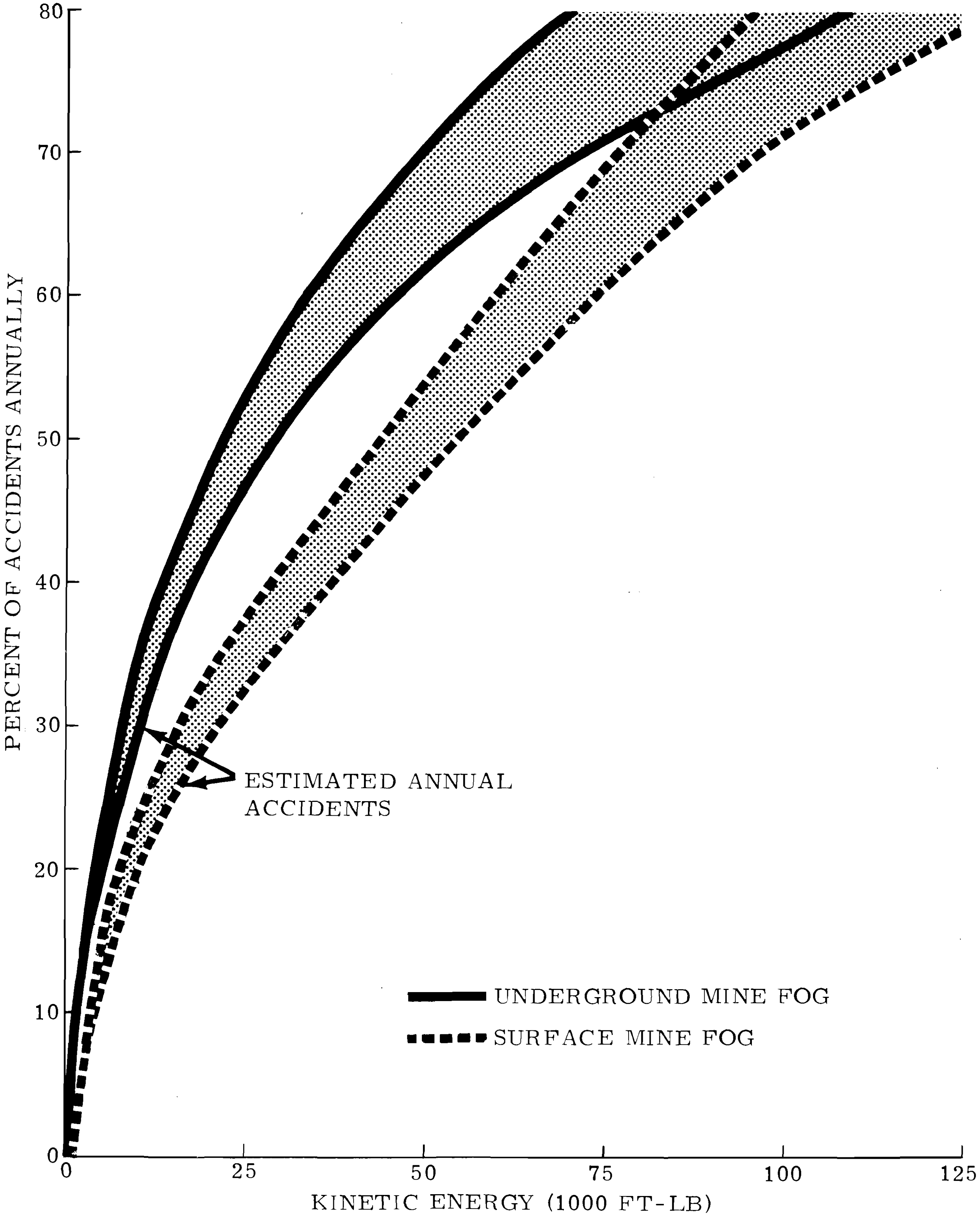


Figure 4-5. Predicted Kinetic Energy at Protection Level – Surface and Underground Mines

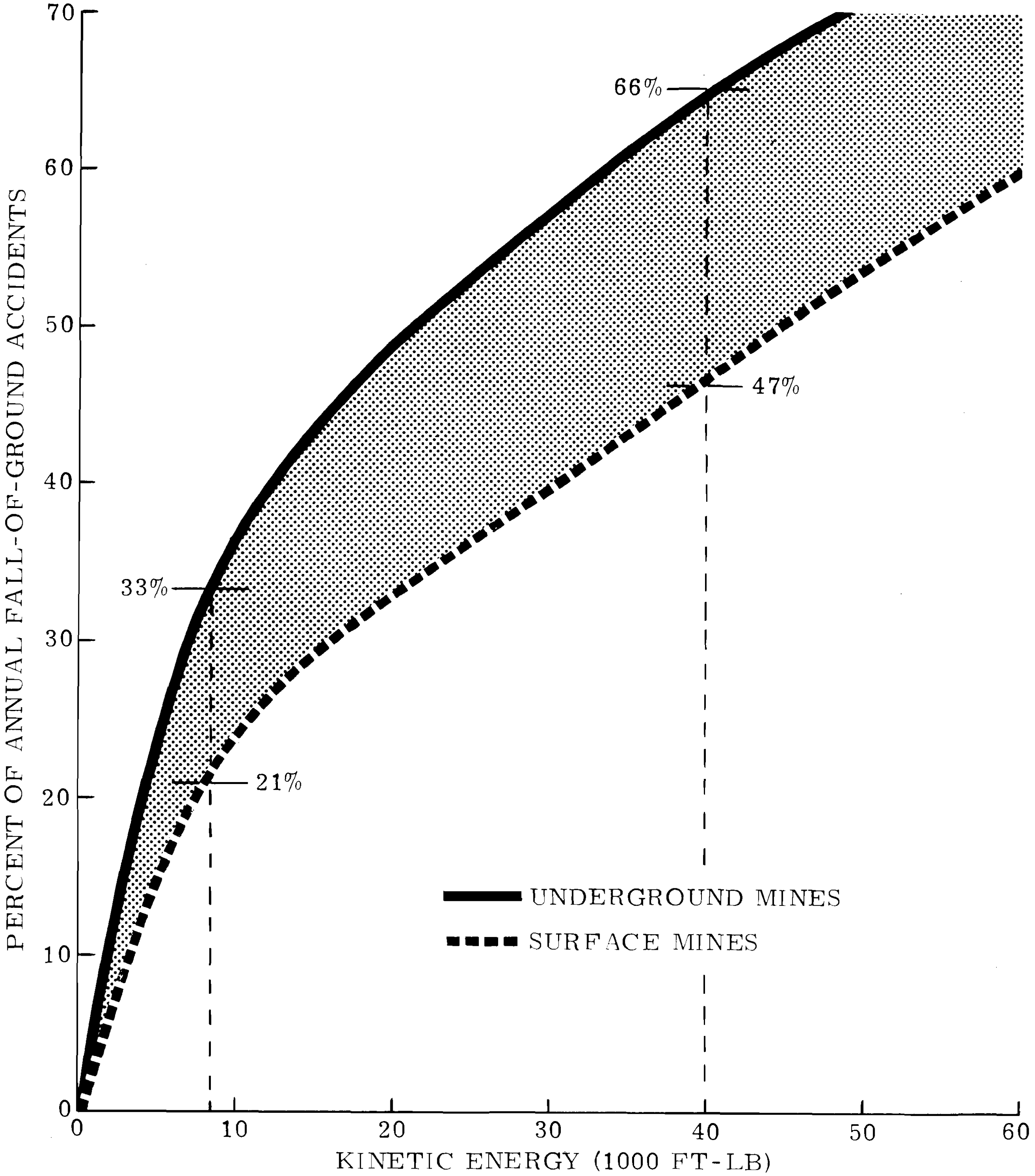


Figure 4-6. Prediction of Kinetic Energy at Protection Level

values and related percentages may be more easily read. Upper limits of the two curve bands from Figure 4-5 were then replotted and the region between them was shaded. The shaded area thus represents the WAI estimates of the distribution of kinetic energy levels in fall-of-ground accidents in any year. The area is bounded on the lower edge by the predicted kinetic energy curve for surface mines and on the upper by the predicted kinetic energy curve for underground mines. The graph may be used as illustrated in the following example (see dashed vertical lines on Figure 4-6):

> If all of the machines of interest were equipped with protective structures capable of transforming 8500 ft-lb of kinetic energy (read 8500 on horizontal axis), protection of the operator in the operator's normal position would be provided for 21% to 33% (read on vertical axis) of the fall-of-ground accidents which occur each year. Likewise, if FOPS capable of transforming 40,000 ft-lb of kinetic energy were installed, protection would be provided in 47% to 66% of the fall-of-ground accidents.

It has been noted by WAI personnel that in many of the MESA accident reports and in many discussions with mine personnel that the rock fall is usually not a single solid section of competent rock that falls. It is often rock that is laced with fissures, cracks, fractures, etc. When it falls this "bad ground", as it is called, is not as a single mass. It drops in pieces or it breaks up immediately upon contact with a resisting force. The energy that is actually transmitted into a FOPS structure may be a small fraction of the expected value based on weight and height measurements. Machines and men have survived rock falls that would seem to possess energy values high enough to destroy anything caught beneath them. It is important that the test procedures prepared for validating the performance of FOPS correctly simulate the characteristics of rock falls in kinetic energy and in state of material. A FOPS test procedure that simulated the rock fall as a large solid competent mass with great structural integrity would be only representing a small portion of the actual rock falls.

Table 4-1 is a summary of some important information which characterizes fall-of-ground accidents.

Table 4-1. Summary Statistics – Fall-of-Ground Accidents

	Surface Mines	Underground Mines
Based on Sample of 198		
Fatal Accidents	19	48
Non-Fatal Injury Accidents	7	26
No Injury Accidents	34	64
Total Accidents in Sample	60	138
Median Fall Distance	24.2 ft	10.0 ft
Mean Fall Distance	35.9 ft	13.7 ft
Median Fall Weight	8,500 lb	12,460 lb
Mean Fall Weight	6,909,890 lb	20,760 lb
Median Protection Level KE	153,000 ft-lb	46,560 ft-lb
Median Protection Level KE, Fatal Accidents Only	99,900 ft-lb	21,975 ft-lb
Based on WAI Estimates of Total Annual FOG Accidents		
Median Protection Level KE	45,000 ft-lb	21,500 ft-lb

FOG = Fall-of-ground

4.2 DEVELOPMENT OF FALLING OBJECT PROTECTIVE STRUCTURE (FOPS) PERFORMANCE CRITERIA

This section describes the various FOPS performance criteria now available to guide the FOPS designer and the test procedures used to demonstrate the attainment of the desired performance. The rockfall kinetic energy data presented in Section 4.1, "Characterization of Rockfalls" are reviewed and approaches to protecting against rockfalls discussed. Structural analysis methods are described which establish the basis for the recommended energy absorption capability requirement for the FOPS. Equivalent static load criteria are developed leading to three alternate methods which are practical for certifying the FOPS.

FOPS Performance Criteria in Use

Several state and federal agencies (including the U.S. Bureau of Mines) have safety regulations in effect that, under certain circumstances, require the installation of a canopy, a FOPS, or some similar structure to provide overhead operator protection. Before addressing possible new requirements for FOPS on mining equipment, the existing regulations should be examined and the level of protection provided assessed. Table 2-3 listed several state and federal agencies that have adopted FOPS regulations and indicated the performance criteria or the design criteria used. As can be seen in that table, in several cases the FOPS is to be "substantial" in construction. The FOPS criteria developed by SAE are mentioned in three of the regulations.

Since canopies have been built and installed on mining and construction vehicles to satisfy these requirements, it is important to understand the relative structural capabilities of FOPS designed to meet these requirements. Table 4-2 illustrates the test requirements for SAE J231 and SAE J167. This table also gives the top load capability of the SAE ROPS criteria and the Corps of Engineers ROPS criteria.

Table 4-2. Falling Object Protective Structure (FOPS) Performance Standards

Performance Standard	Type of Equipment	Kinetic Energy	Test Procedure	Test Type
SAE J231	Crawler tractors, crawler loaders, rubber-tired loaders, motor graders, rubber-tired prime movers, off-highway dump trucks, skid-steer loaders and industrial tractors	8500 ft-lb	A 500 pound shaped steel mass is dropped 17 ft. on to the FOPS top. The impact area must be over the operator area and away from roof structural members.	Destructive Dynamic
SAE J167	Industrial tractors, agricultural tractors	1000 ft-lb	A solid steel sphere weighing 100 pounds is dropped 10 feet. As with J231, the impact area must be over the operator area and away from roof major structural members. A "crush test" is also performed to demonstrate that the canopy can support two times the tractor gross weight.	Destructive Dynamic
SAE J1040a	Same as SAE J231	Strain energy varies with vehicle size	In addition to complying with a side-load requirement, the ROPS must support one times the vehicle gross weight.	Destructive Static
Corps of Engineers	Same as SAE J231		ROPS must comply with SAE J1040a or analytically support a load of two times the vehicle gross weight if not subjected to SAE J1040a test.	Destructive Static
Corps of Engineers	Light industrial tractors	1000 ft-lb	ROPS must also comply with SAE J167	Destructive Dynamic
MESA	Electric face equipment	Approx. 5000 ft-lb	Canopy must elastically support 18,000 pounds or 15 psi, whichever is lesser.	Non-Destructive Static
SAE J334a	Industrial tractors, Agricultural tractors	Strain energy varies with vehicle size	ROPS is struck with pendulum weight (4410 lbs) from both side and rear.	Destructive Dynamic

All vehicles with approved ROPS have top load carrying capability of at least one times the vehicle gross weight and many have substantially greater capability. Gross weights of machines of interest range from a low of 5000 - 6000 pounds for the small industrial tractors up to over 350,000 pounds for the largest front-end loaders. The "built-in" top load capability of ROPS designed for these machines can be assumed to be approximately the same as the gross weight. This fact presents an interesting dilemma. This top load capability is required for ROPS since the machine may come to rest on its top after a roll-over. The ROPS needs to support the vehicle weight to protect the operator from being crushed. It is fairly obvious that many of the structural loads experienced by the ROPS are related or dependent on the machine gross weight. This is not so in a rock fall. There is no direct relationship between the particular machine under a rock fall and the size of the rock fall. Small rocks fall on large machines and large rock falls occur on small machines. And vice versa. The "built-in" structural capability of a machine with ROPS installed will help protect the operator against rock falls but to a much lesser extent in a small machine than a large machine. The following examples illustrate this fact.

Assume that a light industrial tractor is outfitted with a ROPS and that the ROPS has a FOPS capability as required by SAE J167. The rock fall kinetic energy level that this ROPS/FOPS is expected to accommodate is at least the 1000 ft-lb experienced in the SAE J167 falling sphere test. Using the data presented in Figure 4-6 of Section 4.1, it can be seen that a very small percentage of the surface and underground rock falls are expected at this low kinetic energy level. Conversely, a large front-end loader may have a ROPS installed that has a large "built-in" energy absorption capability. If its kinetic energy capability is 50,000 ft-lb then it could be expected to provide satisfactory operator protection in approximately 50% of the surface mine rock falls and about 70% of the underground rock falls. The large difference in kinetic energy absorption capability between ROPS designed for small machines and those ROPS designed for large machines presents a serious problem when considering methods of upgrading the FOPS capability of ROPS that are already installed on machines.

The MESA standard for canopies in underground coal mines is the only regulation that uses a non-destructive static test to demonstrate compliance with the standard. The MESA engineering personnel have devised static test and static analytical analogs of the dynamic performance requirements. The SAE FOPS test procedures use destructive dynamic tests to demonstrate the capability of the FOPS. The SAE ROPS test procedures include both destructive static tests and destructive dynamic tests. Generally, the dynamic tests that expose the FOPS to impact conditions similar to those expected in an actual rock fall are thought to be the best approach to verifying the structural performance of the FOPS. The disadvantage of these dynamic tests is that the FOPS unit and sometimes the vehicle frame are damaged. The cost of the FOPS unit and the vehicle frame must be included in the test cost. A ROPS certification test on a large machine can be very expensive. Costs to certify a ROPS design have been estimated by several equipment manufacturers as shown in Table 4-3. A non-destructive static test would be attractive if a clear derivation from the dynamic situation is advanced.

Development of a New FOPS Performance Criteria

The information presented in Figure 4-6 of Section 4.1 indicates that a FOPS system that could absorb about 50,000 ft-lb of kinetic energy would provide operator protection in about 70% of the rock falls

Table 4-3. ROPS/FOPS Certification Costs

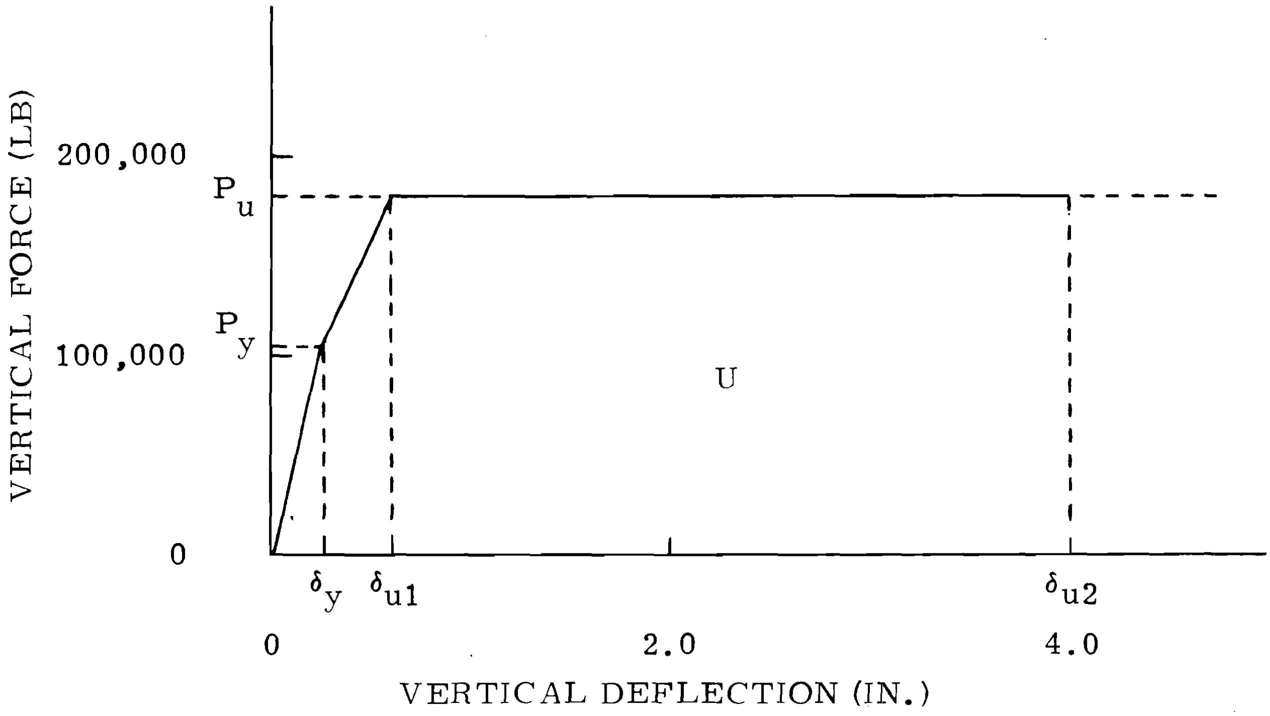
Vehicle Gross Weight	Test Certification Cost
20,000 - 40,000 lb	$ 16,000 - $ 20,000
75,000 - 100,000 lb	$ 25,000 - $ 40,000
150,000 - 200,000 lb	$ 50,000 - $ 75,000
over 200,000 lb	$100,000 - $300,000

experienced in underground mines. To attain protection in 70% of the surface mine rock falls would require a FOPS that could absorb about 75,000 ft-lb. These energy levels are very high compared to the energy absorption requirements of SAE J231 and SAE J167, which are 8500 ft-lb and 1000 ft-lb respectively. The protection afforded through use of FOPS meeting the SAE J231 performance criteria is about 33% of the expected rock falls in underground mines and about 21% of the surface mine rock falls. The protection provided by the SAE J167 FOPS is much lower.

Can FOPS be designed and manufactured to meet the high energy absorption levels necessary to protect operators from the rock falls occurring in metal-nonmetal mines? To attempt to answer this question, WAI has structurally analyzed and examined the energy absorption capability of several representative commercial ROPS.

Description of Structural Analysis Methods

The structural characteristics of representative canopies described in Figure 4-7 and summarized in Table 4-4 were derived using computer aided elastic/plastic analysis methods. The computer program CANOPY, developed by the Bureau of Mines and described in Reference 3, was used extensively to determine elastic force and deformation static response. Plastic behavior was evaluated using the



DEFINITION OF SYMBOLS

P_y = VERTICAL LOAD AT BENDING YIELD STRESS (LB)
δ_y = VERTICAL DEFLECTION AT BENDING YIELD STRESS (IN.)
P_u = MAXIMUM LOAD AT ULTIMATE BENDING STRESS (LB)
δ_{u1} = DEFLECTION AT INITIATION OF MAXIMUM LOAD (IN.)
δ_{u2} = MAXIMUM ALLOWABLE DEFLECTION
U = ENERGY ABSORBED BY ROPS AT 4.0 IN. DEFLECTION (FT-LB)

Figure 4-7. Predicted Vertical Force-Deflection Curve for Representative Canopies (Example: Caterpillar D8 ROPS)

methods and empirical relationships presented in the Reference Section under "Plastic Design Principles". The derivations of each of the parameters presented in Table 4-4 are discussed below.

The yield loads and deflections, P_y and δ_y, were determined from computer analyses using the program CANOPY. A uniform vertical load was applied to all beam members in the plane of the canopy

Table 4-4. Summary of Energy Absorption Calculations for Representative ROPS

Vehicle	ROPS Source	Gross Vehicle Weight (lb)	Yield Load, P_y	Yield Deflection, δ_y	Maximum Load, P_u	Deflection at Maximum Load, δ_{u1}, δ_{u2}		Energy absorption Capability, U
Le Tourneau L-700 Front End Loader	Equipment manufacturer	180,000	487,000	0.027	871,000	0.070	4.000	288,000
Le Tourneau L-700 Front End Loader	Woodward Associates	180,000	294,000	0.576	527,000	1.489	4.000	149,000
Caterpillar D9 Track-Type Tractor	ROPS manufacturer	85,600	96,000	0.288	161,000	0.379	4.000	51,000
Caterpillar 824 Wheel Dozer	ROPS manufacturer	72,300	142,000	0.031	237,000	0.073	4.000	78,000
Caterpillar 988 Front End Loader	ROPS manufacturer	67,000	132,000	0.125	222,000	0.296	4.000	72,000
Gaterpillar D8 Track-Type Tractor	Woodward Associates	62,000	106,000	0.258	177,000	0.603	4.000	55,000
Wagner ST5B Scooptram Load Haul Dump	Mining Company	46,500	74,000	0.115	124,000	0.270	4.000	40,000
Caterpillar 955 Front End Loader (Track-Type)	ROPS manufacturer	30,200	109,000	0.198	182,000	0.331	4.000	58,000
Industrial Tractor (20,000 lb GVW)	Woodward Associates	20,000	47,000	0.684	79,000	1.616	4.000	22,000
Industrial Tractor (5000 lb GVW)	Woodward Associates	5,000	13,000	0.855	21,000	1.907	4.000	6,000

NOTE: See Figure 4-7 for explanation of symbols.

top. The maximum values of P_y and δ_y, were limited to levels corresponding to the bending yield stress allowable at the highest stressed point in the structure. The allowable bending yield stress was obtained by increasing the 36,000 psi normal minimum tensile yield stress of ROPS steels by an appropriate bending modulus of yield factor. The bending modulus of yield factor ranged from 1.16 to 1.28 depending on the shape configuration of the beam bending cross-section. This factor was computed using the methods outlined in the text, "Strength of Materials" by F. Shanley. The deflections presented are for the point on the structure with maximum vertical deformation at the P_y load level.

As shown in Figure 4-7, P_u is the maximum load capability predicted for the canopy and corresponds to the ultimate bending stress allowable of the material. The bending allowable was determined by multiplying the 55,000 psi material minimum ultimate bending strength by a bending modulus of rupture factor. The factor, depending on the cross-section configuration, ranged from 1.27 to 1.50. The deflection, δ_{u1}, was obtained from the force-deflection curve assuming a stiffness between the yield and ultimate load equal to one-half that of the linear elastic portion of the curve.

The deflection over the operator at the center of the canopy was limited to 4.0 inches as depicted by δ_{u2}. In general, the analyses results indicated that the protective structures could deform 7.0 to 8.0 inches before collapsing. However, it was assumed that this amount of deformation was excessive since the canopy top would probably impact the operator's head during a rock fall.

The useful energy absorption capability, U, was determined by computing the total area under the force-deflection curve out to δ_{u2}. This method assumes that all of the kinetic impact energy of the rock fall is absorbed by the elastic-plastic strain energy of the canopy structure. In reality this assumption is conservative since some of the energy is dissipated by the inertia of the canopy members and deformation of the rock fall material.

Energy Absorption Capability

The kinetic energy from a rock fall impacting a protective canopy is absorbed by all of components between the point of impact and the supporting ground. The energy absorption characteristics of several of the important components are discussed below.

1) Protective canopy
2) Vehicle chassis including canopy attachment structure and axles
3) Tires

The results of analyses to determine energy absorption capabilities of protective canopies have been previously summarized in Figure 4-7 and Table 4-4. It is apparent from this table that the predicted energy absorption capability of the ROPS to withstand a vertical impact loading depends generally on the gross weight of the vehicle for which the ROPS was designed. For example, a four-post ROPS designed for the Le Tourneau L-700 front-end loader will withstand 288,000 ft-lb of energy as compared to 6000 ft-lb predicted for a light industrial tractor.

As discussed previously the assumptions used in these analyses were as follows:

1) The rock fall is not of competent rock. The fall energy is transmitted into the ROPS structure as a uniformly distributed load.

2) Maximum deflection of 4 inches is permitted over the operator's head.

3) Material properties of the ROPS steel are 36,000 psi yield and 55,000 psi ultimate.

The energy absorption capability also depends on the configuration of the ROPS design. As shown in the table, a two-post ROPS and a four-post ROPS for the Le Tourneau L-700 front-end loader were evaluated. Energy absorption capabilities of 149,000 ft-lb and 288,000 ft-lb were predicted for the two and four-post designs, respectively. By looking at this comparison, one could reach the conclusion that a four-post configuration is a much better energy absorber. In fact, however, the opposite is probably true. As presented in Table 4-4, the more rigid four-post ROPS reaches a maximum force of 871,000 lb while the two-post maximum load limit is 527,000 lb. To illustrate the comparison in another way, the predicted energy absorption of the four-post design at the 527,000 lb maximum distributed load level shown for two-post ROPS is only 800 ft-lb. The high energy absorption capability of the four-post ROPS (288,000 ft-lb) is realized at very high load levels.

This example and the information shown in Table 4-4 for other representative ROPS demonstrates two important points:

1) A rigid type ROPS generally has the greatest total energy absorption capacity. ROPS designed for large gross vehicle weight machines and four-post configurations usually have these characteristics.

2) A flexible ROPS minimizes the load being transmitted into the vehicle frame. Two-post configurations and ROPS designed for small vehicles are examples of flexible units.

These points constitute an important basis for ROPS/FOPS designs. A configuration which is too flexible or soft will deform into the operator protection zone under vertical impact loading from a rock fall and crush the operator. An extremely soft ROPS/FOPS system is therefore obviously inadequate. Although it is not so immediately apparent, a canopy which is too stiff can also be unacceptable since it introduces other possible failure modes. The cause of the problem, as discussed previously, is that the vertical distributed load must be very high to absorb the kinetic energy of the rock fall. This load must be transferred to the vehicle frame through an attachment joint and an attachment structure. The ROPS is usually bolted to the attachment structure which is welded to the vehicle frame. Bolted and welded joints are the most common source of structural failures. Therefore, a balanced ROPS/FOPS design is required which is flexible enough to limit the load going into the attachment structure, but is sufficiently rigid to withstand the impact loads and limit the deflection to acceptable limits for the operator.

The energy absorption capability of the vehicle chassis and related components is very difficult to determine accurately. It is apparent that the vehicle frame contribution is very different for an industrial tractor with the canopy mounted to the trumpet housing and for a front-end loader with the canopy attached a considerable distance from the axles. In the case of the small tractor chassis, very little energy is absorbed in the vehicle frame since loads are transmitted almost directly into the tires. In contrast, vehicles with canopies installed to members with long lengths loaded in bending will deform appreciably and absorb a considerable amount of energy. Many canopies are mounted on fenders and fender support brackets which also deform quite easily.

Since vehicle configuration and mounting location vary widely, definitive energy absorption capabilities were not obtained. It is safe to assume, however, that some energy is absorbed in all installations. For example, bolted joints overcome frictional resistance and slip to take up dimensional differences between the bolt and the bolt-hole. Experience gained by Woodward Associates personnel while witnessing numerous ROPS/FOPS tests has shown that a considerable amount of energy is absorbed by most vehicle frames.

The energy absorption characteristics of tires were evaluated. The results indicated that large amounts of energy can be absorbed. The curve, Figure 4-8, shows the capability of representative tires for wheeled dozers, motor graders and front end loaders as a function of gross vehicle weight. Tires on a large vehicle, such as the 180,000 lb Le Tourneau L-700 front-end loader, can absorb approximately 400,000 ft-lb of energy. The tires on the Caterpillar 112F motor grader, a 21,600 lb vehicle, can withstand 33,000 ft-lb.

The Caterpillar 988 front-end loader with a gross weight of 67,000 lb will be used as an example to describe the methods used to determine tire capability. The assumptions used in the evaluations were as follows:

1) The total impact loading is reacted by two tires. This assumption is conservative since on most vehicles and canopy installations at least 25% of the force will be transferred to the other two tires.
2) The tire will withstand the maximum load as rated by the manufacturer at the recommended operating pressure. The tires should actually withstand higher loads because the manufacturer utilizes a design safety factor.

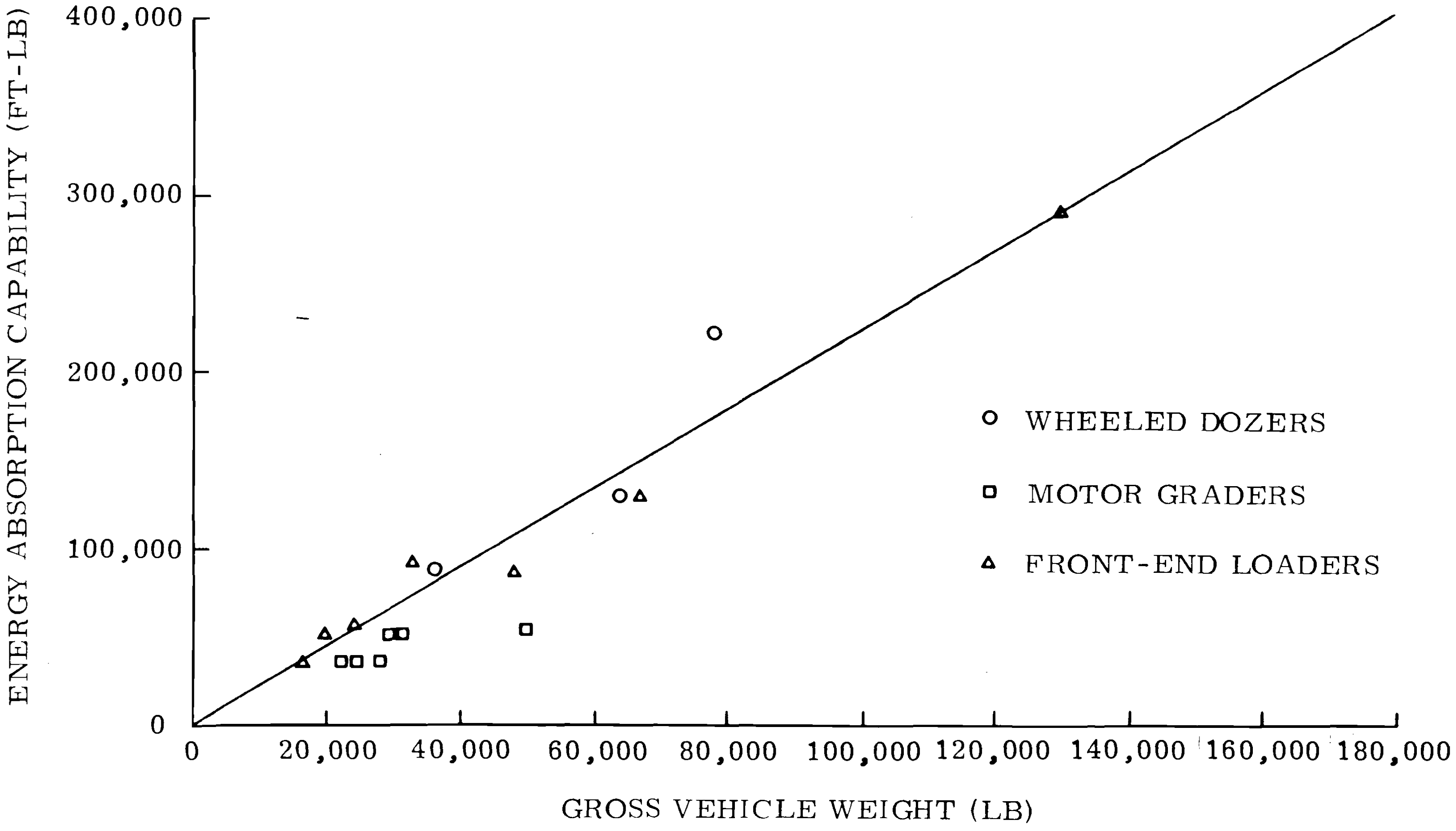


Figure 4-8. Energy Absorption Capability of Representative Tires

3) The force remains constant until the tire is compressed. The force would actually increase due to the decreased volume and increased pressure. The pressure increase is not sufficient to burst the tire.

4) The tire does not fail until it deflects to the rim.

Therefore, for the Caterpillar 988,

Gross vehicle weight - 67,000 lb
Tire diameter - 73.0 in.
Tire size - 26.5-29
Load rating - 34,860 lb
Deflection to rim - (73.0 - 29.0) ÷ 2 = 22.0 in.
Energy absorption capability - (34,860)(22.0) ÷ 12 = 63,900 ft-lb

All of the parameters used in the evaluation of the energy absorption capability of tires appear to be conservative. The range of predicted capability between 33,000 and 400,000 ft-lb is therefore realistic.

It should be noted that tracked vehicles, as a class, can not take advantage of the large energy absorption capability of tires. The configuration of a tracked vehicle does permit some deformation, but the magnitude is very small compared to a rubber-tired vehicle.

A summary of the range of energy absorption capabilities for a typical vehicle and FOPS is shown pictorially in Figure 4-9. The predicted range for the protective canopy under a uniformly distributed top load is 6,000 to 288,000 ft-lb. Predicted levels for the vehicle chassis and canopy attachment structure are not included, even though they are significant, since the magnitudes vary widely due to configuration. The contribution of tires for a rubber-tired vehicle is 33,000 ft-lb to 400,000 ft-lb depending on the gross weight of the vehicle. The energy capability of the tires is not included in the criteria development leading to the 40,000 ft-lb FOPS energy capability.

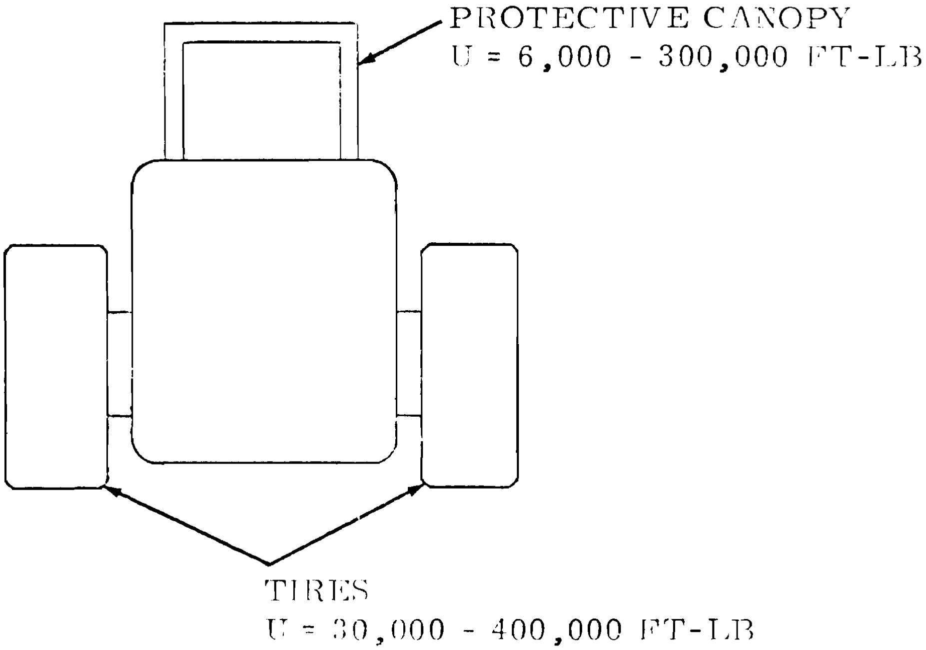
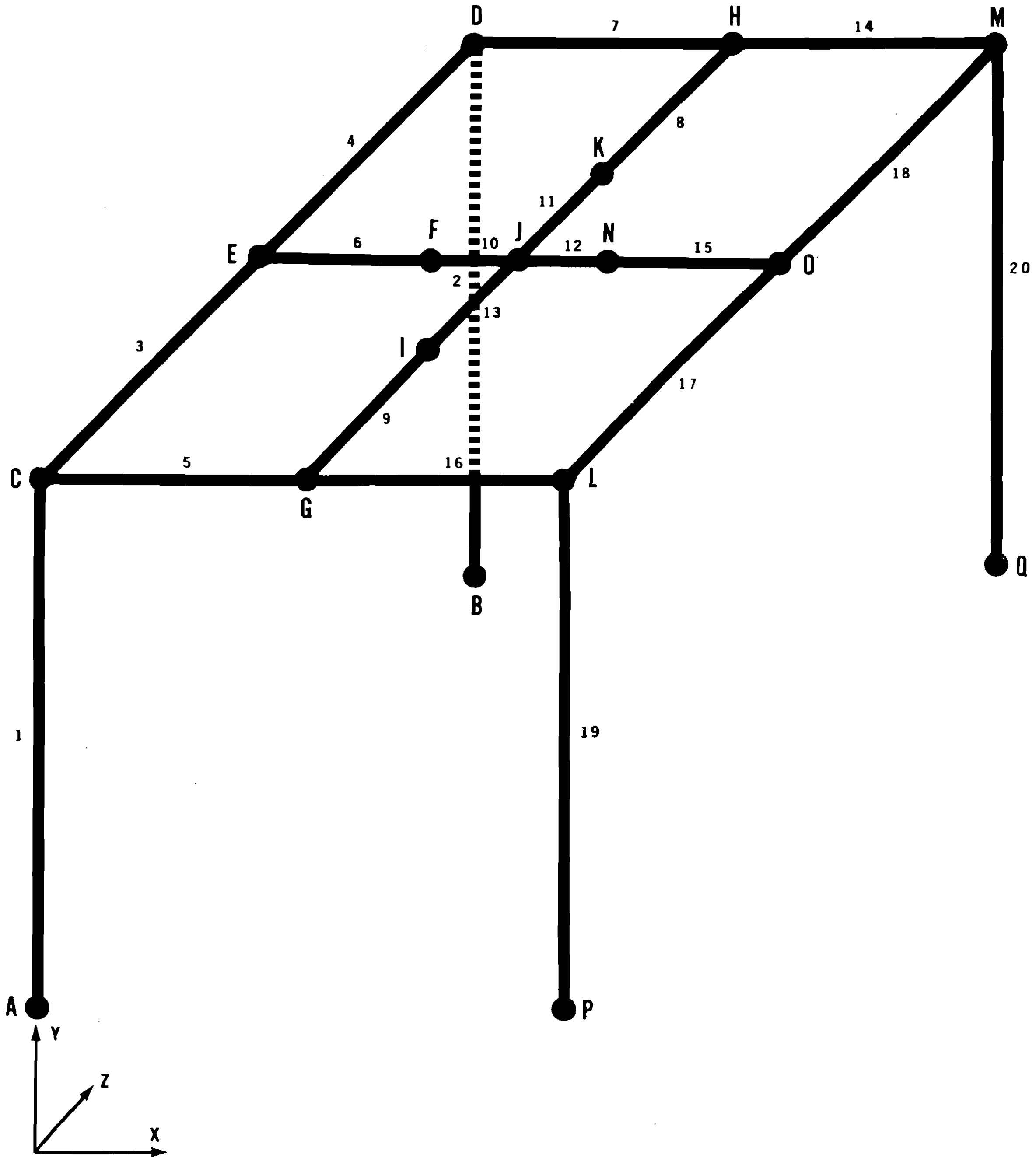


Figure 4-9. Energy Absorption Capability of Vehicle Equipped With Protective Canopy

Non-Uniform Loads

It should be emphasized that all previous discussions of energy absorption capability were based on the assumption of a uniformly distributed force application over the plan view area of the canopy top. The energy absorption capability is very different for other loading assumptions. Figure 4-10 and Table 4-5 summarize the structural capability of a representative FOPS for the Caterpillar D8 tractor under various loading conditions. Rock falls matching these loading condition



LEGEND: LETTERS REFER TO JOINTS.
NUMERALS REFER TO BEAMS.

Figure 4-10. Caterpillar D8 Tractor ROPS/FOPS Structural Model

Table 4-5. Energy Absorption Capability Predictions for the Caterpillar D8 Tractor ROPS/FOPS Under Non-Uniform Loading Conditions

Load Application	Direction	Yield Load, P_y	Yield Deflection, δy	Maximum Load, P_u	Deflection at Maximum Load, δ_{u1}, δ_{u2}		Energy Absorption Capability, U
Beams 3 thru 16 (distributed load-top)	-Y	106,000	0.258	177,000	0.603	4.000	55,000
Beams 10, 11, 12, 13 (center ninth load-top)	-Y	52,000	0.320	87,000	0.751	4.000	27,000
Joint J (point load-top)	-Y	36,000	0.274	71,000	0.807	4.000	22,000
Beams 3, 4 (distributed load-top)	-Y	70,000	0.228	117,000	0.604	4.000	37,000
Beams 5, 16 (distributed load-top)	-Y	75,000	0.216	125,000	0.504	4.000	39,000
Beams 16, 17 (distributed load-top)	-Y	61,000	0.138	102,000	0.324	4.000	33,000
Joint G (point load-top)	-Y	30,000	0.148	51,000	0.355	4.000	16,000
Joint E (point load-top)	-Y	28,000	0.188	47,000	0.443	4.000	15,000
Joint C (point load-top)	-Y	162,000	0.074	—	—	—	500
Beams 5, 16 (45° load)	-Y +Z	27,000 27,000	0.070 0.400	45,000 45,000	0.163 0.933	4.000 4.000	29,000
Joint L (45° corner load)	-X -Y +Z	14,000 14,000 14,000	0.222 0.004 0.204	23,000 23,000 23,000	0.507 0.009 0.466	4.000 4.000 4.000	22,000
Beams 5, 16 (side load)	+Z	31,000	0.461	51,000	1.056	4.000	17,000

NOTE: See Figure 4-7. for explanation of symbols and Figure 4-10. for beam and joint identification numbers.

assumptions are possible, but as discussed in Section 4.1, the majority of rock falls more closely correspond to the distributed load assumption. Therefore, the fully distributed loading model was used throughout the report as the basis for establishing recommended certification procedures and is repeated as the first loading condition shown in the table.

A review of the table shows that the distributed load condition has the highest predicted energy absorption capability. However, the predictions for other loading assumptions are probably somewhat conservative since as the canopy is overloaded and begins to collapse the load starts to redistribute over a greater area of the canopy top.

The most severe condition is the concentrated loading on the corner of the canopy over the support column as depicted by the joint "E" loading condition. A competent rock striking the corner of the canopy is simulated by this condition. The predicted energy absorption capability is only 500 ft-lb. This value is derived by limiting the stress in the column to the tensile yield allowable of the material. Significantly higher loads would result in buckling of the column and some possible load distribution. The energy absorption capability would therefore increase. Also, it should be noted that this condition in most cases represents a small rock fall.

The fall of a large competent rock that bridges between the upright columns must be analyzed in a manner similar to that described above. Four columns are available to react the load. A conservative prediction of the energy absorption capability would be approximately 2000 ft-lb. The predicted level is very low since the center portion of the canopy top does not deform appreciably. The columns must buckle before significant energy will be absorbed. The distribution of load and behavior of the canopy structure during a buckling failure is very unpredictable and difficult to evaluate. As shown in the table, the load in each column would reach 171,000 lb or more. It is very difficult to design attachment structures to withstand loads of this magnitude.

Several examples of angular applied loads are included in the table. A 29,000 ft-lb capability is predicted for a 45 degree load applied to the two beams along the side of the canopy top. The canopy will absorb 22,000 ft-lb if a rock strikes the top corner at an angle of 45 degrees. The energy absorbed for a distributed side load is 17,000 ft-lb at a deflection limit of 4.0 inches.

