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Causes and Prevention of Transportation Accidents in Bituminous Coal Mines

By Ernest A. Curth

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CAUSES AND PREVENTION OF TRANSPORTATION ACCIDENTS IN BITUMINOUS COAL MINES

by

Ernest A. Curth [1]

ABSTRACT

Statistics for 1956-66 show that mine transportation accidents accounted for 19 percent of fatalities in bituminous coal mines, second only to roof deficiencies as a cause of death. Productivity per man-shift increased from 10.2 tons in 1956 to 18.4 tons in 1966, but the fatalities per million man-hours of exposure also increased from 0.19 to 0.21 during that same period, indicating that transportation hazards still persist.

Consequently, the Bureau of Mines reviewed the transportation fatalities that occurred in bituminous coal mines during 1956-66. The data were processed by computer to find what constitute hazardous conditions and unsafe actions as well as to correlate occupation and age of victims, transportation type, and mine production. Environmental factors and equipment defects which create hazards, as well as unsafe actions of personnel, were determined for each type of mine transportation: Track haulage, mobile nonrail haulage, conveyors, hoists, automotive operations, and front-end loaders, and for transfer stations (loading points, slope and shaft bottoms, surface transfers) and railroad yards. Man-trip accidents, a group with a catastrophe potential, also were analyzed. The basic design and operational features of each transportation type were outlined and procedures considered safe in the light of accident experience were suggested.

Findings show that unsafe actions of personnel and hazards created by environmental deficiencies or equipment malfunctions contribute equally in causing transportation accidents. Accordingly efforts should be directed toward improving working conditions, equipment maintenance, and education and training of employees. The trend is toward using safer modes of transportation, notably conveyors. More attention should be given to track haulage operation, railroad yards, and nondestructive field testing of materials.

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INTRODUCTION

Mine transportation involves the flow of products, supplies, and men between the working faces of underground, strip, or auger mines and rail or river loading facilities. The transportation system divides into four subdivisions: Portal haulage through shaft, slope, or drift; main-line haulage; secondary or sectional haulage; and face haulage. Of all major phases in mine operation, transportation is the least affected by ground stress and environmental hazards and therefore should contribute least toward fatalities. Such is not the case, however. Transportation causes 19 percent of the fatalities in bituminous coal mines and is second only to roof in causing death. With advanced mine technology, the overall productivity of bituminous coal mining increased from 10.2 tons per man-day in 1956 to 18.4 tons in 1966. Although the frequency rates of all fatal mine accidents as well as the fatalities associated with transportation, in terms of million tons of bituminous coal for each year, declined appreciably over this period, frequency rates, in terms of million man-hours of exposure, changed very little (fig. 1). Transportation hazards to the workmen persisted. The lower chart indicates that the trend line rose slightly from 0.19 to 0.21 fatalities per million man-hours of exposure (96, 99).[2]

Therefore, the Bureau of Mines has collected and tabulated data on transportation fatalities that occurred in bituminous coal mines during 1956-66. The Computer Center of Virginia Polytechnic Institute (VPI), Blacksburg, Va., has processed coding lists, established in consultation with members of the mining faculty. The data were obtained from Bureau of Mines records of fatal accidents, most of which were detailed and well illustrated. A few reports of nonfatal accidents also were included. Perhaps documentation of future reports on nonfatal accidents should be more thorough to give a larger population for study. A statistical evaluation of mine accident data by Manula and Nelson has brought out that rates of fatal and nonfatal accidents (which often differ from fatals by the factor of sheer luck) are significantly correlated; that is, fatals vary directly as nonfatals. This would infer common causes for both (71).

The reports were analyzed in an effort to obtain as complete a picture as possible. Therefore, all concurring causes for each accident, hazardous conditions as well as unsafe acts, were included in the tabulation of data. The computer program was designed to establish interrelationships by cross tabulation. These interrelations cover distribution of fatalities by age and job category of stricken haulage personnel, type of transportation involved, thickness of coalbed, and daily mine production. These last are of a more general nature and are described under "General Experience With Fatal Mine Transportation Accidents During 1956-66." A source of general accident information was the Bureau series of Information Circulars on injury experience in coal mines, covering the years 1956-66 (66-70, 75-80).

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

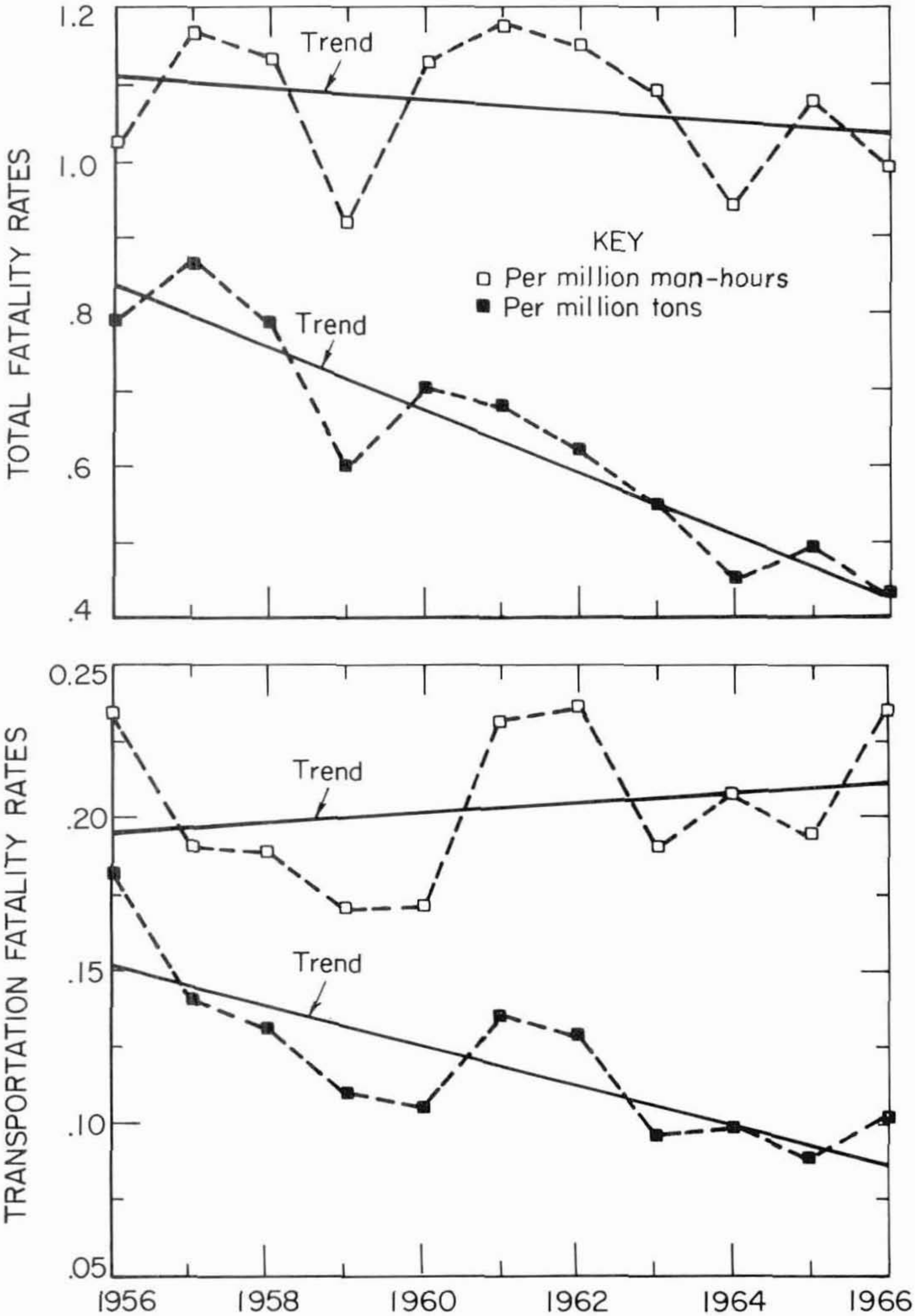


FIGURE 1. - Bituminous Coal Mine Fatality Frequency Rates, 1956-66. Above: All fatals; below: transportation fatalities.

Further cross tabulations lead to a detailed accident analysis, identifying causes of accidents: "hazardous conditions" as well as "unsafe acts" (5). This cross tabulation helps determine the direction of efforts in planning, operation control, and equipment design and maintenance. The physical and environmental causes of accidents show relation between hazardous conditions and specific defects in equipment and environment.

But the fact that unsafe personnel actions also lead to accidents is of great importance in directing education and training. The investigation links the transportation type to unsafe acts.

An unsafe act "identifies the violation of a commonly accepted safe procedure which directly permitted or occasioned the occurrence of the accident" (5). This definition includes failure to do what ought to be done. In terms of time the act is closely associated with the occurrence of the accident. The person committing the unsafe act, knowingly or unknowingly, may become the victim or be the person not injured. Hazards, created by supervisory decision or action, are not defined as unsafe acts, but are designated as hazardous conditions.

Accident experience with each type of transportation is analyzed in detail in the following text. Basic design and operational features are outlined and procedures, considered safe in the light of the accident analysis, are suggested.

ACKNOWLEDGMENTS

The author acknowledges the permission granted him by Armco Steel Corp. to use figure 33; Coal Age to use figures 4, 6-8, 18-20, 22, 27, 29, 30, and 40; Coal Mining and Processing to use figures 5, 26, 28, and 39; Connelsville Corp. to use figures 34 and 35; Engineering and Mining Journal to use figure 44; Link Belt Division of FMC Corp. to use figure 23; Joy Manufacturing Co. to use figure 14; LKAB Photo Börje Rönnberg to use figure 12; Long-Airdox Co. to use figures 9 and 38; Megator Corp. to use figure 24; Mining and Minerals Engineering to use figure 11; Mining Congress Journal to use figure 21; The Mining Engineer to use figure 37; Nachod and United States Signal Co. to use figure 10; National Safety News to use figures 41-43; Nordberg Manufacturing Co. to use figure 31; United States Steel Corp. to use figure 13.

GENERAL EXPERIENCE WITH FATAL MINE-TRANSPORTATION ACCIDENTS, 1956-66

Transportation took a toll of 601 lives during 1956-66. There were 466 victims from the ranks of haulage personnel; 237 of them were track haulage men, including portal bus and personnel carrier operators and three animal drivers, and 133 were personnel engaged in trackless haulage, including two tractor-scoop operators. The tractor scoop is the recently introduced low-seam counterpart of the front-end loader. Fifty-two accidents involved non-transportation personnel riding in man trips and on vehicles, and 83 men were victims of accidents connected with transportation.

The distribution by job category and age, figure 2, reflects the general age distribution of mine personnel in all categories. For instance, the battery tractor operators are generally younger and work in the smaller and newer mines.

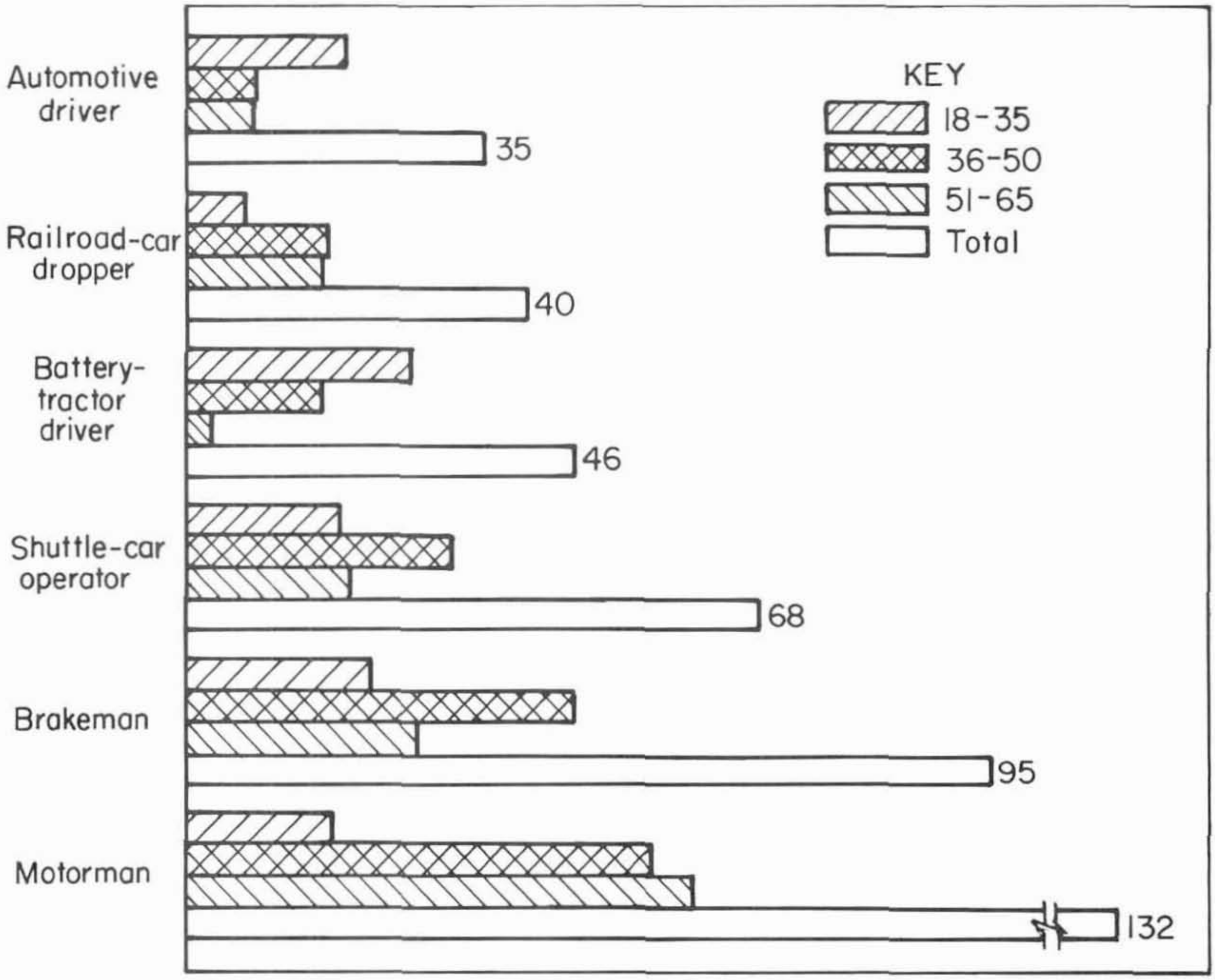


FIGURE 2. - Ages and Job Categories of Haulage Personnel Fatally Injured in Coal-Mine Transportation Accidents, 1956-66.

The technological evolution in mine transportation, notably the trend to trackless haulage, is shown by data in figure 3. In tracked haulage more accidents occurred in 1956-60, but in trackless haulage more occurred in 1961-66 than in the earlier period. Fewer accidents occurred at transfer stations in the later years owing to increased use of well-installed belt-head loading stations with hydraulic car hauls. Considering the limited number of units in operation, the accident record was bad for the front-end loader, which was introduced to the mining industry in the early 60's and used for secondary loading on the surface.

Thickness of the coalbed did not affect the distribution of underground transportation fatalities appreciably. Most occurred in the medium-thickness class where most coal originated. However, examining the data with respect to the productive capacity of a mine shows that transportation is the most hazardous in mines producing less than 150 tons per day. This group accounts for 15 percent of the total number of fatalities while its output of coal is only 9 percent of the total production.

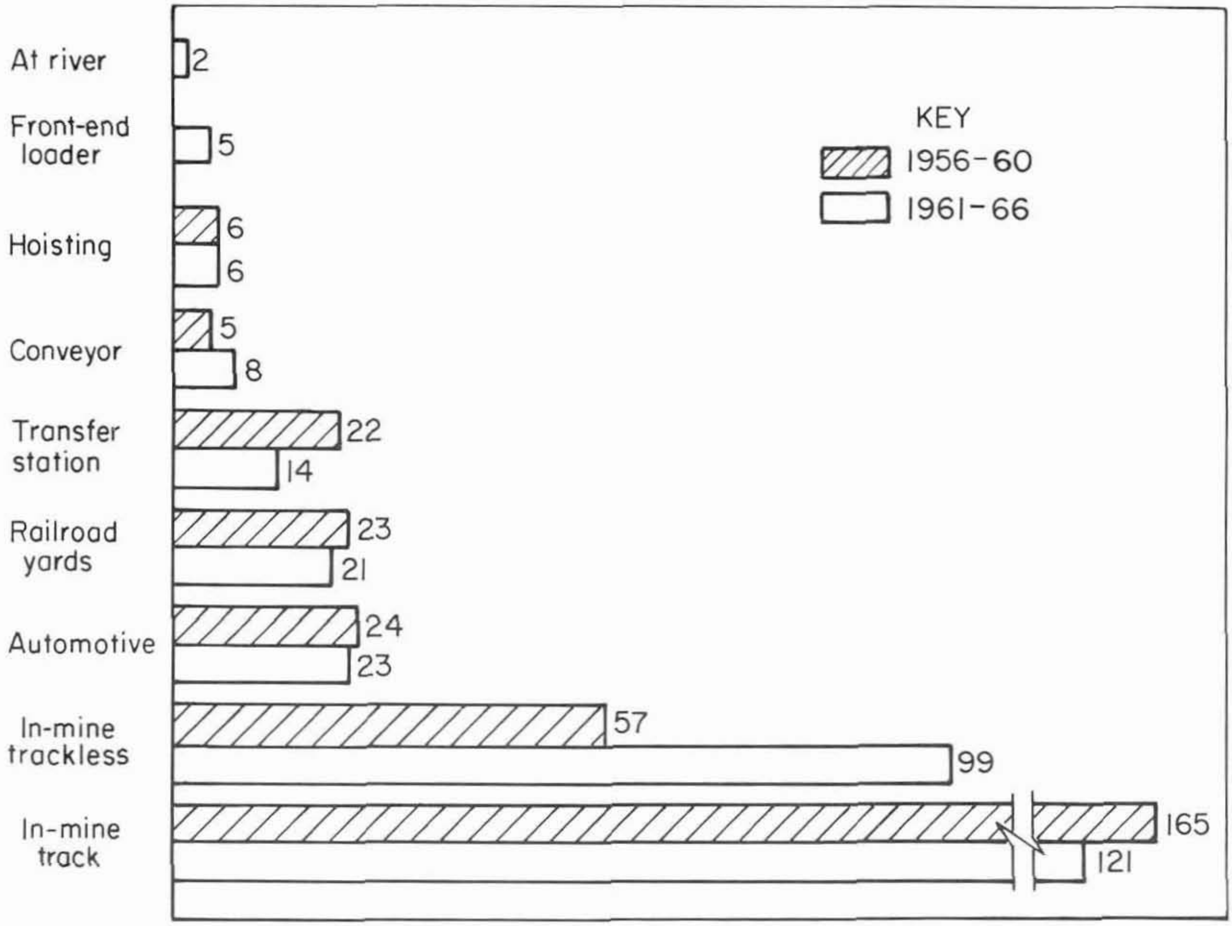


FIGURE 3. - Types of Transportation Involved in Fatal Accidents, 1956-66.

MINE TRACK HAULAGE

System and Trend

The greatest number of fatal accidents in mine transportation during 1956-66 occurred in track haulage, which still remains the main transportation system in deep mines. It is a flexible system particularly suited to mining operations that cannot be concentrated. To be efficient, any haulage system must meet the basic requirements of capacity, reliability, and safety by using modern rolling stock, a track adequate for the purpose, and good communications. However, too frequently increased demands are satisfied by "adding on" to inadequate existing systems instead of adopting new designs (14). As a result, transportation systems with obsolete components and poor planning create a hazardous environment. This accounts for many accidents in addition to those ascribed to poor maintenance of rolling stock and track elements.

Data of figure 3 reflect the technological evolution in mine transportation, notably the trend toward trackless haulage. Direct loading of mine cars by hand or loading machine is vanishing and practiced only in small operations.

Belt conveyors often replace the intermediary or sectional haulage. The design frequently adopted in modern bituminous coal mining is a combination of trackless face haulage, intermediary transportation by belt conveyors, and main-line track.

Because grading and construction costs rule out double track in most mines, single track with passing tracks remains the usual system. Storage and side tracks lend flexibility to the operation. Rail haulage is severely limited with grades in excess of 3 percent. When grades exceed 3 percent, safety and efficiency of rail haulage suffer due to the relatively low coefficient of traction of a wheel on a rail.

Accident Experience

Fatal accidents on track haulage during 1956-66 were, in order of frequency, collisions between vehicles, accidents to persons where the victims were run over or squeezed and crushed between vehicles and top and rib or between two vehicles, and derailments. Runaway vehicles caused 19 percent of the death toll. Table 1 lists the physical and environmental causes of fatal accidents related to track haulage. The hazards usually are caused by defective equipment, adverse environment, poor planning, substandard track, and inoperative or missing protective devices on track roads. Table 2 lists unsafe acts connected with track haulage. Prevailing unsafe acts reflect the functions of the personnel; for example, brakemen getting on or off moving equipment, riding in an unsafe position, or failing to stay in the clear; motormen traveling at an excessive speed or failing to exert caution during the break-in of overhauled retrucked locomotives. Such locomotives should be kept at the rear end of trips until broken in. Haulage crews are mostly on their own with minimum direct supervision (43). Haulage guidelines posted on bulletin boards, instruction, and discussion sessions help to keep them aware of the hazards connected with their work.

Haulage Roads

Data from table 1 on environmental causes of accidents point out the importance of unrestricted, uniform overhead clearance, unobstructed side clearance, shelter holes, smooth ribs, and a suitable type of roof support. Roof bolts or crossbars hitched into the ribs will eliminate the hazard of roof falls when posts or header legs are dislodged by derailed vehicles. Good installation and efficient maintenance of the track minimize derailment hazards. Construction and maintenance of haulage roads including roadbed, rails, joints, turnouts, and all the other elements of trackwork in coal mines are described in detail in the standard specifications of the American Mining Congress and in other sources (6, 16, 43, 62). Whether it is a long-life main line or a secondary road serving as sectional loading track, each road must be accurately laid off on center lines. Curves of radii up to 500 feet and turnouts not less than No. 5 are used on high-speed haulage (25). Curves and turnouts on secondary roads and loading loops should accommodate the type of rolling stock in use.

TABLE 1. - Physical or environmental causes of fatal accidents connected with track haulage, 1956-66

(Numbers in parentheses represent frequencies, if more than 1)

	Frequency
Defective rolling stock and inoperative or missing protective devices	74
Couplers (26), lights (9), cab guards (9), controllers (6), motors (5), brakes (4), auxiliary motor suspension (4), sanding devices (3), rerailers (2), brake rigging, bumper, cable reel, stirrup of mine car, horn or siren.	
Environment	54
Obstructed side clearance (24), abrupt change of overhead clearance (17), restricted overhead clearance (6), unsuitable, inadequate roof support (4), irregular ribs and brows (2), glaring lights (not frosted or shaded) of road illumination.	
Poor planning and obsolete components of transportation system	40
Lack of block signal system (25), lack of traffic control (3), haulage during man-trip time (3), lack of runarounds and side tracks conducive to "flying switches" and "pushing trips on main line" (2), lack of derail, lack of telephone at man-trip station, storage capacity of side track not posted, destination of supplies not marked causing unnecessary switching, need of electric track switch at shaft bottom, stirrup and coupling of locomotive unsuitable for tandem operation on tight curves, airdox line under pressure and no longer in use.	
Substandard, poorly maintained track	33
Joints (13), roadbed (4), rails (2), switch throws (2), bridle bars (2), debris on track (2), switch points, short rails, straight closure rail.	
Inoperative or missing protective devices on track, particularly on grades	19
Derails including inoperative electric derail (6), signs warning of restricted overhead clearance (4), drags (3), positive stopblocks (2), track switch position indicators (2), unused switch not spiked, warning sign at crossover.	
Substandard trolley wire	10
Frogs (3), sectionalizer, suspension, alinement.	
Communication system inoperative or missing	9
Trolley phone (5).	
View obstructed by curtains	6

TABLE 2. - Unsafe acts connected with track haulage and causing fatal accidents, 1956-66

	Frequency
Riding or working in an unsafe position, riding on loaded cars, front bumper, or lead car of a pushed trip, operators standing in their decks	61
Getting on or off moving equipment	36
Failure to stay in the clear of moving equipment, running ahead, walking or working alongside, failure to seek refuge in shelter holes	29
Failure to communicate by visible and audible signals, telephone, trolley phone, paging system, messages, notification of concerned when working on equipment	24
Excessive speed for circumstances	21
Failure to use retarding and protective devices on grades such as slides, skids, car brakes, drags, derails, stopblocks, to keep sandboxes filled, and to use trailing locomotives coupled to trips	20
Failure to secure or block standing equipment effectively	14
Inattention	10
Pushing trips on main haulage roads except from side track to loading points or at shaft and slope bottoms	10
Failure to move only under the direction of a dispatcher where a dispatcher is employed	9
Failure to follow at a safe distance	8
Failure to use trip lights	8
Incorrect travel instructions	8
Failure to face or watch direction of travel	7
Failure to use warning signals, visible or audible	7
Misalining or failure to realine track switches	7
Coupling or uncoupling of moving equipment, coupling inside curves, hitching or unhitching of animals	7
Lack of caution when using overhauled equipment (retrucked or new journals) or new stiff equipment (to be used at the rear end of trips during a break-in period)	6
Improper stacking or loading of supplies or equipment or excessive load	6
Failure to ride man-trip cars and preferably covered man-trip cars when space is available	6
Failure to shut controller off when placing pole on wire	5

TABLE 2. - Unsafe acts connected with track haulage and causing fatal accidents, 1956-66--Continued

	Frequency
Having more than one locomotive in a signal block except for trailing locomotive	4
Flying switches	4
Failure to use proper rerailing devices	4
Improper operation or use of equipment	4
Riding in cars with supplies and tools	4
Backpoling if not necessary	3
Failure to shut off controls, to set brakes tightly, to secure the brake wheel, and to take off the pole when parking locomotive	3
Parking equipment in dangerous locations, for example, near curtains	2
Overcrowding of man-trip cars or personnel carriers	2
Failure to stop at partings	2
Failure to use adequate motive power or braking power	2
Failure to use an empty car between locomotive and man trip or supply trip	2
Failure to use a straight trolley nib when power collection by pole is impossible	2
Failure to unhook cable nibs or to hang them far enough to clear trips	2
Operation of equipment by inexperienced and unfamiliar operators	1
Failure to familiarize with the road environment	1
Use of defective equipment	1
Failure to respond to warning signals	1
Any work on moving or running equipment	1
Failure to shut controls off and set brakes securely on unattended parked equipment	1
Boarding or leaving moving man-trip cars and failure to remain seated when car is in motion	1
Mixing man-trip and loaded cars	1
Failure to provide enough man riding space	1
Failure to cut power off trolley wire when operating surface machines near wire in the vicinity of portals	1
Failure to place pole on wire (trailing locomotive)	1
Failure to stop locomotive when releasing fouled cable	1
Having more than 1 car between wreck and locomotive when rerailing.	1
Failure to move equipment on "low boys"	1
Failure to remove safety chains or ropes	1

Roads are graded to achieve uniform up or down grades because frequent swags complicate the drainage, limit the haulage speed, and cause high power consumption as well as spillage and equipment wear by buffering and snatching (62). Sudden changes in grade can be smoothed by vertical curves which are used in railroad practice on grade changes exceeding 0.5 percent (3). Grading of sidling roads along the strike of pitching coalbeds is preferable to cross leveling of the track by cribbing because a derailment hazard may develop when cribbing sags or slides causing low track joints.

Wheels of rolling stock will bind on curves and, therefore, the track gage must be widened. Short wheelbases of swivel trucks do enable modern, high-capacity vehicles to round curves with greater ease than equipment with long wheelbase. Table 3 contains gage widenings for different radii of curves. The widening is limited by the wheel tread width. Curves are banked consistent with the haulage speed, the track gage, and the curve radius (2, 6). It is not practical in mines to superelevate the outer rail above the inner rail by less than one-half inch or more than 5 inches. If the superelevation exceeds 2 inches, the American Railway Engineering Association recommends the introduction of an easement spiral of varying radius and elevation between the tangent and the circular curve to lessen the derailment hazard and the wear on track and vehicles inflicted by jarring and lurching (4).

TABLE 3. - Gage widening on curves

Curve radius, feet	Gage widening, inch
500	1/8
450	1/4
400	3/8
350	1/2
300	5/8
250	3/4

Source: The Civil Engineers Handbook. International Textbook Co., Scranton, Pa., 1949, p. 187; 1/8 inch widening for each 2° of curvature beginning at 9°.

$$R = \frac{50}{\sin 1/2\ D},$$

where R = curve radius in feet,

D = curvature in degree.

Limestone, crushed to 3/4- to 2-1/2-inch size is the best but most expensive ballast (6). A firm ballast gives solid support to the track and should be maintained by reballasting and retamping. The ballast must be packed tightly under the ties below the rails. However, the traffic action tends to compact the ballast under the center of the ties and loosen it at the ends.

This "center pack" causes misalinement, tie breakage, loose and low joints, and consequently derailments (62). Anchoring ties to the mine floor will help to preserve the track alinement.

Drainage is just as important in maintaining a stable roadbed for mine track roads as it is for railway and highway maintenance. Ditches collect the water and conduct it to low areas of the mine from where it can be siphoned or pumped (6).

The weight of the heaviest piece of equipment, usually the locomotive, determines the selection of rail size. By rule of thumb a minimum rail weight of 10 pounds per yard is allowed for each ton of vehicle weight on one wheel, not counting a margin of safety (16). In many modern mines the main-line track is laid with 70- to 100-pound rails. Welded track joints are preferred on high-speed underground haulage. The advantages are high conductivity and less wear of rail and rolling stock. The welding methods include Thermit, electric arc, and oxyacetylene.

Turnouts are installed and accessories selected in accordance with turnout standards of the American Mining Congress. Long-life main-line turnouts are frequently embedded in concrete. Track switches on modern high-speed haulages are operated electrically. Some are controlled remotely by the dispatcher; others are actuated by the motorman either by overhead hand switch or by selective trolley contactors. Route selection by means of the locomotive controller is called the "street-car" method (23). The motorman will approach the switch with power on to position the switch for the straight track or coast through the current-sensitive trolley contactor with power off to make the turn. The street-car method is not possible for upgrades in excess of 2 percent. Electric indicators with their lenses pointed at trips approaching the turnout show the switch position by horizontal or vertical arrays of three lights. They are wired with the track switch controls.

Track construction is more efficient and safer when mechanization eliminates the hazards of handling heavy material by hand (101). Power equipment is available for such operations as rail hoisting and alining, ballast tamping, bolt stripping, spike pulling, adzing for tie plate seats, spike driving, and rail bending. Ballast can be received and then distributed by special ballast cars. The essential parts of a self-propelled, mine-track tamping machine (fig. 4) are four air-powered tamping heads carried on a transverse slide and hydraulically positioned along the length of the tie (27), hydraulic track leveling jacks, and track hooks.

Daily routine track-road maintenance should include maintaining line gage and surface, tightening bolts, cleaning ditches, renewing ties, lubricating moving parts and sliding surfaces of track switches, loading out the debris and coal spillage by hand or track cleaning machines, and binding dust with calcium chloride and sprinkling. Mechanical rail lubricators like those installed at the approach to railroad curves are of great value in controlling wheel flange and rail wear (101). The rail joints must be maintained at the proper surface; if they are low, they present a severe derailment hazard. Unless the track joints are welded, the track, including turnouts, derails,

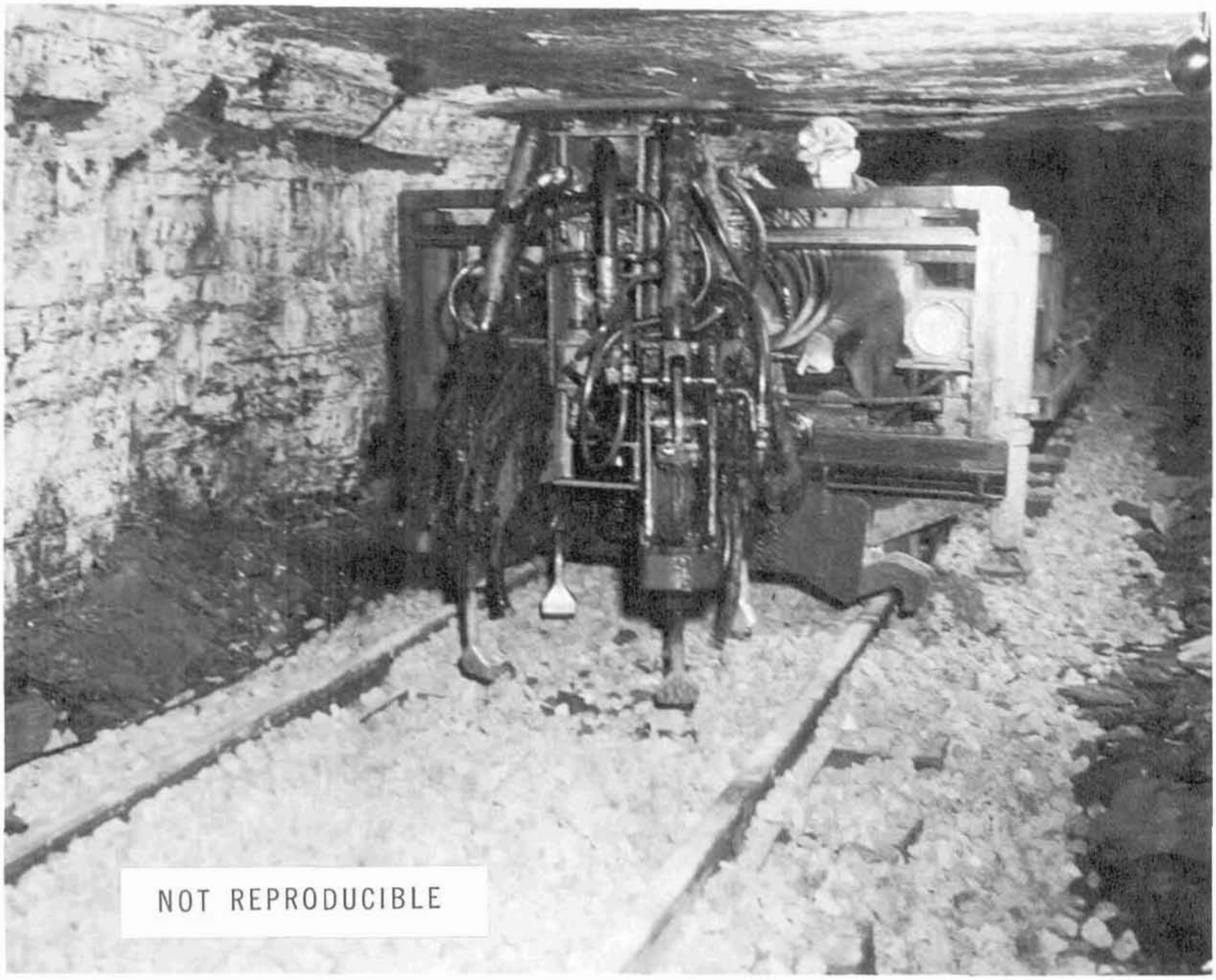


FIGURE 4. - Mine Track Tamping Machine.

and crossings, must be bonded at the joints and crossbonded to insure a continuous path for the current (20). Metal at the rail ends, rolled out by the impact of traffic, can be chipped off and the rail ends built up by welding. Rail renewal, switch repairs, and deepening of ditches, where needed, should not be postponed. Haulage crews appreciate roadways that are well illuminated and whitewashed by rock dust because they then can see far ahead and recognize hazards in time to act (43). The lights should be shaded or frosted to prevent glare. Fluorescent lights are now used, particularly at the bottom of shafts and slopes. They deliver more candlepower than incandescent lights for the same current.

Rolling Stock and Accessories

Defective rolling stock and accessories account for the greatest number of track-haulage fatalities (table 1). The equipment involved are locomotives, mine cars, and personnel carriers. The electric locomotives are trolley, cable reel, and battery units or combinations of these types. Diesel locomotives, which like battery locomotives are self-contained, are widely used in metal mining and in coal mining in Europe and Canada.

Trolley Locomotives

Trolley locomotives operate on dc power, 250 or 500 volts, which is supplied over substations. The overload capacity of the motors permits them to haul heavy trips against severe gradients. Speed of underground haulage is 5 to 9 miles an hour for 4- to 15-ton units, 9 to 12 miles per hour for 20- to 60-ton units, and up to 20 miles per hour on extra-long hauls. The locomotive weight must be adequate for handling the load under adverse conditions. The required motor capacity is determined by root-mean-square calculation based on the track profile (64). Locomotives weighing over 20 tons are equipped with swivel trucks, eight wheels and four motors, to distribute their weight on the rails over more points and to help them negotiate curves with greater ease. Tandemizing of two smaller units will achieve some of the advantages of 8-wheel locomotives. Most tandems have air or hydraulic brakes, since mechanical brake linkage between units is not practical.

The standard locomotive brake is the handwheel, locking-screw type with large shoes acting on the wheels. Caliper brakes have been introduced in recent years. Like aircraft or automotive disk brakes, they clasp the wheels. Hydraulically actuated brakes permit faster stops. Airbrakes are desirable on units above 8 tons.

Many mine locomotives have been in service for 40 years or more and have been overhauled several times during their life. These old locomotives can be rebuilt to meet some of the safety and efficiency standards of modern equipment. The following safety features are applicable according to the size of the locomotives (26, 43, 105):

1. Rounded end frames, as high as the side frames and welded to them, serve as cab guards and offer protection and space for motormen and brakemen within their enclosure. Side cutouts give access to the cabs. Minimum thickness of steel for these cab guards should be 1 inch. In derailments the round end frames will guide the locomotive to a stop parallel to the roadway where a square-ended locomotive, on striking an obstruction, often turns into the rib with sudden impact and devastating effect (43).

2. Frames are made smooth and free of projecting boltheads and nuts. Side frames are cut away along the wheels or trucks to give maximum clearance off the rail for placing of rerailers.

3. Handholds are cut out in the frame or firmly welded or bolted to it.

4. Insulating seats and floor covering protect against the shock hazard.

5. Windshields are recommended for high-speed haulage.

6. Rerailers, jacks, and chains should be kept in easily accessible places.

7. Sanding devices can be hydraulically or air operated.

8. Auxiliary motor suspension by chain, lugs, or bar is a standard requirement to prevent motors from dropping down to the track and causing wrecks when the suspension fails.

9. Strong headlights permit the motorman to discern obstacles in time to stop the trip within the lighted distance (43). Main-line trams usually have two narrow beam sealed-beam headlights of 100,000 candlepower each at each end; gathering locomotives have one wide beam sealed-beam light of 20,000 candlepower at each end.

10. Dimming headlights prevents blinding of personnel.

11. Trolley shoes and shunts must be of adequate size to reduce sparking. Where pantographs or bows serve as power collectors (fig. 5), cabs can be fully enclosed for better operator protection.

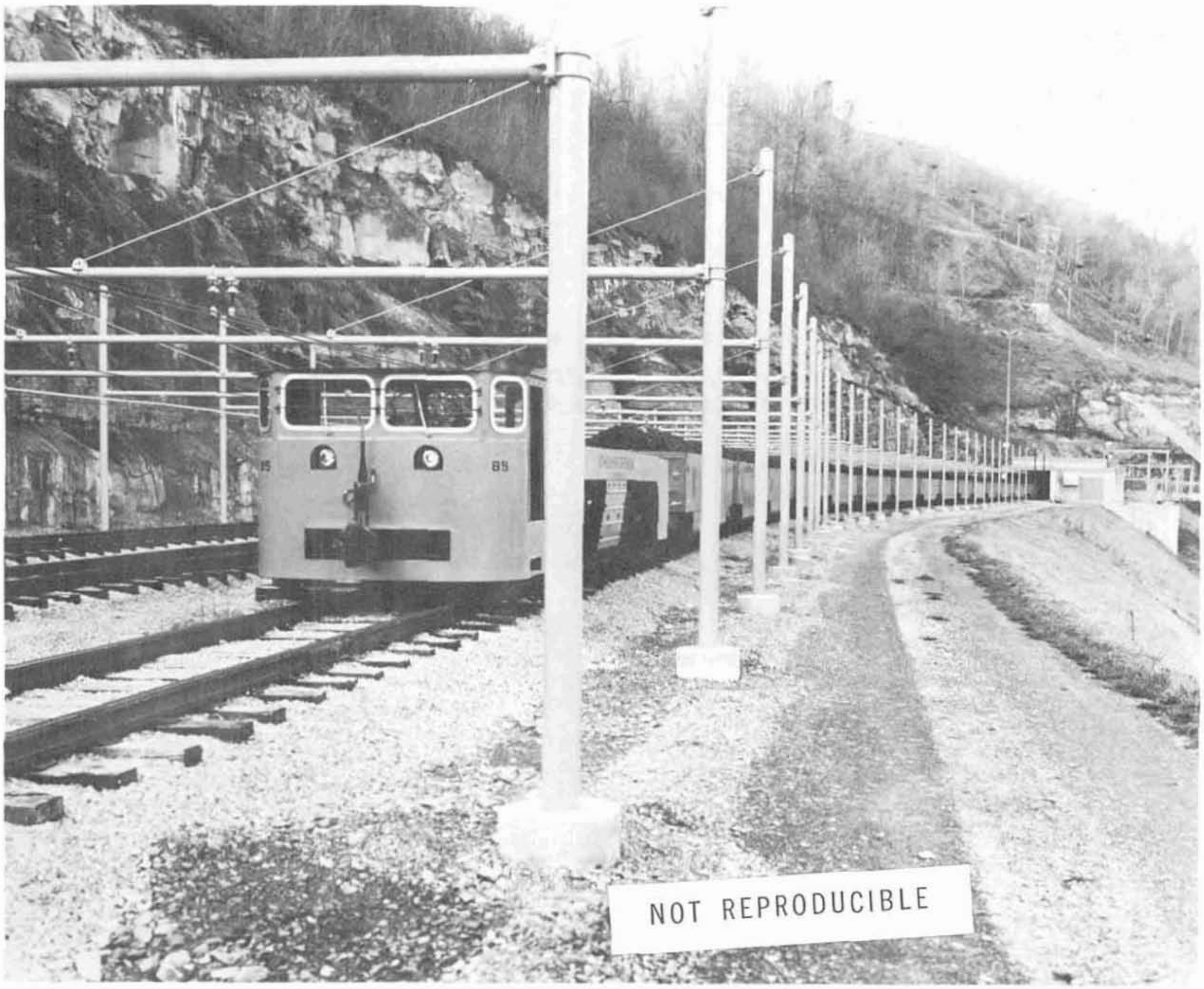


FIGURE 5. - Main-Line Locomotive With Enclosed Cab.

12. Automatic trolley-pole retractors lower the pole if the trolley shoe leaves the wire. Air-operated manual retractors are also available.

13. Reverse and controller drums are interlocked to prevent reversal unless the power is cut off. Locomotives of 11 or more tons need magnetic or electropneumatic contactors. Magnetic contactors are simpler and therefore preferable.

14. Headlight and control systems of main-line trams are powered by 32-volt batteries to assure lighting and dynamic braking even when the mine power fails or the trolley pole flies off the wire. Another advantage is low controller voltage. The battery is charged automatically from the trolley wire. This system replaces motor-generator sets in older locomotives.

15. All protective devices should be replaced after failure and not jumpered out or removed. For instance nullification of the no-voltage relay after power failure or cutoff may cause a runaway whenever trolley power is restored.

16. Dead-man controls by foot switch or handle on the controller will remove power if the motorman is incapacitated. They can also set airbrakes.

17. Dynamic braking is desirable when continuous grades are in excess of 1 percent. The armature current is reversed with respect to the fields so that the motors act as generators. The current is dissipated in the motor resistor. The locomotive is slowed down by dynamic braking and the airbrakes bring the trip to a complete stop. Dynamic braking saves brakeshoes and tires. Staggered dynamic braking by two separate electric circuits will make brake application even safer. Then, if an armature burns out, only two of the four motors become inoperable for brake application (26).

18. A low-pressure alarm will warn the motorman when the main air reservoir is low. Even more effective is a system which incorporates an auxiliary air tank. When main tank pressure drops below 60 psi, air from the auxiliary tank is automatically admitted to apply the brakes until pressure in the main tanks is restored (26).

19. Airbrake interlock will prevent wheels from sliding whenever dynamic and air brakes are applied simultaneously.

20. A track-brakeshoe system can supplement dynamic braking. The track brakeshoes, normally floating above the track, are drawn into contact with the rails when the track brake circuit is closed. The track brake circuit is fed from the dynamic brake circuit. Track braking effort is applied and increased with the dynamic effort (fig. 6).

21. A speedometer can be provided to warn against applying dynamic braking at excessive speeds.

22. All-purpose sealed roller bearings in the journals eliminate all but annual lubrication.

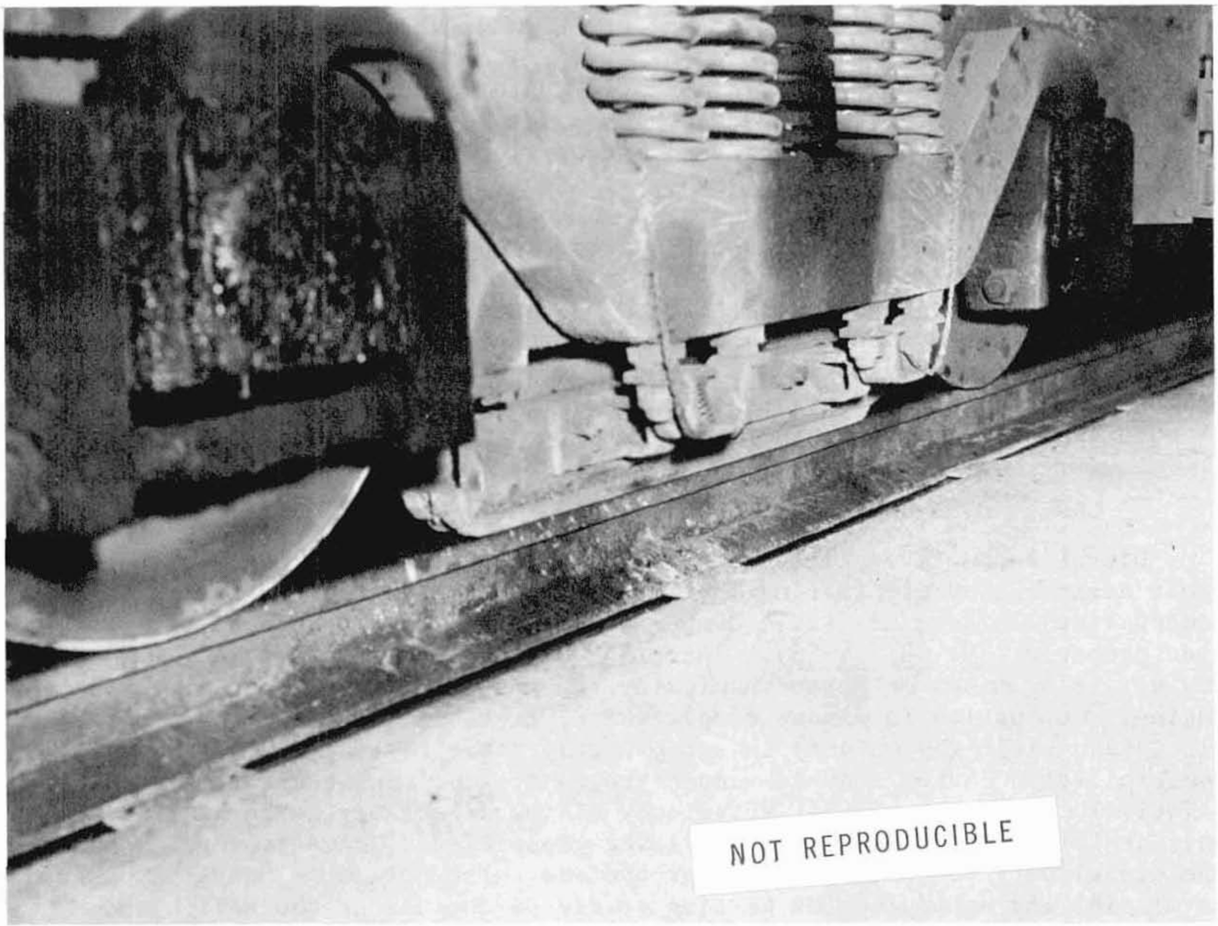


FIGURE 6. - Track Brake.

23. Traction motor bearings and center plates of swivel trucks can be lubricated remotely through hoses.

24. An air-operated device eliminates hazardous manual uncoupling of automatic couplers.

25. Traction motor blowers are essential to maintain the motor capacity.

Cable-Reel Locomotives

Cable-reel locomotives are used for gathering, supply, and development duty and for face haulage where coal is loaded directly into mine cars. Permissible cable-reel locomotives are equipped with two-conductor trailing cables to serve as gathering or face haulage units inby the last open breakthrough in gassy mines. The cable nibs have to be fused adequately. Malfunction of the reel motor control might cause the locomotive to run over the cable or to pull it apart. Also the cable, through abrasion and its contact with rails and steel ties, constitutes a fire and shock hazard (43).

Storage-Battery Locomotives

Storage-battery locomotives are self-contained units which will operate wherever there is track. Any duty which draws heavy current such as main-line service should be avoided. However, battery locomotives of the permissible type compare favorably with the cable-reel units for supply, gathering, and face loading duty in gassy mines. The absence of trolley wire or trailing cable eliminates ignition and shock hazards. Batteries may be of the lead-acid or nickel-iron alkali type. They must be maintained and kept charged in charging stations. Exchange batteries are placed on racks and handled by hand, air, or electrically operated chain blocks suspended from an I-beam. Permanent battery-charging stations must be of fireproof construction and ventilated by separate splits of air conducted directly to the return air course, because batteries under charge liberate hydrogen (20).

Diesel Locomotives

Diesel locomotives, like battery units, are self-contained. They offer a great advantage by eliminating ignition and shock hazards from trolley and feeder lines. There is little danger of fuel oil ignition if the oil is handled properly (39, 48, 55-56). The high compression ratio of the diesel engine, 1:16, makes it thermodynamically the most efficient internal combustion engine. Combustion is almost complete and, if the maximum permissible fuel-air intake ratio (by weight) is set properly after testing, the exhaust fumes contain little carbon monoxide and nitrogen dioxide, and their temperature is relatively low. The thermal efficiency of the diesel engine remains high, not only at full capacity, but also at lower capacities. These properties make the diesel very suitable for underground use. The Bureau of Mines has issued permissibility schedules for testing of diesel engines at the Health and Safety Research and Testing Center at Pittsburgh along with recommendations for ventilation, maintenance including adjustment of maximum fuel-air ratio, temperature of surface, fuel handling, fire protection, and repair-shop specifications in underground service.

Testing procedures are prescribed in the following Bureau of Mines schedules:

S 22. Procedure for Testing Diesel Mine Locomotives for Permissibility and Recommendations on the Use of Diesel Locomotives Underground.

S 24. Procedure for Testing Mobile Diesel-Powered Equipment for Non-Coal Mines.

S 31. Mobile Diesel-Powered Transportation Equipment for Gassy Non-Coal Mines and Tunnels.

Diesel-powered equipment requires the following safety features:

1. Positive intake flame arrester.

2. Water-cooled exhaust manifold.

3. Exhaust conditioner to cool the exhaust gases from 1,300° to 160° F. Temperature of external surfaces shall not exceed 300° F.

4. Fail-safe thermal controls to automatically shut off the engine under the following conditions:

a. Final exhaust gas temperature exceeds 170° F at discharge.

b. Water-jacket temperature of the engine exceeds 212° F.

c. Water in the scrubber is not replenished.

However, early predictions that "diesel locomotives may soon be used in this country's coal mines" have not come true (43).

Mine Cars

When mine cars had to be taken to the face, their size was limited by the face environment and the track. In modern mines the trend is toward larger cars. The largest in underground service carry 30 tons of coal. The majority are solid-body cars that are emptied in rotary dumps. However, modern drop-bottom cars are almost as leakproof as solid-body cars, if well maintained. Their doors are overlapping and locked with safety latches to minimize the danger of their opening during wrecks or derailments, thus spilling the coal. When drop-bottom cars are used on man trips, the doors should be secured with chains or clamps. Endgate cars are used for shaft hoisting with self-dumping cages. They are still found in old shaft and slope mines. Their trouble is that after prolonged use their sides spread and allow a great deal of coal to spill (60). Modern mine cars are made of steel, steel alloy, or aluminum totally welded to give smooth surfaces. Their antifriction wheel bearings are greased every 4, 6, or even 12 months, depending on their use. The old plain bronze sleeve bearings need to be lubricated daily with heavy oil.

Trucks of 8-wheel cars are coil or rubber spring mounted and, like railroad stock, are equipped with centrally located sockets to receive two kingpins on the underside of the car body. Bumpers serve in connection with link and pin couplings to cushion the effects of buffering and snatching. They are often of the spring-loaded design, rounded to facilitate rounding of curves by rolling on each other and designed to maintain a minimum of 12 inches between the bodies of cars on straight track (60). With the swivel link and pin coupling it is possible to rotary dump a string of loaded cars without uncoupling. It is dangerous to couple and uncouple any of the link and pin, multilink, clevis and link, hook and link, or rigid couplings while the vehicles are in motion, particularly on the insides of curves. Using coupling hooks will help reduce this hazard (20). In railroad practice the link and pin method of coupling cars was outlawed in 1893 and automatic couplers have been required since then (82). Automatic couplers were adapted to mine use much later. The coupling is fully automatic, but the uncoupling has to be triggered by hand. Its rigging should permit safe operation from the side of the car. Couplers can be designed with enough horizontal and vertical swing to permit articulation on sharp horizontal and vertical curves and to minimize the hazard of accidental uncoupling (27). Rotary couplers are made for rotary dumping of cars without uncoupling. A winglike design of couplers provides a wide gathering range and permits coupling on sharp curves. Rubber-cushioned draft gears were introduced in recent years for application with automatic couplers. They are composed of rubber pads, sandwiched with steel plates and bonded to them. The hysteresis of these rubber pads allows them to absorb more energy within themselves than the older steel-coil, spring-loaded gear can. Therefore, they are more able to cushion the car structure against jolts, to prevent derailments, and to ease the start of heavy trips.

Both lubrication and inspection of mine cars are best done close to the dump on the loaded side because the car stops at the same spot every trip. A high-pressure grease gun should be available. Visual inspection, of course, will disclose only the exposed parts, and an inspection program for maintenance should be devised to discover worn wheels, broken flanges, and bent axles that could cause derailments. If a hazard is found, the car should be pulled out of service and directed to the carshop. A testing device which senses heat radiations from hot journal boxes is used in railroad car maintenance and has been adapted for mine use (46). Figure 7 shows a detector rail

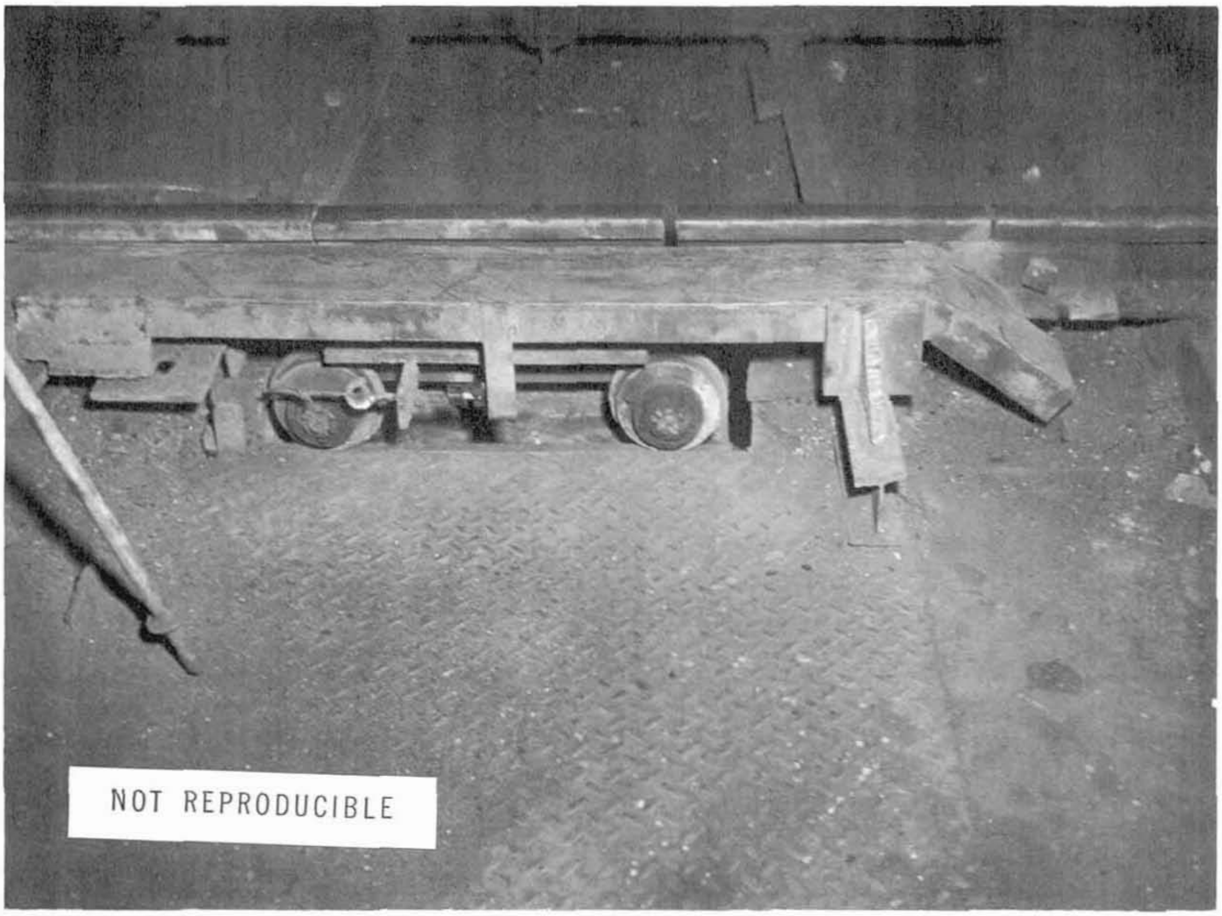


FIGURE 7. - Detector Rail for Defective Wheels.

which operates on the principle that a defective wheel has more rolling resistance than a good one. The short rail is spring loaded and deflected by a bad wheel to close a switch and to light a signal lamp (27). Table 1 shows that failures of couplings take the first place as a cause of fatal accidents due to defective rolling stock. Breakage and accidental uncoupling cause runaways often followed by derailments and collisions. This involves couplings of all descriptions, link and pin as well as automatic couplers. Therefore, the main load-bearing components of couplings should be examined frequently.

When cars have to be taken to the faces, well-maintained hand car brakes are essential in the control of cars. The brake operating lever should be in easy reach of the brakeman so that he does not have to step between cars. However, trip handling in modern track haulage makes hand car brakes unnecessary, though parking brakes are desirable.

Cars for special purposes are supply cars, flatcars, equipment carriers, ballast cars, rail, timber, or fire trucks, and man-trip cars. Defective old mine cars, no longer subject to the routine maintenance of the mine cars in circulation but still used to haul supplies to the face and refuse to the surface, cause many wrecks of supply trips. Modern 8-wheel flatcars, furnished with stakes around their outside edges and often with parking brakes, can move supplies faster and more safely. They can take packaged supplies in pallets from yards to the section with minimum handling, or they can carry the rubber-tired supply cars to a point where they can be pulled off and taken to the face by battery tractor (29). Equipment carriers, called "low boys," are used to move treaded, rubber-tired, or stationary equipment of all descriptions. This eliminates hazards such as contacting trolley wire, running over cables, fouling of cables at ties and switches, and squeezing or crushing operators between equipment and roof or rib, which are likely to occur when rubber-tired or treaded units are trammed along the track.

Man-trip cars are 8-wheel units, mounted on steel coil or rubber sprung trucks. They hold up to 38 men and come equipped with hand parking brakes and safety chains across the access openings. They are covered to protect the workers against the falls of roof and rib and have top insulation to protect against contact with trolley and feeder lines. They provide a comfortable ride and a shelter against high air velocity, flying sand and coal particles, as well as against intemperate weather on the surface. Other advantages of portal transportation by man-trip cars are minimum interference with coal haulage, because the coal cars, relieved of man transportation, can be kept in circulation continuously. Traffic control is simplified and the safety of the system will benefit.

Portal Buses and Personnel Carriers

Self-propelled portal buses were introduced to the mining industry in the midfifties and quickly gained wide acceptance. A bus can carry one face crew and service personnel, 11 to 16 men, with minimum delays directly between portal and face area as far as bonded track and trolley wire go. The crew travels in comfort on cushioned seats with cushioned headrests in upright or reclining position, according to the height. The buses are made to fit the physical conditions of the individual mines. Their height above top of rail is 26 to 60 inches, with wheel diameters from 14 to 20 inches and overall width from 78 to 90 inches. Split roof design allows the operator 360° vision and trolley pole handling (fig. 8). The cars ride on spring-cushioned axles equipped with antifriction bearings. One motor of 15 to 25 hp drives the axles by V-belt, chain, or universal-jointed propeller shaft. Battery-powered vehicles are also available. Controls are drum type or, preferably, fully magnetic contactors.

Important safety features are as follows:

1. Dead-man controls.

2. Hydraulic brakes on each axle and on the traction motor shaft.

3. Dual mechanical parking brakes.

4. Dual sealed-beam headlights, dual red stoplights and reflectors on each end.

FIGURE 8. - Portal Bus.

5. Suspension to assure fixed centers between drive and driven pulley.

6. Sirens or horns.

7. Rubber floormats and rubber-covered seats.

8. Safety chains on all side openings.

Some buses are equipped with trolley phones, a dynamic braking system, track sanders, stretcher brackets, and tool-carrying platforms. Personnel carriers, called "jeeps," furnish transportation to officials, surveyors, and maintenance and emergency crews. They are open vehicles made in all sizes to carry four to seven men. All electric, mechanical, and safety features are the same as those described for portal buses. Windshields of thick Plexiglas at both ends are desirable. Often personnel carriers are made in the mine shops, but it is important that they meet all safety requirements. Usually the upkeep of portal buses is the responsibility of the face maintenance personnel because most buses are parked near the face-area unloading points during the shift. Replacement of light bulbs, sealed beams, or broken windowpanes and adjustment of brakes should not be neglected.

Trolley Wire

Substandard trolley wire caused dewirements with 10 fatal results during 1956-66. The Bureau of Mines recommends the following standards for the installation of trolley wire and trolley feeder wire (20, 43):

1. Hung on the opposite side of the entry from shelter holes and clearance space, except where 6-1/2 feet or more above the roadbed.

2. The hangers on curves spaced so that the trolley wire may become loose at any hanger without exposing the locomotive operator to a shock hazard.

3. Alined properly and installed at least 6 inches outside the track gageline.

4. Provided with cutout switches at intervals of not more than 2,000 feet and near the beginning of all branch lines.

5. Kept taut and not permitted to touch the roof, rib, or crossbars. Particular care should be taken where wires pass through door openings to prevent contact with combustible materials.

6. Guarded adequately where it is necessary for men to pass or work under them regularly, unless the wires are more than 6-1/2 feet above the top of rail; they should also be guarded adequately on both sides of doors.

7. Guarded, anchored securely, and insulated properly at the ends.

Deep section wire, called figure 9 wire, is the preferred wire shape. It does not twist or kink nor pull out of the wire clamps on curves. In addition, its deep section is ample to carry current, yet narrow enough to guide the trolley shoe (59). As a rule insulated hangers are spread at 20-foot intervals on straight track and 10-foot intervals on curves. Hangers are held by expansion shells in the roof rock, by I-beam adapters to steel roof support, or by special adapters to roof bolts in underground service. Where wires must be guarded, boards, old conveyor belting, rubber or plastic sheathing, or old rubber hose are installed as trolley wire guards and attached to the hangers by suitable clamps (51). Automatic electric wire frogs permit fast travel through turnouts. They are actuated by the track switch controls.

Surface trolley wire is hung by insulated hangers from portal or T-type pipe brackets. However, this direct-suspension overhead system is not adequate for high-capacity long distance surface haulage which calls for railroad-type catenary suspension (50). The surface trolley circuits must be protected against short circuit and lightning. Lightning arresters of approved type are required at the point where the trolley circuit enters the mine (20).

Lubricating the trolley wire at regular intervals is important for smooth operation without arcing or shattering. Although this is an item of regular day-to-day locomotive maintenance, lubrication of trolley bases should be emphasized in connection with trolley wire maintenance. A stiff and dry pole base with dust packed around the pivot and pin causes a sluggish pole ride and dewirements. Well-lubricated pole bases help to preserve trolley wire and shoes.

Protective Measures on Grades and Warning Signs

Trailing locomotives or "pushers," coupled to the trip, are the most effective protection on grades. Their braking effort adds to the braking effort of the front locomotive on downgrades and keeps the couplings extended. Their motive power assists on upgrades and their presence offers positive control of trips in case of coupling failure. Communication between the two motormen by trolley phone will help to concert the operation of the two locomotives. Battery-operated brake cars can perform some functions of trailing locomotives. They were originally designed to protect hoist-operated man trips on slopes against hoist rope failure. Brake cars are equipped with one to three pairs of track brakeshoes similar to the locomotive track brakes previously described (87, 94) (fig. 9). When a manual- or govenor-actuated switch closes the circuit, the brakeshoes are activated by the batteries and drawn into contact with the rails. When brake cars are coupled to the rear ends of trips, they safeguard against runaways at upgrades and act as holdback to keep couplings extended on downgrades. The brakes are engaged automatically when the trip starts to run away in the backward direction at a speed in excess of 1 mph. The brake cars are equipped with signal lights indicating if the brakes are ready for operation and whether or not they are engaged. Where positive control on grades by trailing locomotives or brake cars is not available, skids are used on downgrades to assist the locomotive braking effort and also to control cars at mine-car loading points. Drags are used on ascending grades to derail the last car and stop the trip in case of a runaway. Standing cars shall be held effectively by brakes or properly blocked (20). Locomotives should not be uncoupled unless the trip is secured. On moderate

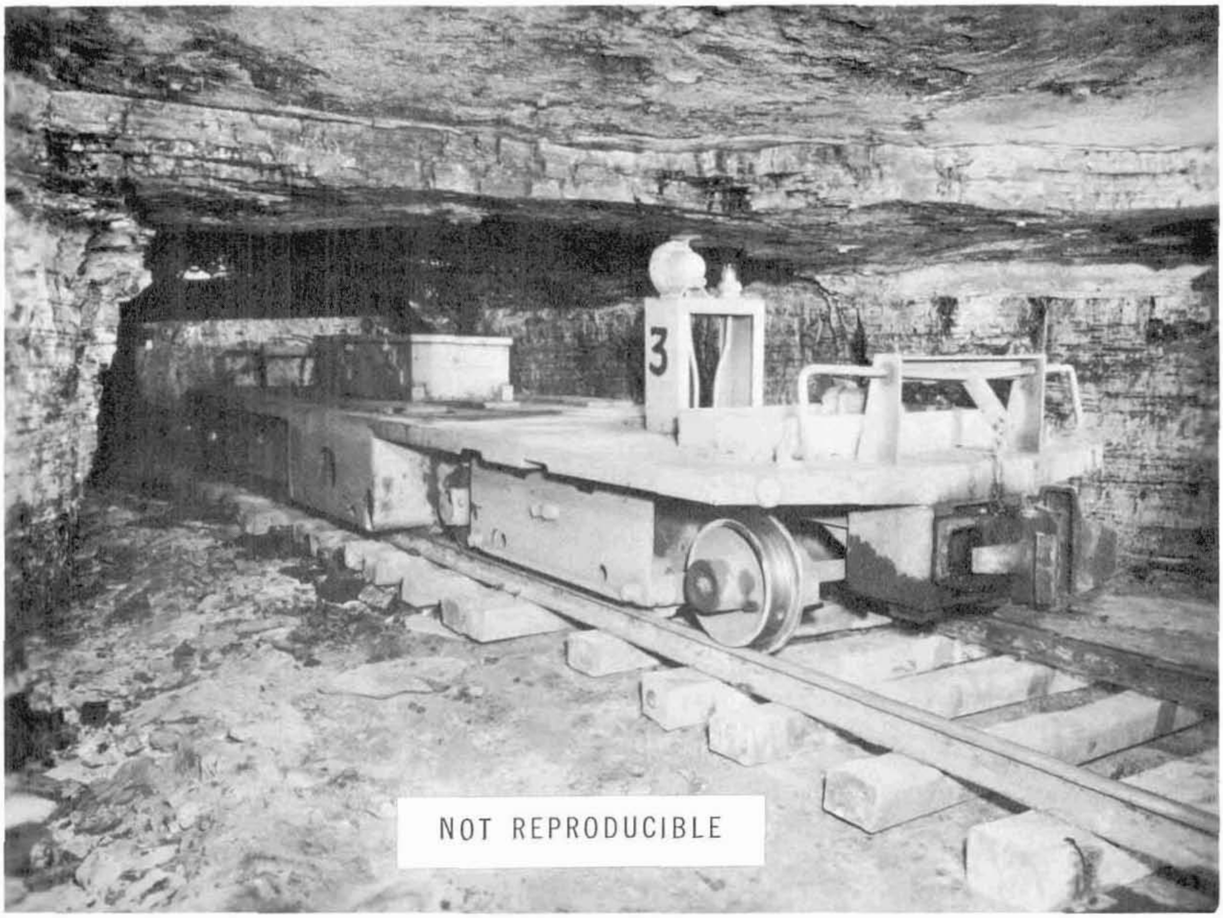


FIGURE 9. - Brake Car.

grades, safety chains anchored around ties and provided with hooks can hold trips on sidetracks and at loading points. The hooks should have handholds. On steep grades above 3 percent, a pole, 8 to 10 inches thick and 8 feet long, is used to secure trips. One end of the pole is braced against the rib, the other is suspended from a roof bolt by a steel rope so that the pole is balanced almost horizontally, hanging over the track and swinging aside when an ascending trip is passing. But it will block standing cars very securely, braced between rib and end of car.