Some of the different load inputs reviewed above are similar to the conditions that might be expected in vehicle-object collisions, vehicle-roof impacts, vehicle-rib impacts, and other side impact accidents. If performance criteria for side impact capability of FOPS were to be developed, these types of loads would have to be considered.

Development of Static Load Criteria

Establishing a static load criterion which gives confidence that a ROPS/FOPS structure will absorb a specified kinetic impact energy is an extremely difficult task requiring many assumptions. A rigorous analytical method of establishing the analogy between static loading and dynamic impact loading was not established. However, analyses were conducted on several representative canopies to develop a reasonable and practical static load criterion. The approach required determining the energy absorption capability of representative ROPS/FOPS structures, computing the yield strength under a distributed uniform top loading, and comparing the latter value with the decreased yield allowable of the structure when subjected to a distributed load over the middle ninth of the plan view area of the canopy top. The results indicated that a structure which can withstand a static load of 74,000 lb uniformly distributed over the plan view area of the canopy top without yielding will be capable of absorbing at least 40,000 ft-lb of kinetic energy.

The 40,000 ft-lb energy absorption requirement was established because it represented a level which could be accommodated by the majority of ROPS/FOPS structures for vehicles under consideration, and because it would provide operator protection for a significant number of rock falls. A review of Table 4-4 shows that vehicles with gross weights ranging from 30,200 lb to 180,000 lb have ROPS with energy absorption capabilities of 40,000 to 288,000 ft-lb. Since these ROPS are representative of existing units within this weight range, it is expected that very few design modifications will be needed to meet these structural requirements. Therefore, the cost of ROPS manufactured to present standards should not have to be significantly increased to meet the 40,000 ft-lb energy absorption requirement.

An energy absorption capability of 40,000 ft-lb will give protection in at least 47% of the rock falls in surface mines and 66% of the rock falls in underground mines as shown in Figure 4-6. This represents protection for over twice the rock falls covered by meeting the SAE J231 requirements.

However, as stated previously, the 40,000 ft-lb energy absorption capability is limited to vehicles with gross weights above 30,000 lb. This lower limit does not appreciably reduce the predicted protection percentages as the value was established primarily for three reasons:

1) A study of the accident statistics shown in Table A5-13 indicated that approximately 70% of the vehicles involved in rock fall accidents had gross vehicle weights above 30,000 lb.

2) The survey of equipment population showed that over 60% of vehicles had gross weights above 30,000 lb.
3) It is believed that the heavier vehicles are generally more subject to rock fall exposure because of their work function.

Selecting a limit below 30,000 lb would actually result in lower overall operator protection from rock fall. The reduction in protection level would occur because the lighter vehicles can not withstand the 40,000 ft-lb energy requirement or the analogous static load requirements. Therefore, the requirement would have to be reduced. Lowering the 40,000 ft-lb specification would result in lighter ROPS/FOPS structures being put on larger vehicles which are more numerous and accident prone. Alternate performance criteria are recommended for vehicles with gross weights under 30,000 lb.

The minimum predicted yield load, P_y, for canopies with energy absorption capabilities above 40,000 ft-lb as shown in Table 4-4 is 74,000 lb. This value represents the distributed load which can be applied over the entire plan view area of the ROPS top without causing yielding. A unit with a yield load capability of 74,000 lb or greater and fabricated with a high elongation material will have sufficient reserve ultimate load and deflection capacity to absorb at least 40,000 ft-lb of elastic-plastic strain energy. Loads below 74,000 lb will not cause permanent deformation of the ROPS/FOPS.

Any static load criterion must therefore induce stresses in critical areas of the protective structure which correspond to stresses induced during a 74,000 lb distributed load over the entire top. Obviously, a test or analytical procedure with a distributed load meets this requirement. Sometimes it is very difficult to accurately apply a uniformly distributed load over a large area. Therefore, alternate approaches were considered.

The groundrule for establishing the load level for alternate approaches is that stresses in critical areas of the structure must duplicate stresses imposed during a 74,000 lb load application distributed over the entire canopy top. Table 4-6 shows a comparison of yield load and deflection for a four-post ROPS configuration for the Caterpillar D8 tractor. A 106,000 lb yield load is predicted for the distributed load condition over the entire plan view area of the ROPS top. The corresponding yield prediction for a distributed load over the middle ninth of the plan view area is 52,000 lb. By using this relationship, a yield prediction of 36,000 lb is obtained for a four-post unit with a center ninth loading ($\frac{52,000}{106,000}$ X 74,000 = 36,000). Therefore, the stresses at critical points in the protective structure are equivalent for the 74,000 lb fully distributed load and the 36,000 lb load over the center ninth of the top.

This relationship appears to be valid for typical four-post configurations since the more concentrated loading produces higher stresses in the structure. The relationship does not hold for two-post ROPS. In this case the critical stress is located along the entire support column and is not affected by changing the top loading from fully

Table 4-6. Yield Predictions for the Caterpillar D8 Tractor ROPS/FOPS

Loading Condition	Yield Load, P_y	Yield Deflection, δ_y
Distributed load over entire plan view area of ROPS top	106,000	0.258
Distributed load over middle ninth of plan view area	52,000	0.320

distributed to concentrated within the middle ninth area. In either case, the effective bending moment is one-half the length of the ROPS top overhang. Two-post configurations must therefore withstand a static yield load of 74,000 lb and can be applied as fully distributed or concentrated within the middle ninth of the top area.

Vehicles with gross weights under 30,000 lb must be covered by special performance criteria. As shown in Table 4-4, all ROPS for vehicles in this weight class can not withstand a 74,000 distributed top load without yielding. The predicted yield loads for representative ROPS for the 5000 lb and 20,000 lb industrial tractors are 13,000 lb and 47,000 lb, respectively. Since small vehicles are exposed to some rock falls, it is recommended that they be equipped with "substantial" canopies. The structural capability of these designs should be consistant with the capability of the vehicle frame structure near the attachment location.

A summary of recommended static load criteria is shown in Table 4-7. As depicted in the table, FOPS which can successfully withstand these static loads will be capable of absorbing 40,000 ft-lb of kinetic energy from a rock fall.

Certification Procedures

A valid certification procedure must demonstrate the capability of FOPS installed on vehicles with gross weights above 30,000 lb to absorb 40,000 ft-lb of kinetic energy with a distributed force applied to simulate a non-competent rock fall impacting the entire plan view area of the FOPS top. Vehicles with gross weights less than 30,000 lb must meet the same requirements or demonstrate that a "substantial" canopy has been provided with a capability consistant with the capability of the vehicle frame.

Table 4-7. Summary of Static Load Criteria

Gross Vehicle Weight	FOPS Design Configuration	Distributed Top Load	Center Ninth Top Load	Energy Absorption Capability
>30,000 lb.	Four-post	74,000 lb.	36,000 lb.	>40,000 ft.-lb.
	Two-post	74,000 lb.	74,000 lb.	>40,000 ft.-lb.
<30,000 lb.	All	Maximum level consistent with vehicle frame capability	Maximum level consistent with vehicle frame capability	Depends on vehicle frame and tire capability

Several certification procedure alternates are described in Table 4-8. It is apparent that a drop test with non-competent material very closely simulates the actual conditions of the recommended rock fall requirement. Although this test is practical as a controlled experiment, it does not appear feasible as a widely used certification test. The test would be difficult to conduct and costly due to the special requirement of non-competency of the drop weight and the destruction of the canopy and vehicle frame.

The other methods described in the table are further removed from the conditions of an actual rock fall. The drop test with competent material, the pendulum test, and the energy absorption static test all demonstrate energy absorption capability. However, these three tests do not match the loading distribution application of a non-competent rock fall. Some members of the canopy are therefore overloaded while others are underloaded. This leads to a condition which does not completely demonstrate the capability of all individual members within the FOPS structure. A disadvantage of all of these tests is that they are destructive to the test specimen.

The elastic/plastic computer analysis method, as described in Appendix A2, is a good simulation of the actual rock fall. (The procedure is currently being evaluated by SAE as an alternate to the SAE J1040a side load energy test for ROPS). However, this certification method has disadvantages of high computer costs, complex input requirements for the analyst, and the need for a large computer which is not widely available.

Woodward Associates has recommended the elastic load static test, the elastic computer analysis, or the engineering analysis approach as the alternate procedures for certification. These procedures appear

Table 4-8. Certification Procedure Alternatives

Certification Method	Description	Advantages	Disadvantages
Drop Test (noncompetent material)	o Weight dropped on FOPS top o Product of weight and height equal to 40,000 ft-lb o Weight must cover entire plan view area of top o Weight comprised of noncompetent material which simulates a uniform load application o Maximum deflection of 4.0 in. permitted during test	o Excellent simulation of actual rockfall o Minimum instrumentation required o Test simple to perform	o Destructive o High hardware and test cost o Difficult to obtain drop weight which meets requirements
Drop Test (competent material)	o Same as above except weight is of competent material which does not deform during test	o Test simple to perform o Minimum instrumentation required	o Destructive o High hardware and test cost o Not always a realistic simulation of actual rockfall, overloads support columns, underloads roof members
Pendulum Test	o FOPS top struck with pendulum weight o Energy input of 40,000 ft-lb required o Weight must cover entire plan view area of top o Weight is of competent material o Maximum deflection of 4.0 in. permitted during test	o Better control of weight during test o Minimum instrumentation required	o Destructive o High hardware and test cost o Not always a realistic simulation of actual rockfall, overloads support columns, underloads roof members o Requires complex tie-down configuration with vehicle on side
Static Test (energy absorption)	o Load applied over center ninth of FOPS top o Area under force-deflection curve (energy) must reach 40,000 ft-lb before exceeding 4.0 in. of deflection	o Analogous to SAE J1040a side load energy test o Demonstrates energy absorption capability o Better control than with dynamic test since test can be stopped if problem develops	o Destructive o High hardware cost o Not a realistic simulation of actual rockfall, overloads roof members
Static Test (elastic load)	o Load of 36,000 lb applied over center ninth of FOPS top o Permanent deflection can not exceed 10% of deflection measured during test	o Non-destructive o Low test hardware costs o Analogous to MESA test for canopies on electric face equipment	o Does not simulate actual rockfall o Requires force and deflection measurements
Computer Analysis (elastic/plastic)	o Product of force and deflection must equal 40,000 ft-lb o Plastic deflection can not exceed 4.0 in.	o Good simulation of drop test with noncompetent material o No hardware or test cost	o High computer and analyst cost o Requires experienced analyst o Possibility of erroneous results o Large computer core requirements o Requires large computer which is not widely available
Computer Analysis (elastic)	o Load of 74,000 lb uniformly distributed over entire plan view area of FOPS top o Stresses can not exceed yield allowable of material	o No hardware or test cost o Analogous to MESA analysis method for canopies on electric face equipment o Can use simple computer program such as CANOPY o Can be run on many types of computers o Relatively easy to input	o Does not simulate actual rockfall
Engineering Analysis (non-computer)	o Load of 74,000 lb uniformly distributed over entire plan view area of FOPS top or 36,000 lb over center ninth of top o Stresses can not exceed yield allowable of material	o No hardware or test cost o Analogous to MESA analysis method for canopies on electric face equipment o No computer required	o Does not simulate actual rockfall o Validity of results are sensitive to experience of analyst

to have the best balance between reasonably demonstrating the ability of the FOPS structure to meet the 40,000 ft-lb energy absorption requirement and being practical to conduct as a widely used certification method.

Methods of conducting the elastic load test are described in detail in Appendix A3. The test requires applying a 36,000 lb force within the center ninth of the canopy plan view top. The permanent deflection remaining after the test can not exceed 10% of the maximum deflection measured during the test. Two testing procedure options are specified in Appendix A3. The first includes a static test of the entire FOPS including protective canopy, attachment joints, vehicle chassis and axles. The second option includes testing of some of the FOPS components or the canopy alone with the remainder of the components being certified with engineering calculations or by meeting certain specified and required design guidelines.

An elastic computer analysis, the second recommended certification procedure, is described in Appendix A2. Several computer programs were compared and the program CANOPY was selected as the best approach. It is recommended that the program be modified by adding a plate element and a beam buckling prediction before using it as a certification procedure. With this method, a load of 74,000 lb is input as a uniformly distributed load over all of the beam members in the canopy top. The resulting stress output can not exceed the yield stress of the material.

Guidelines for the engineering analysis certification procedure are included in Appendix A2. With this method a non-computer analysis is conducted for a 74,000 lb load distributed over the entire canopy top or a 36,000 lb load over the center ninth of the plan view area.

Maximum predicted stresses at critical points in the structure must not exceed the material yield stress allowable. Calculations based on sound engineering principles are acceptable. Guidelines are included in the Appendix A2 to aid the analyst. Approaches for analyzing the canopy top plate, checking for buckling of the support columns, analyzing two post configurations and evaluating combined stresses to determine safety factors are included.

Several other requirements must be met with each of the three recommended certification procedures. As specified in Appendix A1, the FOPS must meet material, welding, and impact resistance requirements in addition to static load/deflection criteria. The material in the canopy must meet ductibility requirements as specified by Charpy V-notch impact strength standards. The Charpy impact test measures the energy absorbed in fracturing a notch specimen that has been prepared according to definite standard dimensions and is supported at both ends in a standard manner. All bolts used in structural applications must be SAE Grade 5 or 8. All welding on the canopy and attachment structure to the vehicle must be in accordance with the "Specification for Welding Rollover - Falling Object Protective Structures (ROPS and FOPS)" currently being prepared by the American Welding Society's D14h Subcommittee.

4.3 EQUIPMENT POPULATION

This section is a summary of the work done with respect to defining the population of the "machines of interest" and estimating the characteristics of that population. The characteristics included machine age, ROPS installation status, size of fleet and others.

Sources of Population Information

The machine data were obtained by means of a survey of metal and nonmetal mines. The sample to be surveyed was selected from a listing provided by the MESA Health and Safety Analysis Center (HSAC) in Denver. The list was in two parts. One part was formally entitled "Surface Metal-Nonmetal Mines Reporting to Mining Enforcement and Safety Administration in 1974," the second was "Underground Metal-Nonmetal Mines Reporting to Mining Enforcement and Safety Administration in 1974." The total number of mines listed, less those which were deleted by WAI because they were mines which would receive accident questionnaires, was 7369. (See Appendices A4 and A5 for survey background.) The very cooperative MESA people also provided a second type of listing. It was entitled "Metal-Nonmetal Mine Reference File." It had an effective date of August 8, 1975. The file showed the most recent MESA inspection date for each mine, the number of employees, and other information which indicated that some mines were not presently active. The file included some details about mine locations, but not about company or mine mailing addresses. Some cross-checking of the two listing types led to the conclusion that the HSAC lists could be used as the frame for survey sample selection. The HSAC list, although not a complete listing of active mines, and therefore not a complete frame, was judged to be a satisfactory surrogate for a complete frame. (A more detailed discussion of the survey matters, including frame considerations, is contained in

Appendix A4.) The total number of active mines in the mine reference file was 13,969.

Table 4-9 shows the number of mines from the HSAC list which were selected for the survey sample. The HSAC list was arranged by state. The sample selection method used was systematic sampling, that is, every kth item was selected with a random start. In the case of underground mines, the value used was k = 4. For surface mines, the value was k = 8. A greater proportion of underground mines was selected because review of the MESA accident investigation reports showed that fall-of-ground accidents were much more frequent in underground mines. Accordingly, it was desirable to obtain a more precise estimate of the machines of interest used in underground mines and, because the survey

Table 4-9. Composition of Survey Sample (Equipment Survey)

Mine Class	Number of Mines on HSAC List	Number of Mines Selected for Sample	Sampling Ratio
Underground (RS-U)	444	111	1/4
Open Pit (RS-O)	1441	182	1/8
Crushed Stone (RS-C)	2320	291	1/8
Sand and Gravel (RS-S)	3164	396	1/8
TOTAL	7369	980	13/100

form also asked for information on no-injury accidents, to obtain a larger sample from underground mines than using k = 8 for all mines would produce.

The survey response rates varied from 45% for crushed stone mines to 73% for underground mines. (The details of responses, follow-up actions and final response rates are in Appendix A4.) The size of the survey response in relation to the total number of mines, rather than to the number sampled, is shown in Table 4-10. The overall percentage of responses relative to the mines on the HSAC list was 7.5%; relative to Mine Reference File, it was 4%. That is, the inferences drawn concerning machine population are based on a modified random sample of 4% of the total active metal-nonmetal mines in the U.S. The inferences drawn concerning machine population in underground mines are based on a modified random sample of about 12% of those mines.

Every state is represented in the total sample. To assure that this would be so was one of the several reasons for using systematic sampling. (In Appendix A4 there is a table which shows the sample and response numbers for all states and for the four mine type classifications.) In addition to the responses from the survey sample, there were 81 machine data responses received with the accident history (AH) questionnaires. These were recorded separately from the survey sample. They were not used directly in making inferences about the machine population and sub-populations, but they were employed in various statistical comparisons. In short, they were treated as results of an entirely separate convenience sample.

The estimate of the total population of machines of interest in metal-nonmetal mines is shown in Figure 4-11. The number 49,293 is

Table 4-10. Responses as Percentage of Total Metal-Nonmetal Mines

Survey Mine Type Classification	Number on MESA "Mine Reference File"	Number on HSAC List	Number of Responses to Cut-Off	Responses as Percentage of Mine Reference File Number	Responses as Percentage of HSAC List Number
RS-U	668	444	81	12.1%	18.2%
RS-O	1,756	1,441	126	7.2%	8.7%
RS-C	4,029	2,320	132	3.3%	5.7%
RS-S	7,536	3,164	216	2.9%	6.8%
Total	13,989	7,369	555	4.0%	7.5%
Plus AH Responses			81		
TOTAL			636	4.5%	8.6%

Key: Random sample (RS) mines:

RS-U = Underground

RS-O = Open Pit

RS-C = Crushed Stone

RS-S = Sand and Gravel

AH refers to those mines which received "accident history" questionnaires.

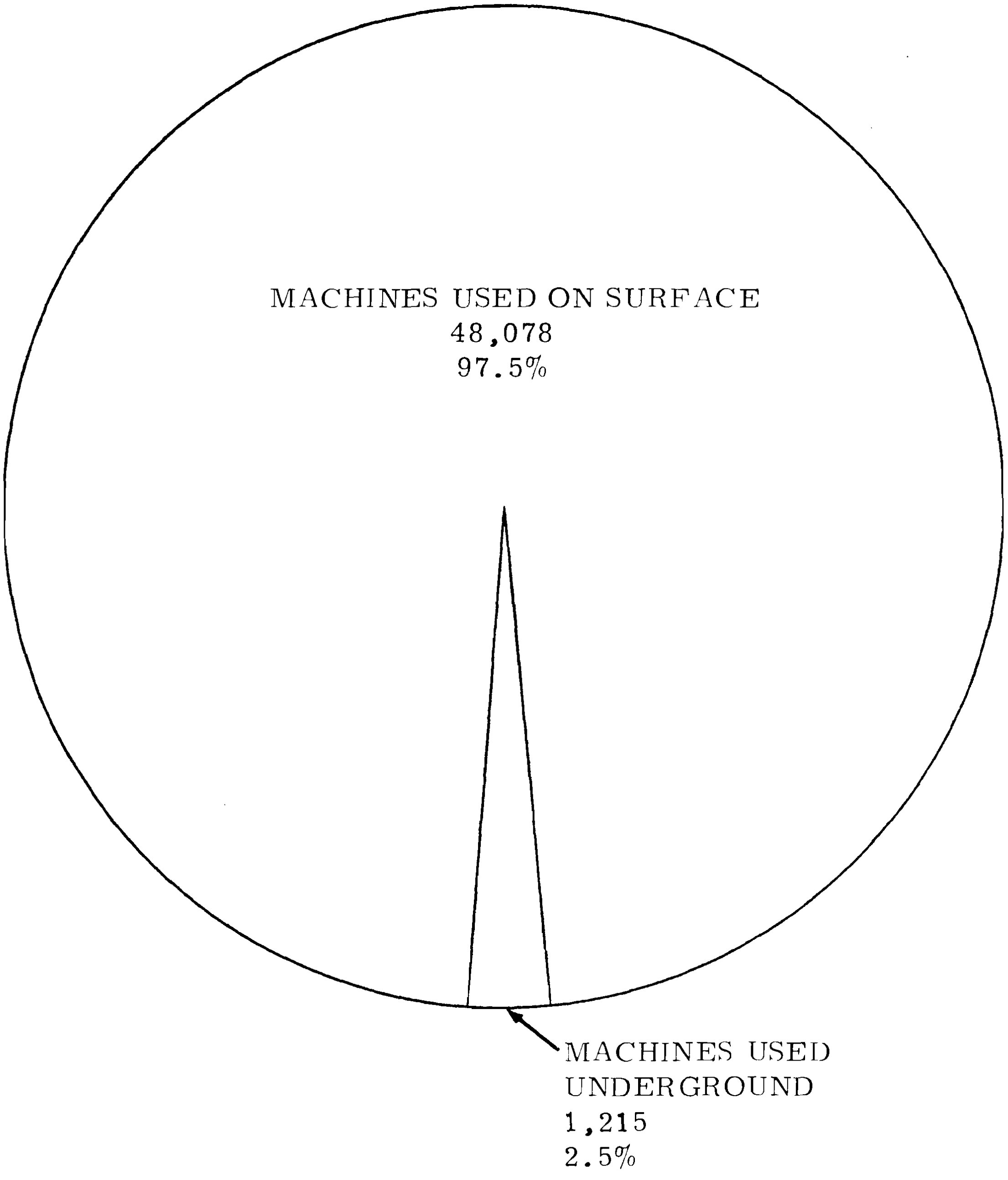


Figure 4-11. Metal-Nonmetal Mines
Estimates of Population,
Machines of Interest
Total: 49,293

the mid-point of the confidence interval for the estimate. Only a small percentage of the population (2.5%) is used in underground operations. The term "used in" is employed here to call attention to the fact that some of the machines of interest which belong to underground mines are not used underground, but rather in the surface operations associated with underground mines. There are approximately 600 machines in this category.

Figure 4-12 shows the estimates of the numbers of machines, and percentages of the total, used in underground mines, for each of the five types of machines of interest. As one would expect, more than half of the total is composed of front-end loaders. It should be noted that the numbers of machines given in Figure 4-12 are based on the responses to the survey and, in cases where the survey response indicated a small number of a machine type, the confidence interval is wide. The survey produced mid-interval estimates of 72 for graders and 36 for prime movers used underground. While it is known that both types of machines are used in underground operations, the validity of the absolute numbers estimated is not high.

Figure 4-13 shows the estimates of numbers of machines, and percentages of the total, used in surface metal-nonmetal mining, for each of the five types of machines of interest. Again, front-end loaders are more than half of the total.

The different models of machine types reported in the survey were of interest to enable the calculation of estimates of the financial implications of possible ROPS/FOPS retrofit policies, as discussed in Section 4.6. The estimating method used did not require detailed analysis of every model reported. The most frequently reported models were identified and used to prepare ROPS acquisition costs, ROPS installation

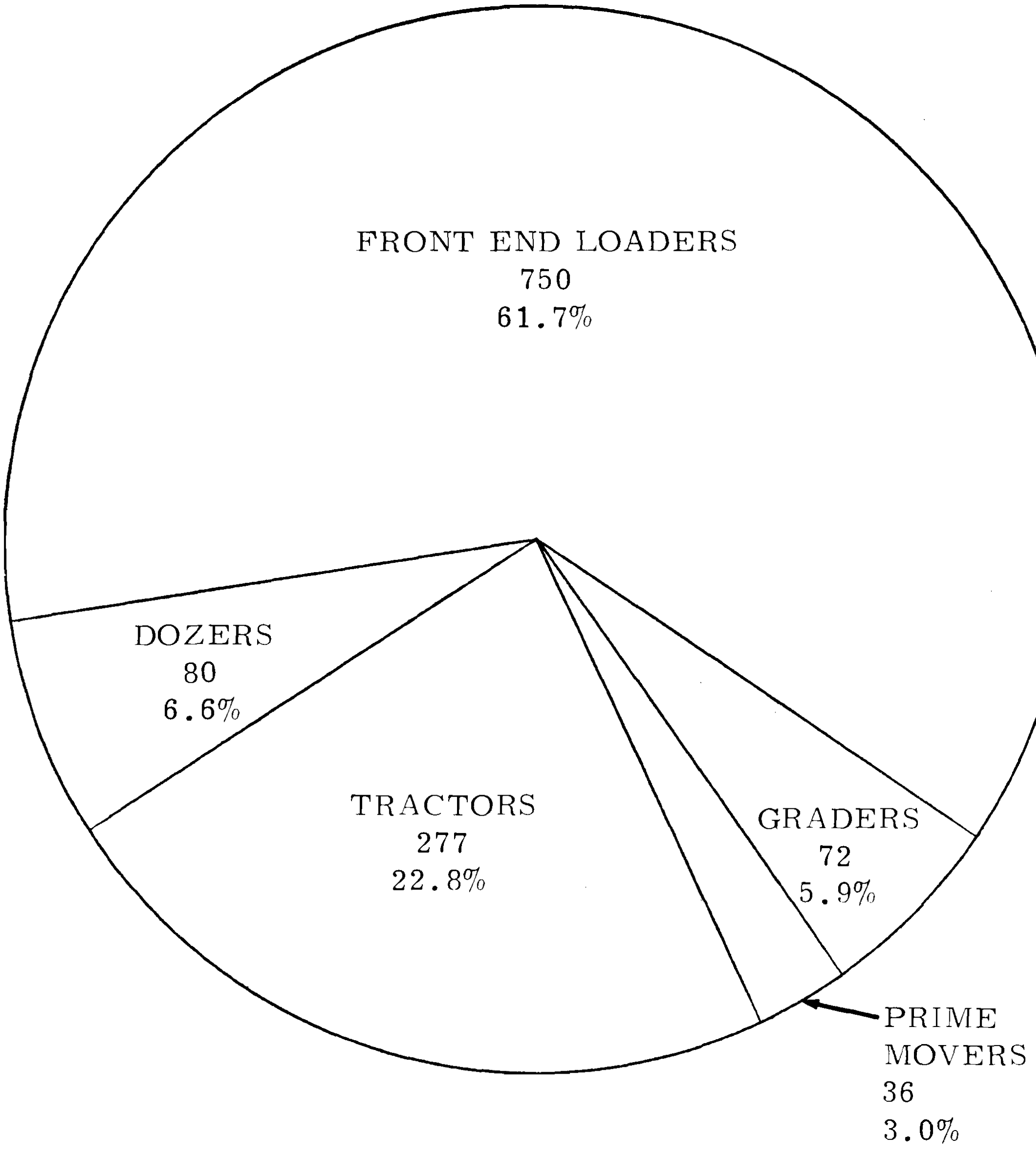


Figure 4-12. Machines of Interest Used in Underground Work Areas

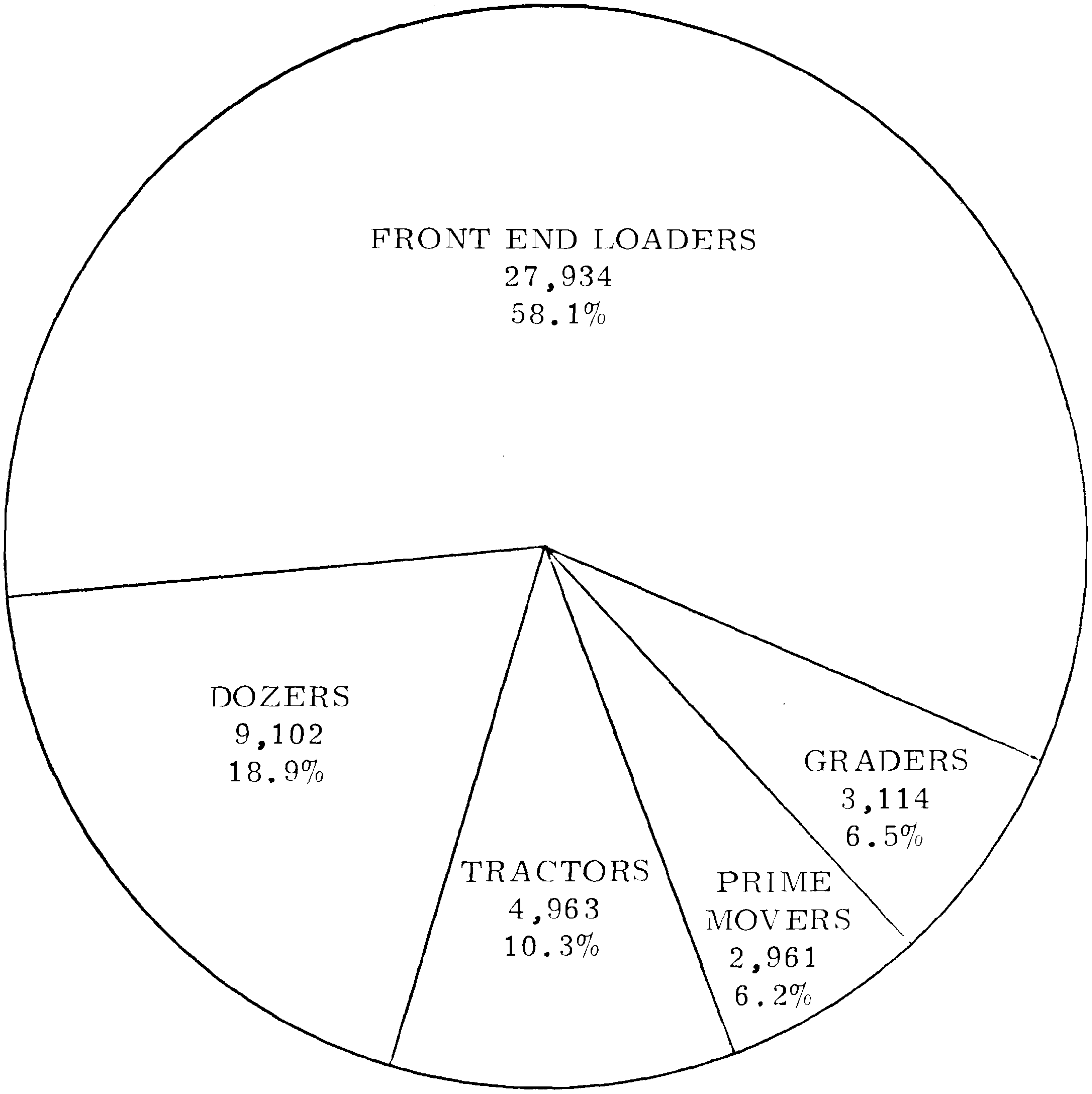


Figure 4-13. Machines of Interest Used in Surface Operations

costs, ROPS transportation costs, and ROPS cost/machine value information.

Figure 4-14 shows the percentage of machines of each type which presently have some form of protective structure installed. With few exceptions, machines which were reported to have a "ROPS" installed had a commercial ROPS which was designed and manufactured to either SAE or Corps of Engineers standards. However, many machines which reported protective structures other than ROPS had non-commercial structures, usually designed and built in mine shops, or some form of commercial cab or canopy locally modified to provide additional falling object protection. The figure reflects all installations which, in the judgment of the reporting mines, provide falling object and/or roll-over protection.

Figure 4-15 shows the estimate of the distribution of the machines of interest according to the year of manufacture groupings used in this study. Approximately 46% of the total population is composed of machines manufactured in the years 1970 through 1975. There are a few machines in the population which are more than 25 years old. Three-quarters of the machines manufactured in 1949, or earlier, are in two type categories, dozers and graders. Wheeled front-end loaders were not made in large numbers until the late fifties. Crawler loaders were available earlier, but only a few models were available in the forties. The estimates for machines in the "1949 or earlier" age category may be high, primarily because the sample for that category was small and the proportion estimators in the range below 0.05 do not permit the construction of good confidence intervals.

Figure 4-16 shows the approximate percentages of machines of interest, by the "year of manufacture" groups, which have protective

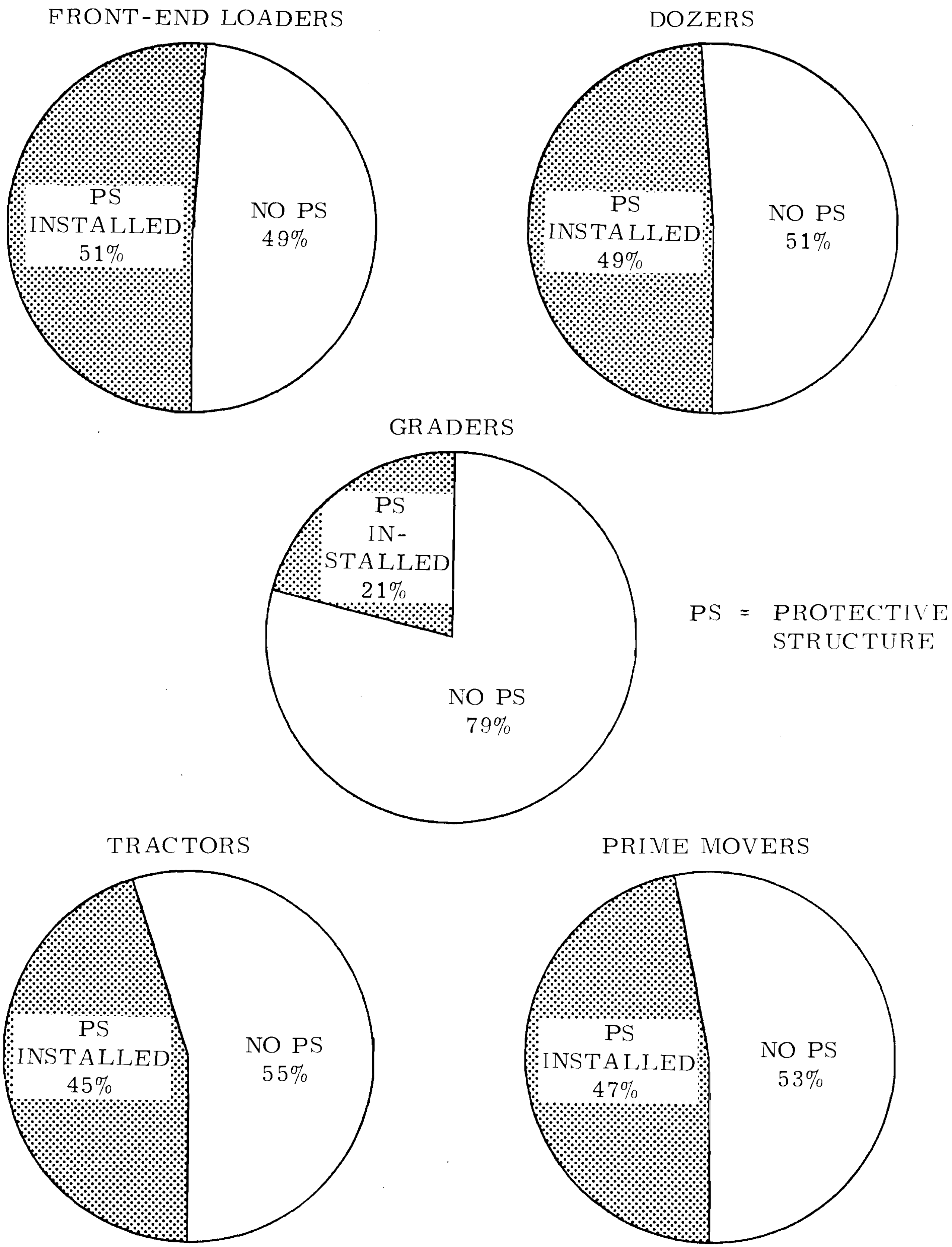


Figure 4-14. Protective Structure Status – 1975
Total Population, Machines of Interest
by Machine Type

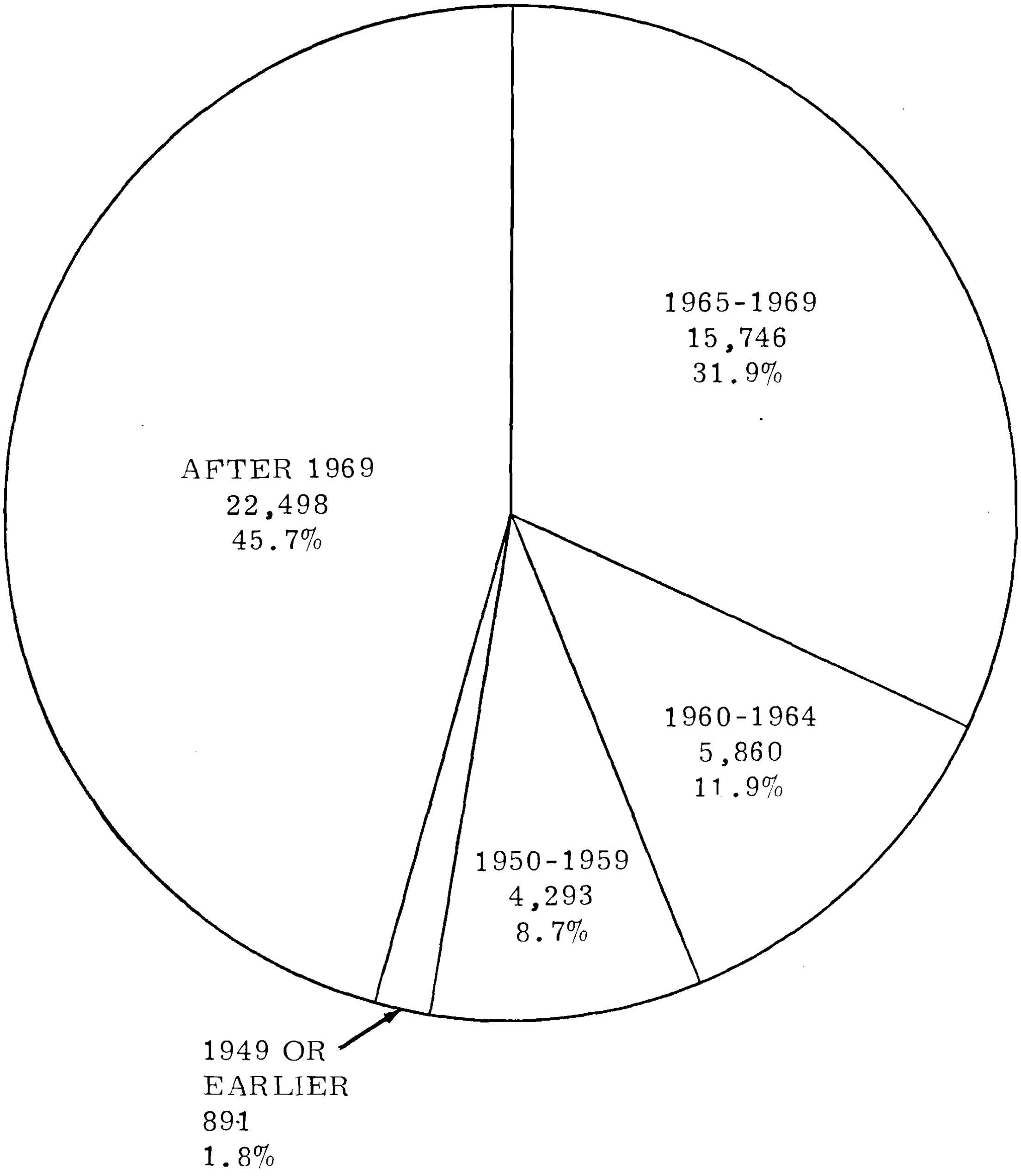


Figure 4-15. Date of Manufacture,
Total Population, Machines of Interest

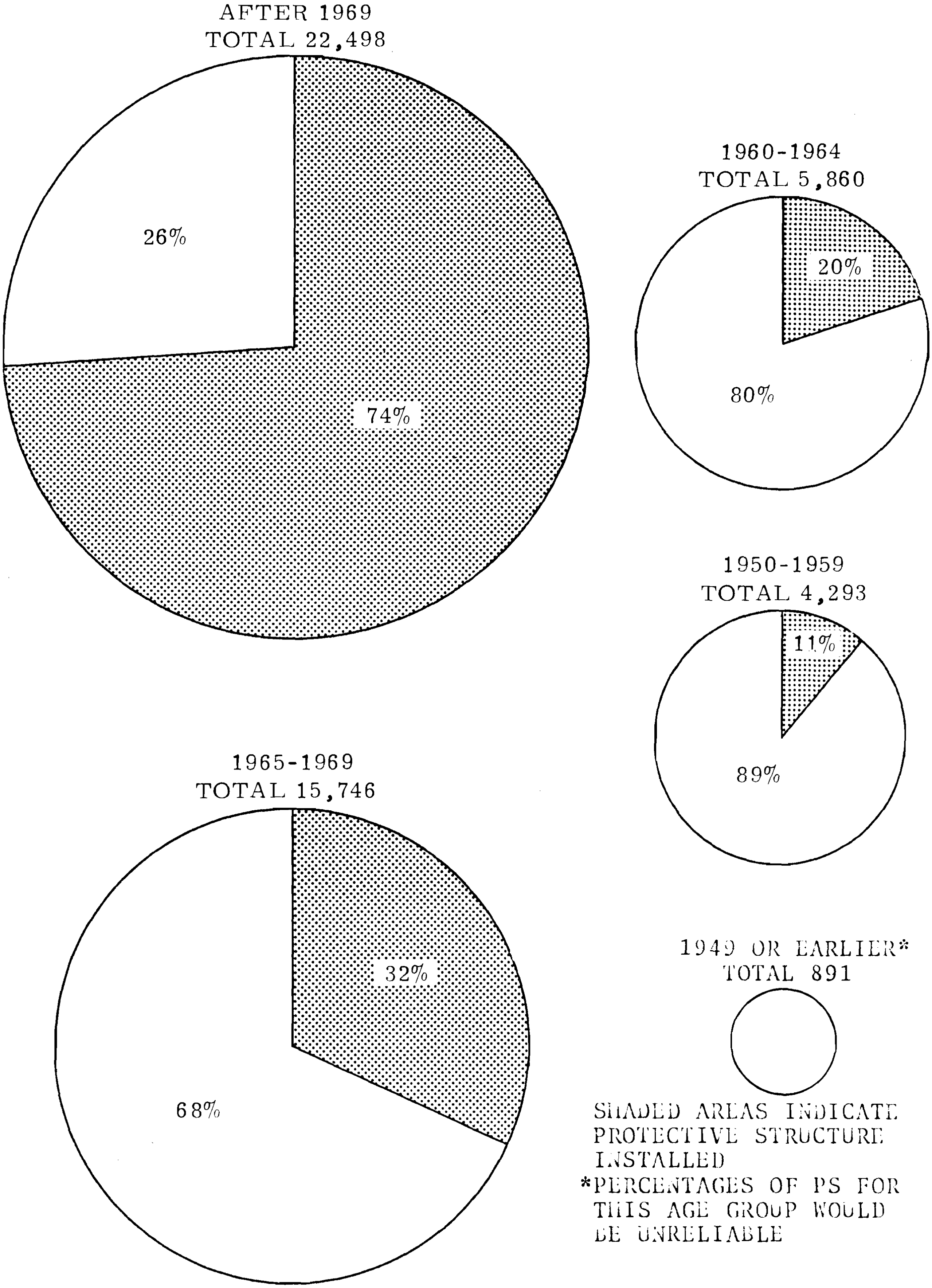


Figure 4-16. Protective Structure Status – 1975
(Machines of Interest by Year of Manufacture)

structures installed. The pie charts in this figure are drawn so that the area of each is approximately proportional to the percentage of the population to which it relates.

In summary, the following can be stated about the effort in this section:

1) The survey of approximately 4% of all of the active metal and nonmetal mines provided the basis for the estimate of the population of machines of interest. The total population was estimated to be about 49,000 machines, of which all but 1200 are used in surface operations.
2) Nearly 46% of the machines were manufactured after 1969; nearly 32% in 1965 through 1969; and approximately 22% before 1965.
3) Nearly three-fourths of the machines manufactured after 1969 have protective structures installed; approximately one-third of those manufactured in 1965 through 1969 have protective structures; and less than one-fifth of those manufactured before 1965 have protective structures.

It should not be inferred that all of the machines in the population are used exclusively for mining, or even for work directly related to mining. In fact, many of the machines, particularly in sand and gravel operations, are used in work not directly related to mining much of the time. The survey did not attempt to determine the proportion of operating time a machine was used in mining. Many telephone inquiries were received about whether a machine which was used only "a small fraction of the time" or "a few weeks a year" should be reported in Section 3 of the survey form. The answer was to report all machines used at the mine, regardless of the amount of time used there. The machines of interest are types which have great work versatility. None is distinctly identified with the mining industry. It is likely the relatively high proportion of machines which have protective structures installed is related to their versatility, that is, they are also used in work in which OSHA or state ROPS requirements apply.

4.4 COMMERCIAL AVAILABILITY OF ROPS/FOPS

The availability of ROPS/FOPS units for the types of mining equipment studied on this program has been determined. The yearly ROPS/FOPS production capacity exceeds 300,000 - 350,000 units per year. Three primary sources of information were used to develop the status of ROPS/FOPS production capability and to determine the availability of ROPS designs for the various models of equipment in the field.

Information Sources

A report prepared by Woodward Associates for the Occupational Safety and Health Administration in 1974 entitled "Study to Determine the Engineering and Economic Feasibility of Retrofitting ROPS on pre-July 1, 1969 Construction Equipment" (DOL Contract L-73-158) contains information on the ROPS Production capacity in the U.S. in 1973. This material has been reviewed and up-dated to reflect the industry capability in 1975. This report has also been used as a basis to determine the availability of ROPS/FOPS for different models of equipment.