Derails are mostly single point. They can be operated electrically like track switches either manually by overhead hand switch or by trolley contactor (24). The trolley contactors or manual controls are located at a trip distance in either direction from the derail, so that the open position of the derail can be restored after the trip has passed. Electric signal lights, wired with the derail controllers and with the light lenses pointed at trips approaching the derail, indicate whether the derail is open or closed. Derails are installed on grades where protection is needed, such as at the mouth of sectional entries and next to loading points or on main lines at intervals adequate to accommodate trips. They then serve the same purpose as block signals, if not more than one trip is permitted to operate between two derails. Derails should be kept open at all times and be closed only to allow the passage of a trip. Portable derails can provide temporary protection.

Lights, flashers, or just reflectors can serve as warning signs on haulage roads and call attention to hazards such as restricted side or overhead clearance. Where surface roads cross mine tracks near a drift mouth, a flashing light and bells shall warn of approaching surface-bound trips. Safety zones should be marked on switches to warn of parking vehicles on the curved part of the turnout.

Traffic Control, Communications, Block Signals, Traffic Control by Computer

Mine traffic control can incorporate such components used in railroad practice as automatic block signals, remote-control switches and signals, and interlocking signals at junctions. But the trolley phone is the primary means of contact between dispatcher and motor crews and between motor crews. The dispatcher can take immediate action in the event of delays, collisions, and derailments or the need of transportation of injured persons to the surface. When directed by trolley phone, trips can be kept moving constantly with power consumption for starting and stopping kept to a minimum (44). A few dispatcher offices have also track display panels where lights indicate the movement of traffic (fig. 12).

But communication by trolley phone does depend on the carrier current of the trolley system and, hence, is vulnerable to power failure. Therefore, an emergency power source shall be provided to carry on communication if there is no alternate system in the mine. In most mines a conventional mine telephone system is available. The Bureau of Mines recommends the following practices for the installation and use of the telephones (43):

1. All telephones should not be placed on one circuit.

2. A cutout switch should be installed in the line of isolated telephones to eliminate the possibility of a faulty phone in a remote place and consequent interference throughout the system.

3. Telephone lines should be carried on insulators, installed on the opposite side from powerlines or trolley wires, and insulated properly where they cross powerlines or trolley wires.

In many mines the conventional mine telephone system with the magnetopowered coded ringing signal has been replaced by modern transistorized loud speaking telephones. The caller pages the person he wishes to contact and, when his call is answered, conversation is carried on over the handset. Special coupling arrangements permit communication between loud speaking telephones and trolley phones.

Block signals are used in railroad practice to keep "following" trains at a safe distance on single as well as on double track and to prevent "opposing" trains from entering the same block on single track (101). The mining industry adopted the automatic block signal system for the same reason; that is, to dispatch rail traffic with maximum safety and minimum delays. A single-track haulage is laid out with sufficient passing tracks to attain the desired system capacity (81). Automatic signals guard both ends and each access road feeding into the blocks. The signals are actuated by trolley contactors which function similarly to those controlling track switches and derails. Figure 10 is a diagram of a block signal system with two signal blocks of two and three units. The main line is protected against outbound sectional traffic. A preference routine can be incorporated into the system; for example, loaded trips are given preference over empty trips or trips on grades over trips on level sections.

Traffic control by computer may greatly improve safety and efficiency of a track haulage system, but to date it has not been attempted in this country. There is an example of computer-controlled underground haulage in the iron ore mines of Luossavaara in Sweden (40, 72) (fig. 11). The computer by a priority routine selects the ore chute where empty cars are needed most and controls all trackside signals and track switches to guide the empty train towards the selected destination. The loaded train follows another destination routine to the appropriate crushing station. Although locomotives could be equipped for full remote control, they are manned for flexibility, communications, and situations which require on-the-spot judgment. A dispatcher supervises the entire haulage by means of a track display panel where lights indicate the movement of traffic (fig. 12). Freed from the task of routing the trips, he can

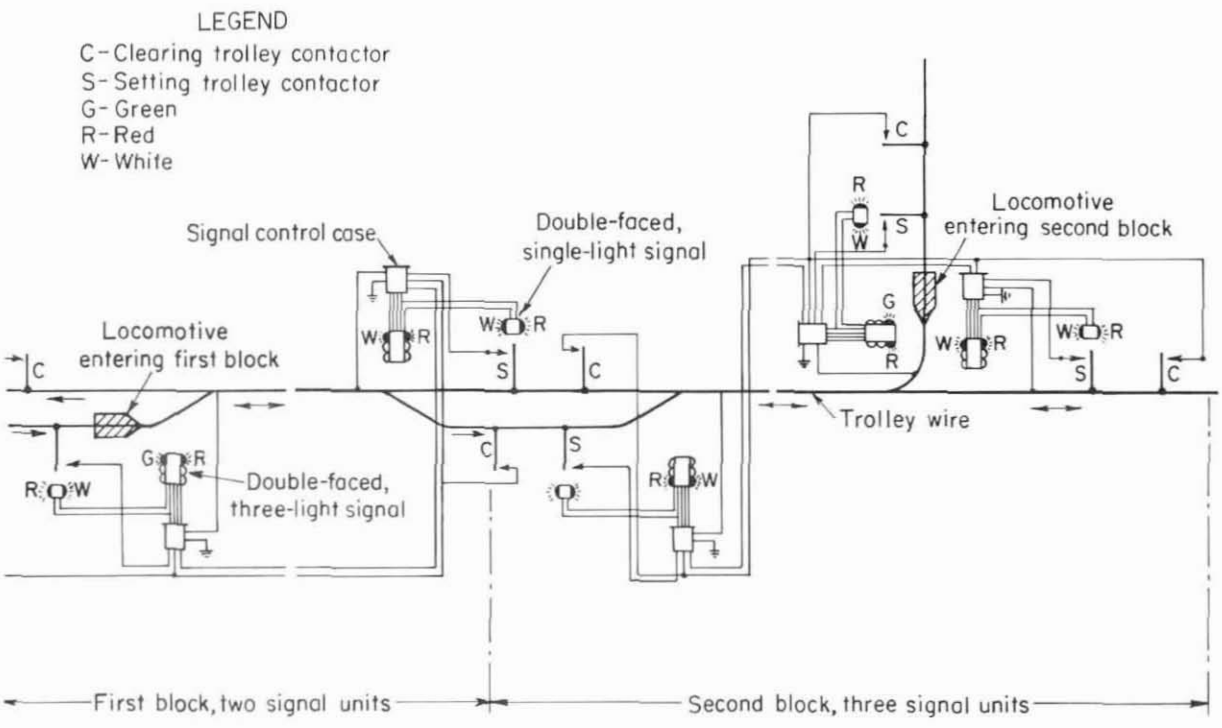


FIGURE 10. - Block Signal System.

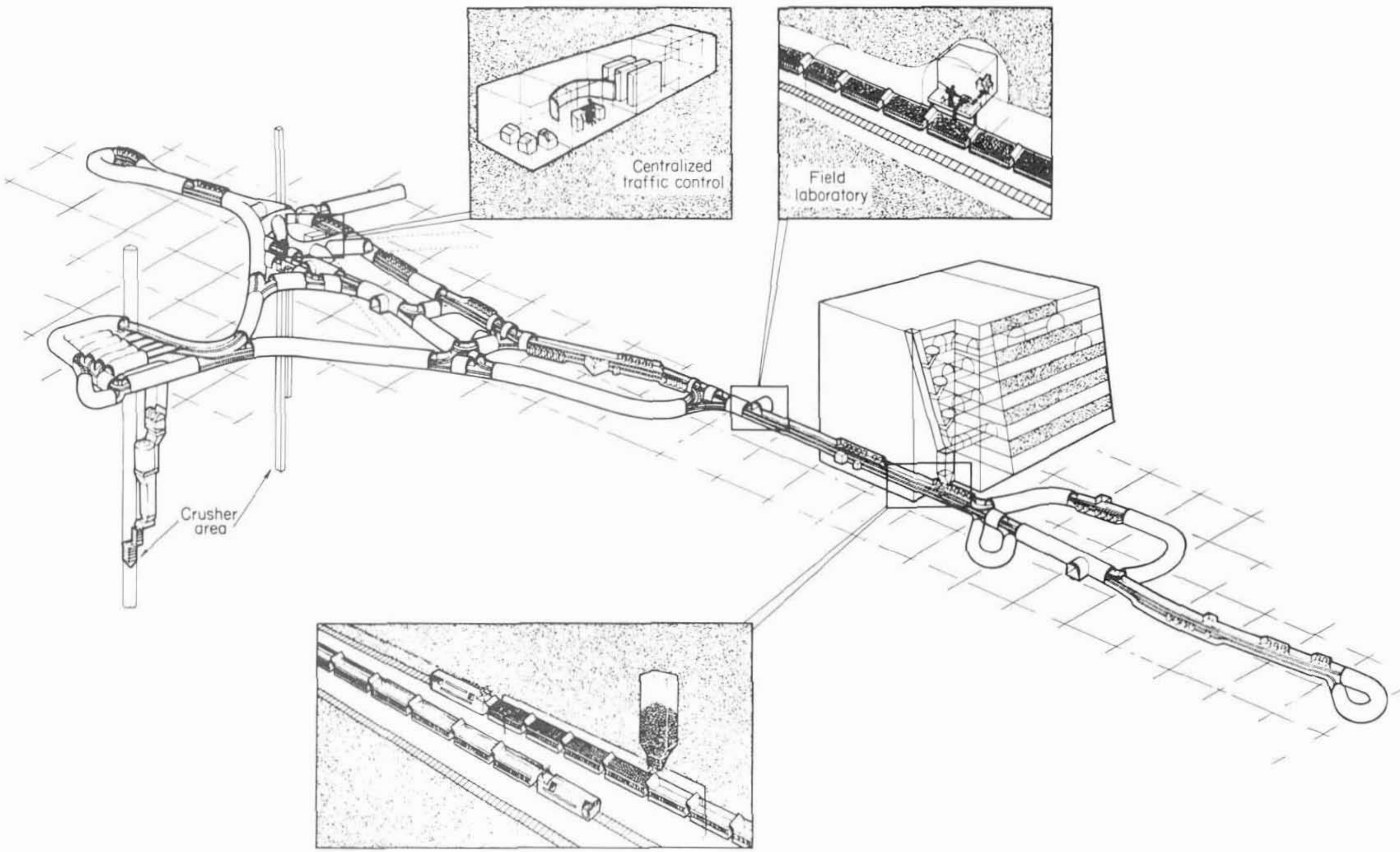


FIGURE 11. - Layout of Haulage Level With Centralized Traffic Control by Computer.

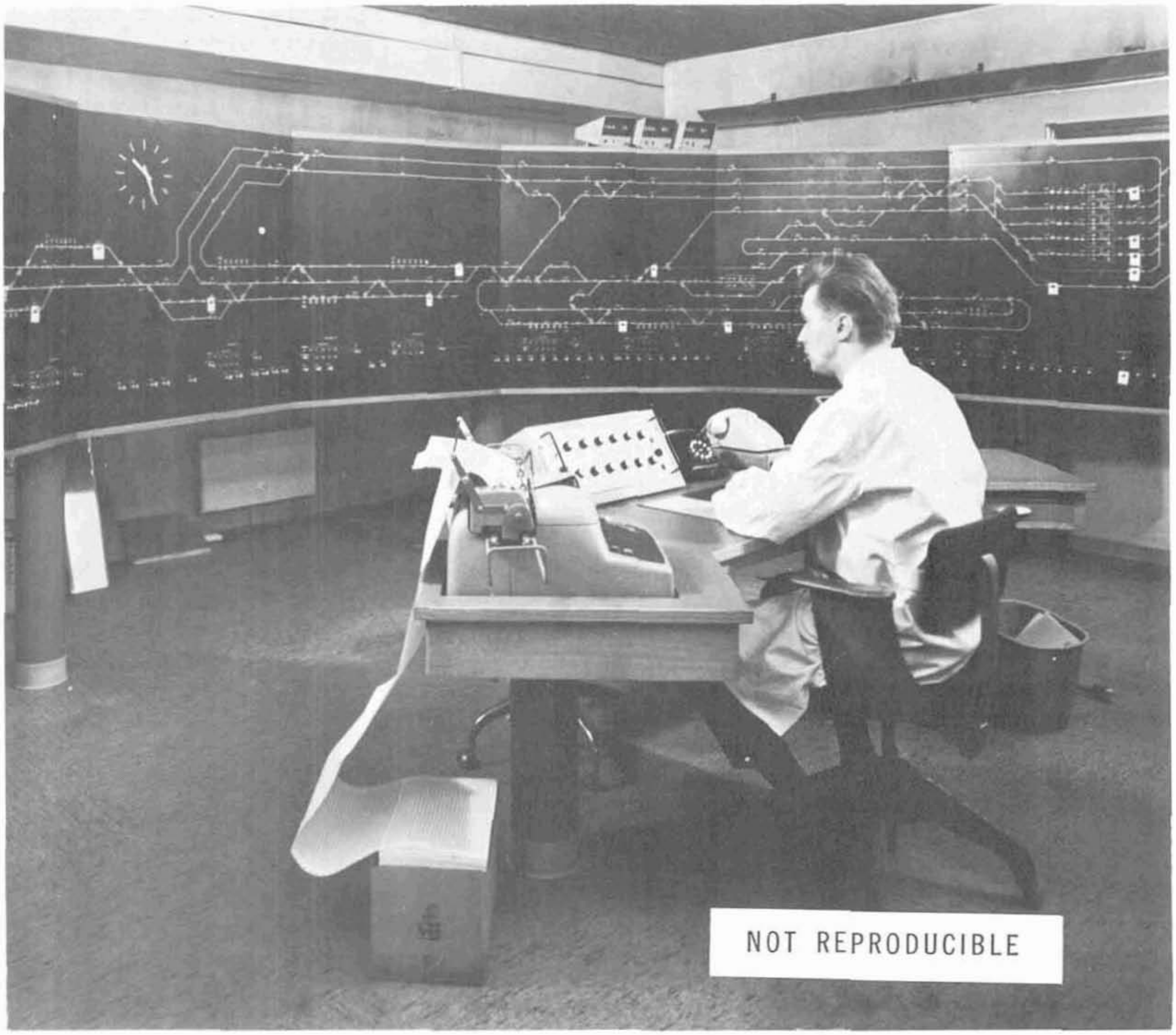


FIGURE 12. - Traffic Control Room.

concentrate his undivided attention on the operation. If necessary, he can control the traffic manually and take action in the event of emergencies. He also routes supply, service, and personnel traffic. Such centralized traffic control by computer could be tailored to the needs of coal mines.

Recommended Safe Practices

The following safe practices are recommended for motor crews (20, 43):

1. Only authorized persons should operate locomotives. The motorman should be seated in his cab when applying power or the locomotive is in motion. He should not get off while the locomotive is in motion. No person except the motorman or brakeman shall ride the locomotive unless authorized by the mine foreman and then only when safe riding facilities are provided. When a

motorman leaves a locomotive, he should shut off the controls, set the brakes tightly, secure the brake wheel, and remove the pole from the wire.

2. Nobody shall ride on a loaded car or on the bumper of any car except the brakeman who may ride on the rear bumpers of the last car of a pulled trip.

3. Maximum speed limits and trailing loads for the haulage system which an individual locomotive can safely handle should be set by management and strictly observed.

4. Backpoling should not be done except with caution only to the nearest turning point or where trips are ascending very steep grades at slow speed.

5. One or more empty cars should be placed between a locomotive and a car hauling rails, pipe, timbers, or similar material.

6. The practice of "flying switches" and the pushing of trips on main lines except for switching should be prohibited.

7. A distance of at least 300 feet should be kept between trips. The rear of a pulled trip or the front of a pushed trip shall be indicated conspicuously by a permissible trip light or a reflector.

8. Vehicles in motion should not be coupled or uncoupled by hand unless coupling hooks are used.

9. Standing cars should be secured effectively, and not parked beyond safety zones on the curved part of the turnout.

10. Where a dispatcher is employed, traffic under his jurisdiction should move only at his direction.

11. Metal whistles should be used in signaling between motor crews, because light signals cannot be seen when the view is obstructed.

12. Haulage crews should wear goggles and tight-fitting clothes.

Inspection and Maintenance

One responsible person, a motor boss or maintenance foreman, should be in charge of the periodic inspection and maintenance of the rolling stock of a mine (43). However, each motorman must carry the responsibility for checking his equipment and filling the sandboxes at the beginning of the shift. The check shall include brakeshoes and rigging, lights, warning devices, and sand rigging, wiring, controller, trolley phone, trolley pole, shoe and base, lubrication (daily for sleeve bearings), floormats and seat covers, and such accessories as rerailers, chains, lifting jacks, long hitching bars, fire extinguisher, and first-aid kit.

Defective equipment shall be kept out of service until repaired and tagged distinctly while it is in the shop, so that it will not be taken out on the road before it is ready to go (43).

MOBILE NONRAIL HAULAGE

Trend

Face transportation by mobile nonrail (37) or trackless haulage has replaced tracked face haulage almost entirely. With proper equipment, it has been extended to mining of thin, pitching, or undulating coalbeds. One of its great advantages is mobility; others are elimination of trackwork and hazardous, noisy mine car loading traffic with a face ventilation hazard when check curtains are disturbed. Data of figure 3 show the trend toward trackless haulage during 1956-66.

Accident Experience

Most accidents in trackless haulage are collisions of vehicle with rib or post. Also numerous are accidents to persons where the victim was squeezed or crushed between car and roof or rib. A few jackknifing accidents of tractors with trailers are reported. Table 4 compiles information on hazardous conditions which caused fatal injuries in trackless haulage. The salient causes were defective equipment and adverse environment such as clearance obstructed by roof bolts, crossbars, irregular ribs, brows and posts; uneven, wet, or muddy floor; and roof falls when roof supports were dislodged. Lesser causes were obstruction of view by ventilation curtains and equipment too high for conditions which put drivers into a cramped position and limited their view. The most frequent unsafe acts causing fatal accidents, according to table 5, were excessive speed and failure to face direction of travel. Others were inattention, operation of equipment by inexperienced drivers, failure to familiarize with the road environment, operators standing in their decks, improper operation of equipment, and failure to come to a complete stop while the operator is changing seats. This information on causes of fatal accidents points out the areas of concern: Selecting and developing haulage personnel, preparation of roadways, selection of equipment, maintenance, and mine planning.

Roadways

Roadways must be driven straight and kept on center lines. Painted sight lines help the driver, particularly in low coalbeds where he may not be able to look over the car and will be guided only by painted sight lines, straight post or bolt lines, or straight ribs. The maximum width of roadways allowable is a matter of roof control, and, therefore, an item of the roof support plan; that is, the space between line posts determines the available side clearance which should exceed the vehicle width by a minimum of 4 to 5 feet. Roadways for trackless haulage must be wider than for tracked haulage, because the vehicle is not confined to the track. Roof bolting is the preferred method of roof support because the entire width of the roadway is available under the bolted span. Where roof conditions dictate posting or 3-piece timbering, post lines must be kept straight to minimize the hazard of posts being dislodged by the vehicles. Boards nailed lengthwise to posts or header legs offer some protection against this hazard. Some companies require crossbars of 3-piece sets to be bolted to the roof as a means of positive protection so that the bars cannot drop out even if their supporting legs are knocked out.

TABLE 4. - Physical or environmental causes of fatal accidents connected with trackless haulage, 1956-66

(Numbers in parentheses represent frequencies, if more than 1)

	Frequency
Defective vehicles including protective devices.................... Brakes (15), lights (15), cab guards (15) mostly on tractors, controls (6), dead-man controls on tractors and small shuttle cars (6), steering (5), wheel alinement, cables, coupling between tractor and trailer, gearshift of small drag-cable tractor, main switch on cat-mounted shuttle car, chain across access to covered man-trip trailer.	68
Environment.. Irregular ribs, brows, ledges (12), uneven, slippery, sidling floor, grades, mud, water (10), inadequate unsuitable roof support (9), abrupt change of overhead clearance (8), debris, coal spillage (5), obstructed side clearance (4), restricted overhead clearance (3), splintered, loose bridge flooring (2).	53
Protective devices on roads.................................. Signs warning of low overhead clearance (5), skidboards along crossbar legs.	6
View obstructed by curtains..................................	6
Equipment too big for conditions.............................	5
Poor planning.. Location of elevator, lack of facility to cross conveyor.	2
Fatigue of operator, doubling back due to absenteeism.............	1

TABLE 5. - Unsafe acts connected with trackless haulage and causing fatal accidents, 1956-66

	Frequency
Excessive speed for circumstances............................	23
Failure to face or watch direction of travel.....................	22
Inattention..	17
Handling of equipment by inexperienced and unfamiliar operators....	16
Riding in an unsafe position, operators standing in their decks....	14
Improper operation or use of equipment........................	10
Failure to familiarize with the road environment..................	7
Failure to stay in the clear of moving equipment..................	4
Failure to use warning signals, visible or audible................	4

TABLE 5. - Unsafe acts connected with trackless haulage and causing fatal accidents, 1956-66--Continued

	Frequency
Parking of equipment in dangerous locations near curtains or track.	3
Using roadway obstructed by equipment..............................	3
Failure to move equipment on "low boys"............................	2
Failure to keep shuttle-car decks clean so that operation of controls is not impaired..	2
Failure to put controls in neutral and to come to a complete stop when changing seats...	2
Getting on or off moving equipment.................................	2
Failure to secure or block standing equipment effectively..........	2
Use of defective equipment...	2
Failure to deenergize when testing or repairing equipment..........	2
Traveling through abandoned works..................................	2
Failure to use a cap light...	2
Riding inside shuttle car when the conveyor chain is not locked....	1
Failure to communicate by visible or audible signals...............	1
Any work on moving or running equipment............................	1
Failure to shut controls off and set brakes securely on unattended parked equipment...	1
Boarding or leaving moving man-trip cars and failure to remain seated when car is in motion......................................	1
Failure to wear effective protective apparel.......................	1

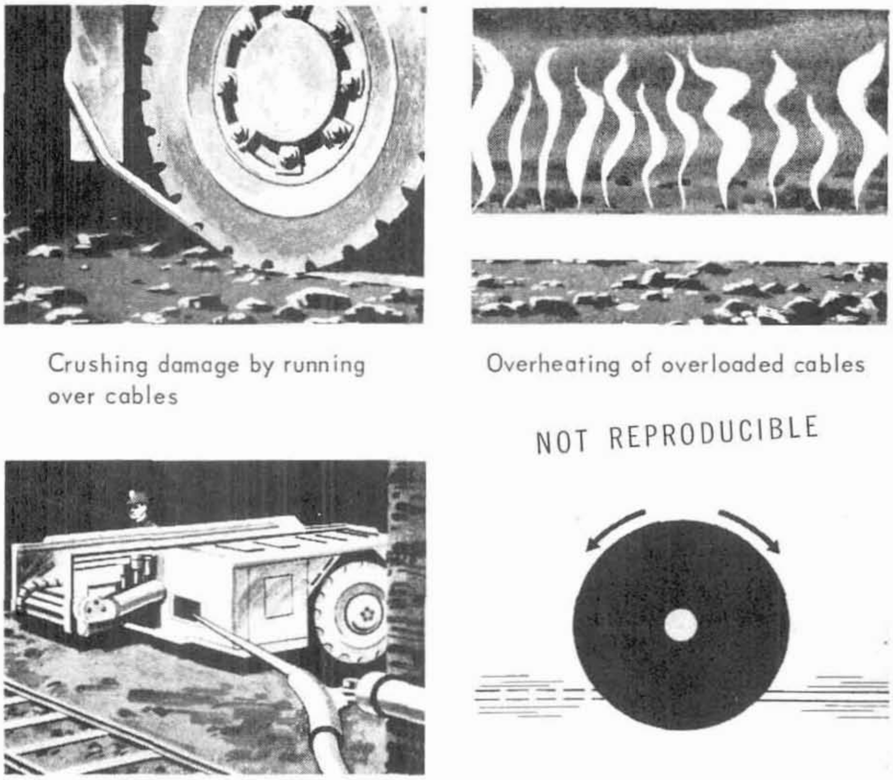
Intersections are critical for roof support. Often a corner or two has to be cut off to permit circulation of the equipment. Roof bolts will support the roof exposed by such widening. However, where roof bolting is not permitted and 3-piece sets are required, the crossbars at the intersection have to be supported by "king bars," extra-long stringer bars, to permit widening of the space so that vehicles can round the corner. Such king bars can cause severe injuries when their supporting posts are dislodged and they fall on the driver. Overhead clearance is critical for safe and efficient operation. The equipment must be selected in accordance with the height of the coal and the type of roof support. Physical conditions in a mine may change and the cars then may be too high for safe operation or unsuitable equipment may be transferred from other mines of the company (43).

Irregular ribs and brows can gravely endanger operators of trackless equipment. Proper placement of rib holes, keeping the cutter bar from gripping, and shearing a rib, if necessary, will control the configuration of the entry cross section in conventional mining. Ripper-type continuous miners cut a smooth rib and the arched bore made by the bore miner favors roof control in solid work, but the arched rib may overturn under the weight of heavy strata in retreat mining. Good housekeeping will eliminate many hazards (43). The runways should be kept free of debris and haphazardly stored supplies. Excessive spillage, which tends to accumulate on turns and at dumping points, should be removed. Treating with calcium chloride will condition the roadbed and allay the dust. Steel drags, hooked to shuttle cars, will keep the runway leveled (43), and crawler treads and rubber tires of the equipment will compact the material. Check curtains should be hung to permit easy passage of the shuttle cars without endangering the operator.

Uneven, soft, muddy, and sidling floors present severe hazards. Short, heavy gradients and bottom rolls can be graded by cutting or blasting. The roads can be drained by ditches with water collected in sumps and pumped out. Sometimes it is necessary to bridge water holes. These bridges are built with 12- by 2-inch planks as stringers and 4- by 12-inch cross timbers. The combined action of water and traffic dissolves soft, clayey bottom rock into mud. Special pumps are used for the muddy water. Often boney coal is dumped on the muddy road to firm it or the road is surfaced with corduroy or planking (43). Sidling roads in pitching coalbeds severely tax the skill of the shuttle-car operator.

Cable-Reel Shuttle Cars

The modern shuttle car has 4-wheel drive, 4-wheel hydraulic power steering, disk brakes, a hydraulically elevating discharge boom, and a hydraulic cable reel. Dimensions range as follows: Height, 26 to 55 inches; width, 112 to 90 inches (the lower cars are the wider ones); length, 22 to 26 feet; minimum outside turning radius, 22 to 18.5 feet; and wheelbase, about 8 feet. Speed is 3 to 5 mph. Power sources are 250 or 500 volts dc or 440 ac. Frames are all welded and have a smooth surface without protruding bolts and nuts. Corners, particularly those of bumpers and discharge booms, are rounded to minimize the danger of dislodging posts and catching coal ribs and check curtains. Cars are painted in a bright color for better visibility. Critical structure areas are strengthened. The modern hydraulic power-steering system functions without the complex mechanical linkage of the older systems and provides moderate steering control for a short distance in the event of power loss. The disk-type brake, developed by the aircraft industries, found acceptance in mining in the early 50's. It rapidly replaced the automotive type, because of the higher braking capacity which is unimpaired by mud and water (43), the smoother operation, longer lining life, self-adjustment, and simpler relining. A separate mechanical parking brake in addition to the hydraulic brake is desirable. Dynamic braking is available on dc cars and occurs on ac models whenever traction motors are driven over synchronous speed on a downhill run. The hydraulic cable reel, unaffected by variation in mine voltage, wraps up or pays out the cable through a spooling device. Automatic torque from 400 to 150 psi maintains proper tension on the cable regardless of travel direction (1). There are 500 feet of trailing cable on most cars and dumping points should be moved up in time so that the car can reach the most distant face without backlashing, which can damage the cables. Anchoring the cables with shock-absorbing devices, either springs or old tire casings, also will prolong their lives (43) (fig. 13). The cables are anchored on opposite sides of the entries to avoid interference between the two shuttle cars on a section and



Crushing damage by running over cables

Overheating of overloaded cables

Excessive tension controlled by shock-absorbing anchors

Harmful sharp bending by frequent back spooling

FIGURE 13. - Cable Hazards.

lessen the hazard of their running over the cables. Accordingly, the cars must have operator decks on opposite sides. The "standard" car has left-hand steering, traveling from the face to the dump, and the "off-standard" car has the steering on the opposite side. Therefore, drivers must get adjusted to whether they operate standard or off-standard cars. Flat cables, type G, 2-conductor for dc and 3-conductor for ac, of approved fire resistance are preferred to round cables. G means that, in addition to the power conductors, there is a ground conductor of 50-percent size of the power conductor. Only trailing-cable nib fuses of the proper rating or automatic circuit breakers of the correct setting will protect cables against low-resistance faults. Effectively grounding the frame by the third or ground wire has always been a problem, particularly in splicing. Frequently the ground-wire splice is not completed. In 1963 the Bureau of Mines accepted frame grounding of dc shuttle cars by silicon diodes (49). Thus, the third wire is eliminated and 2-conductor cables, type W, can be used exclusively with such advantages as cheaper cable cost, easier and faster splicing, and more effective and lasting protection. On equipment with magnetic contactors a small diode in the control circuit prevents operation on reversed polarity.

When the operator's deck is at the discharge end, the cab guards might offer some protection, but they cannot be made high enough due to operation requirements. Locating the operator's compartment between the wheels provides better protection. Protective cabs were developed in the western coal industry where thick coalbeds, steep pitch, and heavy cover present problems of ground control (102). The ribs tend to turn over. This and other injury potentials, such as the operator being caught between the rib or post and the car, being caught in check curtains, or striking his head against the roof or crossbars, are eliminated by well-designed protective cabs. The foot controls are dual and so arranged in the deck that brake pedal and acceleration button are always at the same foot of the operator. Automatic transfer of lights with the direction of travel is desirable. Dimming headlights prevents blinding of personnel. An audible warning device, usually a gong, should be used by the operator to warn at the approach to curtains, turns, or anyplace where persons are likely to be (20).

Six-wheel shuttle cars are hinged in the middle to provide articulation over rough ground (fig. 14). This design allows higher capacity and faster speed than 4-wheel cars. Dimensions range as follows: Height, 24 to 40 inches; overall width, 127 to 107 inches; overall length, 26 to 31 feet; minimum outside turning radius, 25 to 27 feet; and wheelbase, 10 feet. Speed rating is 4 to 6 mph. Six-wheel cars do not have quite the maneuverability of the 4-wheel cars. Therefore, if the roof control system does not permit widening of 90° intersections, breakthroughs have to be turned on 60° and 45° angles, to let the cars round the turns.

A crawler-tread shuttle car, introduced in the 50's, should have offered advantages in adverse floor conditions and pitching coalbeds, but it is not

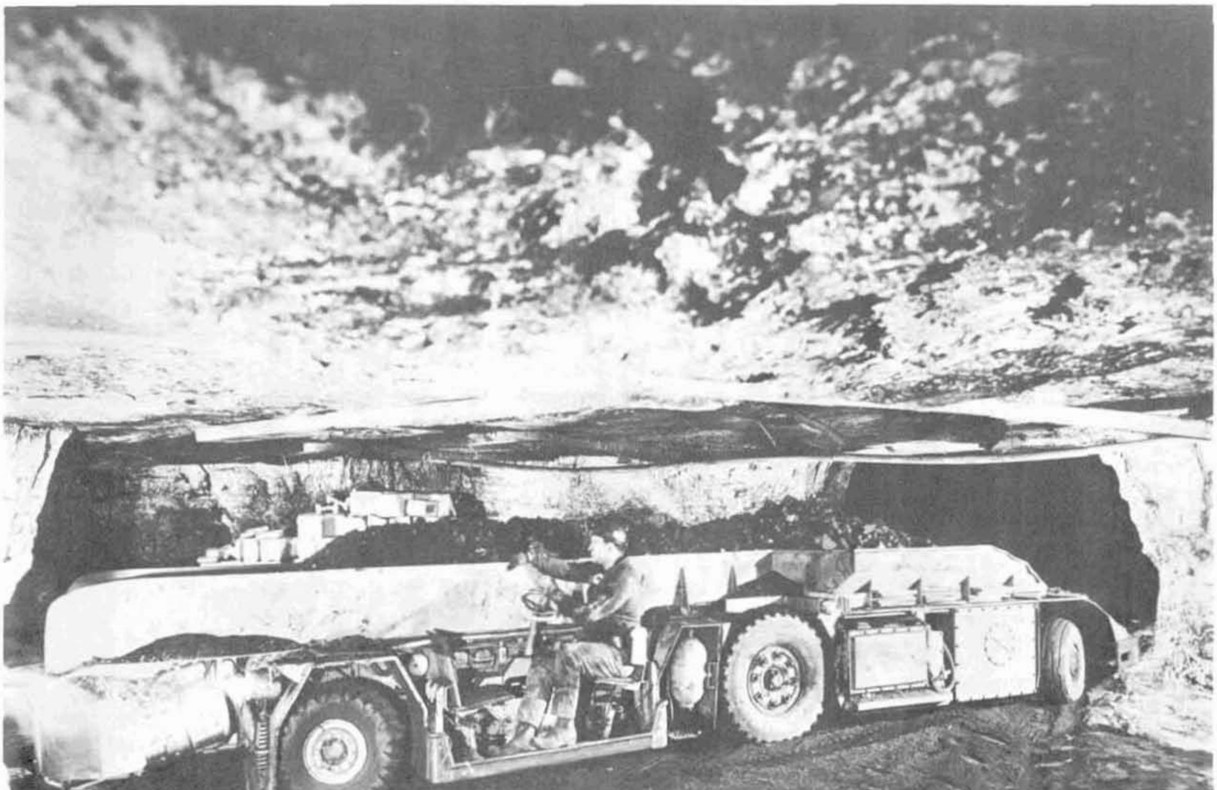


FIGURE 14. - Six-Wheel Shuttle Car.

made any more. One fatal accident to an operator who was squeezed against the rib was attributed to defective electric controls and a stop switch out of reach.

Lubrication, refilling of hydraulic fluid, checking of brakes, lights, steering, electric and hydraulic controls, and tire inflation are daily chores of the operator. Inspection and refilling of fire extinguishers on each vehicle should be done at regular intervals. Servicing magnetic contactors and controller parts, clutches, motors, hydraulic system, and wheel alinement, and rebuilding of equipment are best included in the program of preventive maintenance. Hour meters for shuttle cars are available and will help in setting maintenance and rebuilding dates. Tires should be kept inflated to the correct pressure, about 100 psi. Dual tires provide better traction and a floating ride on soft bottom, but modern, wide-profile, single tires serve the same purpose. Where compressed air is not available, waterfilling of tires, adopted by a number of companies, has proved quite successful for extending tire life with less leakage, mostly because the valve is sealed.

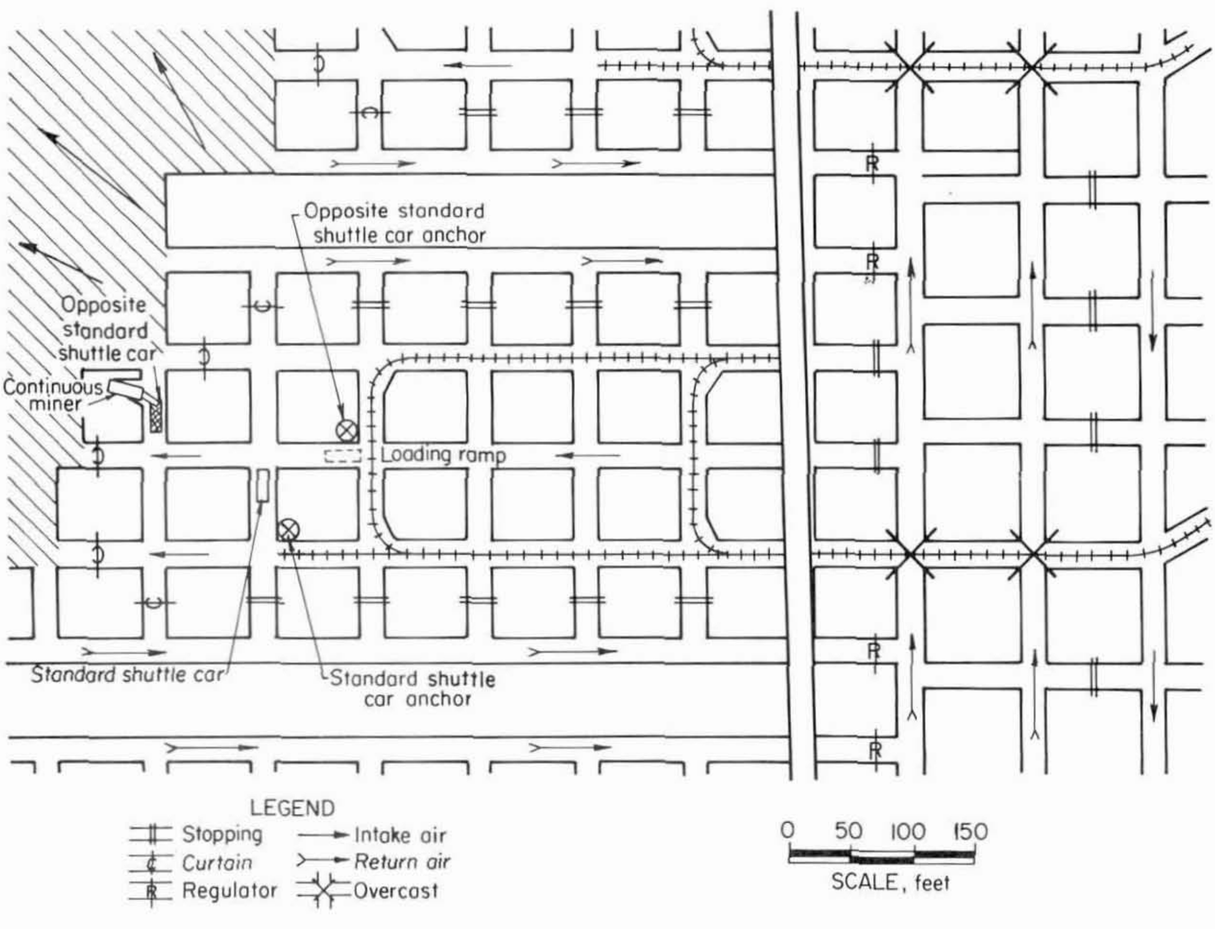


FIGURE 15. - Loop System Mine-Car Loading With Continuous Miner on Pillar Extraction.

Sectional layout of shuttle-car haulage is shown in figure 15. The loop loading point permits continuous car change, but requires extensive trackwork (27). The push-pull loading arrangement takes less trackwork, but is intermittent (25). Boom holes have to be blasted for mine car loading stations, and ramps have to be built to let low shuttle cars dump into mine cars. Old-type shuttle cars with fixed discharge need ramps or elevators. Sometimes the elevator is set at an intersection to allow dumping from two directions. A poorly positioned elevator requires some extra maneuvering of shuttle cars and may cause accidents. Belts permit the shortest shuttle-car hauls. Extension, particularly of modern rope belts, requires much less time and effort than the trackwork connected with mine car loading point moves (27) (fig. 16).

The following arrangements will contribute to safe and efficient shuttle-car haulage:

1. Shuttle-car exchange points should be kept close to the loader or continuous miner.

2. Wherever possible each shuttle car should travel on a separate road.

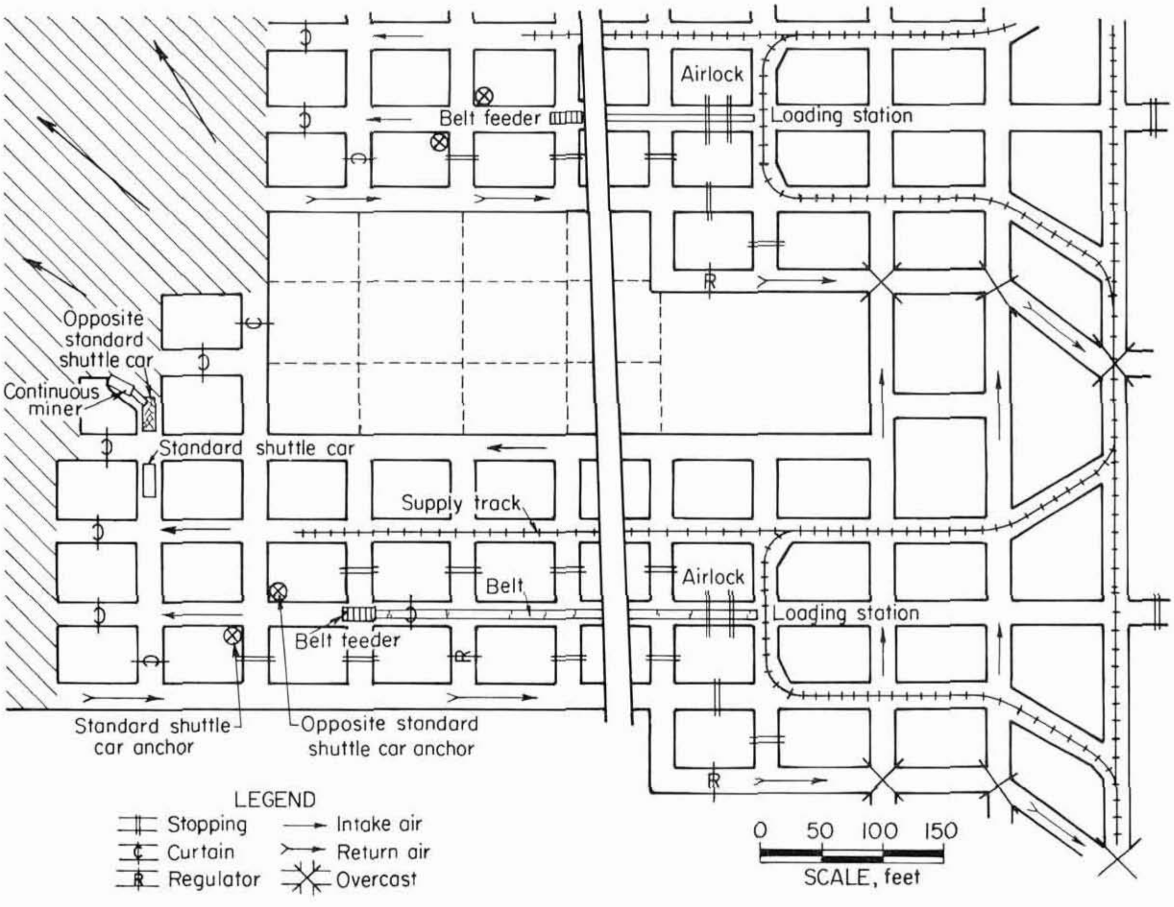


FIGURE 16. - Belt Section With Continuous Miner.

3. Personnel should stay clear of shuttle-car traffic.

4. Travelways should be separate for face equipment and shuttle cars.

5. Cycle of face operation should be maintained and cables of face equipment hung up and anchored in the proper order, particularly on intersections so that they be kept off the roadways and avoid entanglements. The following sequence from top to bottom may be observed in conventional mining: (1) Coal drill, (2) cutter, (3) roof drill, and (4) loader. Then the shuttle cars can freely circulate under the cables without danger of running over them.

Small Drag-Cable, Drop-Bottom Shuttle Cars

The advent of the small drop-bottom, drag-cable shuttle car in the mid-fifties enabled small nongassy mines to operate profitably even in low coalbeds. The coal is mostly loaded by hand, and the car carries it directly to the surface dumping platform which is positioned above a truck loading bin or chute. They are powered by 250 volts ac, single or three-phase, or by 250 volts dc. The single motors range from 5 to 15 hp. Their drag cables are approximately 500 feet long.

Local shops make these cars from used automobile parts and weld the body. The cars hold 1 to 3 tons and are 6 to 7 feet wide so that they can maneuver in 9- to 10-foot-wide roadways without dislodging posts. The short wheelbase is of great advantage in low coalbeds, where it can follow sharp undulations of the coalbed easily, while a vehicle of the same height, but with long wheelbase such as a cable-reel shuttle car, would require more overhead clearance. The small shuttle cars are not made permissible but just like the large cars must be maintained in safe operating condition with effective brakes, steering, headlights, audible warning devices, and dead-man controls. The deck should be covered with rubber mats and large enough to accommodate at least the driver in prone position in low coal so that no part of his body protrudes beyond the outline of the car. The cars should be equipped with cab guards and fire extinguishers. Their cables should be of the approved flame-resistant type with adequate overload protection. Power and light circuits should be protected by fuse or breaker.

Poor maintenance of these small shop-made units appears to be the main cause of fatalities owing to hazardous conditions. This includes defective controls. Environmental hazards such as abrupt change of overhead clearance and roof support that failed when posts were dislodged takes second place. Excessive speed is the most common unsafe act. Failure of the driver to watch direction of travel and inexperience of operators are less frequent causes. Side obstructions and low top clearance cause accidents to persons riding with the operator on the deck of loaded cars.

Battery Haulage

The earlier battery shuttle car was superseded by the more efficient cable-reel shuttle car. But battery haulage came back to the mines this last decade, first as man and supply transportation and later in coal haulage. It has been brought back for several reasons: Greatly improved batteries and chargers, relatively low first cost, simpler maintenance, and flexibility and safety of battery power. Permissible tractors perform face service in gassy mines. Another great advantage of battery tractor transportation is that every open entry can be used as travelway or escapeway (15). This means better survival chances for the face crews when they attempt to escape from smoke or fumes in an emergency, particularly in low coal. Walking rate will depend on coal height, averaging 220 fpm in 6-foot coal and 120 feet in 4-foot coal. Crawling speed will average less than 70 fpm (97). These are travel speeds in clean, obstacle-free escapeways. A tractor traveling at 6 mph will move men at about 550 fpm or fast enough to keep ahead of smoke or fumes at most ventilation air velocities.

Tractor speeds are 2 to 6 mph. They pull one trailer or trains of several cars. Trailers are 3- to 4-wheel units ranging from 1-3/4 to 10 tons of coal-carrying capacity. There are coal and supply trailers and service trailers like lubrication and maintenance centers, fire trucks, and water cars. Supply trucks are also available in rubber-rail combinations with fixed steel wheels to travel on track and movable rubber-tired wheels that can be retracted for track travel and lowered for trackless haulage by means of a hydraulic hand pump. Men can be transported on empty coal and supply trailers, on sleds in very low coal, and in special covered man-trip trailers. These portal trailers seat 10 to 12 persons in comfort on contoured seats. Their height ranges from 28 to 42 inches and width from 114 to 138 inches (figs. 17 and 18).

Modern tractors are equipped with 4-wheel drive, 4-wheel brakes or disk brakes on drive lines, and 4-wheel steering. Axle assemblies are spring mounted and shock-absorbing driver seats are available. Some heavier models have power steering, dynamic braking for steep grades, power takeoff for rock dusting, and front-mounted winch, cargo platform, or dozer blade. The tractors are 2 to 3 feet high, 6.5 to 7.5 feet wide, and weigh 5 to 10.5 tons. Special personnel carriers are made for transportation of supervisors and repairmen. Most tractors carry two batteries with a total of 48 cells and 96 volts. The heavier models carry 64 cells of 128 volts. Battery capacity ranges from 300 to 800 amp hr or 30 to 110 kwhr at the 6-hour rate of discharge.

Table 6 shows how greatly grades affect tractor haulage. Tractors are seldom used where grades exceed 6° (10.5 percent). Information in table 6 is based on a rolling resistance of 80 pounds per ton of gross weight for rutted mine roadway, flexing under load with 1-inch tire penetration and a coefficient of traction of 0.55 for rubber tires on such mine bottom. Traction is much less on wet and muddy roads. Soft, deeply rutted, uneven, and muddy floor makes tractor operation inefficient and hazardous.

TABLE 6. - Haulage capacities of rubber-tired mine tractors in tons

Grade	Tractor weight in tons		
	3	5	10
Level	41	69	138
1-percent	32	54	108
2-percent	27	44	88
5-percent	17	28	56
10-percent	10	16	32
15-percent	6	11	21

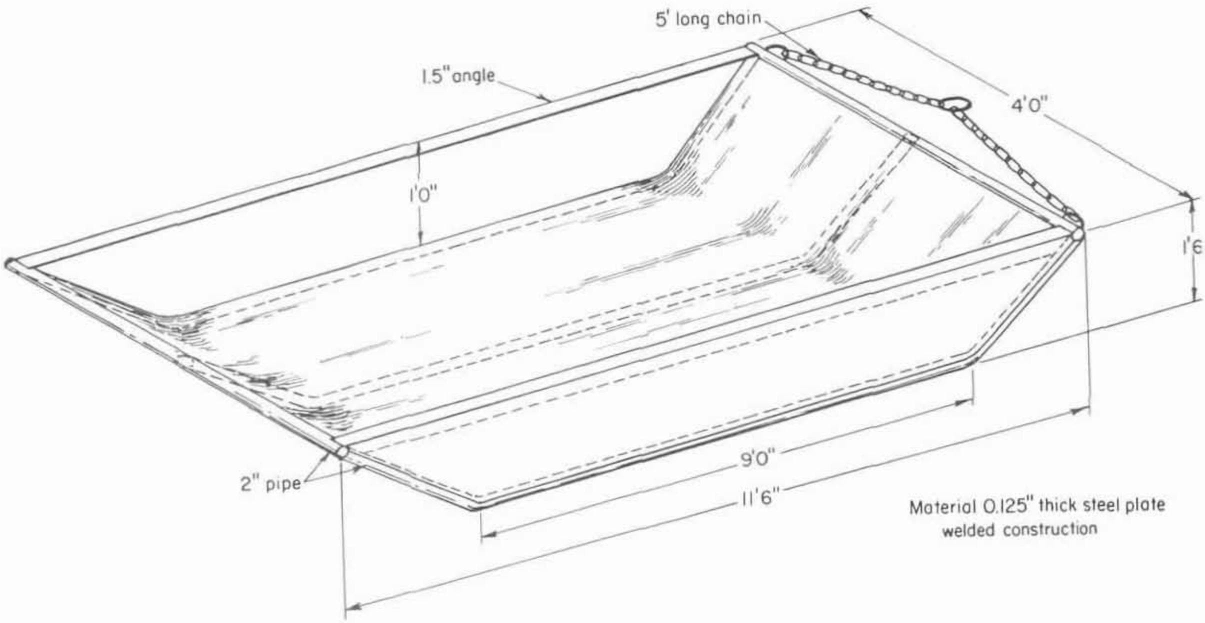


FIGURE 17. - Man and Supply Sled.

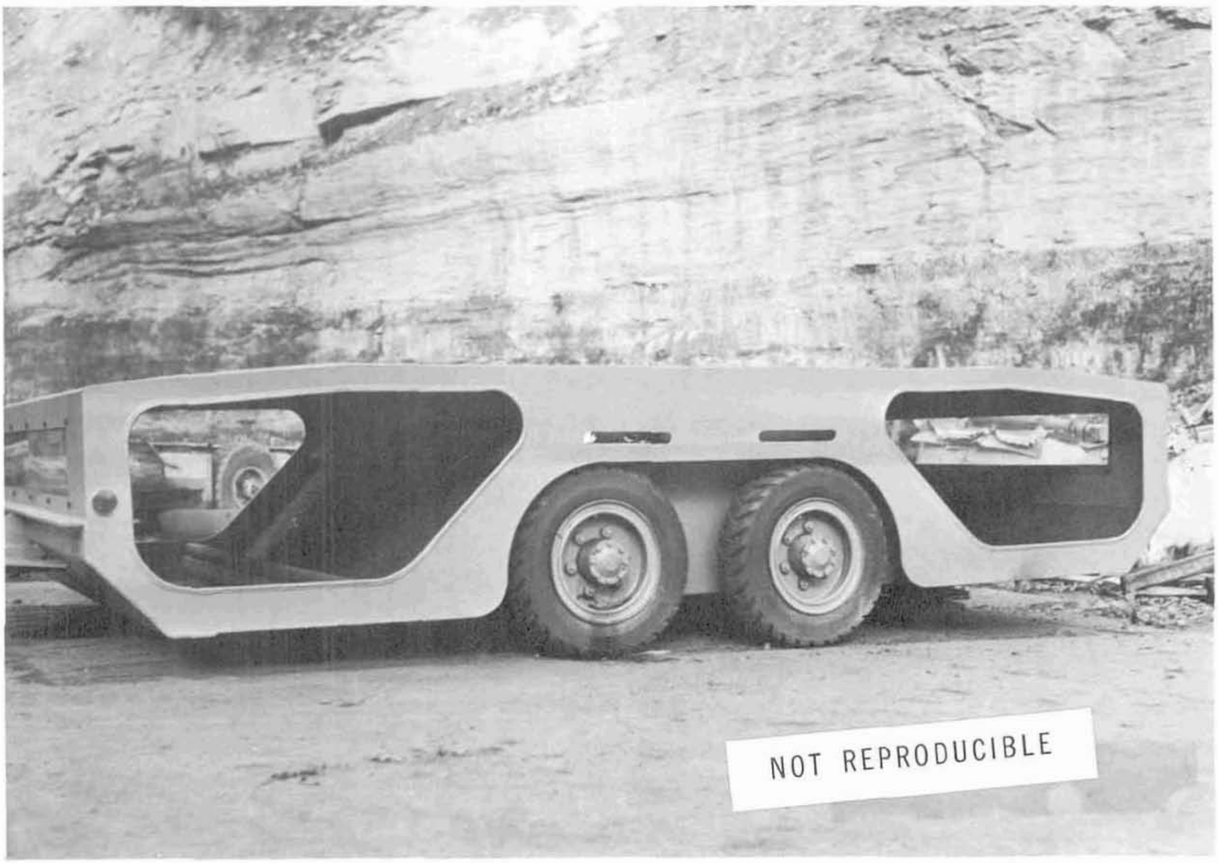


FIGURE 18. - Portal Trailer.

The short wheelbases of tractor trailers allow them to travel in the undulating coalbeds with greater ease than shuttle cars with long wheelbases (15). On the other hand, tractor trailers require more roof span unobstructed by posts when rounding turns or maneuvering under loading machines. Therefore, roof bolting is even more necessary for tractor operation than in shuttle-car haulage.

The main hazards causing fatalities in tractor operation were missing cab guards and defective dead-man controls. The uprights on cabs can prevent the fatal consequences of accidents like jackknifing when trailers are pushed into the cab during backing maneuvers (fig. 19). Environmental hazards such as unsuitable support of a roof that failed when posts were dislodged and abrupt change of overhead clearance also took their toll. Speed excessive for circumstances, inattention, improper use of equipment, and inexperience of operators were the principal unsafe acts with fatal consequences.

Face haulage by battery units must fit the physical conditions and the methods of mining. Hand loaders can load one trailer or even a trip of several trailers, while the tractor pulls the loaded cars to the surface, dumps them, and returns with empties.

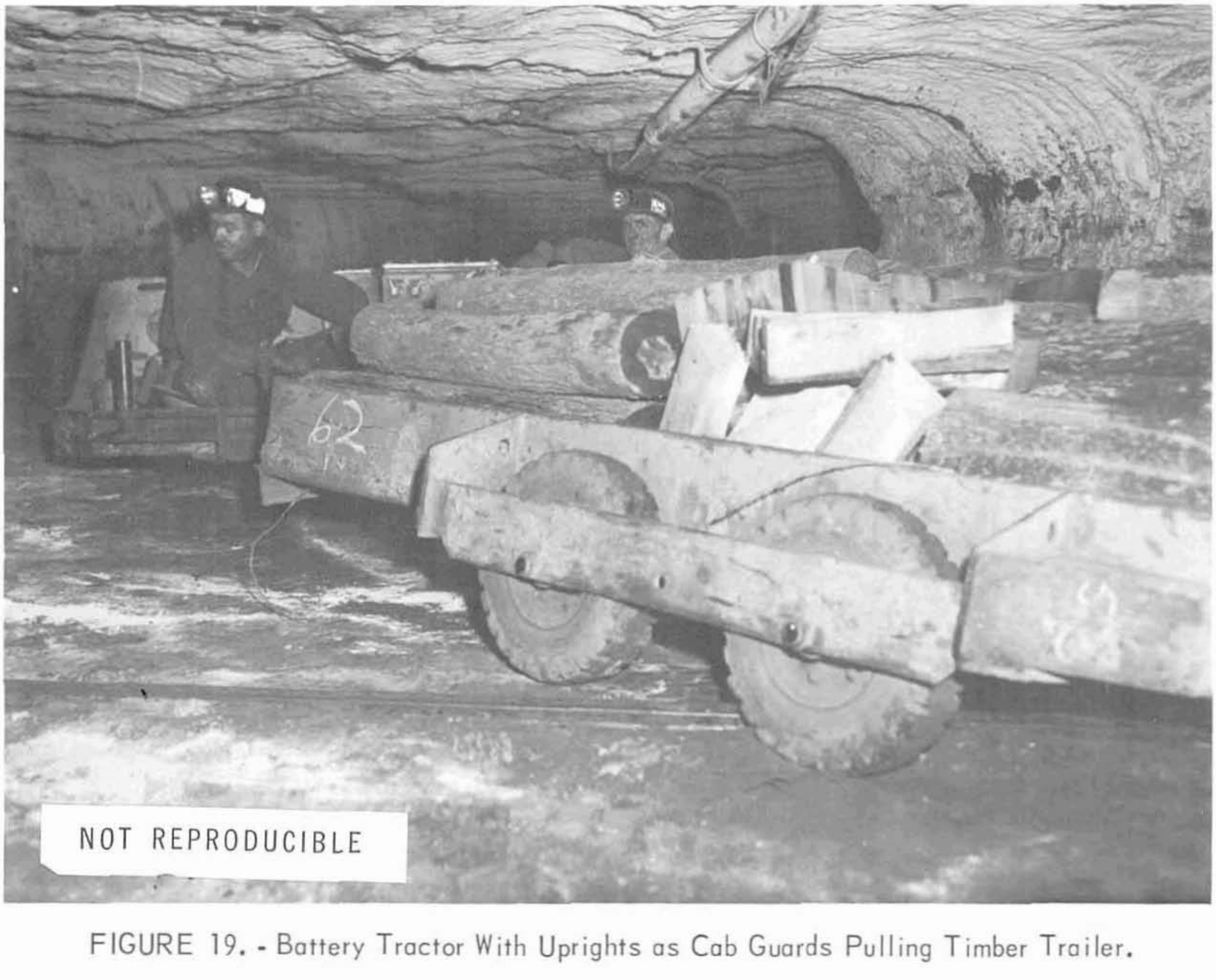


FIGURE 19. - Battery Tractor With Uprights as Cab Guards Pulling Timber Trailer.

Some continuous mining systems in low coal consist of a dual-auger continuous miner, a bridge conveyor, and a swinging boom transfer conveyor. With such a system a trailer train of several 1-3/4-ton trailers is loaded while the train is passing under the discharge of the transfer conveyor. The trailers are equipped with swivel couplings that allow the whole train to be pulled through a rotary dump after it reaches the surface and to be dumped without uncoupling (32). A fatal accident occurred when a foreman attempted to cross such a trailer train in 30-inch coal without notifying the tractor operator. He fell between the cars and was killed as the driver pulled the train away without warning.

A disadvantage of tractor haulage is the need for large areas of underground dumps and battery-charging stations. The permanent underground battery-charging stations must be constructed of incombustible material and be ventilated by a separate split of air conducted directly into the return air (20). They have monorail 2-ton hoists, sometimes motorized, and derricks to lift the batteries to and from the units. Portable charging units can be placed in the intake air near the face area. They require little space and are skid mounted for easy moves. Recent designs have eliminated the need for underground trailer dumps. Trailers have been developed to discharge like shuttle cars in a horizontal position (fig. 20).

Tractor Scoop

A low-coal underground version of the front-end loader is the tractor scoop. It is a regular battery tractor with a 1- to 2-cubic-yard-capacity duckbill-shaped scoop attached to its front. The hydraulic system of the tractor powers the jacks that manipulate the scoop that picks up a load of coal in the face and dumps it at the dumping point. The tractor scoop found some recent use in small mines to replace hand loading. Two fatal accidents of operators were reported in 1966, neither of them pointing to a deficiency of the equipment. Inadequate stopblocks at the dump and missing safety uprights at the deck account for one fatality; broken and splintered floor planking for the other one.

Diesel Shuttle Cars

Diesel power imparts flexibility to the haulage system and eliminates hazardous and inconvenient cables. The haulage potential is not limited as in battery haulage. Diesel-powered shuttle cars, wherever permitted for coal haulage by individual States, have proved their value in safety and productivity (100). The engines are equipped with an intake flame arrester, a water-cooled exhaust manifold, an exhaust conditioner, and fail-safe thermal controls to satisfy Bureau of Mines Schedule 31, "Mobile Transportation Equipment for Gassy Non-Coal Mines and Tunnels."

The maximum fuel-air ratio for an elevation not exceeding 1,000 feet above sea level is adjusted by testing and set so that the undiluted exhaust gases contain, by volume, not more than 0.30 percent CO and 0.20 percent NO_2, when the intake air mixture contains 1.5 percent of Pittsburgh natural gas as a substitute for methane. Engines tested under Schedule 31 are derated to satisfy the above conditions; for example, from 100 to 85 hp.

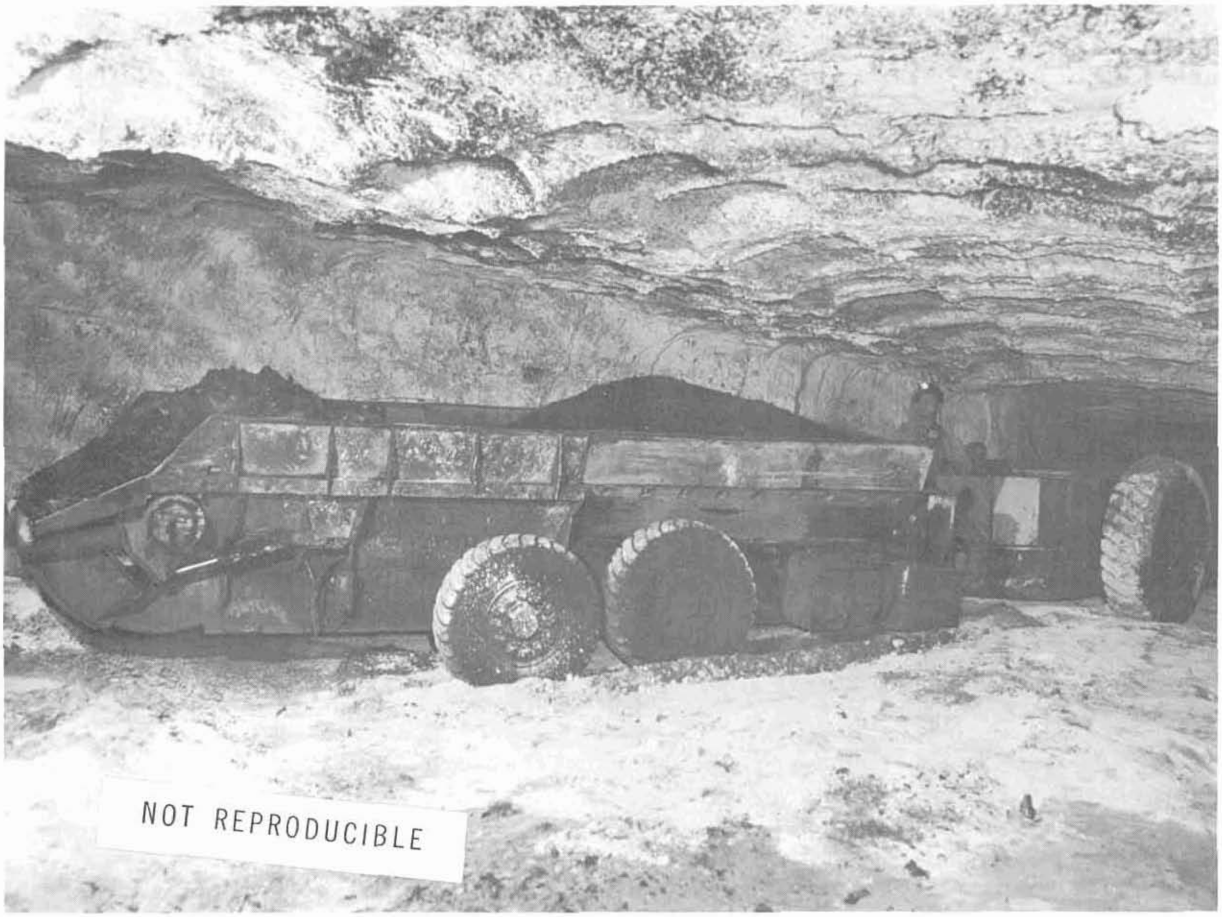


FIGURE 20. - Tractor-Trailer With Horizontal Coal Discharge.

The quantity of air required to dilute the exhaust gas shall be determined and stamped on the approval plate.

Schedule 31 disallows any electric wiring. The engine has to be started by compressed air, and headlights are powered by a storage battery to be recharged after the shift.

In day-to-day operation the foreman supervises refilling of the fuel tank and flushing of the scrubber at the end of each shift for each car in operation. He checks engine and exhaust system for leaks and the exhaust gas for CO and NO_2. If they are found to be approaching the threshold limit, the car shall be stopped until the condition is corrected. The volume of air passing through the last open breakthrough must satisfy the air requirement for the dilution of the exhaust gases. Records are kept of all checks. These are some of the provisions imposed by the respective States.

Safe Practices in Trackless Operation

The Bureau of Mines recommends the following safe practices for shuttle-car operation which apply also to all other types of trackless equipment (43, 61):

1. At the beginning of each shift an operator should check the mechanical performance of his vehicle, including brakes, steering, lights, cable reel, and tires, and should make a trial run through the section, observing changes from his previous shift and such hazards as overhanging ribs, hazardous timber sets, bad spots on the roadway, location of check curtains, stored material, and low overhead clearance.

2. He should face the direction of travel except while maneuvering back of the loading machine.

3. Shuttle cars should not be pushed or bumped by loading machines during loading.

4. A standard code of signals between the car and loading machine operators should be established and practiced.

5. During loading an operator should remain seated and alert, with complete control over the car.

6. No one other than an operator or experienced person expressly designated should move or operate shuttle cars.

7. An operator should be seated, not try to change seats, and not get off a shuttle car while it is in motion.

8. No persons should ride in the bed of shuttle cars.

9. An operator trailing another shuttle car should maintain a distance of three car lengths.

10. An operator should approach check curtains, intersections, and other locations where vision is obstructed with caution; audible warning signals should be sounded.

11. He should be sure that all persons are clear and should sound a warning before he moves the car.

CONVEYOR OPERATION

System and Trend

Single-chain flight and shaker conveyors have always served as transportation in thin coalbeds, or where roof conditions do not permit roadway spans wide enough for track or trackless haulage. Modern continuous-mining systems are combinations of continuous miners and bridge conveyors which discharge into belts. Extensible belts permit immediate belt extension during production time. The armored face conveyor is the face conveyor of longwall mining.

Secondary or gathering belt conveyors are 30 to 36 inches wide and speeds of 500 fpm are common in modern high-production units. Main-line underground, slope, and surface overland conveyors are permanent installations which permit belt speeds up to 650 fpm. Belt widths of 42 to 54 inches are common. Ski tows, chairlifts, and special man-trip belts serve to transport men on some slopes or surface inclines.

High-capacity, well-controlled, and reliable operation with a minimum need of workman exposure and adaptability to various mining conditions such as low undulating coalbeds and steep grades are reasons for the trend towards coal transportation by belt conveyors. When mine operators are faced with modernizing a track haulage system, they quite often decide to install belt conveyors instead. All-belt mines now produce more than 25 percent of the total output of underground coal (33). If belts serve as the means of main-line transportation, tracked or trackless supply haulage and man-trip facilities have to be provided.

Accident Experience

Transportation by conveyors accounted for 13 fatal accidents during 1956-66. Most victims were pulled into belt terminals or head or tail pieces while attempting to clean them of material that had accumulated there because belt-cleaning devices, such as scrapers, were missing and the moving parts were not guarded effectively. One accident occurred as a crew was taking off belting while the drive was running. The victim, sitting on a crosspiece and using his feet to apply traction to the belt, fell into the drive. Three victims were caught and crushed under low clearance at the belt head when they attempted to ride the belt where riding was not permitted. Two victims fell from slippery catwalks into the bins of tipples when they lost their footing while they were cleaning belts. The walkways had neither toeboards nor handrails. Although few fatal conveyor accidents occurred during 1956-66, the ignition hazard always exists. When belting slips on pulleys or over frozen idlers, the frictional heat may set spilled coal or lubricants on fire. Belt systems must be installed and maintained to meet this hazard.

Belt Conveyors

All new underground installations, which are replacing the rigid side frame type, are rope side frame conveyors, because rope belts are not only faster to install, extend, and retract, but also easier to train and to keep clean of spillage. The wire rope absorbs impact loads and the components of the conveyor take but little storage place (33). The belt terminals should be well anchored. All shafts, pulleys, and gears should be guarded adequately.

For belt drives ac power is preferred, but dc power is often used on sectional conveyors when varying speed is necessary as in transporting men. The angle of belt contact is approximately 180° for a driven head pulley on short conveyors, 210° to 240° if a snub pulley is employed, and 420° to 480° for pulleys in tandem for long, high-capacity units where both pulleys are driven either by gearing or by separate motors. Most drive pulleys, as well as snub and takeup pulleys, are rubber lagged to improve friction and to cushion against spillage which gets entrapped between pulley and belting. The angle of wrap and friction between pulley and belting will control belt slippage when tension is applied to the belt. The higher the coefficient of friction and the larger the angle of wrap, the less tension is needed to prevent the belt from slipping at the required capacity.