Direct contacts with major ROPS manufacturers have provided additional information on the availability of ROPS designs for the many models of equipment. Information on production capability changes was also received. Several of these ROPS/FOPS manufacturers provided photographs of ROPS/FOPS installed on mining equipment. These photographs are included later with text describing some of the ROPS/FOPS manufacturers.

Additional information on ROPS/FOPS availability was received during visits to ROPS manufacturers, equipment manufacturers, and mining operations.

Current ROPS/FOPS Production Capability

There are approximately 50-60 manufacturing concerns in the United States that produce ROPS/FOPS as a primary business product line. These companies range in production capacity from the level of 100-200 units per year up to firms that produce 10,000-15,000 per year. The top ten ROPS/FOPS manufacturers produce a yearly production of 50,000-60,000 units and have the facility capacity to produce close to 100,000 units per year. In addition to the independent ROPS/FOPS manufacturers, the original equipment manufacturers also produce ROPS for many of their own new vehicles.

The total ROPS production capacity in 1973 was estimated at 360,000 units/year by Woodward Associates in a program conducted for the Occupational Safety and Health Administration. This capacity has not been required since the demand for ROPS has not reached the estimates made by industry during the 1970-1972 period when OSHA was formulating and promulgating ROPS regulations for the construction industry. The ROPS manufacturers contacted during the current study for the U.S. Bureau of Mines expressed the opinion that this production capacity is still available but has not expanded significantly. Since the total production of machines of interest, for all applications (mining, construction, logging, etc.) is approximately 250,000 - 270,000 per year, there is sufficient ROPS production capacity to supply ROPS or FOPS for any conceivable new ROPS or FOPS regulation that might be promulgated by MESA.

The ROPS/FOPS manufacturers tend to divide into two general classifications. The first classification contains the manufacturers that supply ROPS/FOPS directly to the equipment manufacturer. This class of ROPS manufacturer tends to produce large quantities of relatively few models of ROPS. The ROPS may be shipped to the equipment manufacturer where they are installed on new vehicles and then delivered to dealers. The second classification of ROPS manufacturers may also have ROPS production contracts with equipment manufacturers but tends to depend more heavily on supplying retrofit ROPS or after-market ROPS direct to the equipment owner. This manufacturer must have a large selection of ROPS designs available for production. Table 4-11 has been extracted from the previously referenced ROPS study conducted for OSHA. While admittedly incomplete, it serves to indicate that ROPS are available for equipment manufactured as early as the 1940's and 1950's. There are several ROPS manufacturers that have over 500 designs available; a few companies have over 400 designs available for pre-1970 equipment alone. This extensive selection of ROPS models is illustrated in Table 4-12. This table is a partial list of ROPS models available from a ROPS manufacturer that supplies both the retrofit market and the equipment manufacturer. This listing is somewhat representative of the scope of equipment models covered by the ROPS industry.

The ROPS manufacturers contacted during this study commented on the increase in requests for ROPS units to be installed on machines manufactured before 1969. One ROPS manufacturer stated that about 40% of his ROPS retrofit business in the first six months of 1975 was for pre-1969 units. This particular manufacturer has over 900 ROPS designs available. Designs are available for some machines manufactured back as far as 1938. Many ROPS manufacturers have ROPS designs available for machines manufactured in the 1950's.

Table 4-11. ROPS Availability for Pre-1970 Vehicles (Incomplete)

Crawlers	
Caterpillar	
D4 - 4G	(1936)
D4 - 7U	(1947)
D6 - 8U	(1947)
D7 - 3T	(1944)
D8 - 2U	(1946)
D9 - 18A	(1954)
Allis-Chalmers	
HD-6B	(1955)
HD-9	(1953)
HD-9B	(1956)
HD-11B	(1955)
HD-11E	(1958)
HD-16D	(1959)
HD-21	(1954)
International	
TD-24	(1956)
TD-25	(1962)
TD-30	(1962)
TD-20	(1958)
TD-15	(1958)
TD-9	(1953)

Wheeled Loaders	
Caterpillar	
944	(1959)
966	(1960)
Hough	
H30F & R	(1960)
H60	(1961)
H70	(1959)
H90	(1959)
H100	(1962)
Trojan	
134	(1959)

Crawler Loaders	
Caterpillar	
933C	(1955)
955C	(1955)
977D	(1955)
Allis-Chalmers	
HD-7G	(1962)
HD-11G	(1959)
HD-21GC	(1956)

Scrapers	
Caterpillar	
619	(1959)
DW-20	(1955)
DW-21	(1953)
632	(1962)
641	(1962)
630	(1962)
631	(1960)
657	(1962)
660	(1962)
666	(1962)

Motor Graders	
Caterpillar	
112	(1962)
14	(1962)
12-9K	(1938)

Table 4-12. ROPS/FOPS Model Availability
(Furnished by Saf-T-Cab, Inc., Fresno, California)

Fiat-Allis (Allis-Chalmers)

Crawler Tractors

HD-3	HD-6	HD-12G	HD-41
HD-4	HD-7	HD-16	
HD-5	HD-11	HD-21	

Wheel Loader

D-10	D-21	TL-14	TL-545
D-14	I-600	TL-20	TL-645
D-15	TL-10	TL-30	TL-745
D-17	TL-12	TL-40	

Scrapers

260E	TS-360
460	TS-562

Motor Graders

D	45	M-70	M-150
DD	M-65	M-100	M-200

Agricultural Tractors

160	185	200	7050
170	190	6040	
180	190xT	7030	

Austin Western

Motor Graders

88	200 Pacer	300 Super	500 Pacer
99	200 Super	400 Pacer	500 Super
100	300 Pacer	400 Super	

Mobile Cranes

110	220
210	410

Bros

Rollers

SP 54B	SPV 735	SP 3000	SP 10000
SPV 370	SPV 845	SP 3500	
SPV 725	SP 2800	SP 6000	

Case

Crawler Tractors

310	350	450	750
850	1150		

Wheel Loaders

W-3	W-8	W-12	W-24
W-5	W-9	W-18	W-26
W-7	W-10	W-20	

Wheel Tractors

480	500	530	580
680	780	1530B	1737
1740			

Caterpillar

Crawler Tractors

D-2	D-4	D-5	D-6
D-7	D-8	D-9	

Crawler Loaders

933	941	951	955
977	983		

Scrapers

DW-10	619	621	623
DW-15	627	630	631
DW-20	633	641	650
DW-21	651	657	660
613			

Motor Graders

212	112	120	12
140	14	16	12G
14G			

Wheel Loaders

920	922	930	944
950	966	980	988
992			

Wheel Dozers & Compactors

814	815	824	825
830	834	835	

Champion

Motor Graders

D-560	D-562	D-565	D-600
D-640	D-650	D-680	D-686

Clark-Michigan

Wheel Loaders

12 B	35 AWS	55 AI	55 AII
55 III	55 IIIA	75 A	75 AI
75 AII	75 IIIA	85 AM	85 AI
85 AII	85 III	85 IIIA	125 AI
126 AII	125 IIIA	175 AI	175 AII
175 III	175 IIIA	275 AI	275 AII
275 III	275 IIIA	475	

Wheel Dozers

180 I	180 III	280 I	280 III
280 IIIA	380 I	380 II	380 III
380 A	380 IIIA	480	

Scrapers

110-HT	110-11	110-12	110-14
110-15	210	210-H	310
310-I	310-III	310-III	310-H
410			

Loader - Backhoe

700

Rollers

RW-140	RW-181

Table 4-12. ROPS/FOPS Model Availability (Cont)
(Furnished by Saf-T-Cab, Inc., Fresno, California)

Curtis Wright

Scrapers

226	320

Deere

Crawler Tractors

40C	350	450	1010
2010			

Wheel Tractors

40	300	301	310
400	410	420	500
510	544	620	644
760	860	1010	1520
2010	2510	3010	5010

Scrapers

760 A	860	5010

Motor Grader

570

Dynahoe

Loader/Backhoe

A	AD	140	160
190	200		

Eimco

Crawler/Dozer

103-C

Euclid

Off-Highway Trucks

R-35	R-50	R-75	R-85
B-70	B-100	B-110	

Ford

Utility Tractors

800	820	821	Fordson Super Major
850	2000	3000	Fordson Dexta
3500	4000	4022	County Super 4
5000	7000	841	County Super 6
3400	4000		

Agricultural Tractors

2N	8N	NAA	Golden Jubilee
9N	541	600	601
701	740	800	2000
3000	3300	3400	4000
5000	7000		

Galion

Motor Graders

101	104	104 B&C	104H Series B
118	118 B&C	160	160 B&C
160 L	303	450	503
T-400A	T-500	T-500A	T-500L
T-600	T-600B		

Rollers

3-5 Ton Tandem	5-8 Ton Tandem
8-12 Ton Tandem	10-14 Ton Tandem
10-12 Ton 3-Wheel	12-14 Ton 3-Wheel
9-T-15 9-Wheel	

Hancock (Michigan)

Scrapers

282	292

Huber

Motor Graders

M-52	M-500	M-550	M-600
M-650	9D	10D	11D
D-1100	D-1300	D-1400	D-1500
F-1500	D-1700	F-1900	

Hyster

Compactors

C-350A	C-451A	C-450	C-500
C-530	C-550		

Ingersoll Rand

Rollers

SP 42	SP 54

Ingram

Rollers

3-5 Ton	5-8 Ton	8-12 Ton	10-14 Ton
8 Ton 3-wheel		9-2800P	11-2700
10 Ton 3-wheel		9-3400-P	13-2300
14 Ton 3-wheel			

International Harvester

Crawler Tractors

TD-6	TD-7	TD-8	TD-9
TD-14	TD-15	TD-18	TD-20
TD-24	TD-25	TD-30	

Table 4-12. ROPS/FOPS Model Availability (Cont)
(Furnished by Saf-T-Cab, Inc., Fresno, California)

International Harvester (cont)

Crawler Loader

T-340	500-C	100-C	125-C
150	175 B&C	250	250 B&C
TD-6	TD-9	TD-15	TD-18
TD-20			

Scrapers

TD-75	E-200	E-211	270
E-270	295	295 B	E-295
495			

Payhaulers

100	140	180	330
340	350		

Wheel Tractors

300	444	504	560D
606	706	2400	2424
2444	2500	2504	2544
2606	2656	3200	3414
3444	3514	3544	3616
3800	4100	Farmall Cub	

Payloaders

HH	HAC	HAH	HF
HM	HMC	HOD	H-25B
H-30B	H-40	H-50	H-50C
H-60	H-60B	H-60C	H-60G
H-65	H-70	H-70D	H-80
H-90	H-100	H-120	H-600

Wheel Dozers

D-90C	D-100B	D-120C	D-400
D-500			

Agricultural Tractors

A	AV	B	BN
H	Super H	M	Super M
F-140	F-300	F-350	F-400
F-450	I-454	F460	I-464
I-544	F-544	I-574	F-606
F-656	I-656	F-666	I-674
F-706	F-756	F-766	F-806
F-826	F-856	F-906	F-956
F-966	F-1056	F-1066	F-1206
F-1256	F-1266	F-1456	F-1466
2300	2400	2500	2656

Jacobsen

Wheel Tractors

E-10	F-10	G-10

Koehring

Roller-Compactors

60	100	140	K-550

Komatsu

Crawler Tractors

D-55	D-60	D-65	D-75
D-85	D-125	D-155	

Lima

Loaders

BLH 60	80

Loraine

153 B	ML 309	ML 325	400

M-R-S

Prime Movers

150	200	I-90S	I-100S
I-105S	A-100		

Massey Ferguson

Crawler Tractors

2244	3366	300	500

Wheel Tractors

11	20	30	35
40	50	65	70
175	180	202	204

Wheel Tractors (Cont)

302	302	356	470
1080	2135	2200	2244
3165			

Agricultural Tractors

20	25	30	35
40	135	201	150
165	202	203	204
205	401	1100	1105
1135	1150	1155	2135

Multihoe

Loader/Backhoe

KDE	KDF

Oliver

Crawler

Cletrac

Wheel Tractors

2-44	2-62	55	550
770	1550	1850	

Pactor

3-30	3-40	3-50

Table 4-12. ROPS/FOPS Model Availability (Cont)
(Furnished by Saf-T-Cab, Inc., Fresno, California)

Raygo/Wagner

Rollers

2-36	45	60	400
404	600		

Motor Grader

Giant

Compactors (Wagner)

SF-17	WC-317	WC-317

Tampo

Rollers

RS-16	RS-28	RS-38	RS-166A
RH-48	RP-16	SP-312	SP-750
SP-950			

Terex

Crawler Tractors

C-6	82-30	82-40	82-80

Wheel Loaders

L-15/72-10	L-20	72-21
L-20/72-20	L-25	72-31
L-25/72-30	L-30	72-41
L-30/72-40	72-51	72-71
72-81		

Scrapers

S-7	S-11E	TS-14	S-18
TS-18	S-24	TS-25	S-28
S-32	TS-32	S-35E	

Trojan

Wheel Loaders

104	114	124	134
154	164	204	204-A
254	300	304	400
404	1500	1700	1900
2000	3000	4000	6000
8000			

Vibro Plus (Dynapac)

Roller

CA-25

Scrapers (Le Tourneau-Westinghouse)

C-Pull	C-222A	101-F	111-A
B-70	222-F	229-F	333-A
333-F	333-FT	339-F	

Motor Graders (Adams)

220	312	330	330-H
412	440	440-H	444
512	550	555	610
660	660-B	666	666-B

Vibro Plus (Dynapac) (cont)

Motor Graders (Adams) Cont

777	777-B	888

Off-Highway Trucks

35	50	75-B	85-C
120B	150B		

Wheel Loaders (Scoopmobile)

H	HA	HP	HPD
LD-5P	LD-7A	LD-8A	LD-125
LD-150	300	350	400B
500	1200		

Wagner (See Raygo/Wagner)

Waldon

Loader

5000

Worthington

Wheel Tractor

G-6

ROPS/FOPS Manufacturers

As mentioned earlier in this section, there are 50-60 ROPS manufacturers in the United States. Woodward Associates, Inc. contacted several of these companies during the course of this study to gather information and to solicit opinions of various aspects of potential ROPS/FOPS retrofit regulations. Several ROPS manufacturers are already supplying ROPS to mining companies and some are working directly with the manufacturers of specialized mining equipment.

The following paragraphs give brief descriptions of several ROPS/FOPS manufacturers that supplied information in support of this U.S. Bureau of Mines program. This listing of specific companies is not meant to imply endorsement of their products by the U.S. Bureau of Mines or by Woodward Associates, Inc.

It is of interest to note that sources for ROPS are available in all parts of the United States. Several ROPS manufacturers provided photographs of typical mining machines with ROPS/FOPS installed. These are presented in Figures 4-17 through 4-29.

The Egging Company
Gurley, Nebraska 69141
(308) 884-2233

Manufactures an environmentally controlled protective enclosure for the Caterpillar D8 crawler tractor and for Caterpillar 660B prime mover. Also manufactures ROPS cabs for industrial tractors such as John Deere, Case, Allis-Chalmers, and International-Harvester.

Fleco Corporation

Jacksonville, Florida 32203

(904) 354-8361

Manufactures retrofit ROPS for many different Caterpillar vehicles including crawler dozers, crawler loaders, wheel loaders, scrapers, and motor graders.

Industrial Cab Company

Essex, Massachusetts 01929

(617) 768-6931

Manufactures ROPS cabs for Fiat-Allis loaders and dozers, International Harvester/Hough loaders, GM-Terex loaders and dozers, and Clark-Michigan loaders.

Medford Steel

Medford, Oregon 97501

(503) 779-1970

Manufactures ROPS and ROPS cabs for broad range of Caterpillar crawler dozers and crawler loaders, GM-Terex crawler loaders, and Komatsu crawler dozers and crawler loaders. Medford supplies ROPS for both the retrofit market and the new vehicle market.

Palm Industries, Inc.

Litchfield, Minnesota 55355

(612) 693-2492

Manufactures ROPS and ROPS cabs for equipment manufactured by Fiat-Allis, Case, GM-Terex, Galion, Austin Western, Caterpillar, Deere, Ford, International Harvester, Clark-Michigan, and others. Supplies both retrofit ROPS and ROPS for new equipment. Large number of ROPS models available.

Rome Industries

Cedartown, Georgia 30125

(404) 748-4450

Manufactures both retrofit ROPS and ROPS for new vehicles. Models available for Caterpillar crawler dozers, crawler loaders, scraper prime movers, wheel loaders, wheel dozers, and motor graders. Affiliated with Medford Steel.

Saf-T-Cab, Inc.

Fresno, California 93745

(209) 268-5541

Manufactures both retrofit ROPS and ROPS for new vehicles. Very large number of ROPS models available. Units available for Fiat-Allis, Austin Western, Bros, Case, Caterpillar, Champion, Clark-Michigan, Curtis Wright, Deere, Dynahoe, Eimco, Euclid, Ford, Galion, Gradall, Grove, Hancock, Huber, Hyster, Ingersoll Rand, Ingram, International Harvester, Jacobsen, Koehring, Komatsu, Lima, Long, Loraine, M-R-S, Massey Ferguson, Multihoe, Oliver, Pactor, Raygo-Wagner, Tampo, GM-Terex, Trojan, Vibro Plus, Wabco, Scoopmobile, Waldon, and Worthington vehicles. Both ROPS and ROPS cabs available for many models.

Sequoia Manufacturing Company, Inc.

Fresno, California 93727

(209) 255-1611

Manufactures ROPS and ROPS cabs for machines manufactured by Allis-Chalmers, Case, Caterpillar, Ford, Galion, Hy-Dynamics, International Harvester, Deere, Komatsu, Massey Ferguson, Michigan, GM-Terex, Wabco and others.

Sims Cabs, Inc.

Payne, Ohio 45880

(419) 263-2321

Manufactures ROPS and ROPS cabs for many industrial tractors and front-end loaders. ROPS cab models are available for David Brown, Ford, International Harvester, Deere, and Massey Ferguson vehicles.

Tube-Lok Products

Portland, Oregon 97202

(503) 234-9731

Manufactures ROPS and ROPS cabs for complete Caterpillar vehicle line. ROPS and ROPS cabs are also manufactured for GM-Terex, International Harvester and Ray Go equipment. Both retrofit ROPS and ROPS for new equipment are manufactured.

Young Corporation

Vancouver, Washington 98661

(206) 694-3313

Manufactures ROPS and ROPS cabs for Caterpillar, International Harvester, Euclid, GM-Terex, Deere, Massey Ferguson, Loraine, Allis-Chalmers, Wabco, Michigan, Trojan, Case, Galion, Huber, Ingram, Oliver, Scoopmobile, Ford, Austin Western, Buffalo Springfield, and Wagner. Many different models available; both retrofit ROPS and ROPS for new equipment.

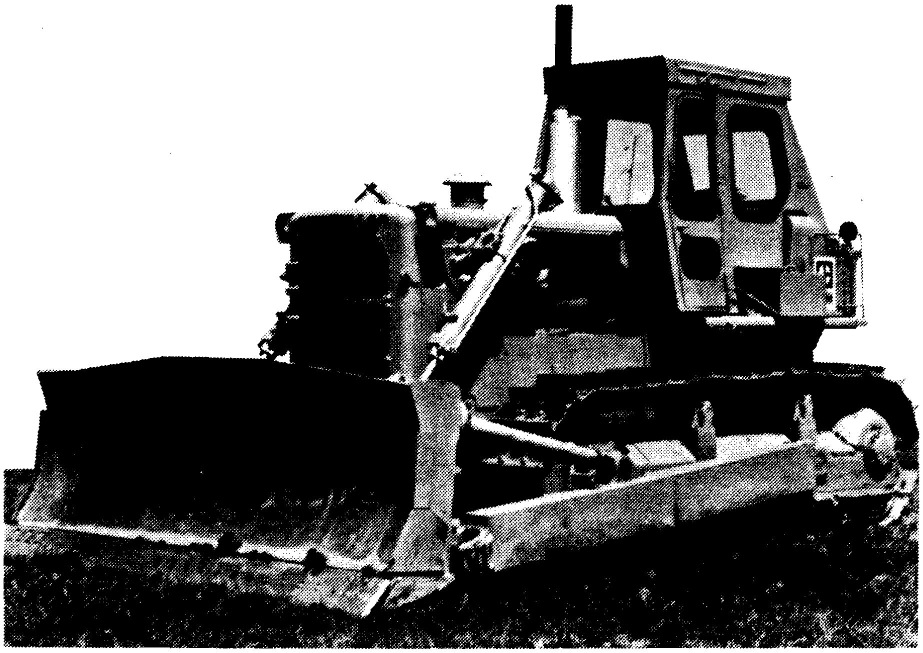


Figure 4-17. Egging ROPS Cab on Caterpillar Crawler Dozer

Figure 4-18. Industrial Cab Company ROPS Cab on GM-Terex Crawler

Figure 4-19. Eimco ROPS on Eimco LHD Units

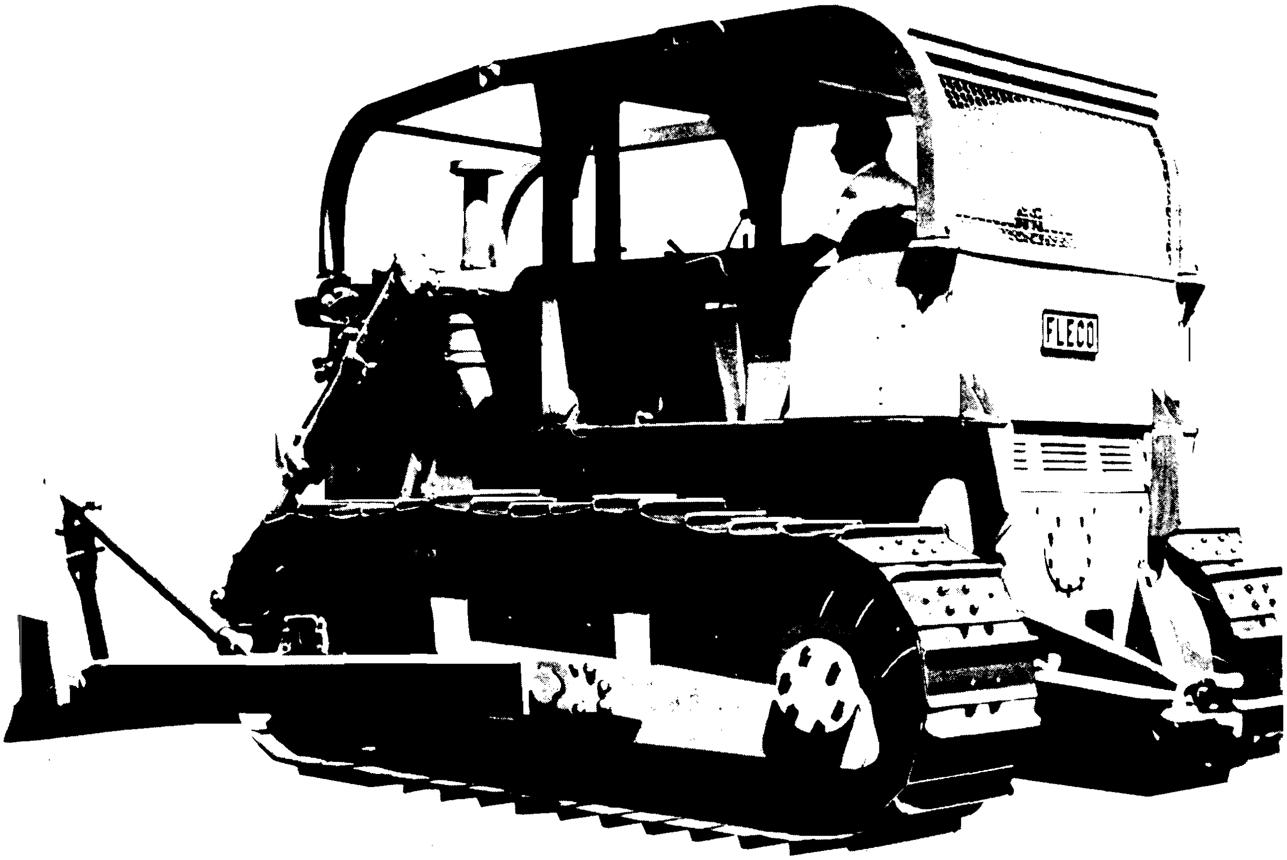


Figure 4-20. Fleco ROPS on Caterpillar Crawler Dozer

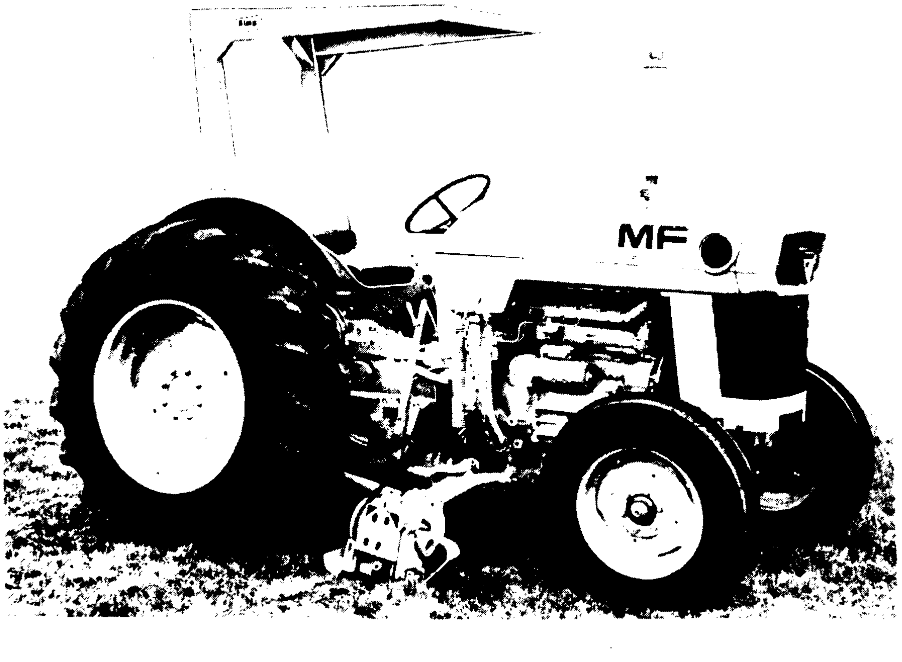


Figure 4-21. Sims Cabs, Inc. ROPS on Massey Ferguson Industrial Tractor

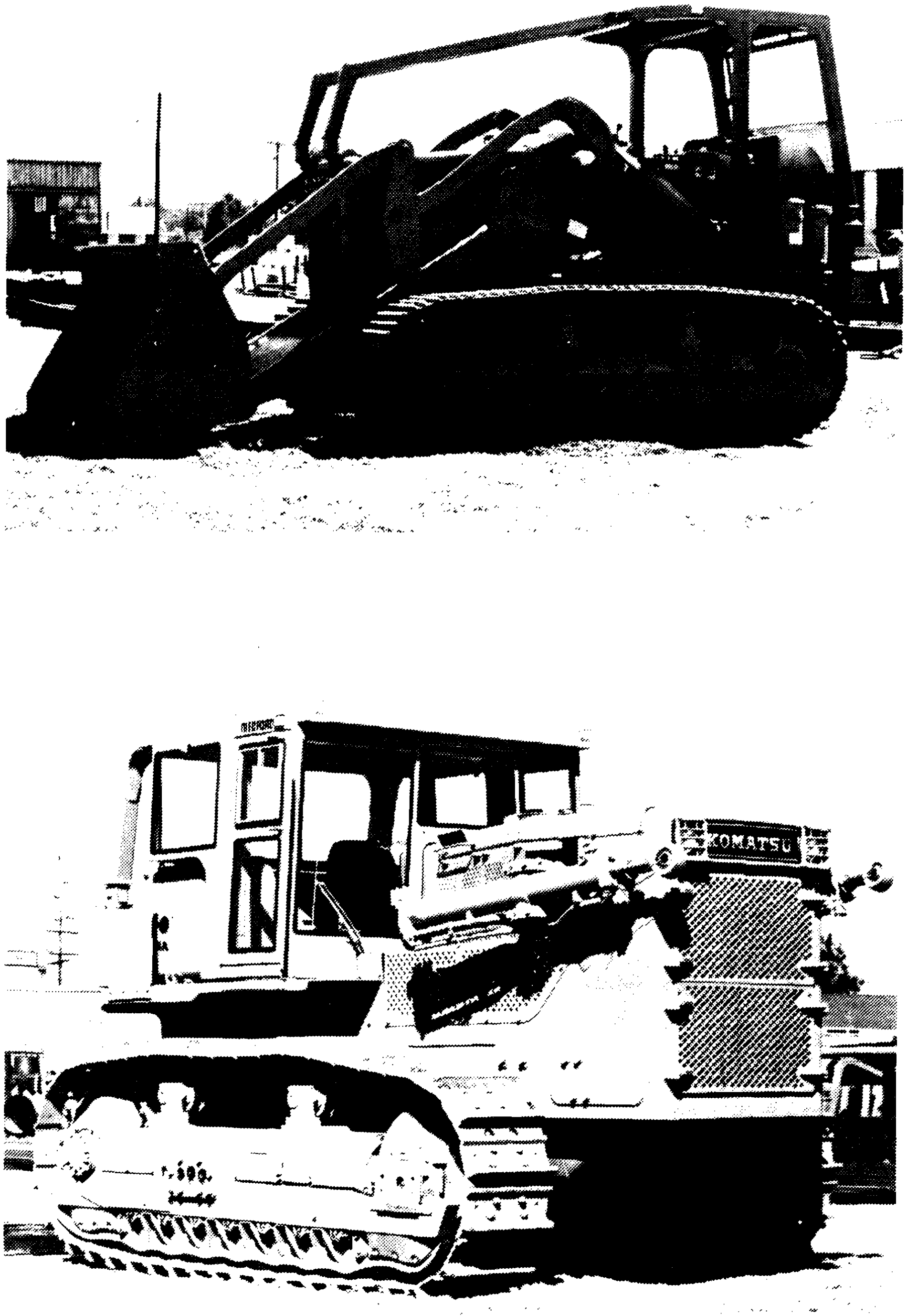


Figure 4-22. Medford Steel ROPS on Komatsu Crawler Loader; ROPS Cab on Komatsu Crawler Dozer

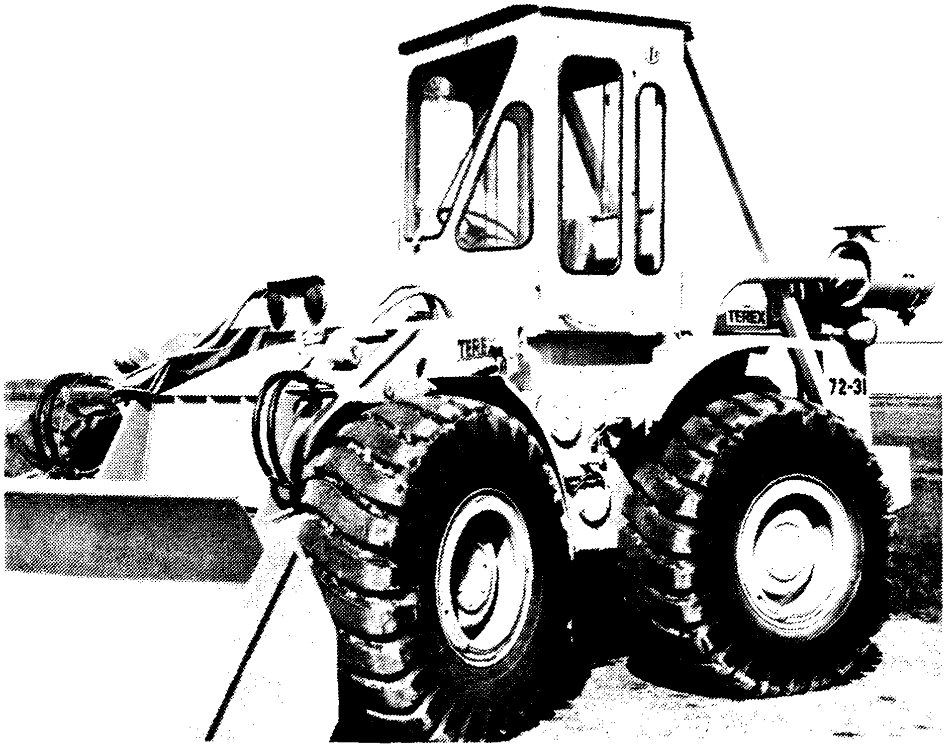
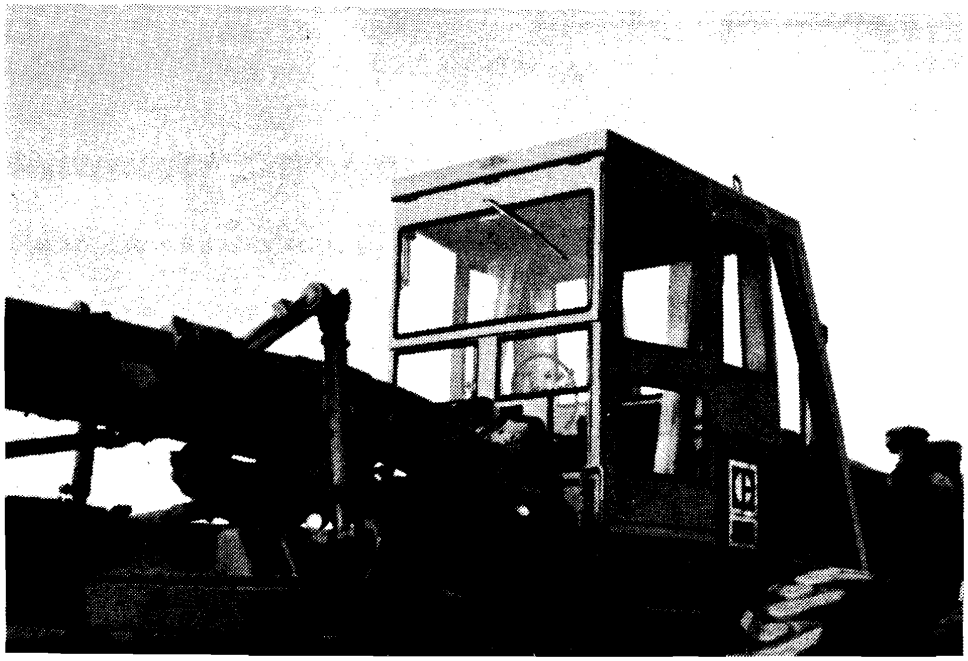


Figure 4-23. Palm Industries ROPS Cab on GM-Terex Rubber-Tired Loader

Figure 4-24. Sequoia ROPS Cab on Caterpillar Prime Mover (Scraper)

Figure 4-25. Saf-T-Cab ROPS on Euclid
Off-Road Dump Trucks;
ROPS Cab on Ford Industrial Tractor



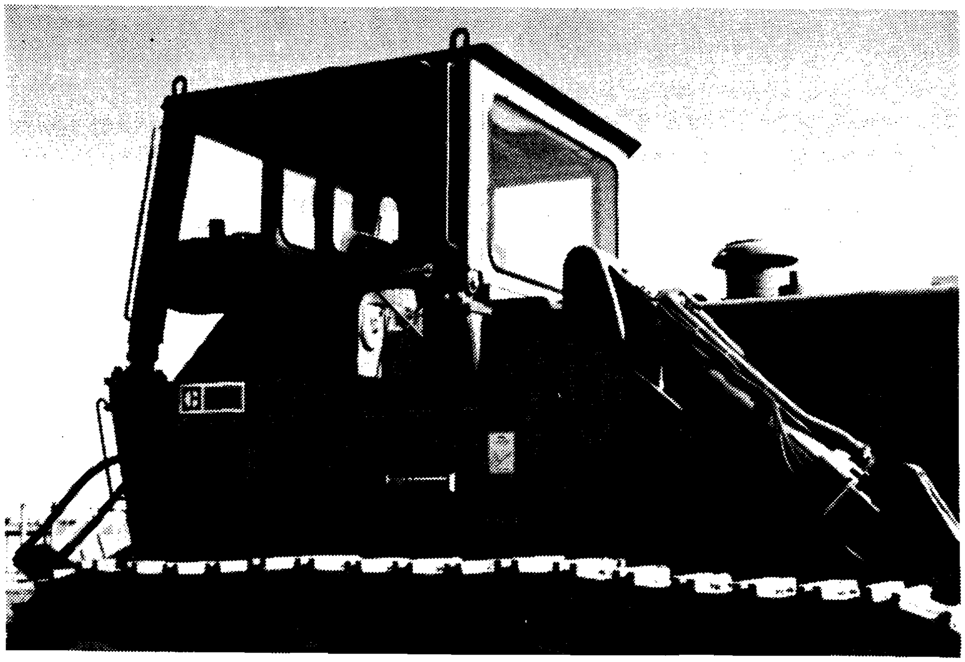


Figure 4-26. Saf-T-Cab ROPS Cabs on Caterpillar Motor Grader and on Caterpillar Crawler Loader

Figure 4-27. Tube-Lok ROPS Cab on Caterpillar Rubber-Tired Loader; ROPS on Caterpillar Crawler Dozer

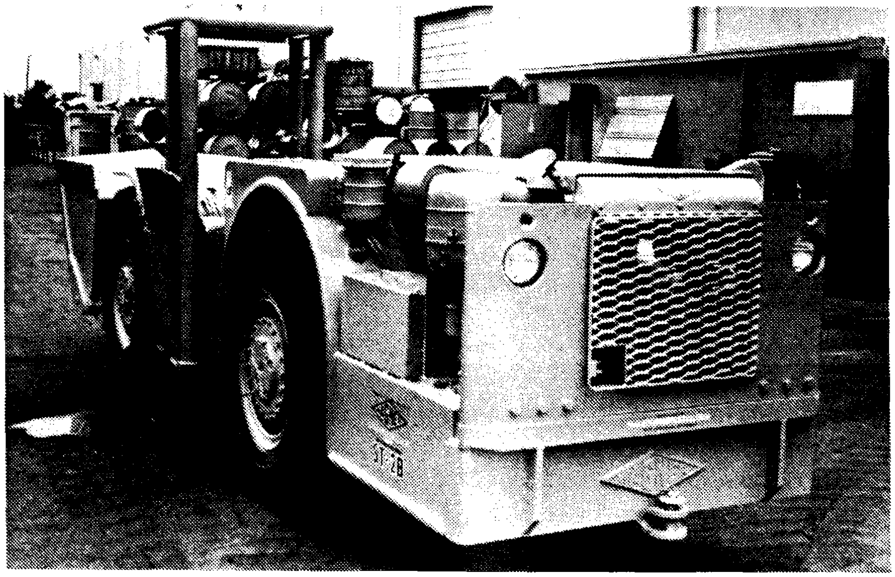


Figure 4-28. Young Corporation ROPS Cab on Clark Rubber-Tired Loader; ROPS on Wagner LHD

Figure 4-29. Young Corporation ROPS on
Massey-Ferguson Industrial Tractor;
ROPS on Massey-Ferguson Rubber-Tired Loader

In summary, it appears that ROPS that meet the ROPS structural performance given in SAE J1040a "Performance Criteria for Roll-over Protective Structures (ROPS) for Earthmoving, Construction, Logging, and Industrial Vehicles", dated February 1975, or the ROPS performance required in the Corps of Engineers Safety Manual EM-385-1-1, Change 1, Paragraph 18.A.20, dated March 27, 1972, are available for almost all post-1959 models of the "machines of interest" covered by this study. Likewise FOPS that meet the performance standards given in SAE J231 "Minimum Performance Criteria for Falling Object Protective Structure (FOPS)", dated May 1971 are an integral part of most ROPS systems or can easily be added to those that do not now have FOPS capability.

The only qualification in the area of ROPS/FOPS availability concerns the light industrial tractors sometimes used to tow small ore trailers or as personnel carriers (boss buggies). While ROPS are generally available and can be readily installed on the post-1964 models, there are some structural problems associated with mounting ROPS on some pre-1965 models. Also, the FOPS routinely provided with the ROPS on light industrial tractors are designed to meet SAE J167 "Protective Frame with Overhead Protection-Test Procedures and Performance Requirements." This FOPS performance standard does not provide the same level of operator protection as do the FOPS that meet SAE J231.

4.5 ROPS/FOPS RETROFIT CONSIDERATIONS

This section reviews the primary engineering and operational factors that must be considered in formulating a ROPS/FOPS regulation that accomplishes the primary goal of increased operator safety without undue adverse effects on the individual mining operation or on the mining industry as a whole. The interrelation of the various considerations is complex and must include an economic evaluation. This section addresses the issues independent of the economic factors. Section 4.7, "Economic Effects of Possible ROPS/FOPS Retrofit Policies," addresses the economic implications of the material discussed in this section.

Engineering Viewpoint

The current ROPS regulations promulgated by MESA for the surface areas of coal mines and by OSHA for the construction industry require ROPS on specific equipment manufactured after July 1, 1969. One reason given for this cutoff date was that equipment manufactured earlier than July 1, 1969 did not have chassis strengths sufficient to accept the structural loads that might be experienced during a roll-over. Subsequent to promulgation of the OSHA ROPS regulation, the Office of Standards of OSHA contracted with Woodward Associates to, among other tasks, investigate the problems associated with retrofitting ROPS on pre-1970 equipment. The following information was derived in part from that study.

A significant and valid concern exists relative to the structural capability of mining and construction equipment of the types studied on this program to accept the loads that will be transmitted into the vehicle chassis during a roll-over or during a rock fall. The question of vehicle chassis structural capability centers around the thesis that the original equipment manufacturers designed and produced equipment for many years with no provision for mounting ROPS or FOPS units on the vehicles. Since there were no nationwide ROPS or FOPS regulations, the original equipment manufacturer did not "design in" the structural areas necessary for attaching ROPS mounting brackets and necessary for reacting the loads that might be experienced during a roll-over or during a rock fall. Thus the question of vehicle structural capability resolves to determining the year that each original equipment manufacturer began producing vehicles with chassis and frames designed to accept ROPS.

The original equipment manufacturers, when asked to define which of their vehicles will accept ROPS, state vehicle manufacture dates that are consistent with their ROPS development and vehicle chassis modification programs. Characteristically, they state that in 1965 or 1966 or 1967, they realized that there would be future requirements to provide ROPS on construction vehicles and perhaps on mining equipment and that they began to redesign their vehicle chassis and frames to accommodate the installation of ROPS. The vehicle chassis were analytically examined for structural adequacy and, where necessary, they were modified to provide the necessary strength to accept the structural loads imparted through the ROPS to the chassis during a roll-over (or at least during a static laboratory test).

As is normal in a manufacturing concern, these design changes were not immediately reflected in changes to the vehicles on the production line. Some models of vehicles were modified soon after the decision to accommodate ROPS, but some other models were not. The time from the decision to modify the vehicle chassis to accept ROPS to the time when the production vehicles are delivered off the end of the production line with the redesigned chassis can be as short as one year but could be as long as four to six years.

The original equipment manufacturers have set "ROPS accommodation" dates that are consistent with their modification programs and that reflect their confidence in the ability of their machines to accept an approved ROPS. These dates vary from 1965 to as late as early 1972. A few manufacturers have indicated that they think (but don't know) that some of their machines manufactured as early as 1961 could accept ROPS.

All original equipment manufacturers express concern about installing ROPS on machines that have been in use for any significant length of time. The unknown condition of the vehicle frame after exposure to the mining or construction work environment prompts the manufacturer to state that their confidence about installing ROPS on their vehicles only applies to new vehicles.

In conflict with the technical judgment offered by the equipment manufacturers is the fact that many vehicles manufactured prior to their specified "ROPS accommodation" date have ROPS installed on them now and are in use in the field. Many scrapers and front-end loaders manufactured in 1967, 1968 and 1969 and used in California have ROPS installed because the California Construction Safety Orders have required ROPS on these vehicles if manufactured after August 8, 1966. Many types of vehicles used on construction projects managed by the U.S. Army Corps of Engineers have had ROPS installed since the Corps started requiring overturn protection in addition to falling object protection in 1959. The U.S. Department of Interior, the states of California, Oregon, and Washington also had some requirements for overturn and falling object protection in 1959.

This apparent paradox where (1) the vehicle manufacturer states that his vehicle is not designed to accept the possible structural loads produced by a roll-over event before a certain date and (2) the fact that vehicles that are now in use that were manufactured before that date have had ROPS installed is really not a paradox at all. The equipment manufacturer is correct in stating that he knows, through engineering analysis, that vehicles manufactured after a certain date are structurally capable of withstanding the rigors of a roll-over. These vehicles were designed with ROPS as a known accessory and, in fact, have been subjected to static laboratory tests. The equipment manufacturer is also saying, though not directly, that the reason he is not confident about earlier vehicle models accepting ROPS is because no engineering analysis has been conducted to define the vehicle chassis or frame capability. It is probable that many of these vehicle frames would be capable of successfully supporting the ROPS dynamic loads transferred during a roll-over. It is also probable that some would not. The cost of reanalyzing each vehicle model produced in the United States would be prohibitive and probably not entirely conclusive.