Tail pulleys of the slatted type are self-cleaning and, therefore, suited for underground service. Takeup assemblies are attached to head or tail terminals to provide the proper belt tension. A manual ratchet or screw-type takeup is adequate for the tail end of low-horsepower belts. Gravity takeups, vertical at the head or horizontal in-line at the tail section, are used with slope and surface conveyors where space is not limited. Underground drives above a certain horsepower require internal automatic, pneumatic, or hydraulic takeups which take minimum space.

Prelubricated idler bearings are suited for most underground belts; but those on heavy-duty conveyors have to be greased. Grease tubes should permit greasing from one side of the belt. Surface conveyors have walkways along the belt for maintenance and lubrication. Some are covered with a roof for weather protection. The walkways should have nonslip surface, be cleated on grades, and provided with toeboards, handrails, and overhead lighting (20).

Belting, the most expensive conveyor component, is more exposed to wear and tear than any other part of it. Two designs are found in underground applications, the multiply fabric belt and the solid woven belt. Nylon and rayon fabrics lend high strength and flexibility to the carcass of multiply belts and neoprene covers, meeting the requirements of Bureau of Mines Schedule 28 for fire resistance, are preferred for underground use. Solid woven belting has a single-ply carcass of high-strength, prestressed nylon fibers (33). The cover is a thermoplastic material, called PVC (polyvinyl chloride). Steel-cable construction is for long centers and high-life installations.

Belt sections are cut square and joined by mechanical splices for extending or retracting belt conveyors. Vulcanized splices are stronger than mechanical splices and are quiet when they pass over pulleys and idlers. They keep the belt sealed against the attack of moisture and do not leak fine material. Therefore, vulcanizing of permanent and semipermanent installations is the rule (33).

Belt training is the procedure of making a belt run true, and it is essential to load the belt properly at the tail section in order to keep it well trained. Where shuttle cars dump directly on a belt, stopblocks should be provided to prevent the cars from bumping the belt out of alinement. Heavy-duty impact idlers, made of tapered rubber disks, are spaced closely under and outby the loading points to cushion the material impact on the belt. Skirtboards center and settle the load on the belt as it leaves a loading point at the tail section or any intermediate dumping point. Hinged and counterbalanced chutes at transfer points of a multiple system permit coal loaded on the inby belt to pass under them (33). Incorporating screenbars or cutting a V-slot into a chute will allow fines to fall through first and form a bed for lumps. Self-alining carrying and return idlers are pivoted in the center of the cradle and designed to automatically correct belt misalinement. They are interspersed along the belt line.

The function of rubber belt scrapers, rotating bristle or rubber vane brushes, or rows of felt sheaves is to remove coal particles adhering to the carrying surface. They are mounted adjacent to the head pulley and prevent a buildup of dust which may cause the return idlers to stick. V-shaped plows are attached to the tail sections and located above the return strands in front of the tail pulleys. They remove the spillage that is carried back on the return strand before it gets trapped between tail pulley and belting (18, 31) (fig. 21).

Belt feeders receive coal at the maximum shuttle-car discharge rate and feed it onto the belt at a speed consistent with the belt capacity. Input to output feed ratio of 4 to 1 is common. A lump breaker can be added to the feeder to crush the lumps to a size convenient for belt operation.

Protective Belt Controls

Multiple controls protect belt systems from a variety of damaging conditions, first of all the ignition hazard from frictional heat.

1. Slippage control--Experiments have shown that even belting satisfying Bureau of Mines Schedule 28 for fire resistance can be ignited and will propagate the flame (73). When a belt gets jammed and starts slipping on the drive pulley, a centrifugal switch, driven by under-belt contact or by V-belt from a return idler, will operate in conjunction with a time-delay relay to stop the belt motor (33). Another method of belt slip control used on main-line belts is by two generators or magnetos mounted on the drive and snub pulley shafts. A difference in speed causes a voltage difference which initiates a relay to stop the drive motor (57).

2. Cascade control--Conveyor operation is sequential. If one flight of a system fails to operate, all inby flights must shut down to prevent pileup of coal and damage to equipment. Cascade start and stop control of a conveyor system is achieved by centrifugal switches similar to slippage control. The cascade control can be extended to belt feeders.

3. Emergency stop controls permit a quick stop from any point along the conveyor line (33). One method is a low-voltage, two-bare-wire control line, suspended along the belt. Pinching the wires together will cause the motor to stop. The other system consists of start-stop switches actuated by pull cords. The cords are strung along the belt. If the cord is installed above the conveyor, a roof fall will actuate the switch and stop the belt before any more harm is done.

4. Test run and jogging provisions in a multiple conveyor system serve to bypass controls, such as material pileup or slippage protection and

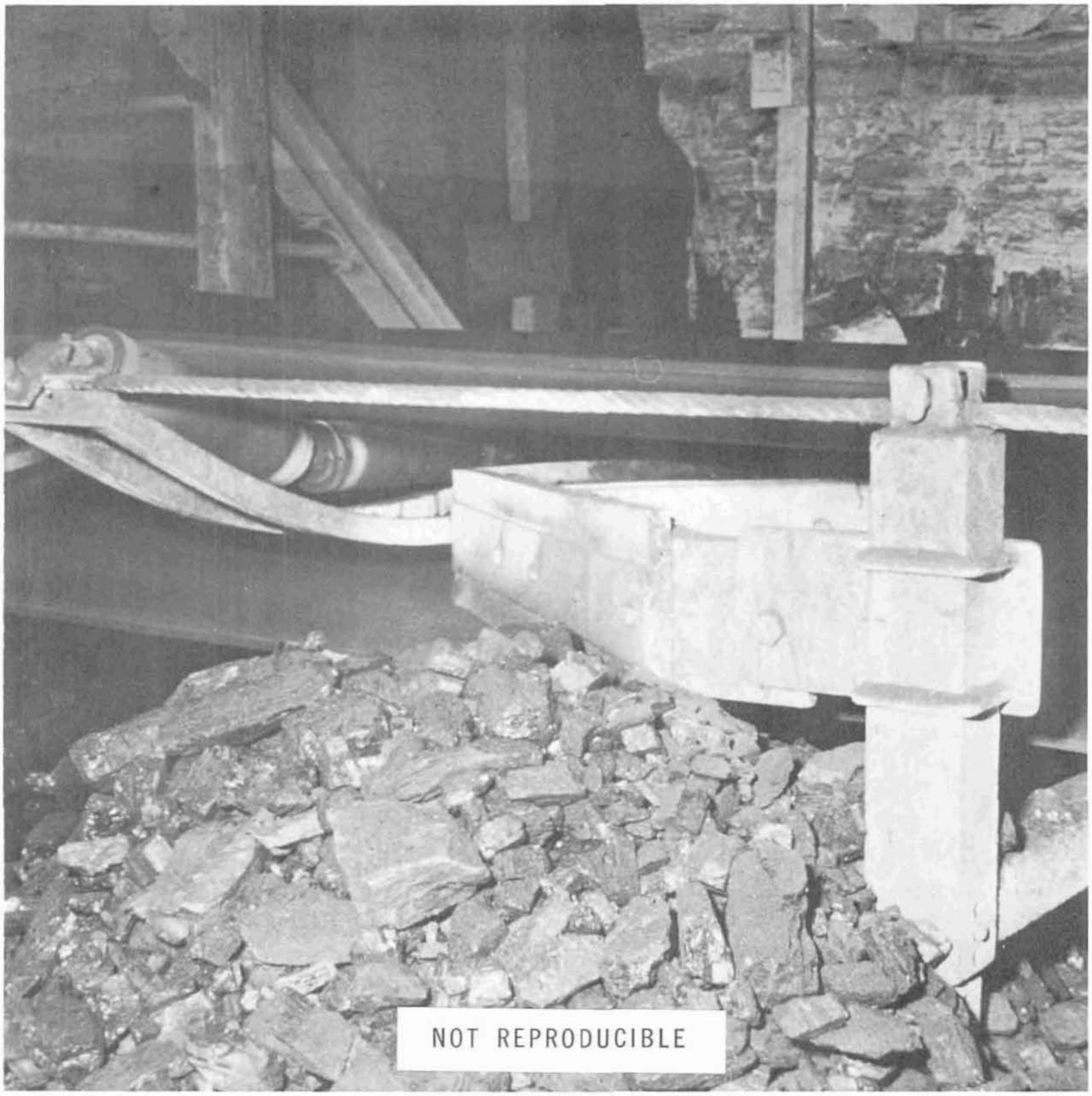


FIGURE 21. - Plow Outby Tailpiece.

sequence control, to operate a flight separately in an emergency (33). A piece of slate may be hung up in a chute, and the belt operator may be able to move it by jogging the belt.

5. Material pileup protection is provided at transfer points where chutes get clogged by oversize material or where the material flow from several panel belts must be regulated to avoid overloading of gathering belts. Load-sensing devices such as free-swinging paddles actuate momentary control switches to shut down the inby belt and to restart it after the pileup is cleared (fig. 22).

FIGURE 22. - Pileup Control by Load-Sensing Switch.

However, such emergency stop controls may cause electric arcs or sparks in the dust-laden atmosphere at the transfer points. Therefore, a protective system that uses load-activated centrifugal switches to control the material flow well in advance of a congestion is preferable.

6. A belt-piercing control will stop a belt immediately if a sharp metal object pierces the belting (57). The tripping mechanism, a free-swinging rod, will actuate the belt stop switch when the metal object strikes the rod.

7. Protection against misalinement consists of limit switches installed at either side of the belt at the terminal and takeup assemblies (19). They are triggered by contact with the edges of the swerving belt and stop it to prevent further excessive sideways wander and eventual edge wear.

8. Backstop or holdback controls apply brakes to prevent reversals of inclined belts in the event of power failure. Declining belts can be controlled by dynamic braking; ac motors, if run above synchronous speeds, will act as retarders; dc drives have to be equipped for regenerative braking (33). On the flights of one main-line haulage system where varying grades pose a problem, the drives are equipped with brakes or flywheels to control the coasting distance of each flight after a shutdown (57).

9. All motors must be provided with overload controls. Some main-line drives are protected also by motor temperature controls to warn against excessive temperatures in wiring as well as in bearings and eventually to trigger a shutdown (57).

10. Thermal warning relays are available with transducers which sense the temperature of the belt as it passes over the drive pulley.

Remote Supervision

Telemetric, multifrequency systems remotely monitor and control belt conveyors over a single pair of wires. The system can be preselected either to just warn or to stop the conveyor. Signals of different frequencies are transmitted from each transfer point to the indicator cabinet of a central console for each of eight possible conditions (42):

Power on/off.
Motors overheating.
Bearing temperature high.
Chutes clogged.
Fire or smoke.
Belt misalinement.
Rock fall.
Belt running.

A pilot light at the console designates each condition and transfer point. In turn the operator can transmit signals from the console to override most belt controls and to start and jog the belt out of sequence when he desires to correct a condition; for example, a clogged chute. Local control consoles at each transfer point also display the warning lights and the central operator can contact conveyor patrol men by telephone to check on the malfunction of the system.

Monitoring by closed-circuit television also has proved effective (57). Television cameras are placed at transfer points (fig. 23). They view the chute and an indicator panel, similar to those described above, where flashing lights indicate various sources of trouble.

Safe Practices in Conveyor Belt Operation

Electric equipment and circuitry should be installed and maintained according to the standard rules for adequate capacity and overload, circuit, and low-voltage protection. Separate frame-grounding circuits for conveyors are recommended in preference to the unbonded conveyor structure (19). In dust-laden atmospheres the motors and controls, such as centrifugal switches, shall be of explosion-proof design, and permissible equipment shall be used in the face area of mines classified as gassy.

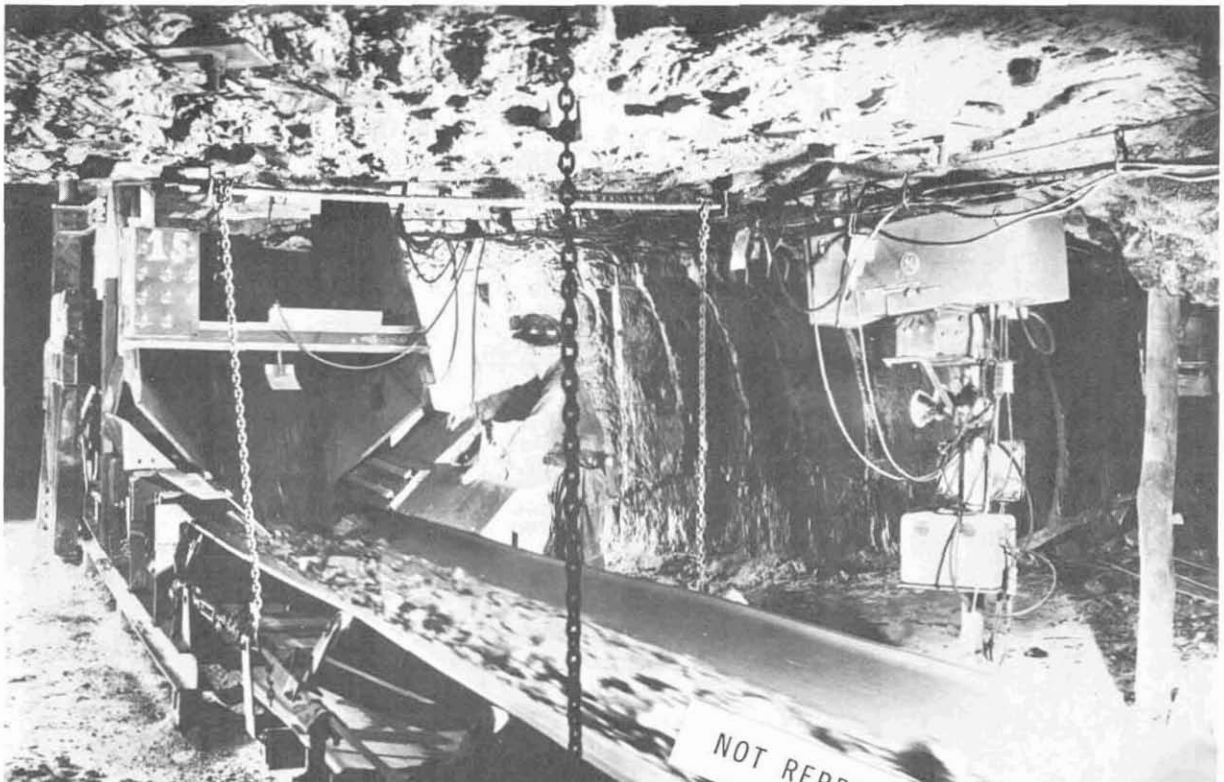


FIGURE 23. - Transfer Point With Indicator Panel and TV Camera.

Power wires should not be installed in belt entries (88). But if this is necessary, they shall be insulated adequately, supported on well-installed insulators, fully protected against mechanical injury, and, if possible, should not pass over the belt (43). Use of fire-resistant belting, approved under Bureau of Mines Schedule 28, is recommended for all underground conveyors. Roof support, preferably by roof bolting, should be kept adequate to prevent roof falls on the belt. Accumulations of coal and lubricants spilled along the belt should be removed immediately (19), and belt entries should be rock dusted periodically. The coal should be sprayed with water at all transfer and discharge points. The sprays may be controlled by load-activated switches (18) (fig. 24). A wetting agent added to the water will allay coal dust more effectively. Well-designed chutes and low air velocities will help to control float dust.

Water mains of 2- to 4-inch diameter, carried along the belt lines, offer the most effective fire protection. Valved outlets with fittings for attaching 1-1/2-inch firehose should be no more than 200 to 300 feet apart (28). Fire extinguishers and rock dust should be kept close to the belt heads and tail sections.

Belt entry ventilation should be controlled to prevent excessive suspension of coal dust in the air and to permit the isolation of the belt in the event of fire. The laws of several States prescribe that ventilation of

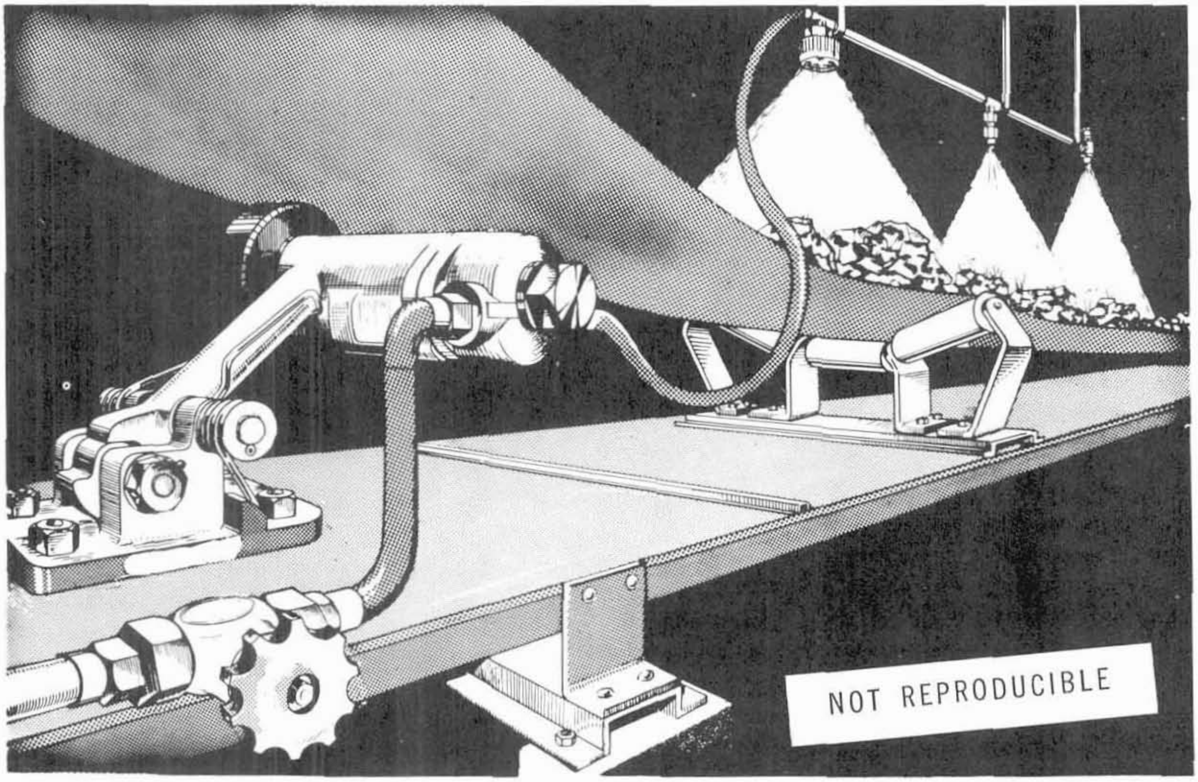


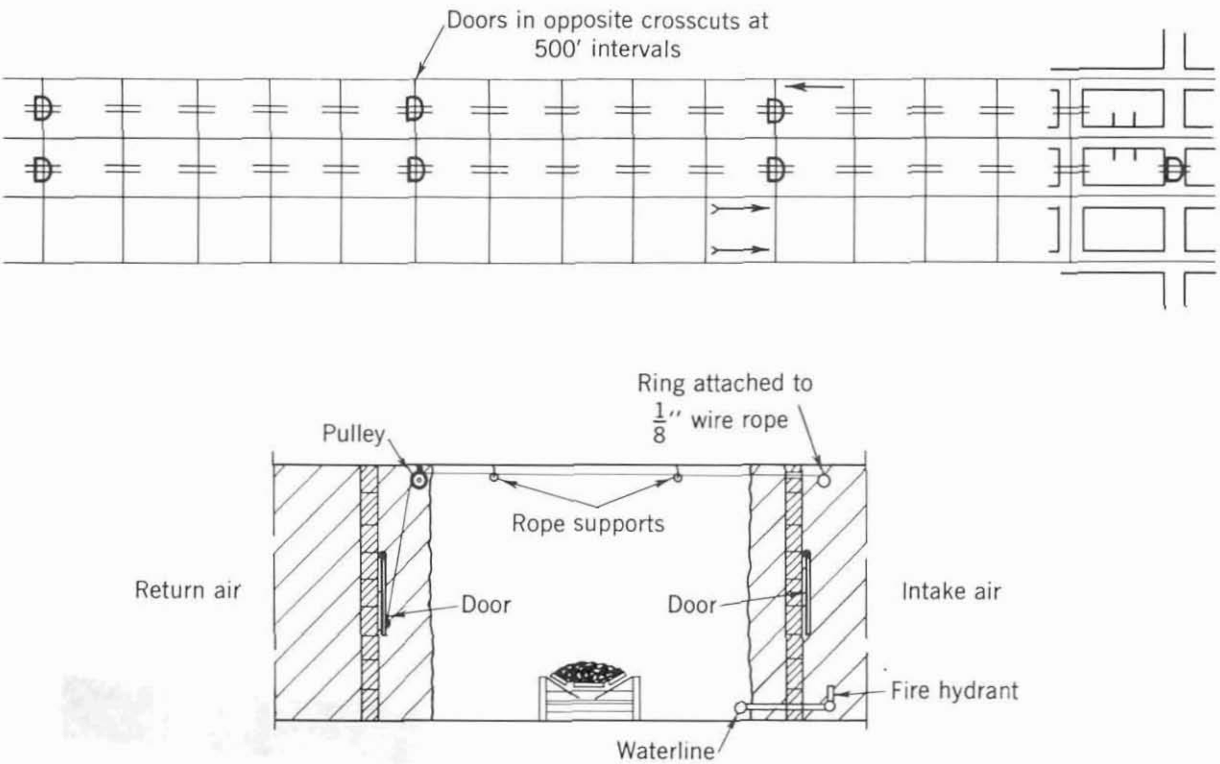
FIGURE 24. - Diagram of Load-Activated Water Spray.

entries where rubber belts are installed shall be as follows: Three or more entries shall be driven and the belt shall be placed on a separate split of air. Permanent stoppings shall close the breakthroughs between the belt entry, return entry, and intake entry, and man doors shall be placed at intervals of no more than 500 feet. Air ventilating the belt entry shall pass directly into the return air course (43, 50). The Bureau recommends the belt ventilation plan and the arrangement of short circuiting the ventilation in the event of a belt fire, shown in figure 25 (97).

Horizontal or vertical track- or trailer-mounted, motorized belt winders are convenient to handle belting for installation and recovery. Only crews trained in safe installation procedures and the use of suitable equipment should handle belting and conveyor components and set up, aline and train, or tear down belts (43).

The belt men who maintain and lubricate the conveyor components should patrol the belts regularly. They should check for frozen idlers, belt misalinement, clogged chutes, damage to belting or chutes, defective splices, and excessive spillage and correct the conditions immediately.

Suitable protected crossovers should be provided where men are required to cross conveyor lines regularly (20) (fig. 26).



DETAIL OF DOOR OPERATION

FIGURE 25. - Belt Ventilation.

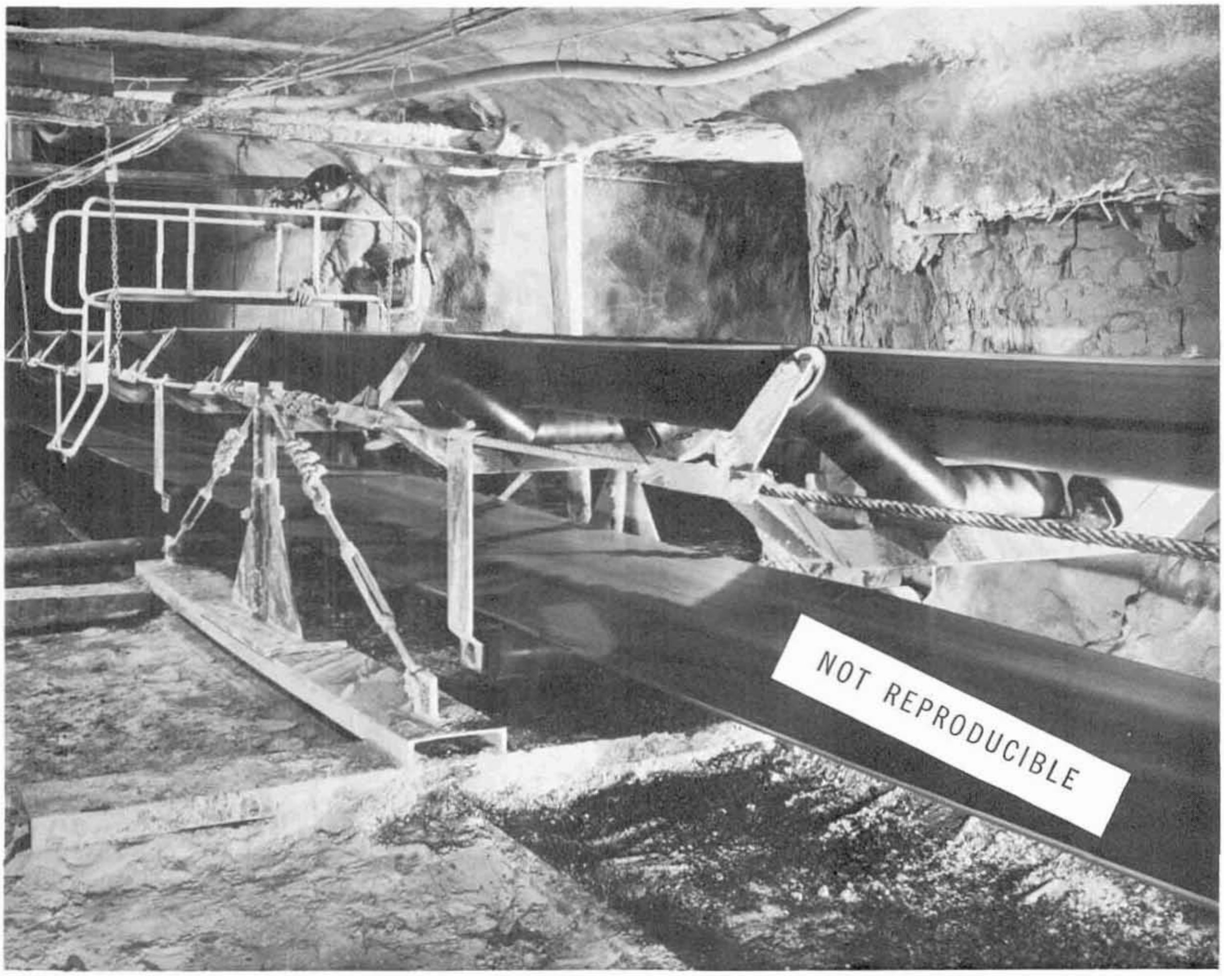


FIGURE 26. - Belt Crossover.

Man Transportation

Main-line belts are reversed in few and mostly smaller operations to carry men and supplies back to the face. Secondary belts are reversed and used for man transportation more frequently, particularly where steep grades and other adverse conditions forbid tracked or trackless transportation of men and supplies to the face. Variable speed controls or two-speed motors are used to slow belts to a riding speed safe for men. The Bureau of Mines recommends the following procedures for man transportation on belts (20, 43):

1. An area of belts where men are riding shall be free of loose coal and rock, and a minimum clearance of 18 inches shall be maintained between the belt and roof or crossbars, projecting equipment, cap pieces, overhead cables, wiring, and other objects; but where the height of the coalbed permits, the clearance shall be not less than 24 inches.

2. The belt speed should not exceed 250 fpm, while men are loading or being transported.

3. The space between men riding the belt shall be not less than 5 feet.

4. Ample unobstructed clearance, proper illumination, and belt control switches shall be provided at loading and unloading areas. An official or a responsible person designated by him shall be in charge when men are boarding or leaving belts.

5. Ample unobstructed side clearance, at least 24 inches, should be maintained along the belt lines.

6. Emergency belt stop lines should be strung along the belt line in easy reach of riders.

7. Warning lights or signs should be placed ahead of unloading stations or stoppings.

TRANSFER STATIONS

Thirty-six fatal accidents occurred during 1956-66 at points where coal is transferred from one type of transportation to the other. The following types of transfer stations were involved:

TABLE 7. - Fatal accidents at transfer stations, 1956-66

	Frequency
Type of transfer station:	
Mine-car loading points including shuttle-car ramps, elevators, and belt heads......	24
Automatic loading station (belt head)......	1
Swinging-boom, transfer-conveyor loading point for rubber-tired trailers...........	1
Shuttle-car dumps at belt tailpieces.......	2
Shaft and belt slope bottoms...............	5
Surface coal stockpile above reclaiming facility................................	1
Small mine dumping points on the surface...	2

It is significant that 16 of the 24 accidents at loading points occurred in the earlier period 1956-60. Mine-car loading points are moved frequently and often installed hastily with sharp curves and substandard track. Also, the control of cars on grades is hazardous. Recent technological advances such as well-installed belt-head loading stations, some of them automatic, and better car control by hydraulic car hauls and retarders have brought the number of fatal accidents at loading points down to eight during 1961-66. Most accidents at loading points happened when loaded cars were pulled off or empty cars were spotted particularly on grades. Some victims were caught and crushed against the rib by derailed cars. Others were crushed between the shuttle-car boom and the rib when mine cars contacted the boom and slewed it over. The most frequent unsafe acts are given:

TABLE 8. - Unsafe acts causing fatal accidents at loading points, 1956-66

	Frequency
Failure to give warning signals and to check the loading points before changing cars	12
Leaving shuttle cars parked on ramp	4
Leaving spotting hoists in gear	4
Failure to use enough skids	4

Accidents at shaft and slope bottoms were caused by poor control of loaded trips. Trips were not blocked securely when locomotives were uncoupled and drifted toward the dump, squeezing attendants between the car and dump. In one case the braking power of the locomotive was not adequate to hold the trip.

Figure 27 shows an automatic belt-head loading station. There are two sets of controls: car loading and car change controls (33). The loading

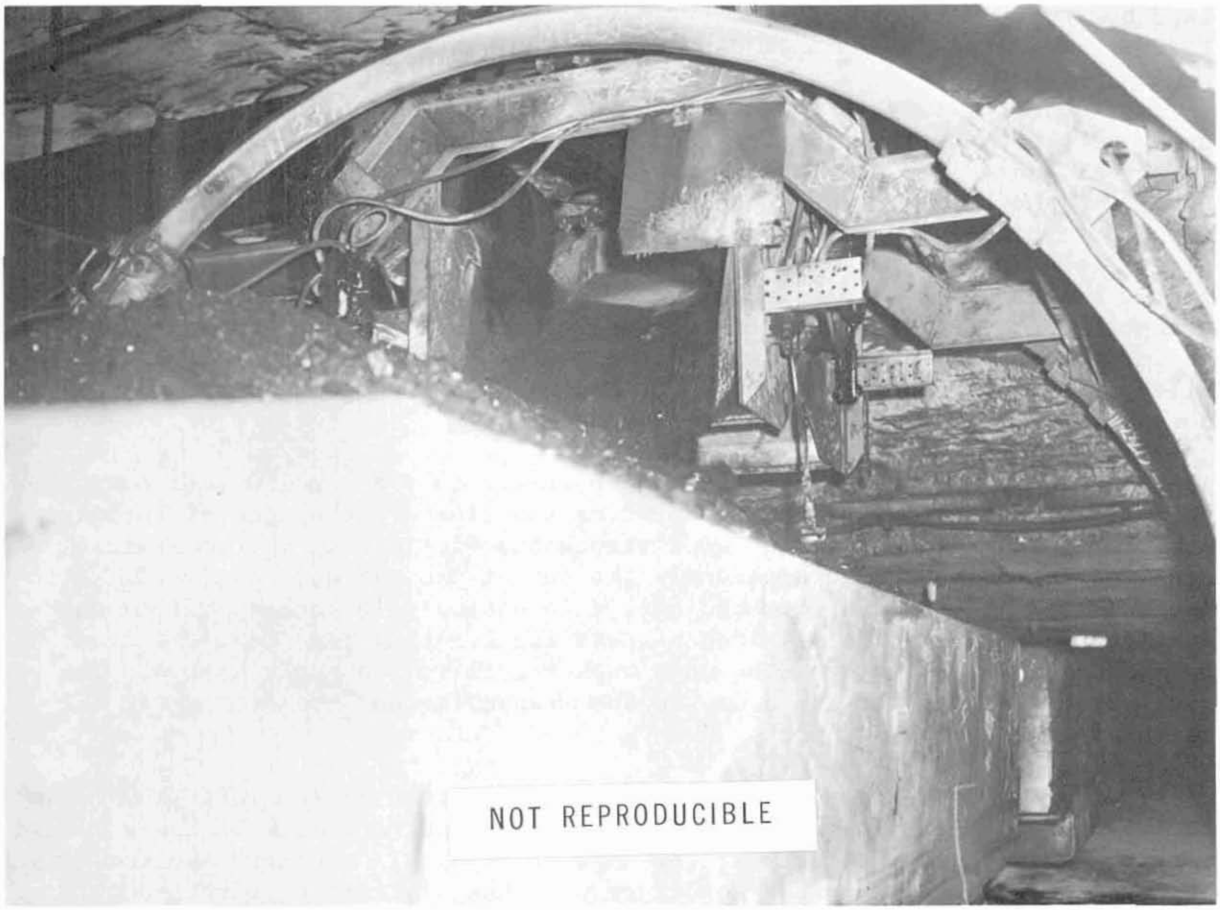


FIGURE 27. - Automatic Loading Station: Paddle Controls.

controls are paddles riding the surface of the coal in the car. They advance the car when the material in it has built up. The car change controls cause the flow of material to be diverted into the next empty when the car being loaded has been filled.

HOISTING

Accident Experience

Hoisting accounted for 12 fatal accidents during 1956-66. Six of them occurred in slopes, one on a surface incline, three during shaft sinking, and two in vertical shafts. Tracked slopes for hoisting coal are vanishing; all newer slopes are belt slopes. It is significant that all fatalities in coal slopes fell into the earlier period 1956-60. Two of the victims were trip riders who are exposed to serious hazards. They were killed when they struck crossbars under low clearance. In another case, a hoist rope caught on the center guardrail of a track switch, came loose, and whipped around to strike a maintenance man walking in the slope. Tapering the center rail or concreting the switch would have eliminated the hazard. Another time a coupling pin broke when empty cars were lowered in a slope. Six runaway cars entered the slope bottom and struck a locomotive parked near the switch. The motorman was killed. Had he parked on a side track, he would have been safe.

In the more recent period 1961-66 two fatal accidents occurred in men and supply slopes of belt slope mines and one on a surface incline. In one case a draft gear and a 7/8-inch safety rope clamped to the couplings of all cars broke, and the runaway trip knocked the timbering out in the slope bottom supply yard. This caused a roof fall and the victim was caught under it. In another case an inexperienced hoisting engineer lowered a trip at high speed without braking. The armature of the hoist motor flew apart and a piece struck the engineer. Another time a rope broke in a surface men and supply incline. A supply man riding the trip with the supplies jumped off and was killed. The rope had worn through from rubbing the edge of a concrete wall where an idler should have been installed.

In one shaft-sinking accident the shaft was only about 150 feet down when the full muck bucket swung during hoisting and ripped out pieces of toeboard from the dumping platform. The wood struck the victim down in the shaft. There was no crosshead and apparently the bucket was not well centered. Also the clearance between platform and bail axle was only 10 inches. In another instance the failure of a 3/4-inch nonrotating hoisting rope cost the lives of two men who were struck when the muck bucket fell to the shaft bottom. The hoist rope, too long for the drum, became wrapped around the drum shaft and was cut in two by the drum key.

The victim in a shaft hoisting accident was cleaning the shaft sump when the hoisting engineer lowered the cage on him without signaling. There should have been an attendant on duty at the cage station. In another case the hoisting engineer climbed up on the headframe when the platform of a self-dumping cage did not completely return to the horizontal position after dumping. The cage suddenly tilted under his weight and squeezed him between the cage and headframe. There was no walkway on the headframe.

Although relatively few hoisting accidents did occur, the potential always exists; for example, rope failure accidents during man hoisting could reach catastrophe dimensions. Failure of all six ropes of a portal elevator caused minor injuries to the only rider when the safety device brought the car to a stop after a 16-foot drop. It appeared that interior corrosion had attacked the ropes. There was little reduction of rope diameter; a grease cover obscured rust on the rope surface. The ropes had been in contact with the counterweight suspension sheave most of the time because the cage automatically returned to the top when not in use. In this position the ropes were exposed to corrosive drip water which gathered inside the counterweight sheave guard. The ropes had been in service for 6 years and the manufacturer's specialists had failed to discover their deterioration on their weekly inspections. Nondestructive rope testing may prevent similar accidents.

Skips and Cages

Elevator shafts serve as mine portals in numerous coal mines. Shaft mines where coal is hoisted to the surface have been relatively few; in recent years some have been opened to extract deeper lying coalbeds. In most American shaft mines the coal is hoisted from a single level. The typical coal hoisting plant had self-dumping cages with endgate mine cars. When men are riding in them, these cages have to be securely latched to prevent tilting (20). Skip hoisting has been accepted by the coal industry whenever degradation of the run-of-mine is no longer a consideration. Men and supplies are then handled in skip and cage combinations or by separate service cage hoists. The latest deep shafts have tower-mounted multirope Koepe hoists (fig. 28).

Modern skips have guillotine-type dumping doors which can be opened only by a pneumatic door opener mounted in the headframe (28). Skip door operation is interlocked with the hoist so that the hoist cannot operate as long as the door is open. Some skips carry inside platforms for emergency man hoisting. These platforms are made up of two hinged halfs which are raised and kept latched to the inner skip sides during production hoisting (28).

Single or multideck cages are used for man transportation. They should be equipped as follows (103):

1. Sides, safely enclosed to at least 6 feet of height from the floor.

2. Enough handholds for the permitted number of riders.

3. Gates which do not let a man or any object roll off the cage.

Some modern cages for carrying men and supplies are 35 feet high and designed to carry heavy and long items within the cage. This eliminates the hazardous and time-consuming practice of swinging bulky equipment under the cage. When such material must be handled, the two hinged halves of the cage's bonnet are raised and latched aside. Then a 20-ton hoist, mounted in the upper crosshead of the bail, is energized. It picks the item up by a swivel hook and holds it suspended in the cage for a safe ride into the mine (28).

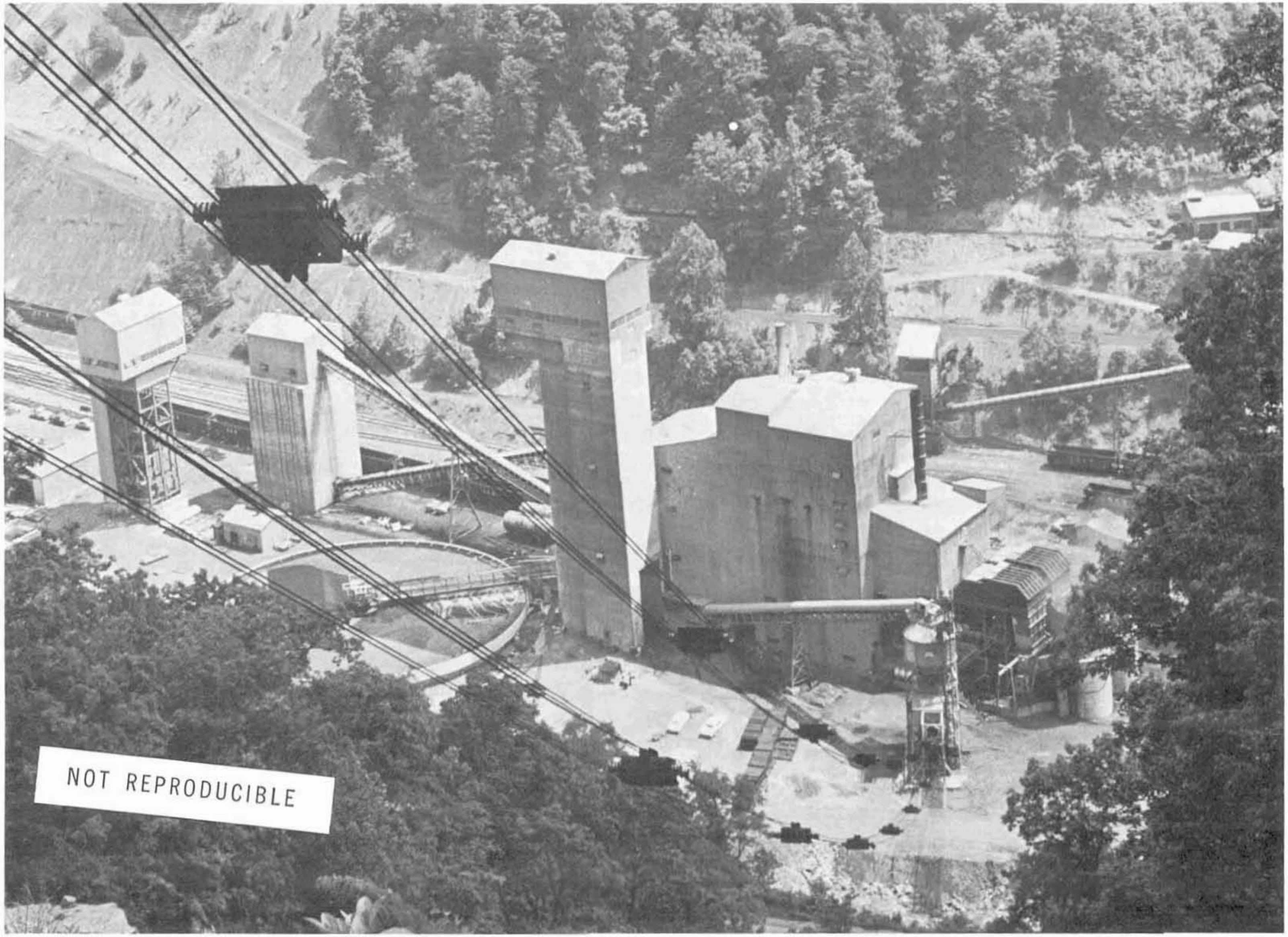


FIGURE 28. - Koepe Hoist Towers. Left: Man hoist; center: coal hoist.

In a production shaft which has recently been put into service, an emergency escape system, consisting of a hoist with an eight-man cage, takes the place of a stairway. A diesel motor-driven auxiliary plant stands by to power the 75-hp ac hoist in the event of a power failure (38).

Headframes

Headframes are built of reinforced concrete or steel. Koepe hoists are often placed in towers above the shaft. The height of the headframe is determined by the height of the conveyance including the suspension gear, plus the height of the dumping point or top landing above the ground, plus a safety margin for overtravel of 1 to 1-1/2 times the circumference of the hoist drum or sheave according to the hoisting speed (64).

Shafts

Most new shafts for coal mines are circular and are lined with concrete to offer minimum resistance to the ventilation current and maximum strength against ground stresses. Timber sets, wood buntons, and lagging of older shafts have to be treated for fire resistance (43). It is most important to effectively seal shafts against water inflow, because ice accumulation is a severe hazard to hoisting. Therefore, cement or chemical grout is injected into the water-bearing strata either prior to sinking or in an effort to seal existing shafts. Buntons at 6- to 10-foot intervals separate shaft compartments and serve as backing to the guides. The stairways or ladderways should be guarded by screens against falling material, and air, water, and electric lines should be secured to the shaft walls and protected against being bumped by conveyances (103). A runaround of ample unobstructed cross section at all shaft stations shall permit easy passage from one side of the shaft to the other (20). Screens that shield shaft bottoms from falling material are often hinged so that they can be lifted aside when long objects are handled (43).

Access to the shaft at surface landings shall be fenced or screened off, and gates at all landings should be self-closing and kept closed unless the cage is at the landing. Derails or stopblocks in the track leading to shaft landings keep runaway or accidentally pushed cars from crashing through the shaft gate and dropping into the shaft (20).

Man Transportation Through Shafts

A qualified hoisting engineer shall be always on duty where men are regularly transported and while any person is underground except for automatically operated cages (20).

Cagers shall be in charge at the surface and at all other shaft stations at the beginning and end of each shift when men are hoisted or lowered, unless a competent attendant rides the cage (20). The cager shall have the following duties:

1. Admit no more than the approved number of riders per cage and maintain order when the workmen enter or leave the cage.

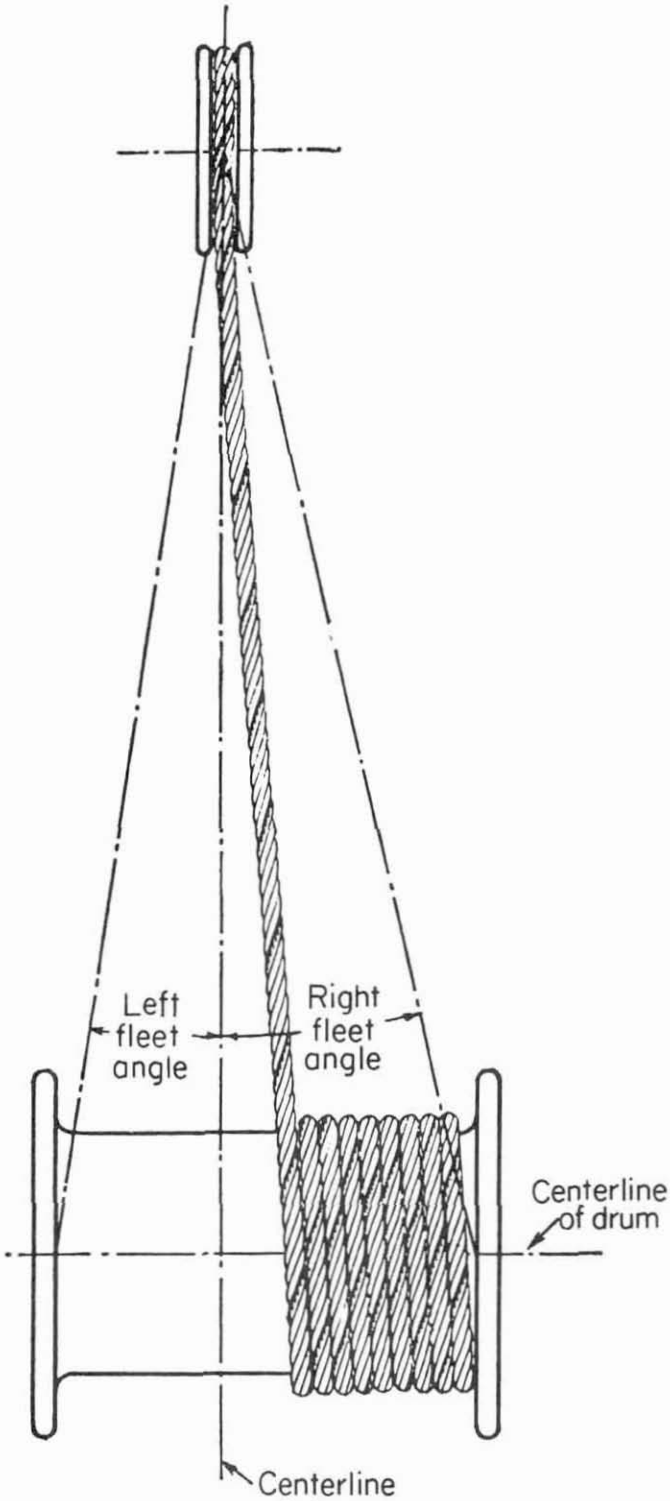


FIGURE 29. - Fleet Angle.

2. Give the proper signals or operate the elevator cage.

3. See that cage and shaft gates are in proper position.

A suitable location securely sheltered from moving mine traffic and with ample seating space should be available to workmen waiting for man trips or man cages (20).

Drums and Sheaves

Single-drum hoists are best used for conveyances in balance. Double-drum hoists with drums clutched allow multilevel hoisting. Brake and clutch must be interlocked so that a loose drum is always held by the brake. Grooved drums permit better spooling and are recommended for multilayer winding. Figure 29 explains the fleet angle. It should not exceed 1-1/2° or a lead of 40 feet per foot of fleet across the drum in order to keep the rope from rubbing against the head sheave flanges and minimize the rope's grinding, turn against turn, on the drum. The minimum limit of the fleet angle for multilayer winding is 1/2° to insure the starting back on the next layer (7). Drum flanges should extend at least 4 inches above the rope when maximum rope is on the drum. Grooves of drums and head sheaves should be machined and reconditioned to proper contour and diameter to support the rope and minimize abrasion of both rope and groove. Smooth drums should be maintained free from worn spots. In order to protect the rope from harmful bending stress, the minimum ratio of drum diameter to rope diameter, D/d, considered satisfactory, is 60 for round and flattened strand ropes and 80 for locked coil ropes (84).

A minimum of three dead turns shall remain on the drum when the rope is extended to its maximum distance. The rope shall make at least one full wrap on the drum shaft or around the spoke of the drum (in case of a free drum) and its end shall be fastened securely by clamps (20). The three wraps will reduce rope pull on these clamps to 5.5 percent of the actual rope pull (84).

Koepe Hoist

The rim of the Koepe wheel is grooved to take the hoisting rope and lined with a friction material. The drive is transmitted to the hoist by friction between the rope and groove. The conveyances or the conveyance and counterweight are suspended from each end of the hoist rope. The weight of the hoist rope is balanced with a tail rope fastened to the underside of the conveyance. If the tail ropes are somewhat heavier than the hoist ropes, a slight advantage is given to the hoist when the load is accelerated (28). The arc of contact of the rope with the Koepe wheel depends upon the hoist arrangement. The Koepe hoist, mounted in a reinforced concrete or steel tower directly above the shaft, appears to be the most favored design for efficient use of space, largest arc of contact, and minimum rope vibration. Its advantages over the drum hoist are many: lower first cost, simplicity, protection by rope slip from the hazards of conveyance jamming and overtravel of cage, lighter rotating masses, and, hence, less inertia for acceleration and deceleration (34). This latter advantage is even greater when multirope hoists are used in deep shafts; a single rope would have to be large and its Koepe wheel of large diameter. But in a multirope hoist, several smaller ropes--as many as six--can be wound on a friction sheave of smaller diameter with less inertia and more assurance against rope breakage (fig. 30).

Tail ropes reduce acceleration horsepower and assist in braking. On friction hoists they must be of the nonspinning type, either nonrotating or flat ropes. But the main function of tail ropes is to maintain the proper T_1/T_2 ratio without which friction hoisting is impossible.

T_1 is the payload + conveyance weight (skip or cage and car) + rope weight per side (hoist and tail rope)

T_2 is the conveyance weight + rope weight per side

$(T_1/T_2)_{stat}$ is the static ratio, and the dynamic ratio is

$$(T_1/T_2)_{dyn} = (T_1/T_2)_{stat} \times \frac{32.2 + a}{32.2 - a}$$ for acceleration and

$$(T_2/T_1)_{dyn} = (T_2/T_1)_{stat} \times \frac{32.2 + d}{32.2 - d}$$ for deceleration

where a = acceleration ft/sec^2, and

d = deceleration ft/sec^2.

The dynamic ratios should be used for investigation of rope slip. Acceleration and deceleration should not exceed 6 ft/sec^2 according to American

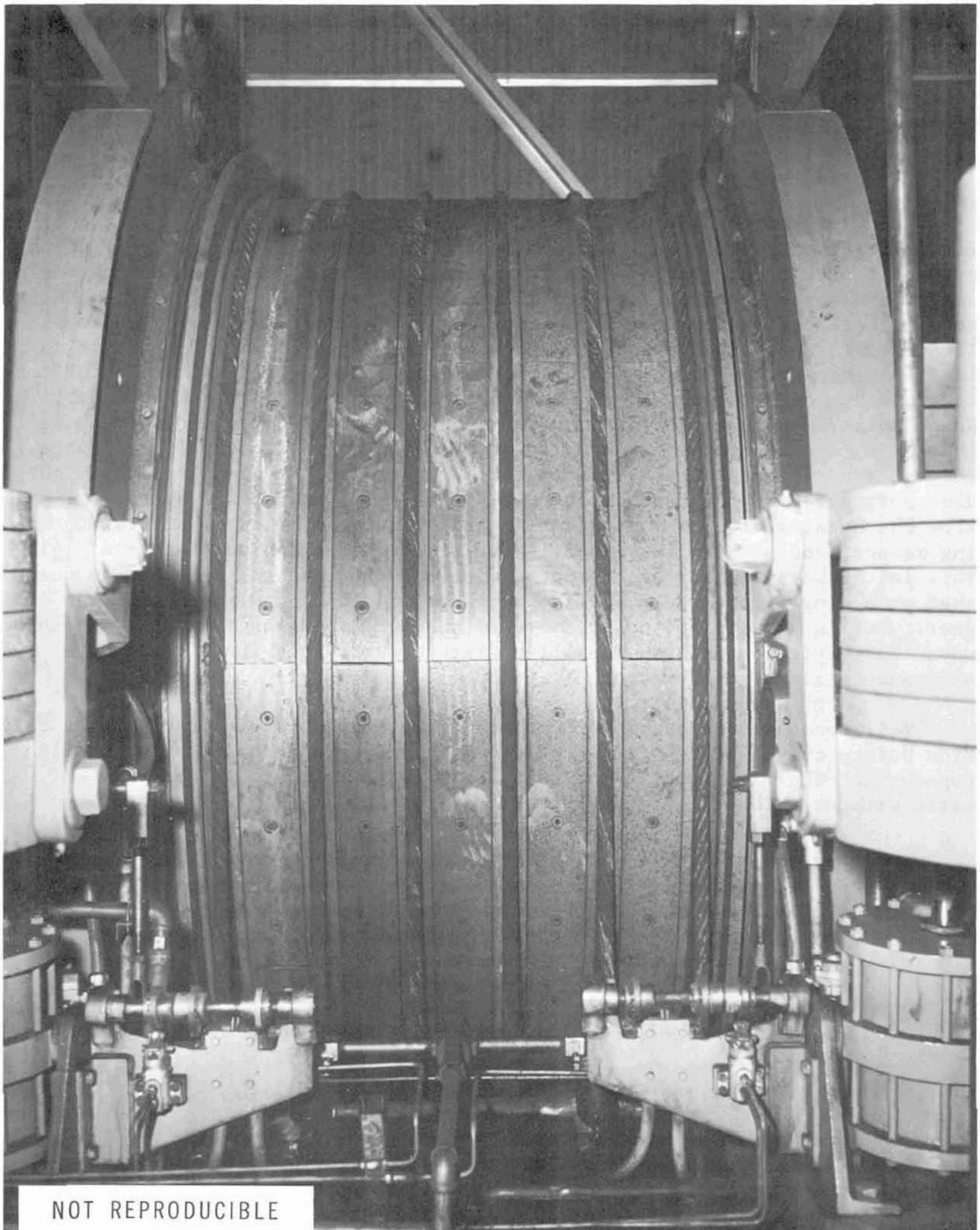


FIGURE 30. - Multirope Koepe Sheave.

Standard Association specifications (7). Rope slip occurs when the dynamic ratios $(T_1/T_2)_{dyn}$ or $(T_2/T_1)_{dyn}$ equal or exceed $e^{\mu\alpha}$

where α = angle of contact (180°-215°) in radians,

μ = coefficient of friction between rope and friction tread of Koepe wheel, and

e = basis of natural logarithm.

Table 9 contains friction coefficients of various tread materials. However, all calculations of slip conditions should be based on a friction coefficient $\mu = 0.2$ which is a conservative figure to minimize any risk of rope slip during normal operation. Table 10 contains calculated critical slip ratios for the coefficients $\mu = 0.2$ and 0.35.

TABLE 9. - Friction tread materials and friction coefficients

Material	Not slipping	When slipping
Wood (elm, poplar, beech)........	0.4	0.2
Bonded fiber......................	0.6	0.3
Plastic..........................	0.6	0.4
Chrome leather, rubber, neoprene.	0.6	0.3

Source: Maerks, J. Bergbaumechanik (Mining Mechanics). Springer, Berlin, 3d ed., 1950, p. 157.

TABLE 10. - Critical slip ratios

Arc of contact	$e^{\mu\alpha}$ Friction coefficients	
α deg	$\mu = 0.2$	$\mu = 0.35$
180	1.9	3.0
190	1.9	3.2
200	2.0	3.4
205	2.0	3.5
210	2.1	3.6
215	2.1	3.7

Source: Reference 53, p. 196.

Rope creep, as distinct from rope slip, is always present due to the elasticity of the rope. This creep cancels out in balanced hoisting. But when alternate trips convey different weights, like conveyance and counterweight, creep is more in one direction than that in the other and the resultant creep is cumulative (36). Then adjustment for creep or slip must be made to the hoist indicator. An automatic synchronizer, actuated by cam-operated or electronic proximity switches in the shaft walls, resets the pointer of the indicator so that it will indicate the conveyance position accurately. This correction is made after each complete hoisting cycle, when the conveyance has come to rest at the top of the shaft.

Standard procedure is to provide the Koepe wheel with renewable rope tread inserts of friction material. These inserts have the form of laminations on edge at right angle to the rope path (53).

Tread pressure is in psi determined by (84)

$$p = \frac{T_1 + T_2}{D \times d \times n},$$

where T_1 and T_2 = rope tensions in lb,

D = Koepe wheel tread diameter in inches,

d = rope diameter in inches, and

n = number of ropes.

Tread pressure should be limited to 250 to 270 psi.

Hoist Drives

While ac drives by geared, wound rotor induction motor are simpler and cheaper than dc drives, they have limited dynamic braking capacity and do not lend themselves well to automatic operation. In high-speed hoisting from deep shafts with duty cycles demanding more than 1,000 rated hp, the Ward-Leonard system, a variable-speed dc drive, is preferred for smooth, stepless, accurate, sensitive, and reliable control. This system permits regenerative dynamic braking at any speed. The movement of the hoisting engineer's control lever corresponds to a certain speed and can be limited by an automatic controller which is required for man hoisting in American coal mines and is used on most production hoists as a valuable assist to the hoisting engineer. The automatic controller is gear driven from the drum or Koepe wheel shaft and can be set by the operator either for production or for man-hoisting speed. By means of a flyball governor, cams, and gears and in conjunction with a solenoid on the brake cylinder which shuts off the power and applies the emergency brake, the controller effects (84):

1. Overspeed control.

2. Overwind control (also may be controlled by limit switches in the headgear).

3. Limitation of acceleration and deceleration to follow the predetermined speed cycle.

4. Emergency stop under these conditions:

   a. Power failure.

   b. Failure of operator to reverse the hoist after the conveyance has reached the limit of travel.

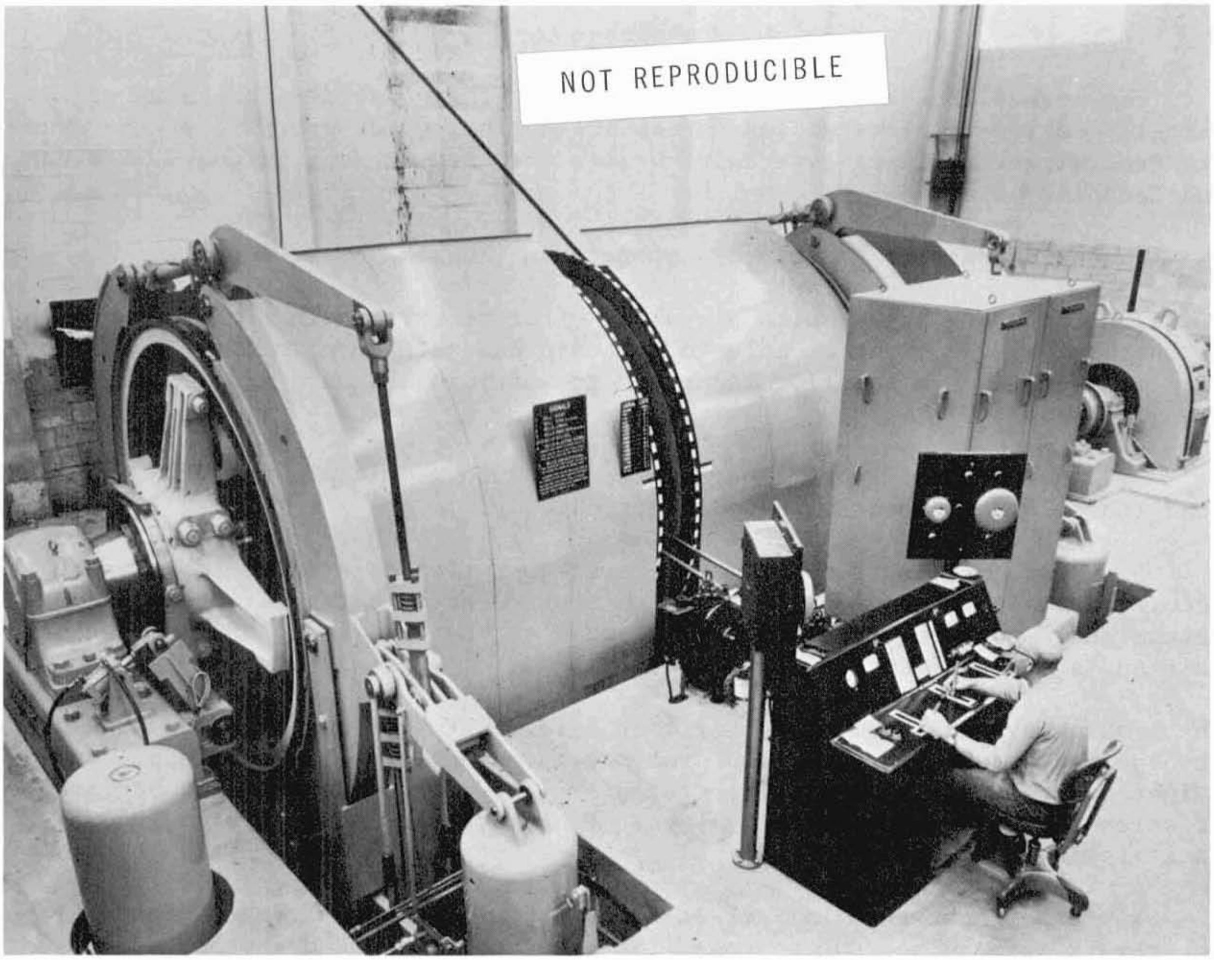


FIGURE 31. - Operator's Console.

The operator's console, usually located in front of the hoist, should be reasonably sheltered so that the noise of other machinery and activity will not prevent the hoisting engineer from hearing signals or otherwise distract his attention (43) (fig. 31). The depth indicator to show the position of conveyances in the shaft and all the signals, pilot lights, safety switches, meters, and gages necessary for manual control are incorporated in the control cabinet in front of the operator. The depth indicator is gear or chain driven from the hoist shaft. All manual controls must be of the dead-man type. Shaft-gate controls keep the gates locked at the top and at all shaft stations when no conveyance is there.

The Ward-Leonard system permits a very reliable automatic or semiautomatic (push-button) control. Automatic operation also incorporates slow speed travel for inspection and a jogging control when it is desired to move the conveyance at creep speed, unless manual control also is provided.

Brakes

The brakes are the most important part of the hoist design. Jaw- or parallel motion-type brakes act on the brake rings which are part of the drum or Koepe wheel. Caliper-type hoist brakes are used at some European, African, and Canadian hoists.

Three separate brake controls operate on the same brake shoes:

1. Operating brake, with a braking effort corresponding to the position of the brake lever, must be able to maintain adequate deceleration, a maximum of 6 ft/sec^2 for man hoisting according to American Standard Association specifications (7).

2. An independent emergency brake must hold a multiple out-of-balance load (threefold in most European countries).

3. Brake priming for automatic hoist operation to stop the conveyance accurately. As the hoist slows down to a creep speed before it stops, a predetermined amount of brake drag is effected so that the final braking can be fast and stopping accurate (84).

The braking system recommended for most hoist installations is defined as gravity applied, gravity primed, and pressure released. The brake is applied by a weight and released by hydraulic pressure. The brakes are actuated by manual or solenoid-operated hydraulic valves. A hydraulic pressure system incorporates following safety devices:

1. Brake operation is fail-safe. If the solenoid of the emergency brake control is deenergized due to power failure, the overwind or overspeed brake weight will drop and thus apply the brake.

2. The speed of braking in an emergency stop is regulated by the automatic controller according to the position of the conveyance in order to obtain a safe smooth stop.

3. A brake wear-limit switch trips the brake when the brake blocks are worn excessively.

4. A brake interlock cuts the power when the emergency brake is applied.

Hoisting Ropes

Ropes of improved plow steel or better grade are recommended for hoisting. Preformed wires prevent twisting and kinking of the rope. Heavily lubricated bright hoisting ropes are preferred to galvanized ropes where corrosive conditions prevail. Figure 32 shows sections of various types of hoisting ropes.

Right lay or left lay depends on whether the strands of the rope rotate to the left or to the right while receding from the observer. Right lay is standard. An ordinary lay rope has the wires twisted in the direction

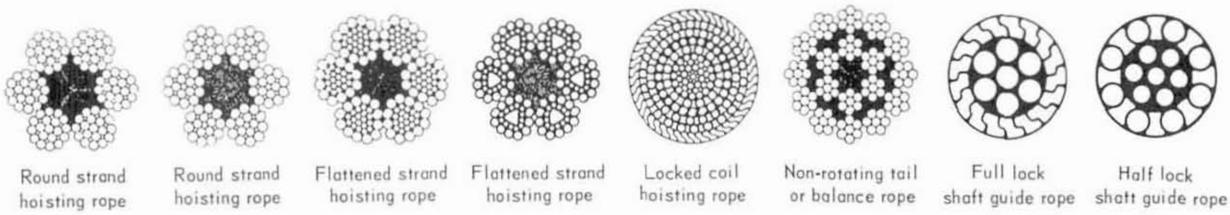


FIGURE 32. - Types of Hoisting Rope.

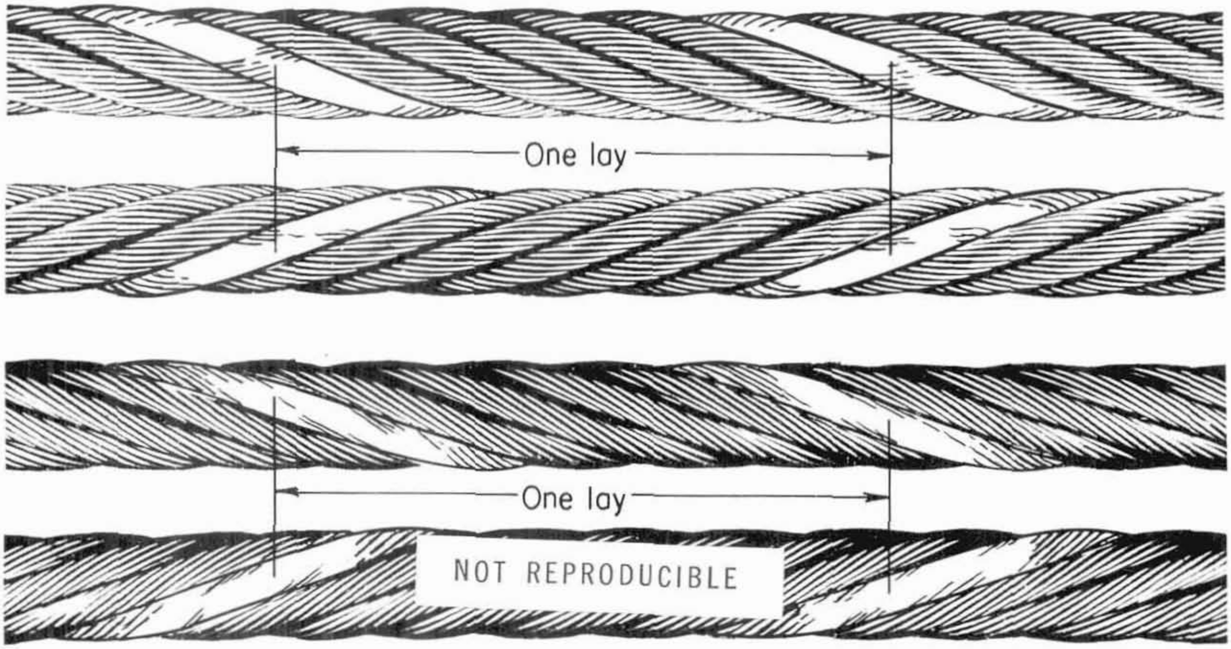


FIGURE 33. - Lay of Rope. Above: Regular right, left lay; below: lang right, left lay.

opposite to the twist of the strands. The langlay rope has the wires twisted in the same direction as the strands. Its outer wires run diagonally across the axis of the rope and are exposed for longer length than those in an ordinary lay rope. Langlay ropes offer better abrasive resistance and greater flexibility than ordinary lay ropes. They are preferred as hoisting ropes, but tend to untwist unless preformed (fig. 33).

Flattened strand ropes are langlay ropes which are designed to give a greater wearing surface than round strand ropes and yet are as strong and flexible. Nonrotating ropes are composed of two layers of strands. Six inner strands are langlay, left lay, and 12 outer strands are regular, right lay. The nonspinning characteristic of these ropes make them suitable for tail ropes in friction-type hoist installations and as hoist ropes for shaft-sinking buckets. Locked coil ropes are assembled of preformed wires in layers of alternate lay about a wire core. They are smooth, wear-resisting, nonspinning ropes serving as track cables for aerial trams and as rope guides. They are recommended as hoist ropes in shafts equipped with rope guides.

Rope diameters are correctly measured between crowns of strands. Table 11 presents some general wire rope data; table 12 gives minimum safety factors suggested in the American Standard Association specifications (7). The rope safety factor is the ratio of the nominal rope breaking strength to the total static load. The Federal Mine Safety Code limits the maximum speed for man hoisting in coal mines to 1,000 ft/min (20) and the American Standard Association specifications hold the recommended maximum acceleration and deceleration for man transportation to 6 ft/sec^2. Reduction of the safety factor in deeper shafts is permitted because the longer the ropes are, the more rope elastic stretch is available to absorb shocks from sudden braking or from slack rope (98).