Even if all previously manufactured vehicles were analytically examined for chassis strength, the serious question of in-use chassis strength degradation is still unanswered. The in-use or service related chassis strength degradation is not easily determined. Discussions with mine operators, construction contractors and dealers of used mining and construction equipment reveal that it is not uncommon for an owner to "modify" a vehicle to fit his particular needs. He may "drill a hole here" and "weld a bracket there" as required for attaching a sun shade or adding an accessory. This owner modification could have very detrimental impact on the vehicle chassis strength in local areas. If these local areas of chassis weakening are coincident with a structural load path required to absorb the force and energy imparted during a roll over, a failure in those areas is possible.

An important facet of the equipment manufacturer's reluctance to confirm the structural capability of earlier vehicle frames to accept ROPS may be related to an understandable desire to refrain from "blessing" a questionable structure for product liability reasons.

Another fact to remember is that the vehicle manufacturer is usually stating that he cannot predict the ability of his older vehicle frames to pass successfully an <u>SAE</u> ROPS static test. Only the SAE ROPS performance standards, through the static testing required, bring the vehicle chassis or frame directly into the ROPS system. The "Corps of Engineers" type of ROPS requirement ignores the fact that the vehicle frame may be the weak link in the ROPS system.

Since the Corps of Engineers type of ROPS is acceptable for retrofitting pre-1970 equipment to many Federal and State agencies (including MESA and OSHA) without static testing or field roll-over testing, this potential weak link could remain hidden until an actual roll-over accident. This may be of less concern than is obvious. To date, WAI has not reviewed any mining or construction accident records that discuss the failure of an approved ROPS system during a "normal" roll-over. Further, in conversations with industry personnel, no mention of this type of occurrence has been made. This lack of information on failure of ROPS systems during actual field overturns is a very positive indication that the great concern over vehicle frame structural capability may be overstated. Certainly it is not a factor to be ignored, but on the larger mining and construction vehicles, the frames are generally designed to survive use in a very rugged, demanding environment. Perhaps more important than the concern about the inherent strength of the vehicle frame is a concern about the possible limited attachment areas afforded on some vehicles. It may be necessary to provide some local reinforcing of the vehicle frame through use of doubler plates or ribbed structures to spread the load out over a larger reaction area. The smaller industrial- or agricultural-type tractor used in mining as personnel carriers or to tow small ore trailers present a more difficult retrofit problem than the larger units. Some of the small farm-type tractors manufactured up to the late 1960's and early 1970's have very limited attachment areas; indeed on some units the only potential attachment areas are on the rear axle housings. These areas are of known weakness in some vehicles and have, at times, exhibited failure when subjected to ROPS testing.

As was shown in Section 4.4, there are commercial ROPS available for a broad range of vehicle models and dates of manufacture. The conclusion of the OSHA review of retrofit problems on pre-1970 equipment was that ROPS were available and could be installed on most "heavy" construction equipment manufactured after 1960, and on many light industrial tractors manufactured after 1965.

Operational Viewpoint

The installation of a ROPS/FOPS on a mining machine can cause problems that are far-reaching and that can have effects on the mining procedures and on the use of the machine and its new ROPS/FOPS. A different set of potential problems exist for the case of equipment used in surface areas and the case of equipment used underground.

In the surface area application, the negative aspects of ROPS/FOPS installation begin with the installation procedure itself. In the instance where a machine is being retrofitted with a ROPS/FOPS at the mine site, provision must be made to have a crane of sufficient capacity available to lift the ROPS/FOPS into position on the machine. The mounting brackets must be welded to the proper areas of the machine chassis by a welder certified to specific AWS criteria. The ROPS/FOPS must then be attached (bolted or welded depending on the design) to the mounting brackets. The machine can now be placed back in service. The total elapsed time for this installation operation ranges from 2-3 hours for small industrial tractors to 10-12 hours for larger machines. Two or three men may be required to complete the operation. There are ROPS/FOPS that take up to 80-100 manhours to install. This cost is not insignificant, especially when the machine's non-productive hours are charged against the ROPS/FOPS installation.

As with any safety device, the user (in this case the machine operator) will have an opinion on the merits of the ROPS/FOPS. The construction industry has been installing ROPS on machines for several years and has met mixed response from machine operators. The lowered visibility, the uncomfortable seat belts, and the reduced ability to jump are frequent sources of complaint from construction industry machine operators. Accident records in the construction industry indicate the reduced risk of injury or death if an overturning machine has a ROPS and the operator is using his seat belt. Many operators still prefer to take their chances in trying to jump from an overturning machine. If the machine has a ROPS installed and the operator tries to jump, he may be crushed by the ROPS itself. The problem of operator acceptance has been experienced in the construction industry and is to be expected in the mining industry.

Certain minor work-function problems may be experienced after a ROPS/FOPS is installed on a machine. A common problem involves using a front-end loader to clean up the area under a loading bin or loading hopper. The height of the ROPS/FOPS may prevent the front-end loader from entering the area under the hopper. A smaller front-end loader will have to be used to perform this task.

On the positive side, an enclosed ROPS/FOPS provides operator protection from adverse weather conditions and permits the operator to effectively work his machine during periods when an open machine could not be operated. Protective enclosures are available that have heaters, air conditioners, positive pressure systems, air filters and noise control packages. These units are more expensive than the standard open ROPS/FOPS but may pay for themselves in increased productivity. Even the open ROPS/FOPS provides increased operator comfort during drizzles and light rains.

The use of ROPS/FOPS in underground mines presents the same installation and operator acceptance problems experienced in surface mines plus added problems in the area of work-function limitations. Since machine roll-overs in underground mines are very rare, there is little need for ROPS on equipment used underground. Fall-of-ground is a serious accident cause in certain areas of underground mines. If FOPS are required on equipment working forward of the unsupported roof or in any area of an underground mine, a problem of "clearance" is encountered. The machine that previously worked in a particular mine area may not be able to continue that work if a FOPS is installed. The present practice of some underground mine operators is to try to mine the mineralized zone with as low a mine back as possible and with the largest load capacity machines as possible consistent with the low height of the back. A simple example is a mine with a horizontal 3 foot thick mineralized zone. The height of the back may vary between 4 and 7 feet in different areas of the mine. This height is determined by the equipment used in the mine. If it were possible, the mine operator would like to mine only the 3 foot mineralized zone but this isn't practical for existing personnel and equipment reasons. The mine operator will use the largest capacity ore moving machines possible in his mine. One

5 cubic yard capacity load-haul-dump unit is more productive and more cost-effective than three 2 cubic yard load-haul-dump units. These larger machines tend to "crowd" the back or the roof.

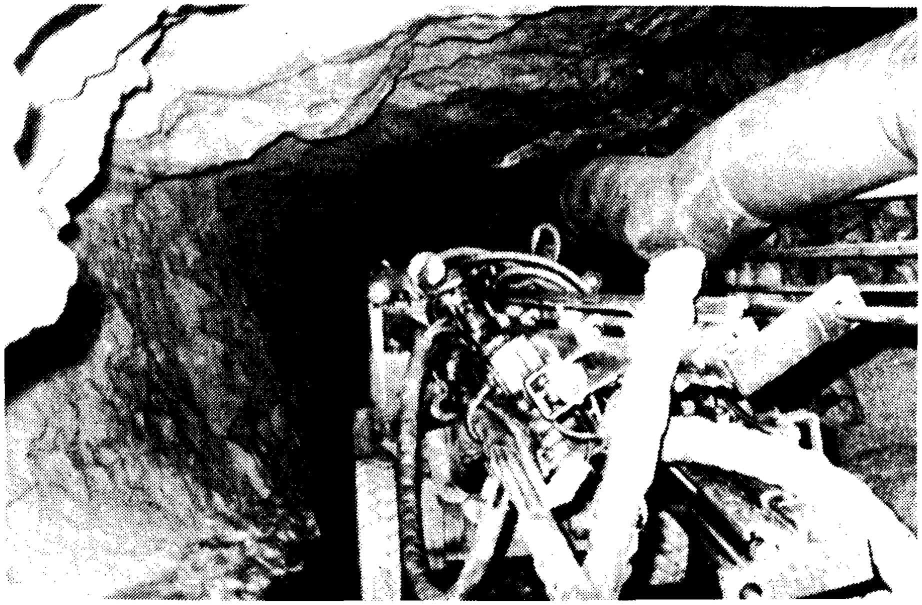
If canopies are required on equipment used in underground mines that have low backs, the mine operator must either raise the height of the mine back (a very expensive and non-productive operation) or substitute smaller mining equipment (another very expensive alternative that doesn't increase production).

This type of problem is not experienced in underground mines with high backs. Large underground salt mines are good examples of mines where the back or roof may be 30-100 feet high.

The clearance problem is not always solved by having mine back high enough to allow a FOPS-equipped machine to travel. It is common practice to hang water lines, compressed air lines, and vent lines from the mine back. These can cause clearance problems for the FOPS-equipped machine. Figures 4-30 and 4-31 illustrate this problem.

Another potential problem could develop for surface or underground mine operators if a FOPS performance criteria different than SAE J231 is used in a FOPS retrofit regulation. If the new FOPS criteria requires structural capabilities greater than SAE J231, many of the ROPS/FOPS units that have been previously supplied and installed must be strengthened in some manner. The mine operator is faced with modifying the ROPS/ FOPS-equipped machines he already owns in addition to acquiring new FOPS for his machines that do not presently have FOPS or ROPS.

The possibility of FOPS regulation that would allow in-the-field modification of an existing ROPS or FOPS is of concern to the ROPS manufacturers. In the past several years, both ROPS manufacturers



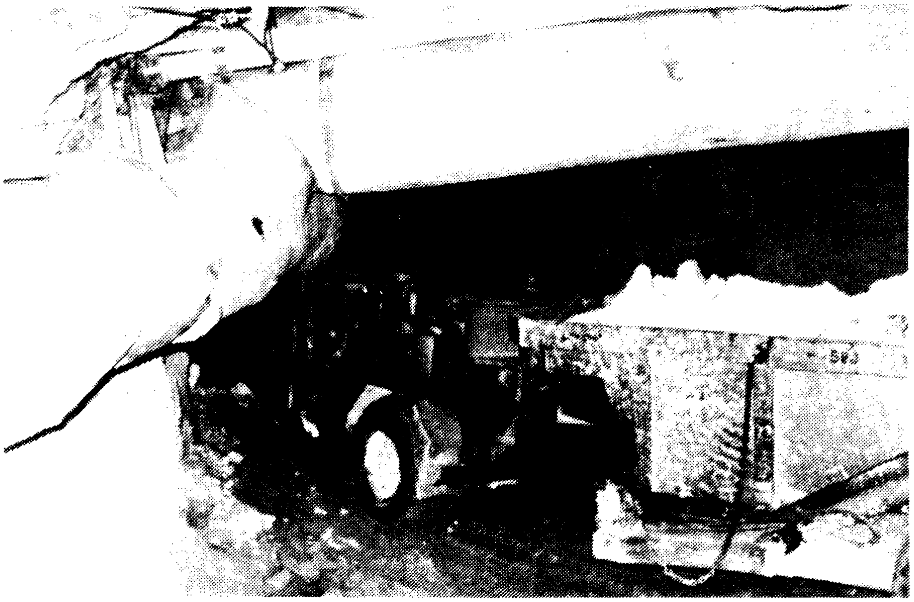


Figure 4-30. Underground Mine Vent Bag Clearance Problems

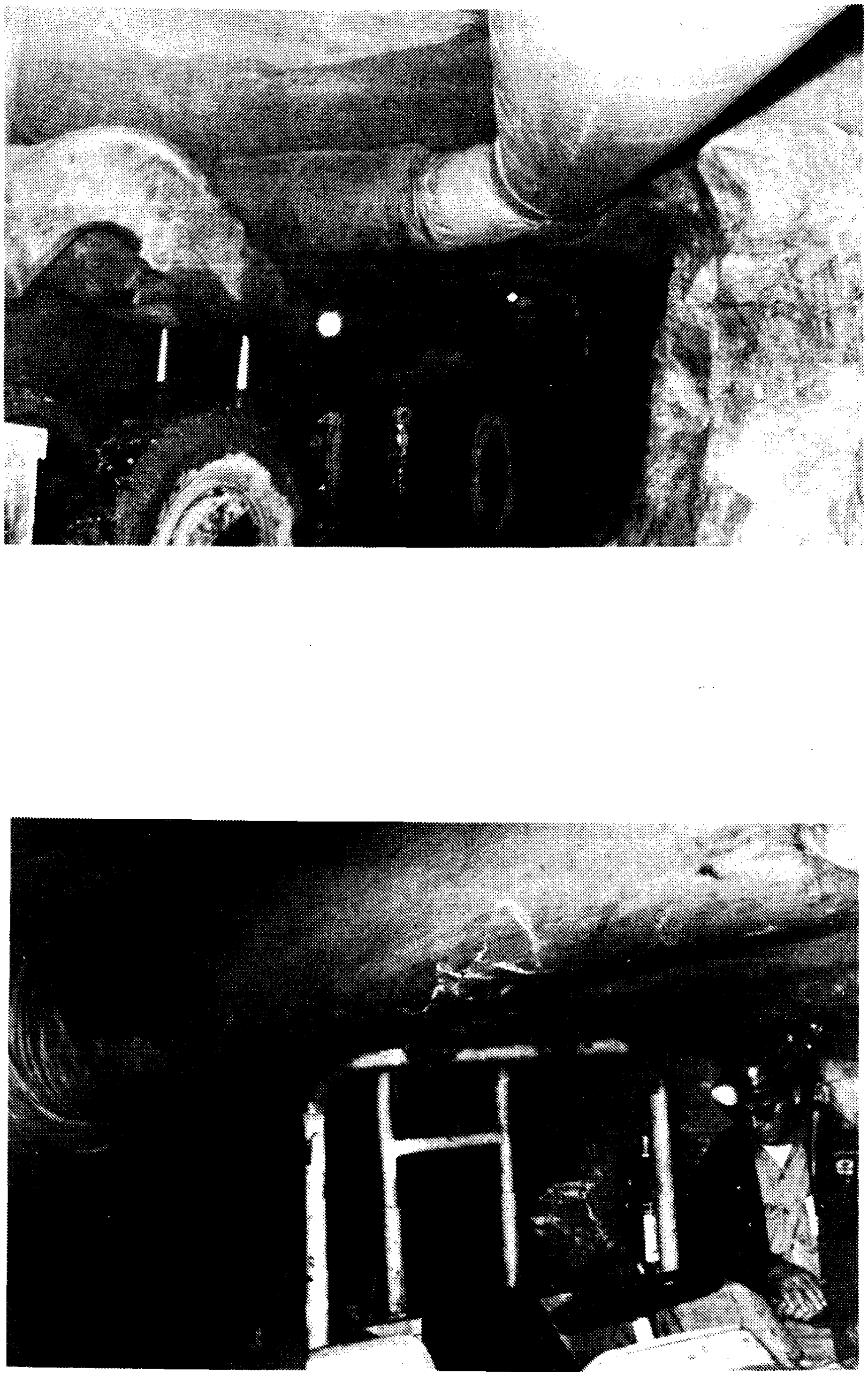


Figure 4-31. Underground Mine Canopy Clearance Problems

and the equipment manufacturers have been involved in an increasing number of liability lawsuits resulting from roll-over and falling object accidents in the construction industry. Typically, the counsel representing the injured operator or the widow of the operator attempts to show that the equipment manufacturer or the ROPS manufacturer contributed to the accident through faulty design, faulty workmanship, or faulty installation. If field modifications or field repair of ROPS and FOPS are performed, the ROPS manufacturer feels that there must be some method of insuring that the field work does not degrade the performance. Welding standards for field work are a help but do not insure that the mine operator's modifications are sound from an engineering standpoint. Requiring a design approval by a registered professional engineer is one way of placing the engineering responsibility, however, the "energy absorption" design approach used in SAE ROPS is not understood by most non-structural registered professional engineers. It is possible that the structural changes performed by the mine operator in trying to meet the FOPS performance requirements may, in some way, alter the energy absorption capability of the ROPS design. In any case, ROPS manufacturers will take the position that any modifications to their ROPS will invalidate the warranty and the SAE performance certification.

The requirement to install FOPS meeting a new performance criteria on new machines manufactured after some date in the future is an approach to upgrading the life-saving capability of FOPS without invalidating the FOPS that are already in use. This approach was used by MESA and OSHA in their existing ROPS regulations. Machines manufactured before a specified date can be fitted with ROPS that meet any one of several approved ROPS standards (State of California, U.S. Army Corps of Engineers, and Bureau of Reclamation). Machines manufactured after the specified date must be fitted with ROPS meeting the SAE performance criteria. As time passes and the older machines are phased out, the percentage of machines covered with ROPS that meet the more optimum SAE criteria grows larger and larger. This same approach could be used on FOPS.

4.6 ECONOMIC EFFECTS OF POSSIBLE PROTECTIVE STRUCTURE RETROFIT POLICIES

This section deals with the financial implications of four possible policies relative to retrofitting protective structures on the machines of interest. It was shown in Section 4.4 that approximately 48% of the population of the machines of interest already are equipped with some form of protective structure. A very large proportion of these structures is composed of what are commonly called "commercial ROPS": they were purchased as installed equipment on the machines, purchased from the machine manufacturer and installed in the field, or purchased from a ROPS manufacturer for field installation. ("Field installation," as used here, includes installation by a dealer, as distinguished from factory installation.) Most of these "commercial ROPS" are designed and constructed so as to meet or exceed the SAE J231 FOPS performance standard. That is to say, most have the SAE J231 capability and more. How much more is related closely to the gross vehicle weight of the machine for which the ROPS is designed. Accordingly, for this analysis, it was assumed that the proportion of the machine population which was estimated, based on the survey discussed in Section 4.3, to have ROPS installed, had "commercial ROPS," and therefore also had at least the SAE J231 FOPS capability. In fact, some commercial ROPS for small machines do not have SAE J231 capability and some machines in the population have "shop built ROPS" which were constructed to design standards known only to the mines which built them. However, the numbers of these are not sufficiently large to invalidate the assumption stated above with respect to estimation of total costs to retrofit large numbers of machines.

The estimate for the population of machines of interest is 49,293 machines; 23,524 of those were estimated to have ROPS installed.

The question addressed here is: "What are the costs to retrofit the estimated 25,765 machines which do not have ROPS installed?" In addition to answering this question, the financial impact on some of the machine owners who have small fleets of only pre-1970 machines is considered and the indirect financial implications of ROPS and FOPS on machines of interest which are used underground are discussed.

Sources of Financial Information

It is appropriate to express the costs of retrofit not only in absolute terms, but also in relative terms, specifically as a percentage of the average market value of the machines considered for retrofit. To do this, it is necessary to have data from a recognized source of market information. In this study, the market value data were taken from latest revisions of the Green Guide, published by the Equipment Guide – Book Company, Palo Alto, California. The "market value" used in the computations was the "average resale value" given in the Green Guide for machines without "extras."

The total cost of installing a commercial ROPS on a machine was calculated by adding to the ROPS manufacturer's FOB price an average transportation cost of $7 per 100 pounds of ROPS weight and installation costs varying from $125 to $250, depending on ROPS size. The transportation and installation cost estimates were obtained through consultation with ROPS manufacturers. The transportation cost will vary, of course, with the distance shipped and the mode employed. Installation cost depends on a great many factors, not the least of which is in the design of the ROPS mountings. Installation cost quotations for one machine varied from $150 to $600. For the calculations, the median values of estimates were used because they were consistently less than the averages. The assumption implicit in this choice is that mines generally have the tools and the skills required to do the installation work very efficiently. No costs were included in the total ROPS cost estimate for lost production time. It was assumed that installation would be done during a time when machines were out of service for other reasons. The ROPS prices used in the calculations are averages of selected high and low ROPS manufacturer's catalog prices (FOB) in effect during the first quarter of 1975. Some representative ROPS retrofit costs are given in Table 4-13. The method of using the ROPS costs was to construct a machine "type profile" for each machine age group in both underground and surface mine categories. The profile is a list of models which, in terms of ROPS costs and machine values, properly represent the machines in a given age group. A proportion was assigned to each model, from the survey data, so that a weighted average of machine value and ROPS retrofit cost could be calculated for each age group.

Figures 4-32 and 4-33 illustrate the relationship between ROPS retrofit cost and machine value. Figure 4-32 pertains to the Caterpillar D8 crawler tractor. A commercial ROPS is available for machines of this general model designation which are more than 20 years old. In the illustration, the years 1953-1973 were used. The average ROPS retrofit cost for 1972 and 1973 machines is \$1510; the average for the older machines is \$1920. The difference is related principally to the fact that many of the newest machines are manufactured with ROPS mountings installed. Although the ROPS retrofit cost is constant over many model years, the market value of the older machines is steadily decreasing, as shown by the market value curve. Thus, for older machines, ROPS retrofit may represent a large proportion of machine value. In the illustration, ROPS retrofit cost for a 1957 machine is 35% of the market value of the machine; for a 1953 machine it is 48%.

Table 4-13. Representative ROPS Retrofit Costs

MACHINE TYPE	MACHINE MODEL	YEAR OF MANUFACTURE	PRESENT MARKET VALUE	AVERAGE ROPS COST FOB	AVERAGE ROPS WEIGHT	AVERAGE TRANSPORTATION COST	AVERAGE INSTALLATION COST	AVERAGE TOTAL ROPS COST	ROPS COST AS % OF MACHINE MARKET VALUE
TRACTOR	Ford 4100	1973	$ 3850	$ 498	500#	$ 35	$ 125	$ 658	17.1
TRACTOR	Deere 300	1969	1500	700	550#	38	125	863	57.5
TRACTOR	Massey MF30	1975	5300	700	600#	42	130	872	16.5
TRACTOR	Case 580	1966	1700	730	680#	48	125	903	53.1
TRACTOR	Cat 814	1970	19,000	1260	1350#	95	220	1575	8.3
TRACTOR	Mich 280 III	1964	14,000	1450	1040#	73	210	1733	12.4
TRACTOR	IH TD-18	1955	2250	1100	1200#	84	200	1384	61.5
DOZER	Cat D-4	1953	1500	1220	810#	57	175	1452	96.8
DOZER	Cat D-7C	1957	6600	1290	1290#	90	200	1580	23.9
DOZER	A-C HD11B	1973	25,750	1225	1340#	94	220	1539	6.0
DOZER	IH TD-15	1962	4300	1230	1430#	100	225	1555	36.2
DOZER	IH TD-25B	1969	32,000	1535	2320#	162	240	1937	6.1
DOZER	Cat D-6C	1973	32,750	1422	990#	69	200	1691	5.2
DOZER	Terex 82-30	1970	31,000	1450	2092#	146	230	1826	5.9
GRADER	Cat 14G	1974	62,000	1172	1500#	105	230	1507	2.4
GRADER	Cat 12	1949	1500	1175	1500#	105	230	1510	100.0
GRADER	Galion T500L	1973	29,750	1150	642#	45	130	1325	4.5
GRADER	Deere 570A	1972	19,000	1400	1490#	104	230	1734	9.1
GRADER	Adams 660	1955	3500	1300	1370#	96	220	1616	46.2
GRADER	Wabco 777B	1968	16,000	1300	1300#	91	200	1591	9.9
LOADER	Cat 988	1965	37,000	1685	2360#	165	250	2100	5.7
LOADER	Cat 966C	1974	52,000	1500	1700#	119	240	1859	3.6
LOADER	Cat 955H	1962	8250	1190	1090#	76	200	1466	17.8
LOADER	Cat 950	1969	24,000	1500	1350#	95	240	1835	7.6
LOADER	Cat 992B	1974	180,000	3870	4046#	283	250	4403	2.4
LOADER	Mich 275	1972	58,500	1700	2180#	153	240	2093	3.6
LOADER	Mich 175	1969	29,500	1520	1820#	127	230	1877	6.4
LOADER	Mich 75	1969	15,000	1335	1320#	92	220	1647	11.0
LOADER	Mich 125AI	1961	5450	1475	1820#	127	230	1832	33.6
LOADER	A-C TL14	1962	4250	1030	630#	44	175	1249	29.4
LOADER	Deere DJ644A	1973	25,000	1700	1540#	108	240	2048	8.2
LOADER	Case W-26	1969	19,500	1243	980#	69	200	1512	7.8
LOADER	Terex 72-15	1971	29,500	1400	1170#	82	200	1682	5.7
LOADER	Trojan 300	1966	9000	1300	1300#	91	220	1611	17.9
PRIME MOVER	Cat 651	1967	49,000	2005	2530#	177	250	2432	5.0
PRIME MOVER	Cat 633C	1973	84,000	1850	1680#	118	230	2198	2.6
PRIME MOVER	Mich 210	1969	27,000	1340	1220#	85	200	1625	6.0
PRIME MOVER	Euclid SS-18	1960	8500	1700	1145#	80	200	1980	23.2
PRIME MOVER	Terex S-24	1972	84,000	2080	2320#	162	240	2482	3.0
PRIME MOVER	Cat DW21	1955	6300	1470	1320#	92	220	1782	28.3

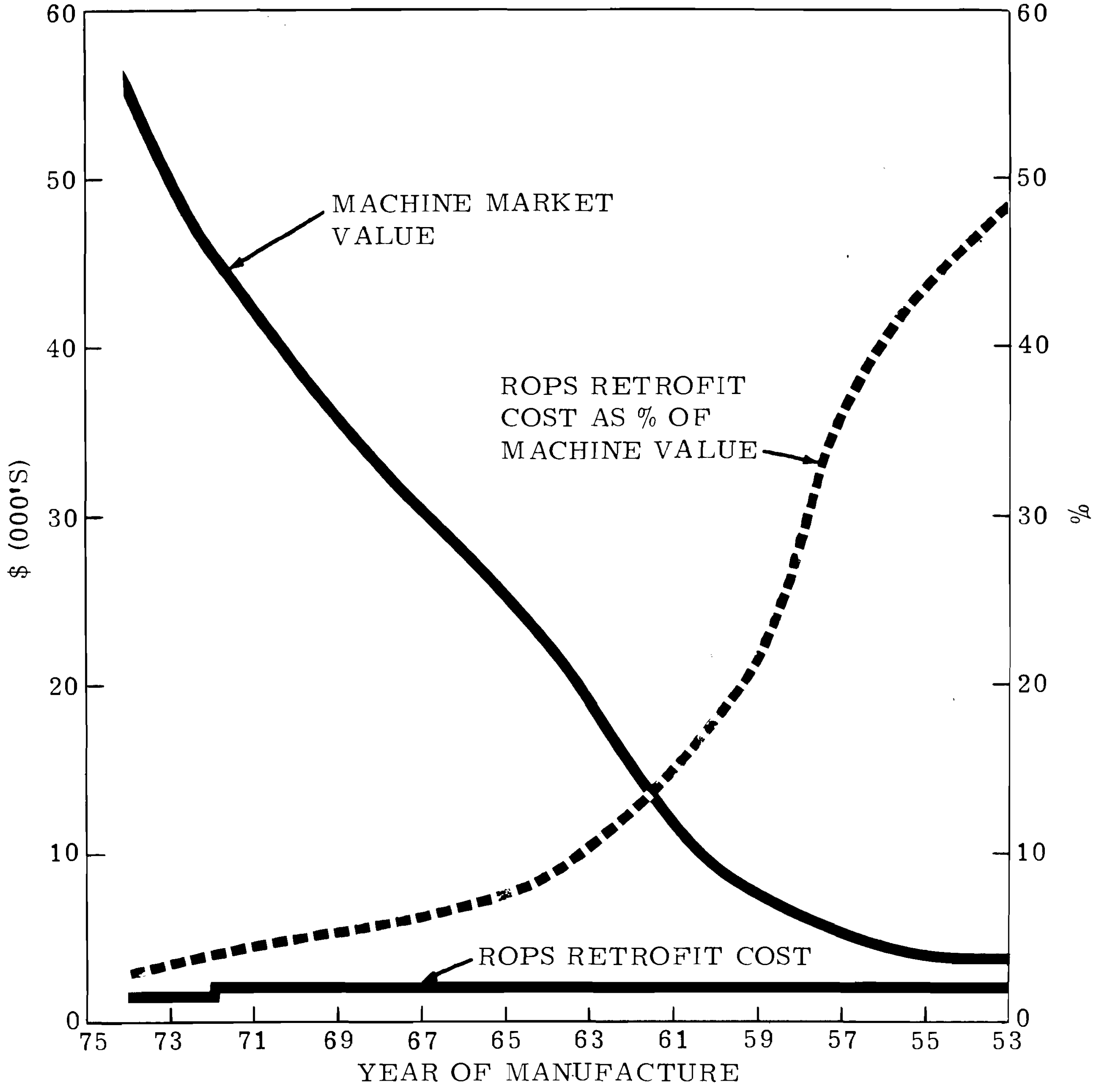


Figure 4-32. Machine Value vs. ROPS Retrofit Cost – Caterpillar D8

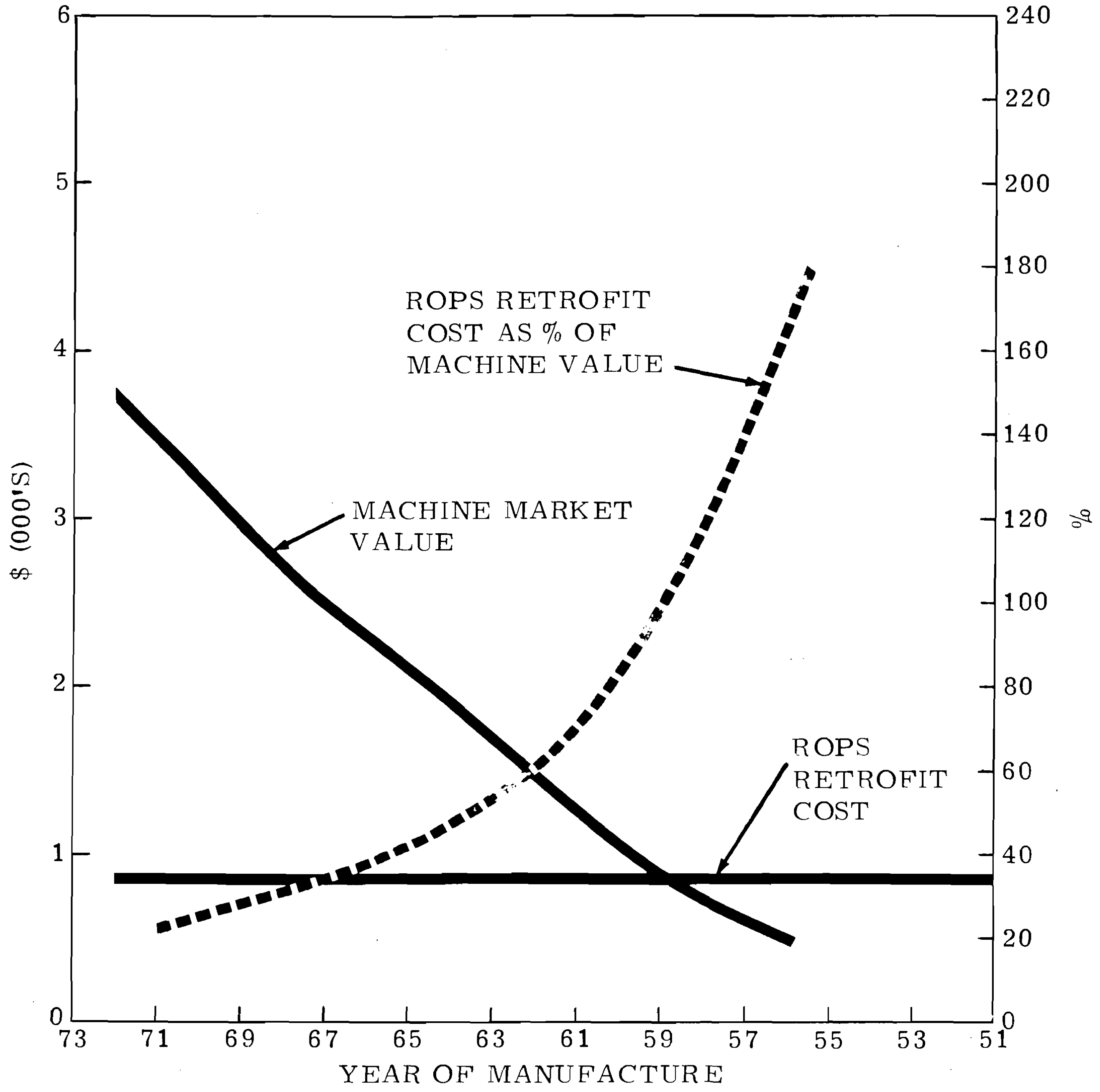


Figure 4-33. Machine Value vs. ROPS Retrofit Cost – Light Industrial Tractor

It is appropriate to call attention here to three points of special interest with regard to financial analysis of ROPS retrofit.

First, the cost of ROPS retrofit as a percentage of machine value is generally lower for heavy machines than for lighter machines. This point is illustrated by comparing Figure 4-32 to Figure 4-33. Figure 4-32 relates to a machine in the 50,000 pound class of gross vehicle weight. Figure 4-33 relates to one in the 6000 pound class.

Second, the ROPS retrofit costs used in this study are for what may be termed the "minimum ROPS," that is, ROPS which do not have any of the "options." Accordingly, the costs are substantially lower than those which actually would be incurred if retrofit were required. For example, the $1920 average ROPS retrofit cost used in the D8 illustration in Figure 4-32 does not include curved front sweeps, tank guard, back screen or side screens. Adding these would increase the cost to $2935. Adding the tank guard only, an option which is very frequently chosen, increases the ROPS retrofit cost to about $2040. The ROPS used in the analysis here is the kind usually referred to in the trade literature as a "ROPS canopy," as distinguished from a "ROPS cab." A "ROPS cab" costs two to four times as much as a "ROPS canopy," depending upon the type of machine and the manufacturer.

Third, the manufacturers' prices for new machines and attachments increased substantially in 1975. For example, the Green Guide reported that "new price average increases" for wheel tractors of 7% to 41%, depending upon the manufacturer, had occurred since the section from which data were taken for this study was printed. Price increases for attachments were in the range 7% to 48%. Under these conditions, used machine market values increase also, approximately in proportion to the new machine price increases. ROPS retrofit cost as a percentage of machine value is not changed appreciably, but the estimates of dollar costs to retrofit ROPS given in this study must be multiplied by some value to obtain a good estimate for the time period in which retrofit might actually be accomplished. The WAI estimate of the multiplier for late 1976 retrofit is 1.24; the expected change in prices will be 24% between early 1975 and late 1976.

Figure 4-33 pertains to a light wheeled tractor (6000 pound class) illustration. The Massey Ferguson MF-302, 304 and earlier 303 models are examples of this weight class. The average cost of retrofit of the available commercial ROPS is $880 for machines manufactured during the 17 years given on the graph. The market value of 1959 machines is $900. For machines manufactured before 1959, the ROPS retrofit cost exceeds the market value. The retrofit cost for a 1956 machine is 170% of its market value.

To conclude the discussion of ROPS retrofit cost relative to machine age, Figure 4-34 is a graph which illustrates the matter in aggregate terms. The ROPS cost curve is flat over a large range of machine ages, but it slopes downward slightly at the low age end and upward at the high age end. The reason for the downward slope is that newer machines are built with ROPS mountings installed. The reason for the upward slope is that the unit ROPS cost is higher for some very old machines which are very few in number. A ROPS is "commercially available" in the sense that one can be purchased from a ROPS manufacturer, but if it is related to a machine for which the manufacturer has had no previous ROPS sales, the cost could be high. At some age, A_x, the aggregate ROPS retrofit cost will equal the aggregate market value of machines of that age.

Table 4-14 shows the estimates, from Section 4.3, of the numbers of present machines of interest which do not have protective structures

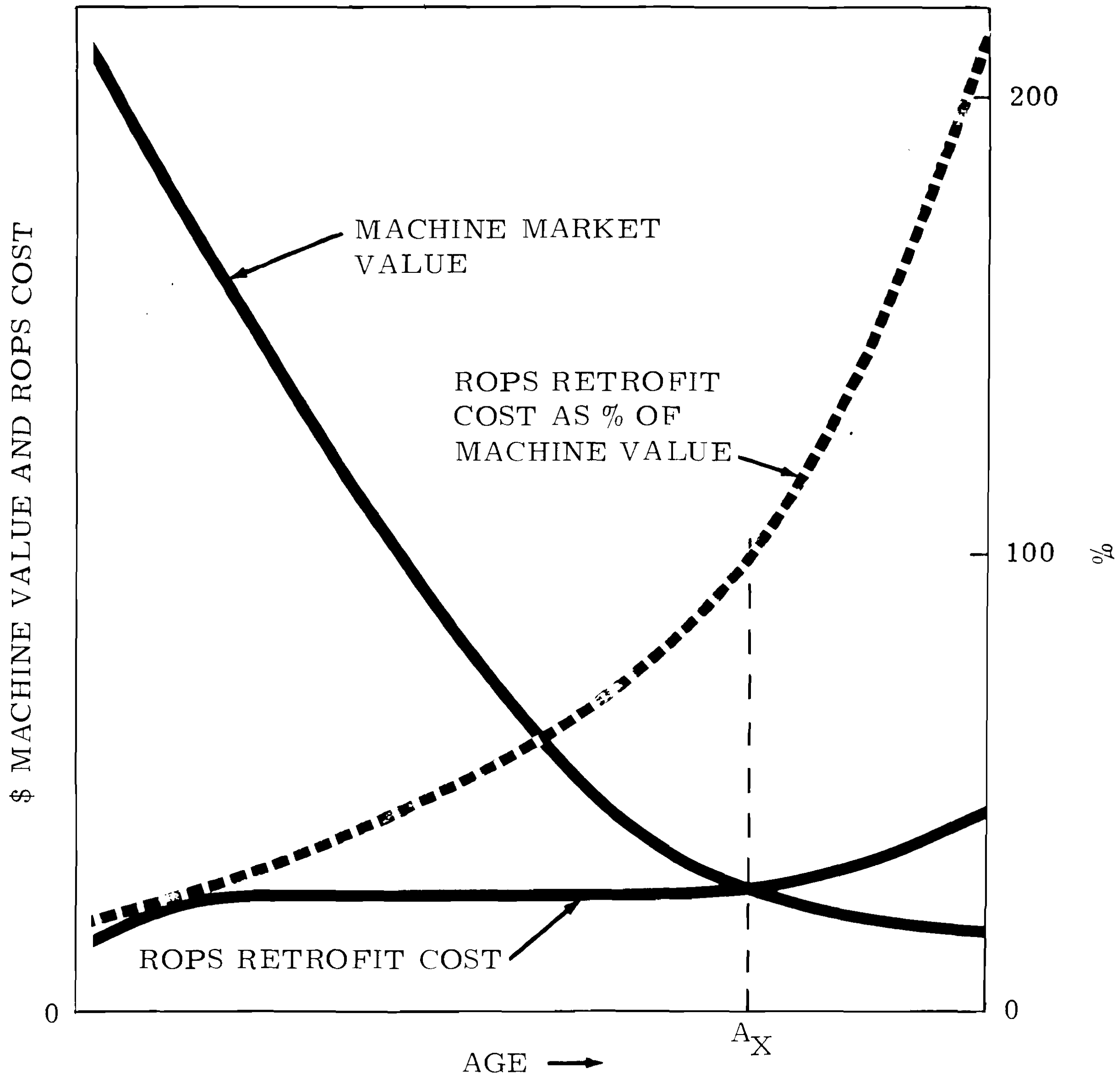


Figure 4-34. Machine Value vs. ROPS Retrofit Cost – General

Table 4-14. ROPS/FOPS Retrofit Costs

Machine Type	Year of Manufacture									
	Post-1969		1965-1969		1960-1964		Before 1960		Totals for Types	
Front-End Loaders										
No. of Machines	4,457		6,239		2,377		1,053		14,126	
Retrofit Cost		$ 1,976		$ 1,905		$ 1,564		$ 1,412		
Total Retrofit Cost		8,807,032		11,885,295		3,717,628		1,486,836		$25,896,791
Dozers										
No. of Machines	459		1,675		1,053		1,485		4,672	
Retrofit Cost		1,775		1,683		1,806		1,644		
Total Retrofit Cost		814,725		2,819,025		1,901,718		2,441,340		7,976,808
Graders										
No. of Machines	297		729		513		972		2,511	
Retrofit Cost		1,607		1,574		1,508		1,493		
Total Retrofit Cost		477,279		1,147,446		773,604		1,451,196		3,849,525
Tractors										
No. of Machines	378		1,405		324		756		2,863	
Retrofit Cost		1,301		1,498		1,432		1,412		
Total Retrofit Cost		491,778		2,104,690		463,968		1,067,472		4,127,908
Prime Movers										
No. of Machines	324		594		405		270		1,593	
Retrofit Cost		1,810		1,782		2,000		1,434		
Total Retrofit Cost		586,440		1,058,508		810,000		387,180		2,842,128
Totals for Age Groups										
No. of Machines	5,915		10,642		4,672		4,536		25,765	
Total Retrofit Cost		$11,177,254		$19,014,964		$7,666,918		$6,834,024		$44,693,160

Note: ROPS unit retrofit costs are weighted averages for machine types.

installed. The table separates the machines by type and age group. The unit cost for retrofit of machines in each block in the type-age matrix was developed in the manner discussed above through the use of the "type profile." It is a weighted average for machines in the type-age block. Multiplying the weighted average by the number of machines in the population to which it applies gives the retrofit cost estimates shown.

A policy decision to retrofit FOPS with greater capability than SAE J231 requires would raise a corollary question about the estimated cost of modifying ROPS already installed to attain that same capability. This question is fraught with a great many implications, technical, financial and political. It is the kind of question which can be answered fully if it can be answered at all, only through an extensive study.

Table 4-15 provides the estimates of costs, for retrofit of commercial ROPS on all machines not presently ROPS-equipped, as a percentage of machine value. The estimates of machine market value were developed from a "type profile" in the same manner as the ROPS retrofit cost estimates were done.

For some of the machines in the population, the costs of ROPS retrofit represent but a fraction of the financial implications of a ROPS retrofit policy. These are the machines used in low back underground mines, that is, mines with a roof height less than 12 feet. The point to be emphasized here is that machines used in this kind of mine, although few in number relative to the total population, represent a special kind of financial problem. The retrofit of a commercial ROPS could, in many cases, make the machines unusable in the mines unless the backs were made higher. This would require extensive removal of additional material

Table 4-15. ROPS Retrofit Costs as Percentage of Machine Value

Machine Type	Year of Manufacture									
	Post-1969		1965-1969		1960-1964		Before 1960		Totals for Types	
Front-End Loaders										
ROPS Retrofit Cost	$ 8,807,032		$ 11,885,295		$ 3,717,628		$ 1,486,836		$ 25,896,791	
Machine Value	263,475,555		141,862,382		19,645,905		3,280,095		428,263,937	
Cost as % of Value		3.34%		8.38%		18.92%		45.33%		6.05%
Dozers										
ROPS Retrofit Cost	814,725		2,819,025		1,901,718		2,441,340		7,976,808	
Machine Value	23,477,850		36,808,125		16,138,279		4,645,080		81,069,334	
Cost as % of Value		3.47%		7.66%		11.78%		52.56%		9.84%
Graders										
ROPS Retrofit Cost	477,279		1,147,446		773,604		1,451,196		3,849,525	
Machine Value	8,550,036		10,971,450		3,601,260		2,753,676		25,876,422	
Cost as % of Value		5.58%		10.46%		21.48%		52.70%		14.88%
Tractors										
ROPS Retrofit Cost	491,778		2,104,690		463,968		1,067,472		4,127,908	
Machine Value	9,273,474		20,428,700		1,317,060		1,468,908		32,488,142	
Cost as % of Value		5.30%		10.30%		35.23%		72.67%		12.71%
Prime Movers										
ROPS Retrofit Cost	586,440		1,058,508		810,000		387,180		2,842,128	
Machine Value	22,708,512		19,453,500		5,629,500		1,599,750		49,391,262	
Cost as % of Value		2.58%		5.44%		14.39%		24.20%		5.75%
Totals for Age Group										
ROPS Retrofit Cost	$ 11,147,254		$ 19,014,964		$ 7,666,918		$ 6,834,024			
Machine Value	$327,485,427		$229,524,157		$46,332,004		$13,747,509			
Cost as % of Value		3.40%		8.28%		16.55%		49.71%		

at great expense or, alternatively, discontinuing the use of the machines and replacing them with "low profile" types or smaller capacity units, also at great expense. Clearly, a detailed analysis of alternatives for all mines which would be affected is beyond the scope of this study. However, through mine visits, discussions, and correspondence during the course of this study it became evident that some underground mine people vigorously oppose any thought of ROPS/FOPS retrofit of all machines of interest. Their reasons are clear and persuasive. It is true that a commercial ROPS increases the height of the machine. This is a problem even in the construction industry. When machines are moved from site to site under overpasses, it is sometimes necessary to remove the ROPS. The low back mines would have a problem for which no low cost solution seems possible.

The ROPS could be reduced somewhat in height, but not without sacrificing a significant degree of protection capability as well as restricting operator vision and freedom of movement and egress. The low back mine operators point out, correctly according to the MESA data, that there are very few fall-of-ground accidents which involve the machines of interest and that underground roll-overs involving the machines of interest are extremely rare.