TABLE 11. - General wire rope data

Diameter, inches	Round strand, 6 X 19 class improved plow steel		Flattened strand, 6 X 27 type H, 6 X 30 type G		Locked coil, improved plow steel		Diameter, inches
	Weight, lb/ft	Breaking strength in tons of 2,000 lb	Weight, lb/ft	Breaking strength in tons of 2,000 lb	Weight, lb/ft	Breaking strength in tons of 2,000 lb	
3/4	0.95	23.8	1.01	26.2	1.37	35.0	3/4
7/8	1.29	32.2	1.39	35.4	1.87	46.0	7/8
1	1.68	41.8	1.80	46.0	2.43	61.6	1
1-1/8	2.13	52.6	2.28	57.9	3.30	76.1	1-1/8
1-1/4	2.63	64.6	2.81	71.0	3.75	92.0	1-1/4
1-3/8	2.18	77.7	3.40	85.5	4.78	115.0	1-3/8
1-1/2	3.78	92.0	4.05	101.0	5.65	135.0	1-1/2
1-5/8	4.44	107	4.75	118	6.88	155	1-5/8
1-3/4	5.15	124	5.51	136	7.56	182	1-3/4
1-7/8	5.91	141	6.33	155	9.00	212	1-7/8
2	6.72	160	7.20	176	9.77	240	2
2-1/8	7.59	179	8.13	197	-	-	2-1/8
2-1/4	8.51	200	9.10	220	-	-	2-1/4

Source: Reference 84, p. 7.

TABLE 12. - Minimum safety factors for man transportation

Length of rope in shaft, feet	Minimum factor of safety, new rope	Minimum factor of safety when rope must be discarded
500 or less	8	6.4
500 to 1,000	7	5.8
1,000 to 2,000	6	5.0
2,000 to 2,500	5	4.3
2,500 to 3,000	5	4.3
3,000 and over	4	3.6

Source: Wire Ropes for Mines. ASA M11.1 - 1960 (7).

Rope diameter in inches can be determined as follows (84):

$$d = \sqrt{\frac{\dfrac{L + C}{\dfrac{K_1}{S} - K_2 \times D}}{n}} ,$$

where L = payload in tons,

C = conveyance weight, cage, and car or skip in tons,

S = safety factor,

D = depth of shaft in feet,

K_1 = coefficient for rope breaking strength in $\frac{tons}{in^2}$,

K_2 = coefficient for rope weight in $\frac{tons}{in^2 \times ft}$, and

n = number of hoisting ropes (multirope hoists).

K_1 and K_2 for different types of rope are as follows:

	K_1	K_2
Rope type:		
Round strand...........	41.8	0.00084
Flattened strand.......	46	0.00091
Locked coil............	61.6	0.00122

The safety factor S is based on the total static load of loaded skip or cage and rope weight from head sheave to conveyance attachment. However, the total load on a rope is composed of the static and dynamic or acceleration load while other loads such as guide friction, rope bending stress, compressive stress between wires, and windage are mostly negligible. An addition of 5 percent for rope speeds below 500 ft/min and of 10 percent for rope speeds from 500 to 1,000 ft/min may account for the dynamic load. The dynamic load in pounds for higher speeds is determined as follows (7):

$$F = \frac{W}{32.2} \times a$$

where W = total static load in lbs, and

a = acceleration in ft/sec^2.

The dynamic load is added to the static load to obtain the total load on the rope.

Lubricants are applied to ropes during manufacturing. They must be sufficiently fluid to insure their migration between the wires while the rope is in operation. But they should be viscous enough that they will not exude to the outside of the rope. Also they should be miscible with lubricants that the mine operator will apply in service (7). Relubrication of the rope in service should be done at suitable intervals. Ropes exposed to corrosive mine water require more frequent applications. Ropes in friction hoist installations are treated with a special resinous lacquer. It is applied hot to the rope at frequent intervals and serves to retain the inner lubricant, to prevent the ingress of moisture and to act as an antislip medium (53).

Either sockets or solid cast thimbles are attached to the rope ends. The procedure of socketing is spelled out in the American Standards specifications and other sources (7, 22, 41, 43). Only high-grade zinc according to ASA specifications for slab zinc, ASTM 24.1 - 1949, should be poured. The pouring temperature of 900° to 926° F must be maintained and accurately measured by pyrometer to prevent annealing the wire if the zinc should get too hot. The finished socket should have 100-percent breaking strength of the rope, but may have a poor resistance to vibration and variable stress. Rope-end attachments by solid steel cast thimbles and clips develop about 80 percent of the rope breaking strength, if clips of the correct size are applied properly.

As an added safeguard for man hoisting, two bridle chains or cables are secured to the rope at least 3 feet above the socket or thimble and to the cross piece of the cage or man car (20). It would appear that a compensating suspension gear would be needed on the ropes of multirope installations to equalize the tension caused by uneven stretch. However, from experience gained in service it became universal practice to connect each rope directly to the conveyance and to insert load cells as a check on rope tensions. The tensions can be equalized by appropriate adjustment linkage incorporated into the suspension gear.

Ropes are tested before they are put into service to assure that quality and safety factors are up to specifications (13). Results of these before-service tests can be compared with those in-service tests during the life of the rope. In-service tests are performed on specimen cut off periodically. They serve to predict the life of the rope. This type of test, however, cannot be carried out on friction hoists. Examination of discarded ropes will reveal the causes of deterioration. The American Standard Association specifications recommend frequent examination of the rope at the end attachments where it is particularly subject to fatigue from vibration and variable stress. If examination of the rope shows a weak spot, the rope should be cut off and refastened. Even if the rope does not show any deterioration, it should be cut off periodically according to a schedule suggested in the ASA specifications (table 13). Also a length of rope 1-1/4 times the drum circumference should be cut off from time to time at the drum fastenings, with the rope pulled through and refastened. This is particularly important for deep shafts where the rope is wound in multilayers and rope contacts should be shifted periodically. Ropes of Koepe hoists cannot be cut off, but the rope contact with sheaves can be shifted by removing or adding plate links at the suspension gear (36).

TABLE 13. - Schedule for cutting rope specimen

Expected life of wire rope, months:	Maximum time between cut offs, months
6	1
8	1-1/2
10 to 15	2
18	3
21	3-1/2
24 to 36	4
Over 36	6

Source: Wire Ropes for Mines. ASA M11.1 - 1960 (7).

The condition of the cut-off specimen shall be reported after the rope is taken apart and carefully examined for broken wires, wear, and corrosion. The Bureau of Mines recommends that a rope be discarded under these conditions (103):

1. Six broken wires are found in any lay.

2. The wires in the crown of a strand are worn to 65 percent of the original diameter.

3. A dangerous amount of corrosion is showing.

4. Three broken wires are found and the cross section of rope is reduced by 30 percent.

5. The rope has lost its resilience; that is, it does not stretch any more.

All rope data should be kept on record. The record should include duration of service, tons hoisted, cutting off and examination of specimen, lubrication, and all observations on wear. Such information may guide the mine operator to assess the conditions and decide if replacement is desirable. Opinions about tolerable rope wear differ widely. The Bureau of Mines recommends rope-life limits as follows (43):

Production hoisting	2-1/2 years
Man and service hoisting	3-1/2 years

Prolonged idleness or irregular operation may modify these limits. Discarded ropes and ropes which failed in service were tested by the Ontario Government cable testing laboratory (13). The tests revealed that serious internal corrosion may exist in many ropes far removed from the conveyance and where the statutory test specimens are cut off. In other words a section of the rope from the conveyance end could give satisfactory results while sections several hundred feet along the rope could be corroded and hazardous for service. Therefore, electromagnetic devices using dc or low-frequency ac have been developed in South Africa, Canada, and in Europe, to perform an in-service inspection of the rope throughout its length. Experimentation during the last decade in which the performance of the device is compared with laboratory tests on cut-off specimens has given generally satisfactory results (63). A low-frequency ac device is approved in Ontario for testing round and flattened strand ropes in place of the statutory tests on cut-off specimens. Such nondestructive testing is very valuable for in-service testing of Koepe hoist ropes which cannot be subjected to the cut-off test.

Guides

Wood guides usually have a cross section of 5-1/2 by 7-1/2 inches. There are two guides for each conveyance and sometimes four guides for large cages. The guides are attached to buntons in the shaft at 6- to 10-foot intervals. The conveyances are equipped with steel guide shoes or solid rubber-tired guide wheels. Steel guides of various shapes and sizes are also backed by buntons. The conveyances are equipped with plain steel or rubber-tired guide rollers.

Rope guides, widely used in England, have been recently introduced to the coal mines in this country. Operation is smooth and vibration stresses, which are common with fixed guides and damaging to hoist rope sockets, are all but eliminated. Locked coil ropes are used as guide ropes. They are anchored to beams at the headframes and shaft bottoms and tensioned by springs or weights. Sometimes each rope is tensioned differently to dampen possible vibrations. No intermediary support is required. Fixed guides must be used at landings and at the shaft bottom, since rope guides cannot withstand the horizontal forces of loading and unloading. There are usually four guide ropes for each conveyance, either one at each corner or all four at one side. The guide ropes pass through bronze-lined, well-lubricated bushings which are attached to the conveyances. In some shafts special rubbing ropes separate the conveyances and keep them from bumping into each other.

Safety Catches

The use of safety catches is required on cages where men are transported (20). The catches are arranged to operate in the event of rope or suspension gear failure. Then the tension in the attachment on top of the cage is relieved; and a spring, which is normally compressed when weight is on the attachment, throws, by means of shafts and bell cranks, the "dogs" of the catches into contact with the guides. The downward movement of the cage thrusts the teeth deeper into the wood. The pressure is proportional to the cage weight plus the dynamic force. Serrated wedge-type dogs serve with both wood and steel guides (fig. 34).

A retardation of 4 g or 130 ft/sec^2 is considered as the limit a human body can bear. It corresponds to a pole vault over a height of 12.5 ft. A knee bend then cushions the impact at a "braking" distance of 3 ft. However, even a 3-g retardation will unleach excessive forces resulting in the destruction of guides and their backings in the entire shaft.

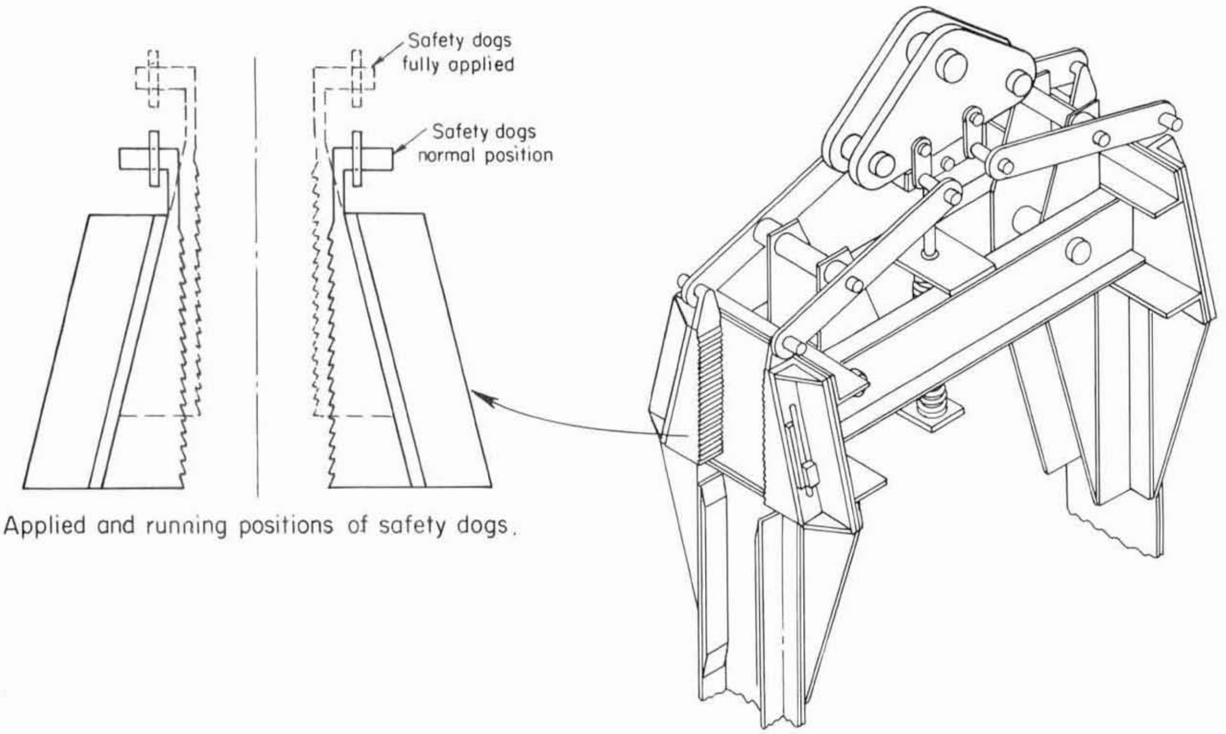


FIGURE 34. - Wedge-Type Dog.

Opinions are divided on the effectiveness of safety catches. Statistics in Germany, where catches were mandatory, brought out that they are of no practical value in the arresting of cages (86) and, therefore, are no longer required on multirope hoist installations. However, considerable research was done in Ontario in testing the effectiveness of catches after a rope failure catastrophe at the shaft of Paymaster Consolidated Mines in 1945 (85). Self-cleaning, single-tooth safety dogs proved to be the most effective design (11) (fig. 35). They engage the guides in a chiseling action without ripping out the entire guide and let the wood spoil pass without clogging the tooth. Depth of penetration is limited by a skid plate at the lower end of the dog. Cutting angle and shape of the bit are designed to slow the conveyance to a gradual stop at a retardation not exceeding 2 g which exerts a force of approximately three times the weight of the conveyance. Antitrailing rope devices also were designed to prevent a momentary drag or hang up of the trailing piece of broken rope from releasing the dogs after they were set.

Testing of the safety catches is required at least once every 2 months (12, 20, 95, 103). In these drop tests the cages, carrying their normal load, are supported on timbers across the shaft collar. A quick release is inserted between the hoist rope attachment and the cage. Then the cage is hoisted several feet and allowed to drop when the quick release is triggered. The safety catches should then operate to engage the guides with a record made of the distance the cage dropped until brought to rest. Safety catches and linkages should be kept clean and lubricated daily.

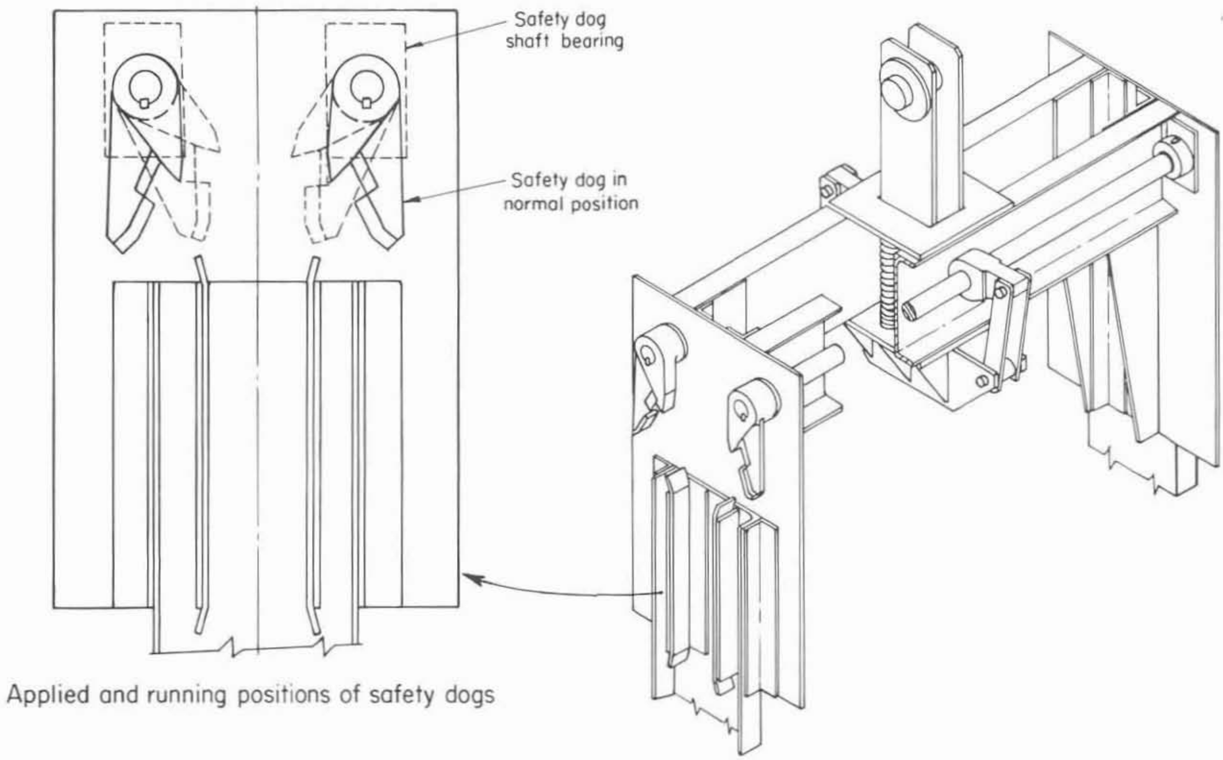


FIGURE 35. - Chisel Tooth Safety.

Signals and Communication

The Bureau of Mines advocates a uniform, industrywide code of hoisting signals to be posted in a conspicuous place in the hoist room in easy view of the hoisting engineer, also at all signaling stations (43).

Reliable electric signal systems have been developed to provide two independent means of signaling at each shaft, slope, or incline station. One of them must be audible to the hoisting engineer. Horns or bells of a specific tune are assigned to each hoisting level and to the top landing and indicate the origin of signals to the operator (103). Telephone or page phones at each shaft station and the hoist room permit direct voice communication, but they should never replace positive signaling by code. Transistorized cage phones for communication between cage and hoist room are battery-powered versions of the trolley phone using a carrier cable strung from the hoist room to the headframe and through the shaft to the shaft bottom. Such a communication is particularly valuable during shaft inspections. Automatic warning signals may be incorporated into the system and even trip the emergency brake. Such a warning signal could be transmitted to the hoist control room when the conveyance drawbar retracts in the event of slack rope caused by a jammed or dogged conveyance.

Automatic operation of hoists requires a fault-finding system which will continuously monitor the operation and, in the event of a malfunction, trigger an emergency shutdown, sound an alarm, and flash lights (28). Signal, speed, and travel recorders may be attached to the automatic controller to deliver a continuous and permanent record of hoist performance.

Portal Shaft Elevators

Portal shaft elevators are similar to elevators in high-rise buildings, but in most coal mines, they serve only a single level. All electric controls are splash proof and moisture sealed. The cage platform area per rider is set by State laws (2.5 sq ft per person in West Virginia) (103-104). Design and installation of elevators follow the specifications of the American Standard Safety Code A17.1 - 1960 (8) and incorporate requirements of both the State laws and the Federal Mine Safety Code. The American Standard Practice for the Inspection of Elevators A17.2 - 1960 (9) serves as a guide for periodic inspection and maintenance usually done by the manufacturer's specialists. But the mine operators must have their elevators inspected daily.

Elevator operation is automatic or semiautomatic when it is controlled by a rider inside the car. The statutory maximum rope speed is 1,000 ft/min and the usual acceleration and deceleration is far below the recommended maximum of 6 ft/sec^2. Elevator cars are 7-1/2 to 8 feet high and fully enclosed. The motorized, automatic operation of the car doors causes the shaft landing doors to open or close also. Cars cannot be moved as long as the doors are open. Roller guide shoes are attached to the cars and counterweights. They engage T-section steel guides which are sufficiently rigid to be fastened to the shaft walls without any backing (10, 54, 89).

There are usually six elevator ropes of special traction construction. Elevator ropes are chosen with safety factors of 10 and higher. Right and left lay ropes are often used in an effort to produce a nonrotating combination. Sheaves are made of cast iron or steel, and rope grooves are not lined with friction insert like Koepe wheel treads, but are of a modified V-shape to improve the traction. Friction-improving rope dressing should be applied to prevent rope slip (89). Equalizing rope tension is important in preventing excessive strain on one rope. The rope attachment screw rods on the car crosshead should be adjusted from time to time.

A few geared ac motor drives are in use. These motors are of 2-speed design with a ratio usually 6:1, 900/150 rpm, to give a slow landing speed. The variable speed or Ward-Leonard method is best for varying the speed of dc motors. Brakes are engaged by spiral springs and released by solenoids. The brakedrums are fitted on the worm shaft side of the coupling to hold the car when the motor armature is withdrawn for repairs. A governor-controlled safety gear protects against overspeed and rope breakage. At 10 percent overspeed the governor actuates a switch to cut the motor power and to release the brake. At 20 percent overspeed it initiates action which causes the safety gear under the car floor to unwind and to grip the guides with powerful jaws, bringing the car to a gradual stop. Oil-filled buffers with spring return protect against overwind. They are placed at the bottom of the shaft. If either the car or the counterweight comes into contact with the buffers, rope traction on the drive sheaves will stop effectively preventing the car or counterweight from slamming into the overhead structure.

Emergency-stop, pushbutton switches are provided in and also on top of the car for the use of maintenance personnel. A car emergency exit, often a hatch in the car top which can be reached by a ladder, is also interlocked with the drive-circuit controls so that the car cannot be moved while the exit is in use. Cage phones allow communication with the top floor in an emergency or during inspection or maintenance.

Shaft Sinking and Repair

Hoisting plants used in shaft sinking are subject to the same provisions of the Federal Mine Safety Act as all shaft hoists used to transport men. This involves automatic overspeed, overwind and stop controls, brakes, ropes, daily inspection, inspection records, service of a competent hoisting engineer, and all the other provisions as far as they are applicable. On the basis of accident experience, the Bureau of Mines and the industry recommend additional safety standards for transportation of men as well as for the protection of crews in the shaft during repair work, muck hoisting, or material lowering (21, 43, 47, 74, 91, 103):

1. A substantial headframe should be used when the depth of the shaft exceeds 50 feet. Since shaft-sinking equipment is often moved and used under various conditions, the span between headgear bearings may be critical. Therefore, it is recommended to determine whether the headgear, particularly the headgear shafting, is designed with an ample factor of safety under maximum load.

2. The bucket should be secured to the hoist rope by a strong, self-closing hook, and the bail should be fastened near the rim to keep the bucket from overturning. The bucket should be deep enough to hold riders in a standing position and should not carry more than four persons.

3. Maximum rope speed for transportation of men in buckets should be 500 ft/min, and the bucket should be slowed to 200 ft/min within 100 feet of any stop. The hoisting engineer should signal the approach of any conveyance to the shaft bottom, bring it to a complete stop, at least 15 feet above men in the shaft, and proceed only after he receives the return signal to do so.

4. To prevent material from falling back into the shaft, the loaded buckets or skips should be trimmed and swung out far enough at the surface while they are being dumped. Shaft collar doors should be kept closed whenever possible.

5. As soon as the shaft exceeds 100 feet in depth, guides should be installed and maintained to within 75 feet of the shaft bottom and a safety crosshead should be attached to all conveyances to keep them from swinging in the shaft. The safety crosshead should be equipped with safety catches and with a lock mechanism to prevent it from hanging up in the guides and leaving the conveyance. The bucket should hang not more than 10 feet below the crosshead. The crosshead should be chaired above the shaft bottom as well as in the headframe to let the bucket swing free for loading and dumping.

6. Men should not ride in a conveyance with heavy tools or equipment unless required to handle the equipment in transit.

7. Voice communication by telephone or two-way radio should supplement the required signal system. The posting of the signal code and permitted maximum speed should be conspicuous and in easy view of the engineer.

8. Strain gages, installed in the cable rigging of work decks, can be wired to indicate and warn of excessive rope loads.

9. An emergency ladderway or stairs or an auxiliary hoist, independently powered, should be provided. Work decks or stages, used for concreting and placing steel or timbers, could also serve as means of escape in an emergency.

10. Men repairing or deepening a shaft below the hoisting level should be protected by a substantial bulkhead which is strong and resilient enough to cushion the fall of a conveyance.

11. Workmen engaged in repair work in or above shafts should wear safety belts. The cage or a second platform should be placed not more than 10 feet beneath a working platform to prevent tools, material, or men from falling down the shaft (43). A qualified attendant shall be on duty at the cage station.

Some modern methods for mucking use clamshells, cactus grabs, or the Cryderman mucker, all of which can be operated from a cab suspended above the shaft bottom (fig. 36). These methods reduce the hazardous exposure of men at the shaft bottom (45). Crawler-tread overhead loaders are also used, and the shortest of them can load in shafts of 15-foot diameter. The loader can scale the shaft walls as high as the loader arms can reach. Figure 37 shows a method for temporarily supporting ground with wire-mesh fencing and rock bolts. Multistage work decks can be advantageous in scaling shaft walls, dropping and alining forms, concreting, and placing steel. These decks are suspended by sheave blocks from three to four ropes and lowered and hoisted by individual hoists on the surface under synchronous or single control (74).

Slopes and Inclines

Slopes, giving access to bituminous coal mines, seldom exceed 18° of pitch. Coal in mine cars is still hoisted in tracked slopes from a few older, large operations and from a number of small mines. Conveyor belts carry coal in all modern slope mines with men and supplies transported through separate service slopes, tracked compartments of belt slopes, or service shafts. Transportation of men in tracked slopes and surface inclines is subject to the same provisions of the Federal Mine Safety Act as hoisting in vertical shafts, as far as these regulations apply. Track should be installed and maintained consistent with the speed and type of hoisting and the rules for safe track design. Also clearance along the track and spacing of shelter holes shall follow the rules valid for track haulage. At each slope landing a shelter hole, at least 10 feet deep, 4 feet wide, and 6 feet high, shall be provided (20).

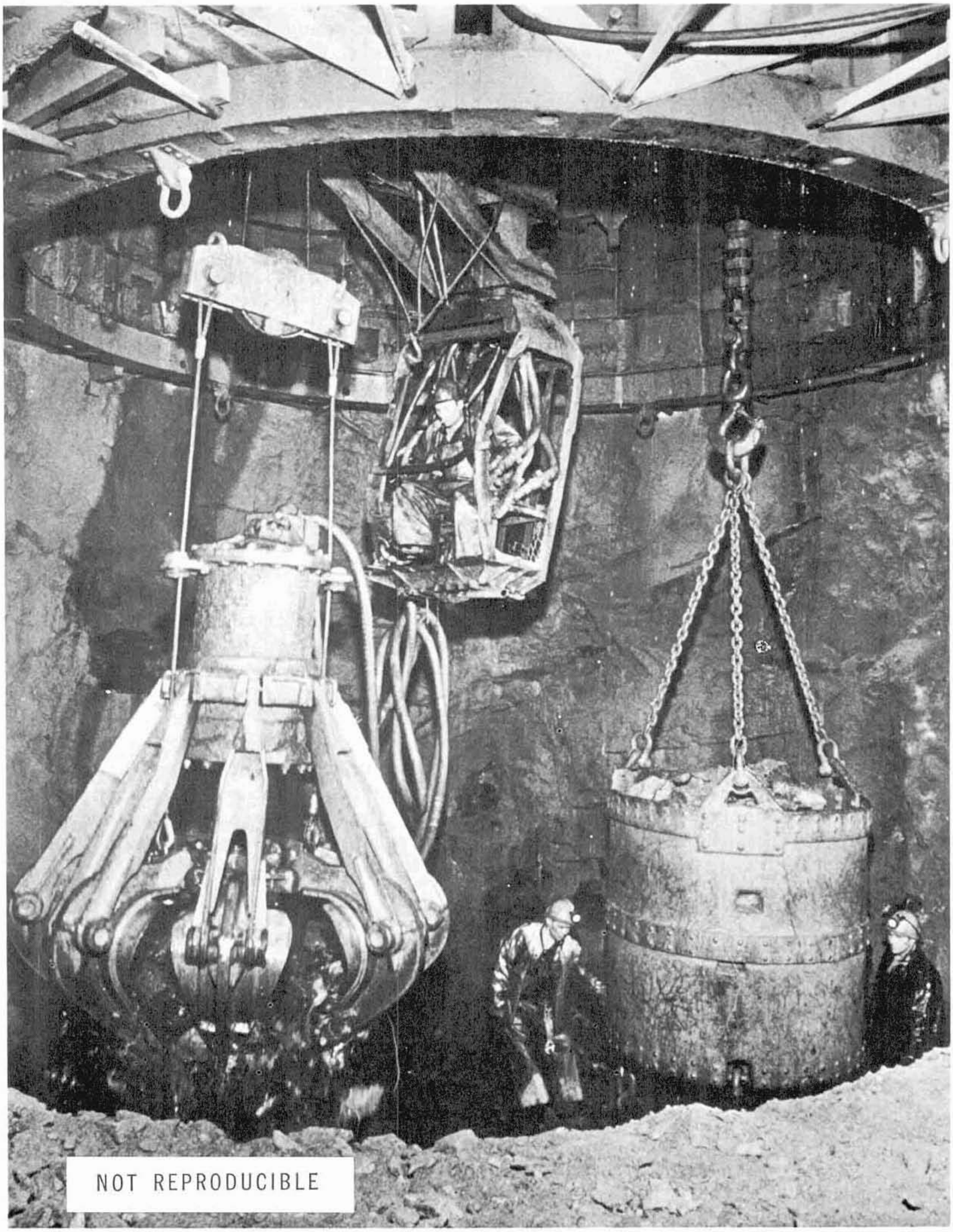


FIGURE 36. - Mucking With Cactus Grab.

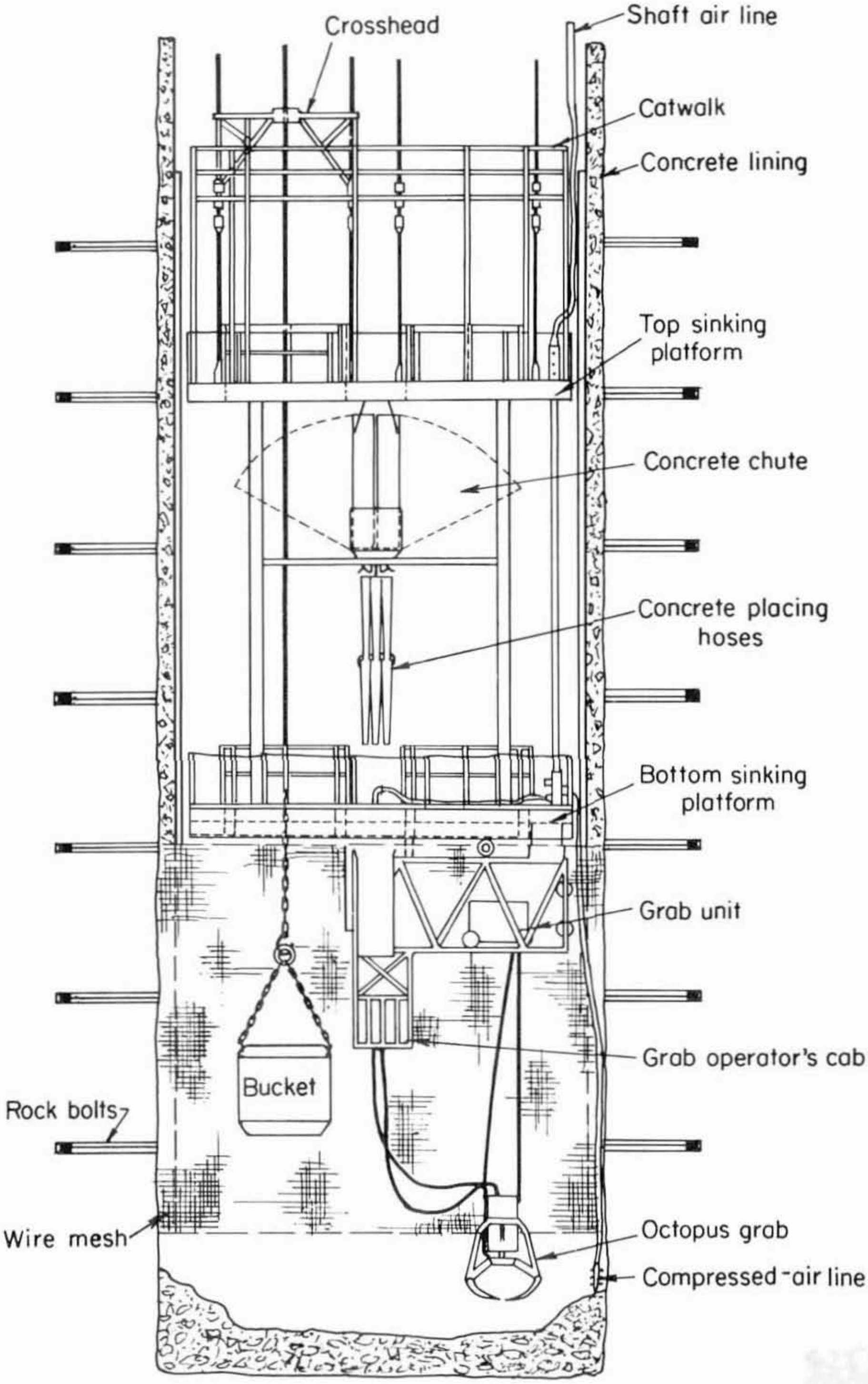


FIGURE 37. - Shaft-Sinking Diagram.

Positive stopblocks and derails shall be placed near the top, at all intermediate landings, and all critical points of a slope or incline where protection against runaway cars is needed (20).

A tracked slope should possibly be graded to a uniform pitch. If this is not feasible, roof rollers and knuckle sheaves or bottom rollers are to be provided to keep the rope from dragging on the ground and along the roof at changes of pitch (7). Rollers should be placed close enough for rope support, but at irregular intervals to prevent rythmic vibration of the rope. Hoist ropes on slopes and inclines are exposed to considerable abrasive wear and therefore have a shorter life than comparable ropes in vertical shafts. They should be inspected, lubricated, and tested by the methods recommended in the American Standard Association specification (7).

Man-trip cars in slopes should have level seats, handholds, and chains across the access openings (47), also two bridle chains in addition to the end attachment of the car. A safety rope should pass through the cars of the man trip and be firmly clamped to them and to the hoist rope. Chains between cars are recommended in addition to each coupling as protection against breakage of couplings and drawbars. Battery-operated brake cars offer effective protection against rope failure (30) (fig. 38). A recent innovation is a brake car that is operated by compressed air from a mounted storage tank and is suitable for steep slopes with a pitch exceeding 25°.

Inspection and Maintenance

Daily inspection of all installations for hoisting men is mandatory, but production hoisting systems are also subject to daily inspection, because a serious hoisting accident might block the escapeway or choke the mine ventilation current. The Bureau of Mines recommends a program of daily, weekly, bimonthly, and periodic inspections (103).

Empty cages, skips, or buckets are operated for one round trip at the beginning of each shift and after prolonged idleness of the hoist to check the

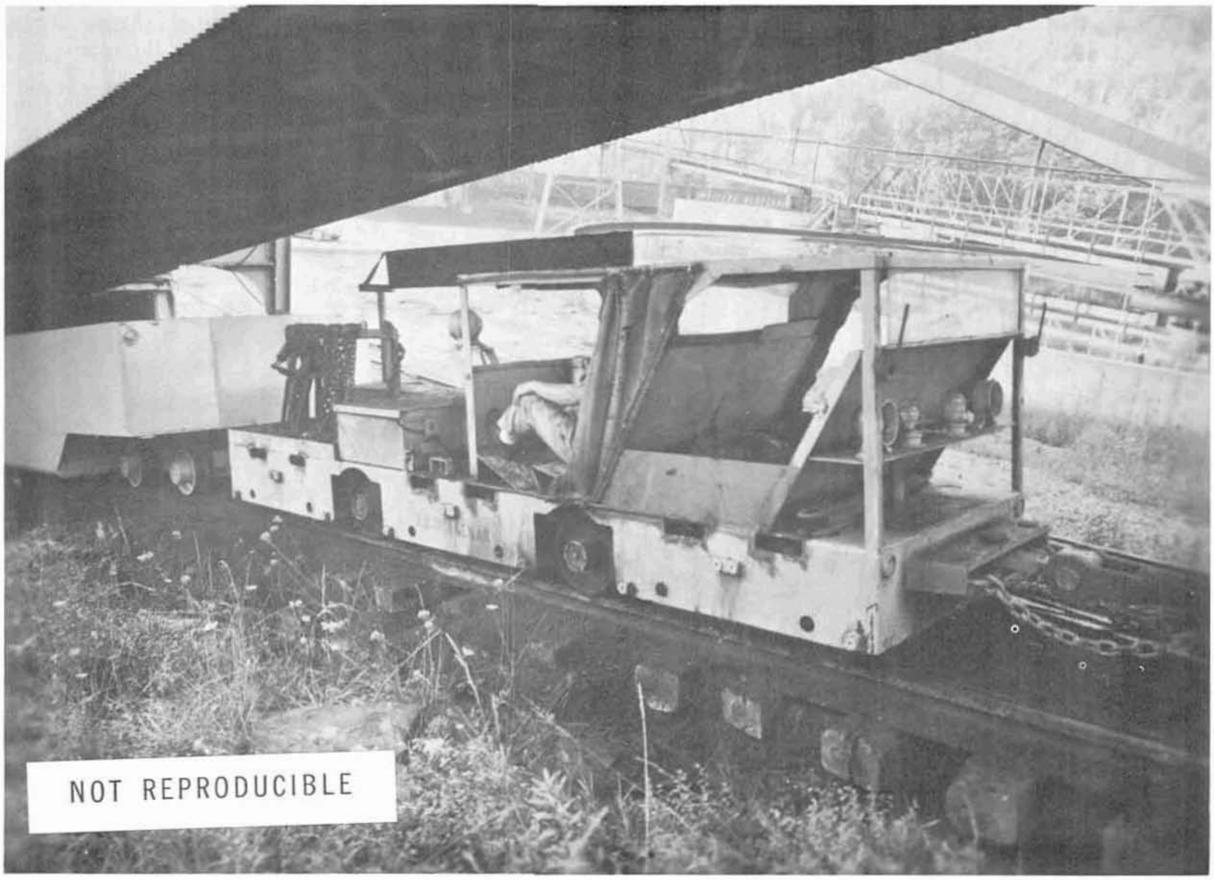


FIGURE 38. - Slope Brake Car.

proper function of overspeed and overwind controls, brakes, cage position indicator, and control of cage and landing gates and doors. Targets of daily visual examination and lubrication, where applicable, are brake linkage, bearings, drums and sheaves, oil level of hydraulic brakes and air pressure of airbrakes, rope attachments, safety catches and linkage, bonnets, side enclosures, gates of cages, the ropes, and the shaft structure. The ropes should be inspected by a competent person and observed while they are moving past him at a rope speed of no more than 50 fpm. The examiner rides in the cage or on top of the elevator car when he observes the condition of the shaft lining, buntons, guides, pipes, power and signal lines, electric controls, and stairways. Signals from each signal point, communication by telephone and cage phone, and the function of landing chairs or swinging platforms should also be tested daily. Ice formation in the shaft must be controlled so that excessive accumulation does not interfere with hoisting.

A daily record in form of a checklist shall be made out and signed by the examiner of the hoisting system. Immediate action should be taken to correct all defects before hoisting begins.

RAILROAD YARDS

System and Accident Experience

Forty-four fatal accidents occurred in yard operation during 1956-66. Forty of the victims were car droppers, two were railroad crew men, and two were track cleaners. All of these accidents occurred at the yards of multi-track tipples where the conventional standard drop-loading technique was applied. In this system each track is assigned to loading one grade of coal into the cars, which is done with swinging booms or chutes. Yard operation involves storage of empty cars, movement and distribution of cars from the storage area to the loading tracks, loading of cars and sometimes weighing them, and movement of loaded cars to the area where the trains are made up. Gravity is the motive force in the great majority of yards. Track grades are 1 to 2.5 percent and car control is effected manually by car droppers manipulating a handbrake or using a pinchbar to start the cars rolling. Movement of cars during loading is controlled mechanically by rope and car retarder hoists at all but very small tipples. But dropping the cars from the empty-car-storage tracks to the loading tracks and from there to the loaded-car-assembly tracks is controlled manually.

Table 14 lists the types of accidents; table 15, the hazardous conditions which caused many of them; and table 16, unsafe acts causing fatal accidents to car droppers and railroad crew men.

TABLE 14. - Accident types with railroad yard operation, 1956-66

	Frequency
Types of accidents:	
Collisions with standing cars (mostly on switches and curves)....	21
Derailments (due to coal spillage under tipple)..................	1
Personal accidents:	
Victim was run over, crushed, squeezed.........................	17
Knocked off by coal or fell from coal chute while applying brake after car retarder hook became detached.................	1
Crushed between top of car and rigid chute.....................	1
Struck by rope of retarder.....................................	1
Fell when brake wheel came off.................................	1
Struck by bolt from improvised pull rope.......................	1

TABLE 15. - Physical and environmental causes of fatal accidents connected with railroad car loading, 1956-66

(Numbers in parentheses represent frequencies, if more than 1)

	Frequency
Defective rolling stock and yard equipment........................	7
Car brakes (2), handbrake assembly, journals, sheave wheel anchoring, improvised pull rope attachment of truck, rope attachment of retarder.	
Substandard yard conditions.......................................	5
Restricted side clearance between tracks, substandard track, coal spillage on loading track, lack of derail, lack of illumination.	
Poor planning...	4
Lack of mechanical means to control cars during loading (3), coal chute not hinged.	

TABLE 16. - Unsafe acts causing fatal accidents to railroad car droppers and crew men, 1956-66

	Frequency
Failure to keep switches and curves clear.........................	13
Dropping or handling more cars than one man can handle............	10
Getting on or off moving equipment................................	7
Failure to use a safety belt where necessary......................	7
Riding in an unsafe position......................................	6
Failure to stay in the clear of moving equipment..................	4

TABLE 16. - Unsafe acts causing fatal accidents to railroad car droppers and crew men, 1956-66--Continued

	Frequency
Failure to face or watch direction of travel	3
Bumping of stalled railroad cars	3
Failure to secure or block standing equipment effectively	2
Operation of equipment by inexperienced and unfamiliar operators	1
Inattention	1
Misalining or failure to realine track switches	1
Flying switches	1
Failure to drop the loaded cars to their final destination of storage	1
Failure to aline couplers	1
Failure to shut off coal chute or boom when leaving loading platform	1
Getting on car before it passes running coal chute	1
Failure to communicate by visible or audible means	1

Recommendations

Manual car movement and control involve serious hazards to car droppers; the following recommendations may help prevent accidents in yard operation (20, 22, 43):

1. The roadbed and track should be installed and maintained consistent with the traffic.

2. Sufficient clearance should be provided at switch throws.

3. The unobstructed clearance on either side between the farthest projections of railroad vehicles on adjacent tracks or between structural tipple supports or any buildings should not be less than 24 inches.

4. Warning signs should be placed at locations where side or overhead clearance is restricted.

5. Safety zones should be marked on track switches to warn of parking vehicles on the curved part of the turnout.

6. Derails should be installed at track junctions with the main line and at any other location where protection is needed.

7. Warning signs or flashing light signals, if needed, should be placed at all surface track crossings.

8. Loading tracks under the tipple should be kept free of spillage and the yard area of stumbling hazards.

9. All equipment such as hoists, car retarders, car hauls, sheaves, ropes, and rope attachments should be kept in good operating condition and inspected daily. The railroad owners should maintain their rolling stock.

Car droppers should wear hardhats, snug-fitting clothing, and safety belts where needed. They should take the following precautions:

1. Move railroad cars by railroad-type pinchbar and use a substantial brake stick.

2. Check brakes before moving empty cars.

3. Not board or get off moving vehicles.

4. Possibly ride the last car.

5. Stand on the braking platform in a safe position and watch the direction of travel.

6. Not start stalled cars by bumping and not make "flying switches."

7. Aline couplers.

8. Not drop more cars than one man can handle.

9. Keep switches and curves clear of railroad cars and drop loaded cars to their final destination.

Tipple men should shut off boom when leaving platforms and not get on cars before they have passed running coal chutes.

Consideration should be given to controlling gravity-induced car movement by hydraulic retarders with electronic speed-sensing controls similar to systems applied at small gravity-controlled classification railroad yards.

The unit-train concept has been adopted in recent years where only one product is shipped. Fully mechanized loading systems entirely eliminate the hazards inherent in manual car handling. Figure 39 shows the tripper loading system. A motorized belt tripper is moved along the tracks while the cars are standing still.

AUTOMOTIVE OPERATIONS

Accident Experience

There were 47 fatal automotive accidents in bituminous coal mines including four tire accidents in shops during 1956-66. The majority of the vehicles involved were coal haulers and served in strip mines. Types of accidents are listed in table 17, physical and environmental causes in table 18, and unsafe acts in table 19.

FIGURE 39. - Tripper Railroad Car Loading.

TABLE 17. - Accident types with automotive operations in bituminous coal mining, 1956-66

(Numbers in parentheses represent frequencies, if more than 1)

	Frequency
Noncollision vehicle accidents	22
Vehicles out of control (19), wheel, drive shafts fell off (3).	
Collision with other vehicles	7
Parked vehicles running away	6
Persons runover, working about and jumping off vehicles	8
Tire changing accidents in shops	4
Rim rings blew off (3), tire blew out.	

TABLE 18. - Physical and environmental causes of automotive mine-transportation fatalities, 1956-66

(Numbers in parentheses represent frequencies, if more than 1)

	Frequency
Defective vehicles and inoperative or missing protective devices... Brakes (7), retaining (rim) rings (3), drive shafts (2), tire cages (2), tire (blew out), door, horn or siren, seat belts.	19
Poor planning... Lack of runaround, passing zone or slow lane, automatic warning signal when trucks back up.	3
View obstructed by dust...	1

TABLE 19. - Unsafe acts causing fatal accidents to automotive drivers, 1956-66

	Frequency
Failure to secure or block standing equipment effectively...	6
Failure to select the proper gear before starting out on a steep grade...	6
Operation of equipment by inexperienced or unfamiliar operators...	4
Failure to obey traffic rules...	3
Excessive speed for circumstances...	2
Getting on or off moving equipment...	2
Failure to keep truck in gear...	2
Riding or working in an unsafe position...	1
Failure to stay in the clear of moving equipment...	1
Inattention...	1
Failure to follow at a safe distance...	1
Pumping airbrake...	1

Coal Haulers

There are two types of coal haulers, the rear-dump truck and the tractor-trailer. Rear dumps are either 2-axle units with one or both axles driven or 3-axle units with two axles driven. The rear-dump truck is easily maneuverable and suitable for off-highway use and rock disposal at rock dumps (17). The newest models have pivot steer design and 4-wheel drive for even better flexibility. Tractor-trailers do not develop as much traction on grades as the conventional rear dump, because weight transfer from the driven wheels to the trailer rear axle reduces the tractive effort on the driven wheels, particularly on wet roads. Bottom-dump tractor-trailers are high-capacity coal haulers. They are used where the roads permit high travel speeds and long grades are less than 6 percent. Figure 40 shows a large coal hauler with diesel electric units at each end.

FIGURE 40. - Coal Hauler of 240-Ton Capacity.

Full-power shift transmission is now standard in trucks over 20-ton capacity. These automatic transmissions incorporate a lockup clutch which automatically locks the torque converter in direct mechanical drive and provides engine braking at closed throttle. Hydraulic retarders are inserted in the drive line between transmission and differential to act as governors in controlling downhill speed. Exhaust braking is an effective engine braking system through the brake pressure induced by a throttle in the exhaust manifold.

Power transmission by dc electric drive has come into prominence with large haulers (17). The powerplant is a diesel-driven dc generator. The latest and most promising drive method is the motorized wheel for engine ratings above 500 hp. A traction motor is mounted in each drive wheel, eliminating the following elements from the conventional power train: torque converter, clutches, transmissions, drive shafts, differentials, and drive axles. Power transfer is smooth and stepless throughout the entire operating range, and concentration of weight on the drive wheels will improve the tractive effort and control wheel spin (52). Dynamic braking on downgrades is achieved when the traction motors act as generators, and the generated energy is dissipated in resistance grids. An overhead trolley system can serve as alternate to the diesel plant or could be the exclusive power supply (93).

Double-actuated shoe- and disk-type service brakes are most effective on heavy-duty hauls. A desirable safety feature is to have brake actuation for each wheel independent from the others so that rupture of the hydraulic line to one wheel will not affect the brakes of the other wheels. A fail-safe brake application for air-over-hydraulic actuated braking systems will automatically set the service brake on all wheels, if air pressure drops below a safe level; that is, 30 psi.

Deep tread tires give extra skid protection and long tire life. But heat dissipation is critical at high sustained travel speeds. Therefore, shallow tread designs are more suitable for long hauls. A program of systematic tire maintenance should emphasize the following points (25):

1. Inflation to the specified pressure.

2. Valve caps on each valve stem.

3. Inspection including evaluation of tire wear and need for retreading.

4. Tire rotation.

5. Complete tire records.

A system warning of low tire pressure is desirable and often combined with a device which detects excessive heat above a limit of say 225° F, indicating bearing failure and possible damage to wheels and axles (35). The sensor units are mounted on the hubs of each wheel with lights on the dashboard to flash warning of low tire pressure or hot bearings. Tires could be inflated en route by airhoses connected to the airbrake reservoir and kept in service until a convenient location for tire repair is reached.

Traffic control and communication by two-way radio require transmitters of 80 to 250 watts at a base station and mobile units of 35 to 80 watts on trucks, cars, shovels, or draglines (58). A license must be obtained from the Federal Communications Commission who assigns a channel to the station.

Haul Roads

Safe and efficient fleet operation depends on haul roads engineered for the purpose (65). Haulage speed is affected by width and routing of the road and the rolling resistance of the road surface. Roads should be laid out with minimum grades, wide banked curves, and passing lanes on long grades and on stretches with limited view. In most mining operations, adverse grades must be overcome. Table 20 gives road design data such as haul speeds, grades, minimum curve radius, and superelevation. Both curves and embankments should be marked with reflector signs and have substantial shoulders (22).

TABLE 20. - Road design data

	Speed, mph				
	10	10-20	20-30	30-40	40-50
Minimum curve radius, feet...........	50	150	300	600	1,000
Curve banking, inch per foot of width	1/2	5/8	3/4	3/4	5/8
Maximum grade, percent...............	9	8	8	7	8

Source: Reference 65, p. 149.

The subbase of the road must have adequate depth, stability, and drainage to be strong enough to support the axle loads of modern large haulers (52). Blacktop is used for heavy traffic on more permanent roads. All other roads should be surfaced by a wearing course of suitable aggregate. Road graders work the surface material to shape, maintain a road crown with lateral slopes of 1/2 inch per foot, and keep the ditches deep enough to drain both subbase and road surface. Water trucks wet the surface and spread calcium chloride and lignosulfate to keep the road moist in dry weather. This treatment will pack the wearing surface and bind the dust. Dust causes collisions on account of bad visibility, inconveniences the drivers, and is harmful to engines and all moving parts.

Safety Procedures

The following safe operational procedures are suggested (20-21, 91-92):

1. Loaded haulers should hug the bankside on ramps on their trips to the tipple. Whether right-hand or left-hand traffic is the adopted standard, depends on the layout of the open cut.

2. Traffic around the shovel is critical; the following practices are recommended:

   a. Drivers, queuing for a load, should be kept at a safe distance from the shovel and be attentive to all traffic, pedestrians, trucks, or dozers.

   b. They should back under the shovel only upon a visual or audible signal from the cleanup dozer operators that the dozers are in the clear.

   c. Trucks should be moved from the shovel only on signal from the shovel operator.

3. Traffic on ramps and haul roads should be controlled by the following rules:

   a. Trucks should follow each other at a distance of no less than 150 feet and should not pass on ramps and haul roads. Slow-moving graders or dozers should be passed with extreme caution.

   b. A loaded truck has right-of-way over an empty one on merging roads. The truck on the right or the truck on the left has the right-of-way according to whether right-hand or left-hand traffic is the adopted standard. Stop, yield, and other traffic signs should be portable to accommodate changing traffic patterns.

   c. Truck lights should be put on at sunset and off at sunrise.

   d. If a truck is stopped on a ramp, its flashers should be used to warn traffic following it.

4. These recommendations apply to rear-dump trucks:

    a. Operating levers for rear-dump hoists should be kept latched to prevent unintentioned tripping of the mechanism.

    b. The body of a rear-dump truck should be securely blocked in the raised position before men are permitted to work on the chassis.

    c. Substantial bump blocks should be provided at dumping points to keep the trucks from backing over the dump.

5. A 20-pound dry-chemical extinguisher should be kept on each truck, and personnel should be trained to use it. A trained fire crew with a fire trailer should be available at each shift.

6. Grip-strut steps, handrails, and grabbers should be installed wherever safe and convenient access is required. Drivers should face the ladder when dismounting from the cabs. Ladders should be lighted at night.

7. Handling of heavy-duty wheel assemblies accounted for four fatal accidents in shops during 1956-66. Three of the victims were struck by rim rings blown off wheels. One man was crushed while he was removing the outer wheel of a dual set. The inside tire blew out and hurled the wheel and the victim against a steel column. Significantly, blowoffs of rim rings, rims, and flanges and blowouts of tires are recognized as the two principal hazards by the National Safety Council (83). The following practices are recommended for safe handling of tires:

    a. Persons handling tires should fully understand the hazards.

    b. Suspicious tires, rims, or rim rings should be checked by magnetic-particle or dry check methods.

    c. Worn and cut tires should be deflated, before wheels are removed.

    d. In moving a tire, the workman should stand directly back of the tire and roll it ahead of him. Handling it from a position to its side is hazardous.

    e. Tires should be inflated in restraining devices such as tire cages, racks, or chains (fig. 41).

    f. Eye and face protection is essential during inflation and deflation of tires.

    g. If ballasted tires are deflated, special safety couplers should be installed to deflect the granulated fines into a ballast depository (fig. 42).

    h. A forklift truck with fork clamp attachments and modified to raise, lower, and rotate tires eliminates many hazards in handling tires (fig. 43).

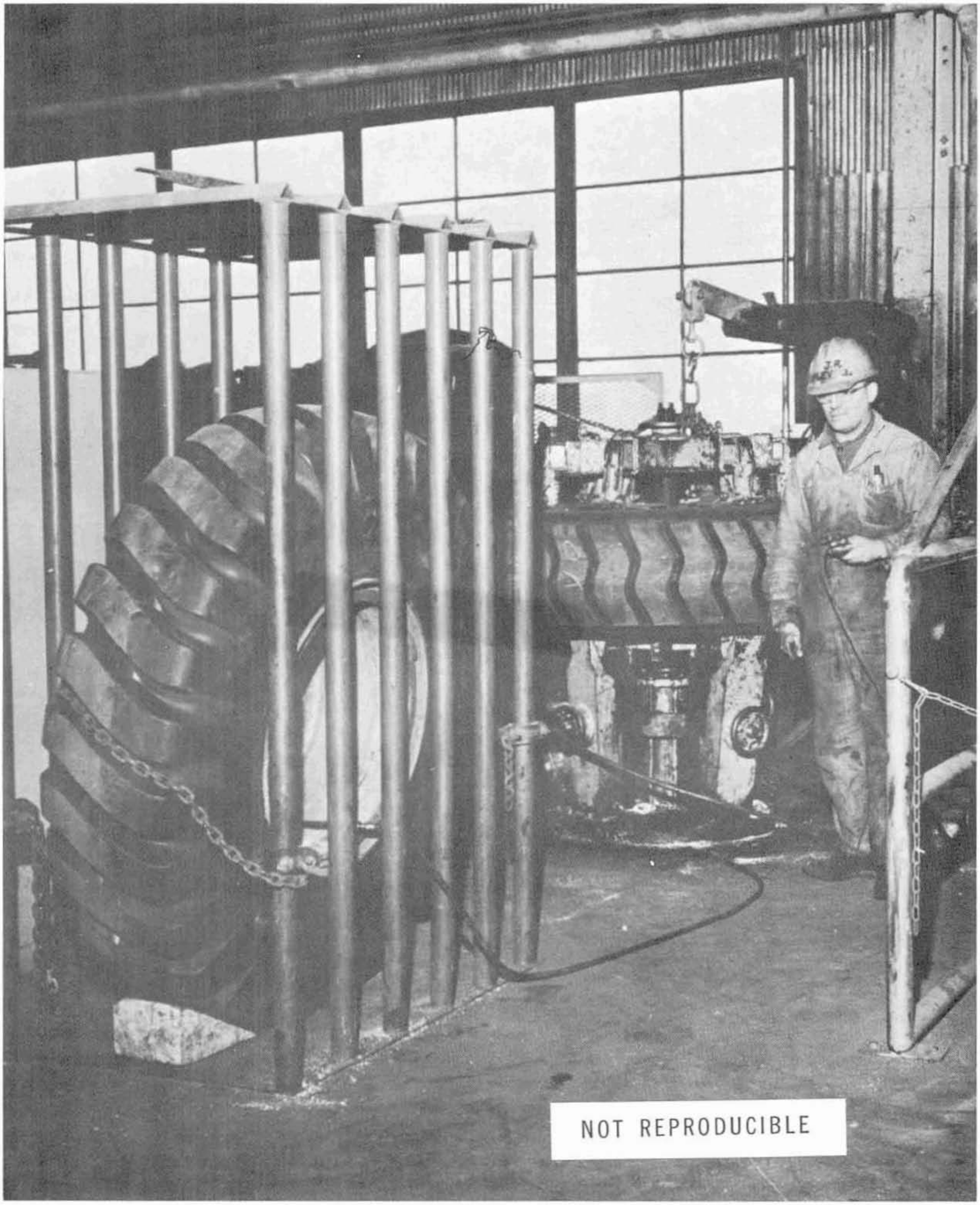


FIGURE 41. - Tire Cage.

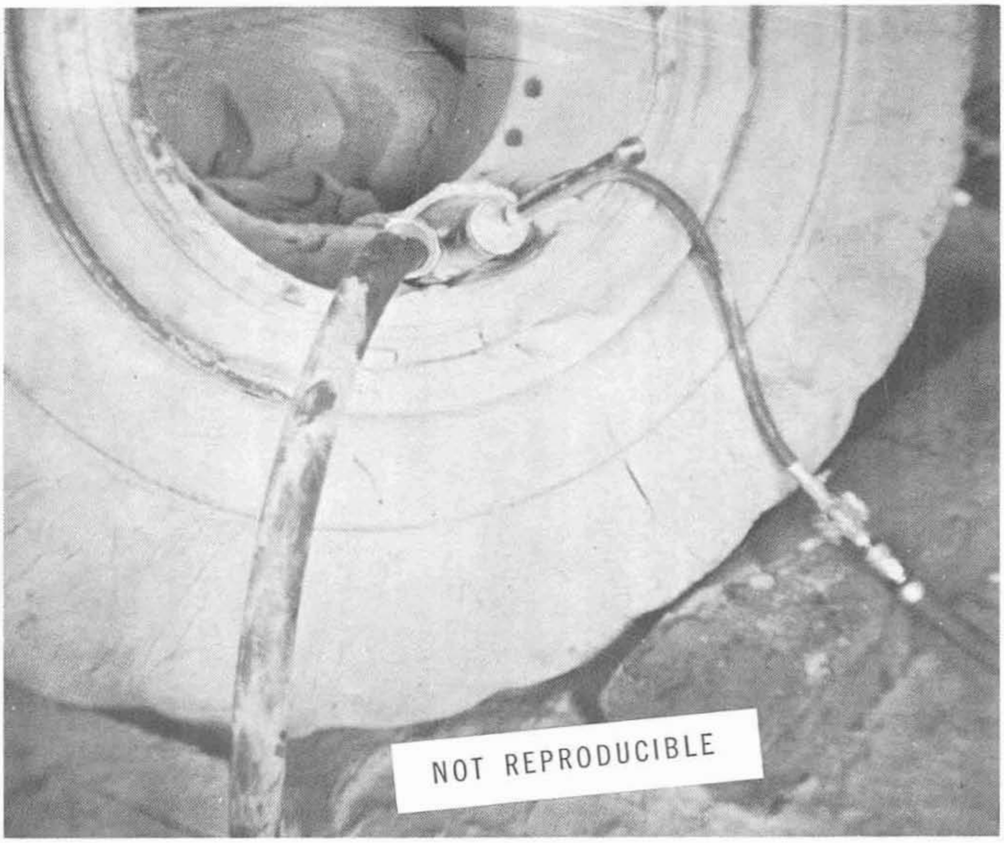


FIGURE 42. - Safety Couplers for Deflation of Ballasted Tires.

8. At the beginning of the shift, each driver should make a daily prestart check including such items as brakes, air pressure, oil level, steering, lights, horns and sirens, and tires. Any repairs should be made before the trucks are taken to the pit. If the lubrication center has competent personnel, it will offer another opportunity to catch defects. It is the driver's responsibility to report to his supervisor any unsafe equipment or mechanical trouble apparent during operation. The trucks should be kept out of service until the defects are remedied. A strict schedule of weekly and monthly preventive maintenance inspections should follow checklists with emphasis on safety items such as fire extinguishers, brakes, air and hydraulic systems, steering and throttle linkage, steps and ladders, glass in the cab, and lights.

FRONT-END LOADERS

Equipment and Accident Experience

In recent years more front-end loaders are being used in secondary loading and road maintenance. Loaders with large buckets and pivot steer design are now replacing shovels as primary loaders at some strip mines (fig. 44). Five fatal accidents with front-end loaders occurred in bituminous coal mines from 1961 to 1966. In four cases, steering control was lost and the vehicle

FIGURE 43. - Forklift Truck With Tire.

FIGURE 44. - Large Articulated Front-End Loader.

turned over while it was tramming. In one case the accident occurred as the loader was pushing an empty truck uphill. Three of the accidents occurred while the loaders were traveling highways and two while they were off the highway. In all five cases the operators appeared to be inadequately trained in tramming operation. This analysis reflects the accident experience with loaders in the entire mining industry. When a rash of fatal accidents with front-end loaders plagued the industry in the early 60's, the Bureau of Mines conducted a nationwide study (90). This investigation showed that tramming appeared to be the most hazardous operation but that improved design of loaders and more careful training of operators had recently reduced the number considerably. Some of the safety features incorporated in newer models are air-over-hydraulic actuated brakes, articulation, and better stability with wider tracks and ballasted tires.

Recommendations

The following suggestions are based on the analysis of fatal front-end loader accidents (90):

1. Training of operators should emphasize safe tramming operations; only well-trained persons should be authorized to handle the loader.

2. Loaders should be equipped with roll bars or the cabs should be designed to support the weight of the loader, if the vehicle should run off the embankment and tip over.

3. Moving a loader on a low-boy trailer or by towing might be preferable to tramming, if length of haul, grades, and road conditions are considered.

4. Recommendable features that can be incorporated into the braking system are:

   a. A device to automatically lock all wheels if the air pressure for air-over-hydraulic actuated brakes should drop below a safe level.

   b. An exhaust brake with exhaust back pressure serving to slow the engine and gain some engine braking effort.

   c. Hydro retarders that act as governors to control speed on downgrades.

   d. A converter lockup to provide engine braking at closed throttle.

5. Where high-speed operation is not required, the high-speed range should be locked out. Speed limits should be set and observed on roadways.

6. The loader should travel with buckets in low position.

7. Buckets should not serve as stages.

8. The ignition should be off, brakes set, and transmission in low gear when the loader is parked and left unattended. If the vehicle is parked on a grade, its wheels should be blocked securely or turned into the bank.

9. Loaders should be inspected daily and repaired before they resume operation. If the defects cannot be remedied in the field, the loader should be towed or hauled to the shop.

MISCELLANEOUS ACCIDENTS

Two fatal river dock accidents were reported during 1956-66. One man lost his footing while he was walking the wet gunnel of a barge which was about 27 inches wide. He was not wearing a lifejacket when he fell into the turbulent water. Another man fell from the gunnel into the hold of an empty barge, a fatal plunge of 10.5 feet. At this dock the barges were handled by breastlines from the riverbank. The lines tighten and slacken in choppy weather. Presumably the victim was swept from the gunnel by such a breastline. During storms river men always should work in pairs, wear lifejackets, and communicate with the line operators where breastlines are used.

Three of the six accidents, which occurred during equipment moves, could have been avoided if the crawler-tread or rubber-tired equipment had been moved on equipment carriers or dollies along tracked roads. Hazards, such as contact with trolley wire, running over cables, fouling of cables at ties or switches, and squeezing of operators between the equipment and roof or rib, would have been eliminated. In another accident two battery tractors, working deck to deck, were moving a belt feeder. One operator was crushed in his deck as one tractor was forced under the other. He could have been protected by coupling bars between the tractors, by uprights serving as deck guards, and by the equipment being pulled instead of pushed.

There were 83 fatal accidents reported for nontransportation personnel such as track, road, and belt cleaners, boom men, and maintenance or wire men who often travel haul roads. Not included were occasional riders, man-trip passengers, or inexperienced equipment operators. These fatal accidents for nontransportation personnel accounted for 14 percent of all transportation fatalities. The three oldest victims, over 65 years, were in this 14 percent but the number of victims over 50 and below 50 were nearly equal. Some of the men were stricken while they were working as haulage personnel coupling or rerailing cars. Their failure to stay clear of moving equipment was the chief cause of accidents. Failure of motormen or shuttle-car operators to give warning signals was the second, and working on moving or running equipment was the third. This included such work as cleaning, oiling, repairing, setting or releasing brakes, or hooking or unhooking hoist ropes on moving cars. Industrywide educational programs and instruction and training at the mines may help prevent many of these accidents.

MAN-TRIP ACCIDENTS

Accidents to man trips may reach catastrophic dimensions and involve many persons. Eight fatal and four nonfatal accidents of man trips on track were reported during 1956-66. The fatal accidents took 13 lives. The two multiple-fatality accidents were the most serious transportation accidents reported during 1956-66. In one, an outbound supply trip with tandem locomotives in front and rear ran back on a 3-percent grade because of inadequate power. An armature pinion at the lead tandem had been lost. The trip collided with an outbound man trip of one personnel carrier and three portal buses. Three man-trip passengers were killed in that collision. A derail and a block-signal system would have prevented the accident. Also, the man-trip operators failed to keep a safe distance between them and the preceding trip ascending the grade. The other multiple accident was a derailment caused by a defective coupling attachment; three of the four lives lost would have been saved had the men been riding in a covered man-trip car.

Most of the man-trip accidents would have been prevented by block signal systems, and two accidents were caused by uncontrolled traffic of loaded trips during man-trip time.

Trackless transportation of men accounted for two fatal accidents during 1956-66. In one a man stepped out of a covered man-trip car that was stopped momentarily and fell under the car as the trip moved on; in the other a man riding an open trailer shifted his position and struck a crossbar.

It is obvious that man trips should be operated under strict rules. Factors which determine their safety include: Type and condition of equipment involved, overhead clearance, traffic control and communications, and discipline of riders in boarding, riding, and leaving the cars (20, 43). Officials should be in charge of man trips, see that they proceed without interference from other traffic, and be responsible for the enforcement of man-trip rules:

1. The men should not board or leave the man trip before the cars come to a full stop. They should remain seated while the cars are moving, walk to and from man trips in an orderly manner, and, except for the motorman and brakeman, ride inside the cars.

2. Only cars and locomotives in good repair should be provided. The cars should not be overcrowded.

3. When men ride in open cars, they should sit on the side opposite the trolley wire.

4. Men should always ride in covered man-trip cars if space is available, never in the car next to the locomotive unless it is a covered man-trip car.

5. When drop-bottom cars are used as man-trip cars, the bottom doors should be secured by chains and clamps.

6. Man trips may haul light tools and machine parts in special compartments or tool cars but not heavy equipment. They should be operated independently from any loaded trips.

7. Man trips should be pulled at speeds consistent with the type of equipment and the condition of the road so that they can be stopped within the limits of visibility.

8. On steep grades a second locomotive should trail the trip and be coupled to it. Man trips should not be operated behind loaded trips on ascending grades nor in front of loaded trips on descending grades.

9. There should be telephones at man-trip stations and trolley phones on locomotives pulling man trips.

10. Wires at man-trip stations should be guarded or provided with deenergizing switches and signal lights to indicate when the wires are deenergized.

As far as applicable, the recommendations are the same for rubber-tired man trips.

CONCLUSIONS

Accident experience in mine transportation distributes the causes nearly equally between hazardous conditions created by defects of equipment and environment and the unsafe actions of persons. Motivation, training, better working conditions, and better equipment maintenance will help to improve the accident record. There are several areas where research may reduce exposure of workmen to hazards; for example, safety in track haulage would benefit from a study of centralized traffic control, possibly by computer, and of communications systems. Another subject of interest is track construction and maintenance by applying modern railroad techniques. In mobile nonrail haulage the trend is to battery-powered traction that eliminates cable hazards. Another source of self-contained power is the diesel engine, already widely used with mobile equipment in metal and nonmetal mines. The underground use of diesel engines to power haulage equipment in coal mines merits further study. Technology is evolving toward safer modes of transportation, notably in the growing use of conveyors in all phases--face, secondary, and main-line haulage. The development of protective systems that through load-sensing devices control the material flow in conveyors well in advance of congestion at transfer points is of great importance. Methods of nondestructive field testing of parts, including in-service tests of hoisting ropes, should be further developed to fit within the program of preventive maintenance. Socketing of hoist ropes by new capping materials (for example, resins) should be investigated. Yard operations in multitrack tipples should be studied to ascertain whether they could benefit by systems that control movement of railroad cars in small gravity-controlled classification yards.

Bureau of Mines reports on fatal haulage accidents that occurred during 1956-66 and took a toll of 601 lives are the sources of this study. Most of them are well detailed and illustrated. However, a more thorough evaluation of nonfatal accidents, indicating both hazardous conditions and unsafe actions, would provide a 20 to 30 times larger population for study. It is also recommended that future analyses expand the classification, haulage, to the more meaningful term, transportation, embracing haulage, hoisting, conveyor operation, barge loading, and handling of such load-haul-dump equipment as scrapers and front-end loaders.

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