Table 4-16 shows the estimate of the machines of interest operated by underground mines and the estimates of those which are actually used underground either full-time or part-time. It does not show how many are used in low back underground mines. The survey did not seek this information and WAI cannot provide a confident estimate of the number. The information in Table 4-16 is presented here because a possible ROPS retrofit policy might be one which required retrofit of machines of interest manufactured after a selected date, except those

Table 4-16. Estimate of Machines of Interest
Used Only Underground or Underground and Surface

	ROPS	No ROPS	Total	Percent
Front-End Loaders	241	509	750	61.7%
Dozers	36	44	80	6.6%
Graders	10	62	72	5.9%
Tractors	9	268	277	22.8%
Prime Movers	27	9	36	3.0%
Total	323	892	1215	
Percent	26.6%	73.4%		100.0%

used in certain underground mines. Under those circumstances, it would be appropriate to estimate the cost of implementing the policy by subtracting from the total population some proportion of the numbers in Table 4-16 which represents the machines used in underground low back mines. The discussion above does not apply to room and pillar mines which have very high backs (as in some salt mines and lead mines contacted during this study) or at least does not apply to the same degree.

Figure 4-35 shows the total estimated population of machines of interest by fleet size and composition. Of special interest is the estimate that nearly 15% of the owners have fleets of 1 to 5 which contain only pre-1970 machines. Some additional analysis was made of the sample data for these small fleets with a view to estimating what proportion of the owners of fleets of 1 to 5 machines of interest owned only machines of interest and only pre-1970 machines because the financial impact on

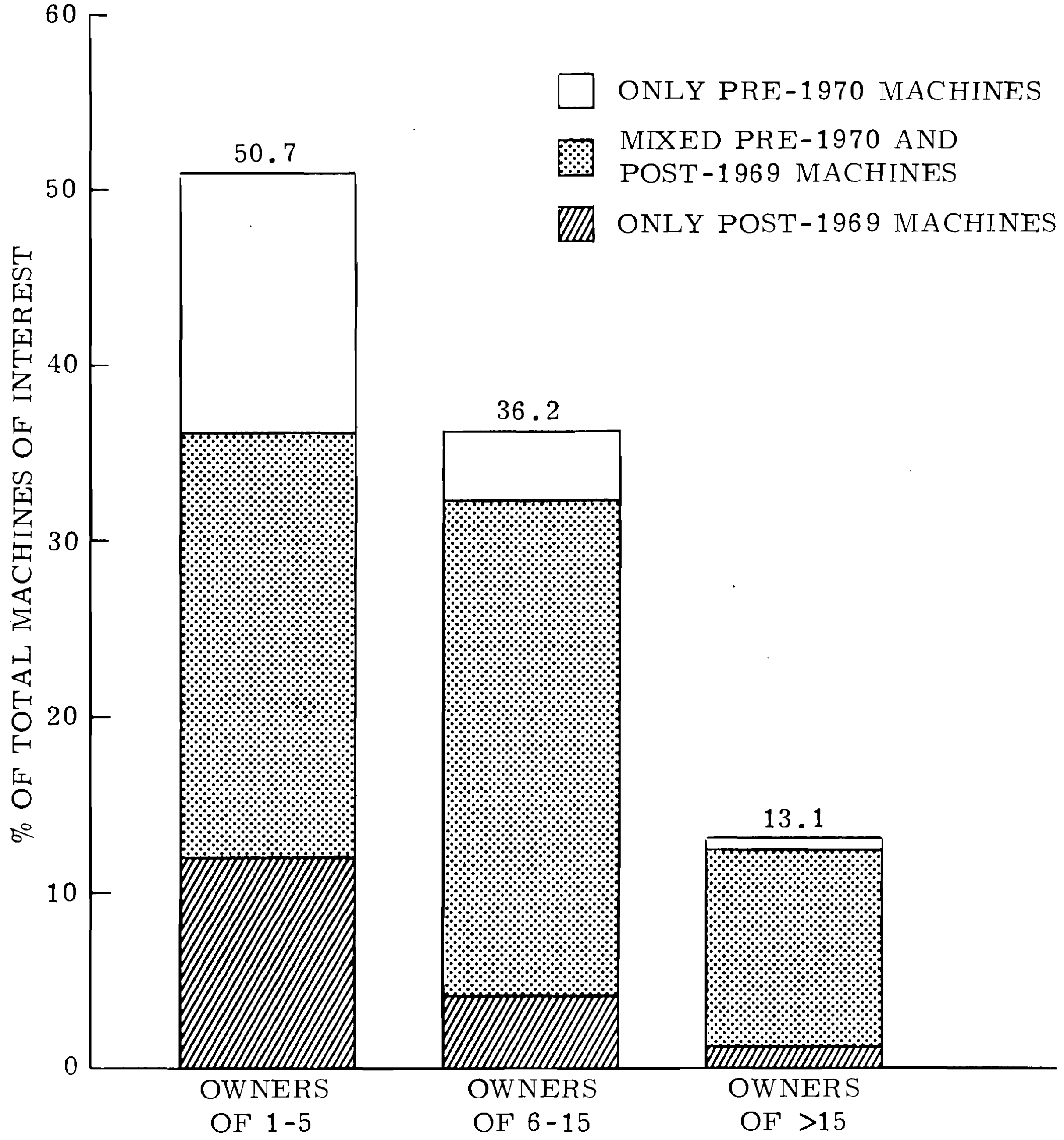


Figure 4-35. Fleet Size and Composition — Machines of Interest

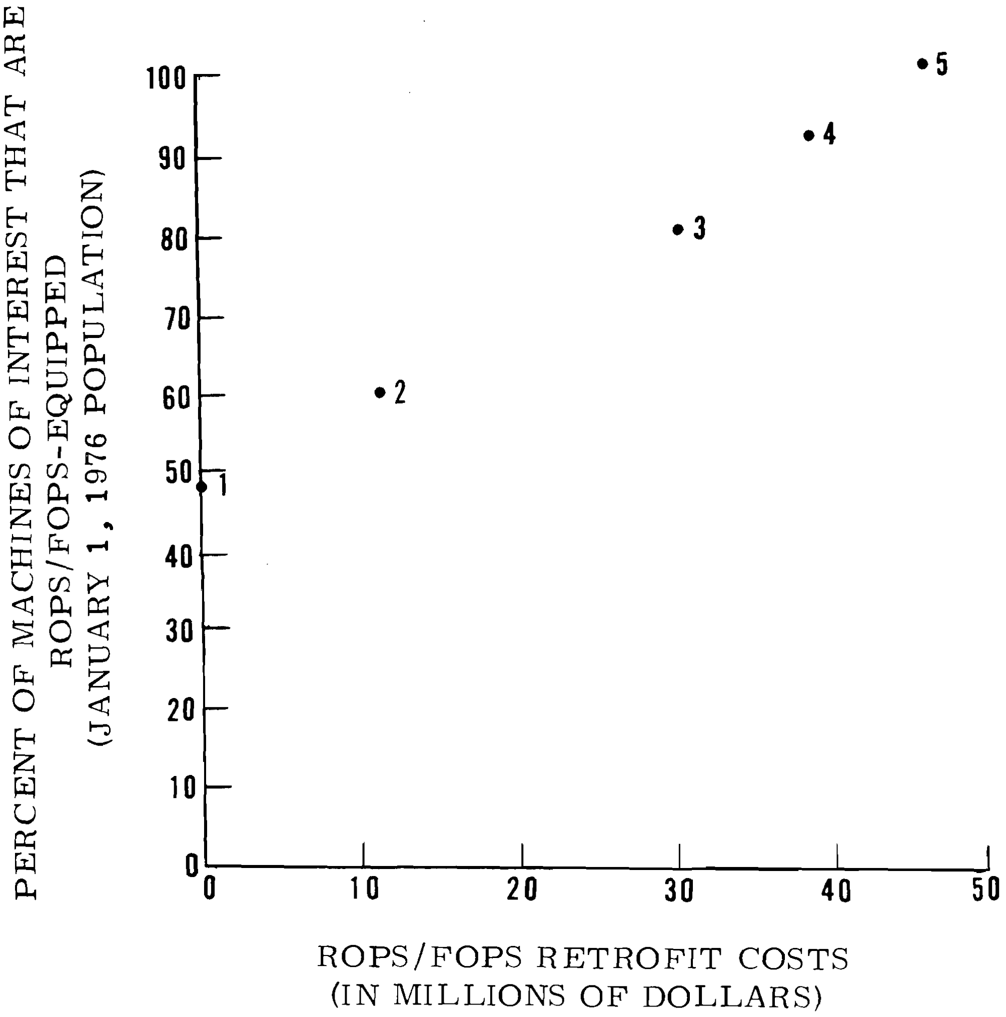
such owners might be relatively much greater than for any other owner group.

Based on the survey data, it is estimated that approximately 7% of all of the owners had fleets of one to five composed of machines of interest only, all of which were manufactured before 1970. In other, more precise, terms, there are approximately 980 mines which have self-propelled machine fleets (except trucks) composed only of machines of interest manufactured before 1970. Approximately 60% of these owners have no protective structures on any of their machines of interest. So, there are about 600 owners of 1 to 5 machines of interest for whom a ROPS retrofit requirement which covered all pre-1970 machines would represent a financial burden of 15% to 60% of the market value of the machines. The majority of these owners are in the sand and gravel industry. For a very small number of owners, ROPS retrofit would represent a cost of 90% to 100% of the market value of the machines. This does not mean, of course, that the greatest financial impact in dollar terms of ROPS retrofit would be on the small fleet owners. Some large fleet owners also have large numbers of machines which are not equipped with protective structures. One company, which operates several mines, reported nearly 90 machines of interest. More than 60 were pre-1970 machines which had no protective structures installed. The cost of total retrofit of ROPS to this company would exceed $120,000 for the pre-1970 machines alone.

Figure 4-36 summarizes the industry costs of complying with five policy alternatives related to providing ROPS/ROPS capability. The five policies are:

1) No retrofit requirement, consider only ROPS on new equipment.
2) Retrofit with commercial ROPS all machines of interest manufactured after January 1, 1970.
3) Retrofit all machines of interest manufactured after January 1, 1965.
4) Retrofit all machines of interest manufactured after January 1, 1960.
5) Retrofit all machines.

Figure 4-36 displays the estimated cost to equip with ROPS all machines of interest not already so equipped. Approximately 48% already have ROPS. The estimates are for fourth quarter 1974 prices and values except for 1975 machines. An appropriate multiplier must be used to estimate costs for the time period in which retrofit may be considered. The machine population estimates are for fourth quarter 1975.



POLICY 1 – NO RETROFIT REQUIREMENTS, CONSIDER ONLY ROPS/FOPS ON NEW EQUIPMENT

POLICY 2 – RETROFIT ALL MACHINES OF INTEREST MANUFACTURED AFTER JANUARY 1, 1970

POLICY 3 – RETROFIT ALL MACHINES OF INTEREST MANUFACTURED AFTER JANUARY 1, 1965

POLICY 4 – RETROFIT ALL MACHINES OF INTEREST MANUFACTURED AFTER JANUARY 1, 1960

POLICY 5 – RETROFIT ALL MACHINES

Figure 4-36. ROPS/FOPS Retrofit Costs vs. Percent of Vehicle Population (January 1, 1976) ROPS/FOPS Equipped

SECTION 5.0

REFERENCES

The following list of publications is presented for the reader who is interested in the details of many of the reports, performance standards, regulations, etc., that are referenced in this report.

ROPS/FOPS REPORTS

1) CANOPY – A Computer Program for the Structural Analysis of Space Frame Protective Canopies, Bureau of Mines Information Circular IC 8546, by Dr. Stephen Sawyer

2) Design and Installation of ROPS for Army Retrofit Program, by Paul D. Hopler and William O. Stewart (SAE Paper 730752)

3) Dynamic Testing of Tractor Protection Cabs, by Harold Ason Moberg (SAE Paper 730761)

4) Earthmoving Equipment Cab Design, by Gardner P. Burton (SAE Paper 730433)

5) Elastic Plane Frame Analysis of Semisymmetric Cabs and Canopies Used on Underground Electric Face Equipment, Bureau of Mines Report of Investigations RI 7799, by Dr. Stephen Sawyer and Darryl Brogan

6) Engineering Basics of Roll Over Protective Structures, by G. L. Klose (SAE Paper 690569)

7) European Legislative Requirements for Agricultural Tractors and Farm Machines, by Horace F. Howell (SAE Paper 730788)

8) Experimental Verification of the Computer Program CANOPY by the Static Testing of a Continuous Miner Canopy, MESA Informational Report IR 1004, by Dr. Stephen Sawyer, Darryl D. Brogan, John L. Dahle, and George J. Karabin, Jr.

9) Nebraska Tractor Test – Programs and Philosophy, by W. E. Spinter, G. W. Steinbruegge, D. E. Lane, and L. F. Larson (SAE Paper 730763)

10) A North European Tractor Cab, by E. Gunner Ahlastrom (SAE Paper 730792)

11) Roll-Over Protective Structures for Farm and Construction Tractors – A 50-Year Review, by James F. Arndt (SAE Paper 710508)

12) ROPS Safety Compliance Testing, by Robert W. Weed and Hartwell C. Davis (SAE Paper 710694)

13) Study to Determine the Engineering and Economic Feasibility of Retrofitting ROPS on Pre-July 1, 1969 Construction Equipment, by Woodward Associates (DOL Contract No. L-73-158)

14) Substantial Underground Cabs and Canopies Provide Needed Protection for Equipment Operators, by Dr. Stephen Sawyer and John McCormick, article published in Coal Mining and Processing Magazine

15) A Testing Procedure for the Certification of Underground Protection Cabs and Canopies, MESA Informational Report IR 1002, by Dr. Stephen Sawyer and Darryl Brogan

ROPS/FOPS REGULATIONS

1) Bureau of Reclamation, Safety and Health Regulations for Construction, Part II – paragraphs 9.6 thru 9.9 (ROPS, FOPS)

2) Corps of Engineers, Safety Manual, General Safety Requirements, EM 385-1-1 including Change 1, March 27, 1972 – paragraph 18.A.20 (ROPS, FOPS)

3) Mining Enforcement and Safety Administration, Part 75, Coal Mine Health and Safety – paragraph 75.1710-1 (FOPS)

4) Mining Enforcement and Safety Administration, Part 77, Coal Mine Health and Safety – paragraphs 77.403, 77.403a (ROPS, FOPS)

5) Occupational Safety and Health Administration, Part 1928, Occupational Safety and Health Standards for Agriculture; Subpart C, Roll-Over Protective Structures – paragraph 1928.51 (ROPS)

6) Occupational Safety and Health Administration, Subpart W, Roll-Over Protection Structures; Overhead Protection – paragraphs 1926.1000 thru 1926.1003 (ROPS, FOPS)

ROPS/FOPS – PERFORMANCE STANDARDS

Society of Automotive Engineers, Inc., 400 Commonwealth Drive, Warrendale, Pennsylvania 15096

SAE J167 – Protective Frame with Overhead Protection – Test Procedures and Performance Requirements

SAE J168 – Protective Enclosures – Test Procedures and Performance Requirements

SAE J231 – Minimum Performance Criteria for Falling Object Protective Structure (FOPS)

SAE J333a – Operator Protection for Wheel Type Agricultural and Industrial Tractors

SAE J334a – Protective Frame Test Procedures and Performance Requirements

SAE J1040a – Performance Criteria for Roll-Over Protective Structures (ROPS) for Earthmoving, Construction, Logging, and Industrial Vehicles

SAE J397a – Deflection Limiting Volume for Laboratory Evaluation of Roll-Over Protective Structures (ROPS) and Falling Object Protective Structures (FOPS) of Construction and Industrial Vehicles

SAE J320b – Minimum Performance Criteria for Roll-Over Protective Structures (ROPS) for Prime Movers

SAE J394a – Minimum Performance Criteria for Roll-Over Protective Structures for Wheeled Front-End Loaders and Wheeled Dozers

SAE J395a – Minimum Performance Criteria for Roll-Over Protective Structures for Track-Type Tractors and Track-Type Front-End Loaders

SAE J396a – Minimum Performance Criteria for Roll-Over Protective Structures for Motor Graders

Note: The SAE Recommended Practice SAE J1040a incorporates material formerly published as SAE J320, J394, J395, and J396.

PLASTIC DESIGN PRINCIPLES

Applied Plastic Design in Steel, by R. Disque

Plastic Analysis of Structures, by P. Hodge

Plastic Analysis and Design, by C. Massonnet

Plastic Design of Steel Frames, by L. Beedle

Plastic Methods of Structural Analysis, by B. Neal

Plastic Methods of Structural Analysis, by B. Neal

Strength of Materials, by F. Shanley

USBM Contract No. J0357110

WA Report 76-22F
February 20, 1976

APPENDICES
TO
PROGRAM FINAL REPORT

"Design Criteria and Guidelines for Falling Object Protective Structure"

U.S. Bureau of Mines
Pittsburgh, PA

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APPENDIX A1

FOPS CERTIFICATION PROCEDURES

A falling object protective structure (FOPS) must be designed to strict standards to achieve a structure which will perform satisfactorily under the complex loading environment during a rock fall. A rock fall imparts dynamic loads to the FOPS which are reacted by the elastic and sometimes plastic deformation of the canopy, vehicle chassis, axles and tires. An extensive engineering study was performed to establish practical methods of certifying FOPS. Designs certified to these standards have been shown to exhibit energy absorbing characteristics needed to withstand the rock fall kinetic energy requirement.

Certification Requirements

FOPS may be required on the following equipment used in surface metal-nonmetal mines and the surface areas of underground metal-nonmetal mines:

- Track-type or wheeled front-end loaders
- Dozers
- Tractors (excluding over the road type tractors)
- Motor graders
- Prime movers

FOPS installed on these vehicles must meet material, welding, impact resistance, and static load/deflection requirements specified in the following paragraphs.

Material Requirements

The material used in the fabrication of the canopy and attachment structure must meet the Charpy V-notch impact strengths specified in Section 7.0 of the "Performance Criteria for Roll-Over Protective Structures (ROPS) for Earthmoving, Construction, Logging, and Industrial Vehicles – SAE Recommended Practice J1040." These values are repeated in Table A1-1. Structural members of the canopy and attachment to the vehicle shall be made of steels that have Charpy V-notch impact strengths as shown in Table A1-1 at -30°C (-20°F). Specimens are to be "longitudinal" and taken from flat stock, tubular, or structural

Table A1-1. Charpy V-Notch Impact Strengths

Specimen Size, mm	J	Ft-Lb
10 x 10[a]	11.0	8.0
10 x 9	10.0	7.5
10 x 8	9.5	7.0
10 x 7.5[a]	9.5	7.0
10 x 7	9.0	6.5
10 x 6.7	8.5	6.5
10 x 6	8.0	6.0
10 x 5[a]	7.5	5.5
10 x 4	7.0	5.0
10 x 3.3	6.0	4.5
10 x 3	6.0	4.5
10 x 2.5[a]	5.5	4.0

[a] Indicates preferred size. Specimen size shall be no less than the largest preferred size that the material will permit.

Reference: ASTM A 370-68, Standard Methods and Definitions for Mechanical Testing of Steel Products.

sections before forming or welding for use in the canopy. Specimens from tubular or structural sections are to be taken from the middle of the side of greatest dimension, not to include welds.

Bolts and nuts used to attach the canopy to the vehicle frame and to connect structural parts of the canopy shall be SAE Grade 5 or 8.

Welding Requirements

All welding on the canopy and attachment structure to the vehicle must comply with the "Specification for Welding Rollover-Falling Object Protective Structures (ROPS and FOPS)" currently being prepared by the American Welding Society's D14h Subcommittee. Final publication is scheduled for the first half of 1976. Adherence to this specification is required during fabrication, installation and repair of the canopy and attachment structure. This specification covers in detail requirements for base metals; welding processes and consumables; joint and welder qualification; joint preparation; workmanship and weld quality requirements; inspection; installation; and field repair and modification.

Canopy Top Design Requirements

The canopy top must be designed to protect the vehicle operator from penetration of the falling object. Compliance with this requirement shall be established by either of the following:

1) Meeting specified design guidelines.

2) Successfully passing a SAE J231 drop test.

Canopy Top Design Guidelines — The canopy top shall be covered with a steelplate with a thickness of 0.1875 or greater; or it shall be covered by steel mesh 0.50 inch minimum diameter with a 2.0 x 2.0 inch maximum center-to-center grid spacing. An equivalent mesh fabricated with bar stock can also be used. With either of the design concepts, the maximum unsupported span distance between roof reinforcement members cannot be greater than 24 inches. A dynamic drop test is not required for designs meeting these configuration requirements.

Dynamic Drop Test – Designs not meeting the guidelines specified above can be certified by a dynamic drop test. The test must be conducted in accordance with SAE Recommended Practice J231 which specifies the minimum performance criteria for falling object protective structure (FOPS). The test requires that a 500-pound weight with an impact diameter of 8.0 inches be dropped onto the center of the canopy. All of the references to the critical zone in SAE J231 shall be deleted. Instead, a requirement that the maximum deflection at the point of impact shall not exceed 4.0 inches under the first or any subsequent impacts of the drop test object shall be added.

Static Top Load Requirement

Protective canopies are required to elastically support a static load of 36,000 pounds applied to the plan view area of the canopy top applied within the middle ninth of the plan view area. Four acceptable methods of certification have been developed as follows:

1) Static test of the canopy, attachment joints, vehicle chassis and axle structure.

2) Static test of the canopy and noncomputer analysis of the attachment joints and vehicle chassis.

3) Noncomputer analysis of the canopy, attachment joints and vehicle chassis.

4) Computer analysis of the canopy and noncomputer analysis of the attachment structure and vehicle chassis.

Method 1 — A static test of the entire FOPS including protective canopy, attachment joints, vehicle chassis, and axles is required with Method 1. The procedure involves the distribution of static loads near the center of the protective structure's top and the measurement of vertical deflection at the center of the load application. The canopy is tested while mounted on the vehicle chassis which is rigidly attached to the test platform at the axles.

With Method 1 all of the load carrying FOPS components are tested; therefore structural analysis is not required. Option A of the FOPS Test Procedure (Appendix A3) presents a step-by-step sequence for conducting this test.

Method 2 — A static test of the canopy attached to a rigid platform, engineering computations of the attachment structure and adherence to certain design guidelines is required with Method 2. The test procedure is identical to that described in Method 1 except the test specimen includes only the canopy. Since the joint and the structure attaching the canopy to the vehicle are not tested, an engineering analysis is required. If the canopy is mounted to the main vehicle frame and meets specified design guidelines, no analysis of the vehicle frame is required. An engineering analysis of the vehicle frame is required for designs not meeting these requirements.

Option B of the FOPS Test Procedure (Appendix A3) presents a step-by-step sequence for conducting this test.

Method 3 — A noncomputer analysis of the canopy, attachment joints and vehicle chassis is required with Method 3. The details of the analysis procedure are described in the FOPS Design Guide (Appendix A2). In general the analysis results must demonstrate that the FOPS can elastically support a static load of 36,000 pounds applied to the plan view area of the canopy top within the middle ninth of the plan view area. Specified safety factors are required for the attachment joints. If the canopy is mounted to the main vehicle frame and meets specified design guidelines, no analysis of the vehicle frame is required.

Method 4 — A computer analysis of the canopy and noncomputer analysis of the attachment structure and vehicle chassis is required with Method 4. This method of certifying the static top load requirement is outlined in the FOPS Design Guide (Computer Method) (Appendix A2). As described in the Design Guide, the computer program CANOPY can be utilized if the program is modified to include plate elements and buckling checks of the structural members.

APPENDIX A2

FOPS DESIGN GUIDES

The procedures presented in this appendix were developed as guidelines for analytically certifying the structural integrity of falling object protective structures (FOPS) for use in metal-nonmetal mines. The procedures are applicable to FOPS installed on the following type of equipment used in surface mines and surface areas of underground mines:

- Track-type or wheeled front-end loaders
- Dozers
- Tractors (excluding over the road type tractors)
- Motor graders
- Prime movers

Methods of determining internal loads and stresses in the canopy top plate, beam members and support columns are described. Safety factor requirements for the canopy and attachment joints are also specified. Several computer programs are compared and a practical method of computer analysis is recommended.

General Approach for Determining Internal Loads of FOPS Designs

Most protective canopies are statically indeterminate structures. Therefore reactions and internal loads cannot be determined from the conditions for static equilibrium. A rigorous solution for a structure with multiple redundancy is quite complex and usually best approached with a computer method.

What alternate approaches are feasible for the analyst that does not have a computer or computer program available? The answer to this question depends somewhat on the configuration of the canopy and attachment structure.

Some four-post canopies can be analyzed by the methods presented in Bureau of Mines Report of Investigations, RI7799, "Elastic Plane Frame Analysis of Semisymmetric Cabs and Canopies Used on Underground Electric Face Equipment." This report describes methods by which some three-dimensional space frame protective canopies can be analyzed by employing the theory of plane frame analysis. Certain geometric arrangements must be present to enable reasonably accurate approximation of three-dimensional behavior:

1) The canopy must be symmetric about at least one plane.
2) Structures with one or more top members in the long direction that do not frame into the columns should be approximately twice as long as they are wide and have two or more internal top members in the short direction.
3) Canopies with symmetric tops that have sets of legs that do not vary in length more than 10% may be treated as symmetric about one plane.

Even when the required geometrical configurations are present approximations must be made to reduce the structure to a series of interconnected plane frames. All members in the loaded plane of the structure that do not frame into columns are modeled as simply supported beams. These approximations ignore the moments at the ends of internal top members, which introduce small errors in calculation of resultant stresses. To account for these errors safety factors must be applied to the computed elastic strength. Safety factors ranging from 1.05 to 1.33 are recommended depending on the geometrical configuration of the canopy.

Two-post protective canopies are increasingly popular on these equipment types. The two-post configuration does not meet the geometric requirements as described previously. In most cases, however, these designs are easier to evaluate since the degree of redundancy is lower.

Generally the support columns, members AB and CD shown in Figure A2-1, can be evaluated using the following approach.

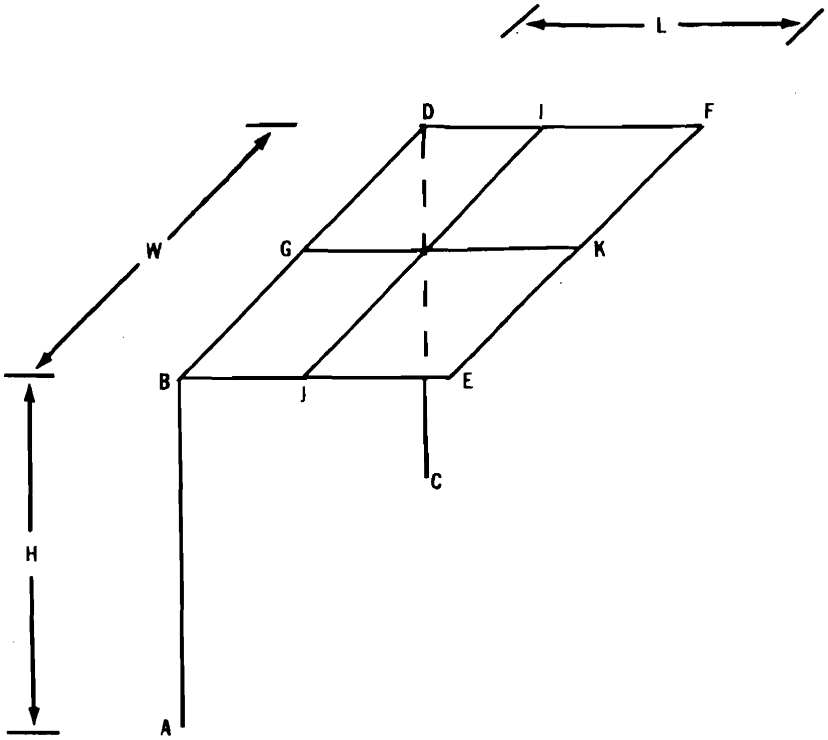


Figure A2-1. Two-Post Canopy

Compute the total load applied to the canopy,

$$TL = (p)(L)(W)$$

where

p = Distributed force

L = Length of canopy top

W = Width of canopy top

The support columns should be analyzed according to the specified buckling procedure in the section entitled "Buckling." The conservative approximation of the applied simple beam bending moment for each member is:

$$M^1 = (0.50)(TL)(L/2)$$

The applied compressive load,

$$P = (0.50)(TL)$$

After computing M^1 and P the factor of safety can be determined by completing the buckling analysis procedure.

The roof reinforcement beam members can usually be analyzed by making conservative load distribution estimates to reduce the degree of redundancy. As an example, consider member BE which must transfer a portion of the bending loads due to the roof overhang to the support posts. An unconservative estimate would be that members BE, GK and DF each carry 1/3 of the applied overhang load. Member GK would not carry an equal share of the load since it does not attach directly to a support column. Therefore overlapping assumptions should be made to assure conservative results. Member BE will be assumed to react 1/2 of the total load and member GK will react 1/3 of the total load.

This example is included to illustrate the type of analysis which can be performed quickly and economically while still obtaining results leading to a safe design. Other more rigorous techniques based on stiffness considerations are acceptable and result in lighter weight structures.

Top Plate

The canopy top plate must be designed to protect the vehicle operator from penetration of the falling object and to distribute the applied uniform loads to the roof support members. The problem of local penetration is addressed in the FOPS Certification Procedure with specified design guidelines and testing requirements. The procedure for verifying the structural adequacy of the top plate to distribute loads to the roof support members is presented in the following paragraphs.

The canopy roof plate must support a uniformly distributed load of 74,000 pounds divided by the plan view area of the roof applied over the plan view area of the roof. The top plate is effectively divided into several smaller plates by roof reinforcement beam members. The length and width of the plates is determined by the spacing of these beam members. The edge fixity of the plates is dependent upon the bending stiffness of the beam on which the plate rests.

Methods for determining edge fixity conditions and plate stresses are presented in the Bureau of Mines Report of Investigations, RI7799, "Elastic Plane Frame Analyses of Semisymmetric Cab and Canopies Used on Underground Electric Face Equipment," pages 36 and 37. Equation D-1 establishes H, the parameter indicating the strength of supporting beam with respect to the plate, which is required to define the edge fixity condition of the plate. The maximum stress in a rectangular plate supported along all four edges can be computed from formula D-2. Equation D-3 defines the relationship for determining the maximum stress for a plate supported on two opposite sides and free on the others which is equivalent to the relationship for a pinned end beam.

A safety factor of 1.0 or greater based on the minimum tensile yield strength of material is required for the top plate. The safety factor is computed as follows:

$$SF = \frac{F_{ty}}{\sigma_p}$$

where

F_{ty} = Material minimum tensile strength

σ_p = Maximum stress in plate

Evaluation of Stresses

Stresses should be computed for all critical points in the FOPS structure. The applied or induced stresses must be determined and compared to the allowable stress of the material to establish the safety factor. The procedure for obtaining the safety factor is straightforward for a unidirectional applied stress, but becomes more complicated for combined stresses. For the unidirectional case:

$$SF = \frac{F}{f}$$

where

F = Allowable stress

f = Induced stress

For the combined stress condition:

$$R_a = \frac{f_a}{F_{ty}} \qquad R_{b1} = \frac{f_{b1}}{F_{ty}} \qquad R_{b2} = \frac{f_{b2}}{F_{ty}} \qquad R_s = \frac{f_s}{F_{su}}$$

where

R = Axial, bending and shear stress ratios

F_{ty} = Minimum tensile yield strength of material

f_b = Induced bending stress in 1 and 2 directions

F_{su} = Minimum ultimate shear strength of material

f_s = Induced shear stress due to direct shear and torsional moment

The resulting safety factor is:

$$SF = \frac{1}{\left[(R_a + R_{b1} + R_{b2})^2 + (R_s)^2\right]^{1/2}}$$

Buckling

The support columns of the canopy must be checked for collapse due to buckling. A simplified approximate method of addressing the buckling problem is presented below.

The bending moment in a beam column with a compressive load P is derived from the bending moment in a simple beam with no axial load by the following relationship:

$$M = \frac{M^1}{1 - (P/P_{cr})}$$

where

M = Bending moment in the beam column

M^1 = Bending moment in a simple beam resisting the same loading without compressive load P

P = Applied compressive load

P_{cr} = Euler buckling load, $\pi^2 EI/L^2$

  E = Modulus of elasticity

  I = Moment of inertia

  L = Column length

The example, Figure A2-2, further illustrates the approach:

Figure A2-2. Beam Buckling Example

3.0 in. steel pipe

$L = 80$ in.

$A = 21{,}228$ in.^{2}

$I = 3.017$ in.^{4}

$C = 1.75$ in.

$E = 29 \times 10^6$ psi

$F_{ty} = 36{,}000$ psi

Loads and reactions

$P = 25{,}000$ lb

$M^1 = 40{,}000$ in.-lb

$$R_1 = R_2 = \frac{M^1}{L} = \frac{40{,}000}{80} = 500 \text{ lb}$$

Compute the Euler buckling load,

$$P_{cr} = \frac{\pi^2 EI}{L^2} = \frac{(\pi^2)(29 \times 10^6)(3.017)}{(80)^2} = 134{,}925 \text{ lb}$$

The bending moment in the beam column,

$$M = \frac{M^1}{1 - (P/P_{cr})} = \frac{40{,}000}{1 - (25{,}000/134{,}925)} = 49{,}097 \text{ in.-lb}$$

Compute the applied beam column bending stress,

$$f_b = \frac{Mc}{I} = \frac{(49{,}097)(1.75)}{3.017} = \pm 28{,}478 \text{ psi}$$

Compute the axial compressive stress,

$$f_a = \frac{P}{A} = \frac{-25{,}000}{2.228} = -11{,}220 \text{ psi}$$

Therefore stress ratios can be determined as follows:

$$R_a = \frac{f_a}{F_{ty}} = \frac{11{,}220}{36{,}000} = 0.312$$

$$R_b = \frac{f_b}{F_{ty}} = \frac{28{,}478}{36{,}000} = 0.791$$

The resulting safety factor is,

$$SF = \frac{1}{R_a + R_b} = \frac{1}{0.312 + 0.791} = 0.907$$

Compute the allowable axial load,

$$P_{allow.} = (SF)(P) = (0.907)(25{,}000) = 22{,}675 \text{ lb}$$

These results show that the example beam cannot withstand the applied compressive load of 25,000 pounds and the 40,000 in.-lb end moment. The maximum allowable axial compression load is 22,675 pounds, approximately 10% under the applied value.

For purposes of illustrating the need for requiring a buckling check in the analysis procedure, recompute the safety factor for the example without considering buckling. Compute the applied bending stress,

$$f_b = \frac{Mc}{I} = \frac{(40{,}000)(1.75)}{3.017} = \pm 23{,}202 \text{ psi}$$

The stress ratio is determined as,

$$R_b = \frac{f_b}{F_{ty}} = \frac{23{,}202}{36{,}000} = 0.644$$

Since the axial stress ratio does not change, the safety factor is,

$$SF = \frac{1}{R_a + R_b} = \frac{1}{0.312 + 0.644} = 1.046$$

Recompute the allowable axial load,

$$P_{allow.} = (SF)(P) = (1.046)(25,000) = 26,150 \text{ lb}$$

The maximum allowable axial compression load as predicted by the procedure not including a buckling correction is 26,150 pounds; or about 5% over the induced load of 25,000 pounds. An analyst would therefore incorrectly certify that the member had a 1.046 positive safety factor when in fact the safety factor is 0.907 and the member would likely fail at a load 15% below prediction.

This example clearly shows the need for a buckling analysis. Structural members with higher slenderness ratios will show considerably greater differences between analyses which do and do not include buckling correction.

Computer Method of FOPS Analysis

The results of this study indicate that a computer method of certifying canopy structures is feasible. A cost effective and technically acceptable method would, however, require additional computer program development effort.

Two computer programs were evaluated during the study:

1) CANOPY – A computer program for the structural analysis of a space-frame protective canopy.

2) Elastic/Plastic SAP – A nonlinear general analysis program.

Description of CANOPY

The computer program CANOPY was developed at the U.S. Bureau of Mines Pittsburgh Technical Support Center. Information Circular 8546 written by Stephen Gerard Sawyer describes the program.

The program permits rapid calculation of the elastic strength of a canopy for a variety of static loading conditions. Stresses in, and displacements of, each structural member are computed and printed out. Additionally, identification of all members that have commenced yielding, weight of the canopy, total loads on the canopy, and maximum loads that the canopy can sustain elastically are output.

CANOPY is a space-frame program which uses the stiffness method of analysis to determine a structures elastic response to static loadings. Axial, bending, shearing, and torsional deformations are considered in the solution routines. The program is divided into five phases as follows: compilation of structure data, formation of stiffness matrix, compilation of load data, calculation of joint displacements, and calculation of member stresses.

Description of Elastic/Plastic SAP

The computer program SAP was developed at the University of California at Berkeley by Dr. Edward Wilson. Plastic routines were added by Woodward Associates personnel for the U.S. Army Mobility Equipment Research and Development Center.

SAP is a general purpose finite element structural analysis program for the static and dynamic response of linear three-dimensional systems. Elastic/Plastic SAP also includes routines to analyze nonlinear deformation of beams and plates and geometric corrections for large displacements. The program is written to analyze structures which are idealized by combinations of structural element type as follows:

1) Three-dimensional truss member
2) Three-dimensional beam element
3) Plane stress membrane element
4) Two-dimensional finite element
5) Three-dimensional solid element: 8 nodal brick
6) Plate and shell elements (quodrilateral)
7) Boundary element
8) Three-dimensional thick shell element (16 notes)
9) Three-dimensional beam element (plastic modification)
10) Plane stress membrane element (plastic modification)

There is practially no restriction on the number of elements used, the number of load cases or the bandwidth of the stiffness matrix. Each nodal point in the system can have from zero to six displacement degrees of freedom.

The elastic solution routine begins by forming a structural stiffness matrix. The analysis is continued by solving the equations of equilibrium followed by computation of element stresses.

The program contains an element modification technique which causes specified three-dimensional beam elements to respond as elastic/plastic beams. This is accomplished by replacing the modulus of elasticity of these elements with one that reflects the composite effect of distributed elastic and plastic responses throughout the cross section of the beam. The effective modulus derived in this manner represents the secant modulus which would be obtained in the elastic plastic section when the local loads are reacted. Solutions are obtained by applying the loads in increments and by iterating each load step to obtain convergence. This permits evaluation of beam structures through a range of loads where in the individual beams are partially elastic and partially plastic. Once a beam becomes incapable of supporting the applied loads, the convergence process will fail and the solution will terminate. It is possible to interpret this solution termination as the collapse load for the structure whenever the primary members are responsible for the failure. In any event, this failure is indicative of complete failure of a member to support additional applied loads.

The program also contains a similar modification technique for the plane stress membrane element.

Comparison of Computer Programs

The computer programs CANOPY, SAP and Elastic/Plastic SAP are compared in Table A2-1. The information contained in the chart is important for evaluating the programs for possible use as a certification method.

It is clear, from the general description and discussion of element types, that the programs vary widely in complexity and capability. In general, it is most efficient to use a program which closely matches the complexity of the problem to be analyzed. Using a general purpose program to analyze a small specific problem results in wasted machine time, operator effort for input and operator effort to evaluate the output

Table A2-1. Comparison of ROPS/FOPS Computer Programs

	CANOPY	SAP	ELASTIC/PLASTIC SAP
Description	o Space frame elastic analysis	o Elastic finite element analysis	o Elastic/plastic finite element analysis
Element types	o Beam	o Truss, beam, membrane, 2-D finite element, 3-D solid element, plate and shell, boundary, and 3-D thick shell.	o All SAP elastic elements o Beam and plate plastic elements
Required machine capacity	o 40K core storage	o 300K core storage	o 300K core storage
Input requirements	o Simple (6 hours/canopy)	o Moderately complex (16 hours/canopy)	o Complex (20 hours/canopy)
Output data	o Very easy to interpret	o Computation of stresses from loads and moments required	o Stresses printed out. o Moderate interpretation required
Analyst requirement	o General engineer	o Structural engineer	o Structural engineer with background in ROPS/FOPS analysis
Accuracy	o Good with any space frame comprised only of beams	o Excellent in elastic range of material	o Excellent in elastic range o Acceptable in plastic range of material
Cost (Machine time)	o $5/canopy	o $30/canopy	o $200/canopy
Total cost (machine time and analyst)	o $200/canopy	o $500/canopy	o $800/canopy

data. In contrast, using a program of inadequate capability will result in an inaccurate solution or excessive input time while attempting to formulate a realistic mathematical model.

The program CANOPY is limited to beam members as contrasted to ten element types in Elastic/Plastic SAP. The computer analyses conducted during this study indicated that beam and plate elements are necessary to adequately evaluate a cab or canopy. Protective canopies are generally constructed with rectangular tubing, square tubing, round tubing, square bar stock, or round bar stock. In any case, these can be modeled as beam members.

FOPS canopies also usually have steel plates covering their tops. Enclosed cabs utilize plates extensively. Since almost all cabs and canopies use plates in their construction, it is apparent that a plate element is a very useful computer analysis tool. The computer program CANOPY does not have a plate element; therefore plates must be modeled as equivalent beams or not included in the analysis. Both of these alternates can result in poor accuracy and extra input effort. SAP includes a plate element which can be effectively used in the analysis of cabs and canopies.

The required computer size is important since it affects the usefulness of the program because of geographical location. The very large computers and data terminals are generally only available in large metropolitan areas. The program SAP requires a large CDC, IBM or UNIVAC machine to handle the core storage requirements. A smaller computer can be used with CANOPY since only a 40K core storage is needed. This is an important factor if the computer analyses are going to be conducted by mine companies which are commonly located in remote geographical areas.

The data input requirements for CANOPY are straightforward and easily interpreted. An analyst should be able to input a simple canopy problem in approximately six hours. The input for SAP is more complex and would require an estimated 16-20 manhours. A more experienced analyst is needed since the input requires more interpretation.

As discussed previously, the output from CANOPY includes most of the information necessary to adequately evaluate a protective canopy. The output of SAP includes only bending moments and forces. Stresses and associated safety factors must be determined by the analyst. Elastic/Plastic SAP computes and prints out all stress data for beams, but it does not evaluate safety factors or load capability of the canopy.

The accuracy of CANOPY and SAP was established by inputting identical problems and comparing the solutions. The results correlated closely for problems falling within the limitation bounds of CANOPY. No attempt was made to evaluate CANOPY for configurations with plates since the accuracy would depend largely on input model simulation.

The program CANOPY could be used by any general engineering graduate or person experienced in structural analysis to conduct analyses of protective structures. Elastic/Plastic SAP requires a Structural Engineer with a background in plastic analysis. The analyst must prejudge points of high stress and input plastic beam elements. If his judgment is incorrect, and an elastic beam exceeds the proportional limit of the material, the computer solution must be repeated at additional overall cost.

Overall cost is an important consideration in selecting a computer program. The total cost includes computer machine time costs and labor costs associated with the analyst preparing the input data and interpreting the output results. The estimated cost for a computer analysis of an average canopy configuration using the program CANOPY would be $200, comprised of $5 machine time and 10 labor hours. As a direct comparison, the same analysis using SAP would cost about $500, including $30 of machine time and 20 labor hours. A more extensive plastic analysis using Elastic/Plastic SAP would cost approximately $800.

In summary, it appears that since a plastic analysis is not required as part of the certification criteria the use of Elastic/Plastic SAP is not warranted. The elastic program SAP is technically acceptable as a certification method. However, the estimated cost for performing a complete analysis of a canopy is 2.5 times that of using the program CANOPY. The lack of a plate element in the current version of CANOPY presents a technical deficiency. CANOPY appears to be the best computer program for a certification tool if the changes recommended in the following section are incorporated.

Recommended Computer Program Changes

Two modifications should be added to the computer program CANOPY to make it a technically acceptable method for certifying protective canopies. The two recommended additions are:

1) Plate element

2) Beam buckling prediction

As a minimum, the plate element should handle in-plane membrane loads and out-of-plane bending loads. Stresses should be printed for both surfaces at the center of the plate.

The recommended buckling routine should be based on general beam column theory. Lateral deflections which change the moment arms of the axial compression forces would be considered. Therefore, the critical buckling load would be determined for each beam element in the model using the primary bending moment as predicted by CANOPY and the secondary (axial load induced) bending moments computed within the new routine.

The plate and buckling modifications should be included as a subroutine to the existing CANOPY program. These changes would not add significantly to the complexity of the program since they would not affect the stiffness matrix. The addition of the plate element would add slightly to the input complexity. No additional input data would be required for the buckling routine. The output should be structured to be directly applicable to evaluating canopies.

Additional Considerations

The methods presented in this appendix are guidelines to help the analyst in several of the important areas of FOPS design. It must be emphasized that other methods based on sound engineering principles are acceptable and in some cases more accurate than the methods outlined here. Sound methods of analysis depend on the configuration of the FOPS. A complete analysis performed by a competent engineer should be submitted for each design to be certified by analysis. In addition, the criteria specified in Appendix A1 must be met.

APPENDIX A3

FOPS TEST PROCEDURE

The testing procedure specified in this document was developed as a method of certifying the structural integrity of falling object protective structures (FOPS) for use in metal-nonmetal mines. The procedure is applicable to FOPS installed on the following type of equipment used in surface mines and surface areas of underground mines:

- Track-type or wheeled front-end loaders
- Dozers
- Tractors (excluding over the road type tractors)
- Motor graders
- Prime movers

Two testing procedure options are presented. Option A includes a static test of the entire FOPS including protective canopy, attachment joints, vehicle chassis and axles. Testing of some of the FOPS components or the canopy alone is required with Option B. The remainder of components must be certified with engineering calculations or by meeting certain specified and required design guidelines.

Option A

A static test of the entire FOPS including protective canopy, attachment joints, vehicle chassis and axles is specified. In addition, several design and fabrication requirements must be met. The requirements are briefly summarized below and described in the FOPS Certification Procedure (Appendix A1).

- The canopy and attachment structure must be fabricated with steel meeting specified Charpy V-notch impact strengths.
- The American Welding Society specification for welding roll-over and falling object protective structures must be followed during fabrication and installation of the canopy and attachment structure.
- The top of the canopy must meet minimum design guidelines or be tested to SAE Recommended Practices J231 which specifies the minimum performance criteria for FOPS.
- A static load must be applied near the center of the protective structure's top. The canopy will be installed on the vehicle in the normal manner and supported in the test bay at the axle location.

Step-by-Step Test Procedure (Option A)

Protective canopies are required to elastically support a static load of 36,000 pounds applied within the middle ninth of the plan view area of the canopy top. Detailed test requirements are presented in the following paragraphs:

a. Test Preparation

The canopy shall be mounted to the vehicle chassis in the same manner as it is for normal operation. All attachment methods such as welding, bolt types and installation torque values shall be in accordance with established procedures. The test specimen will include all of the major load carrying structural members in the load train between the canopy top and the axles.

The axles of the vehicle shall be mounted to a rigid platform. A rigid platform is defined as a surface of such firmness that it cannot be penetrated or appreciably deflected during loading. Other support points beyond the axle locations must be accompanied by engineering calculations which show that they do not react more than 10% of the applied static test load.

b. Test Loading

The canopy will be loaded within the middle ninth of its plan view area with a load equal to 36,000 pounds. Detailed examples of this loading criterion are shown in MESA Information Report IR 1002, "A Testing Procedure for the Certification of Underground Protective Cabs and Canopies."

The loading requirements described above are adequate for certifying most canopies. In some instances, however, this loading location does not represent a reasonable verification of the canopies functional characteristics. An example is a canopy in which the vehicle operator is located under a cantilevered overhang portion of the roof. It is apparent from this example that a test with the load applied over the middle ninth of the plan view area does not demonstrate the structural adequacy of the design to protect the operator.

A second test is required when it is judged that the vertical deflection due to a load applied within the middle ninth of the plan view area is less than the predicted deflection when a load is applied over the operator. In this case the load will be centered over the head of the operator while in the normal operating position and can be distributed within an area equal to one-ninth of the plan view area of the canopy top. It is required that this test shall follow the center load test and meet deflection criteria established for the first test.

c. Instrumentation Accuracy Requirements

Force and deflection measurements are required. The instrumentation used to measure force applied to the canopy must have an accuracy of ±5% of maximum force. The vertical deflection of the centroid of the loaded area must be measured to an accuracy of ±5% of maximum deflection. The above percentages are nominal ratings of the accuracy of the instrumentation and should not be taken to indicate that compensating overtest is required.

d. Measurement Requirements

As a minimum the following must be measured and recorded:

1. The vertical deflection of the centroid of the protective structure's top which is caused by the application of the total load.
2. The value of the maximum load.

3. The residual vertical deflection of the centroid of the protective structure's top after the load is removed. This represents the permanent vertical deflection of the canopy top.

4. If a test with the load applied over the operator is required, measurements 1 and 3 will be taken at the centroid of the load application.

Additional deflection measurements may be recorded at various load increments to more accurately characterize the behavior of the FOPS.

e. Test Acceptance Criteria

The following criteria must be met to successfully pass the static top load test:

1. The recorded residual deformation as measured in Steps d.3 or d.4 must be less than 10% of the recorded maximum vertical deflection as measured in Steps d.1 or d.4.

2. Visible failure of welds or any structural member is not permitted.

f. Special Considerations

1. Should the residual deflection be greater than 10%, the canopy cannot be certified nor retested because damaging permanent deformation of some of the structure's members has probably occurred.

2. Two tests are required for adjustable canopies. The first test should be conducted with the canopy in the

highest position and must meet the acceptance criteria of Step e. The second test will be conducted with the canopy in the lowest position.

3. Hydraulic rams or cylinders may be replaced with equivalently stiff structural members.

Option B

A static test of the canopy attached to a rigid platform in the same manner as it is to be attached during actual use is specified. In addition, engineering calculations must be prepared and several design and fabrication requirements must be met. The requirements of Option A and the following items apply for Option B:

- Engineering calculations are required to establish the adequacy of the attachment structure to the vehicle frame.
- The attachment location of the canopy to the vehicle frame must meet specified guidelines.

Step-by-Step Test Procedure (Option B)

a. Static Top Load Test

The requirements of Option A apply except for some modifications to the specified test preparation, Option A, Step a. Instead the canopy shall be attached directly to a rigid platform in a manner which simulates the actual attachment to the vehicle.

b. Attachment Structure Analysis Requirements

The structural components of the attachment structure between the canopy which was tested in Step a and the main vehicle frame must be certified with engineering calculations. The attachment structure loads should be obtained by determining the reactions of the canopy as a free body subjected to the applied top load of Option A, Step b. A factor of safety of 2.0 above the minimum yield strength of the material is required for primary weld and bolt joints. A factor of safety of 1.0 must be shown for all other parts of the attachment structure.

c. Vehicle Frame Requirements

Analysis of the vehicle frame is not required if the canopy is attached to a main structural frame member. If the canopy is mounted to a secondary frame member, a detailed engineering analysis is required to show a factor of safety of 1.0 compared to the minimum yield strength of the vehicle frame material.

APPENDIX A4

EQUIPMENT POPULATION SURVEY

Survey sampling was the means of obtaining data from which to make inferences about the population of the "machines of interest" used in metal and nonmetal mining operations.

MESA provided a computer listing, called "Metal-Nonmetal Mine Reference File." It listed all of the mines, their locations, and data about number of employees, last MESA inspection, product by SIC code, and other factors. It was dated August 8, 1975. There were 13,989 mines identified as active. Six hundred sixty-eight of these were underground mines; 1756 were open pit mines; 4029 were crushed rock mines; and 7536 were sand and gravel mines.

A visit to MESA in Washington and to the offices of the staff of the Minerals Yearbook produced the information that mine lists used in the annual "canvas" for Minerals Yearbook data were available, but only after several weeks and at considerable expense for the machine time to produce them. The lists were large compared to the Mine Reference File. There were approximately 13,000 on the Minerals Yearbook sand and gravel list alone; the Mine Reference File had a total of 8913 in this category (7536 active). Discussions on the Minerals Yearbook list suggested that it included more inactive and sporadic operations than the Mine Reference File and that the latter was a very satisfactory frame for a survey of the type planned.

The MESA Health and Safety Analysis Center (HSAC) provided two other machine listings entitled "Surface Metal-Nonmetal Mines

Reporting to Mining Enforcement Administration in 1974." These listings had a total of 7369 mines. They were compared to the Mine Reference File in several ways and the differences analyzed. The conclusion was that the HSAC list, although not a complete frame as the Mine Reference File is, was a satisfactory surrogate for a complete frame with respect to the survey for this particular study.

Table A4-1 shows the survey sample selected. Systematic selection was employed on the HSAC list, which was arranged by states. Every k$^{\underline{th}}$ item in each mine category (underground, open pit, crushed rock, sand and gravel) was selected from a random start. For underground mines, k was 4; for all surface mines, k was 8.

Table A4-2 shows the overall response achieved by the survey by state. One of the several reasons for using systematic sampling was to make certain that all mining regions and all states were represented in the sample. It was clear from early discussions of the study with mining people that this feature would be desirable.

Table A4-1. Composition of Survey Sample
(Equipment Survey)

Mine Class	Number of Mines on HSAC List	Number of Mines Selected for Sample	Sampling Ratio
Underground (RS-U)	444	111	1/4
Open Pit (RS-O)	1441	182	1/8
Crushed Stone (RS-C)	2320	291	1/8
Sand and Gravel (RS-S)	3164	396	1/8
TOTAL	7369	980	13/100

Table A4-2. Survey Response Summary by State

	RS-U		RS-O		RS-C		RS-S		Total		
State	Samples	Resp.	Samples	Resp.	Samples	Resp.	Samples	Resp.	Samples	Resp.	Rate
AL	1	1	4	4	6	0	8	3	19	8	42%
AK	0	0	0	0	1	0	1	1	2	1	50%
AZ	4	3	8	6	1	1	7	5	20	15	75%
AR	1	1	1	1	5	3	5	1	12	6	50%
CA	4	1	14	9	7	1	23	18	48	29	60%
CO	18	17	5	5	4	2	8	5	35	29	83%
CT	0	0	0	0	1	1	6	3	7	4	57%
DE	0	0	1	0	0	0	1	1	2	1	50%
FL	0	0	4	2	9	5	3	2	16	9	56%
GA	4	3	14	8	5	4	3	2	26	17	65%
HI	0	0	1	1	2	2	0	0	3	3	100%
ID	1	1	2	1	1	1	4	3	8	6	75%
IL	6	4	5	3	19	7	21	11	51	25	49%
IN	0	0	4	3	9	6	12	7	25	16	64%
IA	2	1	2	2	33	4	21	8	58	15	26%
KS	3	1	5	3	14	10	9	7	31	21	68%
KY	5	4	1	1	9	4	3	2	18	11	61%
LA	0	0	1	0	1	1	6	3	8	4	50%
ME	0	0	1	1	0	0	4	2	5	3	60%
MD	1	1	3	2	1	1	2	1	7	5	71%

Table A4-2. Survey Response Summary by State (Cont)

State	RS-U		RS-O		RS-C		RS-S		Total		
	Samples	Resp.	Samples	Resp.	Samples	Resp.	Samples	Resp.	Samples	Resp.	Rate
MA	0	0	1	1	1	0	8	5	10	6	60%
MI	2	2	3	1	3	2	15	9	23	14	61%
MN	0	0	6	5	6	5	11	9	23	19	83%
MS	0	0	2	2	1	0	4	2	7	4	57%
MO	9	8	9	7	18	7	6	1	42	23	55%
MT	4	3	3	2	0	0	3	1	10	6	60%
NE	0	0	1	1	2	0	23	13	26	14	54%
NV	4	1	5	5	1	1	5	3	15	10	67%
NH	0	0	0	0	0	0	2	1	2	1	50%
NJ	0	0	1	1	4	2	7	5	12	8	67%
NM	8	6	4	2	1	0	6	4	19	12	63%
NY	7	5	6	5	6	3	17	10	36	23	64%
NC	1	1	6	4	10	5	16	12	33	22	67%
ND	1	1	0	0	0	0	3	2	4	3	75%
OH	2	1	8	7	12	7	29	17	51	32	63%
OK	0	0	3	1	4	2	5	1	12	4	33%
OR	1	1	1	0	7	5	5	2	14	8	57%
PA	3	2	10	5	18	8	11	3	42	18	43%
RI	0	0	0	0	1	0	2	1	3	1	33%
SC	0	0	3	1	2	1	0	0	5	2	40%

Table A4-2. Survey Response Summary by State (Cont)

State	RS-U		RS-O		RS-C		RS-S		Total		
	Samples	Resp.	Samples	Resp.	Samples	Resp.	Samples	Resp.	Samples	Resp.	Rate
SD	1	1	2	2	1	0	5	3	9	6	67%
TN	3	1	6	5	11	7	4	2	24	15	63%
TX	1	0	8	6	9	5	17	4	35	15	43%
UT	5	4	4	3	0	0	5	3	14	10	71%
VT	2	2	2	2	1	1	3	1	8	6	75%
VA	1	0	4	3	12	4	8	2	25	9	36%
WA	0	0	2	0	8	3	13	7	23	10	43%
WV	2	2	1	1	4	0	0	0	7	3	43%
WI	1	0	2	1	19	10	15	8	37	19	51%
WY	3	2	3	1	1	1	1	0	8	4	58%
Total	111	81	182	126	291	132	396	216	980	555	57%

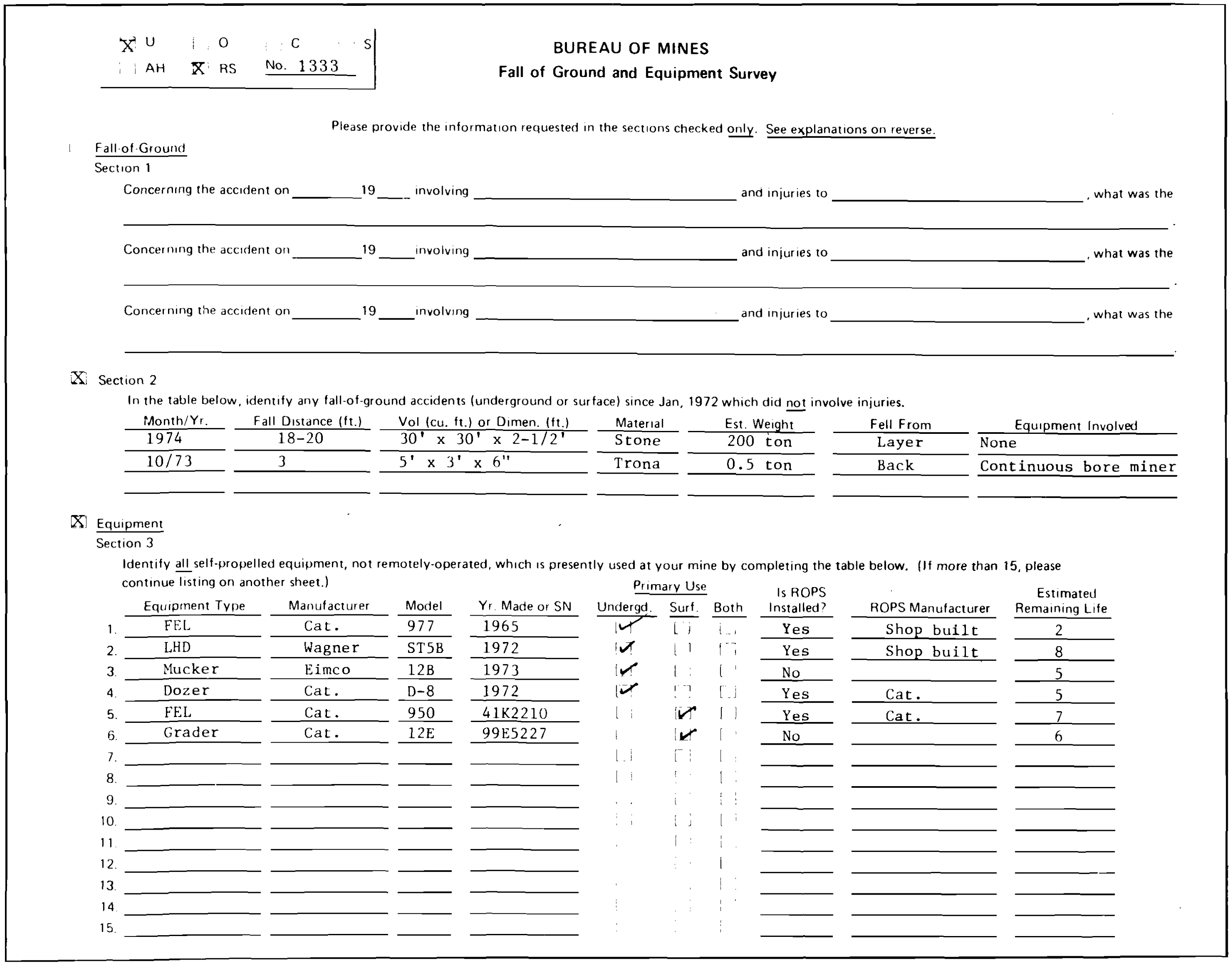
Table A4-3 shows the "usable data" response rates. For the sample shown in Table A4-1 (referred to as the "RS" sample) the usable data response rate was 50%. Responses that reported the mines sold were the subject of follow-up actions when the new owner could be identified. These were few in number; most of the responses in the "closed or sold" column were closed. Table A4-3 also includes data obtained from the accident history inquiries (referred to as the "AH" sample). These data were used only for comparison analyses with the RS sample. In the table, "RS-U" is the underground mine data. "RS-O" is open pit mines; "RS-C" refers to crushed stone and "RS-S" to sand and gravel. The AH data are divided into "AH-U" for underground mines and "AH-A" for all other.

The survey instrument used is shown in Figures A4-1 and A4-2. Figure A4-1 is the face side with illustrative entries. When received by the addressee, the only entries were the identifying number in the upper left-hand corner and check marks in the squares in front of "Section 2" and "Equipment, Section 3." The numbers were assigned in district blocks for each mine category and, in addition, the RS and U, O, C, or S blocks were color coded for each mine category. This was done to minimize initial data processing errors and the time expended by research assistants in data sorting and recording. The equipment and accident entries shown on the form for illustration are some actually received, although not from a single mine. Of course, not all responses were as clear or as complete as those shown here. The "estimated remaining life" data were used only to form some estimates about the average machine life in different mining operations.

Figure A4-2 shows the reverse or mailing side of the survey form. It is self-explanatory.

Table A4-3. "Usable Data" Response Rates

Mine Class Code	Sample Size	Total Response	Total Complete	Closed or Sold	Some Info. Refused	Overall Response Rate	Usable Data Response Rate
RS-U	111	81	60	20	1	73%	54%
RS-O	182	126	112	12	2	69%	62%
RS-C	291	132	118	11	3	45%	41%
RS-S	396	216	196	19	1	55%	49%
RS Subtotal	980	555	486	62	7	57%	50%
AH-U	76	56	47	2	7	74%	62%
AH-A	37	25	20	4	1	68%	54%
AH Subtotal	113	81	67	6	8	72%	59%
TOTAL	1093	636	553	68	15	58%	51%



☒ U ☐ O ☐ C ☐ S
☐ AH ☒ RS No. 1333

BUREAU OF MINES
Fall of Ground and Equipment Survey

Please provide the information requested in the sections checked only. See explanations on reverse.

☐ Fall-of-Ground

Section 1

Concerning the accident on ________ 19____ involving ________________ and injuries to ________________, what was the ________________.

Concerning the accident on ________ 19____ involving ________________ and injuries to ________________, what was the ________________.

Concerning the accident on ________ 19____ involving ________________ and injuries to ________________, what was the ________________.

☒ Section 2

In the table below, identify any fall-of-ground accidents (underground or surface) since Jan, 1972 which did not involve injuries.

Month/Yr.	Fall Distance (ft.)	Vol (cu. ft.) or Dimen. (ft.)	Material	Est. Weight	Fell From	Equipment Involved
1974	18-20	30' x 30' x 2-1/2'	Stone	200 ton	Layer	None
10/73	3	5' x 3' x 6"	Trona	0.5 ton	Back	Continuous bore miner

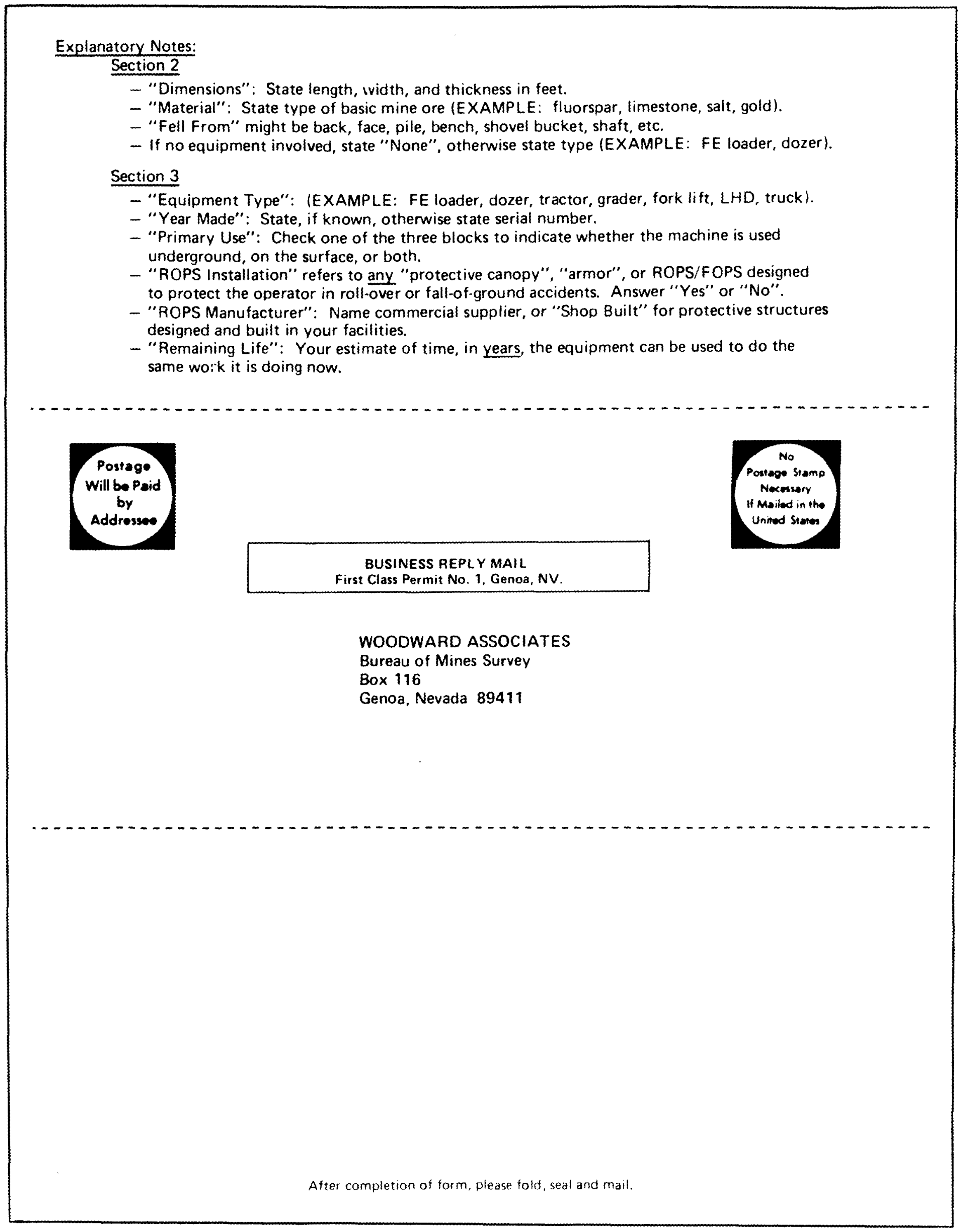
☒ Equipment

Section 3

Identify all self-propelled equipment, not remotely-operated, which is presently used at your mine by completing the table below. (If more than 15, please continue listing on another sheet.)

	Equipment Type	Manufacturer	Model	Yr. Made or SN	Primary Use Undergd.	 Surf.	 Both	Is ROPS Installed?	ROPS Manufacturer	Estimated Remaining Life
1.	FEL	Cat.	977	1965	☑	☐	☐	Yes	Shop built	2
2.	LHD	Wagner	ST5B	1972	☑	☐	☐	Yes	Shop built	8
3.	Mucker	Eimco	12B	1973	☑	☐	☐	No		5
4.	Dozer	Cat.	D-8	1972	☑	☐	☐	Yes	Cat.	5
5.	FEL	Cat.	950	41K2210	☐	☑	☐	Yes	Cat.	7
6.	Grader	Cat.	12E	99E5227	☐	☑	☐	No		6
7.					☐	☐	☐			
8.					☐	☐	☐			
9.					☐	☐	☐			
10.					☐	☐	☐			
11.					☐	☐	☐			
12.					☐	☐	☐			
13.					☐	☐	☐			
14.					☐	☐	☐			
15.					☐	☐	☐			

Figure A4-1. USBM Fall-of-Ground and Equipment Survey Form



Explanatory Notes:

Section 2

- "Dimensions": State length, width, and thickness in feet.
- "Material": State type of basic mine ore (EXAMPLE: fluorspar, limestone, salt, gold).
- "Fell From" might be back, face, pile, bench, shovel bucket, shaft, etc.
- If no equipment involved, state "None", otherwise state type (EXAMPLE: FE loader, dozer).

Section 3

- "Equipment Type": (EXAMPLE: FE loader, dozer, tractor, grader, fork lift, LHD, truck).
- "Year Made": State, if known, otherwise state serial number.
- "Primary Use": Check one of the three blocks to indicate whether the machine is used underground, on the surface, or both.
- "ROPS Installation" refers to any "protective canopy", "armor", or ROPS/FOPS designed to protect the operator in roll-over or fall-of-ground accidents. Answer "Yes" or "No".
- "ROPS Manufacturer": Name commercial supplier, or "Shop Built" for protective structures designed and built in your facilities.
- "Remaining Life": Your estimate of time, in years, the equipment can be used to do the same work it is doing now.

Postage
Will be Paid
by
Addressee

No
Postage Stamp
Necessary
If Mailed in the
United States

BUSINESS REPLY MAIL
First Class Permit No. 1, Genoa, NV.

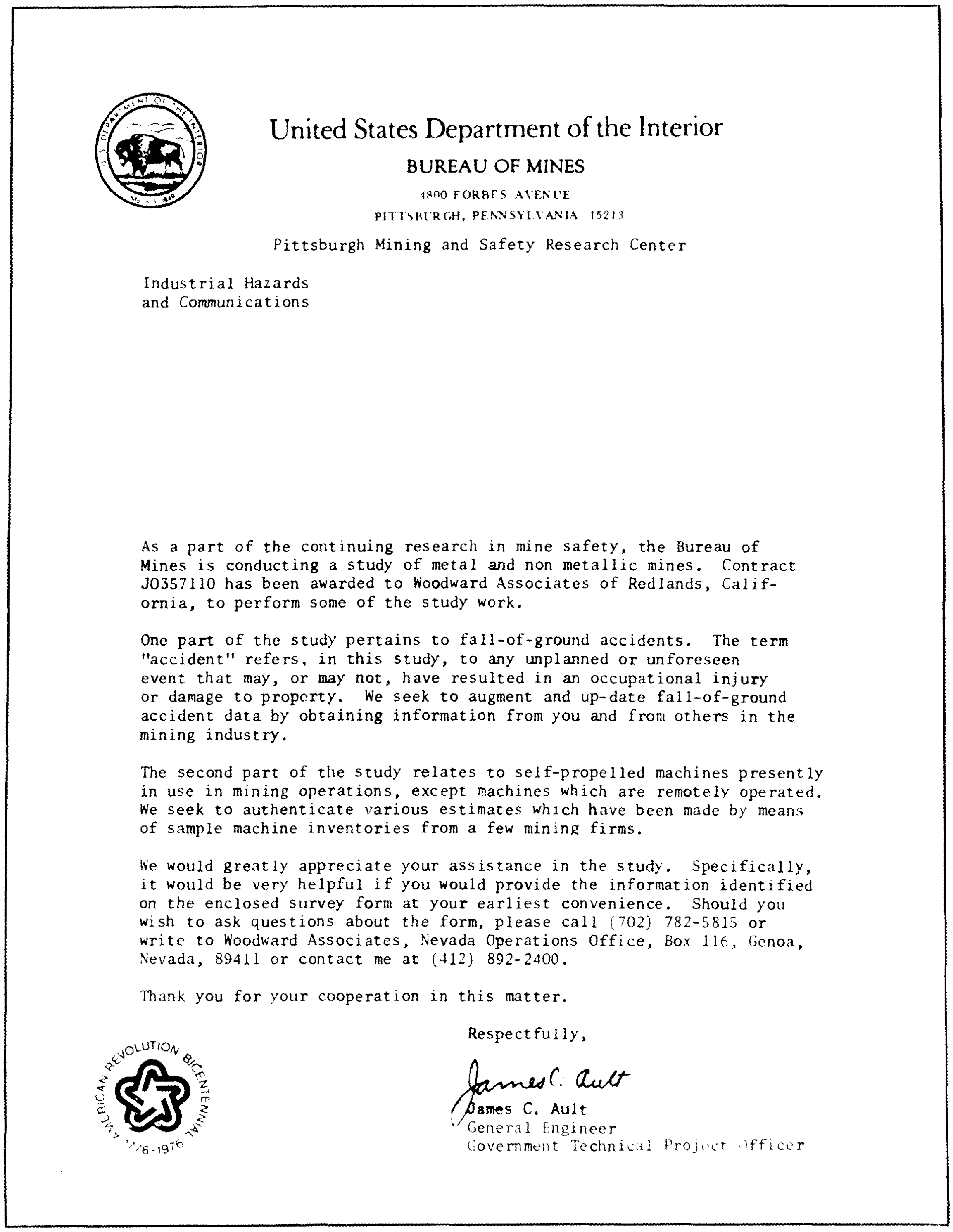
WOODWARD ASSOCIATES
Bureau of Mines Survey
Box 116
Genoa, Nevada 89411

After completion of form, please fold, seal and mail.

Figure A4-2. USBM Fall-of-Ground and Equipment Survey Form (Reverse Side)

Figure A4-3 is the cover letter which was mailed with the survey form, less address and salutation. The fact that the Government Technical Project Officer permitted, in fact encouraged, the use of such a letter accounts largely for the relatively high survey response rates achieved. The initial mailings were made in Bureau of Mines franked envelopes, which also improved the response by decreasing the number of forms discarded by secretaries and so forth. The GTPO cooperated in many other ways to make the survey successful. His effective answers to mine inquiries and his prompt handling of undelivered letters made the survey problems small compared to those experienced in similar work in the past.

Some of the survey administration problems on this survey, typical of all surveys of this kind, are summarized in Table A4-4. Each of these cases was treated as a problem situation and in most cases an individual letter was written to attempt to produce a usable response. The exception to the individual letter follow-up was the three respondents who said that they refused to provide any data. One of these was a large "RS-S" company; one was a large "RS-U" mine; the third was a small "RS-O" mine. Table A4-5 shows the effect of follow-up actions, both the individual actions and routine actions for mines that had not responded within six weeks of receiving the initial survey mailing. A form follow-up letter was sent to the non-respondents, enclosing a new survey form and a copy of the cover letter. Only a single stage mail follow-up was used, with some telephone supplements. Table A4-5 shows results which are slightly above the expectations from past experience. There was about 37% response to the RS mailings before the follow-up and about 57% after. This response is considered excellent. The survey was structured to be valid if only 28% of the



United States Department of the Interior
BUREAU OF MINES
4800 FORBES AVENUE
PITTSBURGH, PENNSYLVANIA 15213

Pittsburgh Mining and Safety Research Center

Industrial Hazards
and Communications

As a part of the continuing research in mine safety, the Bureau of Mines is conducting a study of metal and non metallic mines. Contract J0357110 has been awarded to Woodward Associates of Redlands, California, to perform some of the study work.

One part of the study pertains to fall-of-ground accidents. The term "accident" refers, in this study, to any unplanned or unforeseen event that may, or may not, have resulted in an occupational injury or damage to property. We seek to augment and up-date fall-of-ground accident data by obtaining information from you and from others in the mining industry.

The second part of the study relates to self-propelled machines presently in use in mining operations, except machines which are remotely operated. We seek to authenticate various estimates which have been made by means of sample machine inventories from a few mining firms.

We would greatly appreciate your assistance in the study. Specifically, it would be very helpful if you would provide the information identified on the enclosed survey form at your earliest convenience. Should you wish to ask questions about the form, please call (702) 782-5815 or write to Woodward Associates, Nevada Operations Office, Box 116, Genoa, Nevada, 89411 or contact me at (412) 892-2400.

Thank you for your cooperation in this matter.

Respectfully,

James C. Ault

James C. Ault
General Engineer
Government Technical Project Officer

Figure A4-3. USBM Cover Letter for USBM Fall-of-Ground and Equipment Survey

Table A4-4. Survey Problem
Situations – Individual Follow-Up Letters Sent

Problem Area	Number of Cases
Incomplete information provided	28
Addressee declared survey form lost	5
Addressee declared survey form never received	28
Addressee declared form sent, but not received by WAI	1
Special circumstances:	
Data included in report on other operation	1
Operation limited to 3-5 days/ 3 years	1
Declared no machinery used	1
Mine sold	7
Form referred to another party	2
Addressee refused to provide any data	2
Addressee refused to provide any data unless compensated	1
Definitional questions	22
Verification of survey authority requested	1
Protest of "government surveys"	1
TOTAL	101

Table A4-5. Equipment Survey Response

Mine Class Code	Sample Size	Responses Before Follow-Up	Follow-Up Letters Sent	Total Responses
RS-U	111	57	53	81
RS-O	182	73	107	126
RS-C	291	91	200	132
RS-S	396	140	255	216
RS Subtotal	980	361	615	555
AH-U	76	42	34	56
AH-A	37	19	18	25
AH Subtotal	113	61	52	81
TOTAL	1093	422	667	636

mines receiving survey forms provided usable information. As with previous surveys, it is expected that responses will continue for two to three months after this report is published.

Table A4-6 summarizes a survey problem area for which we can provide no satisfactory explanation. There were 16 cases in which the USPS returned the initial mailing as undeliverable, although the addresses were correct according to the HSAC list. These 16 letters were put in new envelopes and sent out with the same address. None was ever returned and several reached their intended destinations because survey

Table A4-6. Survey Problem Situations – Second Mailings Required

Problem Area	Number of Cases
Initial letter and form declared undeliverable by Postal Service	16
Follow-up letter and form declared undeliverable by Postal Service	14
TOTAL	30

responses were received. An even more puzzling problem occurred with 14 follow-up letters. These were sent to mine owners who had not responded to the initial mailings and whose initial mailings had not been returned by the USPS. The same addresses were used on the follow-up letters, but the 14 were returned as undeliverable. It does not seem likely that 14 mines did an administrative vanishing act within a six-week period. It is left to the reader of this report to explain this matter to his satisfaction.

There were two types of responses which reflected that the respondents had no machines of interest:

1) Mine closed.

2) Mine operational but machine fleet does not include any machines of interest.

These were represented as a proportion of the mines sampled which had no machines. The sample proportion was used as the estimator of the number of "active mines" in the Mine Reference File which had no machines of interest.

Table A4-7 shows the estimates for the population of machines of interest by machine type and age group. The methods of estimating are summarized below.

The numbers of machines of interest reported by each respondent who owned one or more were used to calculate a sample mean and sample standard deviation. The sample mean was used as the estimator of the population mean. The 95% confidence interval for the population mean was calculated as:

$$\bar{x} \pm k \frac{\hat{\sigma}}{\sqrt{n}}$$

where

k is the confidence multiplier (1.96 in this case)

$\hat{\sigma}$ is the sample standard deviation

n is the sample size (number of respondents with one or more machines of interest)

$\bar{x}$ is the sample mean

The estimated population mean and confidence limits were used with the number of mines in the Mine Reference File which had one or more machines of interest to estimate the population. The population used in Sections 4.3 and 4.6 of this report is the mid-point of the 95% confidence interval, which is 44,827 to 53,759.

Proportions of the population representing various machine age groups, fleet sizes and installed protective structures (and the owners

Table A4-7. Machines of Interest Population Estimates (Total Population 49,293)

	POST - 1969		1965 - 1969		1960 - 1964		1950 - 1959		1949 & EARLIER		TOTALS	
	WITH ROPS	WITHOUT ROPS	WITH ROPS	WITHOUT ROPS	WITH ROPS	WITHOUT ROPS	WITH ROPS	WITHOUT ROPS	WITH ROPS	WITHOUT ROPS	WITH ROPS	WITHOUT ROPS
FRONT END LOADER	11,020	4,457	3,025	6,239	378	2,377	108	1,026	27	27	14,558	14,126
DOZER	2,863	459	1,080	1,675	378	1,053	162	1,242	27	243	4,510	4,672
GRADER	432	297	54	729	54	513	108	594	27	378	675	2,511
TRACTOR	1,594	378	351	1,405	270	324	81	675	81	81	2,377	2,863
PRIME MOVERS	675	324	594	594	108	405	27	270	0	0	1,404	1,593
TOTALS	16,584	5,914	5,104	10,642	1,188	4,672	486	3,807	162	729	23,524*	25,765*

* DIFFERENCE OF 4 FROM TOTAL POPULATION FIGURE DUE TO ROUNDING

of no machines, as mentioned above) were estimated using appropriate sample proportions. These were then used with the total population estimate to compute the estimated numbers of machines in each category. The numbers used in Sections 4.4 and 4.7 were computed from midpoints of 95% confidence intervals for population proportions. These confidence intervals were calculated as:

$$p \pm k\hat{\sigma}_p \qquad \text{or}$$

$$p \pm k \sqrt{\frac{p(1-p)}{n}} \sqrt{\frac{N-n}{N-1}}$$

where

p is the sample proportion

k is the confidence multiplier (1.96 in these cases)

n is the sample size

N is the population size

The confidence intervals vary greatly with different values of p. An illustrative calculation for the proportion of the population of machines of interest represented by machines with three attributes i, j, k is:

i is front-end loaders

j is post-1969 age group

k is ROPS-equipped

$$p_{ijk} = 0.2236$$

$$p \pm k\hat{\sigma}_p = 0.2236 \pm 1.86 \sqrt{\frac{0.2236\ (0.7764)}{1,825}} \sqrt{\frac{49,293 - 1,825}{49,292}}$$

$$= 0.2236 \pm 1.96\ (0.0098)(0.9813)$$

$$= 0.2236 \pm 0.0188$$

or 0.2048 to 0.2424

The 95% confidence interval for machines with attributes i, j and k would be 10,095 to 11,949. The finite population correction factor, $\sqrt{\frac{N - n}{N - 1}}$, varies little within the confidence limits of N.

$$\sqrt{\frac{44,827 - 1,825}{44,826}} = 0.9794$$

$$\sqrt{\frac{53,759 - 1,825}{53,758}} = 0.9829$$

Estimates of the LHD type machines and forklifts used underground are given in Table A4-8. The total of these two machine types is nearly 78% of the total of all machines of interest used underground and their exposure to fall-of-ground danger areas is generally greater than for the machines of interest.

Figures A4-4, A4-5, A4-6 and A4-7 show the estimates of the numbers of owners who have 1-5 machines of interest, 6-15 and >15 for the four mine classes used in the study. Note that there is a greater proportion of machines in large fleets in underground mines than in the other three classes.

Table A4-8. Estimates of LHD Type and Forklifts Used Underground

	Some Form of Protective Structure	No Protective Structure	Total
LHD Type	357	241	598
Forklift Type	98	250	348
TOTAL	455 48.1%	491 51.9%	946 100%

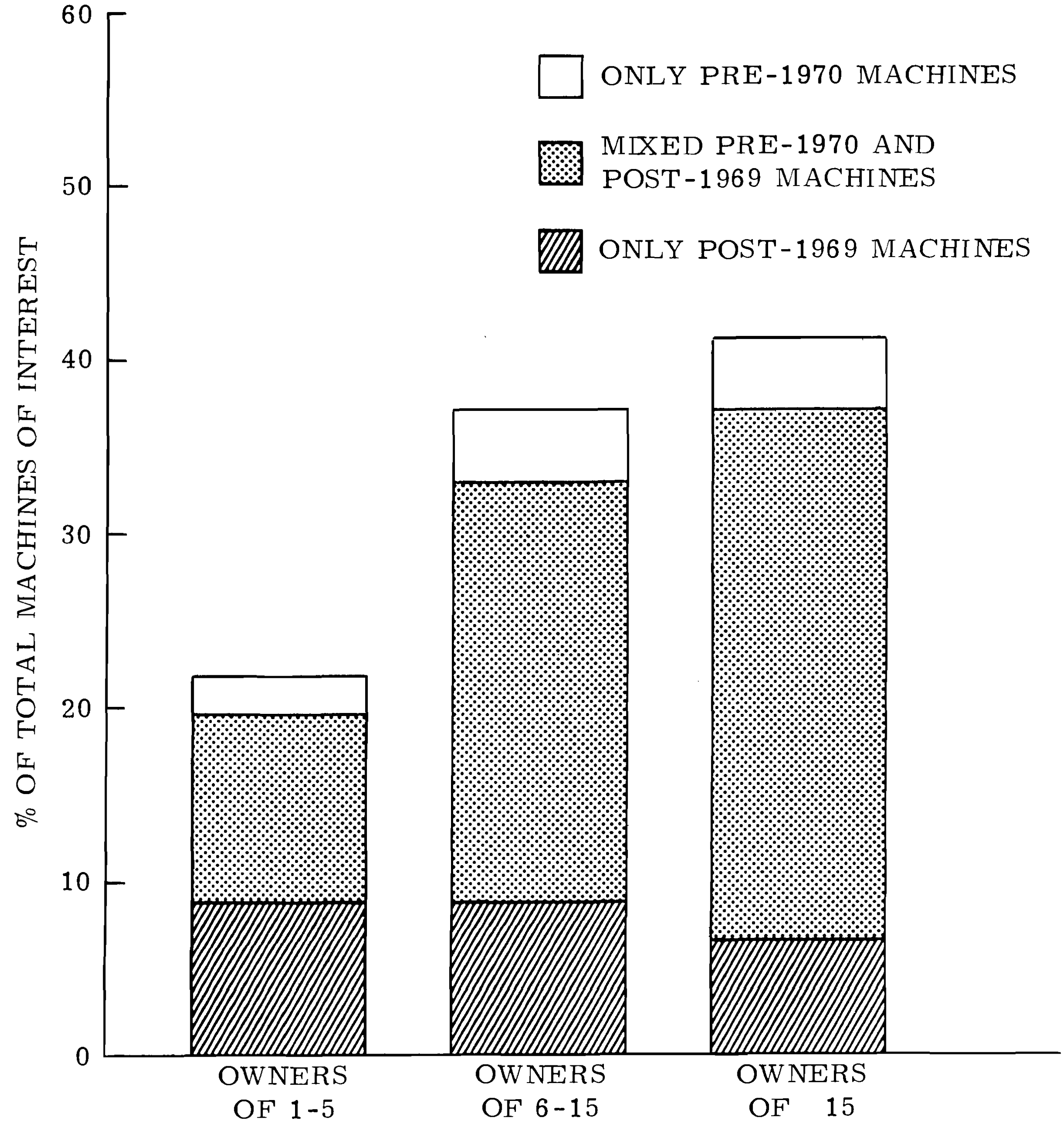


Figure A4-4. Underground Mines – Distribution of Machines of Interest by Owner Fleet Size and Composition

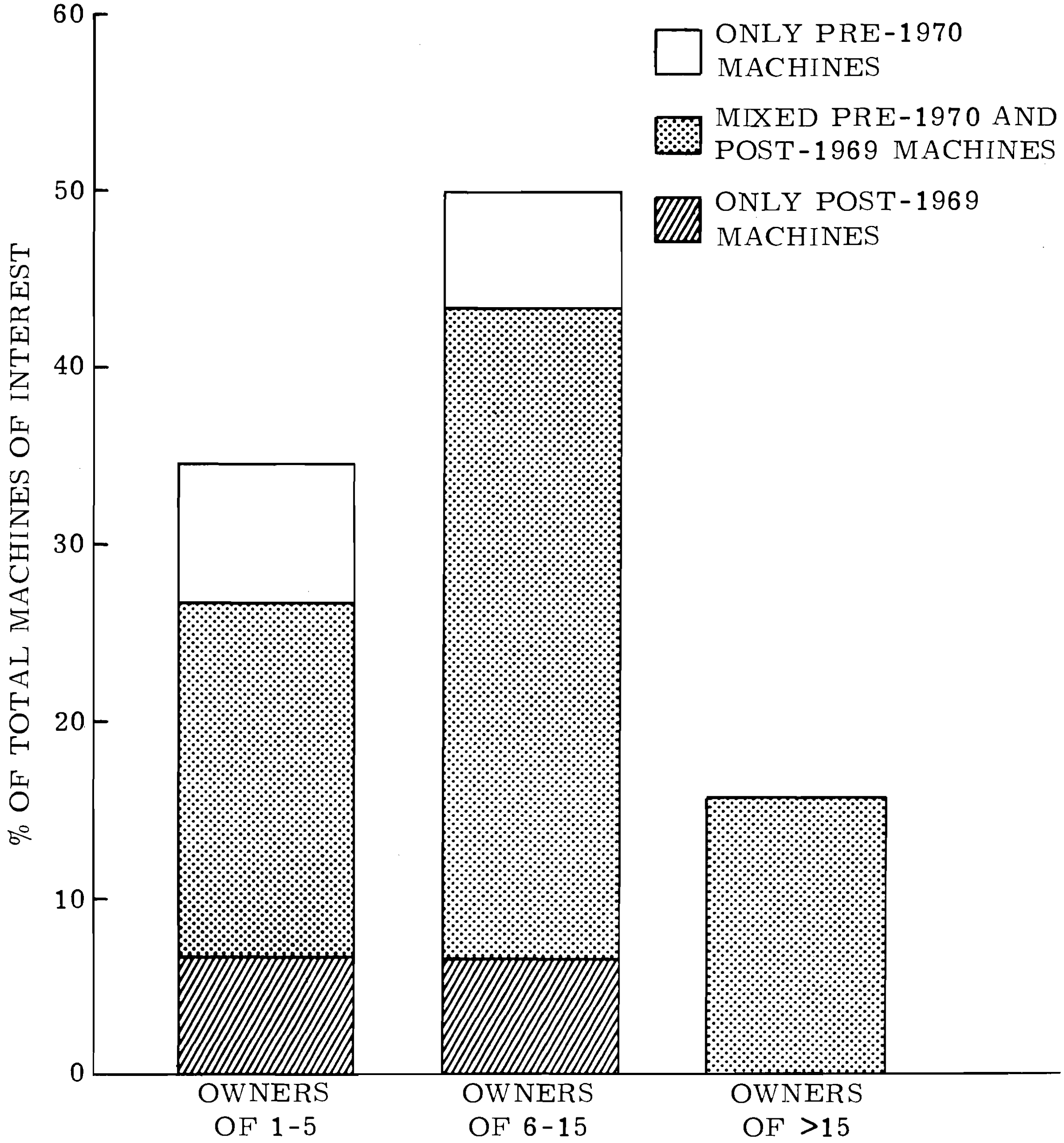


Figure A4-5. Crushed Stone Mines – Distribution of Machines of Interest by Owner Fleet Size and Composition

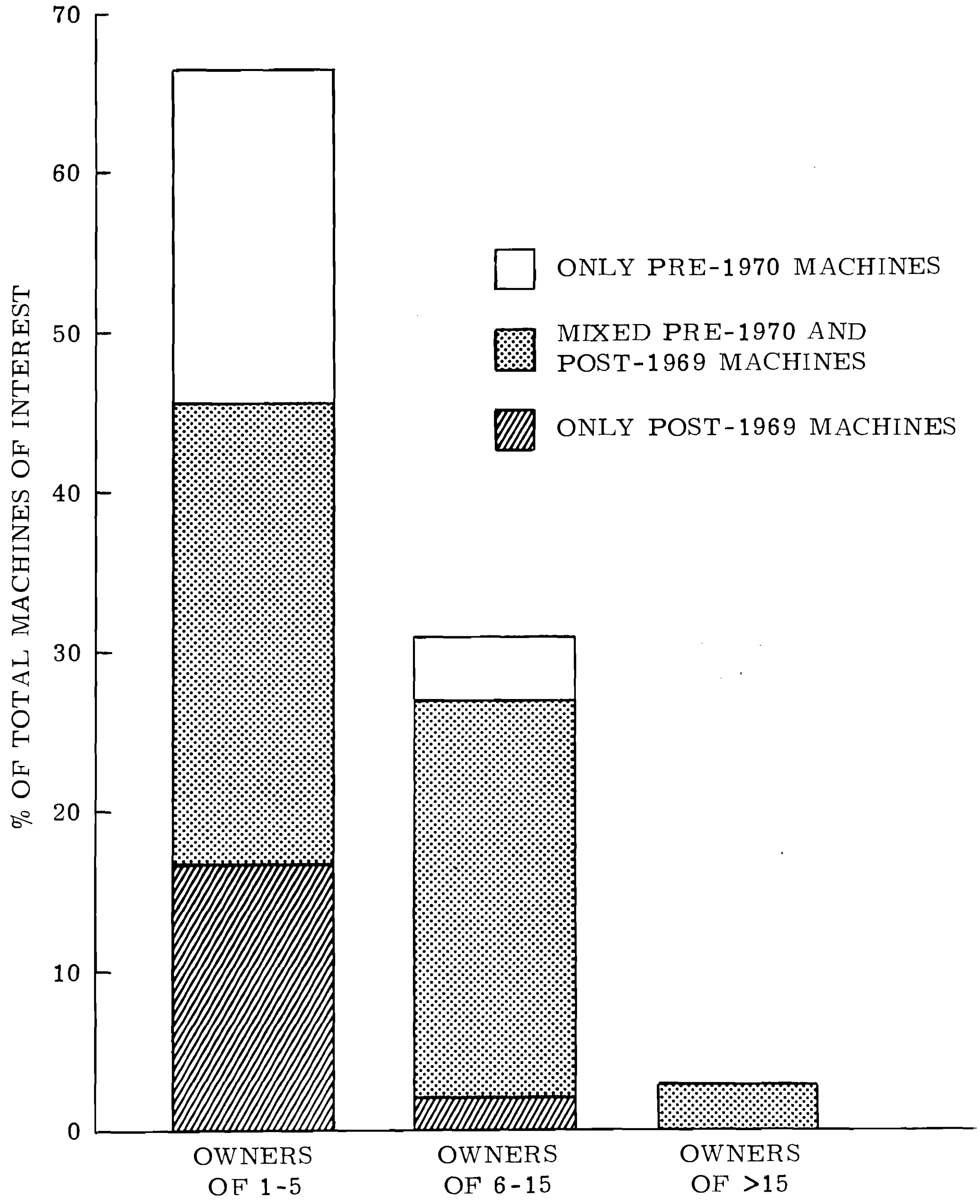


Figure A4-6. Sand and Gravel Mines – Distribution of Machines of Interest by Owner Fleet Size and Composition

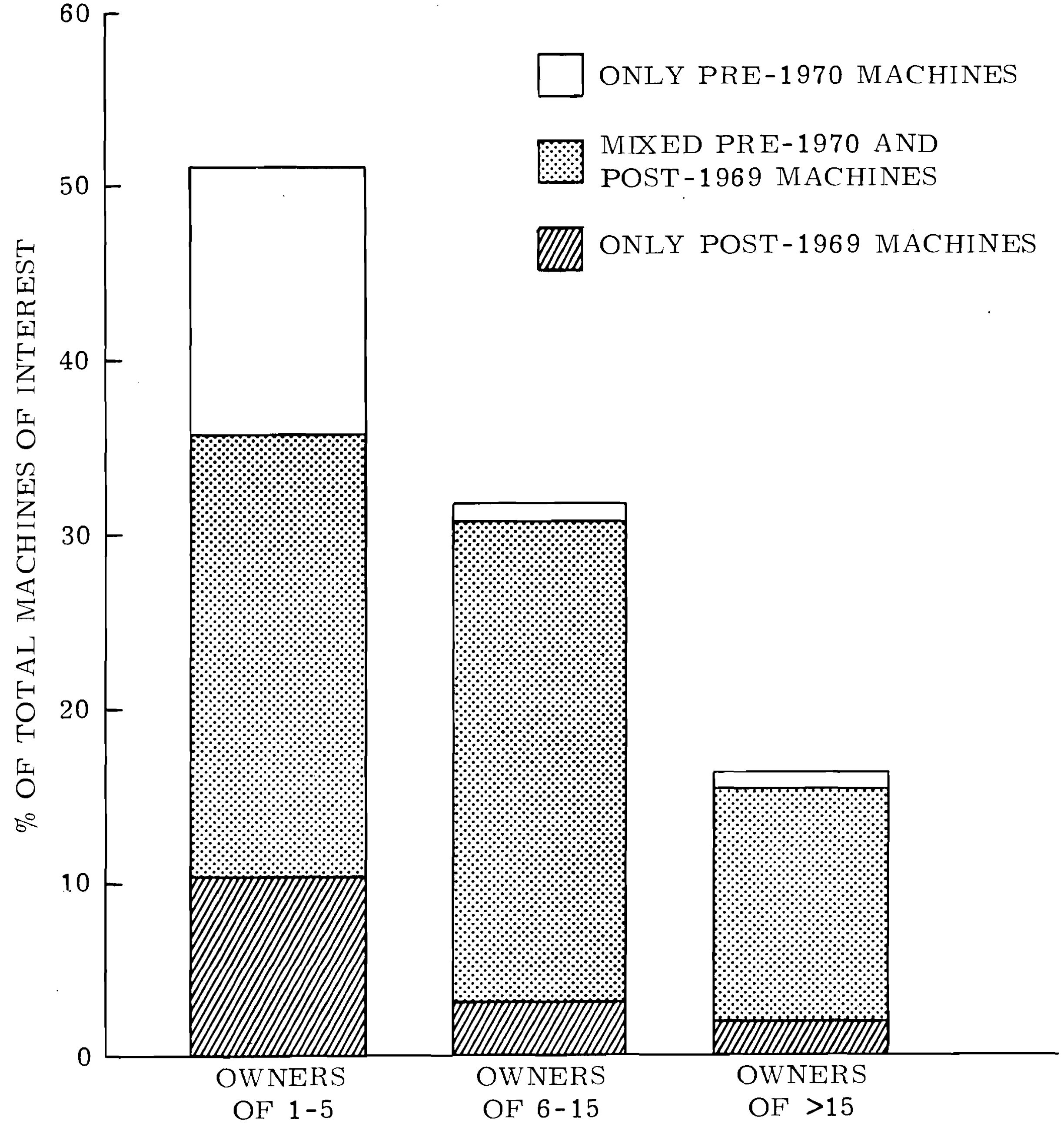


Figure A4-7. Open Pit M-NM Mines – Distribution of Machines of Interest by Owner Fleet Size and Composition

APPENDIX A5

ACCIDENT DATA SURVEY

During the preliminary planning related to this study, WAI staff members familiarized themselves with the MESA accident reporting and investigation procedures. Particular attention was given to the preparation and processing of USBM Form 6-1555-S, "Metal and Nonmetal Mine Injury and Illness Report" and to the contents of accident investigation reports made pursuant to clause (1) of Section 4 of the Federal Metal and Nonmetallic Mine Safety Act (80 Stat. 772).

The USBM Form 6-1555-S has, in Section C, space in which accident occurrence data is to be reported. The instructions require that the reporting official "describe fully the circumstances under which the accident, injury or illness occurred" and "name equipment, material, or tool involved," including model number. Although the descriptions given are usually adequate to give the reader an understanding of the nature of the accident, they seldom provide all of the physical details needed to calculate the energy levels involved. Accident frequency data by type of accident, and lost time data, are readily obtained from an analysis of the forms submitted during a given period. However, for the specific purposes of this study, the principal value of the forms seemed to be the identification of the locations and companies which had experienced fall-of-ground accidents. The initial study planning included procedures for using the forms in this way, provided that access to a central collection file could be obtained and provided that all of the forms pertinent to fall-of-ground accidents could be sorted economically from the rest.

A manual entitled "Inspection and Investigation Manual, Public Law 89-577" prescribes the procedures and report contents for investigations of fatal accidents. Section 9C of the manual requires that "a formal report shall be prepared and distributed for all fatalities determined to be chargeable to the mineral industries." Paragraph 9C(3) requires that the content shall include a description of the accident in "detailed narrative" form. It specifies also that "a suitable sketch of the accident scene should be prepared and included in the report." With the permission of Mr. E. Levi Brake, Phoenix Subdistrict Manager, MESA, and the cooperation of MESA personnel in the Reno Field Office, WAI staff members examined, in the course of preliminary planning for this study, a stack of approximately 150 MESA accident investigation reports. It was observed that, although the reports succeed admirably in identifying and explaining accident causes, and in presenting recommendations for improved safety, they often do not include all of the physical details of the fall-of-ground. For example, some state the weight of the rock which fell, but do not give the fall distance or sufficient dimensional information in the narrative or sketch from which to determine fall distance. Some state the fall distance, but do not give the size or weight of the material that fell. However, they are excellent sources of information concerning the nature and location of accidents, the people who witnessed or investigated the accidents, and some of the physical details. Used collectively, the reports of fatal fall-of-ground accidents provide much data which, we believed, could easily be augmented through mail questionnaires which asked for specific physical details. Further, it was clear that MESA had published a large number of investigation reports on non-fatal accidents. The WAI staff people observed, from the sample included in the reports available for review in the Reno Field Office, that these were, for the purposes of this study, quite as useful as the fatal accident reports. Accordingly, it was decided to use the MESA accident investigation reports, fatal and non-fatal, as the principal source of needed fall-of-ground accident data, and to obtain the data not given in the reports through mail inquiries to individual mines in which the accidents had occurred.

This preliminary planning also included a literature review, particularly of pertinent documents available in the MESA and Bureau of Mines facilities in Reno; the library of the Mackay School of Mines, University of Nevada; and the Nevada State Library. One document, entitled <u>Administration of Public Law 89-577 in 1973</u>, <u>Annual Report to Congress of the Secretary of Interior</u>, stated that there were 568 fatal accidents in the period 1971 through 1973 in all mines and mills. Of these, approximately 90 involved some "fall-of-ground" or closely related phenomena. <u>MESA Safety Reviews</u> indicated that there were approximately three times as many reported (Form 6-1555-S) fall-of-ground non-fatal accidents as fatals. There was no way found to determine readily what percentage of the reported non-fatals were covered by formal MESA accident investigation reports. Conversations with various MESA people and a count of the non-fatals in the chance sample of reports examined in the Reno Field Office suggested that as many as 25% might have been the subject of formal MESA investigation reports. Accordingly, it was estimated that there would be an average of about 50 available MESA accident investigation reports a year. If this estimate was correct, it was expected that data on about 175 fall-of-ground accidents might be obtained if only those which had occurred since January 1972 were considered. Thus, when the study began, emphasis was placed on receiving all available formal MESA accident investigation reports for the years 1972 through mid-1975.

In the course of the work, a few reports of interest on accidents which occurred prior to 1972 were found and were included in the study. Tables and discussion in later paragraphs of this appendix relate the accidents examined to the years in which they occurred. Also, when the final design of the equipment survey was being considered, it was decided to combine the survey with the accident questionnaire and to add a section in which respondents could identify fall-of-ground accidents which did not involve injuries. Such accidents would, with a few exceptions, not have been included in the MESA data. Later tables and discussion show how much information for the study was obtained in this way.

Data Requirement

One of the objectives of this study was to determine the structural requirements for FOPS to be used on underground and surface equipment for metal-nonmetal mines. This required that a determination be made of the size of rock falls most often experienced and the distance they fell. The mining equipment that was of particular interest is defined early in this report.

The data requirement, in other words, is to obtain data which show the energy transformation capability a protective structure must have to protect the operators of certain machines from injuries due to "fall-of-ground" accidents.

One of the two needed types of energy data is that related to a nearly uniform loading of the protective structure. Kinetic energy is the quantity desired:

$$E_k = 1/2mv^2$$

where

E_k = kinetic energy in foot-pounds
m = mass in slugs
v = velocity in feet per second

It is the kinetic energy of the falling object which the protective structure must transform in one way or another. If the energy loss due to air friction is ignored, because it is very small, the principle of conservation of energy requires that the kinetic energy of a falling object at any point in its fall be equal to the potential energy it has lost. An object of weight "w" which is held at a height "h" above some reference plane (such as the floor of a mine) has potential energy equal to the product of its weight and height ($E_k = wh$).

The kinetic energy of a rock fall can be defined at a reference plane that is the same as the level at the top of the FOPS. This level may be from about five feet to thirteen feet above the surface on which the machine is operating. The reference plane defined by the FOPS top is called the "protection level". How the "protection level" was selected for each accident in the data analyses is discussed in later paragraphs. Of course, the total kinetic energy at the protection level is not necessarily the amount with which the design of the protective structure must be concerned. In many cases, only a part of the energy affects the structure. The method of handling this fact in the data analysis is also discussed in later paragraphs of this appendix.

The second of the two needed types of energy data is that related to small area (point) loading of the protective structure. For some fall-of-ground accidents, the provision of protection depends upon the capability of the structure to resist extensive deformation, or top plate rupture.

Kinetic energy data are needed and, in addition, information about the shape of the falling object, especially the impact area. The manner of handling the data in this respect is discussed later.

Data Acquisition

The initial action at the beginning of this study was to arrange, through MESA officials, to review MESA accident investigation reports. The first reviews were made in the MESA Reno Field Office. When work on all of the reports available at that location had been completed, additional reviews were arranged at the Health and Safety Analysis Center, Denver, where a central repository of fatal accident investigation reports is maintained, and at MESA headquarters in Arlington, where a large file of nonfatal accident investigation reports is maintained. At Denver, accident investigation reports for every fatal metal and nonmetal mine accident since January 1, 1972, were reviewed and data were extracted and recorded for every accident of possible interest in this study which had not been previously reviewed in Reno. Similarly, in Arlington, data were recorded for every accident report which had not been reviewed in Reno or Denver. Some reports of special interest for the years 1970 and 1971 were reviewed in Reno. Table A5-1 shows the number of MESA accident reports reviewed by year and type. The total is 1005. Most of the accidents which involved some fall-of-ground were so designated by the MESA officials who were responsible for the investigations. A few, however, were under other designations, apparently because fall-of-ground was not the primary accident cause. The numbers of fall-of-ground accidents which were considered to be of interest to this study are given in Table A5-2 by year and type. The total is 152. Sufficient information to satisfy the data requirements discussed above was available in only a fraction of the investigation reports. Table A5-3 shows the numbers of

Table A5-1. MESA Accident Investigation Reports (Pre-Survey Review)

Fatal Accident Reports	
Denver, HSAC	
Year 1972	139
1973	168
1974	146
1975	57
Fatal and Non-Fatal Accident Reports	
Arlington, MESA	
All Years	191
Reno, MESA	
All Years	304
TOTAL	1005

reports in which needed data were complete, by year and type of accident. The overall percentage of accidents of interest which had all required data in the reports was 14.5%. One hundred thirty of the 152 identified in Table A5-2 had insufficient information for the data requirement of this study. The 130 accidents were those about which mail inquiries were made, using the Bureau of Mines Fall-of-Ground and Equipment Survey form discussed below. Table A5-4 is a summary of the 130 accidents by mine type (underground or surface) and type of accident (fatal or non-fatal). The table also shows, in the first column, the numbers of questionnaires which were mailed to obtain data not available in the accident investigation

Table A5-2. Fall-of-Ground Accidents – Identified from MESA Accident Investigation Reports

Year	Fatal	Non-Fatal	Total
1975	5	6	11
1974	24	18	42
1973	21	15	36
1972	22	8	30
Prior to 1972	26	7	33
All Years	98	54	152

Table A5-3. Fall-of-Ground Accidents – Physical Data Complete in MESA Reports

Year	Fatal	Non-Fatal	Total	Percent
1975	0	1	1	9.1
1974	8	1	9	21.4
1973	2	3	5	13.9
1972	2	3	5	16.7
Prior to 1972	1	1	2	6.1
All Years	13	8	22	14.5

Table A5-4. Accident History (AH) Questionnaires Mailed and Numbers of Accidents Involved

Mine Type	AH Mailings	Fatal Accidents	Non-Fatal Accidents	Total Accidents
Underground	76	56	37	93
Surface	37	29	8	37
TOTAL	113	85	45	130

reports. There are fewer questionnaires than accidents because several underground mines had more than one accident about which inquiries were made.

The questionnaire used is shown in Figure A5-1. It is Section 1 of the survey form which is discussed in more detail in Appendix A4. Three illustrative inquiries are shown on the questionnaire. The 130 accidents were numbered serially starting with AH-101. The "AH" referred to mines which had an "accident history" reflected in the MESA accident investigation reports. Equipment data which was also obtained on the AH survey forms were compiled separately from those obtained on forms with other designations, as discussed in Appendix A4.

Table A5-5 shows the numbers of fatal and non-fatal accidents for which the data required were obtained from responses to the mail questionnaires. The total is 86. The "success rate" of the questionnaire was 86/130 = 0.662, or about 66%. The overall response rate was higher. Some respondents did not provide the information requested, and a few

☐ U ☐ O ☐ C ☐ S
☒ AH ☐ RS No. 777

BUREAU OF MINES
Fall of Ground and Equipment Survey

Please provide the information requested in the sections checked only. See explanations on reverse.

☒ Fall-of-Ground
Section 1

Concerning the accident on 5/5 1975 involving a back fall and injuries to J. Jones, what was the distance material fell before striking victim; weight (or dimensions) of the material which fell.

Concerning the accident on 4/4 19 74 involving a rib fall and injuries to S. Smith, what was the weight (or dimensions) of the material which fell; manufacturer, model (or serial) number and year of manufacture of the Front End Loader involved.

Concerning the accident on 3/3 19 73 involving a back fall and injuries to D. Doe, what was the weight (or dimensions) of the rock which fell; type, model (or serial) number, manufacturer and year of manufacture of the machine involved.

☒ Section 2

In the table below, identify any fall-of-ground accidents (underground or surface) since Jan, 1972 which did not involve injuries.

Month/Yr.	Fall Distance (ft.)	Vol (cu. ft.) or Dimen. (ft.)	Material	Est. Weight	Fell From	Equipment Involved

☒ Equipment
Section 3

Identify all self-propelled equipment, not remotely-operated, which is presently used at your mine by completing the table below. (If more than 15, please continue listing on another sheet.)

	Equipment Type	Manufacturer	Model	Yr. Made or SN	Primary Use Undergd.	Primary Use Surf.	Primary Use Both	Is ROPS Installed?	ROPS Manufacturer	Estimated Remaining Life
1.					☐	☐	☐			
2.					☐	☐	☐			
3.					☐	☐	☐			
4.					☐	☐	☐			
5.					☐	☐	☐			
6.					☐	☐	☐			
7.					☐	☐	☐			
8.					☐	☐	☐			
9.					☐	☐	☐			
10.					☐	☐	☐			
11.					☐	☐	☐			
12.					☐	☐	☐			
13.					☐	☐	☐			
14.					☐	☐	☐			
15.					☐	☐	☐			

Figure A5-1. Accident History Questionnaire
(Section 1 – USBM Fall-of-Ground and Equipment Survey)

Table A5-5. Fall-of-Ground Accident Data
Obtained Through Use of Accident History Questionnaire

Year of Accident	Fatal Accidents	Non-Fatal Accidents	Total Accidents
1975	4	5	9
1974	10	13	23
1973	13	8	21
1972	13	2	15
Prior to 1972	16	2	18
TOTAL	56	30	86
Success Rate: $\frac{86}{130} = 0.662$			

provided it in a form which could not be quantified accurately for energy calculations.

In addition to the data obtained from the questionnaire, from Section 1 of the survey form, and from the MESA reports which had complete accident information, 90 fall-of-ground accidents which produced no injuries were obtained in Section 2 of the survey form. (See Figure A5-1.) On the "AH" survey forms mailed as well as on the "RS" forms, recipients were requested to complete both Sections 2 and 3. Data for six accidents were obtained through field trips to mines.

Table A5-6 shows the total number of accidents for which data were obtained in this study. The table separates the accidents by year, by type of mine and by injury category. The data from the total of 198 fall-of-ground accidents were those on which the analyses were based.

Table A5-6. Accident Data Obtained by Mine Type and Extent of Injury

	Underground			Surface			Totals		
	F	I	N	F	I	N	F	I	N
1975	2	0	22	2	0	10	4	0	32
1974	11	8	26	6	2	8	17	10	34
1973	10	11	9	5	0	9	15	11	18
1972	8	3	3	5	4	2	13	7	5
Earlier and No Date	17	4	4	1	1	5	18	5	9
TOTALS	48	26	64	19	7	34	67	33	98

Total Underground	138
Total Surface	60
	198

Key:
F = Fatal
I = Injury
N = No Injury

Table A5-7 shows the response performance from the 113 "AH" forms mailed. (See Appendix A4 for "RS" response performance.) There were 82 forms returned with the information requested in Section 1, or with some statement expressing a reason for not providing answers to the Section 1 questions. The most frequent reason was that the mine had been closed or that ownership had changed. The next most frequent reason was a statement to the effect that all known information was in the MESA accident investigation report. The overall response rate was 82/113 = 0.726, or about 73%. Nearly 20% of the respondents provided Section 2 information on "no injury" accidents. Many others reported that, although such accidents had occurred, no records were kept and no data were available.

Data Analysis Procedures

The fall-of-ground physical data available, whether from accident investigation reports, from the questionnaires mailed, or from direct

Table A5-7. "AH" Questionnaire Response Information

Total "AH" forms sent	113	100.0%
Full response provided	73	
Response, but no data, Section 1	7	
Response, data incomplete or unusable, Section 1	2	
Total responses to cutoff	82	72.6%
No response or undeliverable by USPS	31	
Responses with data in both Section 1 and Section 2	22	19.5%

interviews, were imperfect in many respects. It was necessary to develop guidelines and correction constants with which to treat the reported data. The objective was to accurately characterize the falls with respect to the energy which would be "seen" by a protective structure. The procedures and corrections chosen were those which would attain the objective, but never underestimate factors which affect energy calculations. The bias which exists in the final data is in the direction of overestimation. The degree of bias is judged in Section 4.1 and reflected in Figure 4-5.

Early in the study interest focused on the surface accidents because the size of some falls, as reported in weight terms, was very large. Data were available for a few accidents from which analyses could be made to judge the maximum weight and volume that would actually affect a protective structure. It quickly became apparent that the kinetic energy with which a protective structure could have been affected was usually very much smaller than that of the total fall. Several models for analyses purposes were considered. One is discussed below to illustrate how the physical data on fall-of-ground accidents were treated.

Model for Surface Mine Ground Falls

Not all of the weight in a large volume fall of non-cohesive material can impact in a small area. It would be inappropriate to estimate the kinetic energy a protective structure must transform by assuming that all of the falling material would impact on it. A method which provides more accurate estimates is needed. If the details of the fall geometry were known in each case, a very accurate estimate could be made. However, as explained earlier, in many cases little about the physical details of the accident is known. It is sometimes difficult to obtain good information even about such fundamental things as the fall distance and volume of fallen material. Several models which would provide reasonable estimates of impact weight and kinetic energy on the protective structures were worked out and tested. It was finally decided to use, for this report, a very basic one. Although the model requires several simplifying assumptions regarding the geometry and kinematics of earth falls, it produces satisfactory approximations which compare favorably with those obtained through more refined models. Further, it satisfies the principal objective, namely, to produce reasonable estimates with bias only in the direction of larger values, as will be apparent in the discussion which follows.

Assume that the material falls in a single, nearly cohesive mass, that it falls vertically, and that the machine upon which it impacts is directly under the fall, parallel to the face, and as near to the face as its normal work allows.

In most of the accidents in the sample, the fall was indeed from a nearly vertical face or wall. A few were from areas above undercuts. Some, however, were slides no more than about 30° above horizontal. The machines involved were usually not far from the wall, but within machine working distance from it.

The "angle of repose" is usually defined in one of two ways. It is the angle which the "natural slope" makes with the horizontal when a mass of earth has been exposed for a time to the elements. Or, it is defined as the angle with the horizontal at which material will stand when piled. The "angle of slide" is the angle at which material will flow. Table A5-8 shows angle of repose values for several materials. Table A5-9 gives some angle of slide values. A fallen non-cohesive material will form some angle with the horizontal after impact. The angle will be one between its angle of repose and angle of slide. In the model, 40° was assumed for all cases.

Table A5-8. Angle of Repose, Some Common Materials

Material	Angle (Deg.)	Source
Clay, Dry, Loose	37	1
Clay, Dry, Bank	45	1
Gravel, Clean, Loose	37	1
Rock (Riprap)	45	1
Sand, Wet	22	1
Sand, Clean, Loose	34	1
Screened Iron and Copper Ore	37	2

Source: 1. Mining Engineer's Handbook; Peele, Robert (ed.), John Wiley and Sons, N. Y., 1961.
2. Marks' Standard Handbook for Mechanical Engineers; Baumeister, Theodore (ed.); 7th Edition; McGraw-Hill Book Company, N. Y., 1967.

Table A5-9. Angle of Slide

Material	Angle (Deg.)
Mine-Run Ore	35-40
Ore, Fine Removed	30

Source: Marks' Standard Handbook for Mechanical Engineers; Baumeister, Theodore (ed.); 7th Edition; McGraw-Hill Book Company, N. Y., 1967.

Strictly speaking, "density" is the mass per unit volume of a material. Its units are slugs per cubic foot or $lb\text{-}sec^2\text{-}ft^{-4}$. The weight per unit volume is "weight density," or "relative weight" expressed in pounds per cubic foot. However, "density" is commonly used to mean weight per unit volume, and it is so used here. Table A5-10 gives density values for some of the materials in the accident samples and the sources from which these values were taken. In most cases, the highest value given in standard references for the material being considered was used. In the few cases for which the material was not known, and could not be estimated from available information, a density of 150 pounds per cubic foot was used. It was always assumed that the material which fell had the same density as the ore being mined, although in some cases it was clear that the fallen material (overburden) actually was lighter than the ore.

It was assumed that falls from a face or wall occurred from a single place, rather than from a long lateral area of the wall.

The general model is illustrated in Figure A5-2, which also shows the symbols used in the discussion and tables which follow.

Consider now what is the maximum volume of "loose" material which could rest entirely on the top of a protective structure after falling, given the conditions of the model. The volume is, of course, dependent upon the area of the top of the protective structure and whether it is flat. Examination of design data for ROPS presently available commercially shows that one of those with the largest top area is a ROPS for the D9 Caterpillar crawler tractor. It is a nearly flat top with dimensions approximately 70 inches by 90 inches. This area, 6300 square inches, or 43.75 square feet, is used in the analysis here.

Table A5-10. Density of Materials
(Lb. Per Cu. Ft.)

Material	Density Range	Average Density	Source
Asbestos Ore or Rock			
Bank		141	1
Loose		81	1
Basalt	169-200	184	2
	150-190		3
	171-201	181	4
Clay	112-162		3
Dry		63	2
And Gravel, Dry		100	2
Compact Bank		111	1
Loose, Dry		70	4
Marl	112-162	137	2
Concrete			
Cement, Stone, Sand	137-150	144	2
Copper Ore			
Sulfides and Up to			
10% Copper, Bank	163-178		1
Loose	113-120		1
Pyrites	256-269	262	2
Dolomite		181	2
		177	3
Bank	148-163		1
Loose	90-104		1
Earth			
Dry, Packed		95	2
Moist, Packed		96	2
Dry, Clayey		110	1

Table A5-10. Density of Materials (Cont)
(Lb. Per Cu. Ft.)

Material	Density Range	Average Density	Source
Feldspar	159-172		3
Bank	152-167		1
Loose	100-111		1
Orthoclase	156-169	162	2
Granite	160-170	166	4
	163-169	165	2
	165-173		3
Bank	148-163		1
Loose	96-104		1
Gravel			
Wet		125	4
Dry		112	4
Bank, Wet	111-126		1
Loose, Wet	100-120		1
Bank, Dry	104-115		1
Loose, Dry	90-100		1
Gypsum	144-145		3
Loose	90-100		1
Alabaster	144-175	159	2
Iron Ore			
Hemotite		325	2
Limonite	225-250	237	2
Magnetite	306-325	315	2
Hematite	306-330		3
Magnetite	306-324		3
Ore, 60% Iron			
Bank	237-259		1
Loose	156-170		1
Ore, 50% Iron			
Bank	211-230		1
Loose	141-152		1
Ore, 30% Iron			
Bank	167-185		1
Loose	119-137		1

Table A5-10. Density of Materials (Cont)
(Lb. Per Cu. Ft.)

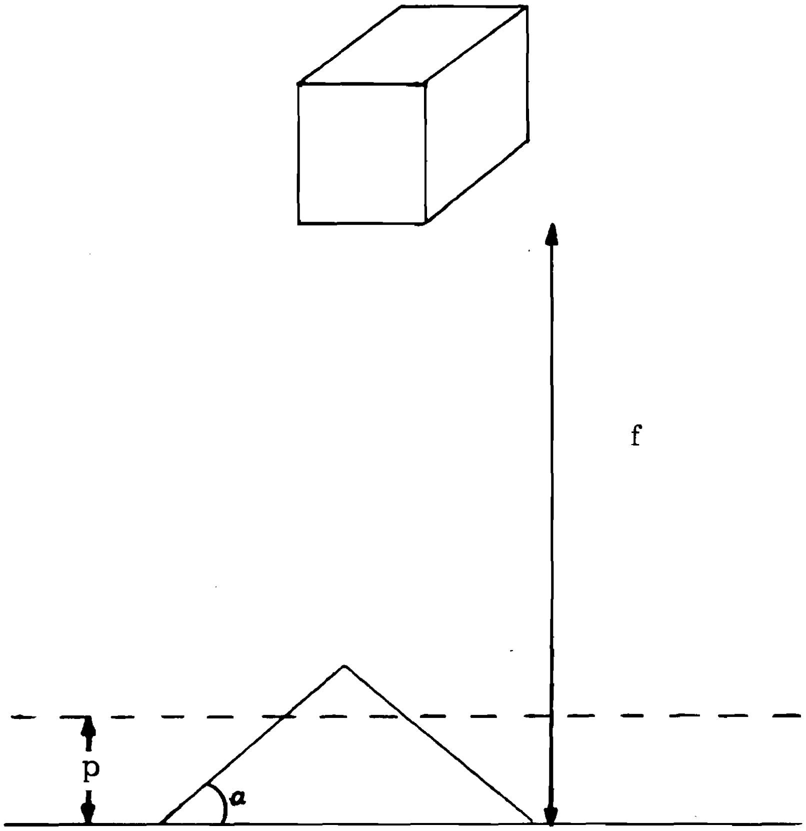
Material	Density Range	Average Density	Source
Lead Ore			
Galena	456-475	465	2
Galena	460-470		3
Limestone	131-178	155	2
	167-171		3
	168-178		4
Bank	148-163		1
Loose	89-104		1
Manganese Ore			
Pyrolusite	231-288	259	2
Marble	160-177		3
	163-179	170	2
Phosphate Rock			
Apatite		200	2
Porphyry	162-181		3
	163-181	172	2
Quartz		165	3
Flint		165	2
Riprap			
Limestone	80-85		2
Sandstone		90	2
Shale		105	2
Sand			
Dry, Bank	100-111		1
Dry, Loose	89-111		1
Damp, Bank	119-130		1
Damp, Loose	111-122		1
And Gravel, Dry, Loose	90-105		2
And Gravel, Wet	118-135	126	2

Table A5-10. Density of Materials (Cont)
(Lb. Per Cu. Ft.)

Material	Density Range	Average Density	Source
Salt			
Granular, Bank	111-119		1
Granular, Loose	70-78		1
Rock		136	3
Slate	162-205		3
Shale	163-181	172	2
Sylvite		125	3
Talc	168-174		3
Bank	126-133		1
Loose	85-89		1
Tremolite	181-200		3
Trona	132-134		3
Uraninite	406-606		3
Zinc Ore			
Blende	244-263	253	2

Sources:

1. SME Mining Engineering Handbook; Cummins, Arthur B. and Given, Ivan A.; Society of Mining Engineers; American Institute of Mining, Metallurgical and Petroleum Engineers, Inc., N.Y., 1973.
2. Marks' Standard Handbook for Mechanical Engineers; Baumeister, Theodore (ed.); 7th Edition; McGraw-Hill Book Company, N.Y., 1967.
3. Handbook of Chemistry and Physics, 54th Edition; Chemical/Rubber Publishing Co., Cleveland, 1973.
4. Mining Engineer's Handbook; Peele, Robert (ed.), John Wiley and Sons, N.Y., 1961.



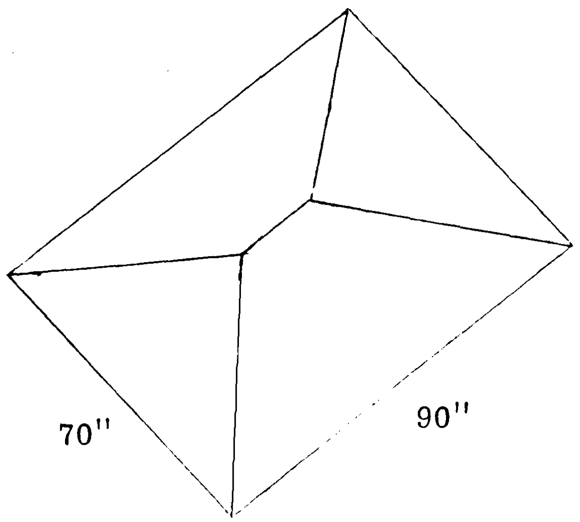
a = SLOPE OF THE FALLEN MATERIAL, 40°

p = "PROTECTION LEVEL" OR HEIGHT OF A PROTECTIVE STRUCTURE ABOVE THE SURFACE ON WHICH THE MACHINE OPERATES

f = TOTAL FALL DISTANCE

Figure A5-2. General Model of Rock Fall

The maximum volume of material, with a 40° angle of repose, which can be retained entirely on the top area, will occur when the protective structure is directly under the fall and the material piles symmetrically with respect to the center line of the structure's top. The shape of the material at rest is shown in the following sketch.



$$\tan 40^{\circ} = 0.839 = \frac{h}{35 \text{ in.}}$$

$$h = 29.37 \text{ in.}$$

$$V = \frac{1}{3}(70 \times 70)(29.37) + \frac{1}{2}(70 \times 20)(29.37)$$

$$= 47{,}971 + 20{,}559 = 68{,}530 \text{ cu. in.} = 39.66 \text{ cu. ft.}$$

$$W = Vd = 39.66 \text{ cu. ft.} \times 150 \text{ lbs./cu. ft.} = 5{,}949 \text{ lbs.}$$

This calculation is important only in that it shows that a relatively small fall of loose material, up to about 6000 pounds, might be retained entirely on the protective structure, provided that the initial contact area was somewhat smaller than 70 inches by 90 inches = 43.75 square feet.

An estimate may be made of the maximum weight and volume which might impact upon the protective structure. The mean thickness (vertical dimension) of the near vertical (>65°) falls for which the vertical dimension was reported was 4.5 feet. The range was 0.5 to 10 feet. However, there were some falls with a vertical dimension of 50 feet, judging from the accident investigation data. These all involved wall collapse. The geometry of the wall collapses suggest that the effective thickness of the portion which might have impacted on top of a machine located at a minimum working distance from the wall was no greater than about 10 feet. All of large collapses examined involved material of density <150 pounds per cubic foot. A maximum thickness value of 10 feet was used in the model, making the estimate for the maximum protective structure impact volume 70 inches by 90 inches by 120 inches = 756,000 cubic inches or 437.5 cubic feet. In the data analyses and the presentations of kinetic energy at the protection level, no greater value than this was considered for impact volume relevant to the protective structure. In those accidents in which fall distance was less than 18 feet, the volume was calculated from the protective structure area (43.75 square feet) multiplied by (f - p), and appropriate related adjustments were made in the weight for those cases. The basis for this procedure is the protective structure height, p, which was taken to be a minimum of 8 feet for the model (but 6 feet in the underground model). In fact, some of the machines of primary interest in this study are equipped with ROPS which have heights in the 10 to 14 foot range. When the machine involved was known, appropriate values were found in manufacturer's data and p was usually taken to be the given value minus one foot. Table A5-11 shows ROPS heights for some of the machines of interest.

It was suspected early in the study that there might be large errors in weight and dimension estimates. It was clear from discussions during the mine visits with safety officials and with MESA inspectors on several occasions that sometimes the dimensions reported were merely "eyeball estimates." In cases where measurements were made, the measurement was of the void from which the fall came. Even if one assumes that the length, width and thickness dimensions given are accurate, the volume of the rock they describe will not be correct if the dimensions are simply

Table A5-11. Protection Levels, Selected Machines, Approximate Height of Machine Plus ROPS

Machine	Protection Level (Feet)
Dozers	
Caterpillar D-8	11.4
Allis-Chalmers HD21	11.0
Loaders	
Hough H-400	14.6
Michigan 175	12.5
Michigan 275	13.3
Allis-Chalmers 745	11.7
Allis-Chalmers 945	13.8
Terex 72-71	13.3
Caterpillar 950	10.8
Caterpillar 977	11.3
Caterpillar 988	12.5
Scrapers	
Michigan 210	11.4
Wabco 333	13.1
Terex TS24	12.6
Allis-Chalmers 261	11.8
Caterpillar 627	10.8
Caterpillar 637	11.9
Graders	
Allis-Chalmers 200C	11.4
Wabco 444	10.8
Caterpillar 16	11.8

multiplied. The point is easily illustrated by considering a sphere with diameter D inside a cube which is D on a side. If the volume of the sphere is expressed in terms of the length, width and height of the cube, it is D^3. But the actual volume of the sphere is $1/6\ \pi D^3$. The error is represented by $\pi/6 = 0.524$, that is to say, the actual volume of the sphere is about half of what it would be stated to be if the dimensions of the cube were used to calculate it. Suppose the sphere were an irregular shape, what "correction constant" would have to be applied to obtain an accurate volume if only the dimensions of the cube were known? This is the kind of question for which a reasonable estimated answer was sought. The method was to obtain nine fallen rocks of various shapes and sizes from mines for an experiment. The greatest length, width and thickness of each rock was measured and a volume calculated from these figures. The amount of water each rock displaced when immersed was measured to the nearest 0.5 ounce and a volume calculated. The ratio of the second volume to the first was then calculated. The results are shown in Table A5-12. The mean V_2/V_1 value was 0.406. It suggests that the correction constant which should be employed for volumes calculated from reported fall dimensions should be about 0.4. However, 0.75 was used. The reason is that another experiment showed that the test subjects quite consistently underestimated length, width and thickness when asked to express these rock dimensions in inches. The resulting error was 0.20 to 0.30 of the volume calculated from the true dimensions. Further, a weight-volume correlation check was done on the first 21 data sets received in which fall weight and fall dimensions were given and densities were known with reasonable accuracy. The check indicated that a correction factor of about 0.70 applied to the volumes would make the weights and volumes correlate well. After some discussion of this matter, a correction constant for volumes of 0.75 was chosen for volumes calculated

Table A5-12. Mine-Run Rock Volume Sample

Sample No.	Dimensions (In.)	V_1 (In.^{3})	H_2O Disp. (Oz.)	V_2 (In.^{3})	V_2/V_1
1	6.125 4.875 5.0	149.30	36.0	64.97	0.435
2	3.375 3.375 8.3125	94.68	18.0	32.48	0.323
3	8.75 4.625 3.5	141.64	34.0	61.36	0.433
4	5.25 3.875 7.125	144.95	32.5	58.65	0.405
5	5.9375 5.0625 6.875	206.65	44.0	79.41	0.384
6	15.5 20.625 11.875	3,796.29	900.5	1,625.12	0.428
7	34.25 12.75 25.125	10,971.77	2,468.5	4,454.88	0.406
8	16.375 29.125 9.875	4,709.60	1,145.63	2,067.51	0.439
9	37.9375 18.5 11.3125	7,939.61	1,750.98	3,159.98	0.398

Mean $\frac{V_2}{V_1}$ = 0.406

from reported dimensions. A corollary decision was to take all weights as reported, based principally on two considerations: no satisfactory basis for correcting them could be found, and it was judged that miners were likely to estimate weight more accurately than any other value.

Table A5-13 gives the study data, from accident reports or survey questionnaires, for the 60 surface mine fall-of-ground accidents in the sample. The W_1 and V_1 columns give the values of weight and volume as reported. W_2 and V_2 columns give the values adjusted as discussed above. When W_1 was not given, W_2 was computed from V_1, with corrections. V_2 is V_1 with correction constants and ROPS area limits applied. Table A5-13 also shows the results of calculations of kinetic energy at the protection level. The machines involved in the accidents are indicated, the degree of injury noted, and the operation being conducted at the time of the fall is given when known.

Model for Underground Ground Falls

A model similar to that for the surface mine accidents was used for underground accidents. One principal difference is that the protection level was taken to be 6 feet (rather than 8 as in the surface model), or 1 foot less than the fall distance, whichever was smaller. Another is that, rather than using a 10 foot vertical dimension limit on fall volume, an 8 foot limit was used unless the reported fall thickness was available. In that case, the reported fall thickness was used with the 43.75 square foot ROPS top area to compute the limiting volume, that is, the maximum volume which would impact on the protective structure.

Table A5-14 gives the data, from accident reports or survey questionnaires, for the 138 underground fall-of-ground accidents in the sample. The table also shows the kinetic energy calculations for the

Table A5-13. Reported Data and Energy Calculations for Surface Mine Fall-of-Ground Accidents

Ident. No.	Reported Fall Dist. f (ft.)	Reported Fall Weight W_1 (lbs)	Reported Fall Volume V_1 (cu. ft.)	Ore	Fall Distance (f-p) (ft.)	Fall Weight W_2 (lbs)	Fall Volume $_2$ (cu. ft.)	Total Fall Kinetic En. E_k (ft. lb.)	KE, Protection Level E_{kp} (ft. lb.)	Machine Involved	Operator Protection	Operation & Injury Code
AH 011	150		1.33	Limestone	142	178	1.0	26,700	25,276	0	0	F
AH 012	23.5	600		Trap Rock	15.5	600	3.5	14,100	9,300	0	0	F
AH 015	35		324	Sand/Gravel	27	30,618	243	1,071,630	826,686	Conveyor	U	I
AH 020	60		5,400,000	Phosphate	52	87,500	437.5 *	4.86×10^{10}	4,462,500	Scraper	U	I
AH 148	50		25,000	Sand/Gravel	38	55,125	437.5 *	118,125,000	2,094,750	Mich 275 FEL	Canopy	F
AH 154	15	50		Slate	7	50	.3	750	350	1-R ECM 250/ URO 475 Drill	U	F
AH 154-2	10	54,000		Slate	2	54,000	314	540,000	108,000	Shovel	U	Loading/ N
AH 149	30	250,000	2,700	Chat	20	40,688	437.5 *	7,500,000	813,760	Cat. 950 FEL, 3 yd.	Cab	Loading/ F
AH 127	20		8	Basalt	12	1,104	6	22,080	13,248	NW 180 D Shovel	U	Loading/ F
AH 111	3		72	Marble (Slab Tip)	0	12,240	72	36,720	0	0	0	F
AH 129	55		2.3	Limestone	47	303	1.7	16,665	14,241	0	0	F
AH 129-2	115	2,000	40.5	Limestone	107	2,000		230,000	214,000	0	0	N
AH 129-3	80	2,000	40.5	Limestone	72	2,000		160,000	144,000	0	0	N
AH 129-4	90	1,500	27	Limestone	82	1,500		135,000	123,000	0	0	N
AH 147	40		3,000	Granite	32	72,625	437.5 *	14,940,000	2,324,000	P & H Shovel	Cab	Loading/ F
AH 143	12	2,000		Clay/Gravel	2	2,000		24,000	4,000	Cat D-7 Dozer	U	F
AH 151	35	8,000		Copper	27	8,000		280,000	216,000	Marion 191M Shovel (Near)	U	F
AH 151-2	35	400		Copper	27	400		14,000	10,800	GMC 1.5T Pickup	0	N
AH 151-3	35	6,000		Copper	27	6,000		210,000	162,000	Marion 191M Shovel	U	N
AH 174	35	100,000		Unknown	27	65,625	437.5*	3,500,000	1,771,875	I-R DM4 Drill	Cab	F
AH 211	20	1,000	8.2	Limestone	11	1,000		20,000	11,000	IH TD-6 & Drott Shovel	U	Loading F
AH 193	16		300	Iron	6	38,250	225	612,000	229,500	B-E 150B Shovel	U	I
AH 156	50	50		Granite	35	50		2,500	1,750	IH H400C FEL	U	Loading N
AH 156-2	30	10		Granite	22	10		300	220	0	0	N
AH 200-S	8	200		Clay (Trench Cave)	2	200		1,600	400	0	0	I
AH 123	15		1,280	Limestone (Earth Fall)	6	65,625	437.5 *	144,000	393,750	Cat Dozer	U	F
AH 124	20		600	Shale	12	75,250	437.5 *	1,548,000	903,000	NW MP12 Shovel	U	F
AH 176	45	20,638,789	199,024	Gravel (Bottom Slide)	35	45,369	437.5 *	928,745,505	1,587,915	Cat D8H Dozer Cat 627 Scraper Cab	U	N
AH 168	20	350		Limestone	10	350		7,000	3,500	FEL	U	I
AH 024	50	15,000		Rock	40	15,000		750,000	600,000	Cat D8 Ripper	U	N
AH 145	45		20	Sand	37	2,700	20	125,500	99,900	0	0	F
AH 116	30		2,700	Gravel	21	54,688	437.5 *	7,593,750	1,148,448	Hough H50 FEL	Cab	F
AH 134	20		2,100	Sand/Clay	10	48,563	437.5	3,496,500	455,630	Cat 944E FEL	Canopy	Loading F
AH 134-2	25		294	Clay	17	24,531	221	611,888	417,027	0	0	N
AH 159	18		6.8	Limestone (From Bucket)	6	890	5	16,220	5,340	Cat 988 FEL	Cab	Loading N
AH 110	14	1,600	13.5	Limestone	8	1,600		22,400	12,800	I-R CM2 Drill	U	F
AH 110-2	20	3,000		Limestone	12	3,000		60,000	36,000	0	0	N

*Indicates volume limited by 43.75 square foot protection surface area.

Table A5-13. Reported Data and Energy Calculations for Surface Mine Fall-of-Ground Accidents (Cont)

Ident. No.	Reported Fall Dist. f (ft.)	Reported Fall Weight W_1 (lbs)	Reported Fall Volume V_1 (cu. ft.)	Ore	Fall Distance (f-p) (ft.)	Fall Weight W_2 (lbs)	Fall Volume 2 (cu. ft.)	Total Fall Kinetic En. E_k (ft. lb.)	KE, Protection Level E_{kp} (ft. lb.)	Machine Involved	Operator Protection	Operation & Injury Code
AH 110-3	25	1,000		Limestone	17	1,000		25,000	17,000	0	0	N
AH 110-4	30	9,000		Limestone	22	9,000		270,000	198,000	0	0	N
AH 182	25	10,000	120	Trap Rock	17	10,000		250,000	170,000	Cat 977 PEL	Canopy	I
RS 7296	13	500		Granite	5	500		6,500	2,500	Boom Derrick	U	N
RS 7296-2	16	1,500		Granite	8	1,500		24,000	12,000	Boom Derrick	U	N
RS 7296-3	9	6,000		Granite	1	6,000		54,000	6,000	Boom Derrick	U	N
RS 7296-4	18	2,000		Granite	10	2,000		36,000	20,000	Boom Derrick	U	N
RS 3072	20	200		Limestone	12	200		4,000	2,400	Shovel	U	N
RS 7444	13		576	Marble	5	73,440	432	954,720	367,200	Bar	0	N
RS 3616	40	100,000		Rock	32	74,375	437.5 *	4,000,000	2,380,000	0	0	N
RS 3360	10	200		Rip Rap	2	200		2,000	400	Dump Truck	0	N
RS 3376	200	300,000,000	3,000,000	Limestone	192	43,750	437.5 *	6 x 10^{10}	8,400,000	Shovel	U	N
RS 2464	30	100,000	378	Limestone	20	77,875	437.5 *	3,000,000	1,557,500	Mich FEL	U	N
RS 4320	14		810	Basalt	4	80,500	437.5 *	1,564,920	322,000	FEL	U	N
RS 11104	18	3,000	54	Sand	10	3,000		54,000	30,000	Mich 75 FEL	U	N
RS 6104	140	80,000,000	100,000	Sand/Clay	132	59,938	437.5 *	1.12 x 10^{10}	7,911,816	Dragline	U	I
RS 7400	22	7,000		Sandstone	14	7,000		154,000	98,000	0	0	N
RS 7400-2	8	1,350,000		Sandstone	2	62,563	437.5 *	10,800,000	125,126	Slusher	U	N
RS 7400-3	10	10,000,000		Sandstone	4	62,563	437.5 *	100,000,000	250,252	Slusher	U	N
RS 6592	20	59,400		Coal	10	59,400		1,188,000	594,000	Cat D-8 Dozer	Canopy	N
RS 6592-2	35	629,000		Gravel/Clay	26	43,750	437.5 *	22,015,000	1,137,500	Int"1, TD25 Dozer	U	N
RS 6592-3	20	337,000		Road Ballast	12	48,125	437.5 *	6,740,000	577,500	Shovel	U	N
RS 6592-4	45	168,000		Road Ballast	37	48,125	437.5 *	7,560,000	1,780,625	FEL	Cab	N

*Indicates volume limited by 43.75 square foot protection surface area.

Table A5-14. Reported Data and Energy Calculations for Underground Mine Fall-of-Ground Accidents

Ident. No.	Reported Fall Dist. f (ft.)	Reported Fall Weight W_1 (lbs)	Reported Fall Volume V_1 (cu. ft.)	Ore	Fall Distance (f-p) (ft.)	Fall Weight W_2 (lbs)	Fall Volume V_2 (cu. ft.)	Total Fall Kinetic En. E_k (ft. lb.)	KE Protection Level E_{kp} (ft. lb.)	Machine Involved	Operator Protection	Operation & Injury Code
AH 001	8		12.5	Copper	2	1,669	9.4	13,352	1,338	0	0	F
AH 002	13		12	Iron	7	2,070	9	26,910	14,490	Jackleg Drill (Near)	U	F
AH 003	20	5,000	90	Salt	14	5,000		100,000	70,000	Eimco M387B Roof Bolter	U	Roof Bolting /F
AH 004	8	450	18	Lead/Zinc	2	450		3,600	900	ST-2B LHD (Near)	U	F
AH 005	9	3,000	21.3	Marble	3	3,000		27,000	9,000	G-D Air Track Drill (Near)	U	F
AH 006	11		144	Uranium	5	14,796	108	162,756	73,980	Slusher (Near)	U	N
AH 006-2	11	1,370	10	Uranium	5	1,370		15,070	6,850	Slusher (Near)	U	F
AH 007	60		.3	Lead	52	93	.2	5,580	4,836	Drill Jumbo, Cat D6 (Near)	U	F
AH 008	12		20	Copper	6	2,670	15	32,040	16,020	0	0	F
AH 009	7		198	Potash	1	18,563	148.5	129,941	18,563	0	0	F
AH010	12	550	3.9	Copper	6	550		6,600	3,300	Joy EHDM BMS-2B Roof B.	U	F
AH 013	28		120	Lead/Zinc	22	41,850	90	1,171,800	920,700	Drill Jumbo	U	N
AH 014	20	5,000,000		Lead/Zinc	14	148,750	350 *	100,000,000	2,082,500	Drill (Near)	U	N
AH 016	35	20,000		Lead/Zinc	29	20,000		750,000	580,000	0	0	I
AH 017	16		33,750	Gypsum	10	90,439	568.5 *	64,395,000	904,390	0	0	N
AH 018	17	27,000	36	Gypsum	11	27,000		459,000	297,000	Drill Jumbo	U	N
AH 019	25	1,000		Limestone	19	1,000		25,000	19,000	Scaling Tower	U	Scaling /I
AH 021	25		1.7	Gilsonite	19	228	1.3	5,700	4,332	Power Chipping Hammer	U	I
AH 022	10	2,000		Lead/Zinc	4	2,000		20,000	8,000	0	0	F
AH 137	12		37.5	Limestone	6	5,002	28.1	60,024	30,012	1-R CM150 Drill Jumbo (Near)	U	F
AH 113	9	6,000	35	Lead/Zinc	3	6,000		54,000	18,000	I-R JR88C Drill	0	F
AH 113-2	14	12		Lead/Zinc	8	12		168	96	0	0	N
AH 113-3	12	0.2		Lead/Zinc	6	0.2		3	1	0	0	N
AH 113-4	10	150		Lead/Zinc	4	150		1,500	600	0	0	N
AH 112	10	6,000		Lead/Zinc	4	6,000		60,000	24,000	0	0	F
AH 122	10		540	Lead/Zinc	4	37,188	87.5 *	1,721,250	148,752	G-D Drill Jumbo	U	F-2
AH 107	11.5		324	Gold	5.5	22,925	131 *	489,038	126,088	0	0	F
AH 115	10		396	Gold	4	22,925	131 *	519,750	91,700	0	0	F
AH 153	11	8,000		Lead	5	8,000		88,000	40,000	A-C 310E Mucker	U	F
AH 141	9	18		Iron	3	18		162	54	0	0	F
AH 152	10		6.7	Uranium	4	2,750	5	27,500	11,000	0	0	F
AH 103	10		89.3	Silver/Copper	4	12,460	70	124,600	49,840	0	0	F
AH 160	8		240	Silver/Lead	2	82,800	180	662,400	165,600	0	0	I-2
AH 104	10		4,800	Copper	4	62,300	350 *	6,408,000	249,200	Roof Bolter	U	F-2
AH 120	9.5		8,512	Copper	3.5	62.300	350 *	10,795,344	218,050	Roof Bolter	U	F-2
AH 128	12		448	Limestone	6	59,808	336	717,696	358,848	G-D JSPD Drill	U	F
AH 221	13		20	Lead/Zinc	7	6,975	15	90,675	48,825	Eimco 21 LHD	U	F
AH 221-2	13		16	Lead/Zinc	7	5,580	12	72,540	39,080	Eimco 21 LHD	U	N
AH 189	8		36	Limestone	2	4,806	27	38,448	9,612	G-D 3100 Drill	U	F
AH 224	24		525	Salt	18	17,816	131 *	1,285,200	320,688	Continuous Miner	U	F

*Indicates volume limited by 43.75 square foot protection surface area.

Table A5-14. Reported Data and Energy Calculations for Underground Mine Fall-of-Ground Accidents (Cont)

Ident. No.	Reported Fall Dist. f (ft.)	Reported Fall Weight W_1 (lbs)	Reported Fall Volume V_1 (cu. ft.)	Ore	Fall Distance (f-p) (ft.)	Fall Weight W_2 (lbs)	Fall Volume V_2 (cu. ft.)	Total Fall Kinetic En. E_k (ft. lb.)	KE Protection Level E_{kp} (ft. lb.)	Machine Involved	Operator Protection	Operation & Injury Code
AH 181	10	12,000	56	Clay	4	12,000		120,000	48,000	Eimco 911 LHD	ROPS	I
AH 217	12	150	2.5	Copper	6	150		1,800	900	Slusher (Near)	U	F
AH 158	11	200		Clay	5	200		2,200	1,000	0	0	I
AH 161	12	8,000	120	Antimony	6	8,000		96,000	48,000	G-D 63 Drill	U	I
AH 180	27	15		Limestone	21	15		405	315	0		I
AH 226	7.5	4,000	60	Lead/Zinc	1.5	4,000		30,000	6,000	Drill	U	F
AH 227	11.5		1,014	Potash	5.5	19,912	131 *	1,329,354	109,516	Joy CD-42 Drill (Near)	U	F & 1
AH 218	14		80	Lead/Zinc	6	27,900	60	390,600	167,400	Explosives Truck	U	F
AH 213	6.5	260,000		Potash	0.5	39,900	262.5 *	1,690,000	19,950	Goodman 2430 Cutter	ROPS	F
AH 223	8.5	4,000		Phosphate	2.5	4,000		34,000	10,000	0	0	F
AH 185	11		48	Uranium	5	19,800	36	217,800	99,000	Eimco 911 LHD (Near)	U	N
AH 209	10		924	Gold	4	36,135	219	361,350	144,540	0	0	F
AH 230	10		69	Gold	4	8,580	52	85,800	34,320	Drill	U	F
AH 208	8	20,000	120	Copper	2	20,000		160,000	40,000	G-D TFL 63 Drill	U	F
AH 194	8	10,000	60	Lead/Zinc	2	10,000		80,000	20,000	0	0	N
AH 212	20		4	Lead/Zinc	14	1,860	3	37,200	26,040	0	0	F
AH 157	10	70		Lead/Zinc	4	70		700	280	0	0	N
AH 178	9	150,000	108	Tungsten	3	87,500	175	787,500	262,500	Eimco 915 LHD	U	1
AH 167	12		49.5	Magnetite	6	11,655	37	139,860	69,930	Drill	U	1
AH 184	7		3.3	Magnetite	1	788	2.5	5,516	788	Drill	U	1
AH 203	9		50	Magnerite	3	11,813	37.5	106,317	35,439	0	0	I
AH 131	16		4	Limestone	8	534	3	8,544	4,272	A-C HD5 Drill	U	F
AH 228	8	1,320	12	Limestone	2	1,320		10,560	2,640	Cat 950 FEL	U	F
AH 125	9	2,000	8.5	Lead/Zinc	3	2,000		18,000	6,000	0	0	F
AH 204	10	792		Trona	4	792		7,920	3,168	Joy 14 BU Loader (Near)	U	Welting I-2
AH 204-2	9	891		Trona	3	891		8,019	2,673	NMS Cont. Miner (Near)	U	Survey I
AH 204-3	8	396		Trona	2	396		3,168	792	NMS Cont. Miner	U	Maint. 1
AH 204-4	8	40,000	303	Trona/Shale	2	29,127	219 *	320,000	29,127	Belt Line	U	N
AH 204-5	8	22,000	141	Trona	2	22,000		176,000	44,000	0	0	N
AH 204-6	8	80,000	606	Trona/Shale	2	29,127	219 *	640,000	58,254	0	0	N
AH 204-7	9	1,000	7.5	Trona	3	1,000		9,000	3,000	Cont. Miner	U	N
AH 204-8	8	80,000	600	Trona/Shale	2	29,127	219 *	640,000	58,254	0	0	N
AH 204-9	8	600,000	4,800	Trona/Shale	2	34,979	263	4,800,000	69,958	Main Belt Line	U	N
AH 204-10	8	40,000	300	Trona/Shale	2	40,000		320,000	80,000	0	0	N
AH 204-11	8	40,000	300	Trona/Shale	2	40,000		320,000	80,000	Joy Loader	U	N
AH 204-12	8	40,000	300	Trona/Shale	2	40,000		320,000	80,000	0	0	N
AH 204-13	8	20,000	150	Trona/Shale	2	20,000		160,000	40,000	Power Line	U	N
AH 204-14	8	160,000	1,248	Trona/Shale	2	46,550	350 *	1,280,000	93,100	0	0	N
AH 198	14		140	Copper	8	15,664	88 *	261,660	125,312	Shotcrete Machine	U	Shotcrete I
AH 155	10		960	Copper	4	46,814	263 *	1,281,600	187,256	0	0	I-2

*Indicates volume limited by 43.[illegible] square foot protection surface area.

Table A5-14. Reported Data and Energy Calculations for Underground Mine Fall-of-Ground Accidents (Cont)

Ident. No.	Reported Fall Dist. t (ft.)	Reported Fall Weight W_1 (lbs)	Reported Fall Volume V1 (cu. ft.)	Ore	Fall Distance (f-p) (ft.)	Fall Weight W_2 (lbs)	Fall Volume V_2 (cu. ft.)	Total Fall Kinetic En. E_k (ft. lb.)	KE Protection Level E_{kp} (ft. lb.)	Machine Involved	Operator Protection	Operation & Injury Code
AH 183	8.5	2,000		Copper	3	2,000		17,000	6,000	0	0	I
AH 229	9.5	2,000		Copper	4	2,000		19,000	8,000	0	0	F
AH 173	10	300		Silver	4	300		3,000	1,200	Roof Bolter	U	I
AH 190	12		18	Silver	6	2,430	13.5	29,160	14,580	0	0	F & I
AH 191	8	400,000		Silver	2	39,384	218.8 *	3,200,000	78,768	0	0	F-2
AH 126	11.5		21	Rock Salt	5.5	2,149	15.8	24,714	11,820	Jeffrey 97 B Loader	U	F
AH 130	45		22.5	Limestone	15	3,008	16.9	135,360	45,120	Hi-Ranger 7-60 Scaling TWR	U	Scaling/F & I
AH 163	25	1,000		Limestone	19	1,000		1,000	19,000	Scaling TWR	U	Scaling I
AH 166	10		300	Shale	4	10,504	131.3 *	180,000	42,016	Alenco Scaler	U	Scaling N
AH 166-2	10	200	16	Shale	2	200		2,000	400	Alenco Scaler	U	Scaling I
AH 166-3	10	150	8	Shale	2	150		1,500	300	Alenco Scaler	U	Scaling I
AH 166-4	20	900,000	5,600	Stone	14	22,978	131.3 *	180,000,000	321,692	0	0	N
AH 166-5	20	400,000	2,250	Stone	14	22,978	131.3 *	8,000,000	321,692	0	0	N
AH 166-6	20	400,000	2,250	Stone	14	22,978	131.3 *	8,000,000	321,692	0	0	N
AH 196	14		204	Lead/Zinc	8	65,025	153	910,350	520,200	Drill Jumbo	U	N
AH 196-2	14	600,000	6,000	Galena	8	81,375	175 *	8,400,000	651,000	0	0	N
AH 196-3	14	200,000	2,188	Galena	8	81,375	175 *	2,800,000	651,000	0	0	N
AH 197	14	50,000	900	Lead/Zinc	8	50,000	175 *	700,000	400,000	Drill	U	N
AH 023	17.5		60	Salt/Potash	11.5	6,300	45	110,250	72,450	Joy 11 BU Loader	U	F
AH 170	9	500	4.5	Zinc/Copper	3	500		4,500	1,500	0	0	I-2
AH 165	8.5	6,000		Copper/ Antimony	2.5	6,000		51,000	15,000	Slusher	U	I-2
AH 177	9	16,000		Copper Antimony	3	16,000		144,000	48,000	0	0	I-2
AH 206	10		30	Silver/Lead	4	9,563	22.5	95,630	38,252	Slusher	U	F
AH 136	30	18,000	100	Salt	18	18,000		540,000	324,000	Cat 988 FEL	ROPS	Loading F
AH 162	11		242.7	Salt	3	21,840	182	240,240	65,520	Euclid 76A Dump Truck	0	I
RS 1053	8	2,912	120	Rock	2	2,912		23,296	5,824	0	0	N
RS 1053-2	13	288,600	2,600	Rock	7	50,750	350 *	3,751,800	355,250	0	0	N
RS 1053-3	12	159,840	1,440	Rock/Sand	6	47,250	350 *	1,918,080	283,500	Drill	U	N
RS 1341	10	24,000	120	Dolomite	4	24,000		240,000	96,000	G-O Drill Jumbo	U	N
RS 1173	20	20,000		Rock/Sand	14	20,000	148.1	400,000	280,000	0	0	N
RS 1369	8	20,000	238	Coal	2	20,000		160,000	40,000	0	0	N
RS 1369-2	5	6,000	71	Coal	1	6,000		30,000	6,000	0	0	N
RS 1373 Multiple	12	100	1	Clay	6	100		1,200	600	0	0	N
RS 1169	15		19,200	Gypsum	9	55,650	350 *	34,344,000	500,850	0	0	N
RS 1269	4	4,000		Waste Rock	1	4,000		16,000	4,000	Bardown Tool	U	N
RS 1269-2	6	16,000	384	Waste Rock	1	41,760		96,000	41,760	0	0	N
RS 1269-3	6	30,000	400	Waste Rock	1	38,063	262.5 *	180,000	38,063	0	0	N
RS 1132	10	7,000	48	Waste Rock	4	5,220		70,000	20,880	0	0	N
RS 1233	13	3,000,000	23,400	Dirt/Rock	7	73,970	569 *	39,000,000	517,790	0	0	N
RS 1233-2	13	6,000,000	62,400	Dirt/Rock	7	73,970	569 *	78,000,000	517,790	0	0	N
RS 1201	24	572,000	3,600	Limestone	18	38,982	219 *	13,728,000	701,676	0	0	N
RS 1201-2	24	1,920,000	12,000	Limestone	18	40,688	262.5 *	46,080,000	732,384	0	0	N
RS 1201-3	24	800,00	5,000	Limestone	18	40,688	262.5 *	19,200,000	732,384	0	0	N
RS 1125	28	22,000		Marble	22	22,000		616,000	484,000	Joy Drill	U	N
RS 1125-2	62	320,000		Marble	54	59,500	350 *	19,840	3,213,000	Sky Rig	U	N
RS 1337	5	64,000	400	Temolite	1	64,000		320,000	64,000	Slusher	U	N
RS 1321	10	312,000	2,500	Limestone	4	54,250	350 *	3,120,000	217,000	0	0	N
RS 1397	6	10,000	180	Sand/ Dolomite	1	10,000		60,000	10,000	0	0	N
RS 1397-2	10	80,000	1,450	Sand/ Dolomite	4	35,000	350 *	800,000	140,000	0	0	N
RS 1105	16		3.3	Oil Shale	8	375	2.5	6,000	3,000	Drill	U	N
RS 1105-2	16	300,000	2,000	Oil Shale	8	52,500	350 *	4,800,000	420,000	0	0	N
RS 1457	6	5		Marlstone	1	5		30	5	Conveyor Belt	U	N
RS 1445	11		196	Potash	9	22,344	147	335,160	201,096	Goodman Loader	U	N
RS 1417	12	30,000	200	Talc	6	30,000		360,000	180,000	Conveyor	U	N
RS 1185	10	26,000	12	Gypsum	4	26,000		260,000	104,000	Joy CD 73 Drill	U	N
RS 1193	20	30,000,000	270,000	Rock/Dirt	14	52,500	350 *	600,000,000	735,000	0	0	N
RS 1449	60		96	Dolomite	54	13,032	72	781,920	703,728	0	0	N
RS 1449-2	30		18	Dolomite	24	2,444	13.5	73,320	58,656	0	0	N

*Indicates volume limited by 43.75 square foot protection surface area.

protection level. The machines involved, and other information, are provided as in the table for surface mine accidents.

Graphs which summarize the data in Tables A5-13 and A5-14 are in Section 4.2, "Characterization of Rockfalls."

As noted under the "Data Requirements" section above, the second type of data needed is related to "point loading" of the protective structure. Unfortunately, the information obtained for this study provided few data points from which to estimate the characteristics of ground falls in this respect. There were only 11 accidents from which sufficient data were available to make a general assessment of the matter. For these 11 accidents, estimates were made of the smallest impact area which seemed likely. Neglected, of course, were the possibilities that an irregular-shaped rock would fall so that a sharp "tip" would impact on the protective structure with an impact area <1 square inch. Using narrative descriptions of the rocks which actually fell in accidents, and observations of many rocks in mine environments, a judgment was formed about a likely area of impact. The results are shown in Table A5-15. It deserves to be repeated that these are judgments only. They are carefully considered judgments, but they have no sound foundation in test or carefully measured empirical data. The judgments are related to SAE J231 in the table. The symbol "+" indicates that the fallen weight or the impact area is greater than the SAE J231 specified value. The last column, "Possible Problem," is checked in appropriate cases to indicate that a machine operator might not have been protected by a commercial ROPS. The SAE J231 test weight is 500 pounds; the test impact area is 50.26 square inches; the kinetic energy is 8500 feet-pounds.

Although this study was directed to the physical characteristics of accidents, in the course of taking accident data from MESA accident

Table A5-15. Summary of "Point Load" Falls

Accident Sample No.	Kinetic Energy at Protection Level (Ft-Lb)	± J231	Weight of Fall (Lbs.)	± J231	Area of Impact (Sq. In.)	± J231	Possible Problem
1	25,276	+	178	–	16	–	X
2	4,332	–	228	–	40	–	
3	54	–	18	–	12	–	
4	99,000	+	19,800	+	36	–	X
5	26,040	+	1,860	+	48	–	X
6	788	–	788	–	42	–	
7	3,839	–	213	–	49	–	
8	4,272	–	534	+	48	–	
9	2,640	–	1,320	+	72	+	
10	6,000	–	2,000	+	54	+	
11	3,168	–	792	+	30	–	

investigation reports, dependent information on fatal accidents was also extracted. There were 98 fall-of-ground accidents for which fatality information was available. Table A5-16 shows the number of fatalities in these 98 accidents by mine type. There were 125 fatal accidents, fall-of-ground and other types related to ROPS or FOPS considerations, for which dependent information was given. Table A5-17 shows the number

Table A5-16. Number of Fatalities – Fall-of-Ground Accidents in This Study from MESA Accident Investigation Reports

Mine Type	No. of Accidents	No. of Fatalities
Underground	67	75
Surface	31	31
TOTAL	98	106

Table A5-17. Number of Dependents of Victims of Fatal Accidents

Accident Type	No. of Accidents	No. of Fatalities	No. of Surviving Dependents
Fall-of-Ground	83	90	270
Other ROPS/ FOPS Related	42	42	93
TOTAL	125	132	363

of fatalities and the number of surviving dependents of the victims in these 125 fatal accidents. These data are not from random samples, but three general observations seem valid:

1) There is a greater probability of multiple fatalities in an underground fall-of-ground accident than in a surface fall-of-ground accident.

2) There is a greater probability of multiple fatalities in fall-of-ground accidents than in machine roll-over accidents and other accidents in which ROPS might have provided operator protection.

3) A fatal accident is very costly in any terms in which one wishes to measure cost.

While extracting fall-of-ground accident physical data, information on other accidents related to operator protective structures was also recorded. The reasons were two:

1) Review of the first 150 accident reports in the MESA offices in Reno suggested that the frequency of fatal roll-over and other fatal accidents in which a ROPS might have protected the operator was greater than the frequency of fatal fall-of-ground accidents. Some comparisons would be interesting to the reader of this report.

2) Protective structures on heavy machines are an area of special WAI interest. Some additional data about their relevance in mining operations might make possible some observations of value to the Bureau of Mines.

Table A5-18 is a summary of the accidents other than fall-of-ground for which data were recorded. The total number is 68. Of these, 58 were fatals. This number is approximately comparable to 38 fatals involving fall-of-ground and machines of interest plus LHD types (see Table A6-3). Again, the sample in Table A5-18 is not a random sample, but several general observations seem valid:

1) The need for protective structures on machines of interest used in mining operations is greater with respect to roll-over and other machine accidents than with respect to fall-of-ground accidents. In Table A5-18, all of the roll-over and machine fall categories are surface mine accidents. The other categories include both underground and surface accidents. The underground accidents include some involving LHD types of machines.

2) To require a ROPS without simultaneously requiring that a seat belt be installed <u>and</u> used in conditions where roll-over or machine fall is a danger is extremely poor policy. Without a seat belt in use, the ROPS may actually increase the hazard to the machine operator in roll-over or machine fall situations. ROPS and seat belts, when properly used, do not assure absolute safety in roll-over accidents, but they greatly reduce the probability of fatal injury.

3) Properly designed FOPS on machines used underground will also provide some high degree of operator protection for other than fall-of-ground accidents. In particular, for those in which the <u>operator</u> struck, or was struck by, an object (roof support, overhang,

Table A5-18. ROPS/FOPS-Related Accidents, Except Fall-of-Ground, for Which Data Recorded

Accident Type	Number
Roll Over (ROPS and SB status unknown)	16
Roll Over (No ROPS, no SB)	24
Roll Over (ROPS, no SB)	2
Roll Over (ROPS and SB)	3
Roll Over (No ROPS, but SB)	1
Machine Fall (ROPS and SB status unknown)	7
Machine Fall (ROPS, no SB)	1
Machine Operator Struck Object (No ROPS, no SB)	4
Machine Operator Struck Object (ROPS, SB unknown)	1
Fly Rock	2
Operator Thrown from Machine	3
Machine Struck by Other Machine	2
Machine Operator Struck by Drill Steel	2
TOTAL	68

Key: SB = Seat Belt
ROPS = Roll-Over Protective Structure

imbedded drill steel, etc.) or another machine (conveyor, bucket arm, etc.), a protective structure will greatly reduce the probability of serious injury.

4) A carefully designed training program to increase machine operators' knowledge of the benefits and limitations of protective structures and seat belts seems highly desirable.

APPENDIX A6

ACCIDENT DATA ANALYSIS

This section is a summary of the work done with respect to the collection and analysis of information about "fall-of-ground" accidents incident to the acquisition of data concerning fall-of-ground physical characteristics. Details are provided in Appendix A5, "Accident Data Survey."

Sources of Accident Information

The information about the time and place of fall-of-ground accidents was obtained principally from four sources. The first was the fatal accident investigation reports published by MESA and maintained in a central repository by the MESA Health and Safety Analysis Center in Denver. The second was the non-fatal accident investigation reports published by MESA. The third was mines which were surveyed by mail in the Fall-of-Ground and Equipment Survey (see Appendix A4, "Equipment Population Survey") and which provided information about "no injury" accidents. The fourth was the field visits made to mines of many types and sizes throughout the United States by WAI staff members, and discussions with MESA people at several MESA offices. The number of fall-of-ground accidents identified through these sources was 211.

Physical Data Collection

The minimum data requirement for each accident, to meet the specific needs of this study, consisted of the general identification of the material that fell, the fall distance, the dimensions (or weight) of the material, whether the fall was in an underground or surface mine, and the identification of any machines involved. Of the 152 fall-of-ground accidents identified through MESA fatal or non-fatal accident investigation reports, only 22 had all of the physical data needed. A questionnaire was employed to acquire the physical data about the accidents which was not available in the reports. Questionnaires were sent to 113 mines, inquiring about specific physical details of 130 accidents. Thirty-seven questionnaires, relating to 37 accidents, were sent to surface mines. Seventy-six questionnaires, relating to 93 accidents, were sent to underground mines. Response rates and related information concerning the questionnaires appear in Appendix A5. Data concerning 198 fall-of-ground accidents was received through the questionnaires and through responses to the Fall-of-Ground and Equipment Survey. These accidents are summarized by type of mine, extent of injury to persons and time periods of occurrence in Table A6-1.

Important Definitions

There are three definitions employed consistently in this study which are very important to a correct understanding of the data discussed in this and subsequent sections.

The definition of the term "accident" was taken from the Bureau of Mines, Miners' Circular 51, "Injury Statistics as an Aid in Preventing Accidents in Metal and Nonmetallic Mines," namely, "an unplanned or unforeseen event that may or may not result in occupational injury." This definition was chosen because, as was discussed in Section 4.1, it was primarily the physical characteristics of fall-of-ground phenomena with which the accident analysis part of the study was concerned.

The term "fall-of-ground" was defined to mean the fall of any material related to mining operations from any mine surface, or from any machine or structure.

Table A6-1. Accident Data Obtained by
Mine Type and Extent of Injury

	Underground			Surface			Totals		
	F	I	N	F	I	N	F	I	N
1975	2	0	22	2	0	10	4	0	32
1974	11	8	26	6	2	8	17	10	34
1973	10	11	9	5	0	9	15	11	18
1972	8	3	3	5	4	2	13	7	5
Earlier and No Date	17	4	4	1	1	5	18	5	9
TOTALS	48	26	64	19	7	34	67	33	98

Total Underground	138
Total Surface	60
	198

Key:
F = Fatal
I = Injury
N = No Injury

The terms "machines of primary interest", "machines of interest", or "equipment of primary interest" refer to those machines specifically identified in the Introduction of this report. To repeat their identification, they are "self-propelled, track-type (crawler mounted) or wheeled (rubber-tired) front-end loaders, dozers, tractors but not over-the-road type tractors, motor graders, and prime movers with or without attachments." The load-haul-dump type machine, although a form of front-end loader, was not specifically included. However, WAI decided to include data about them in parts of the analyses.

Limitations of the Accident Data

There are several limitations of the accident data, in addition to those inherent in the sampling procedures used, which should be taken into account in making inferences from the data obtained.

First, it is a fact, verified by comments on the questionnaires and survey forms received from mine officials, by field visits to mines and examination of records, and by discussions with MESA mine inspectors, that many "accidents," as defined above, are not recorded by anyone and, consequently, were not reported in this study. Some of the known examples of such unreported accidents are:

1) Falls of ground which occurred during periods when no persons or machinery were in the area. Several underground mines stated that falls had been observed to have taken place during times when no shift was working. Many surface mines, particularly sand and gravel operations, remarked about falls which occurred during periods of inclement weather when the pit was not being worked.

2) Falls of ground which occurred during active work periods, but which produced no injuries to persons or serious damage to equipment. Several mines remarked about "occasional," "frequent" or "regular" falls, mostly small in size, which occur in underground mines. These are usually regarded as normal events

in the working environment, rather than as accidents. Cases were mentioned in which routine barring down, scaling or skimming activities produced "unplanned or unforeseen" falls, in addition to those deliberately induced.

3) A special category of Paragraph 2) above, which would be particularly pertinent to this study if it could be quantified properly, is those accidents in which no injuries occurred because the machines involved were equipped with ROPS or some other operator protection structure. Several cases of this kind were mentioned during mine visits but, because of the dearth of information available, no good estimates could be made about them.

4) Falls of ground which produced minor injuries which were treated at the mine first aid station, with no recorded "lost time." During a few of the field visits to mines, opportunities were available to examine treatment logs in dispensary or aid station facilities. It was observed that treatments for minor injuries identified with causes such as "struck by rock" were included, but that there were no physical data about the accidents recorded there or in any other records.

Although there are a few mines which record all known ground falls, as evidenced by the detailed information received from some survey respondents, it is clear that most do not. Generally, accurate physical data are available only for accidents which resulted in serious injuries, but not for all such accidents.

Data Analysis and Inferences

As emphasized above, the principal thrust of the accident analyses in this study related to the physical characteristics of the fall-of-ground accidents. However, it was also desirable to know the importance of fall-of-ground accidents relative to all accidents, and to know the importance of fall-of-ground accidents which involved machines of primary interest, relative to all fall-of-ground accidents. These things cannot be known exactly, but they can be estimated satisfactorily.

In the course of reviewing MESA fatal and non-fatal accident investigation reports, a total of 1005 reports was examined. These reports do not constitute a random sample of all accidents in metal and nonmetal mines to which the laws of probability would properly apply. The MESA reports do not include all accidents, as the term "accident" is used here. Instead, they cover all fatals and some selected non-fatals which were investigated in the interest of safety administration. Further, the set of reports reviewed is complete only with respect to 1972 through 1974 fatals, and other factors, as discussed above under "Limitations of the Accidents Data," apply. The sample is, in the terminology of statistical analysis, a "judgment" or "purposive" sample. The WAI staff believes it to be reasonably representative of the metal and nonmetal mine accident total population with respect to the proportion involving fall-of-ground phenomena. This belief derives from examinations of available accident analyses which suggest that the proportion of fall-of-ground accidents is, considering the definitional limits employed by different analyses, approximately 0.15 for non-fatal as well as for fatal accidents. Accordingly, the estimate used in this study is that 15% of all accidents in metal and nonmetal mines involve fall-of-ground phenomena. Table A6-2 provides some comparative data concerning

Table A6-2. Fall-of-Ground as Percentage of Total Accidents

Year	Total	FOG	FOG as Percentage of Total
MESA Fatal Accident Reports			
1972	139	20*	14.4%
1973	168	20*	11.9%
1974	146	21*	14.4%
1975 (Partial)	57	5*	8.8%
Secretary of Interior, Report on PL 89-577, Fatals			
1971-73	568	90	15.8%
All MESA Reports Reviewed by WAI			
1970-75 (Partial)	1005	152	15.1%

*Includes only categories "fall of roof or back" and "fall of face or side."

FOG = Fall-of Ground

fall-of-ground accidents as percentages of various totals. WAI believes that a random sample of all accidents since January 1970 would produce a 95% confidence interval for the proportion of fall-of-ground accidents of 0.12 to 0.18. Of course, this would apply only to metal and nonmetal mines in the aggregate, not to individual segments of the industry, nor to individual years. For example, the MESA Safety Review covering injury experience for the sand and gravel industry in 1970 shows that only about 3% of the non-fatal injuries and about 16% of the fatal injuries were due to "sliding or falling material." The number of fatals was small (4), so the overall percentage of fall-of-ground injuries was about 3%. There are no comparable data on accidents, as defined for this study, but it is possible that such data might show fall-of-ground to represent as much as 6% to 8% of the total sand and gravel industry accidents.

In discussing this study with mining people in government and in the industry, it became clear that some take the position that all fall-of-ground accidents should be considered. The merit of this view resides principally in the idea that some no-injury accidents could well have produced injuries but for "fate," "good luck," etc. One miner said, "The reason I'm alive instead of dead is that I moved eight inches to the left at the right time." Another credited his survival without injury to the fact that his D-8 ripper had a ROPS. On the other hand, some people took the more pragmatic view that only accidents which resulted in fatalities or serious injuries need be considered. This view has the merit of dealing only with "hard" data, however incomplete. The MESA non-fatal accident investigation reports do not cover all serious injury accidents, but they include some accidents in which there were no injuries.

In this report, WAI has tried to accommodate both points of view insofar as available data and supplementary subjective information permit. This is particularly true with respect to the physical characteristics of fall-of-ground accidents.

The WAI review of MESA accident investigation reports (all fatals published in 1972-1974 plus available non-fatals and selected fatals for other years) identified 152 fall-of-ground accidents. Ninety-eight of these were fatal accidents. Information about the victims was extracted from those reports in which it was given. Several of the accidents had more than one victim. There was a total of 106 fatalities in the 98 fatal accidents and, in addition, there were several disabling injuries. Age information was recorded for 94 persons fatally injured. In this sample of 94, the age range was 18 to 63. The median age was 37 and the mean 38.3. Surviving dependent information was recorded for 90 of the fatalities. The 90 victims left 270 surviving dependents. These data affirm once more a fact that really needs no affirmation: the costs of a fatal accident are high. The pertinent question in this study is how much of the total cost of metal and nonmetal mine accidents relates to fall-of-ground and the machines of interest. Some estimates in this regard may be made from the data collected.

It is important to treat the data concerning underground mine accidents separately from that concerning surface mine accidents, for the reason that the machines of interest are generally more prominent in surface mining than in underground operations. The samples in Table A6-1 are small in both categories, too small in fact to permit the construction of confidence limits, using the normal approximation, for population proportion estimates. Table A6-3 gives a summary of the data from the samples. In the surface mine portion of the sample, machines of primary interest were involved in one-third of the fall-of-ground accidents, in 38.5% of the fatal and disabling injury accidents, and in 36.8% of the fatals. These figures do not permit a good determination of how many accidents per year involve machines of interest because the sample, in addition to being small, is not accurately time-bounded. However, there are ways to get rate figures for fatals and simultaneously to judge how representative is the sample.

First, it is known that the fatal fall-of-ground accidents for the years 1972-1974, as they are defined for this study, were 22, 21 and 24,

Table A6-3. Summary Statistics - Samples of
Mine Fall-of-Ground Accidents Reported in This Study

	Surface Mines	Under-ground Mines		Total M-NM Mines
Fatal Accidents	19	48		67
Non-Fatal Injury Accidents	7	26		33
No Injury Accidents	34	64		98
Total FOG Accidents	60	138		198
			LHD Type	
Fatal Accidents, Machines of Interest (MI)	7	2	3	12
Non-Fatal Injury Accidents, MI	3	0	2	5
No Injury Accidents, MI	10	0	3	13
Total FOG Accidents Involving MI	20	2	8	30
Percent of Fatal FOG Accidents Involving MI	36.8%	4.2%	16.7%	17.9%
Percent of all FOG Accidents Involving MI	33.3%	1.4%	5.8%	15.2%

FOG = Fall-of-Ground

respectively. The total was 67. Of this total, 21 were in surface mines. Nine of the 21 surface mine fatal fall-of-ground accidents involved machines of interest for the three year period. Therefore, there was an average of 3 fatal fall-of-ground accidents in surface mines per year which involved machines of interest.

Second, using the data from the WAI sample for comparison, it is seen in Table A6-1 that information was gathered on 45 fatal fall-of-ground accidents for the years 1972, 1973 and 1974. Sixteen of these were in surface mines. Machines of interest were involved in 6 of the 16 surface mine fatal fall-of-ground accidents. The sample indicates an average of 2 fatal fall-of-ground accidents annually which involved machines of interest in surface mines. Using the number of total fall-of-ground accidents (45) studied in the sample and the total known fall-of-ground accidents (67) for the same period, an estimate of the fall-of-ground accidents occurring in surface mines involving machines of interest can be made. The prediction is 3 fatals per year.

Three fatal accidents a year represent about 2% of the annual total fatals in metal and nonmetal mines for the years 1972-1974.

Non-fatal fall-of-ground surface mine accidents involving machines of interest can be estimated using similar techniques. The WAI estimate is that there may be as many as 133 non-fatal accidents, approximately 6 of which produces some degree of injury.

In the underground portions of the sample (Table A6-3), machines of primary interest were involved in less than 2% of the fall-of-ground accidents, in about 3% of the fatal and disabling injury accidents, and in 4% of the fatals. In fact, there are only 2 accidents in the sample which involve machines of interest, and both were fatals.

Using the same reasoning as discussed above for surface mines, an average frequency of fatals which involve machines of interest is estimated at less than one per year.

One fatal accident a year represents 0.7% of the total annual fatals in metal and nonmetal mines for the years 1972-1974.

The estimating technique indicates there may be as many as 44 non-fatal fall-of-ground underground mine accidents involving machines of interest a year, approximately 28 of which produce some degree of injury.

There are many more surface mines than underground mines in the metal and nonmetal mining industry. The numbers used in this study are 668 active underground mines and 13,321 active surface mines. According to the MESA classifications, 1756 of the surface mines are open pit, 4029 are crushed stone operations and 7536 are sand and gravel operations.

There are more fall-of-ground accidents in underground mines than in surface mines. There are approximately 329 such accidents annually in surface mines, and approximately 877 in underground mines. However, there are fewer fall-of-ground accidents involving machines of interest in underground mines than in surface mines. The annual rate for underground mines is approximately 44; for surface mines it is approximately 133. Table A6-4 summarizes the WAI estimates of fall-of-ground accidents involving machines of interest.

It may be estimated that the addition of a "perfect" operator protective structure on all machines of interest which do not already have some form of falling object protection, presently working in metal and nonmetal mines, might reduce the fatal fall-of-ground accidents by about 4 per year and the accidents which cause some degree of non-fatal injury by 90. This estimate must be qualified by several factors. The two most important of these are:

1) Protective structures protect the machine operators only when they are in the operators' normal operating positions. In some of the fall-of-ground accidents which involve machines of interest, the operator is not in his normal operating position.

2) The degree of protection afforded a machine operator by a protective structure depends upon the energy absorption capability of the structure relative to the energy involved in the ground fall. It is clear that there are some fall-of-ground accidents for which no conceivable machine-mounted protective structure could provide complete operator protection.

Supplementary Note Concerning Machines of the Load-Haul-Dump Type

The low profile load-haul-dump (LHD) machines are commonly used in underground mines in areas in which the larger machines of interest cannot be employed. Indeed, the LHD and similar types were developed largely for that reason.

In the sample, Table A6-3, there were 8 fall-of-ground accidents in underground mines which involved machines of the LHD type. Three of these were fatals and 2 produced some degree of non-fatal injury. The LHD type was involved in nearly 6% of the underground mine fall-of-ground accidents. The annual fatal and injury rates are greater for the LHD type in underground mines than for all of the types of machines of interest specified for this study. The reason is obvious: they are more often "where the action is," that is, their exposure rate to areas in which fall-of-ground occurs most frequently is high relative to that of the machines of interest. Only in mines which have very high backs (some lead and salt mines, for example) do the machines of interest figure prominently in the type of underground operation which have high fall-of-ground exposure.

Table A6-4. Estimates of Average Annual
Fall-of-Ground Accidents Which Involve Machines of Interest

	Surface Mines	Underground Mines	Total M-NM Mines
Number of Active Mines	13,321	668	13,989
FOG Accident Class			
Fatal	7	15	22
Non-Fatal Injury	153	570	723
No Injury	169	292	461
Total FOG	329	877	1,206
Fatal, MI	3	1	4
Non-Fatal Injury, MI	62	28	90
No Injury, MI	68	15	83
Total FOG Involving MI	133	44	177